Encyclopedia of Subsistence Farming Solutions (SAKpedia, 2018 Edition)

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2.1 - Gloves to help subsistence farmers

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Background

The world’s 1 billion women and girls participating in subsistence farming pull weeds by hand to improve their crops and also collect firewood for cooking, resulting in their hands becoming rough and sore (Figure 1). This can be caused by wood splinters being lodged into their skin (Schaffner, 2013). Pulling weeds for hours on end can peel away layers of skin (Food and Agriculture Organization, 2016). The hands of those farmers can also become dirty and smelly from planting seeds in the soil or spreading manure by hand. To avoid the common aforementioned problems as well as hand injuries, such as cuts and scrapes, they could wear gloves on their hands, see the second picture, (Schaffner, 2013). Gloves are very common in the modern world and can be used for construction, farming, and medical practices. Gloves provide a durable layer between the skin on your hands and whatever you are working with (Espasandín-Arias & Goossens, 2014). There are a few different materials used to make gloves, along with different sizes and grips. With over one billion women and girls working on farms around the world, this grueling work can be made safer and more efficient when wearing gloves.

Rubber and cloth are the two main kinds of gloves produced (Melco, 2016). They both have their own benefits and drawbacks respectively. A benefit from rubber gloves is their ability to resist water from coming in contact with a farmer's skin, see part two, (Espasandín-Arias & Goossens, 2014). While cloth gloves can be beneficial because they can draw moisture away from their hands and can be easily washed to be cleaned. Because rubber gloves are usually meant to be disposed of after single use they tend to be cheaper to make and thus cheaper to buy. Yet some rubber gloves can be made thicker to reuse and are slightly more durable (Melco, 2016). Cloth gloves are designed to be washed after being used and last a long time under normal working conditions.

Along with the different materials gloves are made of, there are also different arm lengths. Some gloves are cut off just in front or around the wrist. While others can be up to and over the elbow and everywhere in between (Melco, 2016). The benefits of the shorter gloves is comfort, no bunching around wrist or elbow, and they can be quickly put on or removed. The benefits of the long gloves are more protection, the entire forearm will be covered. All the while there is less of a chance of getting debris in their gloves because the opening is farther away from what you are working with. Farmers can also work in deeper water or mud with the long rubber gloves without getting your hands wet.

When working with smooth items such as hoes and some fruits and vegetables they can be slippery (Food and Agriculture Organization, 2016). A way to help farmer's hold on to the tools is to get gloves with grips (Melco, 2016). Both rubber and cloth gloves can have grips. Rubber gloves will have ridges in the molds to form grips and granular materials can be added to the outside before drying (Melco, 2016). Another option is to make the rubber gloves out of a non-slip rubber (Melco, 2016). Because cloth alone does not provide grip, cloth gloves must be dipped in liquid rubber to be able to grip smooth objects. The rubber used for grips on cloth gloves can either be non-slip smooth rubber or be rigid (Melco, 2016).

Physical Protection

Protection is the main benefit from using gloves. Repetitive motions, such as when pounding grain, can cause irritation to the skin. When collecting firewood the sticks and logs can scratch or cut the skin (Food and Agriculture Organization, 2016). Weeds can be rough and by scratching their hands many times they can become cut and sore (Espasandín-Arias & Goossens, 2014). By lifting and pulling heavy items the top layer of your skin will separate from the next, causing a blister, by wearing gloves they now will prevent blistering because the glove will act as the top layer of skin and prevent the actual skin from separating (Schaffner, 2013). Manure has a lot of bacteria in it which are harmful if they are swallow, so keeping them away from the hands used to eat with is very beneficial (Furlong, *et al.*, 2015). If farmers are working with firewood or in construction the cloth gloves will work better because they are more durable (Food and Agriculture Organization, 2016). The disposable rubber gloves would be the worst to use in this scenario because they are so thin, stick to jobs were the main goals are to keep hands dry and dirt free when using disposable rubber gloves.

Defense Against Moisture and Chemicals

Moisture blocking is a way gloves can prevent your skin from drying out and from getting too wet and dehydrating farmer's hands. By keeping the moisture from the hands inside the gloves they will prevent the skin from cracking and becoming infected (Schaffner, 2013). As well when working in wet conditions your hands can shrivel and become dehydrated if they are constantly in contact with water.

Pesticides can be absorbed by your skin and become harmful to the body, gloves provide an extra barrier to block them from entering in a farmer's body (Furlong, *et al.*, 2015). Fertilizers such as nitrogen can also be caustic, and these are usually spread through broadcasting by hand. Mud can get under your nails and into cracked or cut skin and can infect a farmer's hands. Gloves will keep the mud out and keep hands clean. Both liquid pesticides and dry fertilizers can irritate skin if they come into contact with it (Kim, *et al.,* 2013). Wearing the proper gloves, rubber ones in this case, can save their hands from becoming itchy (Keeble *et al*., 1996). Human skin can also absorb the pesticides which are harmful to your body, wearing gloves would prevent the pesticides from ever touching your skin.

Wearable

Comfortable gloves help farmer's work longer because their hands will not hurt from completing your task. Sizing is very important when finding comfortable gloves (Melco, 2016). Make sure gloves are the proper length and width, as not to restrict movement. There will be less pain from pulling weeds and they will be able to pull more weeds because they would not have to wait a long for the pain to subside between pulling each weed, because there will be no pain if wearing gloves (Food and Agriculture Organization, 2016). If farmer's find they are working hard and their hands start to sweat the gloves should be removed , dry your hands, and put on a new pair. Cloth gloves are more breathable then rubber ones, using them is another way to prevent hands from getting sweaty. The cloth gloves can also be softer and easier to clean, but are more restricting to movement due to their durability and tougher material. Since children will also be farming, smaller glove sizes can be found. Gloves are designed to fit a farmer's hand snugly, so children should not wear adult sized gloves when working.

Constraints To Adoption

Gloves are very useful to farmers, but there can still be some drawbacks. Possible culturable taboos might vary from location to location. Gloves might seem feminine and not easily adopted by men in the community. Gloves act as a second, tougher skin, but they are not a farmer's skin and can slide around while working. This may feel odd and uncomfortable but farmers can get used to the new feeling over time. Gloves can come in many colours and thicknesses, which may make a farmer's hands look funny or larger. Human skin is very stretchy and flexible, while glove materials tend to be tougher than skin and will reduce movement, but not enough to hinder work. Rubber gloves can stretch well, but make hands sweat, while cloth gloves are breathable but reduce dexterity.

Farmers can find gloves to use and get started from local vendors (European Commission For The Control Of Foot-And-Mouth Disease, 2016). Once you have completed your work for the day you can clean them are reuse them, or dispose of them if they were ripped or torn (Kim, *et al.*, 2013). You can get gloves made of rubber and like materials as well as ones made of durable cloths. The thin rubber gloves tend to be made for a single use only. A trick that the European Commission For The Control Foot-And-Mouth Disease mentions that you can wear two pairs of rubber gloves at the same time for extra protection (European Commission For The Control Of Foot-And-Mouth Disease, 2016).

Helpful Links To Get Started

Here are websites to find more information about how to obtain gloves:
www.alibaba.com
www.indiamart.com
www.store.nzfarmsource.co.nz
www.adenna.com
www.farmcity.co.za
www.crazystore.co.za

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2.3 – Soaking seeds before planting (seed priming)

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Introduction

There are many problems that subsistence farmers face all over the world. One major problem that affects both yield and income equally is low germination rates for several important crops. “In the semi-arid tropics, … unpredictable and erratic rainfall, poor soils, [and] low quality seeds” contribute to low germination rates; so as a result, many farmers are forced to plant 2-3 seeds per hole while only expecting one of these seeds to properly establish itself in the soil (DFID, 2000). Poor crop establishment also occurs because these seedlings are unable to outcompete weeds for nutrients in the soil as well as for water and sunlight. The transition from seed to seedling is a very fragile one. If a seed is to grow properly, seeds must germinate and emerge, both fast and consistently in the field so that the seedlings can maximize the growing benefits from water, light and nutrients from the soil (CAZS, 2007). A very simple intervention that farmers can use to improve germination as well as strengthen their seedlings is to soak their seeds in water before planting them. This chapter will describe seed soaking and its benefits, provide a breakdown of methods including correct usage, discuss the issues with seed soaking, as well as provide alternatives to using water to soak seeds.

Description of seed soaking

Seed soaking is a very simple intervention to both understand and to put into practice. This practice includes soaking seeds in water for a prescribed amount of time, drying them, and then planting. “Seeds that are pre-hydrated and then surface-dried have a better chance of absorbing water from the soil because they germinate more quickly and the roots they produce grow faster, seeking moisture deep in the ground” (DFID, 2007). Once seeds are soaked and dried, they can either be immediately sown into a field, or they can be kept in storage for several days if weather conditions delay planting (DFID, 2007).

Benefits to seed soaking

There are many benefits to soaking seeds before planting. First, soaking seeds mainly increases germination rates among many different crops. Studies and farmers have reported, “that primed crops emerge faster, grow more vigorously, and in some cases use less fertilizer” (DFID, 2000). These effects allow seedlings to outcompete weeds for water, light and nutrients from the soil, which in turn suppresses weeds and makes crops less susceptible to disease (CAZS, 2007; Anwar et al., 2012). Next, because uniform germination is much higher when seeds are soaked, farmers can increase their overall yield because, rather than planting 2-3 seeds per hole, they can plant 1 seed per hole, thus giving farmers more seeds to plant, and more yield (reported yield increases have ranged from 20% to >200%) (CAZS, 2007). After soaking chickpea seeds for 16 hours and then drying them to approximately 30% moisture content, there was a reported 40% yield improvement than when seeds were not primed (Ghassemi-Golezani, 2008). Furthermore, soaked seeds are reported to emerge faster (approximately 1-3 days sooner), flower and mature earlier (up to 10 days sooner), which means that if there is a second crop being planted, it can also be planted sooner (CAZS, 2007; Ibrahim, et al., 2013). In a study conducted regarding soaking wheat seeds, seeds that were not soaked reached 50% emergence in approximately 5.5 days, whereas seeds that were soaked for 8 hours reached the same stage at approximately 3.5 days (Murungu, 2011). Upland rice also had similar results – when seeds were not soaked there was a 59% germination rate of seeds planted. However, when seeds were soaked for 12 hours and dried for 2 hours, there was a 78% germination rate among planted seeds (Ibrahim, et al., 2013). Moreover, this practice allows farmers to sort their seeds at the same time and remove those seeds that float to the top because they are deficient or diseased from those that sink to the bottom and should be planted (IRRI, 2016). Finally, there is essentially no cost and low-risk associated with seed soaking, so "it should be very attractive for farmers to prime their seed as a form of insurance" (Rajbhandari et al., 2014).

How to: Seed soaking

Submerge seeds to be planted in a bucket of water.
Once placed in water, remove the seeds that float to the top as they are diseased or defective and will not grow properly if planted.
Consult a 'safe-limit' table to determine the proper amount of time to soak seeds. Do not soak for less or more time than is recommended.
Dry seeds after the soaking period, either by laying them in the sun or by using a cloth.
Sow seeds immediately, or store them in a dry location if sowing is delayed (IRRI, 2016).

Correct usage

The most important aspect of seed soaking has to do with the amount of time that the seeds are soaked for. In order for seed soaking to have a positive effect on germination, the seeds cannot be under or over soaked. If seeds are under soaked, they will not realize all the benefits of seed soaking and if seeds are over soaked, they have the potential to germinate before being planted. This causes new problems for subsistence farmers because they are no longer sowing seeds, but rather transplanting seedlings. The Centre for Arid Zone Studies at Bangor University researched the prime soaking time for many different tropical crops. Table 1 shows these recommended soaking times.

Table 1. Recommended soaking times for tropical crops (reproduced from CAZS, 2007)

Tropical Crop	Soaking Time (in hours)
Bambara groundnut	8
Chickpea	8
Finger millet	8
Lentil	12
Maize	12 - 18
Mungbean	8
Pearl millet	10
Sorghum	10
Upland rice	12 – 18
Wheat	12
Barley	12
Cowpea	8
Groundnut	8
Horsegram	8
Linseed	8
Pigeonpea	8

The majority of crops require 8 hours of soaking before it will make a viable difference to their germination and growth. For most farmers, this would entail soaking the seeds overnight and then using the next day to dry them.

Critical analysis

There are some issues that are associated with soaking seeds before planting. First, while it may not cost farmers much in terms of money, it does take time to soak the seeds and dry them. Many farmers are eager to plant when they anticipate the beginning of the rainy season, and are thus unwilling to wait the prescribed soaking and drying period for each crop. However, when seeds are initially planted, they spend a large amount of time simply absorbing water, so soaking seeds actually jumpstarts the planting process (DFID, 2000). As well, this does take extra labour to soak and dry seeds before planting them. However, it is important that seeds are dried properly, especially if farmers are using any form of sowing machinery, such as a jab planter. If seeds are wet, they will clump together and not plant properly. Many farmers are hesitant to put this practice into their collection of farming customs, especially because they find it difficult to believe that something so simple can have such an important and substantial difference (DFID, 2000). Despite that, much of the research has shown that by encouraging farmers to soak some of their seeds for the prescribed amount of time and plant them beside their seeds that were not soaked, these farmers were able to experiment and share the practice with other farmers in their area (DFID, 2000). There is a need for education for subsistence farmers so that they understand the great benefits that can be realized by such a simple and low-risk practice.

Alternatives to water

While soaking seeds in water alone provides many benefits to farmers, there are alternatives to water that could be used to supplement plant growth, especially in areas with sandy or nutrient deficient soils. Some important nutrients that have been identified that can be added to the water while soaking includes, in the case of legume seeds, phosphorous, molybdenum, zinc, and bacteria like rhizobia (DFID, 2007). This intervention "gives farmers better control because micronutrients [molybdenum and zinc] are difficult to apply evenly to the soil, [and] it also makes the amounts needed much smaller [because] they are absorbed directly by the primed seed" (DFID, 2007, p. 5). Adding nutrients directly to the water means that farmers can spend less money on fertilizers as well as spend less time spreading these fertilizers. This also means that these nutrients are applied evenly to all seeds and that their capacity to support plant growth is fully maximized.

How to get started: Useful links

Seed Priming – The GAIA Movement:
http://www.gaia-movement.org/files/Booklet%2029%20Priming.pdf

A sure bet: seed priming and participation – DFID:
https://assets.publishing.service.gov.uk/media/57a08bf5ed915d3cfd00108a/RIU_pocketguide_9.pdf

On-Farm Seed Priming: Soaking Times – CAZS Natural Resources:
http://seedpriming.bangor.ac.uk/ccstudio/Background/Background_page4.php?id=350

How to treat seeds (Rice seeds) – International Rice Research Institute:
http://www.knowledgebank.irri.org/index.php#seed-dormancy

Priming gets rice off to a good start in upland Africa and Asia:
https://assets.publishing.service.gov.uk/media/57a08be340f0b64974000e4a/PSP25.pdf

Seed priming makes good stands of maize the rule rather than the exception:
https://assets.publishing.service.gov.uk/media/57a08bdded915d622c000f59/PSP28.pdf

A low-cost boost for crops in poor soils:
https://assets.publishing.service.gov.uk/media/57a08bdee5274a31e0000e1e/PSP30.pdf

Seed priming in wheat, barley, sorghum, pearl and finger millet in South Asia and Africa:
https://assets.publishing.service.gov.uk/media/57a08be3e5274a27b2000e2b/PSP27.pdf

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2.4 - Sowing seeds in rows (line sowing)

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Introduction:

Traditionally, subsistence farmers have utilized a method known as broadcasting to sow seeds. Generally, broadcasting involves manually dispersing seeds throughout the field by throwing handfuls over the soil. In order for farmers to obtain a substantial yield with broadcasting, seeds must be sown at a relatively high density. Since the seeds were dispersed on the soil surface, some seeds could be lost to birds or field run-off during rainstorms (Johansen, Haque, Bell, Thierfelder, & Esdaile, 2012). Alternatively, line sowing involves sowing seeds in uniform rows either manually or with machinery (Food and Agriculture Organization, 2007). This sowing method allows for higher yields due to reduced plant competition for sunlight, water, and nutrients. Additionally, sowing seeds in rows allows for enhanced weed and pest management since farmers can more easily move through the field to removed weeds and monitor crops for pests or disease (Barberi, 2002).

Benefits of Line Seeding:

Sunlight, water, and nutrients are all essential components to the development and growth of plants. Plants absorb sunlight using the photo pigments in their leaves, which is then converted into energy for growth (Maddonni & Martinez-Bercovich, 2014). Depending on the plant species the efficiency of this conversion process differs slightly (Tesfaye, Walker, & Tsubo, 2006). When plants become too crowded, competition for access to sunlight, nutrients, and water ensues. Unfortunately, many farmers sow their crop seeds at a higher density than what is recommended by their local extension services resulting in increased levels of plant stress and the subsequent reduction in crop yields (Wiyo, Kasomekera, & Feyen, 1999). Access to sunlight plays a major role in determining crop yield as it is essential to plant growth. A study conducted by Maddonni and Martinez-Bercovich found that maize grain yield is primarily determined by kernel number per unit land, which is positively correlated with the amount of photo synthetically active radiation intercepted by the leaves (2014). Plants, which emerge earlier, will have competitive advantage in this situation, surpassing the others in growth and eventually blocking the surrounding plants access to sunlight (Maddonni & Martinez-Bercovich, 2014). The larger the size of the leaf and the shorter the period required for leaf development will allow for greater radiation interception. Singels and Smit conducted research on sugarcane and row spacing, finding that leaf development is affected by row spacing (2009). The higher rates of leaf development occurred in the wider rows, indicating that plants require adequate space to access sunlight and nutrients required for growth (Singels & Smit, 2009). Similarly, plants, which are able to develop their root systems earlier, will have greater success in obtaining the scarce water and nutrients vital for growth (Barberi, 2002). The practice of sowing seeds in lines allows for optimum sunlight exposure, and soil water utilization. Maddonni and Martinez-Bercovich discovered that grain yield reductions were most prevalent in fields where crops were planted in higher densities (2014). In addition, broadcasting tends to require a higher seed input to compensate for losses, making line sowing a more beneficial choice when seed prices are high.

Sowing in rows enables farmers to monitor their crops for signs of pests or pathogens and have greater access to weeds. This aspect is extremely important as an unnoticed or untreated pest or pathogen could wipe out yields leaving the farmer with no income or food for that season. Common bean (Phaseolus vulgaris L.), cowpea (Vignaungviculata L.), chickpea (Cicer arietinum L.), and pigeon pea (Cajanus cajan L.) are major grain legumes grown in semi-arid regions (Tesfaye et al., 2006).

These legumes are a primary source of dietary protein and income for subsistence farmers. The dry matter production and subsequent yield has been found to be highly associated with the fraction of PAR intercepted by the plant (Tesfaye et al., 2006). Studies conducted by Barberi using pigeon pea (Cajanus cajan L.) found that an inter-row distance of 40-50 centimetres allowed for optimal grain yields per unit and hoeing between rows (2001).

How to Practice

A simple method that can be employed to sow seeds in rows involves the use of string and wood stakes. Depending on the region and species being planted row spacing will vary. Measuring the dimensions of the field is recommended to ensure uniform spacing between rows (Food and Agriculture Organization, 2007). To ensure the rows are straight, tie the string to two wood stakes and place the stakes at either end of the field making sure that the string is tight. The string acts to mark where the rows will be planted, acting as a visual guide for the sowing process. The seeds can either be dribbled into the furrows and covered over or put into a hole, which is created using a hoe (Food and Agriculture Organization, 2007). The method involving the use of a hoe to dig holes is typically used for larger crops, which require greater spacing between crops (Food and Agriculture Organization, 2007). Mechanized tools are also available to farmers at a relatively low cost. Jab planters enable the farmer to plant seeds into untilled soil, eliminating the labours tasks of digging holes and bending down to plant the seeds (Johansen et al., 2012). However, using this tool can bring challenges such as the tip becoming clogged with soil, taking away from its intended efficiency (Johansen et al., 2012). In order for line sowing to be most beneficial it must be employed with a corresponding weed suppression strategy such as a cover crop or herbicide treatment.

Challenges:

Although planting seeds in rows is beneficial for yield levels it is also considerably time consuming. If farmers use manual line sowing methods they will have to prepare the field for sowing with a hoe before they can distribute the seeds. Compared to broadcasting seeds, line sowing requires significantly more time and labour, which may deter farmers from adopting it into their practices. This especially true in the case of lower value crops. However, a farmer may be more inclined to adopt line-sowing practices for higher value cash crops. For instance, farmers will almost always adopt line-sowing practices in the case of many fruits and vegetables, which are high in labour, value, input, and susceptible to pests and disease. Whereas, low value cereals and legumes are more likely to be broadcasted since the perceived benefit of adopting line sowing is not as high as in fruits and vegetables. Broadcasting seeds at higher densities can also be beneficial in suppressing weed populations. If a farmer does not have the time or labour available to keep up with the weeding of their fields broadcasting may be a better option. The field being used by a farmer is not always located near their house, limiting access and time available for weeding making broadcasting more attractive. Line sowing permits spaces in-between the rows of crops in which weeds can grow, where as, broadcasting leaves little space for weeds to develop. Furthermore, broadcasting can be successful in muddy soils, whereas, line sowing, which may require machinery or a jab planter, tends to be problematic. Depending on the land, line sowing may require both the jab planter and plough to loosen the soil first, whereas, broadcasting may need no field preparation. When deciding between line sowing and broadcasting it is very important to consider the crops being grown. Some crops can be quite successful in mixed broadcasting, while other such as corn struggle due to shading.

Further Reading:

http://teca.fao.org/read/7301

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Chapter 3 - Crop and tree intensification

3.6 - Grafting to improve tree propagation

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Introduction

Grafting is a horticultural technique that holds much promise for farmers around the world. To graft, a branch of a tree or shoot of a plant is cut ("scion") and joined onto a decapitated rootstock ("rootstock"). In a successful graft, the vascular tissues of the scion and rootstock will fuse together. With trees or perennials, a primary benefit of grafting is that it permits rapid propagation of a shoot that has desirable characteristics (e.g. desirable fruits) by taking advantage of an already established root system. Grafting allows mixing and matching of traits from different cultivars (e.g. rootstock that is disease resistant to a shoot that bears desirable fruits). Grafting can usually only take place between two plants of the same genetic family. For instance, successful grafting can occur between plants of the *Solanaceae* family which includes tomatoes, eggplants, potatoes and tobacco (Kudo, 2007). Remarkably, grafts can be successful not only within the same species (e.g. tomato with tomato) but also between species (e.g. tomato with eggplant).

One of the main reasons that a plant would be grafted would be out of a desire to maintain certain characteristics of a plant, such as in a fruit tree that would otherwise produce asexually. The offspring of an apple tree, for instance, are not very likely to mimic the parent in terms of flavor, texture. By grafting a branch of the tree with the desired fruit onto a rootstock, the fruit of the resultant tree will be highly similar to those of the parent, and allow for predictable cultivation of specific 'varieties' at a large scale.

Grafting is an effective way to not only replicate traits that are culinary, but also agricultural traits such as drought tolerance, cold tolerance, and salinity tolerance, amongst others. For example, rootstock of a plant may have good tolerance to the cold, but may produce less fruit than another variety. When the 'scion' of the highly productive plant is placed on the 'rootstock' of the cold hardy plant, the plant will often survive and become both cold tolerant and highly productive (Mudge, 2009).

Grafting allows for individual fruit farmers to respond to market changes faster than if they were to plant a young tree, since fruit will be produced quicker from the combination of mature rootstock and scion than from a younger tree (Hart, 2005). Consequently, there remains a stronger possibility that this individual will have access to larger markets and higher asking prices for in-demand fruits and vegetables.

Some trees, such as the Baobob tree from the Sahel countries of Africa, are grafted quite easily, with success rates ranging from 80-95% (Maranz, 2008). However, this is not consistent across all species, and does not account for the 'learning curve' in practicing proper technique. Maranz (2008) notes that 'exotic' varieties of Baobob (those from other Sahel countries) have superior nutritional benefits, and determines that grafting represents an interesting possibility for developing a market for the new varieties, since the local variety has far superior basal diameter, tree height, and resistance to termites. Assah (2011) details the possibility of an emerging market for three novel *Alanblackia* species in Africa for its nutritive, medicinal, cosmetic, and detergent properties. These species could be grafted onto locally available rootstock for local production to take place. Mudge (2009) details the grafting of Ceara rubber tree onto a cassava rootstock, for the purpose of invigorating the rootstock. The resulting yield of cassava tubers was increased by 30-100% depending on the combination of species.

Critical analysis

Grafting at a large scale is labour intensive, and does require some training. The success rate of grafting is highly variable depending on species; research should be performed on the specific species to determine average success rates, or a test plot should be initiated (Mudge, 2009).

There is an ongoing debate about the possibility of the transference of genetic material from scion to rootstock and how this affects the 'heritage' of traditional varieties (Mudge, 2009).

Practical tips

The University of Minnesota has a comprehensive manual on grafting, including timing, species selection, and materials needed.

The University of Arizona publishes free 'how-to' videos on vegetable grafting. While limited to tomatoes, curcubits and eggplants, many of the principles remain the same.

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Chapter 4 - Terrace agriculture

Chapter 5 - Soil health

5.1.1 - Soil testing

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Introduction

The purpose of applying fertilizer to a field is to replace the nutrients that are removed by crops. On most soils, crops will benefit from application of the macronutrients every year. Micronutrients on the other hand are generally removed by crops at a low enough rate that application is not necessary in every season. To apply fertilizers most efficiently, a farmer should ideally know the approximate level of each nutrient in the soil. Soil nutrient levels are most commonly determined through nutrient extraction tests that require specialized equipment and training to perform. Although many of these testing methods are highly accurate, they are generally impractical for poor farmers. Unfortunately, the need for more accessible methods of accurately determining soil nutrient levels has gone largely unanswered. When proactively testing soil nutrient levels is not possible, there are simple ways to characterize the soil and plan its management. Several of these low-tech methods for soil characterization are described below. It should be kept in mind that these techniques, while useful, cannot take the place of conventional soil testing, which should be taken advantage of if available. “On the spot” soil test kits are available that employ colour changing indicators to show soil fertility levels. Although these kits are inexpensive and do not require specialized training or equipment to use, the accuracy of these kits varies widely. In a comparison of the results of 5 different home soil test kits sold in the US to laboratory analysis of the same soil, agreement between the home soil test kit results and laboratory results ranged from 33% to 94% (Faber, Downer, Holstege, & Mochizuki, 2007). The accuracy of nutrient indication also varied between minerals with the accuracy of potassium levels being most consistent and the accuracy of phosphorus levels being the least consistent (Faber et al., 2007). Only pH and macronutrient levels were indicated by the kits tested. It should be noted also that most home test kits indicate soil nutrient levels to be simply “low”, “medium”, or “high”, rather than providing specific values from which the most efficient fertilizer rate could be calculated. For further information on important characteristics to look for in an accurate soil test kit, please see the work of Faber et al., (2007) entitled “Accuracy Varies for Commercially Available Soil Test Kits Analyzing Nitrate–Nitrogen, Phosphorus, Potassium, and pH”. It is important to keep in mind that home soil test kits are not as accurate as laboratory analyses, and should only be employed where more accurate laboratory testing is not available.

To determine if laboratory soil testing is available in a given area, the best course of action is generally to contact the regional or national ministry of agriculture, or local agricultural universities where they are present. These institutions often have internal soil testing labs or may be able to provide contact information to local soil testing labs.

The timing of soil testing can be very important. Some forms of mineral nitrogen (e.g. nitrate) is extremely mobile in the soil and for this reason soil testing (if possible) should be done within a few days of fertilizer application to ensure the test results are still accurate. Mineralization of organic nitrogen and loss of nitrogen to the environment will quickly cause variation from the test levels. Mineral nitrogen can easily be lost within a few days if there is no vegetation to absorb it (*Principals of Plant Nutrition*, 2001). Nitrogen loss is promoted following heavy rainfall causing leaching, and through conversion to gas when oxygen is unavailable (e.g. when a clay soil is waterlogged) (*Principals of Plant Nutrition*, 2001).

Areas such as Africa and South Asia that have not (on a geological time scale) been recently glaciated tend to have soils with lower nutrient holding capacities and overall lower nutrient contents (Lotter, 2010). Although there is variation between areas, this general trend will pervade in most soils within these regions. Global maps of soil characteristics such as depth, pH, dominant soil type, etc. are available from the FAO at http://www.fao.org/nr/land/soils/en/. It should be noted that these maps indicate the general trends in soil types within an area, but one should expect variation within these trends when individual fields are investigated.

The underlying bedrock material will have a strong influence on a soil's mineral content, particularly for potassium, phosphorus, and calcium and this should be considered when planning the management of a soil. Local departments of geology, where established, will often be able to provide information on local bedrock composition.

Soil Nutrient Diagnosis Using Plants

The most effective method of determining whether or not a given fertilizer will have a beneficial effect on crop growth is through doing a small split-plot trial. To do this, a small test plot should be established in which half receives a consistent application of the test-fertilizer, and the other half does not. The management of the entire plot should otherwise be as consistent as possible, and ideally the farmer should not know which half of the plot is which to encourage consistent management. If the application of fertilizer is found to cost-effectively improve crop yields, then wider use of the fertilizer can be considered.

Alternatively, the easiest way to recognize nutrient deficiencies in crops without specialized equipment is through observing symptoms of deficiency as they develop in crops. However, this is not the most ideal method of recognizing nutrient deficiency as by the time a shortage becomes observable in a crop it may be too late for fertilizer application to improve growth in that season. Also, many plant nutrient deficiencies have similar symptoms and thus can be confused with one another. However, where soil testing is not practical this method may be the most effective way to learn which nutrients are most needed in a given field. Links to image galleries of nutrient deficiencies as they appear in common crops are provided at the end of this chapter.

Table 1, below, provides descriptions of nutrient deficiencies as they appear in crops. The relative speed with which a given nutrient is transported through the plant affects where the deficiency will be exhibited. In general, deficiency of nutrients the move through plants relatively slowly will appear in new leaves and shoots, and deficiency of highly plant-mobile nutrients will appear in older leaves and the lower stem. Recognizing the relative mobility of the deficient nutrient can help narrow down the possible range of nutrients that are limiting crop growth.

Table 1: General symptoms of mineral deficiencies

Mineral	Plant Mobility	Symptom Location	Symptom Appearance	pH reaction	Deficiencies with Similar Symptoms	Notes
Nitrogen	High	Older growth (lower leaves)	Yellowing leaves, leaf drying starting at tips	Low pH (<6.3) will can cause deficiency in legumes, high pH (>8) will encourage volatilization loss		Highly prone to loss by both leaching and gasification
Phosphorus	High	Older growth (lower leaves)	Purple or red discolouration	More mobile in the soil (thus more plant available) at lower pH		Deficiency is common in early growth when root system is small
Potassium	High	Older growth (lower leaves)	Drying/ death of leaf tips and margins, weak stalks (toppled plants)	More prone to loss at lower pH	Nitrogen over-application can also cause plants to topple	
Secondary Nutrients						
Sulfur	Medium	Entire plant	Overall yellowing, thin stems			Highly prone to loss by both leaching and gasification
Calcium	Low	New growth (higher leaves)	Dead tissue at fruit and leaf tips			
Magnesium	High	Older growth (lower leaves)	Yellowing between veins, curling of leaf edges			

Mineral	**Plant Mobility**	**Symptom Location**	**Symptom Appearance**	**pH reaction**	**Deficiencies with Similar Symptoms**	**Notes**
Micronutrients						
Molybdenum	Higher	Older growth (lower leaves)	Yellowing between veins	Less available at low pH	Nitrogen, especially in legumes	Molybdenum deficiency will interfere with N fixation in legumes
Boron	Low	Tips of leafs and fruits	Death of newer growth, misshapen leaf and fruit tips	More available at low pH		Prone to loss via leaching
Manganese	Low	Younger growth (upper leaves)	Yellowing between veins	More available at low pH	Zinc, Iron	
Iron	Low	Younger growth (upper leaves)	Yellowing between veins, pale plant colour	More available at low pH	Manganese, Zinc	
Zinc	Low	Younger growth (upper leaves)	Yellowing between veins, poor leaf growth	More available at low pH, can cause toxicity at extremely low pH	Manganese, Iron, phosphorus	Deficiency can cause phosphorus uptake issues, may appear as phosphorus deficiency
Copper	Low	Younger growth (upper leaves)	Yellowing leaves, weak stalks	More available at low pH		Rarely a limiting factor, toxicity is more common

Programs for cell-phones and other mobile devices that provide photo galleries of crop nutrient deficiency symptoms are also useful tools. The International Plant Nutrition Institute (IPNI) offers a Crop Nutrient Deficiency Photo Library that can be downloaded for about $5 (see below). Programs such as this are convenient because they enable on the spot comparison of field conditions to reference photos. The application “Learning Plant Language” from Agronomic Acumen serves a similar purpose, and is available for about $30. The International Potash Institute offers a free App that provides a photo gallery of potassium deficiency symptoms for various crops. The “Nutrient Removal Application” from Ag-PhD is another useful tool that provides estimates of nutrient removal rates of different crops based on yield. Links to these tools are provided below.

Soil nutrient concentrations can significantly vary over a small area, and for this reason symptoms of nutrient deficiency may appear in patches throughout a stand of crops. If patchy symptoms are observed in a field, subsequent soil testing should be performed to compare nutrient levels between areas where deficiency is exhibited and areas where it is not, if possible. When patches of deficiency symptoms are observed, these areas should be prioritized for subsequent application of the apparently deficient nutrient. Applying fertilizer only to areas that exhibit crop deficiency symptoms can also be considered if additional methods of soil testing are not available, or if the nutrient considered to be deficient is in short supply.

It should also be kept in mind that non-nutrient related challenges to the growth of a crop can create the impression of a mineral deficiency. For example, pests such as nematodes can damage a crop’s root system, limiting its nutrient uptake capacity and thus creating the appearance of a mineral deficiency despite potentially sufficient levels of that nutrient in the soil. Many crop diseases can also cause symptoms that are similar in appearance to nutrient deficiencies. For this reason, field testing with a reliable soil test kit or ideally through the establishment of a trial plot (described above) are important tests to perform when nutrient deficiency is suspected.

There is likely potential to understand soil nutrient balances through observing which wild species tend to do well on a given field. The available literature suggests that indicator species are generally used to estimate overall soil fertility, a measure which is obscured by the influence of many different factors. Unfortunately, there is little available information that associates indicator species with deficiencies or abundances of specific nutrients. Indicator species could perhaps be used as indicators of less variable soil characteristics such as cation exchange capacity, pH, and structure, which are each explained in greater detail below. Further investigation, ideally combining indigenous knowledge with modern nutrient testing, may help illuminate the use of wild plant populations to estimate soil nutrient levels.

Texture Diagnosis
Soils can be broadly classified according to texture. Texture refers to the average size of the individual particles that make up a soil. Coarse, sandy soils are mostly made up of relatively large particles and heavy clay soils are mostly made up of relatively small particles. The particular mixture of particle sizes will affect the behaviour of water, nutrients, and plant roots within a given soil.

Knowing the texture of a soil is important in determining an appropriate fertilization rate. In general, sandier soils (sometimes referred to as “red soils”) have lower nutrient holding capacities, because their larger size results in a lower surface area to bind nutrients for a given volume (*Principals of Plant Nutrition*, 2001). This means that nutrients are more likely to drain from these soils and be lost, and for this reason less fertilizer should be applied to sandy soils at a time. Conversely, soils that are heavy in clay (sometimes referred to as “brown” or “black” soil) can hold more nutrients at a time, and are less prone to nutrient loss, because their small particle size translates into a large surface area for binding of nutrients (*Principals of Plant Nutrition*, 2001).

The texture and related water holding characteristics of a soil will often dictate which crops will be produced. For example, rice paddy production, which requires saturated conditions, generally takes place on clay soils. On the other hand, crops with underground edible organs such as peanut and cassava are typically grown on sandy soils as the quicker drainage in these soils discourages root rot. Soils near the equator tend to be coarsely textured although there are exceptions to this trend. For many crops, the ideal soil will be a mixture of both sand and clay commonly referred to as loam.

There are several methods commonly employed to determine soil texture. The most common method is the hand texture test. Hand-texturing is performed by adding a small amount of water to a soil sample and observing how well the soil mass stays together when rolled between the thumb and fingers. If the soil clumps, it is high in clay, whereas sandy soils will not clump together and are coarse to the touch. Specific directions for diagnosing a soil through this method are available from the USDA at: http://soils.usda.gov/education/resources/lessons/texture/

Soil texture can also be determined by submerging a soil sample in water, mixing it thoroughly, and observing the period it takes for the soil to settle. Sand particles will settle in a few minutes, whereas clay particles can remain suspended in water for up to 24 hours before sinking, because of their finer size and hence weight. By observing how much of the soil sample has settled at several points over a 24 hour period, the approximate texture of the soil can be determined. The procedure for this method is explained in more detail at: http://www.nce-mstl.ie/files/Ag_Sc_posters/Agricultural%20Science%20poster%20Soil%20texture%20by%20sedimentation.pdf

Drainage

Soils can become compacted over time due to many factors including the absence of roots in the soil, the frequency and method with which a soil is tilled, and overall traffic overtop the soil. Although tillage will reduce compaction temporarily, it can also encourage future compaction of the soil by disrupting its internal structure. Compaction creates several challenges to the growth of crops, particularly through limiting the passage of water and air into lower levels of the soil. In extreme cases, compaction can create waterlogged soil conditions under which crop root systems will become deprived of oxygen and eventually die. The risk of soil compaction becoming problematic is higher with finely textured clay (brown or black) soils than with sandy soils.

The drainage rate of a soil can generally be estimated with reasonable accuracy through direct observation. To do this, several holes of varying depths (up to the approximate maximum rooting depth of the crop) should be dug throughout the field. Information on the maximum rooting depths of various crops is available from the FAO at http://www.fao.org/docrep/X0490E/x0490e0e.htm. When a hole is complete, a small amount of water (at least a cup) should be poured into the hole. If the water is quickly absorbed into the soil, it is reasonably safe to assume that no significant compaction of the soil has occurred at that soil depth. If water is observed to pool in the hole before being absorbed however, then compaction has likely occurred at that depth. It is important to note that compaction at one level will inhibit the entry of water and air into lower levels of the soil, even if the lower levels are not compacted.

An effective way of reversing compaction is through establishing deep rooted cover crops that can loosen the soil and provide organic matter through a range of soil depths. Tillage can also be a temporary solution to compaction however it is important that root systems are established within the soil shortly after tillage in order to rebuild soil structure before compaction re-occurs.

It should be noted that in some systems such as paddy rice production, compaction and stagnant water atop the soil may be desirable. The specific goals of local production practices should always be considered before suggesting new crop management strategies.

Salinity and Conductivity

"Salinity" refers to the degree to which salts have accumulated in a soil. Saline soil is generally undesirable for the growth of most crop species because it interferes with water absorption by roots and can also cause biological imbalances when salts are taken up in soil water. The concentration of salts within a soil is generally measured by passing an electrical current between two conductors placed within a soil sample and measuring how effectively that current is transferred. As the presence of salts will facilitate electrical conduction within a soil, more salinized soil will have higher conductivity values. Easy to use tools known as conductivity meters (costing $85 and up) can be purchased to estimate this soil property (see below). The supplier Grainger offers several different models of conductivity meter of varying costs and can ship their products internationally. Their catalogue can be accessed online at http://www.grainger.com/Grainger/wwg/search.shtml?searchQuery=conductivity+meters&op=search&Ntt=conductivity+meters&N=0&GlobalSearch=true&sst=subset. The presence of saline soil conditions will also be indicated by a white crust forming on the soil surface during dry conditions. If salinity is apparent within a soil, the management regime should be redesigned to minimize or eliminate potential sources of salt addition and to facilitate flushing out salts that are already present in the soil.

Coastal areas are at especially high risk of soil salinization because of the entry of salts from seawater into adjacent ground water. Additionally, areas that have been heavily irrigated or fertilized (e.g. China) often face issues with salinity because of salt-impurities in the various additives (including slightly saline irrigation water) that have been used.

Salt tolerant cultivars of various crops have been developed, and variation in salinity tolerance between different cultivars of the same species has been widely observed (El-Akhal et al., 2013; Garg & Chandel, 2011; D. L. N. Rao, Giller, Yeo, & Flowers, 2002; Rashid, Qureshi, Hollington, & Wyn Jones, 1999). Cultivars that are salt tolerant can be obtained from national breeding programs and CGIAR institutes (http://www.cgiar.org/cgiar-consortium/research-centers/).

Soil Acidity and pH

The acidity of a soil will affect the availability of the plant nutrients it contains as well as have a direct effect of the growth of plants. pH can be approximately measured using litmus paper.

Organic Matter

The organic matter content of a soil refers to the fraction of the soil that has been derived from the breakdown of once living (organic) material. The presence of organic matter in a soil increases its resistance to compaction, its ability to retain water and nutrients, and provides a highly beneficial bank of nutrients that release slowly over time, reducing the need for synthetic fertilizers. The approximate level of organic matter in a soil can be assessed through observing the smell and colour of a soil. Soil that has higher levels of organic matter will have a more distinctive "earthy" smell than soils low in organic matter, which tend to be odourless. Most organic matter is dark in colour and thus a darker soil can often indicate higher levels of organic matter. When using colour as an indicator, the colour change within a field over time will be more accurate than comparisons between different fields because other soil characteristics (such as texture) that will vary between fields can also influence their colour.

Crop residue and manure are good sources of organic matter that will increase the fertility of a soil over time. Most organic matter will eventually be broken down to carbon dioxide as it is consumed by micro-organisms within the soil. For this reason, some form of new organic matter should ideally be added to a soil every season to replace that which is being lost. Organic matter usually contains nitrogen and phosphorus as a part of larger carbon-based molecules that are not immediately available to plants. As organic matter is broken down over time, these nutrients are released in the form of simple molecules that can be used by plants. Thus, regular addition of organic matter and minimizing removal of crop leaves and stems from the field can help to prevent nutrient deficiencies. However, it must be kept in mind that even when organic matter is being added to a soil on a regular basis, there is potential for nutrient deficiencies to develop if the organic matter being added to a soil contains less of a given nutrient than a crop removes. For this reason, the regular inspection of crops for symptoms of nutrient deficiency is recommended even when organic matter is being regularly applied.

Useful Links

The FAO report "Simple soil, water, and plant testing techniques for soil resource management" provides a detailed overview of different soil testing methods (both laboratory and field techniques) and their applicability to use in Africa. This report is available online at:
ftp://ftp.fao.org/agl/agll/docs/misc28.pdf

FAO information on rooting depths of common crops:
http://www.fao.org/docrep/X0490E/x0490e0e.htm

Images and Descriptions of Nutrient Deficiency Symptoms for Different Crops

Rice: http://www.knowledgebank.irri.org/RiceDoctor/information-sheets-mainmenu-2730/deficiencies-and-toxicities-mainmenu-2734/nitrogen-deficiency-mainmenu-2749.html

Wheat: http://wheatdoctor.cimmyt.org/index.php/en/nutrient-problems/identification-key
http://cropwatch.unl.edu/web/soils/nutrient-deficiency-wheat

Corn/ Maize: http://maizedoctor.cimmyt.org/index.php/en/component/content/article/147-mineral-nutrition

Banana: http://r4dreview.org/2013/01/isfm-for-banana-systems/

Soybeans: http://cropwatch.unl.edu/web/soils/soybean-nutrients

Sorghum: http://cropwatch.unl.edu/web/soils/keysnutrientdef

iPad iPhone nutrient apps: Note that a compatible mobile device is required to use these applications as they will not run on most personal computers

“Crop Nutrient Deficiency Photo Library” from the International Plant Nutrition Institute: http://www.ipni.net/ndapp

“Learning Plant Language” from Agronomic Acumen: https://play.google.com/store/apps/developer?id=Agronomic+Acumen&hl=en

“K gallery” (potassium deficiency image guide) from The International Potash Institute (somewhat limited, but free): https://itunes.apple.com/ca/app/k-gallery/id557224524?mt=8

The “Nutrient Removal Application” from Ag-PhD provides estimates of nutrient removal rates of different crops based on yield: http://www.agphd.com/resources/ag-phd-mobile-apps/ag-phd-nutrient-removal-by-crop-app/

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5.1.2 - Litmus paper and liming for adjusting soil pH

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Introduction
Acidic soil is generally undesirable for the growth of crops for multiple reasons. Acidity can interfere with the availability of some nutrients, can cause aluminum (which is found naturally in some soils) to change to a form that is toxic to plants, and can destroy or shift soil microbial populations.
What is acidity? When a new material is dissolved into water, the mixture is considered a "solution". Often, water (H_2O) molecules will change and become positively or negatively charged when a solution is made. If a water-based (or "aqueous") solution develops an internal electrical charge then it will be considered either acidic (positively charged) or basic/ alkaline (negatively charged). As a solution becomes acidified, H_2O molecules lose one hydrogen atom and one oxygen atom and become H^+ ions, which are positively charged. As the concentration of H^+ ions increases in a solution, it becomes more acidic. Conversely, as a solution becomes more basic, H_2O molecules lose one hydrogen atom and become OH^- ions, which are negatively charged. As the concentration of OH^- ions increases in a solution, it becomes more basic (also referred to as alkaline).

Some soils are acidic, some are basic and some are neutral. A global map of soil pH can be accessed at http://www.fao.org/nr/land/soils/en/. It is important to note that there can be a lot of variation in soil pH within a small area, and hence testing soil pH is important (see below). In general, soils near the equator are often acidic (van Straaten, 2002).

In situations where soil acidification has occurred, lime (calcium carbonate) can be applied to the soil in order to neutralize acidity. This is a well-established practice that has been exercised globally for hundreds of years.

Understanding the pH Scale
Acidity and alkalinity are indicated using the pH scale. This scale uses values ranging from 0 to 14, with a value of 7 representing a "neutral" environment, or one in which there are neither H^+ nor OH^- ions, but simply pure H_2O. Values less than 7 are considered "acidic" and values above 7 are considered "basic" or "alkaline". pH is measured according to a logarithmic scale, which means that each unit represents a tenfold increase over the previous unit. For example, if the pH in a given environment changes from 6 to 5, this indicates that there is ten times the hydrogen ion concentration when pH is 5 than when the pH was 6. If the pH drops to 4, then the hydrogen ion concentration is 10 times greater than it was at 5, and 100 times greater than what it was at 6. Another way to consider pH is that an increase of 0.1 units represents a halving in the hydrogen ion concentration, and a drop of 0.1 units represents a doubling in hydrogen ion concentration.

← Increasing H^+ ion concentration ← Pure Water → Increasing OH^- ion concentration →
← 0 to 6.9 →← 7 →← 7.1 to 14 →

pH Effect on Crops

Every crop has a range of pH that will optimize its growth. Most crops prefer mildly acidic pHs of between 6 and 7 however this will vary between crop varieties.

Cation Exchange Capacity and Buffer Capacity

Soil generally has an overall negative charge, which causes it to attract and hold positively charged particles or “cations” (van Straaten, 2002). The quantity of cations that the soil can hold at a given time is referred to as the “cation exchange capacity” or CEC. As most plant nutrients are cations (nitrate and sulphur are notable exceptions), the CEC can be considered a measure of the quantity of soil nutrients a soil can hold at a given time. In general, clay soils will have high CECs and sandy soils will have lower CECs.

H^+ is a cation and thus will be held on the CEC of the soil. In the soil environment, a balance will naturally form between H^+ ions on the CEC and H^+ ions in the soil water. As high CEC soils can hold more H^+ ions, they will take longer to become acidified, however they will also require more lime to ameliorate acidity when it becomes necessary. Conversely, low CEC hold fewer H^+ ions and thus will become acidified more quickly, but will require less lime to raise the soil pH when it becomes necessary to do so. The property of having a high CEC and thus resisting rapid pH changes is referred to as “buffer capacity”.

A map of soil characteristics including CEC (use the “Soil Nutrient Retention Capability” overlay) is available through the Centre for International Earth Science of Columbia University and can be accessed at http://www.ciesin.columbia.edu/afsis/mapclient/ . Unfortunately there is currently no data on soil pH available through this service. High soil nutrient retention capability would indicate a high buffer capacity and thus a higher requirement for lime when its application becomes necessary.

Liming

Calcium carbonate, commonly known as lime, can be applied to a soil in order to counteract acidity. When introduced to the soil environment, lime will react with H^+ ions in such a way that they are converted to H_2O, thus decreasing acidity.

Step 1) $CaCO_3$ (lime) + H_2O (soil water) ➔ Ca^{2+} + 2 OH^- + CO_2
Step 2) 2 OH^- (from lime breakdown) + 2 H^+ (cause of soil acidity) ➔ 2 H_2O (acidity neutralized as water is formed)

The nutrient holding capacity of the soil must be considered when determining the appropriate amount of lime to add. Ideally the nutrient holding capacity of a soil will be measured before lime application so that a specific lime rate can be formulated. In general, soils that are predominantly composed of clay will have a high CEC and soils and that predominantly sandy will have a low CEC. If the equipment to determine buffer capacity is not available, then the CEC can be estimated based on soil texture.

Relieving soil acidity through the application of lime frequently has a strong effect on improving crop growth (Bailey & Laidlaw, 1999). Because of their reliance on soil bacteria that are commonly sensitive to acidic conditions, legumes crops often demonstrate the most benefit following the application of lime (Quaggio et al., 2004). The availability of the micronutrient Molybdenum, which is especially important to legumes is also very sensitive to changes in pH and will become available at pH less than 5.2 (Franco & Munns, 1981). See Chapters 5 and 6 for further detail on the interaction of legumes with acidic soil conditions.

It is important to avoid over-applying lime, as this may cause some micronutrients to become unavailable for crop uptake (Bambara & Ndakidemi, 2010).

Lime Production

Lime is produced from calcium or magnesium based bedrock materials. Lime is a “blanket term” that can refer to several different chemical compounds, however it is most commonly used to refer to $CaCO_3$, or calcium carbonate. Lime is also used to refer to Calcium Oxide (aka Quick Lime, Burnt Lime) and Calcium Hydroxide (aka hydrated lime). These materials are used to make concrete and are not appropriate for agricultural use because their highly reactive nature presents danger to those handling the materials. Calcium Carbonate will effectively raise soil pH and does not require specific handling precautions, thus it is the choice material for improving acidic soils. Production of agricultural lime is a fairly simple process. Essentially, agricultural lime is produced by extracting limestone material from the bedrock and grinding it into a fine powder.

Lime should be graded according to purity and fineness. Fineness refers to the size of the individual particles in the powder. Commercially produced lime should have a specific fineness rating based on what percentage of the liming powder will pass through a series of progressively finer sieves. Fineness rating are used to adjust liming rates to increase the accuracy of its effect on pH. More finely ground material will be more effective. If fineness ratings are not available then lime should be ground as finely as possible before application. The purity of lime should also be considered. A “pure” agricultural lime would be 100% calcium carbonate, and would be given a neutralizing value of 100. Magnesium based carbonates will have a similar neutralizing value. The presence of other materials (non-lime mineral compounds, etc.) will decrease this purity.

Assessing pH

Soil pH can be most accurately tested using a simple pH meter. Basic pH meters usually cost from $15 to $30 although this price may increase with shipping charges. A pH meter is a good investment that can be used for many seasons if properly cared for. These tools are available from a number of suppliers, some of which are listed at the end of this chapter.

Litmus paper can also be used as an approximate indicator of acidity. Litmus papers are small strips of paper than contain a dye that will change colour when exposed to change in pH. Although litmus paper will indicate acidic conditions it will not indicate a specific pH value. Blue litmus paper is most appropriate for soil testing as it will turn red at pH below 4.5, indicating extremely acidic conditions. It should be noted however that as even pH values around 5 can be problematic for plants, acidic conditions may be limiting to crop growth but undetectable with litmus paper.

More advanced pH indicator strips are also available that will gradually change colour in reaction to pH. The final colour of the strip can be compared to a chart (provided with the indicator strips) which will show the approximate pH of the solution the strip was exposed to. These strips are more appropriate for soil testing as they can provide more accurate pH readings.

To test soil pH with either litmus paper or pH indicator strips, enough rainwater should be added to the sample area to make it very muddy, just short of causing water to pool on the surface. The indicator strip should then be placed in the muddy soil for the period of time specified for the variety of indicators being used (usually a few minutes). The soil can then be gently rinsed or wiped from the indicator and its colour can be observed. Rinsing the indicator strip will not influence the reading as the colour changing reaction should be complete by the time the indicator is removed from the soil. When testing pH (by any method) at least three areas of the field should be tested to decrease the likelihood of an isolated area with a significantly different pH value causing an inaccurate conclusion regarding soil acidity. As well, both surface soil and soil approximately 1 foot beneath the surface should be tested in order to recognize potential pH variation between soil strata.

Useful Links

pH meter suppliers:
South Africa: http://www.gumtree.co.za/cp-garden-braai-in-port-elizabeth-western-region/multi-purpose-3-in-1-soil-ph-moisture-and-light-test-meter-377614222

India: http://www.watertreat.co.in/ph-tester.htm

Hach International (based in India) also ships to many African and Latin American countries:
http://www.hach.com/AfricaDistributors

Grainger International will ship to many international locations:
http://www.grainger.com/Grainger/GENERAL-Soil-pH-Tester-3MLA1

pH indicator strip suppliers
Sigma Aldridge (will ship internationally)
http://www.sigmaaldrich.com/catalog/product/fluka/37109?lang=en&region=D

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5.3 - Shallow trenching to prevent erosion and conserve water *(revision pending)*

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Introduction to Soil: What is Erosion?

Soil is a multi property living organism full of rich organic matter, that if treated correctly and strategically, can be the much needed resource of many struggling farms to generate the highest and most successful crops possible (Pimentel and Kounang, 1998). By adopting simple strategies, farmers are able to sustain idealistic soil properties, such as adequate moisture and nutrients (Pimentel and Kounang, 1998). An important part of understanding how to keep soil in this ideal state is being aware of the processes that deteriorate, and degrade it; erosion is one of these processes. Caused by wind, rain and other natural agents, erosion is the wearing away of top soil, which consequently compacts, leaches, and dries farmland (IIRR and ACT, 2005). In Africa alone, there is approximately 630 million hectares of arable land available to practice agriculture (Munyaradzi et al., 2006). However, over the past half century productivity has seen a huge decline across this arable land due to the impact erosion has had on soil fertility. Africa's diverse climates including deserts, savannas and rainforests, and diverse range of highlands and lowlands make it difficult to control the natural processes of erosion. Though all farmlands are susceptible to this phenomenon, it is most prominent, and devastating along hillsides. There are approximately 250 million people practicing agriculture along hillsides in Africa (Munyaradzi et al, 2006) and globally there are more than 2 million subsistence farmers who rely on successful yields to maintain food security. The more soil depreciates, companies and developed countries get incentives to push heavy reliance on expensive and sometimes dangerous fertilizers (Moldenhauer et al., 1988). However, by simply adopting strategic agricultural techniques, these impacts can be weakened.

To learn more about Africa's land and potential treats to its ecology please visit http://www.unep.org/dewa/africa/docs/en/aeo-2/chapters/aeo-2_ch03_LAND.pdf

Why is Erosion a Problem?

As the runoff of soil happens, the soil begins to lose moisture, to compact and cause nutrient leaching (Pimentel and Kounang, 1998). This has two major implications. First, once the crops are planted, they are deprived of the essential nutrients needed for growth due to the nutrient poor, depreciated soil. This results in significantly less successful yields; especially on sloping lands. Nigeria experienced a loss of 221 t/ha/yr on land with a 12% slope due to erosion, and a loss of 3 t/ha/yr on land with only a 1% slope (Pimentel and Kounang, 1988 (Pimentel and Kounang, 1998). Second, it becomes substantially more difficult to plant crops because the soil is much denser and drier, because the rich and moist topsoil layer (humus) is lost. In addition, labour and energy costs increase because it requires much more time, energy and attention to plant (Pimentel, et al., 1995).

The biggest devastation is that these impacts are not short term (Pimentel and Kounang, 1998). Unfortunately, once soil loses its moisture, nutrients, and organic matter (the essentials to successful crops) it is extremely difficult, if not impossible to get them back (Pimentel, et al., 1995). Corn yields alone have seen declines of up to 80% due to erosion (Pimentel, et al., 1995). Techniques that are simple and have potential for high adoption are needed to stop this devastating cycle.

To see the visual impacts of this phenomenon, please visit
http://www.gettyimages.ca/photos/soil-erosion

SOLUTION: SHALLOW TRENCHING

What is Shallow Trenching?

Shallow trenching, otherwise known as contour ripping, shallow contour ripping or Keyline ripping, is a solution that can be adopted by farmers to prevent and control soil erosion caused by runoff (IIRR and ACT. 2005). Shallow trenches are ditches with little depth that are dug horizontally along farmland to catch rainwater to prevent soil runoff (Moldenhauer et al., 1988)

How will Shallow Trenches Solve the Erosion Problem and Conserve Water?

The ditches that are dug along the farmland act as a cup and catch water rather than letting the rainwater or wind move the soil. This prevention of soil runoff allows water to infiltrate into soil which means that soil will not depreciate in nutrients, moisture and organic matter (Moldenhauer, Hudson, & Editors, 1988). Not only does this solve the problem of erosion, but by planting the crops in between the trenches that the farmer has created, the seeds and roots get nourished by rainwater. This juristically reduces the amount of water that the farmers need to water their crops (Pimentel, et al., 1995).

IMPLEMENTING THE SOLUTION: HOW TO CREATE SHALLOW TRENCHES

Materials

A major advantage to this method is the minimal requirement for materials. If available, a trenching hoe/grub hoe or shovel is ideal, however a stick is just as sufficient Anything that can be used to make groves in soil works. Seeds will also need to be chosen to plant after the trenches have been dug.

Steps

<u>Step 1:</u> Establish the contour and slope of the farmland. The farmer will be digging the ditches perpendicular to the slope of the land because when rain falls, the holes, which are called 'contour ditches', will catch the water rather than letting it run down the slope (IIRR and ACT, 2005). This is critical because if the trenches are not dug in the correct direction, the dug trenches may act as a slide for rainwater and runoff will actually worsen.
<u>Step 2</u>: After the farmer has established the direction that the trenches will be dug, grab the chosen digging instrument, i.e. the trenching/grub hoe, shovel or stick, and start digging the contour ditches horizontally along the terrain. The steeper the slope, the deeper the holes should be due to an increased probability of experiencing erosion.
<u>TIP:</u> If the terrain is on a steep incline, a contour ditch could be dug at the very top of the hillside to further protect the terrain (IIRR and ACT, 2005)
<u>Step 3:</u> Once all the contour trenches have been dug, take the selected seeds and plant them between the trenches as the farmer normally would.
<u>Maintenance:</u> It is common that after extreme weather, the trenches may fill in. Constant checking of the depths and size of the trenches is critical to this methods success. Re-dig if necessary.

Having trouble deciding on depth, distance and length? Please refer to Table 1

Having trouble understanding the method to creating shallow trenches? Please refer to the SAK Picture book that corresponds to this chapter.

BENEFITS

Water Conservation, Reduction in Soil Depreciation and Improved Crops

There have been many studies administered by the FAO, NGOs etc. to examine the effectiveness of the shallow trenching method, especially in the dry lands of sub-Saharan Africa. A specific study, administered in 1999 though-out Eastern and Southern Africa evaluated the shallow trenching technique and found that this method was successful in reducing land degradation due to soil erosion (Rockström, 1999). The ditches were successful in retaining large amounts of water which aided fertilization of both the soil and the seeds (Rockström, 1999). This study is not unique in its conclusion. There are countless studies that demonstrate that this method is successful in conserving water. Why is this considered such a significant benefit? Retrieving water for plants is not only time consuming, but it takes a huge toll on the farmers themselves; carrying water on foot multiple times a day takes up a lot of energy. By making use of the rainwater being caught in the trenches to fertilize the seeds, it permits water infiltration and conserves the amount of water that is needed to be salvaged. This poses a major benefit as the saved time and labour can be used towards other pressing farming needs (Pimentel, et al., 1995).

To read more about the study administered in Eastern and Southern Africa, as well as other studies examining the benefits of conserving water, reducing soil depreciation and improving crops, visit http://ac.els-cdn.com/S1464190900000150/1-s2.0-S1464190900000150-main.pdf?_tid=6f5b0e4c-b8ee-11e6-993f-00000aacb362&acdnat=1480724669_dec5bc41bbea1592d2aaea107bb01d3d

To learn more about water conservation methods, principles, causes and advantages, please visit http://www.fao.org/docrep/T0321E/t0321e-11.htm

CRITICAL ANALYSIS: ISSUES

Labour, Time and Maintenance

Before implementing any significant changes in farming practices, critical analysis of many factors needs to be considered to ensure that the farmer is adopting the technique best suited for their land. For instance, farmland soil needs to be managed differently depending on its texture, i.e. sandy, versus silty, versus clay soils. This method is best suited for silty soils because of its low clay content (Hillard and Reedyk, 2014). Rainfall causes clay soils to compact, dry and crust which in turn, causes more runoff. Trapping water in the contours to later be absorbed by the soil could actually increase speed up the erosion process. Silt soils do not have this clay content that would otherwise cause the soil to dry out from the rain water (Hillard and Reedyk, 2014). Implanting this solution on soils other than silty ones will further increase the labour, time and costs.

Maintenance is a heavy burden associated with shallow trenching. After intense rainfall there is a good possibility that the soil will move due to the water, and fill in the trenches. Unfortunately, it is a constant battle against soil accumulation and there are no actions that can be taken to prevent it.

Depending on the size of the farm, and the amount of trenching that need to be dug will decide whether or not this is a good solution.

Though this method can be very effective, the energy costs, including labor, time and maintenance are heavy. If the ditches are dug by hand, this can be not only time consuming, but more importantly can cause significant physical hardship (Pimentel, et al., 1995) which would prevent the adoption of this practice. However, it is important to consider that by taking on extra labour and time costs now, greater labour and time may be saved in the future. It is up to the farmer to compare these costs with other techniques to determine what is the most effective and sensible option.

Please see http://www.fao.org/ag/AfricaTrainingManualCD/PDF%20Files/08WATER.PDF to learn more about shallow trenches, and other soil and water conservation techniques. Pictures and diagrams are provided.

Table 1: Distance Between Ditches on Hillsides

SLOPE (%)	ANNUAL CROP		PERENNIAL CROP OR PASTURE	
	Distance (m)	Maximum Length (m)	Distance (m)	Maximum Length (m)
2	42.0	90		
4	25.0	120		
6	19.3	160		
8	16.6	200		
10	14.9	260	40.2	140
12	13.8	280	33.5	140
14	13.0	300	28.9	140
16	11.4	340	25.3	160
18	10.2	380	25.0	180
20	9.2	420	24.0	200
22	8.4	470	23.2	200
24	7.7	500	21.4	210
26	7.2	500	19.8	220
28	6.6	500	19.5	220
30	6.3	500	18.9	220
32			18.7	220
34			18.6	230
36			17.7	230
38			16.9	230
40			16.2	230

Retrieved from http://www.nzdl.org/gsdlmod?e=d-00000-00---off-0hdl--00-0----0-10-0---0---0direct-10---4-------0-1l--11-en-50---20-about---00-0-1-00-0--4----0-0-11-10-0utfZz-8-00&a=d&cl=CL2.14.5&d=HASHbdde2fe3749493c1a0de2d.4.2.3

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5.4 - Contour farming on hillsides to prevent erosion

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Background

Soil degradation and erosion is one of the most prominent issues that subsistence farmers face. Impacts of soil erosion are wide ranging, and the amount of erosion around the world has been accelerated due to human activity. In South Africa for example, recent studies show that soil has eroded at 12.6 tons/ha/year under cropland whereas natural soil erosion is 5 tons/ha/year (Le Roux & Smith, 2014). In India, over 45% of all geographical surface area (130 million hectares) is seriously affected by soil erosion (India Netzone, 2012). Simpson (2010) defined soil degradation as, " (the) decline in the productive capacity of the soil as a result of soil erosion and adverse changes in the hydrological, biological, chemical and physical properties of the soil." It is also worth mentioning that soil erosion has impacts ranging much further than the agricultural sector. Although the immediate impacts can be felt on the farm with the loss of soil fertility and stability, the effects of erosion can leave communities in a state of chronic hunger, can flood lowland plains as sediment fills river systems, and can ruin the land for future generations of subsistence farmers (Simpson, 2010).

Contour farming is a simple, yet underused practice to prevent erosion along hillsides. The practice consists of sowing crops in rows, perpendicular to the slope (Sussman, 2007). It improves yields and greatly reduces soil erosion, including preserving soil fertility along slopes and works best in combination with hedgerows. This is a low cost, low labour practice that requires few materials that are often readily available on the farm already. Additionally, the practice of contour farming is easy to teach and once a farmer is comfortable with the process they are able to further demonstrate the practice to others farming on sloping lands. Contour farming consists of measuring lines perpendicular to the hillside and planting crops along these lines. The use of an A-Frame device can help quickly identify these lines and furthermore improve yields immediately.

Process

Implementing contour farming is the most labour intensive part of the practice. It begins by assembling an A-frame. This tool is used to mark out level pathways perpendicular to the slope of the hill. A level pathway is a measured line across a hillslope that farmers identify in order to plant their crops on level ground even when attempting to cultivate on a hillside (Sussman, 2007). An A-frame is easy to make and can use locally found materials. To make an A-frame one will need two poles around two meters long, another shorter pole about one meter long, some string and a stone (Evans et al, 2012). To assemble the A-frame, the two-meter poles and the one-meter pole need to be tied tightly (or nailed if available) together in the shape of a letter A. Once the poles have been connected use the rope to hang a stone from the top of the frame so that it hangs below the cross bar (Evans et al, 2012). Refer to Figure 1 for an illustration. This tool is used to measure out contour lines by marking out level pathways perpendicular to the slope of the hill.

After the contour lines have been marked its time to prepare hedgerows. Hedgerows allow uphill water to absorb into the hillside as opposed to running down the slope washing away nutrient rich soil (Evans et al, 2012). An optional intervention is the use of ditches which help in erosion prevention, irrigation, and cash crop yields. Hedgerows can be created by digging ditches along the previously marked contour lines, for an illustration as the how the process appears, refer to Figure 2 of the appendix. The ditches should be about 60 cm wide and 30 cm deep. The distance between hedgerows down a hillside is determined by the gradient of the slope. Refer to Table 1 for guidance. When excavating the ditches farmers are taught to dig from an uphill position as to maintain structural integrity of the uphill slope (Sussman, 2007). As the ditches are carved out the excavated sediment is to be placed downslope along the edge of the trench and packed in to create berms. Another optional intervention is to plant grasses, legumes or perennials along the berms as their root structures are capable of holding the berms in place and in the long run eases labour for the farmers, as they will no longer need to repair the berms after harvest. It is advised to mulch the berms while the roots develop over the first few seasons to maintain berm integrity (Sussman, 2007). If a farmer elects to plant legumes or perennials, such as pigeon peas or cassava, the farmer can harvest these vegetables to either consume or sell for money (Humphries, 2000).

Labour, Time, and Materials Involved

The most labour intensive aspect of contour farming, as previously mentioned, is the initial stages of preparing the land. After the contours have been marked, the ditches excavated, and the berms packed and mulched, substantial additional labour is not required. Sussman (2007) reported that contour farming requires little maintenance from season to season, with the most labour intensive aspect of this practice being the periodic removal of collected sediment in the trenches. The benefit of clearing this sediment, other than maintaining the integrity of the hedgerows, would be transporting the collected sediment to the top of the slope. The transported sediment highly fertile as it would have been collecting nutrients from organic matter, as it is the top layer of soil.

The materials required to run a successful contour and hedgerow practice would be the aforementioned A-frame device for measuring and leveling purposes, stakes are used to mark out contour lines, and shovels, hoes, or other tools used to dig out the trenches.

Benefits of Reducing Soil Erosion

By using hedgerows to catch rainwater this in turn prevents soil erosion from occurring. This is beneficial to farmers as it saves valuable nutrients in the soil from being washed away during heavy rainfall seasons. Steudel et al (2015) reported that contour banks (hedgerow berms) increased trapping capabilities by as much as 90% compared to hillsides with no soil conservation approaches. Reducing erosional discharge allows for intact soil and berms to absorb water and increase nutrient intake to the roots of crops, again improving yields (Simpson, 2010). By using these approaches to prevent soil erosion and degradation a farmer can preserve soil fertility and integrity for generations.

Farmers are influenced to measure the rate at which their hillside farms erode using a “Jumbie” (Simpson, 2010). A Jumbie is a metal rod or a stick that is driven into the ground to a depth between 30-60cm, or to the point in which it is securely anchored into the land. Placing multiple Jumbies evenly down and across a slope allows a farmer to figure out where along the hill needs the most maintenance and treatment. The farmer is to make a mark on the Jumbie where the tip protrudes from the ground. Farmers should check the Jumbies monthly and compare how much more of the tip is exposed compared to the previous markings. Hudson (1987) documented that 1mm of soil depth change measured is equivalent to the loss of 15 tons of sediment per acre per year. This figure further represents the importance of implementing contour plowing and hedgerows into a hillside farm.

Therefore, Jumbies are a simple yet effective method to demonstrate to farmers the severity of erosion and the effects it can have.

Problems

The challenge for farmers to adopt this practice is the labour and time required to integrate contour farming into their practice. Humphries et al (2000) brought to light the idea of sensitizing farmers to the issue of soil degradation. This is a problem that requires government assistance to overcome. Without the population of farmers cultivating on a hillside becoming aware of the importance of maintaining soil fertility they will not be in a hurry to alter their traditional farming practices.

Another problem that arises in regards to hillside contour farming is the gradient of the slope the farmer is trying to cultivate. Contour plowing and hedgerow implementation is an extraordinarily effective method for reducing soil erosion and degradation and improves harvest yields but is only effective to a certain point. Referring to Table 1 again, the highest degree of the slope this practice is useful for is up until 33 degrees (Sussman, 2007). Beyond that measurement the contour lines would have to be measured too closely together in order to reap the benefits of the practice. Additionally, it becomes increasingly difficult to have livestock assisted labour as the slope a farmer chooses to cultivate becomes steeper and steeper.

Additional Readings and Information

The following link will direct the reader to an informative and descriptive video produced by CropLife (a global organization in the plant science industry (CropLife, 2016) on their efforts to teach and implement contour farming practices in the Philippines.
https://www.youtube.com/watch?v=fpdcEf-npr4

This link will bring the reader to a simple manual describing and further illustrating the process of contour farming and hedgerow construction.
http://www.bebuffered.com/downloads/sussman_contour_trenches.pdf

This video demonstrates to the viewer how to use an A-frame to measure and identify contour lines.
https://www.youtube.com/watch?v=kU2rvOF60J0

The following PDF file is a very informative manual for soil conservation and slope cultivation (as the title suggests). Refer to pages 9 and onwards as the content covers topics such as erosion, cover crops, cultivation methods, and erosion measurement instruments and instructions.
A Manual of Soil Conservation and Slope Cultivation

Appendix

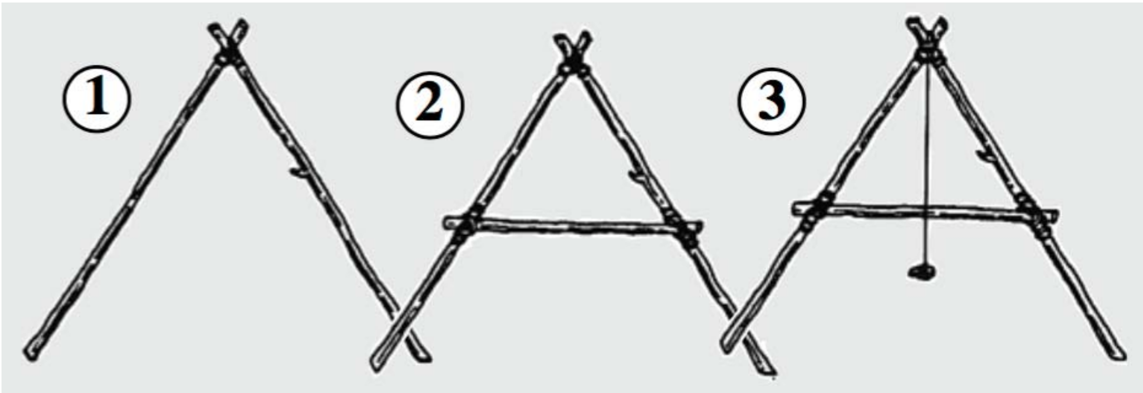

Figure 1. Illustration of A-Frame Assembly (Evans et al, 2012)

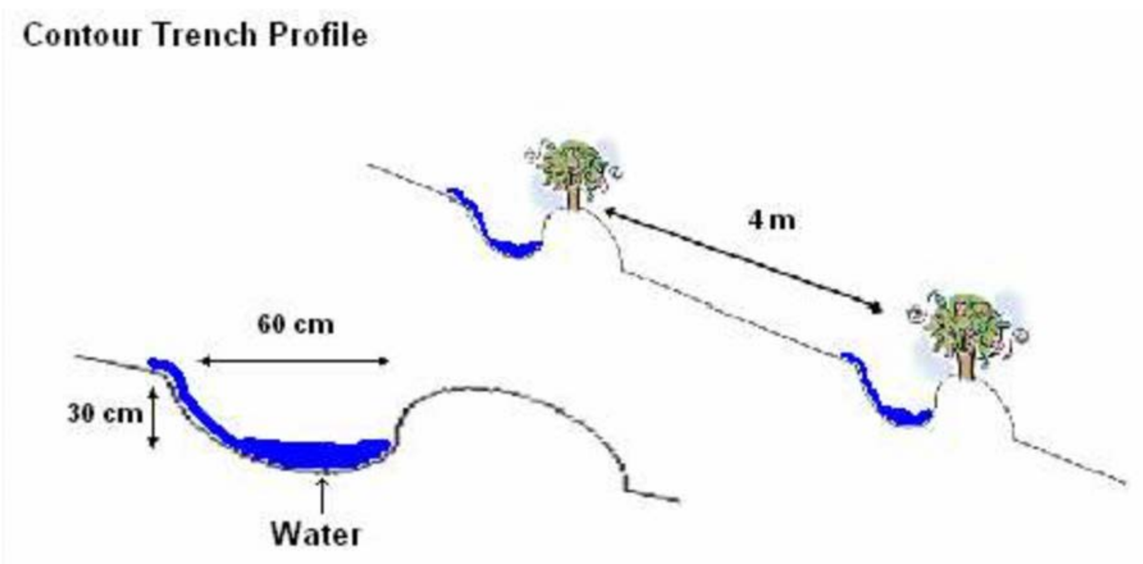

Figure 2. Contour Trench Profile (Sussman, 2007)

Hillslope (%)	Distance between trenches
0 to 4	10 to 12 m
4 to 8	8 m
8 to 15	6 m
15 to 33	4 m

Table 1. Trench Spacing Interval by Hillslope (Sussman, 2007)

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5.5 - Living grass barriers to prevent erosion *(revision pending)*

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Background and History

Every year, a large quantity of soil is lost due to erosion caused by both wind and rain. Sheet erosion generates the greatest amount of destruction and occurs when “raindrops pound the ground dislodging soil particles which are then carried away by the surface runoff” (de la Garza, n.d.). It is a constant, yet slow form of erosion that covers large amounts of land. Unlike gully erosion, where soil is removed via drainage lines in the earth, sheet erosion is detected too late because it removes small quantities of soil over an extended period of time (de la Garza, n.d.). To combat erosion, living grass vegetative barriers can be implemented to slow water flow via their dense root system. An example of this is vetiver grass, a vegetative barrier system introduced by the World Bank in India as a low cost development project aimed at soil and water conservation (Grimshaw, 1993). Vetiver grass was already being used by South Indian farmers for approximately 200 years (Greenfield, 1990).

Description of Living Grass Barriers

Vetiver is a dense, wiry, tough perennial grass that promotes effective detention and infiltration of sediment runoff. Enhancing soil moisture and conserving soil itself is crucial for sustainable agriculture and key for societal survival (Grimshaw, 1993). Soil loses moisture from erosion which is caused mainly by the removal of vegetative ground cover by humans and livestock and our growing consumption of natural resources (Greenfield, 1990).

The grass is planted as a narrow hedge (less than 1 meter wide) to create a barrier across the slope of the land. If applied correctly it will slow rainfall runoff by spreading it out evenly and trapping runoff sediments to create natural terraces down the hillside. Vetiver grass is fairly inexpensive compared to more traditional practices that try to tackle the problem of soil erosion (Grimshaw 1993). Typically, there is a lack of funds, costs are too high, and the solutions put in place are ineffective and/or inappropriate for small farms. Vetiver grass can also grow over under a variety of conditions, is non-competitive with surrounding crops, is not a weed, is both pest and disease resistant, and can be used as fodder for livestock. Additionally, the grass is used to stabilize embankments and roads, is fire resistant and needs little maintenance (Grimshaw 1993).

Possible Benefits

<u>Soil conservation and moisture retention</u>

From Louisiana to India to Malaysia, farmers have witnessed both increased soil and moisture retention by implementing vegetative barriers, especially vetiver grass. As runoff races down a slope, it cause unnecessary erosion and very little moisture is stored. Once runoff reaches the grass hedges, it slows down, spreads out, drops its silt load, and oozes through the hedges as most of the water soaks into the soil (Greenfield 1990). No soil or excessive amount of water is lost. An effective vegetative barrier like vetiver grass slows and almost permanently reduces soil loss from almost 143 tons to 1.3 tons per hectare in one year. On protected land, with any sort of slope, there is a chance that valuable fertilizers and topsoil will be lost. Vetiver’s spongy root system binds the soil up to 3m below the plant, creating a “curtain” that prevents gullying and tunneling (Greenfield 1990). Gully erosion is created by the removal of soil via rain along drainage lines (Agriculture Victoria, 1999), wherein tunnel erosion is the removal of subsoil by rain, leaving a tunnel in its place (Queensland Government, 2013).

<u>Durability and Versatility</u>

Vetiver grass is both a xerophyte and a hydrophyte plant and can undergo long periods of drought, as it can withstand very little water, and flooding, whereby it acts as an aquatic plant. Therefore, it will have no problem growing in upland or wetland settings (Aalbersberg, n.d.). Vetiver grass will grow under a variety of conditions, in both the tropics and semi-tropics, on almost all types of soils, regardless of their pH level or salinity. “This includes sands, shales, gravels, even soil with high levels of aluminum toxicity” (Aalbersberg, n.d.). However, it does best on well-drained sandy loam. Vetiver will grow in climatic conditions of 200-6000mm of rainfall per year, with temperatures ranging from -9 to 45°C. It will also grow at most altitudes, taking the temperature into consideration (Grimshaw and Helfer, 1995).

<u>Animal Fodder</u>

If managed correctly, the young leaves of vetiver grass are edible and can be used as fodder for livestock. However, in most cases vetiver is generally not eaten by livestock. For example, a case study in Malaysia shows that sheep will not eat vetiver when there are other vegetative options but “cut tops” were consumed when given to penned sheep (Grimshaw 1993).

<u>Low Competition</u>

Vetiver grass is non-competitive, meaning it will not significantly hinder the crop it is meant to protect and will therefore not have a negative impact on crop yield. Vetivers’ roots contain beneficial mycorrhiza, so the grass may actually improve crop yields (Aalbersberg n.d.). For example, when grown with cassava, elephant grass hedges were shown to reduce yield by almost 33%, wherein there was no yield loss when grown with vetiver hedges (Grimshaw 1993). Similarly, vetiver is not considered a weed because it is effectively sterile as its roots are not stoloniferous and it does not produce rhizomes. A rhizome is “a horizontal underground plant stem capable of producing the shoot and root systems of new plants” (Encyclopaedia Britannica, 2014). There is a possibility that natural spreading will occur under swamp conditions but not under upland conditions. It is recommended that only the non-seeding “accessions” be used (Grimshaw 1993).

<u>Low Cost</u>

Vetiver grass is a more economically sound option than conventional engineered systems that can cost up to $500 per hectare, compared to $30 per hectare for vetiver grass. The economic return is more than 90% compared to only 20% with conventional systems. Costs can also vary between site conditions: on slight inclines, vetiver grass can be implemented in 50 m intervals, in which case only 100 m of hedge is needed per hectare. Likewise, on steeper clines of approximately 60%, the distance between hedges is much less, wherein 2500 m of hedge is required per hectare. Hedges may stand 4m part or less. The cost also depends on how planting materials are acquired. For example, plants grown in nurseries are more expensive than those produced through mechanical methods. The most economically viable solution is to divide pre-existing vegetative hedges for replanting as new hedges (Grimshaw 1993). This method might be the best option in situations where access to seeds is limited.

How living grass barriers are conducted

Vegetative barriers, especially vetiver grass hedges, are versatile and can be applied on multiple eroding sites, not just cropland. In a parallel formation, barriers are planted on or near the contour of the land and across the highest concentration flow of runoff at angles that are convenient for the farmer. Eventually, “sediment and tillage will fill in the swale areas and contours will adjust to be closer to the barriers” (de la Garza, n.d.). Farmers will plow their fields according to the formation of the vegetative barriers which will contribute to the creation of terraces between each row. Note that proper vegetative barriers must be 3 feet wide and have a stem density of 50 per square foot.

Grass Selection

When selecting a grass for vegetative barriers, consider a stiff stemmed perennial species that is resistant to water flow and good at retaining sediment. Spear Grass (*Heteropogon contortus*) is a grass used in India to prevent erosion on a slope on and up to 20 degrees. It is native to Africa and South Asia and is versatile in use (Heuze et al, 2015). Another grass used to prevent erosion is foxtail millet (*Setaria italica*), a grass found in southern Asia that is commonly used in India and China (FAO 2011). When selecting grass species, it is ideal to select locally adapted grasses that do not spread as they will encroach onto the cropland.

Obtaining Plant Material

Vetiver plants are commonly regenerated in nurseries, where slips are cut from the main clump of plant and used in the fields. The slips, a handful of grass and roots, are harvested from the preceding crops so that the nursery remains viable (Grimshaw and Helfer 1995). Before slips are planted, the tops are cut 15-20cm above the base and the roots are cut 10cm below the base. “This will improve slips chances of survival after planting by reducing transpiration level and thereby preventing them from drying out” (Grimshaw 1993). Slips are planted at the beginning of the wet season and are planted directly into the furrow that marks the contour of the land. When planting them, it is important to ensure that roots remain turned down and are spaced 10-15 cm apart.

Correct Usage and Common Problems

Vetiver grass can grow in areas of low rainfall (300-400mm) but will require more maintenance. In these conditions, and in conditions of extreme weather, vetiver grass suffers. It will not grow in cold climate or permafrost sites (Grimshaw 1993).

Competition with Crops

The major problem with vegetative barriers is that they take up space and thus might try to encroach on the main plots as a weed. It may compete with crops for water, light and nutrients leading to decreased yields (Guto et al. 2011). A method for deciding what to plant is a “split plot” agriculture design, where blocks are used as experimental units for a variety of factors. Fields are divided into whole and split plots and then individual plots to monitor different treatments (Jones and Nachtsheim, 2009). In the case of vegetative barriers, farmers should plant only half of their field with barriers in order to see if crop yield decreases.

Slow Economic Return

A vegetative system’s full potential is only met when a hedge has formed. A thick hedge can be grown in the first season but it usually takes two or three for the grass to be dense enough to stop sediment and withstand torrential rains. Hence, gaps must be filled until plants are strong (Greenfield 1990).

Helpful Hints

This vetiver training manual offers the basics for understanding what vetiver grass is, how to create nurseries and how to go about planting the grass.

http://www.vetiver.org/USP_vetiver%20training%20manualo.pdf

This source, collaborated between CIAT and FAO, allows one to look up the description of any grass species.

http://www.fao.org/ag/AGP/AGPC/doc/GBASE/Default.htm

This website sells a variety of grasses from all around the world

https://www.seedman.com/ornamentalgrass.htm

The Vetiver Nursery in Australia

http://www.vetiver-grass.com/vetiver-plants

Helpful Images

This picture demonstrates how vegetative barriers prevent excessive runoff. As you can see in the picture, the barrier has stopped soil from flowing down in the hill and has developed terraces in the process.

http://www.nzdl.org/gsdl/collect/hdl/index/assoc/HASHf4f4.dir/p062.png

This picture illustrates how proper vegetative barriers should look on a steep incline

http://pool.howtopedia.org/images/thumb/e/e3/MadagascarRailwayslopeVetiver.jpg/2 80px-MadagascarRailwayslopeVetiver.jpg

This picture gives a better understanding of the different types of erosion that plague farmers who do not protect their fields.

http://images.slideplayer.com/17/5334503/slides/slide_19.jpg

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5.8 - Adding organic nutrients to home gardens

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Background

There are numerous advantages associated with adding organic nutrients to the home gardens of subsistence farmers in the developing world; including soil sustainability, environmental quality, and increased yield. These organic nutrients can include collecting kitchen scraps to make compost and using human urine (especially at night).

There are many existing practices of adding organic nutrients to home gardens that are practiced around the world and worth acknowledging. For example, there are people living in the Himalayas in Nepal who use forest litter for bedding material for livestock, and later when it has been enriched with urine and manure, they spread it across fields for extra nutrients (Giri and Katzensteiner, 2013). The Ngwa people in southeastern Nigeria commonly use a pit to collect waste, and after covering it for several months, they dig it up and use the rich hummus soil in their agricultural area (Izugbara and Umoh, 2004). Additionally, there are reports from populations in India, China, Cuba, Philippines, and Ethiopia that deserve further research and development (Misra and Roy, N.D; Edwards et al., 2007). Therefore, it is important to keep in mind that practices pertaining to organic nutrient addition to home gardens are widespread and unique, and must be implemented according to what is most appropriate for the particular context.

Benefits

There are a number of benefits associated with adding organic nutrients to home gardens and smaller plots of farmland. Organic ingredients added to soil help improve soil health and structure, particularly sandy soils, increasing their workability and allowing the soil to hold moisture better (Pleasant, 2012; Román, 2015). Organic addition also helps to regulate soil moisture, reduce water loss through evaporation, and lower the risk of erosion (Román, 2015). These qualities are invaluable to the long-term sustainability of soil. Not only do the organic nutrients benefit the physical properties of the soil, but they add chemical nutrients that assist with increasing yields, such as nitrogen, potassium, and phosphorous (amongst others) (Román, 2015; Lynch, 2014). Another advantage of organic fertilizer is that it reduces pollution of the soil, water, and air, when compared to synthetic fertilizers (Schwarz and Bonhotal, 2011). Finally, an advantage of organic nutrients is that they work to increase yields without costing farmers money. Organic fertilizers can be made using household waste, human waste, and cooking waste. Though synthetic fertilizers can be advantageous to farmers, they are often unavailable in very remote regions of developing countries. Additionally, they can be expensive and farmers may be unclear about how to apply them. When farmers know how to add inexpensive and easily accessible organic nutrients to their gardens and fields themselves, they become more self-reliant.

Table 1: The following table provides some examples of compost inputs and their macronutrient contents

Kitchen Scraps	*Nitrogen Content (%)*	*Phosphorous Content (%)*	*Potassium Content (%)*
Cow dung	1.30	0.58	2.15
Cassava Peelings	1.70	0.86	1.50
Rabbit Dropping	1.04	0.99	2.05
Poultry Manure	2.21	2.98	2.05
Cane Rat Droppings	1.95	2.06	3.30
Neem Oilcakes*	5.22	1.08	1.48
Groundnut Oilcakes*	7.29	1.65	1.33
Cotton seed (undecorticated) Oilcakes*	3.99	1.89	1.62
Cotton seed (decorticated) Oilcakes*	6.41	2.89	1.72
Hair and Wool Waste	12.3	0.1	0.3
Fish Meal	4-10	3-9	1.8

(Source: Adeniyan et al., 2011; Roy, 2006)

*****Oilcakes are crop residues following the extraction of oil from oilseeds

Instructions

This section will outline two different methods of adding organic nutrients to gardens and fields previously mentioned: compost, and urine.

Composting: Composting is more intensive than using urine, but high quality compost can be created through a variety of inputs and combinations; it is about balancing the green and brown inputs. This means that farmers in Bolivia, Sudan and Laos alike can use whatever compost ingredients they may have at their disposal and can be successful. Green feedstocks (compost ingredients) are nitrogen-wet materials, including food scraps, manure, and green trimmings. (Schwarz and Bonhotal, 2011). By contrast, brown feedstocks are carbon-dry materials, such as straw, woodchips, brown leaves, and soiled paper (Schwarz and Bonhotal, 2011). First, kitchen scraps must be collected from the household (although meat and dairy products should be excluded as they are not ideal for home composting) (Schwarz and Bonhotal, 2011). It would be helpful to have a location outside or a container to place the kitchen scraps. The second step is to collect scraps such as leaves, brush, and weeds. Third, a place must be chosen to mix the compost and allow it to decompose. This space must be large enough for a large quantity of compost, since the pile must retain its own heat in order to decompose faster (minimum size of one cubic yard). The temperature also should be considered when selecting a spot; in cool climates the compost should sit in the sun to allow it to receive the maximum amount of heat possible, while in warmer climates it should be in the shade so as not to dry out (Schwarz and Bonhotal, 2011). The next step is to mix the compost, which is done by layering the browns and greens, starting with a layer of brown feedstocks and followed by greens in a well on top. Another layer of browns should be added, followed by greens, and so on. These steps of layering should be continued until all the ingredients have been used, all while keeping the greens towards the middle, so that only the browns are visible (Schwarz and Bonhotal, 2011). Turning the pile with a pitchfork or shovel, as well as adding water can help to speed up the decomposition process (Schwarz and Bonhotal, 2011). The compost takes about six months to a year to transform, and then can be added to the soil to enable crop production (Schwarz and Bonhotal, 2011).

Human Urine: A second strategy for organic nutrients, one that is very simple, is for the residents of the farm to urinate on the fields. Urine contains high levels of nitrogen, phosphorous and potassium, and is free and usually wasted (Richert et al., 2010). It can be added to fields by collecting it in jerry cans directly or in composting toilets. If collected and stored, it should be done so in a sealed container in order to avoid ammonia emissions (Richert et al., 2010). Otherwise, people can urinate directly onto the soil (ideally at night). It is important that urine be added directly (and only) to the soil for two reasons: first, nutrients are most needed at the beginning of the growing period (before crops are covering the soil) and second, it should not be added within a month of the harvest of crops that are eaten raw, for sanitary reasons (Richert et al., 2010). Commonly, people dilute urine with water, reducing the risk of applying too much urine, which can make it toxic to crops. It can diluted from anywhere between 1:1 to 1:15 ratios of urine to water, but most commonly it is diluted about 1:3 (Richert et al., 2010). Some studies have found very high success rates with urine as fertilizer, doubling financial returns when compared to mineral fertilizer, and increasing the amount of macronutrients in the soil (AdeOluwa and Cofie, 2012).

Common Problems and Critical Analysis

Each of these methods has its drawbacks, particularly space and time. Mixing compost requires considerable labour and patience, as well as a large amount of space. For all three inputs, the smells may attract unwanted pests or animals, and diseases can spread through urine in some parts of the world (Richert et al., 2010). Pathogens and diseases such as *Salmonella*, *Shigella* and *E. coli* can be spread through manures, as well as *Clostridium perfringens*, *Cryptosporidum parvum*, *Bacillus cereus* and *Listeria monocytogenes* which can be found in compost (Román, 2015). Some other risks include heavy metal content, which if they are found in great concentrations, can be damaging to human health (Román, 2015). Therefore caution must be taken while engaging in these composting activities. Furthermore, it is important not to discount the ease and immediate benefits of commercial fertilizers, and both organic and synthetic fertilizers can be integrated. Synthetic fertilizers are beneficial to be used along with organic nutrients, since compost generally has low concentrations of iron, copper, and zinc (He et al., 2001). Soil quality and compost ingredients are important factors that contribute to whether the compost will be effective; testing the soil remains important.

Cost Analysis

These solutions are very low cost, with the only tools required being a shovel or pitchfork for turning compost and a jerry can for urine storage. However, if farmers do not own sufficient livestock then manure must be purchased, which can be expensive.

Further Reading

Here are some reports for further understanding on each of these organic fertilizing practices:

Composting:

http://cwmi.css.cornell.edu/compostingathome.pdf
http://www.fao.org/3/a-i3388e.pdf
http://www.fao.org/docrep/014/i2230e/i2230e14.pdf

Urine:

http://www.ecosanres.org/pdf_files/ESR2010-1-PracticalGuidanceOnTheUseOfUrineInCropProduction.pdf

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Chapter 5.10 – Livestock sheds and collecting urine to add to manure

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Introduction

The soils of smallholder farmers often lack the proper amount of nitrogen, phosphate and potassium which are essential for healthy and bountiful growth of crops. Urine collected from livestock and humans is very rich in nitrogen, phosphorous and potassium which is important for plant growth. A family of four can produce the equivalent of a 50 kg bag of NPK fertilizer from urine alone every year (Feineigle 2011). This urine has a 10:1:4 ratio of NPK which is a higher nitrogen content than many mineral fertilizers (Feineigle 2011). Humans produce roughly 500 litres of urine and 50 litres of faeces per person per year (Caldwell & Rosemarin 2014). These contain about 4 kg of nitrogen, 0.5 kg of phosphorous and 1 kg of potassium, the three basic elements for plant growth. The exact amount varies from region to region depending on food intake. Seventy per cent of the nutrients excreted by humans are in the urine fraction (Caldwell & Rosemarin 2014). Livestock consumption of leguminous fodder such as Acacia, Calliandra and Erythrina can increase the nitrogen content of their urine (Devendra 1992).

Since the most prominent nutrient found in urine is nitrogen, it is important to have balanced nitrogen levels in urine that is mixed with manure and to balance urine addition with other nutrients required for plant growth. The importance of nitrogen to plant growth is outlined in Chapter 1.4 – Balanced Fertilization. Using urine as a way to enrich manure is a more cost-effective substitute for fertilizer. In areas where there is not as much livestock, human urine can also be added to crops as noted above. Akpan et al. (2012) recently demonstrated that human urine is strongly alkaline and contains a moderate amount of nutrients (N, P, K, Mg, Ca and Na). Application of either urine or inorganic fertilizer significantly ($P<0.05$) increased plant nutrient uptake compared with the control (Akpan-Idiok et al. 2012). Human or livestock urine can also be used directly in home gardens.

How the practice is conducted

Urine can be collected from livestock using a concrete floor that is sloped toward a PVC pipe that empties into a manure pit. This pipe leads to a pit or inside a mud/stone wall where it is stored. The mixture is then transferred from the storage area and spread along the soil where the crops are to grow. An alternative to this process is that the urine pipe leads to a storage drum from which urine can be added to the manure. These practices require time and effort from the household. Building a concrete floor with a slope towards a PVC pipe would cost a total of $12 USD in materials and would require up to 3 days of construction labour (Sustainable Soil Management Programme 2007). A smallholder farmer can undertake this labour, but it requires specialized knowledge and training (e.g. how to mix concrete). The construction of this can be done by digging a manure pi within the livestock shed in which the urine will be emptied into (SSMP 2007). Then, the smallholder farmer will have to make a floor at the bottom of the shed where the urine will be collected out of a compact of soil or clay, or cement if they are able to afford it (SSMP 2007). Other costs for this would be a collection devise for the urine after it is disposed into the manure pit (SSMP 2007).

There is an easier alternative to collecting urine from livestock, specifically by penning the livestock in a certain area where crops will grow prior to planting so that their urine and feces will directly mix with the soil (Bedford et al. 2016). The animals are able to graze the land and release urine and feces and are able to comfortably move around the land rather than be restricted (Bedford et al. 2016). This process requires little labour on the part of the farming household.

The urine of the livestock is collected within the livestock shed. It is suggested that the livestock shed be created out of fabric as it provides more ventilation and filtration for sheds in hot climates and is more cost-effective for smallholder farmers and industrial farmers alike (Megadome Buildings 2016). As resources are sometimes limited for smallholder farmers, the fabric livestock shed will work as long as they have constructed a proper concrete floor and slope towards the manure pit.

This is not a new concept and has been utilized by many smallholder farmers. In a study conducted by Powell & Williams (1996) in the West African Sahel, the yield was compared over the course of six years using urine from livestock as fertilizer compared to chemical fertilizer. The authors found that there was a 52% increase in yields within the first year of the study (Powell & Williams 1996).

Ammonia Emissions

Ammonia emission is one of the greatest environmental threats from farms (Fangmeier et al. 1994). This is an increasingly destructive threat since ammonia released into the air can affect the crops in the surrounding area as well as the possibility of ammonium contamination into groundwater and river/lake water (Fangmeier et al. 1994). Livestock urine can lead to ammonia losses. It is necessary to mix liquid and solid manures to reduce ammonia emissions (Sommer & Hutchings 2001). Due to ammonia emissions being linked to global warming and climate change, it is necessary to change the diet of livestock and add the required nutrients to soil to reduce these ammonia emissions (Fangmeier et al. 1994). It is important for livestock to be fed a well-balanced diet, including carbohydrate rich foods as it balances out the nitrogen and reduces ammonia emission into the air. Addition of fermentable carbohydrates, such as bran or pulp, into grow-finishing diets, resulted in a 14% reduction of ammonia emission for each percentage increase in carbohydrate (Powers 2004).

Useful Links

To learn more about the benefits and challenges of using human urine to improve agriculture, follow this link:

http://voices.nationalgeographic.com/2013/04/10/human-pee-added-to-compost-boosts-crops/

http://permaculturenews.org/2011/11/27/urine-closing-the-npk-loop/

http://modernfarmer.com/2014/01/human-pee-proven-fertilizer-future/

http://www.gardeningknowhow.com/garden-how-to/soil-fertilizers/feeding-plants-with-urine.htm

Refer to SAK Picture Book Lesson 5.10a and 5.10b p. 54-55 for step by step picture instructions

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5.11 - Compost Improvement

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Background

Soil fertility in crops is a constant problem and one of the main factors limiting crop production in subsistence farms globally (Becx et al., 2012). With the increased prevalence of cattle and livestock in some regions (for ex. in the northern regions of Ghana) that heavily rely on agriculture but are constant victims to the sub-tropical climate, collection and redistribution of animal manure can become a solution to restoring crop fertility (Becx et al., 2012, Thapa 1996). While the direct application of animal manure aids in fertilizing soils, it is essential to compost it alongside other organic wastes to create more efficient fertilizer in larger amounts (Tanner, Holden, Winugroho, Owen and Gill, 1995, Paudel and Thapa, 2004, Sotamenou and Laurent, 2013, Wondimagegn 2014, Harris 2002, Amisi and Doohan, 2010, Tilman, Cassman, Matson, Naylor and Polasky, 2002 and Quamruzzaman 2006). Composting is the biological process of decomposing organic wastes in which bacteria, fungi and other microorganisms break down organic materials into stable, usable organic substances called compost (Bernal, Alburquerque and Moral, 2009). Compost has nutritional and disease-suppressant benefits that restores organic matter to soil, increasing water holding capacity of soil and acts as a storehouse for nutrients.

Description of practice

Collecting ingredients: livestock, crop and household residue

Only organic materials should be used as composting ingredients, including crop, livestock and household residues (Harris 2002, FAO 2015). More specifically: (1) *leftover crop residues* from harvests or garden plants (mulch or dead coverage from crop waste/cultivated fallow), chopped branches, tree and shrub leaves, forages and dried grass; (2) h*ousehold organic waste* from the kitchen such as fruit and vegetables, damaged/expired food, crushed egg shells, coffee and tea waste, dried fruit and nuts shell, fruit peels, as well as napkins, tissues, hair or animal shear; (3) *livestock manures* and even livestock urine. If family does not own livestock, local villages usually have waste piles in which they could collect manure (Harris 2002, FAO 2015).

Creating compost pile

Compost techniques can be divided into closed and open systems (FAO 2015, FAO 2003). Open systems are carried out outdoors, whether in piles above ground, or in dug up pits below ground. Closed systems are carried out in holding units, such as in plastic drums or containers made from bricks or wooden panels. The size (specifically height) of the compost pile directly affects moisture, oxygen content and temperature (which determine rate of decomposition of organic material), therefore it is recommended that compost (whether in open or in closed systems) should be 1.5-2 m high and 1.5-3 m wide (FAO 2015). This, along with downsizing and shredding of raw materials prior to composting, ensures high porosity and proper aeration when turning and mixing compost pile, so that microorganisms responsible for decomposition of organic materials can flourish uniformly (FAO 2003). The initial layout of the compost pile should be similar to that of lasagna, with alternating layers of manure and crop/household residue, with a bottom layer of stone to allow for water drainage. This design provides a proper ratio between plant matter and manure and avoids the risk of leaching nutrients from compost into soil (FAO 2003).

Monitoring compost

Once the system has been created with initial layering, compost should be left outside over a span of a few weeks to a couple of months (Tanner et al., 1995). During the first few days of decomposing, temperatures should increase in the compost pile, where the peak temperature destroys micro-organisms that are human or plant pathogens as well as weed seeds (FAO 2003). During the process of composting, one should perform frequent clump tests to determine the moisture content of the compost: if material is too dry and crumbles away in one's fist, one should add more water, urine or manure to the compost; if the material is too wet and one can see excess water squeezed in the fist, one should modify the compost by adding more dry matter, such as dried grass or legume forages (FAO 2003).

For optimal results, compost should be ventilated by mixing frequently (FAO 2003, FAO 2015). This increases aeration and oxygen exposure, which aids in the process of decomposition of organic matter. Aeration also removes excessive heat, water vapour and gasses trapped in the compost pile. When mixing, one should also be testing moisture content of soil as well as temperature in the soil in comparison to the ambient (outside) temperature (FAO 2003, FAO 2015).

While the process varies from weeks to months, the final product of the compost can be characterised by soil in the pile being uniform, dark brown to black in colour, having a pleasant smell of earth, particles being reduced in size with a consistent, soil-like texture (FAO 2003, FAO 2015). It is vital for compost to complete all stages of decomposition and sterilization in order to be viable as a source of fertilizer without the possibility of spreading weeds or pathogens onto crops (Amisi and Doohan, 2010).

Benefits

Biophysical Benefits

Compost offers many benefits with respect to improving the physical and biological properties of soil. Having higher nutrient content, compost can be used to restore nutrients in soils that are needed to produce higher crop yields (Thapa 1996, Tanner et al., 1995, Harris 2002). Use of a compost can stimulate soil fauna and increase the water holding capacity in drought-prone soils in semiarid climates, which is a major biophysical constraint of subsistence farmers (Becx et al., 2012) and can also reduce runoff and soil loss in areas (e.g. Burkina Faso) (Baptista et al,. 2015). Compost has disease suppressant properties, especially for young plants not yet predisposed to infection, and can be used as a replacement to fungicides (which is not always readily available to subsistence farmers) (Ndiaye et el., 2010).

Economic Benefits

Increasing the use of organic matter that is accessible from home will decrease a farmer's reliance on purchasing commercial fertilizers. The money saved by buying less fertilizer could be used to put children (especially daughters) in school, or to afford better tools that will make weeding or planting easier, and will decrease the labour and time requirements of farming in the long term (Wondimagegn 2014). Once subsistence farmers have incorporated these techniques in compost use and management and have begun to produce higher yielding crops, increased production could be the push for subsistence farmers to transition towards entrepreneurial farming, and being able to produce more for markets. With the ability to create a profit, these farmers will now be exposed to the possibility of investing in inputs and new technologies, which will eventually increase overall productivity (Becx et al., 2012)

Labour and time requirements

Lack of knowledge is perhaps the main contributing constraint for subsistence farmers moving towards compost use, with extensive labour as second and lack of transport as third, with farmers stating that “soil is not yet that bad to do so much work” (Becx et al., 2012 and Akalu et al., 2016). Composting results in work pertaining to maintaining the compost as well as the need to manually collect, mix, monitor and applying the final product to fields (Paudel and Thapa, 2004, Shroeder 1985, Sotamenous and Laurent, 2013 and Quammruzzaman 2002). If some supplies are required that are not present on hand (e.g. if the family does not keep livestock on the farm), transportation and time would be needed to acquire those materials (Harris 2002).

Helpful hints and Further Reading

It is important to take into account that the nutrient balance in soils varies across regions and that areas adjacent to one another could be deficient in different nutrients (Smaling et al., 1997). In areas such as Northern Ghana, soils are coarse with low organic matter content, poor structure and fertility, with two most commonly deficient nutrients being nitrogen (N) and phosphorus (P). In order to help replenish these deficiencies, farmers can add residue from crops that are high in nutrients needed (e.g. crop residue from legumes, such as cowpea, soybeans and groundnut, which are high in N) to compost in order to re-supply soil and fertilise crops such as corn, that take up large amounts of N from the soil (Eghball 2002).

Further information about composting is available in:

FAO’s *Farmer’s Compost Handbook* 2015 at: http://www.fao.org/3/a-i3388e.pdf

FAO’s *On-farm Composting Methods* 2003 at: http://www.fao.org/docrep/007/y5104e/y5104e05.htm

GardenAfrica's training film - *Black Gold: The Secrets of Compost* at: http://www.gardenafrica.org.uk/audio-and-visual/ (gives a step-by-step explanation of how to create a compost pile, specific towards subsistence farmers in African regions)

FAO’s *Composting: let’s give the soil something back* article at: http://www.fao.org/soils-2015/news/news-detail/en/c/280674/ (focuses on the impact of food wastage on soil sustainability and how to reduce one’s food waste footprint)

FAO’s *Impact of compost use on crop yields in Tigray, Ethiopia* by Sue Edwards, Arefayne Asmelash, Haily Araya and Teworld Berhan Gebre Egziabher, at: http://www.fao.org/3/a-ai434e.pdf

FAO’s *Waste Management opportunities for rural communities – composting as an effective waste management strategy for gaarm households and others* at: http://www.fao.org/3/a-k1455e.pdf

FAO’s *How to make and use compost* by Sue Edwards and Hailu Araya at: http://www.fao.org/docrep/014/i2230e/i2230e14.pdf

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5.13 - Treating seeds with urine

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Background

A prominent issue that affects worldwide crop production is soil acidity, especially in developing nations. India for example is particularly affected with 95% of their soil being acidic (Kumar, 2014). This acidity creates deficiencies in minerals such as phosphorus and zinc which in turn reduces crop yields. In these developing nations where the farmers are economically poor, high cost commercial fertilizers to solve the problem are simply unattainable (Kumar, 2014). Another issue is the lack of ability by many smallholder farmers to manage soil texture and structure leading to insufficient seedling emergence which is pronounced in low rainfall regions (Nawaz et al., 2013).

Indigenous agricultural practices have potential to combat these challenges and help to create a sustainable agricultural system. The knowledge and technologies in traditional practices have been developed over generations and are deeply rooted (Karthikeyan et al., 2006). It is argued that in contrast to modern agricultural practices, traditional practices are “socially desirable, economically affordable, sustainable and involved minimum risk to rural farmers and producers” (Karthikeyan et al., 2006).This chapter concerns seed priming with urine, an indigenous technology to add nutrients to crops and improve seed germination.

Seed Priming with Urine

Good quality seed is a crucial factor in agriculture for obtaining higher yields and sustained productivity (Amarnath et al., 2015). Seed priming simply means the soaking of seeds just prior to sowing. Seed priming techniques, both traditional and modern, have been practiced in many different countries such as India, Pakistan, China, Australia (Nawaz et al., 2013). and such techniques have also been used recently in parts of West Africa (Peace Corps Mali, 2009). It is simple, low cost, easy to practice long-term and not time consuming (Nawaz et al., 2013).. Seed priming has been shown to help promote seed germination, and activate seedling enzymes involved in making available seed nutrients and promoting natural pathogen/pest defence systems (Nawaz et al., 2013).. A study testing the effects of seed priming techniques using water, found that seed germination increased to 91.4% from 71.2% (Soleimanzadeh, 2013). Good establishment of seeds is important in controlling weeds, drought tolerance, and increasing yields (Nawaz et al., 2013). The same study found that seed priming led to an increase in seed yield from 4.291 $ton.ha^{-1}$ to 5.413 $ton.ha^{-1}$ (Soleimanzadeh, 2013). These factors are important for crops in tropical regions including sorghum, rice, maize and pigeon pea (Nawaz et al., 2013).

One very effective seed priming technique is the soaking of seeds in human or cow urine. Urine promotes plant growth. Urine is abundant in essential plant nutrients, with one litre containing 11grams of nitrogen, 0.8 grams of phosphorus and 2 grams of potassium. Urine also has a high water content, important for areas that are dry at the time of sowing (Morgan, 2004). Nitrogen is a building block for chlorophyll and protein. Phosphorus promotes seed germination and helps with root formation (Morgan, 2004).

The use of urine as a seed primer has been shown to improve crop yield and growth, particularly on low-fertility and acidic soils (Kumar, 2014). Studies have shown that seed priming with urine increases seed germination from 76.5% to 85.2%,seedling length from 28.16 cm to 39.53 cm, root length from 10.68 cm to 16.65 cm and shoot length from 17.48 cm 22.88 cm (Amarnath et al., 2015) . The technique is extremely simple, as there are only two steps. First the urine is diluted by 2.5 times in water and added to the seeds which are soaked in it for 16 hours. Second, in order to reduce moisture in the seeds, they are let to air dry, after which they are ready to be sown in the field (Kumar, 2014).

Case study: Indigenous Indian method of seed hardening of finger millet seed (*ragi*) using cow urine (Karthikeyan et al., 2006). -- Seed hardening is effective in helping seeds cope with poor soil moisture conditions and water stress. The method has been found to be capable of combatting seed borne diseases (e.g. Smut) and in activating drought resistance. When testing seed hardening techniques effects on growth under drought conditions it was found that seed germination increased from 51% to up to 89% with grain yield increasing by up to 37% (Amin et al., 2016). The method has been adopted by 60% of farmers in Thondamuthur village, Tamil Nadu, India.

Method:
1. Mix 100 ml of fresh cow's urine with 1 L cold water (6 L of solution is needed for 6 kg of finger millet seeds)
2. Keeping solution 3-4 cm above the seed level, soak the seeds for about 16 hours
3. Seeds are shade dried for 24 hours before being used for sowing operation

Spraying Crops with Urine

The most common use of urine for plants, which has similar positive effects on crop growth and yield as priming, is to dilute human urine (or cow's urine, however many rural farmers do not have cows) and spray it on crops as an organic fertilizer (Peace Corps Mali, 2009). The collection and application is described below:
Estimated cost for the entire process: 1.85-3.06 US$
Collection Method (Peace Corps Mali, 2009)*:*
1. Obtain a 20 L clear jug and a large mouth funnel that fits tightly in the jug
2. Tightly tie a piece of rubber where the funnel and jug meet in order to ensure ammonia does not escape
3. Make a seal for the mouth of the funnel using 3 or 4 plastic bags inside one another, the inner most filled partly with water, and place in the hole of the funnel
4. The mixture should be 1 part urine, 3 parts water so mark a line half way up the jug and a quarter way up the jug
5. When creating the mixture fill water up to the first line than only urine until the half way mark
6. Let the jug sit for 2 days in order to kill any schistosomiasis (disease caused by parasitic flatworms)
7. Fill the jug the rest of the way with water and mix together

Here is a link to helpful illustrations of the collection method:
http://forest.mtu.edu/pcforestry/resources/studentprojects/Urine%20Fertilizer%20Sheet%20in%20English.pdf

**Women and children can use a bucket or cup in order to pour urine into the container. Or see the Ecosan or Skyloo options below.*

Ecosan toilets: This is a new environmentally friendly, dry sanitation system that is being constructed around the developing world including India and South Africa (Ecosan Waterless Toilet System, n.d.). The toilets are being implemented in countries that suffer from chronic water shortage as they do not use any water and do not contaminate ground water. They are sustainable as they are easy to install and maintain and are easily transported. Many adaptations of the system are constructed to separate the feces and the urine in order to use the urine as a fertilizer/insecticide on plants immediately while the feces go through a composting and disinfection process.

Helpful resources for Ecosan:

- Ecosan toilet Website: http://www.ecosan.co.za/
- Constructing an Ecosan toilet: https://www.youtube.com/watch?v=YV-1To9DkJQ
- The "Skyloo" urine diversion toilet: http://www.ecosanres.org/pdf_files/PM_Report/Chapter_11_Urine_diversion-how_to_build_single_vault_toilet_a.pdf

**When collecting urine it is important to ensure that there is no contamination with fecal matter*
Application Method (Peace Corps Mali, 2009)*:*

1. Start applying the urine 2 weeks after sowing and stop applying it 3 weeks before harvest. If one applies it too early it stunts growth, and applying it after 3 weeks will be ineffective.
2. Use 4 L of the mixture for 1 square meter of crops.
3. The mixture must be poured near the ground as to not get on the leaves; apply mixture evenly.
4. Once the mixture has seeped into the ground (which should take less than a minute) immediately water it in order to ensure the nitrogen does not escape.

Case study: Pest control using cow's urine (Karthikeyan et al., 2006). – This is an organic and traditional method of pest control using green leaves of specific plants and cow urine. The method is cost effective. The green leaves and urine have insecticidal properties at no extra cost. The method is likely restricted to South Asia as the green leaves are found there:

- Sources of green leaves: neem (*Azadirachta indica)*, pungam (*Pungamia pinnata*), nochi (*Vitex negundo*), erukku (*Calotropis gigantea*), and Tulsi (basil)
- Shown to be effective on the following crops: paddy rice, red gram (pigeon pea), black gram (mungo beans), brinjal (eggplant) and bhendi (okra) as well as many others
- Shown to be effective in repelling the following pests: aphids, leafhoppers, borers and beetles

Method:

1. Crush 1 kg of each of the green leaves using an 'ural' (granite stone milling tool)
2. Mix the crushed leaves in with 100 L of cow urine
3. In a vessel, allow the mixture to ferment for 10-15 days until it obtains an "obnoxious" odour; using a wooden stick stir solution daily
4. Once fermentation is completed, filter solution using a cotton cloth
5. Use 10 L of the solution spray on 1 acre of cropped land on 1.5 month old crops

Important considerations: Helpful hints and potential problems

Do not apply undiluted urine directly to the roots of plants: Plants will most likely die if treated with undiluted urine because too much nitrogen will burn the plant roots. One can apply undiluted urine to the topsoil several weeks before planting which will help enhance growth; but one must be careful as heavy rain can flush out the nutrients. Undiluted urine can also be applied to soil near the plant but must be watered immediately after (Morgan, 2004).

Soil type and quality are important: Fertile soil contains more bacteria which makes it more effective at converting urine from urea to nitrate salt and is therefore more effective than poor soils. If one applies urine to poor, sandy soil the urine will not convert properly and it can stunt the growth of the plants. In order to use urine effectively it must have good quality, humus-like soil (Morgan, 2004).
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The age of the plant is important: More mature plants are able to handle a higher concentration of urine and water. If the quality of soil is poor, young plants can be killed even with diluted water (Morgan, 2004).

This process takes time: whether one is soaking the seeds or spraying on crops both processes take time. One must take into account both soaking and drying time. With the use of any traditional or modern planters, seeds may stick so one must re-dry during the soaking process. Most nutrients in the urine must be converted into plant food first meaning they are not available right away to the plant, and therefore must take time for the conversion process before spraying. Nitrogen for example must be converted to ammonia from urea, then to nitrate and then eventually nitrate salt. Pure nitrate is actually toxic to plants (Morgan, 2004).

Storing urine: use plastic containers for storage as metal containers will corrode. Keep in mind when storing urine to keep it well sealed in order to prevent ammonia from escaping (Morgan, 2004).

Urine can be used as pest control during storage: Many rural farmers use wooden bins for storage of seeds which can be easily penetrated by pests. In order to prevent this, an effective indigenous Indian method is to take cow dung, mud, mustard cake and carbon from an iron plate and mix with cow urine to make a paste which can be plastered on the storage bins acting as a pest repellent (Mehta et al., 2009)

Adding plant matter to urine can balance nutrients: Plants can be added to urine that will ferment and therefore change the balance of the nutrients (Morgan, 2004).

- Comfrey leaves (*Symphytum*) increase proportion of potassium to nitrogen
- Peels of bananas are high in many nutrients including phosphorus, potassium, calcium,
- magnesium and sulphur, and hence can potentially adjust nutrient balance

Table 1. List of crops that are suitable or not suitable for urine fertilization (Peace Corps Mali, 2009)

What to Fertilize with Urine	
Bad for	Carrots: will grow big leaves and small roots
Little effect on	Legumes, beans and peanuts: they fix nitrogen
Best on	Corn, millet, sorghum, salads, spinach and other greens: grows bigger leaves and lots of seeds
Great on	Everything else: Onions, tomatoes, potatoes, eggplant, bananas, peppers, garlic, cucumber, melons, squash, sweet potatoes, cassava etc.

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5.15 - Using worms to create manure (vermicomposting)

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Introduction

Livestock populations are declining in many developing nations, and with them the supply of manure. Animal manure is an important source of nutrients that will improve yields when applied to the soil. Where little or no animal manure is available, worms can be intentionally introduced to compost piles to help break down food waste and crop residue. This process, known as "vermicomposting" creates biologically active compost that will benefit soils in a similar manner to animal manure, especially in terms of providing organic matter and micronutrients. Vermicomposting has been demonstrated by several studies to improve the quality of the final compost product in comparison to regular composting by improving mineral availability and concentration (Arancon, Lee, Edwards, & Atiyeh, 2003; Bhattacharya & Chattopadhyay, 2002; Ndegwa, Thompson, & Das, 2000; Suthar, 2009). Worms can be broadly classified according to their habitat. "Epigeic" worms are those that live on the Earth's surface in decomposing materials and do not have permanent underground burrows (Munroe). Epigeic worm species such as Red Wrigglers (*Eisinia fetida*), African Night Crawlers (*Eudrilis eugeniae*), and *Perionyx excavatus* are the most commonly used species for vermicomposting because a compost pile is very similar to their natural habitats. Epigeic worm species will predominate in untended compost or other decaying plant matter, so these are generally good places to collect worms to use for vermicomposting. Most epigeic worm species can reproduce rapidly, because this is necessary for competition in the wild (i.e. they must quickly grow in number when food becomes available) (Munroe). With this in mind, worm species found in an untended compost pile will probably have naturally good growth and reproduction rates, and therefore will likely be suitable for vermicomposting. More information on find an appropriate worm species is included below under *Feeding and Caring for the Worms*.

Labour and Time Requirements

Vermicomposting generally requires more work than traditional composting, although a vermicomposting pile has the benefit of not needing to be regularly turned over. This is because the tunnels made by the worms will allow air into the compost in a similar way that turning it over would (Munroe). Keeping enough moisture in the pile will probably be most of the daily work involved with a vermicomposting pile. Food and bedding will also have to be added to the pile every few days, depending on the management technique.

The harvest of a vermicomposting pile requires separating the worms and the compost as much as possible. This generally requires more labour than simply taking an entire finished compost pile to a field. However, with proper management separating the worms and the compost can be done without too much extra work. See the section on Harvest (below), for further detail.

Vermicomposting can take more or less time than traditional composting. This depends largely on worm population density and the climatic conditions of the compost pile. Under ideal conditions, vermicomposting will require less time to produce finished compost than traditional composting (Munroe).

Feeding and Caring for the Worms

Worms can be fed with almost any crop or food waste (Munroe). Exceptions include materials that are high in protein such as meat, blood or offal or materials that are high in salts (Munroe). Pre-composting such materials before introducing them into the vermicomposting environment can make them more suitable. Citrus based materials should not comprise more than $1/5^{th}$ of the feed material because of their acidity.

A bedding material must also be included in the compost environment to retain moisture and provide adequate carbon (an energy source for the worms). The most important characteristics for bedding materials are high water absorbance, resistance to compaction, and a high carbon to nitrogen ratio. Shredded waste paper or cardboard is ideal although most absorbent carbon based material can meet this requirement. See Table 1 of the OACC manual [(Munroe), link included below] for carbon to nitrogen ratios of commonly available bedding materials. Different materials also can be mixed to create bedding that retains moisture and resists compaction. For example animal manure, which is highly absorbent, can be mixed with straw, which resists compaction but is not very absorbent (Munroe). Manure from pasture animals (cattle, sheep, goats) should be pre-composted on its own before addition to the manure pile so weed seeds can germinate and die off well before the manure is introduced to fields (Munroe). The ideal ratio of bedding to feed material will vary depending on the materials used. Foul odours or persistently dry conditions can be an indication that the vermicompost pile requires more bedding relative to feed material.

The compost pile must be kept moist (> 50% moisture at all times, ideally 70 to 90%) (Munroe). This is important because the worms will die if they dry out. Basically, 70 to 90% moisture means that the bedding material should be as wet as possible without dripping. Worm compost piles will often require being sprayed or sprinkled with water to maintain their moisture (Munroe).

Temperature is also important for the survival of the worms, and should be as constant as possible (Reinecke, Viljoen, & Saayman, 1992). Shielding the compost pile from direct sunlight will help encourage constant temperature. If native worms species are being used for the project a shaded compost bin will likely be enough precaution to ensure their survival however if an imported worm species is being used their ideal temperature range for growth and reproduction should be considered.

Worms can be expected to eat approximately half of their weight per day, although this will change depending on the feed material being given to the worms and their environment (Munroe). If the worm reproduction or compost production rate is less than ideal despite good culture conditions, the purchase of a worm species specifically intended for composting can be considered, if available. A guide to feed material digestion over time is provided in Table 1.

Table 1: Digestion of feed material for different worm stocking rates

Worm Stocking Rate (kg/ m^3)	Feed Material Conversion per Day (kg)	Days to Convert 100 kg of Feed Material
2.5	1.25	80
5	2.5	20
7.5	3.7	14
10	5	10

Adapted from Munroe (original figures)

Making a Vermicomposting Pile

Vermicomposting can be performed either above ground in a sturdy container, or in a pit dug into the ground. If a pit environment is chosen it should be lined with an impermeable material to prevent the escape of worms (Munroe). Plastic bags or similar material could be used, though there should be as few gaps in the lining as possible. Pits have the advantage of being very easy to build and maintain, as well as being insulated from temperature changes. Harvesting of a pit will be less convenient as it will be lower down and the operator will have to bend over further to access the compost. This will be a greater concern for some than others depending on age, height, physical health, etc.

Above-ground vermicomposting can either be performed either in containers or in open piles. Enclosed containers are recommended because they protect worms from predators and discourage their escape.

Above-ground containers can be made from most materials, although metal is not recommended because it transfers heat quickly and is likely to rust. Concrete is a popular option for its sturdiness and availability (Munroe). Large plastic containers can also be successfully used if available. Wood containers can be made but will require more frequent maintenance because of their tendency to rot (Munroe). Pressure-treated wood should be avoided because of its toxicity. Rammed earth could also be used to create the worm environment if the techniques for its construction are known in the area. If practical, the sides of an above ground container should have some vent holes to encourage air flow through the worm environment, as well as some kind of drainage outlet to remove excess moisture (Munroe).

The worm population for a new compost pile should be 2.5 to 5 kg worms per m^2 of bedding and worm feed. An established vermicomposting pile should have 5 to 10 kg of worms per m^2 (Munroe). Producers should use higher stocking densities when maximum compost creation is desired, and lower stocking densities when maximum worm production is desired (see Table 1).

The compost pile should be no more than a meter deep (Munroe). Because surface dwelling worms are used for vermicomposting, they will not perform well if covered by an excess of material due to lack of available oxygen (Munroe). As long as the vermicomposting pile is not excessively deep, its shape can vary depending on the desired management technique. Smaller piles will be easier to harvest but will generally require more labour per unit of compost harvested. With this in mind, compost piles should be as large as can be reasonably managed for harvesting. A rectangular shape will be more convenient for some harvesting techniques, for more information see *Harvesting* section below.

The construction of a vermicomposting container is very flexible and a wide variety of designs can potentially be successful. The most important characteristics of a container's design are air flow, moisture retention, drainage, and accessibility, particularly for the removal of finished compost. Additionally, the container should prevent the escape of worms from the compost environment. Non-biodegradable materials should be used if available as they will require less frequent replacement.

Harvesting

There are two broadly practiced, low-tech methods of harvesting worms. In the "vertical harvesting" method, the finished compost is spread on well-lit surface (daylight is ideal). The worms will burrow downward in the compost to avoid the light, and the upper level of worm free compost can be removed in layers. Worms will continue to move downward as the upper layers are removed (Munroe). This method is best suited to smaller worm composting operations.

In the "horizontal harvesting" method, new feed material is added only to one side of the compost pile at a time. As one side of the pile approaches completion, the worms will migrate to the side of the pile where the new material is being added. After material on one side is completely digested, most worms will have migrated to the other side of the pile and the completed compost can be removed with minimal loss of worms (see Table 1 for approximate timing). Addition of new feed material can then begin on the just-harvested side of the compost pile. The horizontal harvesting method is less time consuming but is more likely to cause some loss of worms.

A final method of harvesting worms can be used with open compost piles. In this method new material should be added in thin layers (approximately 10 cm thick) evenly to the top of the pile. When this layer is close to being fully digested, a new layer can be added on top. The worms will then migrate up into the new food material. In this system, the lower levels of the windrow remain fairly free of worms. When harvesting is required, it should be performed a few days after a new feed layer is added. The top layer (containing most of the worms) can then be removed and added to a new pile or used for feed and the lower layer can be applied to crops with minimal loss of worms (Munroe).

Species

As mentioned above, African Nightcrawler (*Eudrilus Eugeniae)*, Red Wriggler (*Eisenia Fetida*), and *Perionyx excavates* have all been identified as ideal species for vermicomposting because of their suitability to the compost environment and high rates of growth and reproduction. In Africa, African Nightcrawler worms as well as other potentially suitable epigeic worm species can commonly be found in the environments described in Table 2. Those interested in vermicomposting should first try gathering worms from the environments described in this table. If the collected worms are not surviving or showing poor growth in the compost pile, the purchase of one of the popular vermicomposting species can be considered if available.

Table 2: Habitat and temperature range of popular vermicomposting species

Species	Habitat	Temperature Range	Reference
African Nightcrawler *Eudrilus Eugeniae*	Top 10 cm of soil, especially where constantly moist (riverbeds, near bathhouses), decomposing surface material	> 25° is good, > 30° C better, 18 to 35° C is overall range for growth	(Mainoo, Whalen, & Barrington, 2008; Reinecke et al., 1992)
Red Wriggler *Eisenia Fetida*	Decomposing surface material, untended compost piles	0 to 40° C (temperature limits for survival)	(Reinecke et al., 1992)
Perionyx excavates	Decomposing surface material (Species is native to India)	Optimum growth at 25°C, growth rate sharply declines above 30° C and below 15° C	(Edwards, Dominguez, & Neuhauser, 1998)

In general a temperature in the mid-twenties (˚C) that is kept as constant as possible is ideal for the growth of worms. Temperatures over 35°C should be avoided. Excessively cold temperatures are not likely to be limiting factors on worm growth for farmers in tropical climates.

Other Uses

Worms are a dense source of high-quality protein, and could be used to supplement livestock diets (Sun, Liu, Sun, & Song, 1997). Producing worms for feed could potentially be a small business opportunity for farmers if there is demand in their area, however available studies report that worms reproduction rates must be very high for this kind of system to be economically viable (Reinecke & Albert, 1994). Further study in this field is required.

Limitations

There will usually be more day-to-day work required to maintain a vermicomposting pile in comparison to traditional composting (especially in ensuring adequate moisture for the worms), although careful management (especially to limit moisture loss) can limit the additional labour required.

There is limited information available on the cultural acceptance of vermicomposting. This will obviously vary widely between communities and individuals, however it is likely that some people will not like handling worms. This could be a barrier to the uptake of vermicomposting techniques over traditional worm-free composting methods in some areas. It is possible that children (especially little boys) may find worms fun and could potentially be employed when handling worms is necessary.

Additional Reading:
Munroe, Glenn. OACC Manual (Focused on Red Wriggler worms)
http://www.organicagcentre.ca/docs/vermiculture_farmersmanual_gm.pdf
Village Volunteers Manual
http://www.villagevolunteers.org/wp-content/uploads/2011/05/Vermicomposting.pdf

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5.16.1 - Synthetic fertilizers: primer and raising yields

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Introduction

Synthetic fertilizers are concentrated, typically commercial sources of plant nutrients that are generally more stable and easier to ship than organic nutrient sources. Though the term “synthetic” is used, fertilizers are composed of naturally occurring minerals that may be processed to improve their availability to plants; the exception is nitrogen fertilizer which is extracted from the atmosphere through a catalytic process that consumes natural gas (Standage, 2009) (**p. 212**). Nutrients are classified broadly by the relative quantities in which they are needed for plant growth (Table 1). Macronutrient fertilizers, which are needed in relatively high amounts, include nitrogen (N), phosphorus (P), and potassium (K). The secondary nutrient fertilizers are sulphur (S), calcium (Ca), and magnesium (Mg), which are needed in moderate amounts for plant growth. Micronutrient fertilizers include zinc (Zn), molybdenum (Mo), manganese (Mn), iron (Fe), copper (Cu), and boron (B), all of which plants need in relatively small amounts (*Principals of Plant Nutrition*, 2001)(**p2**).

Table 1: Relative plant requirements of the 12 nutrients.

Nutrient	**Relative Requirement**
Macronutrients	
Nitrogen (N)	100
Phosphorus (P)	6
Potassium (K)	25
Secondary Nutrients	
Sulphur (S)	3
Calcium (C)	12.5
Magnesium (Mg)	8
Micronutrients	
Iron (Fe)	0.2
Manganese (Mn)	0.1
Molybdenum (Mo)	0.0001
Boron (B)	0.2
Zinc (Zn)	0.03
Copper (Cu)	0.01

Adapted from: Epstein, E. 1965. Mineral Metabolism*. Plant Biochemistry*. 438-466.

Each fertilizer required by plants has a unique, natural biological function. Nitrogen is a building block for amino acids **(p 419)**, which make up proteins, while phosphorus is a component of DNA **(p 467)**, and potassium is required to maintain hydraulic pressure within plant cells and transmit biological signals **(p 492)** (*Principals of Plant Nutrition*, 2001). Similarly, each of the secondary and micro-nutrients have specific functions within plants: for example zinc is required for approximately 100 “master genes” in plants to function properly (Li et al., 2013). Molybdenum is required for biological nitrogen fixation by bacteria that are symbiotic with legumes (Bambara & Ndakidemi, 2010).

Synthetic fertilizers can contain one or more of the 12 plant nutrients, but some governments promote formulations that contain only N or N+P, which can become less effective as other minerals are depleted from the soil. Similarly, many farmers are primarily concerned with supplying the macronutrients (N, P, and K) to the soil, and in this situation shortages of secondary and micro-nutrients can as limiting on plant growth as a macronutrient deficiency.

There are some negative opinions towards synthetic fertilizer use, some of which is justified (Rees et al., 2013). Firstly, because synthetic fertilizers are associated with industrial chemical agriculture, they are commonly equated with pesticides, despite their inherent differences. Second, production of the non-mined fertilizer, nitrogen (ammonia, nitrate, urea), consumes natural gas and hence contributes to global warming (Rees et al., 2013). Finally, the concentrated application of most synthetic fertilizers can potentially create an imbalance and lead to pollution of nearby ecosystems (Badruzzaman, Pinzon, Oppenheimer, & Jacangelo, 2012). However, when responsibly used, synthetic fertilizer can significantly improve yields and can improve the overall sustainability of agroecosystems that face absolute shortages of minerals necessary for plant growth (*Principals of Plant Nutrition*, 2001)(**p 338**). Each nutrient has a specific function within the plant, and thus an abundance of one nutrient will not make up for a shortage of another. For this reason it is important that an appropriate balance of synthetic fertilizers and/or organic nutrient sources (e.g. manure) is employed in order to provide all of the necessary nutrients for plant growth.

Though all 12 nutrients are required for plant growth, every crop requires these nutrients in a specific ratio. To illustrate this point, the approximate ratio of nutrients required by corn and cabbage are provided in Table 2 below. Commercial fertilizers (and organic nutrient sources) will contain different combinations and ratios of nutrients (see Fertilizer Formulation section). In some areas of the world (Ethiopia, Haiti), government policies have made primarily only one fertilizer blend available to farmers.

Table 2: A comparison of the relative nutrient requirements of corn versus cabbage.

Nutrient	**Corn**	**Cabbage**
Macronutrients		
Nitrogen (N)	+++++	+++++
Phosphorus (P)	+++	+++
Potassium (K)	++++	++++
Secondary Nutrients		
Sulphur (S)	++	+++
Calcium (C)	+++	++
Magnesium (Mg)	+++	++
Micronutrients		
Iron (Fe)	+	+
Manganese (Mn)	+	+
Molybdenum (Mo)	+	+
Boron (B)	+	+
Zinc (Zn)	+	+
Copper (Cu)	+	+

Adapted from (*Principals of Plant Nutrition*, 2001)(**p340**)

The above ratios should be interpreted as a general guideline. Where available, specific crop requirement guidelines based on local trials should be used. In general, cereals such as corn, rice, millet, sorghum and wheat will require more nitrogen than any of the other nutrients (*Principals of Plant Nutrition*, 2001)(**p369**). For legumes such as soybean, common bean, cowpea, chickpea, lentils, and peanut (groundnut), phosphorus and potassium are needed from the soil in the greatest amounts (*Principals of Plant Nutrition*, 2001)(**p369**). For starchy crops such as cassava, potatoes, sweet potatoes, yams, bananas and plantains, potassium is generally the most needed nutrient (*Principals of Plant Nutrition*, 2001)(**p369**). Sulphur is also commonly limiting in tropical soils (B. K. R. Rao et al., 2012). Although this is the general trend for nutrient requirements, there is great variation according to soil type, climate, and management history, and shortages of additional minerals can also become limiting if they are not being added to the soil.

Mobile and Immobile Nutrients

Fertilizers can be leached from the soil or lost after application, which wastes money, however this vulnerability varies between nutrients. In general, positively charged nutrients will be attracted to soil particles (which tend to be negatively charged) and are thus less prone to loss, whereas negatively charged or neutral nutrients (sulphur, nitrogen in nitrate form, and boron) travel in soil water and are easily lost from the soil (*Principals of Plant Nutrition*, 2001). Although the relative risk of nutrient loss is lower with positively charged nutrients, it can still occur and any synthetic fertilizer should be applied shortly before planting, ideally after heavy rains have occurred (*Principals of Plant Nutrition*, 2001)(**p342**).

Most crops require high levels of nitrogen for their growth, which can be an especially great challenge as nitrogen is also one of the most easily lost nutrients (*Principals of Plant Nutrition*, 2001)(**p342**). There is some evidence that nitrogen will be more used more efficiently in certain crops if a portion of the nitrogen application is delayed until a crop's root system has developed (Mohammed et al., 2013). Nitrogen can also easily be converted into a gaseous form and for this reason there is some indication that incorporating synthetic nitrogen fertilizers into the soil can also increase uptake efficiency (Schnier, Dedatta, Mengel, Marqueses, & Faronilo, 1988).

Commercially produced "super-phosphate" fertilizers and their derivatives are highly plant available, however it has been reported that they can become bound to soil particles, especially in highly-weathered tropical soils, limiting their effect (van Straaten, 2002).This phenomenon has been reported to be especially severe in acidified soils (*Principals of Plant Nutrition*, 2001).There is some evidence that phosphorus availability can be increased by applying it in concentrated bands beneath the soil surface, as this will reduce the degree of direct contact between phosphorus and soil particles (*Principals of Plant Nutrition*, 2001)(**p367**).

Over-application of any nutrient can cause damage (often referred to as "burning") or even death to a growing crop (*Principals of Plant Nutrition*, 2001). For this reason it is very important to follow nutrient application guidelines for the crops under cultivation, and to ensure that fertilizer is spread evenly throughout the field. See *Practical Tips*, below, for suggestions on applying fertilizer evenly. Much of the way nutrients move through the soil has to do with their individual static electrical charges (*Principals of Plant Nutrition*, 2001)(**Ch. 2**). Positively charged nutrients will naturally reach a balance between particles that are directly associated with the soil and particles that will exist in soil water (*Principals of Plant Nutrition*, 2001)(**Ch 2.1.2**). The degree of attraction between a positively charged nutrient and the soil will vary depending on both the nutrient and the soil type, however it is important to keep in mind that in most situations a certain fraction of each nutrient will exist in soil water and thus be somewhat mobile. The relative mobility of common minerals in the soil is described in Table 3.

Table 3: Relative mobility of minerals in the soil

Nutrient	**Charge**	**Relative Mobility**
Macronutrients		
Nitrogen: Nitrate	Negative	High
Nitrogen: Ammonium	Positive	Moderate
Phosphorus (P)	Positive	Very Low
Potassium (K)	Positive	Moderate
Secondary Nutrients		
Sulphur (S)	Negative	High
Calcium (C)	Positive	Low
Magnesium (Mg)	Positive	Low to Moderate
Micronutrients		
Iron (Fe)	Positive	Low, less available at high pH
Manganese (Mn)	Positive	Low, less available at high pH
Molybdenum (Mo)	Positive	Low, less available at low pH
Boron (B)	Neutral	High
Zinc (Zn)	Positive	Low, less available at high pH
Copper (Cu)	Positive	Low, less available at high pH
Non-nutrient minerals		
Sodium	Positive	Moderate
Aluminum	Positive	Extremely low, however potentially toxic at extremely low pH

Adapted from (*Principals of Plant Nutrition*, 2001)

Unlike most plant nutrients, sulphur and some forms of nitrogen (nitrate) exist in the soil as negatively charged molecules (*Principals of Plant Nutrition*, 2001). As negatively charged nutrients are not attracted to soil particles, they will travel exclusively in the soil water and are thus much more mobile. Similarly, boron (the only uncharged nutrient) has no attraction to soil particles and is also highly mobile (*Principals of Plant Nutrition*, 2001)(**p621**). Because of these unique properties, the behaviour of these nutrients is more affected by soil texture than those that are positively charged. In general, as sandier (often referred to as “red”) soils drain more quickly, there will be a much higher risk of leaching loss for these nutrients. There is a lower risk of loss through leaching on clay (often referred to as “brown” or “black”) soils, however waterlogged conditions (more common to clay) can also cause loss of nitrogen and sulphur through gasification (*Principals of Plant Nutrition*, 2001).

As noted above, splitting nitrogen application into two doses (one before planting, followed by a second application into an already established crop) has been shown to improve yield in wheat and corn (Abbasi, Tahir, & Rahim, 2013; Mohammed et al., 2013), however this trend is not consistent for all crops (Zebarth, Leclerc, & Moreau, 2004). The most reliable way to determine if splitting nitrogen application into two doses will be beneficial is through setting up a small trial plot that compares split application of nitrogen to the current practice. If split application confers a yield benefit with the local combination of crop and soil, then wider application of this practice can be considered.

Some commercial fertilizers are prepared with an outer coating that slows the release of nutrients into the soil (Notario Del Pino, Arteaga Padron, Gonzalez Martin, & Garcia Hernandez, 1995). This is valuable as an insurance against nutrient loss and also to decrease the risk of over-applying a particular nutrient, which can damage crops. Other techniques such as incorporating synthetic fertilizers into charcoal have also shown some potential to slow the release of nutrients (Khan et al., 2008), however the additional labour required by this technique may not justify the practice depending on the nutrient loss potential of the soil.

Nutrient Forms

Nitrogen

Most plant nutrients can only be taken up by plants as fairly small, simple particles. Most commercial fertilizers are composed of such particles that are immediately plant available, or will quickly break down to these forms once introduced into the soil. Organic material on the other hand must be broken down by decomposer organisms before the minerals it contains are available to plants. The slower release of minerals from organic matter decreases the risk of loss, although it should be noted that organic matter may not be an independently reliable source of nutrients. For more information on using organic matter as a nutrient source please see Chapter 3: Balanced Fertilization.

Plant available (often referred to as "mineral" nitrogen) can refer to either ammonium (NH_4^+) or nitrate (NO_3^-). There is also some evidence that small organic nitrogen containing molecules such as amino acids can be taken up directly by plants (Jones & Darrah, 1993; Warren, 2013), however almost all synthetic fertilizers will contain minerals forms of nitrogen. Both nitrate and ammonium molecules are plant available, although it has been recognized that some plant varieties have a preference for one or the other (Zhao et al., 2013). However, in most situations either source of nitrogen will be equally effective (Mengel and Kirkby, 2001 **p431**). Common forms of N fertilizer and notes on their individual characteristics are summarized in Table 4.

Table 4: Common sources of synthetic nitrogen

Fertilizer Type	**Formula**	**% N**	**Ammonia vs. Nitrate based**	**Notes**
Ammonium sulphate	$(NH_4)_2SO_4$	21	Ammonia	Unsuitable for paddy rice production because of sulfur volatilization
Ammonium chloride	NH_4Cl	26	Ammonia	Not widely used

Ammonium nitrate	NH_4NO_3	35	Contains both	Potentially explosive, banned in some areas
Ammonium nitrate sulphate	$NH_4NO_3(NH_4)_2SO_4$	26	Contains both	Unsuitable for paddy rice production because of sulfur volatilization
Potassium nitrate	KNO_3	14	Nitrate	-Also contains 44% K_2O -Best fertilizer for highly alkaline soils (pH > 8) -Not appropriate for rice paddies or saturated soil conditions
Urea	$CO(NH_2)_2$	46	Ammonia	Contains highest N concentration of solid fertilizers
Calcium cyanamide	$CaCN_2$	21	Breaks down to ammonia in soil	Breaks down more gradually than other N fertilizers
Anhydrous Ammonia	NH_3	82	Ammonia	Highly unstable gas, requires specialized equipment for application

Adapted from (*Principals of Plant Nutrition*, 2001)**Ch 7.3.4**

Ammonium is at lower risk of loss through leaching from the soil because its positive charge causes it to be attracted to soil particles, whereas nitrate will exist almost exclusively in the soil water and thus can easily be lost. In many soils ammonium will quickly be converted to nitrate by bacteria through a process called nitrification, thus increasing the risk of loss through leaching (*Principals of Plant Nutrition*, 2001)(**pg 410**). Additionally, in waterlogged soils where oxygen is a limiting factor, nitrate can be converted to a gaseous form by soil bacteria and lost to the atmosphere (*Principals of Plant Nutrition*, 2001). Ammonium will rapidly convert to ammonia gas in soils with especially high pH (loss begins around pH of 8, and increases with alkalinity). For this reason, ammonium containing fertilizers should not be applied to highly alkaline soils or mixed with calcium containing compounds (such as lime) as this can cause acute pH increase and gasification of nitrogen (*Principals of Plant Nutrition*, 2001)(**p432**).

Soil tests for levels of nitrate and ammonium levels will generally only remain accurate for a few days because mineralization of organic nitrogen and loss of nitrogen to the environment will quickly cause variation from the test levels. For this reason, soil testing of nitrogen levels should be done within a few days of fertilizer application to ensure that an appropriate fertilizer rate is calculated. As most crops will need a fairly high quantity of nitrogen (legumes are a notable exception) and because nitrogen is highly prone to loss, it is usually a safe assumption that nitrogen will be needed by crops in some degree.

Phosphorus

Phosphorus fertilizers are also available in a variety of forms. Some basic information on a few of the most common sources of phosphorus is provided in Table 5.

Table 5: Common sources of phosphorus

Fertilizer Type	Formula	Solubility	%P	Notes
Superphosphate	$Ca(H_2O_4)_2$ + $CaSO_4$	Water soluble	18-22	Suitable for most soil types, can be absorbed into highly weather soils
Triple Superphosphate	$Ca(H_2PO4)_2$	Water soluble	46-47	Suitable for most soil types, can be absorbed into highly weather soils
Monoammonium phosphate (MAP)	$NH_4H_2PO_4$	Water soluble	48-50	Suitable for most soil types, can be absorbed into highly weather soils, also contains 10 – 12% N
Diammonium phosphate (DAP)	$(NH_4)_2HPO_4$	Water soluble	54	Suitable for most soil types, can be absorbed into highly weather soils, also contains about 18% N
Ground rock phosphate	Apatite	Acid soluble	29	Solubility varies greatly, processing is often required
Fused Mg phosphate	Ca-Mg phosphate	Acid soluble	30	Solubility varies greatly, processing is often required

Adapted from (*Principals of Plant Nutrition,* 2001) **Ch 7.3.4**

Phosphorus can exist in many different forms within the soil, of which each has varying degrees of availability to plants(van Straaten, 2002). There are many deposits of phosphate-containing rock throughout the world which could potentially be employed as crop amendments, however there is wide variation in the composition of the rock and its suitability for agriculture (van Straaten, 2002). For more information on phosphate rock and other useful mineral sources for farms, please see “Rocks for Crops: Agrominerals of sub-Saharan Africa” by Peter van Straaten (2002). A link to an online version of this book is provided at the end of this chapter.

Understanding Fertilizer Formulations

Most commercial fertilizer formulations will be defined by an NPK value that will appear as three numbers separated by dashes such as 10-10-10 or 46-0-0. These numbers represent the percent concentration of nitrogen, phosphorus and potassium, respectively, in the fertilizers.

Nitrogen is expressed in fertilizer formulations as the percent of the total weight of fertilizer that is elemental nitrogen (i.e. made up of nitrogen atoms), whereas phosphorus and potassium are expressed as percent of the total weight that is phosphorus or potassium in an oxidized form (P_2O_5 and K_2O, respectively). This is important to note because the oxidized form of a mineral will be heavier due to the attached oxygen molecules. For example, a portion of fertilizer that is 16% oxidized phosphorus will contain less actual phosphorus than an equal portion of fertilizer that is 16% elemental phosphorus (weight made up exclusively by phosphorus atoms).

Most fertilizer recommendations will be expressed in terms of elemental nitrogen and oxidized phosphorus and potassium, so conversion of units is not necessary. However, one must be careful when interpreting soil test results to ensure that a suggested fertilization rate for P or K in an elemental form is not mistaken for a fertilization rate for P or K in an oxidized form, or visa versa. Conversation factors for elemental P to P_2O_5 and elemental K to K_2O are provided below:

$P = P_2O_5 / 2.29$
1 gram of elemental phosphorus would weight 2.29 g if fully oxidized

$P_2O_5 = 2.29 \times P$
1 gram of P_2O_5 contains 0.44 g of elemental phosphorus

$K = K_2O /1.21$
1 gram of elemental potassium would weigh 1.21 g if fully oxidized

$K_2O = 1.21 \times K$
1 gram of K_2O contains 0.83 grams of elemental potassium

Adapted from Colorado State University Extension Fact Sheet no. 0.548 available online at:
http://www.ext.colostate.edu/pubs/crops/00548.pdf

The ideal mixture and total quantity of fertilizers to be applied should be based on the approximate quantity of each nutrient already in the soil, the relative requirement of the crop for each nutrient, and the nutrient holding capacity of the soil. Additionally, the cost of fertilizer in relation to its effect on yield should be considered, as the quantity that maximizes yield may be prohibitively expensive or simply greater than the quantity that will maximize profit. In situations where fertilizer is highly expensive, a low rate may be the most effective in generating a profitable yield.

Fertilizer Manufacturing
Most fertilizers are derived from mineral deposits within the earth that are accessed through mining. In some cases minerals will be suitable for application immediately upon extraction however further processing is often employed to ensure the purity and plant availability of the final product. For example, phosphorus is generally mined as rock phosphate, which is composed of tightly bound phosphorus and calcium (van Straaten, 2002). As rock phosphate only minimally available to plants, it is commonly treated with sulfuric acid to convert it to H_2PO_4 or “Super-phosphate” (*Principals of Plant Nutrition*, 2001)(**p 473**).

Unlike other nutrients, synthetic nitrogen produced through a chemical reaction involving air and hydrogen gas. Our air is about 80% nitrogen, in the form of highly stable N_2 gas. This gas can however be converted into ammonia (NH_3) through natural enzymatic reactions (such as those performed by bacteria that live inside legumes) or through an industrial method known as the Haber-Bosch Process (*Principals of Plant Nutrition*, 2001). Through combining the N_2 gas in the air with hydrogen gas under extremely high temperature and pressure in the presence of an appropriate catalyst, ammonia will be produced. Ammonia is a highly reactive gas which can be applied directly to soil using specialized equipment however it is usually processed further into more stable forms such as urea (*Principals of Plant Nutrition*, 2001). The hydrogen gas used in this reaction is generally derived from natural gas, and for this reason the market price of ammonia based fertilizer will generally follow the market price of natural gas.

Practical Considerations

Fertilizers cost money and unfortunately are required at a point in the growing season when many farmers have little available cash. Small, short-term loans and other micro-financing arrangements are often very effective tools to improve agricultural productivity by enabling farmers to afford fertilizer before profits from harvest have been realized.

Unfortunately there have been cases of fraudulent fertilizer sales where the product being sold either did not contain the advertised nutrients or was highly diluted. For this reason it is important to purchase fertilizers from credible dealers. When uncertain of product quality but faced with few other options, performing a small split plot trial (described below) can be an effective method of assessing fertilizer value before investing heavily.

It should be noted that the availability and behaviour of many crop nutrients is highly influenced by soil acidity. For more information on this relationship please see Chapter 8: Soil Acidity.

The highly concentrated nature of synthetic fertilizers increases the risk of problems stemming from applying too much at once. As noted above, too much of any nutrient can damage a plant, symptoms that are commonly referred to as "burning" (*Principals of Plant Nutrition*, 2001). Additionally, the entry of plant nutrients into groundwater through leaching can cause environmental imbalance as well as human health risks associated with contaminated well water. Loss of nutrients through surface runoff can also cause imbalance to local ecosystems, particularly when field runoff enters waterways (Badruzzaman et al., 2012). The economic consequences of these losses can be very significant for many small share farmers.

Fertilizer can be applied to a field through a variety of methods. Broadcasting, or spreading fertilizer evenly over the soil surface is the most common method of fertilizer application. This is often followed by working the fertilizer into the soil through tillage to reduce the risk of nutrient loss and to increase the proximity of the fertilizer to plant roots for less mobile nutrients. Fertilizer can also be placed in shallow trenches between crop rows that can be made with a furrow and then covered, a process referred to as side-banding. Microdosing is another method of fertilizer application that is most appropriate for situations where applying high rates of fertilizer is impractical or prohibitively expensive.

When broadcasting fertilizer it is important to ensure it is spread evenly in order to avoid concentrated pockets of fertilizer that can cause crop burning and nutrient loss. Mechanical broadcast spreaders should be tested before use to ensure they are functioning properly. When spreading fertilizer by hand, it can be helpful to divide the field into small subsections with posts and string. Using a container marked to indicate the proper volume of fertilizer per section, sections can be fertilized one by one ensuring that the appropriate amount of fertilizer is spread evenly within each subsection.

Coarse soils, especially in tropical areas generally have lower nutrient holding capacities and are especially prone to leaching loss (*Principals of Plant Nutrition*, 2001). For this reason it is important to avoid over-application of fertilizer as nutrients that are not held in the soil can easily be lost to leaching. Fertilizer recommendations for North America and Europe are generally intended for soils with higher nutrient holding capacities than what tropical soils can carry (van Straaten, 2002). Thus, it is important to use locally generated fertilizer recommendations where available and to err of the side of caution when applying fertilizer.

As most nutrients are taken up by plants in soil water, it is important that there is some degree of moisture in the soil when fertilizer is applied or shortly thereafter. Although it cannot be stressed enough that heavy rainfall can cause significant or total fertilizer loss, a moderate degree of soil moisture is necessary to ensure that the nutrients in the fertilizer can make their way to plants. Commercial fertilizers are most commonly available in powdered or granulated forms, however liquid formulations are also available. Liquid formulations may be more convenient to apply in some situations however they are also generally more expensive. There is no inherent advantage to using a liquid fertilizer apart from the possibility of more convenient application depending on management style.

To fully ensure that a fertilizer will be effectively both economically and in terms of yield response, testing a given fertilizer combination in a small trial plot before widespread application is often a wise precaution, especially when fertilizer is a significant expense.

Practical Links

The International Plant Nutrition Institute (IPNI) offers several up to date publications on best management practices for fertilizer use: http://www.ipni.net/publications

Another guide to the basics of fertilizer use is available from VirginiaTech: http://www.dcr.virginia.gov/stormwater_management/documents/nmagscsthe01.pdf

An online version of "Rocks for Crops: Agrominerals of sub-Saharan Africa" by Peter van Straaten is available at: http://www.uoguelph.ca/~geology/rocks_for_crops/

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5.16.2 - Balanced fertilization

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Introduction
There are approximately 14 different nutrients that plants need to grow (*Principals of Plant Nutrition*, 2001). These nutrients are classified broadly by the relative quantities in which they are needed for the growth of plants. The "macronutrients", which are needed in relatively high amounts, include nitrogen (N), phosphorus (P), and potassium (K). Carbon and oxygen are also included in this group however as they are provided by the air they are not considered soil nutrients. The "secondary nutrients" are sulphur (S), calcium (Ca), and magnesium (Mg), which are needed in moderate amounts for plant growth. "Micronutrients" include zinc (Zn), molybdenum (Mo), manganese (Mn), iron (Fe), copper (Cu), and boron (B), all of which plants need in relatively small amounts. The specific quantity of each nutrient needed by a crop will vary according to species and the growth environment. Deficiencies are most common for macronutrients because much greater quantities of these nutrients will be removed by crops each year, however secondary or micro-nutrient deficiency can potentially be equally limiting for crop growth. Secondary and micro-nutrient deficiency is especially prevalent in developing countries where national fertilizer policies that almost exclusively promote nitrogen and phosphorus fertilizer use (e.g. India) are in place (B. K. R. Rao et al., 2012).

As mentioned above, every plant species will have a unique balance of nutrients that it will take from the soil. As soon as the supply of any of the necessary nutrients runs out, the plant will not be able to make use of the other nutrients available to further its growth. This problem can be visualized as a barrel with boards of different lengths (Figure 1).

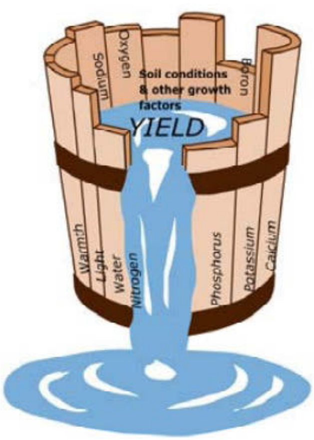

Figure 1. Visualizing the importance of balanced fertilization. Image from: http://www.yara.com/doc/37694_2012%20Fertilizer%20Industry%20Handbook%20wFP.pdf

Each board of the barrel represents the available quantity of each nutrient relative to the amount it is needed in by the plant. The level of the water represents the growth potential of the plant. In the above image, nitrogen is the limiting nutrient. Although all the other necessary elements for the growth of the plant are available, the plant does not have enough nitrogen to continue growing. Thus, it cannot make use of the other available nutrients and no further growth occurs. In this situation, only making more nitrogen available to the plant would enable further growth whereas adding any of the other nutrients would not provide any benefit. Deficiency of any nutrient will affect a crop in the same way.

Each element required by plants has a unique, natural biological function. Nitrogen is a building block for amino acids, which make up proteins, while phosphorus is a component of DNA, and potassium is required to maintain hydraulic pressure within plant cells and transmit biological signals (Mendel and Kirkby, 2001). Similarly, each of the secondary and micro- nutrients has a specific function within plants. For example, zinc is required for ~100 “master genes” in plants to function properly (Li et al., 2013), and molybdenum is required for biological nitrogen fixation by bacteria that are symbiotic with legumes (Bambara & Ndakidemi, 2010) (see Chapter 5: Maximizing Legume Productivity through Molybdenum Addition). With few exceptions, one mineral cannot serve the purpose of another and thus an abundance of one nutrient will not make up for a shortage of another.

For example, if a fertilizer such as di-ammonium phosphate (DAP, 18-60-0) is the only one that is applied to the soil for several seasons in a row, crops will rely exclusively on potassium already in the soil and quickly deplete the supply. When this occurs, additional application of DAP will have no effect. Similarly, if only NPK (macronutrient) fertilizers are applied to a soil for an extended period of time, the supply of at least one micronutrient within the soil will eventually become exhausted, making further application of NPK fertilizers ineffective until the supply of the missing micronutrient(s) is replenished. Put simply, every nutrient required by plants must be regularly provided to the soil in a balance that is similar to the needs of the crops under cultivation. This will rarely require the application of every nutrient every year, and careful observation of plant symptoms as well as regular soil testing are important strategies to recognize and avoid nutrient deficiencies (See Chapter 2: Soil Testing). Where soil testing is impractical, the most effective method of determining whether or not balanced fertilization will have a beneficial effect on crop growth is through doing a small split-plot trial. To do this, a small test plot should be established in which half receives balanced fertilization, and the other half does not.

Although regularly returning organic matter to the soil will generally reduce the risk of nutrient deficiencies developing, absolute deficiency of a mineral within an area will not be alleviated through this practice as returning on-farm organic matter to the soil will only recycle the minerals that were initially there (Bonilla & Bolanos, 2009). Manure from animals raised on crops or pasture grown on mineral deficient soil will often not contain appreciate quantities of the deficient nutrients. Deficiency is exacerbated through the removal of a certain quantity of each mineral from the soil each year when crops are harvested. Because of this consistent removal of minerals from the soil, replenishing the soil with an outside source of minerals may eventually become necessary, and is a current necessity for many already depleted soils. When this is the case, the introduction of synthetic fertilizers can be extremely beneficial.

Recent investigation of soils in the semi-arid tropical regions of India has indicated widespread deficiency of the secondary and micro- nutrients sulphur, boron and zinc (B. K. R. Rao et al., 2012; B. K. R. Rao, Srinivasarao, Sahrawat, & Wani, 2010; Rego, Sahrawat, Wani, & Pardhasaradhi, 2007; Sahrawat, Wani, Pardhasaradhi, & Murthy, 2010; Srinivasarao, Wani, Sahrawat, Rego, & Pardhasaradhi, 2008). Rainfall has traditionally been considered to be the limiting factor on plant growth in these areas, which has discouraged farmers from thoroughly considering soil fertility (Rego et al., 2007; Sahrawat et al., 2010). However, field trials performed in these areas have observed significant yield increases (20-80%) for a wide variety of crops through the addition of sulphur, boron, and zinc compared to the farmers' usual fertilization practice. Crops tested in these trials include maize, castor, groundnut (peanut), mung bean, finger miller, sunflower, and soybean (B. K. R. Rao et al., 2012; Rego et al., 2007; Sahrawat et al., 2010; Srinivasarao et al., 2008). Micronutrient addition increased crop yields when added alone, but had increased effect when added alongside nitrogen and phosphorus (B. K. R. Rao et al., 2012). In multi-year trials, micro-nutrient application was shown to improve yield in comparison to controls each year for the duration of the test period (B. K. R. Rao et al., 2012; Rego et al., 2007; Sahrawat et al., 2010). Areas where only macronutrients have been applied for long periods of time are at especially great risk of developing micronutrient deficiency, and the reintroduction of these minerals into the soil can often significantly improve yields (Mahajan, 2009).

In situations where farmers rent the land that they cultivate there will often be less interest in using organic matter to build long term soil fertility. Although long term management plans should ideally be developed for all soils, this is unfortunately not always a realistic expectation. One option for degraded soils is to add synthetic fertilizers in one or more seasons to rebuild nutrient levels, and then to integrate longer-term organic strategies to recycle the minerals that have been introduced. In situations where immediate benefit is the primary concern, microdose fertilization can often bring a good return on investment with low initial costs. Please see Chapter 4: Fertilizer Microdosing for further detail.

As nutrients will be removed from the soil every year for human consumption, it is ultimately necessary to recover nutrients from human waste in order to have a fully sustainable agricultural system. However, there are significant challenges to re-introducing nutrients from human waste to agroecosystems in a fashion that is safe for human health. Further research in this field is necessary to responsibly take advantage of this potential resource.

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5.17 - Microdosing of synthetic fertilizers

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Introduction

Soil fertility is often the limiting factor on crop productivity. Where fertilizer is available, yield-maximizing application rates are rarely practical for many small scale farmers. However, by applying even very small quantities of fertilizer, significant returns can be realized on the investment when soil fertility is extremely lacking. The practice of fertilizer "micro-dosing" has been investigated as a method of maximizing the return on fertilizer investment by maximizing crop uptake.

In the practice of micro-dosing, small quantities of synthetic fertilizer are applied to the soil surface directly surrounding individual plants or buried with the seed in "micro-doses" of up to about 6 grams measured using a beer or Coca cola bottle cap. This technique is an alternative to the more commonly practiced broadcast method of fertilizer application, in which fertilizer or a mixture of fertilizer and seed, is spread over the field. The theory behind micro-dosing is that low rates of fertilizer can be most efficiently applied by minimizing the distance between the fertilizer and the root system. This is thought to be beneficial for both mobile and immobile nutrients which can either be lost before they reach the root system (Zhang et al., 2010) or remain fixed in a field area that crop roots will not access in early stages of growth (Eghball & Sander, 1989; Zhang et al., 2010), respectively. Additionally, direct placement of fertilizer to seeds and seedlings has been observed to stimulate early root growth and subsequent nutrient uptake (Zhang et al., 2010).

When a high rate of nitrogen fertilizer in the form of urea (210 kg N/ ha) was applied onto corn, nitrogen uptake efficiency did not significantly vary between broadcast and seed-placed application (Rees et al., 1997). It should be noted however the recovery of applied N was fairly low (< 30%) for all trials in this study (Rees et al., 1997). Nitrogen recovery could potentially be improved at lower application rates by combining micro-dosing techniques with interventions to improve nutrient retention such as adding manure (Ncube, Dimes, Twomlow, Mupangwa, & Giller, 2007).

It should be noted that micro-dose fertilizer application is more time consuming than broadcast application. Despite this drawback, enhanced nutrient uptake can justify the increased labour requirement in situations where yield maximizing fertilizer application is not practical. In the comparison of these two methods on pearl millet in Sadoré, Niger, it was found that the yields achieved with a micro-dose application of 7 kg P/ ha were 88% of those achieved with a 13 kg/ ha broadcast application, indicating that comparable yields can be achieved with much less fertilizer using micro-dose application techniques (Muehlig-Versen, Buerkert, Bationo, & Roemheld, 2003). This study also found phosphorus use efficiency to be increased with seed placed phosphorus application over broadcast phosphorus application (Muehlig-Versen et al., 2003). In another micro-dosing study performed over 4 field seasons on pearl millet in Mali, Burkino Faso, and Niger, low micro-doses of NPK fertilizers were observed to significantly increase grain and stover yield compared to trials where no fertilizer was applied (Bagayoko et al., 2011). Though the micro-dose yields realized in this study were lower than those associated with higher doses of broadcast fertilizer (Bagayoko et al., 2011), micro-dosing was likely more cost effective.

The key lesson to emerge from field trials in Africa using various crops (pearl millet, sorghum, cowpea, groundnut, sesame) is that even very small amounts of fertilizer, where needed, when applied using the micro-dosing technique, can significantly increase crop yields in nutrient poor soils (Aune, Doumbia, & Berthe, 2007; Buerkert, Bationo, & Piepho, 2001; Hayashi, Abdoulaye, Gerard, & Bationo, 2008; Ousman & Aune, 2011). Furthermore, and of critical importance to poor farmers, was that the value to cost ratio (yield increase per unit of expenditure) of fertilizer investment increased by up to 70% when micro-dosing was employed compared to broadcasting (Muehlig-Versen et al., 2003). Highly positive value to cost ratios have also been realized in the comparison of micro-dose fertilization to unfertilized controls in multiple trials, especially for fertilizer doses of under 1 gram per hill (Aune et al., 2007; Ousman & Aune, 2011).

Micro-dose fertilizer application may not be practical at planting time because of labour constraints, high early-season cost or fertilizer unavailability. To address this reality, the effect of delayed micro-dose application to millet (variety is unclear) was investigated by Hayashi et al. (2008). 6 g micro-doses of 15-15-15 fertilizer were employed in this study. It was shown that although yields were maximized when fertilizer was applied at planting time, yield improvement in comparison to unfertilized crops could be realized even 45 days after sowing (Hayashi et al., 2008).

Other Challenges

It should be kept in mind that fertilizer micro-dosing will only be effective if nutrients that would otherwise be limiting factors on the growth of a plant are applied, so a prior soil nutrient test can be helpful if available. Additionally, synthetic fertilizer must be available to the farmer in some quantity. This technique is more time consuming than broadcast fertilizer application and this may pose a barrier to adoption in some communities. It is not clear that crops requiring high doses of a nutrient (e.g. nitrogen for corn) would significantly benefit from low micro-doses of that nutrient. Finally, it should be noted that germination has been shown to be inhibited by the presence of seed-placed fertilizer, especially in moisture limiting conditions (Muehlig-Versen et al., 2003). In situations where limited moisture at planting time is a reality, fertilizer should be placed near to the seed but not in direct contact with it.

Further Reading and Links for Practical Tips

ICRISAT Micro-dosing Manual: http://www.icrisat.org/impacts/impact-stories/icrisat-is-fertilizer-microdosing.pdf

ICRISAT Micro-dosing Video: http://www.youtube.com/watch?v=c4-AB1jg3Sg

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5.18 - Split application of synthetic fertilizer *(major revision pending)*

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Background:

Plants need 13 different nutrients to grow which can be purchased as commercial fertilizers, of which the macronutrients include Nitrogen (N), Phosphorus (P), and Potassium (K) (Gach, 2012). Typically, commercial fertilizer is added as a single dose before planting or at the seedling stage, when the plant does not have the demand or root capacity to absorb the fertilizer – as a result, it is leached, especially on sandier soils during rainfall (Soil Texture and Soil Structure, n.d). In general, the demand for fertilizer increases as the crop ages, becomes larger and produces seeds (Butzen, n.d.). For example in corn (maize), 50% of the nitrogen fertilizer demand occurs when the seeds (kernels) form (Butzen, n.d.). Another important factor affecting leaching is whether the nutrients are mobile or immobile. Mobile nutrients are more likely to leach like a nitrite, but phosphorus on the other hand is less likely to leach because it is very immobile (Dr. Al Ludwick, 1998). This is because of the charge of the nutrients, since soil is negatively charged positively charged nutrients tend to stay put and negative charged nutrients like nitrate, boron and sulphur tend to leach more (Nutrient Management, n.d.). Leaching reduces farmer profits and pollutes the environment. Subsistence farmers in particular, many of whom cannot afford commercial fertilizers, apply small amounts, and are vulnerable to the effects of leaching . A way to prevent the negatives of fertilizer is to split the application across different times during the growing season.

Typical Fertilizer Application Practices:

Application of fertilizers can be performed in many ways, of which most common is spreading or broadcasting fertilizer over the top of the soil early in the growing season, but can result in leaching (Microdosing , n.d.). After spreading it is common to incorporate the fertilizer into the soil to help prevent loss and to make it closer to the crop roots. Also, other applications can consist of applying the fertilizer beside or in the row of the seeds, a method called fertilizer banding (Rehm, 2002). This method works well for fertilizers that are less mobile and it brings the nutrients to the developing roots. Another method used by wealthier farmers is in season side dress or y-drop. Side dressing places the fertilizer right in with the plants at the roots using a disk that runs beside the plant (The Agronomy Guide, 2015). Y-dropping uses liquid fertilizer and involves running hoses from a high clearance sprayer in between the rows, dripping nitrogen right beside the plant (The Agronomy Guide, 2015). These methods are very good for splitting up fertilizer applications but are very expensive. For small scale farmers, they could try microdosing wherein a small dose of fertilizer is added at the base of each seedling using a bottle cap, which makes it very labor extensive (Microdosing , n.d.).

Split application: (good addition but where are the references?)

Split application is taking the total fertilizer intended for addition to a field and dividing it up into separate applications. The split application is important for mobile nutrients. Application of less mobile nutrients like phosphorus and potassium cannot be expected to have the same effect as application close to the seed row at seeding. Split application works best for nitrogen and sulfur mid-season. It is also very important that fertilizer is applied before it is expected to rain. The nitrogen will flow with the water into the soil towards the roots but one must be careful because a large rain event can wash away the nutrients away and cause leaching. Split application is preferred because of nutrient leaching if considerable rain or a warmer winter occurs. The best option would be applying some fertilizer at planting time and right beside the plant in the spring. Then later in the season, one could apply the remaining nutrients required. This can be done in several passes. For farmers with the use of equipment they could split nitrogen application by side dressing. This is a common practice in growing corn. Another option would be to attach y-drops on a sprayer to apply liquid nitrogen in corn just before tasseling which is just before the point that the crop needs it the most. The costs of using this equipment is very high but there is increased yield and there is much less leaching. For subsistence farmers, the practice of split application would be as simple as taking the time to walk through the field and apply fertilizer when the crop is growing.

Pre-plant (single dose) vs. split application:

Experiments comparing spring pre-plant nitrogen with split Nitrogen application for corn were conducted at 32 sites in southern Minnesota from 1989 to 1992 (Schmit & Randall, 2007). The yield differences are shown in Table 1. In a total of 88% corn had a higher yield because of the application of nitrogen. Split application was better compared to pre-plant. In these cases, excessive rainfall in the growing season and sandy soils had negative impacts on yield. This result shows that split application works different in different soil types. In sandy soils, there are larger particle sizes allowing water to move through making it easier for nutrients to leach. Clay soils hold more nutrients and water preventing leaching (Soil Texture and Soil Structure, n.d.). For slopes and hills there would be a similar effect: nitrogen applied at the top of the hill would run off from the top of the hill to the bottom (Soil Texture and Soil Structure, n.d.).

Therefore, it would be a good idea to split the applications so that nitrogen is not being lost at the top of the hill throughout the growing season. In another study done at Penn State University, researchers applied all the nitrogen in the first trial and then they split up the nitrogen application in the second trial. The results were that the plants all absorbed nitrogen the same rate no matter how much was available to them (see Table 3). Another study performed at Penn State showed that when incorporating and splitting the nitrogen, there were higher yields (See Table 4).

Environmental impact:

The environment is affected greatly by nitrogen application: NO^3 is very soluble in water and has been linked to blue baby syndrome. The disorder has been reported to be caused by pregnant women and infants ingesting nitrogen preventing the blood in the baby to carry enough oxygen through the body. Splitting the nitrogen application help with groundwater contamination (Oram, 2014).

Fertilizer Burn:

Fertilizer burn is a problem with plants it causes the leaves to fade and turn brown. It is caused by nutrient excess and is from excusive fertilizer. It is important to make sure that the fertilizer does not get onto the leaves or the plant above the ground. (Fertilizer Burn)

Alternative:

Controlled-release nitrogen or slow release nitrogen are alternatives for splitting application of nitrogen. This fertilizer is coated with compounds that makes it release slower than normal (Fertilizers – Quick-Release and Slow-Release Nitrogen, n.d.). Controlled-release N fertilizers can reduce these losses by delaying the initial release of N and providing it gradually to better match its availability with crop uptake needs. Controlled-release products may be most useful for high-value crops, environmentally sensitive areas, fields highly susceptible to N losses or with limited opportunities for repeat applications, contest plots, and foliar applications. (Fertilizers – Quick-Release and Slow-Release Nitrogen, n.d.). The slow release nitrogen is a good alternative however it is more expensive and less accessible.

Additional Resources:
For a good resource on different crops fertilizer needs and how to go to
https://content.ces.ncsu.edu/north-carolina-agricultural-chemicals-manual/fertilizer-use

For agricultural fertilizers and equipment go to
https://www.alibaba.com/trade/search?fsb=y&IndexArea=product_en&CatId=&SearchText=fertilizer

Table 1. (Schmit & Randall, 2007)
Table 2. (Schmit & Randall, 2007)

Table 1. Comparing preplant N to split N application using corn grain yield response as an indicator at 32 sites in southern Minnesota.

Sites	Total	Glacial till	Loess	Outwash
Number	32	14	11	7
N responsive	28	14	9	5
Preplant yield = Split yield	16	7	7	2
Preplant yield < Split yield	8	4	1	3
Preplant yield > Split yield	4	3	1	0

Table 2. Corn yield as affected by method of N application on fine-textured glacial-till soils.

Time of application		Year	
Preplant	12-inch corn	1991	1992
N rate (lbs/A)		bu/A	
0	0	84	107
30	0	129	132
60	0	143	144
30	30	161	141
90	0	158	156
30	60	157	137
120	0	165	164
30	90	182	153
	Advantage for split =	+11	-11

Table 3. (The Agronomy Guide, 2015)

Effects of method and time of nitrogen application (Penn State).

Reference: Table 1.4-5, The Agronomy Guide

Time	Method	bu/A
At planting	Surface	135
At planting	Incorporated	141
Sidedress	Surface	148
Sidedress	Incorporated	152
Note: Sidedressing nitrogen when corn is 10 to 20 inches tall is a practical way to significantly improve the efficiency of nitrogen fertilizer use.		

Table 4 (The Agronomy Guide, 2015)

Effects of method and time of nitrogen application (Penn State).

Reference: Table 1.4-5, The Agronomy Guide

Time	Method	bu/A
At planting	Surface	135
At planting	Incorporated	141
Sidedress	Surface	148
Sidedress	Incorporated	152
Note: Sidedressing nitrogen when corn is 10 to 20 inches tall is a practical way to significantly improve the efficiency of nitrogen fertilizer use.		

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5.20 - Leaf colour change to diagnose fertilizer needs
(major revision pending)

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Leaf colour and symptom charts to help smallholder farmers detect nutrient deficiencies

Leaf colour and symptom charts are simple tools that can help subsistence farmers to detect whether the soil and therefore the crop, has a sufficient or deficient amount of macro or micronutrients. Nutrient deficiencies cause changes to the colour of leaves and other visible symptoms.

Plant terminology

Chlorosis	yellowing of plant tissue
Necrosis	plant tissue is dead, tissue turns brown and dies
Interveinal chlorosis	in between leaf veins there is yellowing, yet the veins remain green
mottling	Inconsistent, irregular pattern of spots

Macronutrient deficiency symptoms

1) Nitrogen	Maize	• Appears on lower leaves • chlorosis starts on lower leaves and moves upwards • Plants will appear pale green to yellow • Spindly stalks and slow growth • Yellowing from leaf tip in a v-shape pattern
	Rice	• Leaves become yellowish • Old leaves become light green and chlorotic at tip
	Wheat	• Yellowing color appears on lower leaves (oldest) • New leaves will remain green when deficiency first starts • As it spreads, older leaves turn a white color, newer leaves(at top) begin to turn pale green • Less growth from a wheat plant as opposed to a healthy wheat plant • Pale green or yellow patches in the crop • Chlorosis sets in but necrosis can take time to set in
	Cassava	• Yellowing of older leaves
2) Phosphorus	Maize	• Plants remain an abnormal dark green • Purple discoloration develops • Thin, short stalks
	Rice	• Narrow, dark green, stiff, erect leaves • Older leaves turn brown and die • Reddish purplish color may develop on leaves
	Wheat	• Reduced growth in plant and plant physically doesn't look healthy

		• All leaves are affected at once and will appear a dark green • Spots on oldest leaves will appear • Older leaves will show signs of chlorosis, (the tip begins to turn yellow) and crawls towards the front • Necrosis set in fast: tip turns orange to dark brown and will shrivel • The base of plant and leaf will remain dark green • Leaves appear coiled • New leaves look spindly • New leaves may stay folded • a crop will can appear stunted and fewer shoots
	Cassava	• plants are short and spindly • thin stems • in severer cases: older leaves will be dark yellow to orange and in other varieties they may be purple
3) Potassium	Maize	• Lower leaves show yellowing on tips, this moves along the leaf edge and a brown discoloration follows • Midrib of leaf remains green • Chlorotic areas can develop on leaf • Ears look chaffy and unfilled • Stalks are weak
	Rice	• Dark green plants with yellowish brown outer edges • Leaf tips are yellowish brown • Upper leaves short, droopy, dirty dark green
	Wheat	• ALWAYS appears in OLDEST leaves • All leaves have a spindly form • Rapid necrosis occurs in the length of the oldest leaves with yellowing on the tip and edge of leaf • Green strip/arrow will be left in middle of leaf • Signs of chlorosis shown as blotch/spots • Old leaves may appear as if dead from drought
	Cassava	• Upper leaves experience chlorosis • Burnt looking leaf tips • Decreased plant growth • Excessive branching • Thick stems

Secondary Micronutrient Deficiency Symptoms

4) Magnesium	Maize	• Interveinal chlorosis on older leaves and deficiency moves upwards • Purple color in older leaves • Older leaves experience orange-yellow interveinal chlorosis • Plant appear pale color • As deficiency continues younger leaves experience interveinal chlorosis • Green and yellow stripes run parallel to leaf • Tips and outer edge of leaf die • Older leaves can fall off
	Rice	• Interveinal chlorosis on older leaves, color will look orange-yellow • Pale color • Green and yellow strips running parallel to the leaf • Severe case: chlorosis turns to necrosis • Leaf number and leaf length greater • Leaves are wavy and droopy
	Wheat	• Resembles potassium and iron EXCEPT *new* leaves are pale compared to older leaves • The leaves experience chlorosis and do not open appearing twisted, this can look similar to drought symptoms • After time the leaves experience necrosis • Older leaves can develop a red tint along edges • Extreme cases the leaf stays closed and rolled • crop may look a patchy yellow and stunted • poor root system below ground
	Cassava	• Lower leaves experience yellowing or chlorosis in between veins • Can spread throughout whole plant
5) Sulfur	Maize	• In confusion with iron, manganese and zinc deficiency • large amount of nitrogen: Interveinal chlorosis on younger leaves • Low amount of nitrogen: interveinal chlorosis on older leaves • Small, spindly plants • Short slender stalks • Growth rate reduced
	Rice	• Whole plant looks yellow or pale green • Newer eaves are chlorotic , tips becoming necrotic • Lower leaves will not shoe necrosis • Leaves are paler yellow
	Wheat	• Similar to nitrogen, expect the WHOLE plant develops chlorosis, even new leaves; plant becomes pale • Plant becomes a pale yellow color

		• If it is extreme there may not be a head • In the field, slight pale yellow color
	cassava	• Upper leaves experience chlorosis and this spreads throughout plant
6) calcium	Maize	• rare • severely stunted • new leaves leak a jelly like substance and stick together • aluminum and manganese toxicity symptoms will appear prior to calcium deficiency
	Rice	• youngest leaf tips appear white or bleached, roiled and curled • necrotic tissue can develop along outer edges of leaves and older leaves can turn brown and die • stunting
	Wheat	• appears in NEW growth • roots first to show signs • leaves do not show signs of chlorosis, instead older leaves remain dark green color • newer leaves shows signs of necrosis spotting on middle of leaf, necrosis spreads and leaf collapses • section above collapse remains green
	cassava	• new leaves distorted/abnormal shape and show signs of chlorosis • leaf tips look burnt • bad root formation

Micronutrient Deficiency Symptoms

7) zinc	Maize	• interveinal chlorosis on upper leaves • veins, midrib and outer edge of leaf remain • green • feather like bands appear on both sides of the outer edge of the leaf and the leaves almost turn white • stunted plants
	Rice	• upper leaves show dusty brown spots • stunted plant • chlorotic midribs • leaves turn brown as brown blotches and streaks appear on lower leaves • white lines might, but not always appear on leaf midrib
	Wheat	• muddy grey-green color appears first on middle aged leaves • variation between plants; it can appear on old leaves first • necrotic area appears in middle of leaf, it spreads going to the outer edges of the leaf • leaves become oily • mottled yellow green areas appear around necrosis area • middle regions collapses and young leaves are affected now
	cassava	• on newer leaves there will be yellow or white spots
8) iron	Maize	
	Rice	• chlorosis of emerging leaves and interveinal yellowing • other leaves appear chlorotic and will become very pale • entire plant becomes chlorotic and dies
	Wheat	• new leaves effected first and experience chlorosis • noticeable contrast between effected old and new leaves • green and yellow striping; different cereals experience different variations of this • plants mostly remain erect
	cassava	• may be mistaken for nitrogen deficiency • symptoms in newer leaves • chlorosis of leaves • decrease in plant height and leaf size

9) Boron	Maize	• yellow and white spots appear between veins on younger leaves; spots eventually form streaks • bushy appearance • leaves may curl • severe: short bent cobs, underdeveloped tips, poor kernel development
	Rice	• appear on younger leaves first • tips of emerging leaves are white rolled • decreased height in plant
	Wheat	• new leaf splits where the middle is • indentations along length of leaf • narrow strip along leaf showing different color • on young leaves, sawtooth effect can occur • new growth looks water-soaked
	cassava	• decrease in plant height • upper leaves are small and abnormally shaped and dark green • lesions develop on stem and a brown gummy substance leaks out and these form stem cankers
10) Manganese	Maize	• interveinal chlorosis on uppermost oldest leaves
	Rice	• color is pale grayish green with interveinal chlorosis spreading from tip of leaf to the base of leaf • necrotic brown spots, leaf becomes dark brown • new leaves look short, narrow, and light green
	Wheat	• mainly affects new and middle leaves • appears first in new leaves • new leaves look pale and limp in comparison to older leaves • small amount of grey appear at base of youngest open leaf, over time as leaves becomes middle leaves necrosis can set in and they will collapse • more intense symptoms on lower half of each leaf
	cassava	• interveinal chlorosis on upper and middle leaves or there can be yellow of leaves
11) Molybdenum (Mo)	Maize	
	Rice	• No deficiency symptoms have been identified
	Wheat	• is effected by nitrogen • plant leans more compared to healthy wheat • paler green • longitude yellow striping on middle leaves • white heads-very severe
	cassava	• newer leaves show chlorosis

		• decrease in leaves, shoots and tuber size • dead patches present
12) copper	Maize	• interveinal chlorosis appears on whorl and young leaves • new leaves emerging from whorl remain curled • leaf tips and outed edge of leaf die and curl in spiral manner • stunted plants
	Rice	• rare for rice to get this deficiency • midrib on either side shows chlorotic streaks • leaf tips show dark brown necrotic lesions • near leaf tip shows bluish green and chlorotic • new leaves appear rolled
	Wheat	• pale and wilted • older leaves and new leaves show withertip • new leaves experience necrotic growth in middle of leaf • section above necrosis spotting withers and necrosis spreads to top • wilting of entire plant • plant will appear lighter in color when compared to a healthy plant • grain head will look like a rat tail; full grain at base and withered grains at top • purpling of the stem and nodes can occur • can be confused with frost damage
	cassava	• Upper leaves show chlorosis and abnormal formation, leaf tips and outer edges bending up or down

Fertilizer remedies

If deficient, various formulations of fertilizers can be added as remedies:

Nitrogen(N)	MAP Potassium sulfate Ammonium nitrate Potassium nitrate
Potassium(K)	MAP Potassium sulfate Ammonium nitrate Potassium nitrate

Phosphorus(P)	MAP Potassium sulfate Ammonium nitrate Potassium nitrate
Magnesium(Mg)	Magnesium, nitrate Magnesium sulfate
Sulfur(S)	
Calcium(Ca)	Calcium Nitrate
Zinc(Z)	Zinc sulfate Zinc-ammonia Zinc-oxysulfates Zinc oxide Zinc chelate
Iron(Fe)	Fertilizers containing iron chelate
Boron (B)	Sodium tetraborate Solubor Fertilizers containing the word Borax http://www.agnet.org/library.php?func=view&id=20110804134401
Copper(Cu)	Copper sulfate
Manganese(Mn)	Manganese sulfate Manganese oxysulfate
Molybdenum (Mo)	Sodium molybdate

Helpful Resources

- The following are a list of websites to help determine more accurately the cause of the deficiency in the plant.
- http://cropwatch.unl.edu/soils/keysnutrientdef
- This website will show real life pictures of the deficiencies you may be experiencing. Click the link http://anz.ipni.net/article/ANZ-3216
- Another helpful resource is an app that can be downloaded on an iPhone: just open iTunes and type in Crop Nutrient Deficiency Photo Library and begin downloading. This will provide a user with pictures of specific crops and how they look when a nutrient deficiency is present.

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For corn info taken from http://aesl.ces.uga.edu/DiagnosticsII/Symptoms_/Corn/corn.html#B
Corn…everything but iron and molybdenum

All information on rice was taken from here http://www.knowledgebank.irri.org/training/fact-sheets/nutrient-management/deficiencies-and-toxicities-fact-sheet
Rice information for potassium is taken from here
http://www.ipni.net/publication/bci.nsf/0/3E4652D399C882AD85257BBA006531E6/$FILE/Better%20Crops%20International%202002-3%20p23.pdf

Molybdenum and phosphorus and nitrogen info for rice taken from here
http://www.knowledgebank.irri.org/ericeproduction/IV.1_Essential_nutrients.htm

Nitrogen for cassava info from here http://www.cardi.org/cfc-rt/files/downloads/2012/08/Reference-Materials-Session3_RC.pdf

Information regarding chlorosis definition and etc. taken from here
http://www.ipni.net/publication/pnt-na.nsf/0/BFD9E805881BEC3585257FD40063A349/$FILE/PNT-2016-Summer-03.pdf and http://landresources.montana.edu/nm/documents/NM9.pdf

Fertilizer info from here http://www.agnet.org/library.php?func=view&id=20110804134401
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5.23.1 - Optimizing legume productivity using molybdenum fertilizer

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Introduction

Rather than having to purchase synthetic nitrogen fertilizer, farmers can take advantage of certain types of naturally occurring soil bacteria ("nitrogen fixing bacteria" or "rhizobial/*Rhizobium*" bacteria) that can infect specialized root organs, called nodules, in legume plants (e.g. beans, lentils) and green manures (e.g. alfalfa, clover). Once rhizobial bacteria have successfully "infected" a plant, they can convert naturally occurring atmospheric nitrogen gas (N_2) to plant-available nitrogen in the form of ammonia. The nitrogen fixation reaction uses an enzyme called Nitrogenase which preferentially employs the mineral molybdenum (Mo), and thus the presence of this element in the soil is essential for successful fixation of atmospheric nitrogen (Bambara & Ndakidemi, 2010). If lacking in the soil, molybdenum as well as improved strains of nitrogen fixing bacteria can be coated onto legume seeds as a powder or by soaking seeds in a molybdenum solution prior to planting. As molybdenum is required in only trace amounts, this is a generally cost-effective intervention.

Effect of Molybdenum on Crops and Application Methods

Where deficient, the application of molybdenum has been shown to increase the yield and nitrogen fixation ability of legumes in many studies (Bailey & Laidlaw, 1999; Hafner, Ndunguru, Bationo, & Marschner, 1992; Jongruaysup, Dell, Bell, Ohara, & Bradley, 1997; Lopez, Alvear, Gianfreda, & Mora, 2007; Quaggio, Gallo, Owino-Gerroh, Abreu, & Cantarella, 2004; Rosolem & Caires, 1998; Togay, Togay, & Dogan, 2008; Vieira, Cardoso, Vieira, & Cassini, 1998; Vistoso, Alfaro, & Mora, 2012). The effects of various molybdenum application rates and methods on legumes popular for human consumption are summarized in Table 1.

Table 1: The effect of molybdenum application on legumes popular for human consumption

Crop	**Application Rate, Method, and Notes**	**Effect**	**Reference**
Common bean	40 g/ ha applied as foliar spray	Over 100% increase in Nitrogenase activity, 20% increase in yield	(Vieira et al., 1998)
Peanut	100 g/ ha as seed coating	2 to 3x Increase in Nitrogenase activity compared to no Mo addition	(Hafner et al., 1992)
Peanut	100 g/ ha as seed coating (higher rates were also tested but were not associated with greater yields)	30% increase in total yield	(Quaggio et al., 2004)
Soybean	17 g/ ha applied as	30 to 100% increase	(Parker & Harris,

	seed treatment or foliar spray (varied between years)	in total yield (varied between years)	1977)
Crop	**Application Rate, Method, and Notes**	**Effect**	**Reference**
Lentils	Seeds were soaked in ammonium molybdate solution at 6 g/ kg seed	20% increase in total plant growth	(Togay et al., 2008)
Cowpea	Pelleted seeds with nitramolybdenum at 0.4g/100g seed	1.39 tons/ha (21% increase over the control)	(Rhodes & Kpaka, 1982)
Chickpea	Broadcast at 500 g/ha (Mo was mixed with sand before broadcasting to encourage even distribution)	Approximately 20% increase in grain and stover yield	(Johansen, 2005)
Chickpea	Seeds were soaked in 0.5 g/ L sodium molybdate solution for 8 hours	Approximately 20% increase in grain and stover yield	(Johansen, 2005)
Black gram	0.64 mg/ kg soil	Plants with adequate Mo and no available mineral nitrogen had double the growth of Mo deficient plants	(Jongruaysup et al., 1997)
Egyptian Clover	0.95 kg/ ha as leaf spray (905 L total spray/ ha)	Increased yield and water use efficiency was observed (not statistically significant however)	(El-Bably, 2002)
Red Clover	Soil application at 0, 0.23, 0.46, 0.58 mg Mo/ kg soil (greenhouse study)	Nodulation and shoot protein was maximized at 0.23 or 0.46 mg/ kg soil (varied between fields), decreased with higher dose	(Lopez et al., 2007)

It should be noted that the molybdenum seed treatment method employed in several of the above studies involved soaking the seeds before transplanting (Johansen, 2005; Togay et al., 2008). Soaking seeds alone has been shown to improve germination and growth for some species (Aune & Ousman, 2011; Ousman & Aune, 2011). As such, the soaking method of applying molybdenum to the seed may have caused a falsely positive effect on the observations drawn regarding the effect of Mo in these studies.

It has been observed that neither broadcast nor seed-application of molybdenum is necessarily a more effective method of Mo application, and that the ideal method of Mo application for achieving maximum nodulation will vary between fields (Johansen, 2005). With this in mind, simple field trials should be conducted at a given site to determine the ideal method of Mo application where practical.

Identifying Molybdenum Deficiency

Conventional soil testing methods are not effective or often available for molybdenum (McKenzie, 1966). As molybdenum deficiency will interfere with nitrogen fixation in legumes, symptoms of nitrogen deficiency in these crops (yellowing and tip drying of older leaves) can be a simple indicator of molybdenum deficiency, though other factors such as the absence of nitrogen fixing bacteria or acidic soil conditions (see below) can cause the same symptoms. Legume nitrogen fixation can be more accurately estimated by gently digging up the root system and counting the number of root nodules. Nodules have the appearance of small beads on the roots. Nodules that are actively fixing nitrogen appear red (inside and/or out) and this colour in particular, along with nodule number and size, indicates the total level of nitrogen fixation per plant. To gauge whether there may be a molybdenum deficiency, nodule observations from fields with low-yielding legumes should be compared with fields with high-yielding crops of the same species.

Molybdenum may be present in the soil but not available to crops when the soil is acidic thus adding more molybdenum may not be beneficial under these conditions (Franco & Munns, 1981). For example, common beans (*Phaseolus vulgaris)* have been shown to not respond to Mo addition when the pH is below 5.2 (Franco & Munns, 1981). Soil acidity can be estimated using inexpensive litmus paper.

If the cause of low yielding legumes remains unclear, a small test plot of legumes should be planted, in which half will receive an addition of molybdenum and half will not. Ideally, the farmer and whoever is measuring yield should not know which sub-plot received the treatment ("blind study") so that the treatment of the entire plot is as consistent as possible once established.

Improving Molybdenum Availability Using Liming

Applying lime to the soil is common practice to overcome acidic soils and has also been shown to improve plant molybdenum uptake by several studies (Franco & Munns, 1981; Lopez et al., 2007; Mandal, Pal, & Mandal, 1998; Quaggio et al., 2004). In a field trial carried out with peanuts on soil with an initial pH of 4.2, liming at a rate of 2 t/ha was found to be equally effective as molybdenum seed coating without liming (Quaggio et al., 2004). This suggests that if molybdenum is already present in the soil but unavailable because of acidic conditions, applying molybdenum with the seed may be unnecessary if the soil can be treated with lime. Similarly, a field trial with Egyptian clover on an alkaline soil (pH 8.15) and an initial soil molybdenum concentration of 0.18 mg/ kg found no statistically significant yield benefit from a molybdenum leaf spray, suggesting that molybdenum availability is less problematic when soil is not acidic (El-Bably, 2002). It should be noted however that urea (a nitrogen containing fertilizer) was also applied to the experimental fields in this study, obscuring the effect of molybdenum on nitrogen fixation (El-Bably, 2002).

Drawbacks and Limitations

Molybdenum has been shown to enhance the beneficial effects of rhizobial inoculation in comparison to inoculation alone (Bambara & Ndakidemi, 2010; Johansen, 2005), however at high application rates (e. g. more than 30 micrograms per litre of seed priming water), molybdenum was shown to decrease the symbiotic interaction between rhizobia and pea (Pisum-sativum) (Chahal & Chahal, 1991). High doses of molybdenum applied directly to the seed may discourage symbiotic interaction between rhizobium and other bacteria species as well, so it is important to be careful not to use too much molybdenum when adding it directly to a seed preparation.

Additional Notes on Interactions between Inoculation and Mo Seed Coating

Although neither seed coating nor soil application of Mo was consistently more effective in improving nodulation of chickpea than the other, both application methods improved nodulation in comparison to inoculation alone (Johansen, 2005). This suggests that seed coating with molybdenum does not necessarily interfere with successful rhizobial inoculation. It should be noted that acidity was not a limiting factor in this study (Johansen, 2005), and that acidic conditions may favour Mo seed coating because Mo will be closest to the seed with this application method.

It was found in another study that applying Molybdenum with seed inoculants increased yield benefits with increasing Mo rates. Yield from inoculated seeds were higher than yields from uninoculated seeds, indicating a positive effect from combination of Mo seed coating and inoculation in this study (Bambara & Ndakidemi, 2010).

It should be noted also that as with seed-placed fertilizer, seed-coating will decrease moisture availability to the seed. For this reason seed-coating is not recommended in situations where available moisture is likely to limit germination rates.

As a cautionary note, when acidity related unavailability is not as issue, there is potential for molybdenum toxicity to occur to the plant (Brenchley, 1948) so molybdenum additions should be carefully measured as a seed preparation is made.

Practical tips

Molybdenum can be coated onto seeds at the same time as rhizobial inoculatants. A method for the preparation of inoculant seed coatings is outlined in the May 2010 N2 Africa Workshop report (Saidou Koala, Baijukya, Qureish Noordin, Abdullahi Bala, & Ngokho, 2010). This guide does not include molybdenum in its seed coating preparation method however powdered molybdenum fertilizer such as ammonium molybdate could be substituted for a portion of the mineral mix. An adhesive should also be employed to ensure lasting contact between the seed and its coating (Saidou Koala et al., 2010).This adhesive can be prepared using locally available materials such as gum Arabic, granular sugar or sugarcane molasses. Please see Table 1 (page 16) of this guide (link provided below) for the correct ratios of adhesive, water and inoculant/mineral mix. The preparation of the seed coating will also require plastic bags without holes or a bucket with a lid for larger volumes of seed.

Molybdenum can also be broadcast or applied as a foliar spray. Foliar spray application has the advantage of avoiding the pH-dependant availability issues associated with molybdenum however the potential for over-application and resultant toxicity is higher with this method. It must be kept in mind again however that this risk is present for all methods of molybdenum application. Seed preparations through coating or soaking with molybdenum are likely the least labour intensive methods of Mo fertilization for most situations, and have the additional advantage of encouraging even application and proximity of Mo to the seed. The most effective method for fertilizing with Molybdenum will vary between fields (Johansen, 2005). As such, determining the ideal molybdenum application method is best achieved through small scale field testing, although this will require waiting through the test season before molybdenum application can be applied to production fields if determined necessary. Molybdenum fertilizer can be purchased in several forms. Commercially prepared micronutrient mixes containing molybdenum are available however these are often unavailable to poor farmers. Isolated forms of molybdenum fertilizer also exist. These sources will contain either a very simple mineral form of molybdenum such as ammonium-molybdate or sodium-molybdate, or as molybdenum prepared into a "chelated" compound. Chelated compounds are those in which the molybdenum mineral has been incorporated into a more complex carbon molecule in order to enhance plant uptake and availability. Although this preparation may increase molybdenum availability, simple mineral forms of molybdenum have also been shown to be effective.

Additional Resources

This workshop report from the N2 Africa organization suggests a seed coating method into which Mo fertilizer could be incorporated. Related YouTube videos are also available through this link:
http://www.n2africa.org/N2media

Mavuno Fertilizers offers a micronutrient mix that includes molybdenum
http://www.armafrica.com/?page=mavuno-fertilizers

Bongani Minerals is a South African firm that is involved in Molybdenum mining
http://www.mbendi.com/orgs/1413/e133.htm
901 Broadway Centre
Hertzog Boulevard
Cape town, Western Cape, South Africa

Listing of Fertilizer Producers in India:
http://agriculture.indiabizclub.com/manufacturer/bio_fertilizers

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5.24.1 - Rhizobia bacteria inoculants for legumes

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Background

Legumes (e.g. soybeans, beans, lentils, chickpeas) are a very important part of a balanced diet especially in developing countries, because they contain a lot of protein. Nitrogen (N) is a building block for proteins (Hayat et al., 2010). Other crops like corn or wheat use the nitrogen that is in the soil to build up protein and therefore need a lot of synthetic nitrogen fertilizer. However, legumes can produce their own nitrogen fertilizer by forming a symbiotic relationship with special nitrogen-fixing bacteria species called *rhizobia*. The *rhizobia* infect the root and form small spheres on the roots called nodules. Once inside the nodules, the *rhizobia* bacteria are able to use the nitrogen gas that makes up 80% of the atmosphere on earth to form plant available organic nitrogen out of it – specifically ammonia that is a building block for protein. The protein is then transferred to leaves and grain. As a result, legumes require minimal commercial nitrogen fertilizer (Hayat et al., 2010).

However to form a beneficial relationship between the legume and the bacteria the compatible nitrogen-fixing bacteria must be present in the soil, because not all rhizobia bacteria work well with all legume species (Wielbo and Jerzy, 2012). Therefore, it is often necessary to introduce the specific bacteria for the specific crop in the soil by coating the legume seeds with a small population of the beneficial bacteria - a process termed rhizobia inoculation. Then the plant roots get infected and are able to form the nodule spheres where the nitrogen fixation occurs (Hayat, 2010). Nitrogen is a building block of chlorophyll and so increased nitrogen availability increases yield and makes the leaves appear greener (Thies, 1991).

Inoculation

First, the farmer should determine if there is a need for an inoculant. To determine if there is a N deficiency the farmer can observe the color of the leaves, because a lack of nitrogen makes a leaf appear paler, less green and more yellowish.

To determine if a legume is already infected by nitrogen-fixing bacteria, the farmer can carefully dig out plant roots and count the number of nodule spheres on the legume roots. Then a farmer can compare the number of spheres to high yielding legume plants. In addition, the farmer can cut open the spheres and check the color inside, because a pink color is an indicator for functional nitrogen-fixing bacteria. Active spheres are pink, because they carry oxygen to the rhizobia bacteria similar to oxygen-carrying red blood cells in humans.

If nitrogen is deficient and the roots are not already infected by bacteria it makes sense to inoculate rhizobia into the soil.

To inoculate the seeds with rhizobia, the farmer needs to purchase a bag of rhizobia inoculant and some kind of sticky substance. This sticky substance helps to attach the bacteria on the seeds. Then one places the seeds, the sticky substance and the inoculant powder in a bucket or plastic bag after which it should be mixed until all the seeds are coated by the powder. When the seeds are then planted the bacteria infects the roots. In the end to make sure the inoculation is successful, the farmer should have a small plot, in which half is inoculated and half is not. The yield and the leaf color should differ between the two plots if the inoculant is effective.

Possible Benefits

A successful inoculation leads to higher nitrogen uptake and therefore to more chlorophyll synthesized and more photosynthesis (Hayat et al., 2010). So the farmer can achieve higher yields. The increase in yield for inoculated legumes ranges from 60% to 300% depending on crop species (Chianu et al. 2011). In addition, the input costs decrease, because there's less need to purchase nitrogen fertilizer and usually fertilizer costs are one of the highest expenditures of a small-scale farmer (Kahindi et al., 1997). Thus, it is a cheaper and usually more effective agronomic practice to inoculate to ensure adequate N nutrition of legumes (Chianu et al. 2011).

Introducing nitrogen-fixing bacteria also has environmental and ecological benefits. Because no synthetic fertilizer needs to be applied, over applying of nitrogen fertilizer and nitrate leaching are avoided.

In addition, if one leaves the rest of the legume plant, which is high in protein on the field, it can act as an organic nitrogen fertilizer for other plants later grown on that field. Therefore, legumes are a valuable crop to include in a crop rotation (Hayat et al., 2010).

It is also has also been shown, that inoculation not only increases yield, but can also increases the stress tolerance of the legumes. For example, it could be observed that inoculation improves drought tolerance of some legume species (Yanni et al, 2016).

Common Problems and Issues

In general, the presence of inoculant infrastructure and expertise are low in developing countries (Mutuma et al., 2014). Another problem is that the farmer needs to be able purchase the compatible inoculant for the specific legume species. As mentioned above not all rhizobia species work for all legume crops. There are some legumes that can form a relationship with many different rhizobia species and others that can only form a relationship with only one. It depends on the crop species if an inoculation with a specific species is necessary and which inoculant the farmer needs to purchase (Mutuma et al., 2014).

Another problem caused by the poor infrastructure is the shipping and storage of the inoculant. The bacterial cells in the inoculant are sensitive to temperature. So the challenge is to secure lower (but not freezing) temperatures during storage and shipping (Chianu et al., 2011). To overcome the storage problem, low-tech food storage techniques can be used. Given the storage problem the inoculant should only be used in one growing season and not be stored for subsequent seasons (Balume et al., 2015). Therefore, it is important for small scale-farmers to be able to purchase small bags of rhizobia inoculants.

While nitrogen deficiency is not an issue for legumes after a successful inoculation, phosphorus (P) takes the role of the most limiting nutrient. Therefore, it should be noted that is it is important to secure a sufficient P supply to generate a successful outcome.

Micronutrient fertilizers are also critical for rhizobia to function, specifically boron (B) and molybdenum (Mo). It has been shown that the soil boron content effects the symbiotic relationship and the formation of the nodules and therefore B must not be deficient in the soil (Abreu et al., 2012). Also soil molybdenum affects the nitrogen fixation rate as it is required for the key bacterial enzyme that converts nitrogen gas into ammonia fertilizer (Figueiredo et al., 2016). Therefore, it is important to make sure that Mo and B are not deficient. These nutrients can be added to the soil as commercial fertilizers or coated on the seeds along with the inoculant.

There can also be problems with the establishment of the bacteria in the soil. Specifically, if there are native rhizobia bacteria in the soil, the inoculant can have difficulties to infect the legume roots and to form nodules, because the native bacteria can outcompete the introduced inoculant (Wielbo, Jerzy, 2012). That is why the inoculation works best for a crop that is new to the region.

Normally if the correct bacterial strain is added to the soil, it can stay there for years. This is only true when favorable soil conditions apply. It has been shown that low pH soil or saline soil conditions can affect the time the bacteria stay in the ground (Ventorino et al., 2012). This is an issue, because inoculation is especially practical in developing countries, if it is not necessary to inoculate every year.

Overall, the soil pH affects the symbiotic relationship between plants and bacteria negatively (Hungria and Vargas, 2000). While the crops are usually adapted to mostly lower soil pH of tropic soils, the bacteria and especially newly introduced species are not adapted to these unfavorable soil conditions. The ideal pH for *rhizobia* ranges between 6 and 7. Specifically, an acid soil has an effect on the infection of the roots and the formation of nodules, which results in a decrease of the total nitrogen-fixation rate. To overcome this problem, one can either apply lime to increase the soil pH or choose a bacteria species that is more adapted to low pH values. The second attempt might not be practical for subsistence farmers due to the already limited availability of rhizobia inoculants in developing countries (Hungria and Vargas, 2000).

Practical Tips, Further Information and Online Links

First of all, to enhance the adoption rate of a rhizobia inoculant, it is important to provide farmers with background information on legumes, rhizobia bacteria and nitrogen fixation, because this information can enhance the willingness to pay for the extra treatment of the seeds (Chianu et al., 2011).

There are studies on legume production that suggest that the main reason for the low rate of inoculation, at least in Africa, is not the price (Chianu et al., 2011). For example, a 100 g packet of Biofix (a form of rhizobia inoculant), which costs or US$1.20, is sufficient to inoculate 15 kg of common bean seed, enough to plant 1 acre. By contrast, the cost for the required nitrogen fertilizer is about US$34. Furthermore, these price ratios usually apply to the other legume species (Chianu et al., 2011).

Thus the main issue for NGOs or local companies, as already mentioned above, is to help to distribute/sell living inoculant and make it available to farmers. Some inoculant supplier links are noted below.

As mentioned above, the shipping of **rhizobia** poses a problem due to the temperature sensitivity of the bacteria (Balume et al., 2015). As a result, shipped commercial inoculants contain only a few living bacteria cells. Thus, it is important to find a reliable supplier and to maybe find an effective system to control the quality of the purchased product. In case of a low quality product a refund should be requested (Balume et al., 2015).

Rhizobia suppliers

•China

https://vastland.en.alibaba.com/

•India

https://indogulfgroup.trustpass.alibaba.com/

http://www.indiamart.com/nivshakti-bioenergy/

•BASF Canada

https://agro.basf.ca/East/Products/Product.html Under Inoculants.

•In Africa a potential supplier for an inoculant may be MEA Fertilizers. **http://www.mea.co.ke/Organic**

And they also provide information on how to inoculate with their product.

•In Latin America a potential supplier is Monsanto BioAg. **http://www.monsantobioag.com/global/las/Pages/default.aspx**

To get further information on how to inoculate, and information on specific legume species, NGOs are encouraged to use the provided links (below) and to contact commercial seed or inoculant suppliers.

In general, it is important to rely on the local resources of the specific country and to use simple low-cost and low-tech techniques and strategies. For example, it is best to use the local available resources to create a sticky substance to attach the inoculant to the seeds. Depending on the region, the sticky substance could be gum Arabic, molasses, etc. To measure the correct amount of inoculant per unit of seed, it is possible to use a bottle cap or spoon, because farmers may not have access to weight scales.

•Many tips and practical training manuals, not only relevant for Africa, may be found at:

http://www.n2africa.org.

http://aciar.gov.au/publication/mn173

http://aciar.gov.au/project/lwr2/1993/103

http://aciar.gov.au/publication/mn147

•And also videos:

https://vimeo.com/taskscape

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5.24.2 - Optimizing rhizobia inoculants for legumes

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Introduction

Rather than having to purchase synthetic nitrogen fertilizer, farmers can take advantage of certain types of bacteria ("nitrogen fixing bacteria" or "rhizobial/*Rhizobium*" bacteria) that inhabit the root organs of legume plants (e.g. beans) where they can convert naturally occurring atmospheric nitrogen gas (N_2) to nitrogen fertilizer (ammonia). There is a wide variety of nitrogen-fixing bacteria in nature, and certain varieties will be better at forming a symbiotic relationship with a particular legume plant than others (Wielbo, Kidaj, Koper, Kubik-Komar, & Skorupska, 2012). A compatible nitrogen-fixing bacteria strain for the desired crop must be present for nitrogen-fixation to happen. Most soils already possess nitrogen-fixing bacteria, and on a given soil some legumes will be able to form relationships with the native bacteria and others will not. When legumes are not able to form successful relationships with native bacteria, inoculation with a bacterial strain that is known to form successful relationships with the desired crop can often be beneficial.

Inoculation is usually performed by coating legume seeds with a powder containing a small population of the desired rhizobial bacteria just before planting. Inoculants are commercially available and generally must be purchased because on-farm production is beyond the capacity of small scale farmers in most cases, however in some situations the introduced bacteria may be able to persist in the soil and will only need to be acquired once. Microbial inoculants usually cost approximately $1.20 to $6 (US) per acre. If inoculation is successful, the cost of the inoculant is generally much less than purchasing an equal amount of nitrogen fertilizer to that which that the bacteria will produce.

Determining Need for Inoculation

Symptoms of nitrogen deficiency in legumes (yellowing and tip drying of older leaves) suggest soil conditions are not ideal for nitrogen fixation, which can sometimes be caused by a lack of compatible rhizobium bacteria in the soil. As also noted in the previous chapter, legume nitrogen fixation can be estimated by gently digging up the root system and counting the number of root nodules. Nodules have the appearance of small beads on the roots. Nodules that are actively fixing nitrogen appear red (inside and/or out) and this colour in particular, along with nodule number and size, indicates the total level of nitrogen fixation per plant. To gauge whether there may be a lack of ideal rhizobial strains, nodule observations from fields with low-yielding legumes should be compared with fields with high-yielding crops of the same species. If nitrogen fixation is determined to be poor, it could be because there are no compatible nitrogen-fixing bacteria for the legume species in the soil. Soil acidity or molybdenum deficiency can also cause problems with nitrogen-fixation (see Chapters 5 and 8 for further information).

Some legume varieties will form successful relationships with only a few rhizobium species whereas other legumes can form relationships with a wide variety of rhizobia. The ability to form successful nitrogen-fixing relationships with a wide variety of rhizobial species is referred to as "promiscuity". Promiscuity varies between different legume species and also between different cultivars of the same species, as shown in Table 6.1. For example, in Sub-Saharan Africa, soybeans will generally form relationships with only a few strains of rhizobial bacteria, so they will generally require inoculation (Giller, Murwira, Dhliwayo, Mafongoya, & Mpepereki, 2011). However, though soybean is not generally considered promiscuous, certain varieties have been observed to demonstrate this quality more than others (Mpepereki, Javaheri, Davis, & Giller, 2000). Cowpea on the other hand is a highly promiscuous legume that will form successful relationships with native bacteria in most soils and thus will generally not benefit from inoculation (Chianu, Nkonya, Mairura, Chianu, & Akinnifesi, 2011; Guimaraes et al., 2012).

The effect of a rhizobial inoculant on a particular crop and soil will vary widely. Seed providers should provide information about the promiscuity of their seeds (and whether or not inoculation is recommended) but this may not always be the case. As with many of the interventions discussed in this book, the most effective way to determine if a given combination of legume, inoculant, and soil will improve yields is through the establishment of a small test plot. Such a test should be setup so that one half of a farmer's field is planted with inoculated seeds and the other half with non-inoculated seeds. The management of the plot should be as consistent as possible throughout the entire area, and ideally the farmer should not know which half is which to encourage even treatment. If improved nodulation and yield response is shown to be associated with the inoculated legume seeds, a larger purchase of inoculant for wider field use can be considered.

Table 1: Promiscuity of several common legume species

Crop	**Degree of Promiscuity**	**Geographical Area of Study**	**Reference**
Soybean	Low but promiscuous varieties are available	Southern Africa	(Mpepereki et al., 2000)
Cowpea	High	Kenya	(Mathu et al., 2012)
Cowpea	High	Western Amazon	(Guimaraes et al., 2012)
Common Bean	Benefits from inoculation have been reported, suggesting low promiscuity	South Africa	(Bambara & Ndakidemi, 2010)
Mung Bean	High	Kenya	(Mathu et al., 2012)

Additional Benefits and Challenges to Rhizobial Inoculation

As noted above, most soils already host a varied population of microbial species and a given inoculant may not be able to survive in a soil if it cannot compete with native bacteria (Mathu et al., 2012). Additionally, saline soil conditions can destroy many rhizobial species and these conditions may also interfere with successful inoculation (Ventorino et al., 2012). Many rhizobial species are also sensitive to acidity (Guimaraes et al., 2012). When salinization and/ or acidic soil is a reality, tolerant rhizobial strains (if available) should be introduced to enable ongoing N fixation.

High temperatures, especially during storage and shipping, can damage inoculants, decreasing or eliminating their effect (Chianu et al., 2011). Low-tech food storage techniques (see Chapter X: Food Storage) could be used to protect inoculants between delivery and use if such practices have been established. Temperature control during shipping is also a major challenge to the distribution and widespread practice of legume inoculation in Africa. Given the sensitivity and storage difficulties of rhizobial inoculants, it is usually only practical for a farmer to purchase enough inoculant for one planting at a time. For this reason, small package sizes (approximately 25 g, or enough to inoculate ¼ acre of land) are ideal so that farmers can purchase the right amount of inoculant for their current plantings (Chianu et al., 2011).

It is also worth noting that improved drought tolerance has been observed in several legumes species when reliant on biological nitrogen fixation rather than fertilizer (Antolin, Yoller, & Sanchezdiaz, 1995; Frechilla et al., 2000; Kirova, Tzvetkova, Vaseva, & Ignatov, 2008; Lodeiro, Gonzalez, Hernandez, Balague, & Favelukes, 2000).

Practical Tips and Further Information

Given the sophisticated materials required to make a rhizobial inoculant, NGOs or local farm groups are encouraged to contact a commercial company or other suppliers in order to obtain these materials (see below). Once obtained, the bacteria must be coated onto legume seeds. A method for the preparation of inoculant seed coatings is outlined in Appendix 3 of the May 2010 N2 Africa Workshop report (Saidou Koala et al., 2010). An adhesive should be used when inoculating seeds to ensure lasting contact between the seed and its coating (Saidou Koala et al., 2010). This adhesive can be prepared using locally available materials such as gum Arabic, granular sugar or sugarcane molasses.

See Table 1 of “Workshop Report: Training of Master Trainers on Legume and Inoculant Technologies” for correct ratios of adhesive, water and inoculant/ mineral mix, available online at http://www.n2africa.org/sites/n2africa.org/files/images/images/N2Africa_Workshop%20Report-Training%20of%20Master%20Trainers%20on%20Legume%20and%20Inoculant%20Technologies.pdf (page 16). The preparation of the seed coating will also require plastic bags without holes, or for larger volumes of seed, a bucket with a tight-fitting lid. The application rate recommended by N2 Africa for seed inoculation is 10 g of inoculant per kilogram of seed for most common legumes (soy, bush bean, climbing bean, cowpea, ground nut) (Saidou Koala et al., 2010).

In central East Africa seed inoculants can be sourced from MEA Fertilizers located in Nakuru, Kenya http://www.mea.co.ke/Downloads/. The rhizobial species used in their Biofix product is unclear, however specific inoculants are available for beans, cowpeas, peanuts and soybeans as well as a few leguminous pasture and tree species. The approximate cost of the Biofix inoculant is $1.20 (US) per acre (Chianu et al., 2011). Legume Technology Limited of the United Kingdom has shipped their products to Nigeria in the past and could potentially ship to other African countries as well. This company offers specific inoculants for pea, broad bean, soybean and groundnut however the exact rhizobial species contained in each inoculant product is again unclear. Other African producers of rhizobial inoculants include the Grasslands Research Institute (Marondera, Zimbabwe), Madhavani Ltd., (Jinja, Uganda), and Soygro Pty Ltd. (Potchefstroom, South Africa). Inoculants have also been produced in Tanzania and Rwanda however these facilities are no longer operational. Links to providers of rhizobium inoculants are provided below.

A given provider may not have an appropriate inoculant for the legume species intended for production and it should be kept in mind that substitutions between rhizobial strains are not likely to be successful. It is important to note that rhizobial inoculants can vary widely in effectiveness and thus the reputation of a provider and any available third-party information on the quality of their products should be considered before making an investment. As inoculants can be compromised by heat during shipping, the product delivery method must be considered also.

Additional Information and Links

See (Chianu et al., 2011) for further information regarding previous successes and failures in the establishment of rhizobial inoculant techniques in Africa (the full reference is included at the end of this chapter).

For further detail on production of rhizobial inoculants in Africa see the N2 Africa report "Production and use of Rhizobial inoculants in Africa" (Bala et al., 2011) (Milestone reference number 3.4.1, available online at http://www.n2africa.org/node/165).

The N2 Africa organization provides useful information and videos on maximizing nitrogen fixation by legumes in Africa: http://www.n2africa.org

Marondera, Zimbabwe - Soil Productivity Research Lab:
http://www.drss.gov.zw/index.php?option=com_content&view=article&id=111&Itemid=129

Lilongwe, Malawi - Chitedze Agricultural Research Station:
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5.27 - Pigeon pea for degraded soils

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Introduction
Traditionally, *Cajanus cajan* (pigeon pea), a type of legume, had little significance on a world scale, however it's now rapidly becoming an integral crop for food security, trade and income (Boukar, 2013). Food security is a large issue for subsistence farmers, especially in India where the country has the land area to produce enough food to feed the population, however millions live without two full meals a day (Ninkovic, 2013). Much of India is populated by subsistence farmers, who may not afford the tools to properly cultivate the land and replenish soils with nutrients. Poor quality soils and low levels of fertilization highly contribute to food shortages in India and other developing countries. Pigeon pea should be considered as an important first crop to help restore degraded soils.

In order to restore the soil of its nutrients, pigeon pea may be sown to fix nitrogen in the profile and to solubilise rock phosphate – the two most limiting nutrients to grow crops. Pigeon pea, or "yellow split pea" is thought to have originated in India, then later made its way to Africa where it obtained the name "Congo pea". This was named by the women in the region and it refers to the high amount of protein in the crop (ICRISAT, 2016). Yellow split pea may give people living with malnutrition the protein they need. This may be especially valuable in Haiti, where 80% of the population is living in poverty, and most of its residents live on less than $2 per day (Sionfonds for Haiti, 2016). The perennial crop is sown primarily for food however may also be used for fuel, forage, fodder and medicinal uses. Pigeon pea is increasingly becoming more widespread with global production increasing from 1.96 million tons in 1980 to 3.46 million tons produced in 2006 (Bradtke, 2016). Overall, pigeon pea is grown over 4.74 million hectares worldwide, where 77% of this is produced in India (Youn, 2014) where the crop originated. Soil fertility is considered one of the largest problems limiting successful crop production, hence addressing this issue is vital for sustainability of the land. If the production of pigeon pea is increased in developing countries such as Haiti, it will have great potential to reduce hunger and food insecurity.

Benefits of pigeon pea for subsistence farmers
Pigeon pea is a highly sustainable crop due to its ability to improve degraded soils. It has deep roots which may hold the topsoil down, protecting the nutrients in the A horizon. This offers protection from erosion when grown on mountain slopes, benefiting the millions of farmers growing crops on hillsides in Africa (Adjei-Nsiah, 2012). Similarly, the deep roots (up to 2 m) may benefit the soil in droughts as it may extract water from deep in the soil (CGIAR, 2016). Thus, pigeon pea may tolerate the dry regions in India and Sub-Saharan Africa. Moreover, pigeon pea has the capability of fixing 41 to 280 kg/ha of nitrogen, which may provide the soil with adequate nutrients for succeeding crops (Bradtke, 2016). The nitrogen is fixed by rhizobium on root nodules, which may release plant available nitrogen in the soil. Hence, pigeon pea may act as a substitute for fertilisers, which is an advantage for subsistence farmers, especially for residents in Haiti who may not afford synthetic fertilisers (ICRISAT, 2015). Nitrogen is an essential macronutrient in soils, and access to nitrogen may greatly increase yield. Pigeon pea or "red gram" may also amend degraded soils through solubilizing rock phosphorus (Delgado, 1999). This occurs, via extracting phosphorus from deep in the profile and releasing soil bound P into plant available form. These adaptations provide farmers with valuable organic matter and micronutrients. Pigeon pea seeds offer high nutritive value as it contains

carbohydrates, vitamins and 10-25% crude protein (Adjei-Nsiah, 2012). Immature stems may also be cut and used as green manure which may Improve soil nitrogen and organic matter (CGIAR, 2015). Cajanus cajan is a low maintenance crop, therefore reduces the labour intensity for subsistence farmers. The deep roots allow the legume to withstand periods without rainfall and irrigation, due to its ability to hold water and access it at great depths (Saishi, 2016). This may save time for women who would otherwise need to regularly apply water to the field, in the arid areas of India and Africa. Pigeon pea would have great potential as a staple crop in Haiti, as large droughts have affected production of their major crops such as maize and rice (Haiti Agriculture, 2016). Lastly, as the crop is a perennial there will be fewer harvests than an annual crop. Thus, farmers may use their extra time tending to the livestock or other crops. Pigeon pea is also high yielding and low cost crop allowing increased income for subsistence farmers, as discussed in the cost analysis.

Sowing pigeon pea

Desirable growing conditions for pigeon pea include non-saline and free draining soils. The crop may tolerate a range soil textures from sandy to heavy black clays, and may be grow on different pH levels, however prefer the pH 5-7 range (Delgado, 1999). It should be noted to farmers that the crop is a perennial therefore must fit the cropping calendar or may be used as an initial crop to improve degraded soils. To prepare the seed bed, it is necessary to remove the previous crop and cultivate the soil, by harrowing or discing. Pigeon pea prefers deep ploughed soil, for the removal of previous crop residue and lifted seed beds for better drainage. Seeds are generally sown in the last week of May on flat land but may change dependant on the topography and are broadcasted and covered or drilled into the rows at 35 cm apart. The depth of these seedlings should be 2.5-10 cm at a rate of 0.5-4 kg/ha. Seedlings should emerge at 2-3 weeks and the first six weeks is critical for weed and disease management (Saishi, 2016).

How to cook

Once the crop is harvested, it may be cooked in a variety of dishes. Yellow split pea may be eaten fresh, as a green leafy vegetable or let fully mature and dried to give a mealy texture when cooked. As it's a large grain, a pressure cooker is preferable as it may take as little as 10 minutes to cook. Alternatively, pigeon pea may be soaked overnight in water and cooked on the stove top with spices, onions and vegetables, and served with rice. In developing countries pigeon pea is commonly be eaten with cereals such as sorghum and millet for a mix of nutrients. These cooking methods are commonly used in South Asia, Eastern Africa, Central America and Caribbean, however it's most common in India, where 80% of the world's pigeon pea is produced (Oulton, 2004).

Cost analysis

In the semi-arid conditions of parts of Africa, pigeon pea may yield around 500-600 kg/ha of grain, while dry matter yield may reach 25-40 t/ha (Delgado, 1999). Seeds cost approximately $11 a kilogram, and as fertiliser and irrigation isn't required, the input costs are low (CGIAR, 2015). When sown with maize in the crop rotation, yields may be increased by 75-200%, compared to a field with only maize (Waldman, 2016). International and domestic trade is another important aspect of aspect of pigeon pea production. The imported market for the crop in India is 250,000 tonnes annually, which increases the economy of developing nations (Youn, 2014). As pigeon pea has a variety of uses, the income is not limited to grain revenue. As shown on Table 1, soil amendment is as high as 89% in Zomba (Malawi) which may allow long term benefits to the soil, including fertilisation for subsequent crops. This increases the economic value of pigeon pea, as following crops may benefit from increased yield.

Table1: The main products of pigeon pea in relation to the region in Malawi, Africa.

	Dedza	Ntcheu	Zomba
Fuelwood	44%	80%	95%
Soil amendment	74%	85%	89%
Forage	40%	38%	51%
N	43	97	152

From: Boukar, O., Bhattacharjee, R., Fatokun, C., & Kumar, L. (2013). Cowpea. *Genetic and Genomic Resources of Grain Legume Improvement*, 181-202.

Critical analysis

The primary issue in pigeon pea production is the perennial nature of the crop, making the crop less desirable to farmers, in part because it excludes the ability to plant annual crops. Furthermore, pressure is placed on subsistence farmers as income is delayed for perennial crops to mature. However, recent hybrid varieties have been developed by ICRISAT and partners in India which allow pigeon pea maturation in 4-6 months. These hybrids may also allow resilience to drought, salinity and greater root to shoot biomass. A challenge with adopting these hybrids, is that seeds may be too expensive for subsistence farmers to afford. However, the Indian government heavily subsidises these hybrid costs (ICRISAT, 2016). Another alternative may be sowing pigeon pea as an intercrop with maize as this may maximise the productivity of the land area.

The storage of pigeon pea may attract Fusarium fungal pathogens and pod borers which may reduce farmers' income. The pod borers attack pigeon pea and is responsible for US $1.1 billion annual loss of production (Le, 2014). To avoid this issue, Hermetic grain storage bags (PICS or GrainPro) may be used to prevent contamination from these pests and diseases (Agrilinks, 2016).

Pigeon pea productivity may also be limited by environmental conditions. In areas of high rainfall, there is poor pollination for pigeon pea, this is a major initial challenge, as it may greatly reduce the yield. Pigeon pea is also not suited to high frost areas and waterlogging; however new varieties are currently being developed with resilience to these environment factors (Saishi, 2016). Lastly, in areas where the crop is not commonly consumed, it may be difficult for subsistence farmers to sell their crop in the local market stalls. However, what is not sold may be fed to livestock as crushed dried seed, which may increase cattle's live weight by 0.7-1.25 kg a day (Adjei, 2012).

Links to helpful resources

•To access pigeon pea, the following links show different seed varieties, and provide a point of contact to order the seed.

•ICRISAT, in India, has primary responsibility globally for collecting, storing, breeding and distributing pigeon pea seeds:
http://www.icrisat.org/new-hybrid-and-varieties-of-pigeonpea-released-by-telangana-india-3/

•To purchase general pigeon pea seed locally, in India, the following link is an alternative option:

http://dir.indiamart.com/impcat/pigeon-pea-seeds.html

•To purchase general pigeon pea seen in Africa

http://www.veseys.com/ca/en/store/flowerseed?gclid=CMHV_JrG0dACFcEbgQod8K8G8w

•To purchase general pigeon pea seed in Haiti:

http://www.reimerseeds.com/pigeon-peas.aspx

•Other sources:
https://www.edenseeds.com.au/?name=Product-Info-Seeds&product=trees-pigeon-pea
http://www.seedsforafrica.co.za/products/pigeon-peas-sprouting-seeds-200-grams

•To view a training manual for more information of pigeon pea establishment, use the following link

An example of a useful manual for pigeon pea in Malawi:
http://www.cabi.org/gara/FullTextPDF/2009/20093200517.pdf

•*A manual for pigeon pea in India, released by ICRISAT:*

http://oar.icrisat.org/6617/1/EngagingSmallholders_205-216_2012.pdf

•*For further information of pigeon pea and alternative crop production in Haiti, follow the link below. This manual may give more in depth information regarding crop alternatives which directly relate to environmental conditions in Haiti.*

https://www.wfp.org/sites/default/files/Haiti%202010-2013%20Report_English.pdf

•For an idea of the size and appearance of pigeon pea crop, use the following link

https://www.google.ca/search?q=cajanus+cajan&biw=1280&bih=633&source=lnms&tbm=isch&sa=X&ved=0ahUKEwiz15Dx04_QAhXm5IMKHTuzAQ4Q_AUIBigB#imgrc=_

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5.28 - Azolla-Anabaena symbiosis in rice paddies

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Background: Azolla-Anabaena Symbiotic Relationship

Azolla is a type of aquatic fern that floats and grows at the surface of water – it is the well known green layer that floats on the surface of rice paddies in Asia (Bhuvaneshwan and Singh, 2015). Although the practice of using Azolla in rice paddies is most prominent in eastern Asia, species of Azolla can be found on all continents, providing farmers the opportunity to incorporate the fern into their rice paddy crops (Carrapiço et al., 2000). It is naturally found in sources of freshwater such as ditches, lakes, and ponds and uses vegetative propagation (asexual reproduction without the use of spores or seeds) to reproduce (Azolla Foundation, 2016). The fern is extremely small and is one of the fastest growing plants on earth, having the potential to double the area it covers in 3 to 10 days (Hasan and Chakrabarti, 2009). Anabaena bacteria live within small oval pockets inside the Azolla leaves (Carrapiço et al., 2000). In exchange for this safe living environment, Anabaena bacteria provide a source of organic nitrogen to the Azolla ferns, allowing for the plant to rapidly reproduce. Anabaena is able to supply this organic nitrogen to the Azolla through a process called nitrogen fixation. Nitrogen fixation is when an organism has the ability to take nitrogen out of the atmosphere, which cannot be directly used by a plant, and change it into usable nitrogen. Consequently, the symbiotic relationship between Azolla and Anabaena generates a high concentration of nitrogen inside of the Azolla plant (Carrapiço et al., 2000).

Azolla Application

The easiest way to incorporate Azolla into a new body of water is by taking a bucket full of Azolla from an area where Azolla naturally occurs, and throwing this bucket of water into an area that does not have any Azolla (Raizada and Smith, 2016) This concept is illustrated in the SAK picture book and a video demonstration by Indian farmers shows how easy it is to introduce Azolla into a new body of freshwater. They essentially release Azolla from a bag and leave it to reproduce (Azolla Philippines, 2013). Once the Azolla is introduced into the new water source it has the potential to begin to reproduce and cover the surface of the water. If Azolla cannot be found naturally it may be available for purchase from a local farmer who is cultivating it (Lumptkin, 1987). Online purchasing of Azolla may be made available soon in developing nations as it is now listed, but not in stock, on a number of plant websites supplying countries such as South Africa (Plants in Stock, 2015). The ideal temperature for Azolla is between 18˚C and 28˚C (Azolla Foundation, 2016). Some Azolla species are capable of surviving temperatures as low as -5˚C and as high as 35˚C. No species of Azolla can survive temperatures exceeding 45˚C (Azolla Foundation, 2016). Azolla grows the best in shallower rice fields of 5 cm or less as its roots grow closer to the soil, but the fern can grow to suitable levels in deeper waters (Talpur et al., 2013). Azolla grows best under partial sunlight as the light regulates photosynthesis and nitrogen fixation (Azolla Foundation, 2016). Azolla can grow in a source of water with a pH level of 3.5 to 10, but grows best in pH levels from 5.5 to 6.5. (Azolla Foundation, 2016).

Species of Azolla

There are several different species of Azolla and they all facilitate the nitrogen producing symbiotic relationship with Anabaena. The different species are found across the world from China, to South America, to central Africa (Carrapiço et al, 2000). *A. pinnata* is a species of Azolla established in a number of continents, including Africa, which has been found to grow best under low levels of phosphorus compared to other species of Azolla (Watanabe and Liu, 1992). *A. microphylla*, common in the Galapagos Islands, is particularly in need of high phosphorus levels for optimization of its growth. At the same time *A. microphylla* has a highest resistance to heat, whereas, *A. filiculoides,* found throughout China, is the least heat resistant Azolla species (Watanabe and Liu, 1992).

Benefits of Azolla-Anabaena relationship to paddy rice yields-
The symbiotic relationship between Azolla and Anabaena has led to Azolla being used as a bio-fertilizer, primarily used in rice paddy production (Azolla Foundation, 2016). Azolla is commonly grown within rice paddies, in the water directly alongside rice plants. Nitrogen is slightly leached into the water during Azolla's lifecycle (Azolla Foundation, 2016). When the rice plants near maturity, the canopy resulting from their leaves blocks sunlight from reaching the Azolla (Wagner, 1997). As a result the nutrients in the Azolla are depleted and the Azolla begins to rapidly decompose. It releases its fixed nitrogen into the water which rice plants can then absorb as they begin grain development (Wagner, 1997). This additional source of nitrogen is especially important for the growth of rice plants as a lack of nitrogen is the most limiting factor in rice production (Vaishampayan et al., 2001).

Higher Rice Production Yields
Numerous studies have shown that growing Azolla alongside rice plants can increase rice yields from anywhere between 14-40% (Talley et al., 1977). Experiments have found that Azolla may slow the growth of rice plants in their early stages, mostly likely from competition for nutrients. Even so, as the rice plants reach maturity, a taller plant with more shoots is developed (Wagner, 1997). When Azolla is used on a rice paddy alongside synthetic fertilizer, farmers have seen yield gains as high as 73% (Carrapiço et al, 2000).

Reduced Input Costs
Using Azolla as a bio-fertilizer means that farmers will not have to spend as much money on purchasing synthetic fertilizers. Studies have shown that a single crop of Azolla provides the same level of nitrogen acquired from 30 kg N/ha of urea which contains the highest concentration of nitrogen in solid fertilizers (Watanabe, 1987). Azolla can also be used effectively with synthetic fertilizers such as urea. For instance 2 kg of Azolla used with 30k g N/ha of urea provide the same amount of nitrogen as 60 kg N/ha of urea (Watanabe, 1987). Azolla can produce as much as 2-3 kg of nitrogen per hectare, per day (Hasan and Chakrabarti, 2009).

Additional Benefits
Azolla can quickly cover the entire surface of a rice paddy due to its rapid rate of reproduction (Azolla Foundation, 2016). The surface cover of Azolla can prevent mosquitoes from reproducing as the Azolla has blocked off access to the water. The inhibiting of mosquito reproduction in turn limits exposure to potentially disease caring mosquitoes (Azolla Foundation, 2016).

The thick cover of Azolla also prevents weeds from growing in the rice paddy as sunlight is blocked, preventing photosynthesis from occurring (Azolla Foundation, 2016). The suppression of weeds can be seen as a major benefit of growing Azolla as woman spend a disproportionate amount of their time on the farm pulling weeds, preventing them from engaging in other forms of work (Foster and Rosenzweig, 1996).

The use of Azolla as a natural fertilizer bypasses many of the negative impacts associated with synthetic fertilizers. Synthetic fertilizers are usually washed away in runoff from farmland and end up polluting aquatic ecosystems as well as leaching into groundwater (Wagner, 1997). Long-term use of synthetic nitrogen fertilizers causes the acidification of soils, greatly reducing the growth rate of plants. The production of synthetic fertilizers is another cause of pollution as the process is highly intensive (Wagner, 1997).

Problems Associated with Azolla Growth

Azolla cannot survive for more than a few days without the presence of water (Wagner, 1997). Once the Azolla fern is put under moisture stress, even in the slightest where the moisture content of the tissue decreases to 80%, Azolla nitrogen production changes to one fifth of the optimal nitrogen fixing level which requires 88-95% moisture tissue content. Azolla plants are also susceptible to insects such as moths, snails, flies, and fungal diseases especially in tropical, hot, and humid weather. Measures can be taken against these pests but they are usually costly (Wagner, 1997).

In terms of nutritional needs, phosphorus is the most limiting for the Azolla plant (Wagner, 1997). Azolla does not grow directly from the soil and phosphorus has a low mobility which prevents it from being available in abundance in the water (Ludwick, 1998)). Farmers may have to purchase phosphorus fertilizers to promote Azolla growth if phosphorus levels are insufficient in the rice paddy water (Wagner, 1997). Although Azolla can be used effectively alongside synthetic nitrogen fertilizers, nitrogen levels in the water that are too high can limit nitrogen fixation of Anabaena and the growth rate of Azolla.

Pesticides have a mild effect on Azolla depending on which pesticide is being used. For example Molinate reduces the nitrogen fixing levels of Anabaena but increases the level of chlorophyll whereas a different pesticide, Carbofuran, increased both chlorophyll and Anabaena nitrogen fixing levels (Wagner, 1997). The vast majority of herbicides are detrimental to Azolla-Anabaena life by either inhibiting their growth or by preventing photosynthesis from taking place (College of Tropical Agriculture and Human Resources, 2013).

Regardless of the potential benefits of Azolla on crop yields, Azolla use as a natural fertilizer is fairly low across the world (Kollah et al.,2016). Many farmers are unaware of the potential benefits of Azolla and consider it a weed, pulling it out of their rice paddies. Other farmers continue to buy synthetic fertilizers as some are subsidized by their governments. Besides the subsidized price, farmers purchase these synthetic fertilizers in large part because they have not been taught about the potential benefits of Azolla-Anabaena (Kollah et al.,2016).

Azolla in Practice

Although Azolla is most commonly associated with eastern Asia, species of Azolla can be found across the world. Azolla experiments in Guinea-Bissau have had positive results. Azolla can be found in abundance in Guinea-Bissau's eastern river systems (Carrapiço et al., 2000). After a number of trials a mixture of Azolla and urea was found to have a yield increase of 73% compared to the control, and only 20% less of an increase from the highest yield using only urea, but at half the cost due to the incorporation of Azolla. In a mainly agrarian country where synthetic fertilizer prices hold great influence over a farmer's ability to produce crops, Azolla has the potential to give farmers more freedom with their income as they can gather Azolla for free from these river systems or purchase it from other farmers at a significantly lower price than synthetic fertilizers (Carrapiço et al., 2000).

Additional readings and helpful links

https://www.scientificamerican.com/article/can-the-fern-that-cooled-the-planet-do-it-again/

Link to an interesting article about how Azolla helps regulate the earth's climate.

http://www.sciencedirect.com/science/article/pii/S0094576508000519

This article discusses how Azolla my be incorporated into the human diet of astronauts headed to Mars.

http://theazollafoundation.org/features/space-and-planetary-colonization/

This link explains the dietary potential for Azolla in space as well as its ability to purify urine. The link also discusses the findings of a Chinese team which demonstrated how 16 m^2 of Azolla can produce enough oxygen for two adults in a controlled ecological life support system.

http://theazollafoundation.org/azollas-uses/other-uses-2/

Check out this link for more information on some additional benefits of Azolla.

http://www.azollaamrit.com/

This is a link to an Indian NGO which aims to spread the benefits of Azolla amongst farmers in the region.

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Chapter 6 - Water

6.2 - Tied ridging to capture and prevent erosion

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Introduction

In arid and semi-arid nations, those with <1000 mm of annual rainfall, subsistence farmers are faced with the difficulty of growing their crops while reliant on low and often inconsistent rainfall (Nyamangara and Nyamgumbo 2009). The Northern and Southern parts of Africa for example, are often plagued by these rainfall issues with erratic rainfall years correlating to low crop yields (Kijne et al., 2003). When rain does come, the water comes at high intensities, proves to be very erosive, and results in soil runoff (Biamah et al., 1993). A secondary issue is that water runoff detaches soil particles resulting in erosion and loss of soil fertility (Aina 1993). The effects of this issue can be seen when looking at the strong correlation between overall GDP growth in African nations and heavier rainfall seasons. (Biazin and Stroosnijder 2012). Adversely, long lasting droughts have been shown to have dire effects globally including crop yield, poor human nutrition, severe malnutrition and famines (Sivakumar 1992). This pattern shows the importance of water retention practices for subsistence farmers in low rainfall area. One such method which has shown to be effective, is tied ridging. Tied ridging has been shown to be successful in harvesting rainwater in low rainfall areas, reducing water runoff and creating higher water retention in crop fields (Biazin and Stroosnijder 2010).

Practice and Products Required

Tied ridging is the practice of creating small, divided furrows 2 to 3 m long in order to create small basins within which the water accumulates (Araya and Stroosnijder 2010). Tied ridging is similar to many subsistence farmers' current tillage practices of creating long ridged furrows in a field, with the addition of repeated walls of soil in the furrows in order to create small soil basins. This method involves adding a disk to the back of an ox-drawn ridging plow, dropping the disk down for 2-3 m to leave small ridges of soil after which the disk is lifted for a few seconds (to establish the position of the mound of dirt or tie) and then dropped down again to create the next basin. A typical resulting basin should be around 15 cm wide and 15 cm deep (Biazin and Stroosnijder 2012). The recommended length of the furrows is between 2-3 m long (Bimah et. al., 1993). In order to prevent breakage of the ridges, it is best to create the ridges before the first rainfall (Biamah et al., 1993). Tied ridging is optimal for lands with less than a 7% slope gradient, after which the runoff benefits of the practice are negated (Lal 1995). This practice aims to prevent uneven distribution of rainfall, promote soil productivity and create higher water retention in crops (Araya and Stroosnijder 2010). Tied ridging's similarities to current tillage practices allows for easier understanding of the practice and more seamless introduction to subsistence farmers.

Possible Benefits

Tied ridging has been shown to prevent runoff and improve water retention, resulting in higher crop yields. Empirical evidence shows improved water retention when this method is used in the drought season and more even distribution of water across the crop field (Araya and Stroosnijder 2010). As the soil is now contained within small ridges, it drastically reduces the amount of soil and water runoff (Donovan and Casey 1998). In a 1993 study in Kenya, tied ridging resulted in 13.7% seasonal runoff, significantly lower than the 38.0% and 42.7% runoffs observed in manure and conservation tillage practices respectively (Biamah et al., 1993). In a 1967 study in Burkina Faso, tied ridges were shown to result in 0.9% water runoff, a vast improvement over ploughed ridges with water runoff rates of 12.2% (Aina 1993). These studies lend strong support to the water harvesting powers of the tied ridging method.

A secondary benefit of reducing water runoff is the retention of the nutrient-rich organic matter which maintains soil nutrients, thereby resulting in better soil fertility (Donovan and Caset 1998). This nutrient retention benefit, along with the water retention, has been shown to increase crop yields. Tied ridges can make dramatic improvements to farmers' yields, especially in low rainfall seasons, which can create more consistent year-round profits (Biazin and Stroosnijder 2012). In the aforementioned study conducted in Kenya, researchers found the soil moisture content to be 1.8% to 2.1% higher in tied ridging plots versus minimum and conventional tillage practices up to a soil depth of 100 cm (Biamah et al., 1993). In that same study, tied ridging resulted in 513 kg/ha^{-1} in maize green yield versus less than half that, 221 kg/ha^{-1}, using conventional tillage methods (Biamah et al., 1993).

Environment Best Suited to Tied Ridging

The method of tied ridging has been found to be most effective in coarse soils rather than dense clay soils, and areas with up to 1000 mm of annual rainfall (FAO, 2016). Tied ridging on clay soils has been shown to create water-logging and thus is better avoided (Aina 1993). Water-logging has also been shown in high rainfall areas and seasons, and therefore best used in areas characterized by low rainfall (Ogunwole 2004). In times of unseasonably high rainfall, a solution to avoid water-logging is to open up the ridges further creating larger surface areas within which the rainwater collects (Araya and Stroosnijder 2010).

Limits to Adoption and Proposed Solutions

Despite the empirical evidence supporting its efficacy, there are issues which require attention in order for subsistence farmers to adopt the practice (Dube et al.) There are important impediments in promoting the adoption of this practice, which lie in the economical and labour requirements of the practice, as well as the promotion both of insects and weeds.

With respect to the machinery needed, the practice is reliant upon equipment with assumed costs of around $300 CAD (Dube et al.). This presents resistance in adoption, especially for farmers who are without any of the equipment (Dube et al.).

Tied ridging also requires heavy labour upon inception of the practice, and requires upkeep throughout the season in order to ensure the ridges stay intact (Dube et al.). The high levels of labour required, often by men, have seen the method faced with resistance when introduced (Dube et al.). Another difficulty lies in the need for animal labour, which is not readily available to all subsistence farmers (Dube et al.).

A proposed solution to the above challenges is to create the practice as a communal operation, which is seen as a way of circumventing apprehensions surrounding labour requirements and associated costs (Dube et al.). Alternatively, a local entrepreneur may be able to rent the equipment on a fee basis. Another way to reduce the labour time is to lengthen the ridges up to 4 m long, as little to no difference has been found in terms of yield between basins of 2 and 4 m in length (Wiyoa, Kasomekerab, Feyena, 1999).

With the increase of still water comes the potential for the proliferation of insects in the soil. As a result of the pooling of water, which is especially prominent in more dense soils, insects may be attracted (Vesterager et al., 2007). This has been addressed by increasing the use of insecticides on the soil, as a preventative measure (Vesterager et al., 2007).

Another challenge that can be encountered is that of weeds. With the creation of extra water as well as bare soil between the rows of ridges, it creates conditions prone to more weeds (FAO 2016). A possible solution to this is to plant a cover crop over the bare land. As well as preventing the emergence of weeds, the core crops can also serve a variety of other uses such as animal feed and firewood or fuel sources (FAO 2016).

Practical Resources and Links To Get Started

Indiamart primarily sells in India, with low end prices for ploughs starting around 14,000 INR ($277 CAD) http://www.indiamart.com.

Alibaba is a global online marketplace from China primarily selling products in bulk orders. Ploughs are available for as little as $18 contingent upon the ordering of 100 items. This may present an opportunity for community or governmental intervention in order to help facilitate this purchase within a community https://www.alibaba.com.

The University of Nebraska has published a guide for smallholder farmers to determine whether or not the tied ridging practice will work well with their field conditions, entitled 'A Decision Guide for Tie-ridging in the Semi-Arid Areas of Ethiopia' https://www.google.ca/#q='A+Decision+Guide+for+Tied-ridging+in+the+Semi-Arid+Areas+of+Ethiopia' .

It also might be helpful to provide farmers with visual resources, such as this image of the traditional machinery needed for tied ridging (http://www.fao.org/docrep/t1696e/gif/plate50.jpg) and pictures of the field with tied ridges (https://energypedia.info/images/thumb/b/bd/TieRidge.png/275px-TieRidge.png).

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6.4/6.5 Rainwater collection around fruit trees including use of rocks

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Background:
Fruit trees are an important biological resource for developing nations. They add vital micronutrients especially to pregnant women and children and they're also important in commodity markets where they can make a profit (FAO, 2016). For example the bush mango tree is a highly demanded fruit tree in Cameroon Africa, locally and beyond, which generates income for local farmers (OUYA, 2103). Unfortunately, many subsistence farmers live in the sub-tropics where there is limited rainfall to grow fruit trees. One of the main problems in the subtropics is that it can get very hot and dry and only receive about 200-750 mm of rain each year, resulting in failure of crops and trees (Rainwater Harvesting Handbook, n.d.). Because a lot of people cannot afford expensive irrigation systems in developing countries, the need for a technique to collect rainwater or moisture from air around fruit trees is needed. This article will explain low costs approaches to irrigate fruit trees.

Benefits:
Water harvesting techniques can have enormous benefits especially in places where it can get really dry. Once they're set up, not only do people use them again and again without any maintenance problems but also they're very cheap and efficient.

In terms of dealing with desertification and degradation, water harvesting seems to be the perfect solution because the best feature about this technique is that it can be built on any slope, thus farmers can use large flat lands in the deserts (Zhang, Carmi & Berliner, 2013).

There was a study done in the Negev desert of Israel, where water harvesting methods were practiced on a large scale by the Nabataean people of Israel in the past (Fidelibus & Bainbridge, 1994). Crop production by these people was very impressive in a desert with an annual rainfall of 3-4 inches annually (Fidelibus & Bainbridge, 1994). Due to these results, microcatchment has been used as a means for supporting crops as well as to establish vegetation for parks and roadside rest areas (Fidelibus & Bainbridge, 1994).

There are a lot of other crops that have had successes with the microcatchment. A study was done in the semi arid regions of California where there is very low sporadic rainfall, the growth and seed production of jojoba trees were compared (Fidelibus & Bainbridge, 1994). Three jojoba trees were given three different treatments. The first one with no water harvesting catchments, the second with a clear-smoothed 20 metre square catchment, and another with no water but with a water repelling coat. The trees that received micro catchment produced more flowers and seeds compared to the untreated ones. This resulted in a much higher fruit yield (Fidelibus & Bainbridge, 1994).

Another experiment was done in the arid areas of Rajasthan, India, where jujube trees were planted. It was found that the growth and fruit production was improved significantly by microcatchment techniques (FAO, 2016).

Some of the other benefits are that the leaves and fruits provide food for the family as well as fodder for livestock. Perhaps one of the main benefits is that its wood is not only used for building purposes but it also provides fuel for cooking and heating (Ffolliott, Gottfried and Rietveld, 1995). That means that it can also be a way to generate income (as they can expand marketing opportunities) for poor households. Women don't have to walk miles and miles just to collect wood. Trees also protect soil, which can be important for growing crops because the leaves can act like a fertilizer when they fall to the ground and add nitrogen to the soil, which is very important to the growth of crops (Rainwater Harvesting Handbook, n.d.). Some trees also offer many nutritional benefits for both women and children. For example, citrus, papaya, avocado and guava trees provide important micronutrients such as iron and vitamins C and A (FAO, 2013).

Description:
Even during sporadic rainfall, if rain can be concentrated on a smaller area, reasonable yields will still be achieved (FAO, 2013). In the last few years significant focus has been on the use of micro catchments. This is a technique of harvesting rainwater in order to improve vegetation and prevent land degradation in low rainfall zones (< 250 mm), whereas the required amount is 300-400 mm to be able to grow trees (FAO, 2016). One of the practices is to create a short wall or pit around the tree. This will make sure that when it rains, the water will stay inside the pit instead of running off.

In very dry or desert like environments, the focus should be on atmospheric moisture. For example, in deserts there is morning dew that can be collected (FAO, 2016). There are also other indigenous practices in the desert that should be practiced when there is a shortage of rain. For example, in the Middle East, a very effective technique is used which is the use of porous rocks around fruit trees (FAO, 2016). The rocks are used to collect dew in the morning. The pores in the rocks will help to condense morning dew, from where it will drip down into the soil.

An experiment carried out on the Canary Island of Lanzarote consisted of the use of porous volcanic rock to grow vegetation and trees; such rock is available abundantly on the island (Graf, Kuttler & Werner, 2008). This not only reduced evaporation losses but also supplied water to the roots by condensation, which increased fruit yields by 40. (Graf, Kuttler & Werner, 2008).

Another really good example come from China where there is a long history of growing melons in soil beds covered with a layer of gravel that is 100-150 mm thick; the dew on the gravel drips down to the soil through condensation. As a result of this practice, yield increased by as much as 28% (FAO, 2016).

Lastly, another simple method is specifically for hillsides. The idea is to create a stone or contour bund that will surround the fruit tree to collect rainwater. There are several designs a farmer can use based on the type of landscape and soil they have (Ibraimo, Munguambe, 2007). For example, contour bunds are effective for dry and flat lands whereas semi-circular bunds are useful for tree planting on degraded lands (Ibraimo, Munguambe, 2007).

Another indigenous practice is the use of filling unglazed porous clay pots with water and burying them beside fruit trees. The pots slowly leak water. The best feature about this technology is that the pots can be made locally with available materials and skills and are also less likely to be damaged by animals and insects (Bainbridge, 2001). A study in Pakistan showed that the survival rate of tree seedlings with the use of clay pots was 96.5% compared to 62% for hand watering (Bainbridge, 2001).

However, there are some drawbacks which include the cost of the labour which is $40/ha and the energy required to fire and install them (United Nations Environment Program, 2003).

The availability of water for trees depends on how much water is collected in the soil that is not lost to evaporation and percolation (Zhang, Carmi & Berliner, 2013). Therefore, it is important to consider making a deeper pit compared to a shallow one to have effective results. The trees planted inside the deeper pits had much higher survival rate compared to the ones planted in the shallow ones in the study that was done in Negev, Israel, noted above (Zhang, Carmi & Berliner, 2013).

Critical Analysis:
Although there are some appropriate techniques to accumulate rainwater when needed, there are some trade offs. They all require labour. Building a pit or a bund may be a bit challenging, as the tools to make the pit may not be available. In order to make a stone bund, a farmer will need stones but not everyone will be able to afford or physically transport these stones (FAO, 2016).

For the use of clay pots, one of the disadvantages is that the porosity of pots decrease with time, therefore they have to be replaced (United Nations Environment Program, 2003). It is also possible that the turbid water with a high silt and clay content may accumulate in the pores of the pots and thus clog them (United Nations Environment Program, 2003).

In addition, in order to collect the morning dew, there may not be porous rocks available to farmers in their area, which puts them at a disadvantage.

It is also essential that the benefits outweigh the costs when growing a specific tree. Individuals have to take care of the soil and tree needs, which can take a few years before the tree becomes productive, so the farmer has to be very patient (Noordwijk & Verbist, 2000).

Resources & practical tips to get started:
http://www.panoramio.com/photo/101153494:
As you can see, water has accumulated in the pit surrounding the tree.

Rood, Sicco, Steve Netto, and Debbie Waldecker. "Restoration." Restoration (n.d.): n. pag. Microcatchment Water Harvesting. Web. 6 Nov. 2016. Retrieved from:
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This contains lots of information regarding what micro catchment is and how it can help contribute towards agriculture.

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http://www.fao.org/docrep/U3160E/u3160e0a.htm#TopOfPage
This source contains easy information on "how to" make bunds around fruit trees that farmers can easily read and follow.

Sourcebook of Alternative Technologies for Freshwater Augmentation in Africa. N.p., 2003. Web. 30 Nov. 2016: Retrieved from: http://www.unep.or.jp/ietc/Publications/TechPublications/TechPub-8a/clay.asp
This contains Information on "how to" install clay pots, costs, sustainability and more.

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6.7 - Foldable plastic tanks and tarpaulin to collect rainwater

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Introduction

Rainfall in the sub-tropics can be sporadic with much of it occurring in short bursts, that if collected can benefit smallholder farmers. This is creating a demand for cheap methods for collecting and storing water. Methods to collect rainwater include foldable plastic tanks, or pits at the base of hillsides lined with tarpaulin to collect surface run-off. They both have the potential to provide numerous benefits for smallholder farmers (Barron & Okwach, 2005).

A foldable plastic tank is designed to unfold and serve as a vessel for both water collection and storage. The light weight collapsible design allows it to fold up for transportation or storage when not in use, similar to an inflatable swimming pool. By contrast, as noted, the tarpaulin method uses a pit at the bottom of a hill, or slope, lined with a tarp or tarpaulin kit. The theory behind this practice is to use the runoff caused by a rain storm, and as the water flows downhill it will pool into the pit becoming readily available. Investigations have shown that 73% of households have potential to harvesting rainwater from iron roofed houses (Nanyeeya, Mutumba, & Wanyama, 2009). While there is concern over the taste and debris of the collected rainwater, local peoples seemed interested in harvesting it (Handia, Tembo, & Mwiindwa, 2003). These interventions provide all the benefits of a regular barrel, with the addition of being light weight and easy to relocate, however the costs of these systems may be their major constraint.

The costs of these systems range according to their specifications: foldable plastic tanks range from 60-5000 USD, while tarpaulin ranges from 0.5-2.5 USD per square foot (Alibaba.com, 2016). Thin material will be cheaper, while thick material will be less prone to abrasions or punctures. The life span of these systems is also dependent on the treatment of the system and how many patch kits can be made available. If these systems are damaged beyond repair, the material can be used for artificial mulch, a management technique that can increase moisture, decrease weeds, and ultimately increase the yield.

How the practice is conducted

To harvest the rainwater using a collapsible water tank, the tank should be placed beneath a drainage pipe or any funneling system, and as the rain flows down the drainage pipe the tank will fill, with water becoming available for multiple uses. Please note that if this system has the intended use of collecting potable water, it is vital to close the lid, or seal the top of the foldable plastic tank in order to discourage any buildup of microbes, disease or algae. A soft military bladder is a good substitute for a collapsible barrel as it is a sealed system that blocks sunlight and pathogens from entering. This system can also be used to collect grey water so long that it is used for irrigation and no other purpose (Van Staden, 2015). A link below will provide the rules and important information for harvesting grey water.

To harvest rainwater using a tarpaulin system one must first located a proper slope that will provide the most efficient runoff. The next step is to dig a pit at the base and line the pit with the tarpaulin cover or a tarp. Properly undertaken, the water will run down the slope and pool into the pit conserving it for use later on. As mentioned before this system is considerably cheaper however environmental conditions must be considered when preparing this system.

Major benefits of this system

These systems have the potential to increase yields by not only providing the necessary water during critical plant stages, but can also be easily adapted to establish nurseries by using a simple tubing system that allows the tank to be directly connected to a drip irrigation system. This will effectively reduce weeding, extend the growing season, decrease competition for soil nutrients, and increase yields (Feijter, 2015). The harvested water can also be used as drinking water for cattle, that in turn contribute to food, income and social capital (Nanyeeya et al., 2009). Assuming the water can be treated and become available for consumption, this method of rain collection could mean a new source of drinking water in places like Zambia where only 43% of the urban population has access to potable water (Handia et al., 2003). In addition to access to potable water, these systems will also increase sanitation, as recent studies have shown that sanitation is directly related to quality and availability of water (Kahinda, Taigbenu, & Boroto, 2007). New water sources will effectively lower sickness caused by water borne disease, which in turn will increase labor availability for farming (Kahinda et al., 2007). Finally with regards to gender allocation, a analysis has shown that water collection is performed by 24% of boys, 15% of girls, and 13% of woman; 48% of these males used bicycles, while woman carried water on their heads 75% of the time. Hence, improving the availability of water and its storage will provide relief especially for girls and women (Nanyeeya et al., 2009).

Challenges

Although the foldable plastic tanks provide a number of benefits, the cost of the material is far from attainable for many subsistence farmers, and on top of this, a drainage system must be created and implemented into the roofing system. Further constraints of rainwater harvesting include the safety of using it for potable water. A team of researchers from Stellenbosh University investigated the potential for rainwater harvesting in Africa. Unfortunately although the chemical test results revealed the water qualified to be potable, the microbial test indicated that the water far exceeded recommended safe drinking water guidelines (Kalebaila, 2013). This study analyzed the results and revealed a number of bacteria, pathogens, and fecal coliforms were present from various sources including bird defecation on roof tops (Kalebaila, 2013). The study explained that without a pretreatment, such water would not be recommended for use except for agricultural purpose.

The tarpaulin method also has its constraints, although the startup costs appears low, labor is required to dig the pit, and access to a pit is critical for this technology. This method is also far less likely to be able to provide potable water even when treated.

In summary, these systems enable harvesting of rainwater, making them available for agricultural purposes. The use of these systems for potable water may or may not be possible.

Where to buy

There are a number or places to purchase rainwater harvesting equipment. Alibaba.com has a number of different styles of foldable tank designed to fit a customer's specifications and budget. As for tarpaulin systems, the startup costs of the material is typically low and priced by the square foot and hence can accommodate different budgets. The following links can be used to purchase these materials:

Additional resources

Manual for rainwater harvest (note that this uses a normal barrel, simple replace it with a foldable tank)
http://www.sswm.info/category/implementation-tools/water-sources/hardware/precipitation-harvesting/rainwater-harvesting-r

Picture manual of collecting surface runoff
http://www.amshaafrica.org/projects/rainwaterharvesting/plasticlining_pan.jpg

Where to buy:
https://www.alibaba.com/showroom/agriculture-water-bladder-tank.html
https://www.asianproducts.com/hotproduct/manufacturer_Agriculture-water-bladder.htm
http://www.mpccontainment.com/millitary-applications-pages-41.php
https://www.alibaba.com/trade/search?fsb=y&IndexArea=product_en&CatId=&SearchText=tarpaulin+covers

Harvesting grey water:
http://www.waterwise.co.za/export/sites/water-wise/gardening/water-your-garden/downloads/Greywater_pamphlet.pdf

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6.8 - Irrigating a crop nursery using rainwater (revision pending)

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Background

Many subsistence farmers especially in the sub-tropics work in areas where precipitation patterns are characterized by periodic swings between wet and dry conditions (Dike, 2014). In South Asia, climate change is altering the seasonal predictability of the monsoon rains (Naidu, 2012). Farmers typically plant at the onset of the first rains, but climate change is sometimes causing the subsequent early-season rains to be delayed, causing the death of germinating seedlings. Thus strategies are needed to mitigate early-season sporadic rainfall. Furthermore, solutions are needed to artificially extend the growing season normally fed by consistent rainfall (Davies, 2010).

Farmers living in these conditions have adapted a method for growing finger millet, by using the practices from the rice intensification program SRI (Abraham, 2014). The farmers first make shallow furrows with a plow in the form of a square grid 45x45 cm; this ensures proper spacing, which is the essential focus of SRI. The farmers transplant seedlings of finger millet along with a handful of manure around the roots. Between 15 and 45 days after transplanting, farmers then pull a light board across the field in several directions. Bending the plants over in different directions promotes greater growth of roots. This process boosts the yields of rice and has been adapted to many other crops; the transplanting of young seedlings developed in a nursery is an important part of this practice (Abraham, 2014). The nursery, irrigated using harvested rainwater, artificially extends the growing season by allowing seedlings to get a head start; reliable irrigation improves seedling survival.

Practice

In order to implement irrigation of a crop nursery using rainwater, the farmer must first harvest the water and then store it until it is needed. There are a number of methods to capture water; the most efficient way depends on the location of the farmer, the topology of the land, and the resources available. Irrigation ponds work by using a large area to catch the rainwater and direct it into the pond (Rockstrom, 2015). However, smallholder farmers farm on extremely small land holdings (FAO Glossary) so rooftop catchment systems are ideal and can be used for drinking water (Kahinda, 2007). To catch the rain, a farmer can use a PVC pipe cut in half and fastened at the edge of the collection surface at the bottom of a slope. This is a very cost effective way of catching the water. The water then needs to flow into a covered reservoir (Davies, 2011).

Without resources, a subsistence farmer can create a simple nursery to meet his/her needs. For more elaborate nurseries, FAO recommends (FAO, 2012) two different types of nurseries for subsistence farmers growing a variety of crops: a block nursery, or a polybag nursery.

Block nursery

A block nursery is set of about 4 small garden beds in a total area of about 400 m^2, the beds should be separated by paths so that the farmer can comfortably walk down between the beds. The reason for the separation of the beds is so that there can be good water drainage between the beds during monsoon season, and the paths allow the farmers to easily work on and water the beds. If possible the beds should be arranged in an east to west direction to provide proper distribution of sunlight. The nursery beds can be 1 m in width and about 3-4 m in length. It is recommended to have 2 ft wide pathways between the beds. Between the paths canals of approximately 6 inchs in depth are required to give better drainage of monsoon rainwater (FAO 2012).

For the preparation of the block beds: it is recommended that the bed size be about 4 ft X 10 ft. First, the soil is dug deep so that the clumps are broken up. The soil is allowed to dry in the sun for 2-3 days for sterilization. This is to prevent fungal diseases. Next about 10 baskets of sand, which are bamboo baskets that are about medium sized, and 3 baskets of good compost are added to the soil. Everything is mixed well together. By this point the beds should be raised and separated by paths that have small drainage ditches so that the beds do not get washed out. The final step before planting is to water the bed very well a few hours before planting (FAO, 2012).

Polybag nursery

A polybag nursery on the other hand is the use of plastic nursery bags in which to grow the seedlings in. For polybags, one needs nutrient enriched soil. First, the bag needs to have holes for drainage. The farmer can poke his or her own holes using any kind if tool like a pencil or a stick. If they have access to one they can use a hole punch machine. It is recommended that the bag have about 6 holes in the bottom of it. Next, the farmer makes a triple mix by taking local soil and depending on how dense the soil is they add a proper amount of sand. Just enough to loosen up the soil, then they add compost. The farmer then fills the bags with the triple mix and pats it down but not to hard. Finally, an area for the poly bags is cleared and leveled. It is recommended to build frames around the beds to keep the polybags upright. Frames can be made from any available resource (FAO, 2012). Possible advantages of polybags are that it delivers nutrients required by the plant, and nutrient rich soil can accompany the transplant.

Candidate crops for transplanting

Crop species vary in terms of their ability to thrive after being transplanted (reference). For instance, corn and wheat do not transplant well so it is better to plant from seed. However, some other cereal crops transplant well such as rice, finger millet and tef. Sugarcane also transplants well, as well as mustard, turmeric, and many vegetables (Davies, 2011).

Benefits

Nurseries ensure guaranteed seedling germination, and the controlled environment of a nursery helps to control the unpredictable variables of the climate. Nursery planting also allows the farmer to extend the growing season and offers better yields. Transplanting establishes crops early with a greater focus on the overall care of the plant (Abraham 2014). As well, transplanting through the practice SCI planting the seedlings further apart allow for better plant growth below and above the soil. For example, tef seeds are traditionally thrown on cultivated soil. In 2008 some farmers planted tef seedlings that had been started in a nursery. Using the spacing system of SCI tef yields went from 1 ton/ha to 3 to 5 ton/ha. Not only are the yields higher, but also proper spacing of the seedlings reduced lodging, a major problem of tef. Planting in a nursery and then transplanting may be more labour intensive but the pay off is worth it (Abraham, 2014). Finally, weeds have a faster growth rate then crops (Weiner, 2001)

Problems, critical analysis

The main problem is that nurseries require extra labor (Abraham 2014). The farmer is handling and moving the plant a few times. It takes time to water and set up the required systems for the nursery to function. And women typically are responsible for transplanting seedlings, which is long and arduous work (FAO, Woman in Agriculture). Access to water for irrigation is a significant issue;

either the farmer has not enough or too much. It also may be difficult to get enough bags of the right size, and the costs may be too high.

Helpful Links and additional reading:

Additional Readings:

http://www.fao.org/docrep/008/ae946e/ae946e03.htm

http://www.fao.org/docrep/013/i2050e/i2050e.pdf

http://www.worldagroforestry.org/sea/Publications/files/manual/MN0001-04/MN0001-04-4.pdf

Helpful pictures:

Polybag nursery :

http://www.geocities.ws/cheriachangelmathews/images/mucuna_seedlings.jpg

block bed nursery:

http://www.thebetterindia.com/wp-content/uploads/2012/01/INDkb29c.jpg

catchment system:

http://www.gdrc.org/uem/water/rainwater/Rooftop.gif
http://www.oasiswildlife.com/images/560_DSC00069.JPG
http://www.dadychery.org/wp-content/uploads/2011/11/Rain_Catch_Fig2B.gif
http://www.primalsurvivor.net/wp-content/uploads/2015/09/collecting-rainwater-with-plastic-tarp-tent.jpg

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FAO: Women in Agriculture, environment and Rural production. ftp://ftp.fao.org/docrep/fao/008/ae946e/ae946e00.pdf

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6.9 - Drip irrigation in a greenhouse

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Introduction

Drip irrigation (often called trickle irrigation) involves dripping water onto crops near their base at a very moderate rate. This system is typically made of small diameter plastic pipes fitted with outlets (emitters) which drip at a rate of 2-20 liters per hour (FAO, 2016). It is an efficient way of watering crops to ensure the greatest yield for the least amount of water and gives higher yields of crops as compared to traditional furrow irrigation (Ibragimov, 2007). Drip irrigation can also be easily modified to fit many selected environments and can be utilized for a variety of different crops. Drip irrigation systems can be used for a multitude of different crops, however they are often and effectively used for regional cash crops as an additional source of income. In fact, implementing cash crops within this system might be the best option as they may be needed to offset the cost of supplies depending on the materials used. When implementing this system it is best to know what kinds of cash crops grow well in the region and its soil to maximize yield.

System layout

The system detailed in this chapter utilizes a row line model which distributes water from a single large source into multiple pipelines that align with their crop rows. This form of a drip irrigation system generally allows for an equal distribution of water amongst crops when applied correctly (Frielander, 2013). This system is made up of multiple pipe units known as **Mainlines, Submains, Laterals** and **Emitters** that connect to a large **Storage Tank.** All of these parts in unison allow for water to be efficiently collected, stored, and distributed for use.

Common Layout: http://homesteadlifestyle.com/wp-content/uploads/2013/10/diypvcdripirrigation.png

Storage tank

The first, and most crucial part of assembling this system is setting up the means by which water can be properly stored. Ideally, this would take the form of a large storage barrel (like a rain barrel) which can store water for a long time and is also able to be connected to the pipelines. It is also highly recommended that this storage facility be connected to any type of rain collection system that will take advantage of any local precipitation.

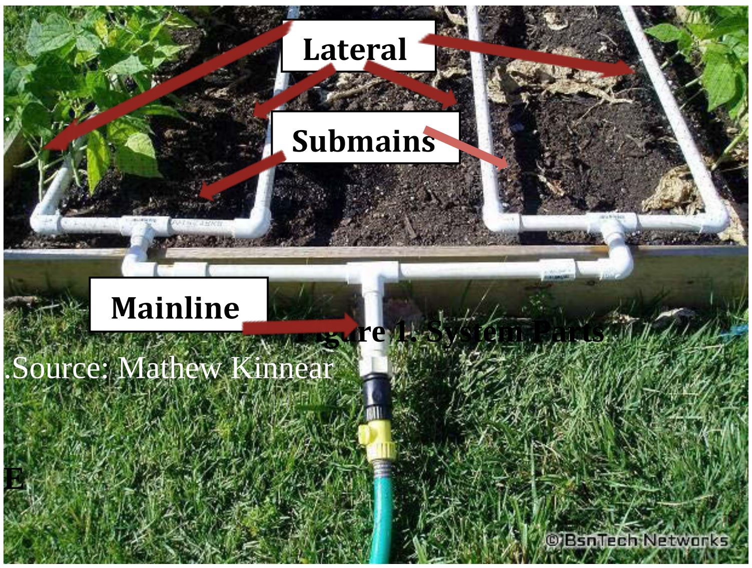
Alternative forms of storage tanks

Although a plastic storage tank is ideal it is not the only option for water storage. Other methods exist that may be more practical and available for use. An example of this would be a Silpaulin trench which utilizes a silpaulin tarp and a large trench dug in the ground. The trench provides the depth needed for storage while the tarp ensures that the water is not absorbed into the ground. Keep in mind that while this form of water storage is practical, it is more labour intensive. It also requires different methods of transporting the water to the pipelines either via pumping or by manual collection.

Silpaulin storage trench:
https://www.google.ca/search?q=silpaulin+tunnels&source=lnms&tbm=isch&sa=X&ved=0ahUKEwi3wf3bzr_QAhUL3IMKHbLGBt4Q_AUICCgB&biw=1366&bih=662#imgrc=1FSysA_x9OWc8M%3

Mainlines, submains and laterals

Mainlines, Submains, and Laterals supply water from the Storage Tank into the fields (Figure 1). The idea of Mainlines and Submains is to provide a connection to the source of water which allows the Laterals to distribute water to the crop lines. Mainlines connect directly to the Storage Tank and then split up into two Submains. The Submains allow the water to be split in two directions, covering the width of the crop lines, and allow the water to be distributed by the Laterals. The Laterals are the lines that attach to the Submains and lie over the crop lines. The amount of Laterals corresponds to the amount of crop lines that are in the field. The water is then distributed by the emitters (FAO, 2016)



gure 1: System Parts
.Source: Mathew Kinnear

E

Emitters

Emitters, otherwise known as drippers, are mechanisms used to operate the amount of water from the laterals to the crops. They are usually spaced more than 1 metre apart with one or more used for a single crops such as trees, however can be modified as needed. For row crops more closely spaced emitters are needed to hydrate each crop properly (FAO, 2016). Multiple different designs of emitters have been produced in recent years however a basic 3.2 mm hole will prove just as useful and more cost efficient.

Simple emitter holes:
https://solarbeez.files.wordpress.com/2013/07/drip-watering-siletz.jpg

Alternative Forms of Piping

While drip irrigation is both efficient and produces higher yields, using PVC pipes may require a significant financial investment. While PVC pipes are the most reliable form of water transportation (as they last longer), they are not the only means in which drip irrigation can be produced. If PVC pipe cannot be afforded, the system can still be used with natural low-cost material such as bamboo. Simply use the same method as detailed below (or modify as needed) while replacing PVC pipe + connectors with a bamboo-like alternative (Rainwater Harvesting, 2016). Keep in mind, although bamboo does act as a cheap alternative it is much more susceptible to the elements and may require frequent maintenance.

A drip irrigation system made of bamboo may look something like this:
http://www.cseindia.org/userfiles/bamboo_drip.jpg

Here's a website with step by step procedures:
http://permaculturenews.org/2014/02/28/bamboo-drip-irrigation/

Set Up
Step by step procedure

1. Attain supplies (Mainlines, Submains, Laterals, and Storage Tank)
2. Create correct hole size (matching Mainline diameter) in lower level of Storage Tank
3. Attach Mainline to hole in Storage Tank
4. Seal Mainline end within Storage Tank (any form of plug will do)
5. Create and attach Mainline to Submains (if using PVC apply T-connectors)
6. Create 3.2 mm Emitter holes in Laterals relative to crop line spacing
7. Attach Laterals to Submains along crop lines
8. Seal-off all ends on Mainlines, Submains, and Laterals

Similar end product:
https://s-media-cache-ak0.pinimg.com/736x/a6/8e/ae/a68eaee4c210cefac1008ab267f2a17e.jpg

Greenhouses

Using a greenhouse for crops is an effective way to keep moisture from evaporating into the atmosphere. Not only do greenhouses retain moisture, they also aid in pest prevention. Coupled with a drip irrigation system, a greenhouse can add benefits such as increased yields and a longer growing season (Agritech, 2016). What is even more appealing about greenhouses is the simplicity involved in making them. Essentially, as long as there is adequate spacing, coverage, and support a simple silpaulin tarp can be made into an effective small-scale greenhouse.

Set up

To construct a small greenhouse requires minimal (and likely low cost) materials accompanied by a fairly simple set up process. Mandatory materials are as follows: silpaulin tarp (or similar material), staking pieces, holding materials, and supports. Staking pieces can be simply sturdy sticks (though plastic or metal stakes will work best), holding materials can take the form of nails or string, and supports are typically any form of wood, plastic or metal. In many rural environments (where wood is available) a fairly simple greenhouse can be constructed using local trees and nails or tied bark string. The lumber from the trees is staked around the perimeter of the irrigation system and the tarp is draped over and held into place. (Agritech, 2016)

Step by step procedure

1. Attain Supplies (supports, stakes, holding material, tarp)
2. Lay supports around perimeter
3. Secure cross supports atop perimeter supports
4. Drape tarp across supports (enough to allow excess on the ground)

5. Secure tarp with staking materials
6. Secure tarp on perimeter and cross supports

Examples of basic greenhouses:
https://illuminumgreenhouses.com/portfolio-items/kadogo/#prettyPhoto
http://4.imimg.com/data4/SL/HF/MY-14033358/greenhouse-shading-500x500.jpg

General benefits of drip irrigation systems.

A drip irrigation system complete with greenhouse is a smart investment for those working in the rural agricultural sector due to a multitude of benefits. A study done by USAID in Haiti found that drip irrigation provided an additional $5000 worth of income within 40 hectares of land (USAID, 2014). It is also likely that these types of systems will reduce household energy spending. USAID support in Karnataka, India found that smallholder farmers reduced electric pump use from 84 to 25 hours per week of use. This was enough for one farmer to send his son to college as he was no longer needed to water the fields and there was more money in savings (USAID, 2016). Furthermore a 3 year study by the IDRC in Guyana showed that water usage was reduced by 25% while crop yield increased by 34% in some instances (IDRC, 2014).

Considerations and possible issues

Drip Irrigation within a greenhouse can be a fantastic way to use water efficiently on crops, however there should be some considerations to keep in mind when planning to use this system. The drip irrigation system described in this chapter has taken into account the importance of practicality and efficiency of use, but should be modified for regional situation and needs. Suitable crops, slopes, and soil types also need to be taken into consideration. Building a greenhouse can be equally as challenging in regards to logistics, financial requirements, and available resources.

Crops

Drip irrigation is best suited for high value row crops (carrots, etc.), tree and vine crops where each emitter will be able to effectively water each crop. Typically cash crops are farmed using drip irrigation as greater capital will be produced and greater product will be made per crop. Therefore, it is recommended that this system is utilized with local profit-based crops (FAO, 2016).

Slopes

Drip irrigation can be reasonably modified to any arable slope. Normally the crop would be planted along a soil line and the laterals (dripping pipes) would then be laid atop the crops. This is done to minimize changes in emitter discharge as a result of land elevation changes (FAO, 2016).

Soils

Drip irrigation is generally suitable for most soils, though there are some precautions needed for certain soils. For instance, water on a clay soil must be applied moderately to avoid surface water ponding and runoff. In contrast, more sandy soils require a higher discharge rate in order to ensure adequate lateral wetting of the soil (FAO, 2016).

Greenhouse construction

As previously stated, a greenhouse is a fantastic way to maximize water efficiency on crops, however there are some challenges associated with building one. Mainly these challenges take the form of materials available such as a silpaulin tarp or proper supporting and holding materials. If someone would like to build a greenhouse they must have the proper materials for it, some of which may be difficult to acquire based on location. If the user does not live in an area which is abundant in trees then lumber may have to purchased, something not everyone can afford. Even more so might be the difficulty to acquire a silpaulin tarp. A properly sized silpaulin needs to be manufactured, sold or donated. If the user cannot acquire/afford this important piece of material then they should consider whether the cost of construction outweighs the benefit.

Possible suppliers

iDE: https://www.ideglobal.org/

iDE provides users with low-cost international products as well as provides instructions on home-made low-cost technologies that can be easily adopted.

Jain Irrigation : http://www.jains.com/PS/index.htm

Here's a fantastic website that can provide low-cost product for both the drip system as well as the greenhouse which it also shipped internationally

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6.10 - Plastic mulch prevents water loss

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Background

Plastic is used in agriculture for constructing tall or short greenhouses/tunnels or as mulch covers for many row crops, as protective seed beds (Wittwer 1993). The use of plastic in agriculture has propelled the development of controlled agriculture significantly over the last 40 years (Wittwer, 1993). Due to the various compositions and designs of plastic films, they can assist in mitigating some major climate and weather hazards. Some major agricultural constraints include adverse temperatures, moisture and light deficiencies, weeds, and deficiencies in soil nutrients and atmospheric CO_2 (Wittwer, 1993). The following chapter will detail how plastic mulch can assist in minimizing these hazards, which crops grow best with mulch and some of its drawbacks. In general, plastic mulch is an appropriate technology for high value fruit and vegetable crops, though has been effectively introduced into grain crops including corn/maize and upland rice.

Practice

Types of Plastic Mulch

Black films made out of polyethylene are the most commonly used plastic mulch. They come in various sizes, rolling up to 2,500 feet or more in length (Schonbeck, 2012). They are often used in conjunction with drip-irrigation systems, which are installed under the films, in order to provide nutrients to the crop without watering weeds (Schonbeck, 2012). Other types of plastic mulch include clear, translucent and colored, which evidently provide more warmth to soil then black plastic. Both clear and darker films of plastic mulch speed soil warming and early crop growth (Schonbeck, 2012). Black and greyish mulches aid in effectively suppressing weeds. Alternative to the common synthetic plastic mulch is biodegradable plastic mulch. While not yet approved by the national organic program (NOP), plant-startch based biodegradable film has been shown to degrade completely.

The cost of plastic mulch varies depending on the quantity and type. Black plastic mulch can cost between $0.10 and $0.90 per meter (should be m2?) and clear mulch can be between $0.09 and $0.25 per meter (Alibaba 2016). When purchasing the film it is important to consider thickness, which can span between 0.015 to 1.5 mm (??) and each thickness may require varying application methods and equipment (Orzolek & Lamont, 2015).

Using and preparing Plastic Mulch

Before laying mulch, the soil must be in a specific condition. Specifically, the plant beds must be loose and stripped of any organic residue because it may reduce the effectiveness of the mulch. In addition, the soil has to be exceptionally moist. Once the surface is prepared, the mulch can be applied (Serrano, 2015). The application process can be done by using a mechanical layering device for medium to large scale farmers, or else manually for smaller farms. The machine "rolls over the fields laying sheets of plastic mulch over the plant beds" (Serrano, 2015). At this point, if needed the machine can also install drip irrigation. After the mulch has been placed down and sealed, farmers can then use special equipment to create holes and fill then with water and fertilizer; then finally the farmer will plant or transplant the crop in their respective holes (Serrano, 2015). When it is time to harvest, the farmer can use equipment to cut the plastic and pull the harvest out the sides. Depending on the thickness the film can last anywhere between one season to 2 years, with the more thicker mulches being more durable (Orzolek & Lamont, 2015). When the film is at the end of its life cycle it must be disposed of appropriately.

Crop production with plastic mulch

Of the various vegetables, fruits and flowers that are grown using plastic mulch, strawberries are the most extensively grown using this technology. Plastic mulch is used for winter production of strawberries in California, Japan, China, Israel, Egypt and various countries in Europe. By the early 1990s, there were 8000 ha of strawberries in California mulched with plastic (Lamenet, W, 1993). In addition, watermelons and muskmelons are very responsive to mulch, especially in China, where they are grown extensively in all provinces. Other crops include honeydews, cucumber, squash, peppers, eggplants, tomatoes, okra and sweet corn crops (Lamenet, W, 1993). Plastic mulch has proven to increase crop yield for different farm sizes around the world. For instance,

Additionally, the use of plastic mulch is becoming more popular in the production of wheat and maize (corn). Wheat and maize account for 70% of crop production in the world and demand continues to rise (Qin et al 2015). Due to all the benefits above (i.e. reduced evaporation, modified soil temperature, reduced weeds), plastic mulch is a useful technology (Qin et al 2015).

Benefits

Soil temperature

The impact that plastic mulch has on soil temperatures are heavily influenced by the color of the mulch, by regulating the amount of solar radiation absorbed and transferred to the underlying soil. For instance, black plastic mulch interrupts the sunlight so as to warm the soil (Lamenet, 1993). Soil temperatures under black plastic mulch during the daytime are 2.8˚C higher at a 5 cm depth and 1.7˚C higher at a 10 cm depth compared to bare soil (Lamenet, 1993). This warming effects promotes faster growth of crops and earlier harvesting. On the other hand, clear plastic mulch absorbs much less solar radiation, however due to the formation of water droplets, it manages to transmit between 85% - 95% of solar radiation to soil (Lamenet, 1993). Soil temperatures under clear plastic mulch are 4-7˚C higher at a 5 cm depth and 3-5˚C higher at a 10 cm depth compared to bare soil (Lamenet, 1993).

Weed management

Weeds are a problem for many small-scale farmers all around the world. For those who cannot or do not wish to use herbicides, weeding can be very time consuming. Plastic mulch physically suppresses weeds. Opaque plastic mulch reduces light penetration form the soil, and while it provides nourishing benefits for crops under the mulch it also makes it difficult for most weeds under the mulch to survive (Lamenet, 1993).

Reduction of water lost

Farmers have observed other benefits of plastic mulch. For example, farmers in Minqin County in China have remarked that water saving through plastic mulch is the main reason for its use (Ingman et al, 2015). Plastic mulch is a small-scale water conservative measure that can help to mitigate water scarcity. It has been shown to conserve water by significantly reducing the evaporation of soil moisture in the upper layer of the soil (Ingman et al, 2015). A study conducted in Nigeria found that clear polyethylene mulch increased soil moisture content by an average of 40% compared to bare soil for the duration of the growing season (Ingman et al, 2015).

Critical evaluation

While there are many benefits of plastic mulch it still requires significant financial capital and intensive management (Ingman et al, 2015). It must be available locally at a cheap price which may not be the case. As the material is heavy and is shipped as rolls, transportation may be challenging and costly, especially to remote areas. As it is a new technology and practice for many subsistence farmers, the concept of plastic mulching must first be taught to subsistence farmers, otherwise adoption rates may be low. Among plastic mulch's major problems, disposal is problematic. For decades plastics have been disposed routinely by open burning, burial, dumping or burning in landfills, and hence they contribute to unwanted environmental degradation. Biodegradable, photodegradable and paper mulch is an alternative.

Practical Tips plus future readings

Plastic mulch is available globally and can be purchased in many different countries. One online global trader is Alilbaba.com, where farmers can purchase various types of plastic mulch. Prices will depend on the scale of farming. Plastic mulch for medium to large-scale farms is often purchased at Alibab or directly from the supplier. Other websites include Indiamart.com and RobertMarvel.com, which sells biodegradable mulch as an alternative.

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Chapter 7- Weeds

7.1- Kneepads to assist with weeding (revision pending)

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Introduction

It is important that a product is easy to use, inexpensive, durable, and makes everyday life for a subsistence farmer easier. There are countries that have well over 50% of their workforce in agriculture such as, Zambia with 85%, Tanzania with 80%, Nigeria with 70% and Nepal with 69%; that is to just name a few (CIA.) On farms, smallholder women farmers do a lot of the work that requires them to be kneeling for long periods of time both in the home and on the farm (Suthar and Kaushik, 2013).

Background

Kneepads are a useful invention because the average woman farmer has so many uses for them. A woman spends a lot of her time in farming doing tasks like, sowing crops, weeding, harvesting, removing dead weeds from fields, and collecting and spreading manure (Varma, 1992). Not only do they spend all this time taking care of crops and animals but they also have household chores and must take care of their children (Suthar and Kaushik, 2013). Women usually do most of these tasks and the men typically look after animals and go to the towns to do business (Varma, 1992).

Knee, thigh, and lower back pain could possibly be improved with the use of this simple product. The kneepads protect the knees from the hard ground whether it’s in the field or in the home; this in turn helps the legs and back. The user does not have to keep squatting or bending over and putting strain on their back, because they can just kneel and stay kneeling longer. The constant standing would also cause the legs to become very tired and when women are doing this work day after day (Suthar and Kaushik, 2013), they need to be able to do it without pain.

In a study about agricultural worker discomfort, it was found that women usually had a higher percentage of body pain doing agriculture activities, especially when weeding. In another study (Suthar and Kaushik, 2013) that looked at only the women’s side of agriculture, sixty women were surveyed and they were asked about different levels of pain that ranged from very light to very severe in their body parts. The survey specifies the various body parts that pain could arise in. In total, 56.7% of women reported pain in their thighs, which could be cut down immensely by kneepads. They would not have to squat or stand as much, therefore it would reduce the stress put on the thighs. About 81% of women said they had lower back pain, which can be from bending and twisting. The kneepads would help with this problem because the user could kneel instead of stand and bend and rotate their body instead of twisting at the waist (Suthar and Kaushik, 2013).

The same study (Suthar and Kaushik, 2013) examined how many hours these women spend on farming, household chores and animal care, in both peak and off-season. Some numbers that stood out in this study were, during peak season over 60% of these women spend 7-8 hours on agriculture, 3-4 hours on household chores and 2-3 hours on animal care. Women who spend this amount of time doing hard labour need products such as kneepads to make some of their tasks more bearable (Suthar and Kaushik, 2013). Similar studies show parallel outcomes (Vyas, 2012).

Benefits

There are both long-term and short-term effects of the long and hard hours of work that woman put into the farming. In the short-term, extended kneeling and squatting cause general pain in joints and muscles (Suthar and Kaushik, 2013), which they usually work through or have small breaks. When injuries or pain are not given the proper attention that they need that is when long-term problems will arise. Some issues that may occur are, arthritis (inflammation in the joints), meniscus injury (small disc in the knee), and Chondromalacia Patellae (deterioration in part of the knee) (Suthar and Kaushik, 2013). These injuries can make it extremely difficult, if not impossible for someone to keep working. Kneepads have the potential to reduce such chronic injuries, thus improving the productivity and health status of smallholder women farmers. Many women squat during their work on farms, which would mean knee pads would not prove as useful, however if they could change their habit of squatting then they could avoid a lot of pain and injury. They would have to be educated about the benefits of kneeling instead of squatting. In their study, Suthar and Kaushik (2013 show that a lot of women report pain from squatting, in the legs and in the back. The change of kneeing instead of squatting could eradicate some of this pain, by taking the pressure off of the legs and back.

Problems with this product

Although kneepads are potentially very beneficial, there are some issues that could occur. There may be problems with adopting this product: women might be embarrassed to wear them because of the colour or because they are too bulky or attract unwanted glances or comments because this product may be new to a culture. In this situation, farmers may prefer non-attached foam pads that sit on the ground that similarly cost $2 USD. Many women squat rather than kneel in which case the product is not useful. As stated earlier, some women will not want to change traditional habits, like squatting. While marketing this item there would have to be a strong emphasis on teaching women a better, more efficient way of farming. If worn for extended periods of time the kneepads may cause chaffing, they could be too tight or they might pinch the skin. Most kneepads are inexpensive, however that means they may not be durable. Finally, a major challenge will be the availability, accessibility and marketing of the product as it is so new.

Useful links to get started:

https://wholesaler.alibaba.com/product-detail/Professional-kneepads-EVA-foam-paddling-knee_60287518981.html?spm=a2700.7782932.1998701000.47.q8MyRm

https://wholesaler.alibaba.com/product-detail/Color-customize-Polyseter-cap-garden-knee_60072158174.html?spm=a2700.7782932.1998701000.122.q8MyRm

Photos of kneepads

https://www.google.ca/search?q=cheap+knee+pads+for+gardening&biw=1280&bih=597&source=lnms&tbm=isch&sa=X&ved=0ahUKEwiqya_or73QAhWhy4MKHUf6CNsQ_AUIBygC#tbm=isch&q=knee+pads+for+gardening&imgrc=qDV_PCZiBm72BM%3A

https://www.google.ca/search?q=cheap+knee+pads+for+gardening&biw=1280&bih=597&source=lnms&tbm=isch&sa=X&ved=0ahUKEwiqya_or73QAhWhy4MKHUf6CNsQ_AUIBygC#tbm=isch&q=knee+pads+for+gardening&imgrc=1DabbSY3penNhM%3A

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7.2 - Low Cost Weeding Tools for Women

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Background Information:

Women represent about 43% of the agricultural labour force in developing countries as well as globally (FAO, 2011). Today, women account for one third of the total agricultural input in most parts of Asia and Africa (Aggarwal et al., 2003). Furthermore, women carry a disproportionate work burden compared to men (Grassi et al., 2015). For example, in India women work 10 hours more per week compared to their male counterparts on agricultural tasks (Aggarwal et al., 2003). Time surveys show that predominant female activates include weeding and harvesting (FAO, 2011). These two tasks are likely the most time consuming and the most difficult in terms of physical labour compared to all other agricultural tasks. These tasks are very physically straining for women because of their limited access to labour saving technologies (Grassi et al., 2015). In particular, it is estimated that hand weeding consumes 400-600 work hours per hectare per growing season (Raut et al., 2013).

A low cost solution to this problem is to introduce improved weeding tools to women. These tools will allow the task of weeding to be less physically demanding and time consuming compared to the pre-existing indigenous tools that have been used for generations (Langill and Landon, 1998). For many tools available today, women were not involved in the design process even though they are the primary users and have special needs (e.g. low weight and height specific). These improved tools will be specific to the women's desired designs, for increased productivity. The purpose of this chapter is to provide detailed options and information about how this intervention may reach women in developing countries and how they can then use this specialized product and practice to benefit their daily lives.

Description of Practice and Product:

The obscure task of weeding is usually performed manually by bending over and pulling the weed and its roots above the ground (Raut et al., 2013). The posture used while weeding leads to induced back pain for the women involved (Raut et al., 2013). Improved weeding tools are helpful because they allow the women to remain in an upright body position and can be used to remove the weed without the women having to touch the weed or put difficult labour into pulling it out (IFAD, 1998). There are several types of tools that are available for different purposes and preferences. Please refer to *Table 1* to assess the types of weeders available and what they are best used for.

Table 1: Types of Weeders

Type of Weeder	Description of Tool	Type of Weeds Removed by Tool	Estimated Cost
Cono-weeder	Two spinning cone shaped barrels, with width adjustability and long handle (WASSAN, 2006).	"Weedy rice" in rice paddies (*Rice Knowledge Bank,* 2016.	$14.58 USD (WASSAN, 2006).

Motorized weeder	Motorized push machine, 9-10 horsepower engine, 500-1050mm work width, light weight (Alibaba, 2016).	For intercrop weeding, widely with vegetables plots and on hillside and terraces, removes deep-rooted weeds (Alibaba, 2016).	$150-980 USD (Alibaba, 2016).
Long/short handled weeder	Long handle: 85cm long, weighs 700gm Short handle: 72cm long, weighs 625gm Unbreakable plastic handle and strong hoe at end (Kismat Engineering Works, 2016).	Any type of weed, can also pull deep root weeds one at a time. Short handle is used for more force, in a no-till field with harder soil (Kismat Engineering Works, 2016)	$1.17 USD (Kismat Engineering Works, 2016)
Long handled weed puller	Long handle with claw on end that digs into the ground and pulls weeds at their roots, 39 inches tall with lightweight aluminium shaft (Fiskars, 2016).	Can break hard soils easily, great for removing deep root weeds (Fiskars, 2016).	$39.99 USD (Fiskars, 2016)
Fork weeder	120cm long fibreglass handle with carbon steal fork head (Alibaba, 2016).	Easily pulls surface weeds (Alibaba, 2016).	$2.00-4.50 USD (Alibaba, 2016).
Wheel hoe	Push wheel with three arrows behind to dig weeds out of the ground (India Mart, 2016)	Removes small weeds on dry land (India Mart, 2016)	$31.07 USD (India Mart, 2016)

The farmer may choose their type of weeding tool according to price, availability, preference and weed type. It is important to realize that the motorized weeder would be the most costly option and may not be of financial reach to all farmers. However the other tools, which are less expensive, will still be of great assistance to women farmers while weed picking. These weeding tools can be purchased from a local vendor or can be made by a local blacksmith.

Weeding Tool Criteria:

There are specific criteria that make a weeding tool effective and efficient for women subsistence farmers. Firstly, it is important that the tools are of low cost. Most subsistence farmers live under the international poverty line, meaning that most farmers make less than $1.90 USD per day (The World Bank, 2015). To ensure that the tools are of low cost, a local blacksmith can be employed, crafting the tool with wood handles to reduce the cost of the tool. Secondly, it is important that vendors have versatile and appropriate tools available for sale to meet the challenges of different types of weeds (e.g. deep roots versus horizontally spreading; different soil types; different income levels). It is also important that there are different models available that cater to different women's heights and tool weight preferences. It is best to employ participation of women both in the design and implementation process. Allowing women to fully participate in the tool crafting process will allow them to feel empowered and in control of the decisions being made on their farm, it provides women with a voice that is often always over-ruled by their husbands (Narayanan, 2003). Lastly, an important characteristic for a weeding tool to have is durability. Since subsistence farmers are very poor and the product will be used a lot, the product must be strong and of good quality to last for a long period of time.

Possible Benefits:

<u>Reduction of Time and Physical Labour:</u>

A study conducted by *Mitchell, 2016* concludes that farmers who use an improved weeding tool experience an average decrease of 6.5 hours of weeding time, which results in an 80% overall decrease in time spent weeding (Mitchell, 2016). The time that is saved by using these tools could be put towards household duties or other agricultural tasks. In addition to the reduction of time, the use of weeding tools will reduce the physical strain that manual weeding causes (IFAD, 1998).

<u>Increase in Crop Production:</u>

The removal of weeds is extremely important for achieving high crop yields (Holm, 1969). Weeds can cause soil degradation, limit nutrients and space and furthermore negatively impact the growth of the desired crop (Kingley and Rudolph, 2009). It is very important to remove weeds early in the growing season because competition between weeds and crop seedlings at this stage forever reduces the yield of the crop (Frick and Johnson, 2012).

With the use of weeding tools, more weeds can be removed in a reduced time frame. Less weeds in the fields results in less nutrient and space competition and overall increased yields (Kingley & Rudolph, 2009). If farmers have access to mechanical weeders, the re-working of weeds back into the soil can also help build up organic matter, this mobilizes micronutrients in the soil to ensure the healthy growth of a plant (WASSAN, 2006).

<u>Increase in Profits:</u>

With an increase in crop yields, subsistence farmers will have an increase in profit from the additional crops they will now able to harvest and sell. Also, with the time they will save using weeding tools, women may have more time to spend on other profit making activities, which will then result in additional profit for her family.

Critical Analysis:

<u>Cost Analysis:</u>

As mentioned in the *Weeding Tool Criteria* section above, it may be difficult for subsistence farmers to purchase the tools because of their low incomes. Farmers, who lack knowledge of the full extent of the tool's benefits, may choose not to spend their money on a tool and fail to see it as a worthy purchase. To get an idea of how much a farmer would have to spend on a weeding tool, a study done by the *Food and Agriculture Organization* notes that a traditional weeding tool made by a local blacksmith would cost between 1.00-4.25 USD and an imported industrial weeder would cost $2.50-8.00USD (FAO, 1998). Furthermore, the motorized weeders would again be a higher price than those previously listed. Refer to *Table 1* to see an estimated break down of prices.

In addition, the traditional weeding tools that are of a lower price range may not be as time efficient as the motorized tools. The motorized tools are expensive and may be outside the budget of a subsistence farmer. Moreover, the farmer may not be able to totally maximize efficiency with a low cost traditional weeder, but it would still bring benefits to them by cutting down time requirements and the amount of physical labour by a noticeable amount.
A major cost will be the size and/or weight of the tool, which will increase transportation, costs, especially to remote areas. A way to reduce costs is to not sell the handle and let farmers create their own from local wood.

Potential Problems:

The main problem of this intervention is the ability of the women to access the weeding tools. In many societies in developing countries, women have low socio-economic statuses and are not often able to make decisions without the approval of their husband (FAO, 1998). This therefore constrains their ability to invest in gender-specific technologies (FAO, 1998).

Another potential problem is the lack of information transmission from seller to buyer. In order for women to use these tools properly, they must be trained on how to use them. The vendor can transmit the information to the women or the **SAK picture book** could be attached to the product with picture examples of how to properly utilize the tool.

Useful Resources:

Images and Videos of Tools:
Wheel Hoe: http://dir.indiamart.com/impcat/wheel-hoe-weeder.html
https://www.youtube.com/watch?v=MUwSmojsUxY

Motorized Weeder: http://www.indiamart.com/sharpgarudafarmequipments/power-weeder.html
https://www.youtube.com/watch?v=HNe5h471td0

Cono-Weeder: http://www.indiamart.com/agrovision/manual-agricultural-weeder.html
https://www.youtube.com/watch?v=q5HohX3TwHY
https://www.youtube.com/watch?v=vIqXa9y4XHY

Long Handled Weeder: http://tierragarden.com/ProductImages/DeWit/31-0806.jpg
http://www.selections.com/media/catalog/product/cache/1/image/485x/9df78eab33525d08d6e5fb8d27136e95/G/F/GFA375.jpg
https://www.youtube.com/watch?v=6ERMmRF9Fqo

Short Handled Weeder: https://gallandt.files.wordpress.com/2012/07/img_0771.jpg?w=300
http://cdn2.bigcommerce.com/n-pktq5q/1we6yb79/templates/__custom/images/prdct-img1.jpg?t=1454504760
https://www.youtube.com/watch?v=blPXjavqPJ8

Long Handled Weed Puller: http://cdn.gadgetsandgizmos.org/wp-content/uploads/2012/05/fiskarsweedpuller-600x450.jpg
https://www.youtube.com/watch?v=cruAPsZJwFQ

Links to Potential Suppliers:
http://www.alibaba.com/Agriculture-Machinery-Equipment_pid100009395?spm=a2700.8190021.199001.27.NJnzZB

http://www.indiamart.com

http://dir.indiamart.com/industry/agro-poultry-dairy.html

Instructional Resources:
http://saknepal.org/resource/sample-images-of-agricultural-tools-machines-supplies/ (Austin Brush, University of Guelph)

Refer to the SAK picture book for picture illustrations of how to use different types of weeding tools:
A Picture Book of Best Practices for Subsistence Farmers: South Asian version

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7.5 - Cover crops suppress weeds (revision pending)

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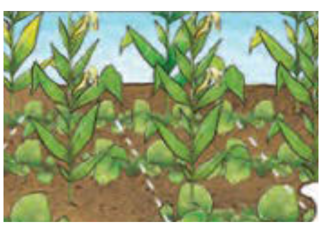
Introduction

Weeds are naturally invasive and aggressive competitors for nutrients, space, light, and water against a main crop (Robacer et al, 2016). As suggested by the FAO (2011), weeding is time consuming and requires strenuous labour which causes drudgery for female subsistence farmers who remove weeds by hand, bending over or crouched. Women spend up to 50% of their time weeding as indicated by statistics from Kenya (Grassi, Landberg & Huyer, 2015). A low cost solution for supressing weeds is to incorporate a cover crop that blankets the soil surface either during the dry season prior to planting or as an intercrop in between rows of staple crops. Cover crops provide an alternative to herbicides while significantly reducing the time and effort spent weeding manually (Robacer et al, 2016). Problems including soil erosion in the wet to dry season transition, poor nitrogen levels, leeching, pest abundance, and lack of animal fodder in the dry season are of concerns to subsistence farmers. Additional benefits of cover crops include soil protection, pest deterrent, nitrogen level maintenance, and supplementary source of animal fodder (FAO, 2015).

Practice Techniques

A variety of cover crop techniques can be applied, however the climate, type of soil, and geographical location vary between practices. One technique is to spread the cover crop by broadcasting (Figure 2). By doing this, the area in between each main plant is covered while reducing labour and time, as they are thrown onto the soil. Broadcasting allows for more soil coverage. Another technique is to plant the cover crop horizontally, in between rows of the main crop (Figure 1). This technique allows better management and visibility of crops, as well as soil protection and coverage while displacing weeds.



(Images adapted from Smith and Raizada, 2016)

Figure 1. Plant In-between rows

Figure 2. Broadcasting

Benefits and Opportunities

In the tropics and sub- tropics, the transition season can cause the soil to cake leaving it vulnerable to run-off potentially leading to nutrient loss and soil erosion. A cover crop can alleviate this problem at the end of the rain season by using residual moisture, however it should also permit trampling. Another benefit is that in the dry season, cover crops can be used as animal fodder. Thierfelder, Cheesman, and Rusianmhodzi[1](2013) suggest that cover crops provide an alternative opposed to using crop residues as animal fodder. A cover crop could provide farmers with sufficient fodder supply for their own livestock, along with a business opportunity to sell the extra supply.

[1] From the Purdue owl APA guide, 'et al' is used after the first time fully citing it with 3-5 authors.

Additionally, if the cover crop is viable for human consumption, profit can be made from selling the raw product or further processing as value is added. Sorghum or pearl millet would be suitable candidates for this business opportunity. Another benefit is that legume cover crops (Table 1) maintain and potentially increase the amount of nitrogen in the soil (Tian, Kolawole, Kang & Kirchhof, 2000). In much of Africa and other sub-tropical areas, nitrogen levels in the soils are limited (Tian et al, 2000). As most legumes are nitrogen fixing, over time these crops can increase the nitrogen levels while providing the family with protein rich meals (Tian et al, 2000). Other benefits include money saved from the use of herbicides, protects the soil against leeching and erosion, and deterrent of pests in some cases.

Costs and Challenges

The challenges of cover cropping are that the practice requires detailed planning and adds labour for planting, maintaining and harvesting the additional crop. Another major challenge and a substantial barrier is the accessibility and expense of additional seed (Thierfelder et al, 2013). While there are many efforts to decrease the cost of seed, such as farmers saving their own seeds for replanting or local seed banks, finding a cover crop variety suitable to the local environment while obtaining healthy seeds are challenges. Another challenge to cover cropping is additional competitors for nutrients, space, light and water in the plot. Root depth is important to consider as a cover crop with the same depth as the main crop would potentially take over (USDA).

Choosing a Cover Crop

Farmers should be encouraged to experiment with different types and combinations of cover crops that is best suited for the land, environment and farmer needs. If soils are particularly lacking nitrogen, legume cover crops would be beneficial (Tian et al, 2000). Legume crops are typically rich in protein, which is valuable in terms of animal and human nutrition while act as good inter-season crops. Grasses and members of the cucurbit family easily spread, providing full soil coverage and permit trampling while often used as an intercrop. Table 1 briefly outlines different potential cover crops, specifically those suitable for dryland farming in arid (semi-desert) and semi-arid (savannah) areas of Africa, Haiti and South Asia. For further insight and examples see FAO's chapter on soil coverage and the USDA page on cover crop choices. More information on seed availability from seedbanks can be found in the "seed sources table for green manure/cover crop" in Restoring the Soil (2012).

Table 1. Characteristics of Common Cover Crops

Legumes	**Climate**	**Uses**	**Other**
jackbean *Canavalia ensiformis*	semi-arid to humid	fodder, human food	immune to most pests
cowpea *Vigna unguiculata*	semi-arid to humid	fodder, human food (protein)	high drought tolerance, intercrop with cereals
pigeon pea *Cajanus cajan*	semi-arid to humid	fodder, firewood, human food (protein)	deep roots, high drought tolerance
lablab *Dolichos lablab*	semi-arid and sub-humid	fodder, human food (protein)	good intercrop, high drought tolerance

mucuna *Mucuna pruriens*	semi-arid and sub-humid	food	spreads, good intercrop, high drought tolerance
Grasses			
sunn hemp *Crotalaria juncea*	semi-arid to humid	fodder, firewood	medium drought tolerance
finger millet *Eleusine coracana*	arid to semi-arid	fodder, human food	rich in amino acids
Other			
pumpkin *Cucurbita spp.*	semi-arid to humid	food	spreads
watermelon *Citrullus lunatus*	semi-arid to sub-humid	food	spreads

(Table adapted from USDA and FAO, n.d)

Labour and Time Requirements

Although cover crops greatly suppress the amount of weeds, they are not fully eliminated and therefore some weeding will still need to take place. More time and labour are required for planting, maintaining, and harvesting the cover crop in addition to the farmer's main crop. However, it is less strenuous labour in comparison to weeding by hand. It is recommended that initial plots are small so if the cover crop is too aggressive or not healthy it does not take out the main crop. However, this does require a longer time investment as a trial and error period. Many tools and resources are available to assist in crop decision making and information on crop characteristics as indicated below.

Helpful Tools

Choosing a Cover Crop:

Cornell University Cover Crop Decision Tool
http://covercrops.cals.cornell.edu/decision-tool.php
FAO Cover Crops Seed Sources and Decision Making
www.fao.org/ag/ca/CA-Publications/Restoring_the_Soil.pdf

Cover Crop Characteristics and Specifics:

Rodale Institute provides cover crop characteristics and mixture suggestions for no-till
http://rodaleinstitute.org/choosing-the-best-cover-crops-for-your-organic-no-till-vegetable-system/
USDA provides an extensive list of cover crops and their characteristics
https://plants.usda.gov/java/coverCrops

Further Readings

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7.6 - Striga weed suppression using Desmodium intercropping

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The Problem: Striga

For over 100 million farmers in Africa, food insecurity and crop failure is sealed by the sudden appearance of a few brightly flowered plants nestled between their cereal crop (Hooper et al., 2010). These flowers while visually attractive are an indicator of a Striga infestation. Striga, an overarching term used to describe a Genus of parasitic weeds, is by far one of the most destructive weeds in Eastern Africa which causes annual economic losses of over 132 million dollars (Woomer and Savala, 2008). The most common variety S. hermonthica can be identified by its bright green stems and leaves and small purple, pink or white flowers, and grows to around 1m in height (CTA, 2007). Striga, as a parasitic weed, needs to exploit a host plant, stealing its nutrients in order to complete its life-cycle. Studies have found it can reduce crop yields well over 50% or in certain cases cause complete crop failure (Khan et al., 2016).

Striga can be difficult to recognize early as it penetrates the crop roots and feeds off a plant for several weeks before any stems appear above ground, and once it has emerged it is quick to produce flowers and seeds. Effected host plants may at first show signs of various nutrient deficiencies, appearing stunted or of below average biomass, ultimately leading to severely reduced grain yield (khan et al., 2016). Corn, sorghum, rice and sugarcane are generally the greatest victims of the weed, though other grains like millets are affected as well (Midega et al., 2010).

Rooting out striga is made more difficult by the nature of its seeds. Striga is a prolific producer of thousands of tiny black seeds, commonly called “black dust” by locals. These seeds germinate in response to root exudates (or signals) from nearby planted cereal crops, but can also persist dormant in the soil for over 15 years (Khan et al., 2016). Therefore, it is no surprise that striga currently infects more than 40% of arable land in Sub-Saharan Africa (Hooper et al., 2010).

The Intervention: Desmodium

Despite the concern of striga’s prevalence in countless cropping systems, there is great potential to eliminating not only the plants themselves, but also their seed bank in the soil through the use of desmodium. Desmodium, is a sprawling, perennial legume variety, indigenous to South America, that can be used as a forage, green manure and cover crop. Therefore, it can be used to add nitrogen to the soil, reduce erosion, and increase the health and milk production of livestock such as goats and cattle. Additionally, it has been observed to not cause bloat when fed to ruminants, even in large quantities (FAO, 2016). However, its arguably most important aspect is its impact on striga. Intercropping desmodium with striga-infested cereal crops, reduces the weed population dramatically. For instance, one study found striga counts were reduced up to 95% (Kifuko-Koech et al., 2012).

This feat can be explained by the release of various phytochemicals by the plant roots into the soil. Some of which cause the dormant striga seeds to germinate followed by others which then inhibit the striga root growth, preventing those seeds from attaching to a host plant and ultimately causing death. (Khan et al., 2008). This suicidal germination offers a proactive solution to the problem, targeting striga seeds before they can fully grow while clearing out the seed bank. Some researchers estimate that by incorporating desmodium into cropping systems one could eliminate striga seed entirely from a field within 6 years (Khan et al., 2008). As a cover crop, it reduces opportunities for other weed varieties to spread through the soil and complete with the main crop as well. It has also been found to repel stem borers which in combination with reduced striga prevalence has shown to increase cereal yields (Midega et al., 2010). Two main species of desmodium are used for intercropping and push-pull systems, D. uncinatum (Silverleaf) and D. intortum (Greenleaf).

Main Desmodium Varieties Analysis

	D. uncinatum	**D. intortum**
Variety	Silverleaf desmodium	Greenleaf desmodium
Rainfall Requirements	>900mm required, shown not to handle alluvial soils with rainfall of 3000mm.	>875mm favours, can handle rainfall up to 3475mm though pest and disease susceptibility increases.
Soil Requirements	Will grow at pH from 5.0-7.0, though 5.5-6.5 is best. Does not tolerate Salinity. Needs more fertile soils than D. intortum.	Grows on wider range of soils than D. uncinatum. Requires pH >5.0 Does not tolerate Salinity.
Flood Tolerance	Fairly tolerant, better than D. intortum.	
Drought Tolerance	Poor	Wilts less readily than D. uncinatum, especially in fertile soils.
Response to Fire	Can recover from moderate fires once well established.	Not advised, but if established taproot can shoot again.
Pests	Aphids, the amnemus weevil, and herbivorous bister beetles.	Aphids, the amnemus weevil, and herbivorous bister beetles.
Toxicity	None recorded.	None recorded.
Diseases	Susceptible to little-leaf disease.	More resistant to little-leaf disease than D. uncinatum.
Altitude Response	Shown to grow from sea level to 2400m in Kenya.	

Field Prep, Planting and Maintenance:
Desmodium can be planted from seed or cuttings. If planted from seed, desmodium will grow best in finely textured soil, enriched with phosphorus fertilizer. However, if fertilizer is too expensive or unavailable mixing the seed a handful of seed with fine sand at a 1:2 ration is recommended (Khan et al., 2005). Around 1 kg of seed is needed for a 0.4 ha field, which should be drilled into 1-2 cm deep furrows between the maize rows, and then gently covered with a small amount of soil (Khan et al., 2005). If desmodium cuttings can be obtained from neighbouring farms or local agricultural extension services, they can be an easier and quicker method to establish desmodium. Provided the cuttings have at least two internodes and adequate soil moisture, desmodium cuttings can be an effective mode of propagation.

Maize and desmodium should be planted at the same time during the first season in alternating parallel rows. Also during the first season (around 4 months) it is recommended that desmodium be left to establish and that no cuttings of the plants foliage be done (Kifuko-Koech et al., 2012). In following seasons, the plants should be cut at the start of every season, again 4 weeks after the cereal crop was planted (to ensure proper crop establishment) and then a third time 18 weeks after planting for optimal striga reduction (though a range between 12-18 is acceptable) (Kifuko-Koech et al., 2012). The process of trimming desmodium is important in preventing it from outcompeting its companion crop.

Challenges:

While Desmodium offers many opportunities for improving the livelihoods of subsistence farmers there remain some challenges in integrating this plant into current agricultural systems. Desmodium has shown to have varying results growing in soils that are either too dry or too acidic (below a pH of 5) (FAO, 2016). Desmodium can also be victim to other pests like the herbivorous bister beetles whom if left to feed on its flowers could negatively affect seed production (Lebesa et al., 2012). These pests are concerning as desmodium is not a prolific seed producer, which while adding value to the sale of its seeds, makes the loss of these potential profits a concern. Initial access to the desmodium seeds can also be a limiting factor as currently they are often not stocked in commercial seed enterprises.

Also, while desmodium has shown to increase the net profits of the farmers that intercrop it, there is a greater initial cost and labour requirement than mono-cropping systems. However, these costs (which include the initial purchase of desmodium seeds, and the labour required for planting and weeding) have been shown to significantly decrease after the first year, as it does not need to be replanted (Kifuko-Koech et al., 2012). Some further maintenance will be required to maintain the desmodium's sprawl, taking cuttings to keep the spread contained, but the plant is not known to spread uncontrollably (rather one must be careful not to overcut or graze upon it). These cuttings can offer new economic prospects as well for farmers who choose to use them for fodder or sell to others for similar purposes. It should also be noted that some studies have found that during the first couple seasons the impacts of desmodium regarding striga suppression, increased yields and financial returns were not always pronounced, though in subsequent seasons they became much more evident and consistent (with striga being reduced by 76% and then 90%) (Kifuko-Koech et al., 2012).

Further Practical Resources and Useful Reading:

1). The CTA Practical Guide Series, No. 2: How to control Striga and stemborer in maize
https://publications.cta.int/media/publications/downloads/1361_PDF.pdf
2). The Striga Technology Extension Project: Long Rains 2008 Report
http://aatf-africa.org/userfiles/Striga2008report.pdf
3). Tropical Seeds LLC
About: A potential source for desmodium seeds, while currently desmodium seeds are not in stock, they hope to have a supply for 2018.
www.tropseeds.com
4). Dr. Samuel T. Ledermann
Project Coordinator and Scientific Advisor for Biovision
About: For more information regarding local organizations, providers or farmer co-ops with a desmodium material supply. Biovision has implemented previous projects focused on integrating desmodium into farming systems in Sub-Saharan Africa in partnership with ICIPE.
Email: s.ledermann@biovision.ch
Tel: +41 44 512 58 58
Website: http://www.biovision.ch/en/projects/sub-saharan-africa/push-pull/

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Chapter 8 – Crop pests and disease

8.1 - Crop rotation with a legume (bean) reduces pests/diseases (revisions pending)

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Introduction:

Pests, pathogens, and weeds are a predominant challenge faced by farmers worldwide. Pathogens and pests can spread via decomposing material (e.g., fungal spores) or the environment (e.g., aphids) and reside in the soil for varying periods of time depending on the species (Corradi & Bonfante, 2012). Pathogens and pests tend to have preferred host plants for reproduction and overwintering. Integrating distantly related species into cropping rotations is a valuable tool for managing the spread and severity of pest and disease infection. This tool is commonly referred to as a 'break crop' in that it acts to break the cycle in the life cycle of the pest or disease. The adoption of crop rotation techniques can help to mitigate yield loss attributed to pest or pathogen infestation. The practice of crop rotation can be defined as the sequential production of different plant species on the same land (Ball et al., 2005). Unlike intercropping which is widely used in subsistence agriculture, crop rotation requires that the land is divided into multiple plots. Each plot would have only one continual crop in a season. For instance, one plot could be a cereal, and the other could be a legume in year one then in year two you would rotate what is grown in each plot. Rotations incorporate a minimum of 2 or 3 different species.

Benefits

Pest and pathogen management is most effective when the crops being rotated are distantly related and are non-host species (Angus et al., 2015). Once a pathogen has entered a field various factors can either enhance or suppress the infection. Environmental conduciveness, host quality, and resistance are all important influences in the success of infection. Planting times can also be adjusted to avoid heavy aphid flights or periods in which certain diseases are known to surge. (Hc Van Bruggen, Gamliel, & Finckh, 2016).

Legumes are commonly used in crop rotation practices and are particularly attractive to small-scale farmers as they can act as a source of food and livestock feed. Legumes also provide benefits such as nitrogen fixation, increased soil organic content, and increased water residue (Angus et al., 2015). Various studies have found that legumes increase the yields of subsequent cereal crops grown in rotation by improving the soil chemical, physical, and biological properties (Marschner, Joergensen, Piepho, & Buerkert, 2004; Rao & Mathuva, 2000). Studies conducted by Angus et al. found that wheat following a legume rotation benefited from increased availability of soil nitrogen, as well as, a break in the life cycle of soil-borne pathogens (2015). Nonhost species incorporated in rotations are sometimes referred to as break crops, which have been found to reduce the incidence and severity of most root and crown diseases in cereal crops as well as foliar disease in wheat (Angus et al., 2015). According to Sanginga, soil depletion is a prominent issue facing many subsistence farmers in West Africa (2003). The ability to maintain soil structure and aggregate stability plays an imperative role in preventing pest and pathogen infestation (Ball, Bingham, Rees, Watson, & Litterick, 2005).

Research conducted by Marschner et al. on subsistence farms in Western Africa found that regular cereal-legume rotations increase cereal yields (2004). The incorporation of groundnut (*Arachis hypogaea* L.) in a rotated cropping system increased the subsequent yields of sorghum (*Sorghum bicolor* L. Moench) or maize (*Zea mays* L.). This is primarily due to higher soil nitrogen (N) released from decomposing legume roots, higher availability and uptake of phosphorus, and increased pH and phosphatase (Marschner et al., 2004; Sanginga, 2003).This study also found that by rotating with legumes allowed for enhanced colonization with arbuscular mycorrhizaa fungi (AMF), leading to a decreased rate of plant-parasitic nematodes in crop roots (Marschner et al., 2004). Arbuscular mycorrhizal fungi (AMF) develops symbiotic relationships with the roots of various plant species providing the plant with increased access to immobile soil nutrients such as phosphorus and carbon (Corradi & Bonfante, 2012). Legumes tend to foster beneficial relationships with both rhizobial bacteria and AMF, to provide them with fixed nitrogen and access to phosphorous (Scheublin, Ridgway, Young, & van der Heijden, 2004).

Plant associations with AMF can reduce the effects of roots pathogens on crop yields, however this outcome is highly dependent on the plant species and the pathogen species in question (Detheridge et al., 2016; Ronsheim, 2016). AMF colonization has been found to be effective in reducing the availability of infection sites on roots, as well as providing various defence mechanisms including root morphology (Ronsheim, 2016). These mechanisms provided by AMF-plant associations can result in reduced crop loss from pathogens and pests. Experiments conducted by Wahbi et al. found that the inclusion of faba bean (*Viscia faba* L.) which are highly dependent on mycorrhizal associations for growth, stimulate greater levels of mycorrhizal fungi colonization and hyphal extension when compared to other crop species (2016).

How to Practice:

Cropping Systems	Practices	Overview	Example Rotations
Sequential Cropping	Single Cropping	Only one crop is grown in a year	e.g. Rice, wheat, maize, or legumes in plane areas; buckwheat or potato in hill/mountainous regions
	Double Cropping	Two crops are harvested in a year from the same land	e.g. Summer rice in July-November followed by Spring rice in April-July or combinations such as rice- wheat or rice-maize in plain area and maize-millet or maize legumes in hills
	Triple Cropping	Three crops are harvested in a year	e.g. Rice-Wheat-Maize

	Ratoon Cropping	The regeneration of crops from their stubs or vegetative planting material	e.g. Sugarcane

Potential Challenges:

Although crop rotation is an effective approach to minimize crop loss due to pests and disease, it is not an ideal practice in all scenarios. For instance crop rotation has limited effect in managing disease development if the pathogen is transmitted over a long distance via wind (Hc Van Bruggen et al., 2016). Some root inhabiting pathogens such as fungal spores can survive in the soil without a host for relatively long periods of time, thus the adoption of crop rotations is ineffective since the absence of a host is not a deterrent (Ball et al., 2005). The practice of crop rotation alone can not minimize the rate pest and pathogen infection, additional measures such as using clean seeds and regularly sanitizing tools are required to reduce transmission (Hc Van Bruggen et al., 2016). Another instance in which crop rotations may be ineffective in preventing damage is where the pest or pathogen has a wide range of hosts. For example, *Fusarium* species such as *F. avenaceum* are a major threat to wheat yields, but due to their expansive range of hosts, require additional soil management in order to avoid crop loss (Hc Van Bruggen et al., 2016). Another challenge of adopting legume crop rotations is finding crops, which are compatible with the existing crop calendars, so not to interfere with the planting and harvesting of staple crops. Some short duration varieties exist which could be successfully implemented in the cropping calendar. For instance, a possible rotation could be short duration chickpea and maize. Chickpea is relatively drought tolerant and would be able to grow using the residual soil moisture left over from the previous maize crop and could be used as a silage or fodder since the grain would not develop in time for harvest. The legume rotation crop should be relatively valuable to encourage farmers to adopt legume rotation practices and subsequent labour and costs required. The cost and availability of legume seeds will also affect the willingness of farmers to adopt legumes into their rotation practices. Subsidizing legume seeds could be a valuable policy in supporting the adoption of legume rotations in the future.

Further Reading

https://imagedatabase.apsnet.org/search.aspx - provides a comprehensive overview of a variety of common pathogens and pests, along with diagnostic images.

http://teca.fao.org/read/8367 - Provides companion planting ideas for various legumes.

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8.4 – Seed selection and water floatation to remove sick seeds before sowing

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Introduction to Careful Seed Selection and Methods

The importance of high seed quality for achieving a productive harvest cannot be overstated, especially over multiple harvest seasons. This paper will discuss what to look for in seed quality as well as describe methods on how to efficiently separate poor quality seeds from high quality seeds. In general, spotted or discoloured seeds mean diseased or unhealthy seeds (Rural Development Academy, 2006). In order to increase the yields of many grain crops globally, simple and low-cost solutions for seed quality control should be considered for farmers in developing countries (CSISA & IRRI, 2014; Mathur, Talukder, Veena, & Mortensen, 2004). The major method this paper will discuss is the Water Floatation Technique, a simple strategy that can be used to rid seed stocks or planting materials of infected or diseased seeds through separation. There are various techniques that can increase crop production by separating diseased seeds from healthy ones, including careful visual inspection of seeds or planting material and manual removal of discoloured or spotted seeds from the stock, hereby referred to as careful seed-selection (Rural Development Academy, 2006). One study in Bangladesh showed that careful seed-selection increased rice germination from 66% to 87%, increased seed quality and yields, and reduced disease and pest infestations in the local soils (Mathur et al., 2004). Similarly, the Water Floatation Technique can rapidly separate healthy, properly coloured seeds with those that are discoloured, malformed, and infected. Water floatation techniques assist in the rapid removal of sick or infected seeds, reducing the workload that is required in careful seed-selection by hand. Many farmers are currently employing water floatation techniques or careful seed inspection techniques but there are more who could benefit from these methods.

Why choosing the best seeds matters

Farmers tend to select the best seeds over time and use them in the following seasons. Sometimes there are contaminated seeds that continue to be missed in the seed stock and unfortunately can be planted in following planting seasons, reducing yields and spreading infection (Mathur et al., 2004). This paper offers techniques to remove the contaminated seeds and maintain a fresh stockpile of healthy seeds for future planting, increasing seed germination and boosting yields over multiple years. In order to be confident in seed quality farmers must buy certified seeds or produce their own good seeds, and they should be constantly selecting for the healthy seeds, removing any infected seeds through water floatation or careful seed-selection (CSISA & IRRI, 2014). If a farmer is using their own seeds, the seeds should be clean and containing no weed seed, soil, or stones (CSISA & IRRI, 2014). Seeds must also be pure (only one variety), and healthy, meaning they are the same color with fully filled grains and free of cracks (CSISA & IRRI, 2014).

Supply of certified seeds is extremely limited in most developing countries, with more than 95% of the seeds used in these countries coming from the informal seed sector, mostly from farmers' own saved grains (Mathur et al., 2004). Yields can be low due to diseased seeds that result in poor germination rates and ultimately sick, unproductive crops (Mathur et al., 2004). A crop management project that started in Bangladesh in 1998 showed that rice seed samples collected from local farmers were infected by bacteria, fungi, or disease and resulted in poor germination rates (Mathur et al., 2004). The seeds that were causing low germination rates were shown to be those seeds that visually looked discoloured or spotted (Mathur et al., 2004). After careful seed-selection and manual removal of these spotted seeds, germination rates of the rice seed increased to rates of 87% on average compared to 66% on average in the original (or unaltered) seed stock samples (Mathur et al., 2004). For a thorough explanation of the methods of this study see Mathur et al. (2004). Mathur et al. (2004) results show that rice seed samples that contained the discoloured or spotted seeds had low germination and poor looking seedlings compared to the carefully selected seeds (see Table 1.0). Discolouration and spots on rice seeds are coloured due to infectious fungi and bacterial infections (Mathur et al., 2004; Singh & Rao, 1977; Rural Development Academy, 2009), and the germination of such infected seeds is diminished. Thus, this paper proposes that simple manual removal of seeds through careful selection or by water flotation techniques will greatly benefit farmers by improving their seed stores and crop health and productivity.

Table 1: Percent germination in soil of seeds from Original Stock (OS), Healthy Sorted Seeds (HSS), and Discoloured or Spotted Seeds (DSS) (adapted from Mather et al., 2004).

Samples (10 samples of 500g of seeds from Tangail district in Bangladesh)	OS (% germination)	HSS (% germination)	DSS (% germination)
	30°C	30°C	30°C
1	67	92	36
2	67	91	45
3	60	90	45
4	62	89	37
5	60	91	38
6	57	89	38
7	60	90	38
8	66	92	35
9	61	92	39
10	61	89	38
Average	62	91	39

Adapted from Mather et al., 2004: *Each sample of seeds was mixed using a Boerner divider, as required to satisfy the International Rules for Seed Testing (Mather et al., 2004). A third of the Original Stock (OS) of each sample (500g of seeds from Tangail district) was kept while the remaining two thirds OS was cleaned by hand. Using a seed spatula and forceps discoloured and spotted seeds (DSS) were removed (Mather et al., 2004). These remaining non-spotted and non-discoloured seeds were put into the category Healthy Sorted Seeds (HSS). Next, sub-samples were taken from these three categories of seeds (OS, HSS, and DSS) and germination rates were tested via the Between Paper method at 25°C and 30°C. (Mather et al., 2004).*

Table 2. Percent seedlings emergence in soil from farmers' original seeds (OS) and from clean, healthy-appearing seeds (CS) and discoloured and spotted seeds (DSS) obtained after manual cleaning of farmers' original samples.

Farmers	Cultivars	Percent emergence					
		OS		CS		DSS	
		30°C	25°C	30°C	25°C	30°C	25°C
T.Aman season (July-December)							
1	BR-25	67	65	92	90	36	35
2	BR-25	67	68	91	91	45	41
3	BR-14	60	59	90	87	45	34
4	BR-14	62	62	89	89	37	36
5	BR-14	60	61	91	91	38	38
6	BR-14	57	58	89	90	38	36
7	BR-11	60	58	90	90	38	37
8	BR-11	66	66	92	91	35	35
9	BR-11	61	60	92	91	39	38
10	BR-11	61	59	89	89	38	37
Average		*62*	*62*	*91*	*90*	*39*	*38*

The recommendations proposed by Mathur et al. (2004) would increase the healthy seedlings of rice per hectare over multiple years, but also resulting in lower contamination of disease organisms in planting soils (Mathur et al., 2004). Over the years there would be less seed and soil-borne infectious organisms in areas that practice careful seed-selection either manually or by water floatation (Mathur et al., 2004). Higher quality grains and increase yields will ultimately generate greater incomes for famers that can only access their own seedlings (Mathur et al., 2004; Rural Development Academy, 2009).

In order to assess and improve the quality of their own seed, farmers can employ the germination test and then employ the water flotation technique to select for the higher quality seeds from the original stock (CSISA & IRRI, 2014). These two methods are briefly outlined as follows:

1. The Germination test (or Between Paper, BP, method): This test involves carefully placing seeds on a wet rag and rolling the rag around a stick laid across the rag for support, while leaving the seeds undisturbed and inside the wet rag (CSISA & IRRI, 2014). After five days, unroll the rags and count the number of seeds with roots (CSISA & IRRI, 2014). The number of sprouted seeds represents the germination rate, with a rate of 70% or less being very unfavorable (CSISA & IRRI, 2014). It is the unhealthy and diseased seeds that will not

germinate, lowering the germination rate of a sample. See CSISA document in the **Reference List** or the paper by Mathur et al. (2004) for more details.

2. Water Floatation Technique: ensure you have quality seeds for planting before soaking your seeds for germination or planting (CSISA & IRRI, 2014). Place seeds for planting into a bucket containing clean water and stir gently. Discard all grains that float to the surface (CSISA & IRRI, 2014). Carefully sort seeds and remove floating seeds, which are infected or deformed seeds, and extract all empty or partially filled grains (CSISA & IRRI, 2014). See the water floatation video in the **Resources Moving Forward Section** or **Reference List** for more details. More extensive credible water flotation information and research follows directly below.

The Water Floatation Technique

The water floatation technique involves separating hollow, diseased, or partially filled seeds from healthy seeds using water or salt water (Rural Development Academy, 2009). As seen in a video by the Rural Development Academy (2009) in collaboration with the International Rice Research Institute, after placing seeds into a bucket of clean water, unfilled or partially filled seeds will float to the surface because they are lighter. Following this separation, remove the floating seeds while keeping those that sunk to the bottom (Rural Development Academy, 2009). Washing with salt water can then refine this seed-selection, as infected partially filled seeds, which are harder to remove via unsalted water floatation, will float in salt water, when enough salt is added that a raw egg will float (Rural Development Academy, 2009). These seeds can then also be removed, resulting in only clean seeds that should be washed with freshwater and then dried before planting (Rural Development Academy, 2009). Rural Development Academy (2009) and CSISA & IRRI (2014) accredit this technique for increasing seed quality and maximizing the speed of selection.

Sivakumar et al. (2007) also showed that seed flotation techniques are not necessarily limited to water flotation, but that petroleum ether flotation techniques also were extremely advantageous in improving seeds germination percentages in certain seeds. They tested the viability of petroleum ether as a separation medium to increase the germination of *Casuarina equisetifolia* Forst seed lots. Petroleum flotation resulted in 90% germination in the sunken fraction and 4% in the floating fraction (Sivakumar et al., 2007). The percentage of seeds discarded as floaters that germinated was remarkably low in this study (Sivakumar et al., 2007). Thus, petroleum flotation appears to be able to increase the germination of *C. equisetifolia* seed lots through flotation and seed-separation, although its efficacy is influenced by variables such as wing surface area and seed density of filled and empty seeds. (Sivakumar et al., 2007). Sivakumar et al. (2007) showed that new techniques, such as the use of petroleum ether for flotation, could enhance seed floatation procedures, given the proper seeds and conditions.

Limitations of Floatation Method

There is a natural degree of seed variation that will be observed while farming, including within the seed morphology (colour, size, and weight), seed germination (viability, germination percent, etc.) and seedling growth parameters (survival percentage, seedling height, seedling biomass, etc.) (Ginwal, Phartyal, Rawat, & Srivastava, 2005). Farmers should understand this natural variability and select the seeds with the desired traits, looking for major discrepancies that indicate a diseased seed from a normal one. Furthermore, germination of seeds can be strongly influenced by genetic control and the heritability of genetic components, which can be exploited to increase germination rates of certain species (Ginwal et al., 2005). As such, farmers should not only look at careful seed-selection and water floatation as the only factor that can influence high germination or crop yields, especially across all grain crops and in all environments. Despite this variability, water floatation and seed-selection are proven techniques.

Another limitation of the water floatation technique is the potential for loss of viable seeds in the discarded fraction, reducing the genetic diversity of seed lots (Sivakumar et al., 2007). However, this can be addressed by carful seed-selection and following the procedures of these flotation techniques. However, floating seeds are proven to have a very low probability (sometime only 4%) to be capable of germination and are generally undesirable or diseased (Sivakumar et al., 2007; Mathur et al., 2004; Singh & Rao, 1977). The advantage of petroleum flotation techniques is the accuracy of the technique. The proportion of germinable seeds discarded as floaters is remarkably low, at 4% (Sivakumar et al., 2007). This is an important advantage, as a high loss of viable seeds in the discarded fraction as floaters may not be economical, and would reduce genetic diversity of the seed lot (Sivakumar et al., 2007).

Resources Moving Forwards and Video Protocols for Removing Discoloured/Spotted Seeds:

Hand Picking and Water Floation Technique Videos:

1. Seed Flotation [TECAxFAO YouTube video]:
https://www.youtube.com/watch?v=e6G8bU9OkqE

2. Spotted Seeds Means Diseased Seeds [IRRI YouTube video]:
http://www.youtube.com/watch?v=0NKVCNyPwuI
IRRI is the International Rice Research Institute. Please see the YouTube Video description to get more information on how to get this video on multiple formats. Other useful videos for subsistence farmers are provided by *TECAxFAO* and *IRRI* on YouTube.

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8.5 - Heat treatment of vegetable seeds

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Introduction to Heat Treatment of Seeds

Physical seed treatment technologies aim to eliminate seed-borne pathogens without the use of pesticides or synthetic active ingredients. Heat treatments of seeds have been widely used due to their broad-spectrum of disease control and ability to give more productive yields when pesticide seed treatments are not possible (Mancini & Romanazzi, 2014). Thus, heat treatment of seeds is a practice that can be used when problems such as low germination and poor pest or pathogen control arise.

Heat treatment is based on the premise that applying controlled heat to seeds, the heat will destroying pathogens or pests. These treatments function by killing pathogens on and within seeds, denaturing their proteins and membranes, while leaving host tissues viable (Mancini & Romanazzi, 2014). There are various methods for the physical heat treatment of seeds, but the most common physical treatments employed today include hot water, hot air (steam), dry air and electron treatments (Mancini & Romanazzi, 2014). The hot water method is the most popular and was used widely to sanitize vegetable and cereal seeds before the rise of synthetic chemical treatments (Gullino & Munkvold, 2014; Mancini & Romanazzi, 2014). This method requires the immersion of plant seeds in hot water for a specific time at a specific temperature, with stirring, and this method is now being used prior to planting for numerous seed varieties (Mancini & Romanazzi, 2014). Cornell University researchers were able to create a table listing different crop types matched with the optimal temperature and time of heat treatment necessary to successfully control the diseases respectively listed with each crop. This table is presented below as Table 1.1.

Table 1.1: Heat Treatment Temperatures, Times, and Diseases Controlled

Crop	Temp (ºC)	Time (min)	Diseases Controlled
Brussels sprouts	50	25	Alternaria leaf spot, bacterial leaf spot, black leg, black rot
Broccoli	50	20	Alternaria leaf spot, bacterial leaf spot, black leg, black rot
Cabbage	50	25	Alternaria leaf spot, bacterial leaf spot, black leg, black rot
Carrot	50	20	Alternaria leaf blight, bacterial leaf blight, cercospora leaf spot, crater rot/foliar blight
Cauliflower	50	20	Alternaria leaf spot, bacterial leaf spot, black leg, black rot
Celeriac	50	30	Bacterial leaf spot, cercospora leaf spot, septoria leaf spot, phoma crown and root rot

Celery	47	30	Bacterial leaf spot, cercospora leaf spot, septoria leaf spot, phoma crown and root rot
Chinese cabbage	50	20	Alternaria leaf spot, bacterial leaf spot, black leg, black rot
Collards	50	20	Alternaria leaf spot, bacterial leaf spot, black leg, black rot
Coriander	52	30	Bacterial leaf spot
Cress	50	15	Alternaria leaf spot, bacterial leaf spot, black leg, black rot
Eggplant	50	25	Anthracnose, early blight, phomopsis, verticillium wilt
Kale	50	20	Alternaria leaf spot, bacterial leaf spot, black leg, black rot
Kohlrabi	50	20	Alternaria leaf spot, bacterial leaf spot, black leg, black rot
Lettuce	47	30	Anthracnose, bacterial leaf spot, lettuce mosaic virus, septoria leaf spot, verticillium wilt
Mint	44	10	Anthracnose, cercospora leaf spot
Mustard	50	15	Alternaria leaf spot, bacterial leaf spot, black leg, black rot
Onion (seeds)	50	20	Purple blotch, stemphylium leaf blight
Onion (sets)	46	60	Botrytis, downy mildew, purple blotch, smut, stemphylium leaf blight
Parsley	50	30	Alternaria leaf blight, cercospora leaf spot
Pepper	51	30	Anthracnose, bacterial leaf spot, cucumber mosaic virus, pepper mild mosaic virus, tobacco mosaic virus, tomato mosaic virus
Radish	50	15	Alternaria leaf spot, bacterial leaf spot, black leg, black rot
Rutabaga	50	20	Alternaria leaf spot, bacterial leaf spot, black leg, black rot
Shallot	46	60	White rot
Spinach	50	25	Anthracnose, cladosporium leaf spot, cucumber mosaic virus, downy mildew, fusarium wilt, stemphylium leaf spot, verticillium wilt
Sweetpotato (roots)	46	65	Scurf, black rot
(Cuttings,	49	10	Scurf, black rot

sprouts)			
Tomato	50	25	Alfalfa mosaic virus, anthracnose, bacterial canker, bacterial speck, bacterial spot, cucumber mosaic virus, early blight, fusarium wilt, leaf mold, septoria leaf spot, tomato mosaic virus, verticillium wilt, double virus streak
Turnip	50	20	Alternaria leaf spot, brown spot, black leg, black rot
Yam (tubers)	44	30	Nematodes

Adapted from: (McGrath, Wyenandt, & Holmstrom, 2017)

Benefits of Heat Treatment of Seeds

Physical heat treatment of seeds provides numerous advantages over other seed treatments: they have a wide spectrum of activity (seen in table 1.0), they leave no toxic or pollutants in the environment, and they do not require registration or approval in most countries (Gullino & Munkvold, 2014). Because these treatments are non-toxic, treated seeds can be used for multiple purposes, including animal feeds (Gullino & Munkvold, 2014). Outlined below are some more advantages:

- Target pathogenic microorganisms, bacteria, fungus, and viruses, in large variety of plants and plant parts (Grondeau, Samson, & Sampson, 1994).
- Main means of producing virus-free explants from infected mother-plants (Grondeau, Samson, & Sampson, 1994).
- Satisfactory control of several bacterial diseases impacting seeds (Grondeau, Samson, & Sampson, 1994; UMA, 2017)
- Disinfects seeds, preventing disease transmission and potential outbreaks (Grondeau, Samson, & Sampson, 1994) and prevention of soil-borne pathogen establishment on the farm (UMA, 2017)
- Hot water treatments are still vital for the treatment of vegetative plant propagation material (Gullino & Munkvold, 2014)
- Significant interest increasing around physical treatments that reduce disease while increasing earliness and percent emergence of crop seeds (Taylor & Harman, 1990).
- Decreased time for seeds to germinate by priming seeds (UMA, 2017)

It is important to emphasize the utility of hot water treatment for treating plant propagation materials. This is used on a commercial scale for the eradication of the causal agent of ratoon stunting disease of sugarcane from seed canes, and the management of nematodes that are transmitted through banana and plantain (Gullino & Munkvold, 2014). There are multiple reviews available for description of the treatment of propagation materials by physical means (Grondeau, Samson, & Sampson, 1994; Gullino & Munkvold, 2014).

A comparison between hot water treatment and hot steam treatment is also warranted. Compared to hot water seed treatment, the key advantages of hot air steam treatment are more accurate temperature control, seeds that require less dying after treatment, and steam often results in reduced insufficiency of seed germination (Gullino & Munkvold, 2014). Dry air treatments have the advantage of being easy to apply and lack high-level equipment (Gullino & Munkvold, 2014). Furthermore, dry air treatments have been shown to inactivate viruses in seeds and vegetative propagation materials (Grondeau, Samson, & Sampson, 1994; Gullino & Munkvold, 2014). However, there are many disadvantages of hot water, hot air, and dry treatments, which are discussed next.

Disadvantages of Heat Treatment of Seeds

The main disadvantages for the physical heat treatment of seeds are as follows: the need for optimization of the treatment (time and temperature) for each new seed-lot (i.e. no uniform treatment for all seeds), possible high energy and investment costs for equipment, and no effects on or prevention of soil-borne pathogens (Gullino & Munkvold, 2014). It is also important to note that many of the non-chemical heat treatments of seeds, such as hot water treatments, are much less effective and/or reliable compared to pesticide seed treatments, which is the primary method for treating seeds globally (Gullino & Munkvold, 2014).

Hot water and hot steam, and dry air treatments has the advantages mentioned in the previous section, but they have disadvantages, which are mentioned here. Hot water treatment disadvantages are mentioned in the preceding paragraph and are not discussed further. Hot steam treatment has been found to be only marginally successful in the prevention of bacterial diseases (Gullino & Munkvold, 2014). Dry treatments can range from a few days to as long as two weeks durations, representing a long time for a fully completed seed treatment (Gullino & Munkvold, 2014). This treatment also leads to reductions in seed germination (Gullino & Munkvold, 2014). Unlike the notable ability for dry heat to inactivate viruses, there are few documented cases of seed-borne bacterial or fungal control by dry heat (Gullino & Munkvold, 2014).

Precautions are necessary when using heat treatments. Phytotoxicity symptoms can occur if the heat treatment is not followed correctly (Paula & Pausas, 2008). If the temperature is too hot, it may kill the seed. Users are advised to perform a simple germination test: treat one batch with heat and the other without heat (control) then sow the seeds and check if the heat treatment caused a decrease in seed germination. If the answer is yes, then the heat treatment was too extreme.

Like any agricultural tool, heat treatments of seeds have many advantages and disadvantage. These tools require frequently require more conclusive evidence and research to be optimized, and the results vary by the plant used, as well as by disease (Martine, 2009). Although the heat treatment of seeds is often a beneficial treatment for various seeds and plants, it should not be seen as a magic bullet to treat every seed or crop impacted by pests and pathogens. If a farmer chooses this cheap and simple treatment over more established treatments that he or she could afford (e.g. pesticide seed treatments), it may be an unnecessarily risk.

Procedures and Tools for Heat Treatment of Seeds

Since many subsistence farmers in countries around the world do not have the means to purchase the most efficient seed treatment techniques and tools, some affordable heat techniques and procedures that might aid them are listed in this section:

1) According to Cornell University researchers (*McGrath, Wyenandt, & Holmstrom, 2017*), a step-by-step process for the heat treatment of seeds is outlined in the following steps:

Procedure:

1. Put weight in seed package (i.e. a coffee filter). A quarter is an ideal weight.
2. Add seed to partly fill container. Do not fill to the point that water will not be able to easily move into the center of the seed mass or that there will be stress on the seems of the coffee filter.
3. Roll top of package over twice to close then staple shut with no gaps that could enable seed to escape.
4. Treat seed at 37°C for 10 min to pre-heat and then at the treatment temperature for the seed type. Then cool with cold water.
5. Promptly either plant or dry seed. Large quantities should be spread out on paper towel to dry.
6. Once dry, put in a new envelope to hold until planting time. Seed should be put in a new envelope rather than returned to the envelope it came in, as this may cause contamination. Store as usual (e.g. refrigerate if planting won't occur for multiple weeks, as this will preserve the seed).

2) Another procedure similar to the one previously mentioned is outlined next. It should be noted that certain treatment procedures might not work for a specific varieties of fruits, vegetables, seeds or grains. Outlined below is a description of a specific for Tomato seeds, developed by a research group at Rutgers University in New Jersey (Guest, 2012). This treatment is useful for crops prone to seed-borne infections, such as pepper and tomato (Guest, 2012).

Procedure:

1. First is to make two baths, which are temperature controlled. The first bath is for the initial pre-heat cycle and the second bath is for the effective temperature cycle. For subsistence farmers, a thermometer would be ideally used for each of these steps to monitor temperature.
2. Place seeds in porous containers (multiple holes cut in), and dip in to the hot bath
3. Turn the temperature of the water up to 37°C, remove container and put in the second hot water bath (which is for pathogen killing)
4. Remove container from second bath and rinse seeds with cold water to stop the heating cycle (also known as seed priming)

One tool, which is essential for measuring the temperate levels of a hot water bath, is a thermometer. Sites such as Aliexpress.com and Alibaba.com can provide subsistence farmers with cost-effective thermometers that will provide a direct reading of the temperature while a farmer is heat-treating seed, enabling the farmer to ensure pathogens are killed without damaging the plant tissue. Tools such as a thermometer can be purchased individually or in bulk, potentially reducing prices for farmers.

Comparison of Heat Treatment of Seeds with Pesticide Seed Treatments

There are many available chemical and non-chemical seed treatments documented (Gullino &

Munkvold, 2014). Physical treatments were shown to be the most effective seed treatment, after chemical treatments, in a study that compared chemical and various non-chemical seed treatments (Mancini & Romanazzi, 2014). This study compared fungicide seed treatments to physical treatments (heat treatments), plant extracts, bacterial control agents, and plant extracts plus bacterial control agents treatments (Mancini & Romanazzi, 2014). Table 2.0 shows the results of the comparison between fungicide treatment efficacy to that of physical treatment efficacy, specifically hot water treatment (Mancini & Romanazzi, 2014).

Table 2: Effectiveness of the Fungicides seeds treatments Versus Physical Heat Treatments of Seeds Against Certain Pathogens

	Fungicides		Physical Treatments	
	Rate	Cases (n)	Rate	Cases (n)
Alternaria dauci *Alternaria radicina*	[a]+++	9	+/+++	3
Alternaria brassicicola *Leptosphaeria maculans*	+++	5	+/+++	5
Fusarium oxysporum f.sp. lycopersici, Alternaria solani	+++	1	/	/
Ascochyta spp.	+++	9	-	3

[a]+++ = effectiveness >80% compared with control; + = effectiveness between 20 and 50%; - = effectiveness <20%. Adapted from: *(Mancini & Romanazzi, 2014).*

Often, no single pest control method provides adequate control of pests and pathogens, and seed treatments can be supplemented with other control measures (Paulsrud et al., 2001). As can be seen form this section, pesticides seed treatments, although highly effective, are not the only method to help control pests and pathogens. Heat treatment of seeds is not the golden standard used by major agricultural industries, but in many countries, heat treatment of seeds is seen as a cheap and easy way to combat pathogens.

Resources Moving Forward

This seller on Aliexpress currently has 200 thermometers, which could be bought at once: https://www.aliexpress.com/item/Underground-Soil-Thermometer-Stainless-Steel-Thermometers-Thermometric-Tool-Gardening-Tools/32648981758.html?spm=2114.01010208.3.1.Qrc5za&ws_ab_test=searchweb0_0,searchweb201602_4_10065_10068_10084_10083_10080_10082_10081_10060_10061_10062_10056_10055_10054_10059_10099_10078_10079_426_10073_10102_10096_10052_10050_425_10051,searchweb201603_8&btsid=8eb0275a-6e1b-4484-b602-333893836620

Here is a link that step-by-step allows farmers/homeowners to properly monitor the temperature levels in their soil:
https://www.todayshomeowner.com/how-to-measure-soil-temperature-for-planting/

Excellent research book of many aspects of seed treatments: Gullino, M. L., & Munkvold, G. (Eds.). (2014). *Global Perspectives on the Health of Seeds and Plant Propagation Material* (Vol. 6). Springer.

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8.6a,b,c - Vinegar, bleach and saltwater treatment of seeds

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Introduction to seed treatment as a preventative measure

Options for reducing seed-borne pathogens in organic agriculture are limited to physical heat treatments and certain organic treatments, as synthetic pesticide protections cannot be used (Van der Wolf, Birnbaum, & Van der Zouwen, 2008). Saltwater and vinegar seed treatments represent organic options, while bleach is an synthetic compound that sterilizes seeds and can subsequently be washed off. Disinfecting seeds prior to sprouting helps prevents the possibility of plant disease epidemics by killing disease-causing organisms living within or on the surface of the seed (Munkvold, 2009). Preventative measures can decrease the probability of contamination in a field and reduce the use of pesticides to control plant epidemics that could have, with hindsight, been controlled through seed treatment.

Seed disinfection can kill seed-borne pathogens, or external pathogens living on the seed surface, while also protecting the seed, depending on the type of seed treatment (Munkvold, 2009; RPD, 1992). In addition to killing plant-pathogens, seed treatments can protect seedlings from common soil-inhabiting fungi that cause seed-rots (Munkvold, 2009; RPD, 1992). Finally, an effective seed treatment can reduce the need for multiple field applications of fungicides or bactericides later in the growing season (Mancini & Romanazzi, 2014). Aggravated use of pesticides is damaging to the local environment, economically costly, and posits a health hazard to farmers using these applications without respirators or advanced safety equipment. Subsistence farmers interested in minimizing pesticide use and improving crop health can use the preventative disinfection measures as outlined in this chapter. Within this encyclopedia, chapters on “Pesticide Seed Applications” provide more information on effective seed treatment technologies.

Solutions for Seed Disinfection: Bleach, Vinegar, & Saltwater

Bleach

Sodium Hypochlorite, or commercial liquid laundry bleach, is a common choice for surface sterilization and it is readily available in many places. It can be diluted to proper concentrations needed for seed disinfestation from its original concentration of 5.25%-5.45% sodium hypochlorite (RPD, 1992). Seeds can be sterilized by immersion in a solution of 1 part bleach (~5.25% sodium hypochlorite) and 3 parts of water, for about two minutes (RPD, 1992), or 0.5% - 1.0% sodium hypochlorite for 10 minutes. This procedure works best when seeds are shaken periodically in the solution and then rinsed with water at least twice (Sauer & Burroughs, 1986). The time period and concentration may have to be adjusted for certain varieties, as optimal sterilization conditions that still allow for good seed germination can be different between seeds (Sweet & Bolton, 1979).

Bleach can be used for protection against fungus, and other clearing solutions have been used against viruses. Bleach soaks can also free seeds from root rot fungus and Fusarium wilt (RPD, 1992). Using a fine mesh or stringing bag, continuously agitate seeds for 40 minutes using 1 pint of liquid household bleach to 8 pints of water, and for each pound of seed treated, use 1 gallon (~3.78 Liters) of solution (RPD, 1992). Finally, use of the alkaline cleaning solid trisodium phosphate in solution can eliminate or reduce transmission of tobacco mosaic virus in pepper and tomato seeds (RPD, 1992).

After treating multiple different species' seeds with multiple different chemical seed treatments, Sweet and Bolton (1979) came to the conclusion that a 0.5% solution of calcium hypochlorite may be the most effective seed-sterilization agent when applied for 10 minutes. Calcium hypochlorite is known as chlorine powder or bleaching powder and is used in many water-treating activities and as a bleaching agent. Sweet and Bolton (1979) found that this solution was the least detrimental to the emerging seedlings while being easily prepared, safely handled, and convenient to store. Following application of bleach, seeds should be thoroughly rinsed with water, with three subsequent washes with water shown to be most effective (Sweet & Bolton, 1979).

Sweet and Bolton (1979) also studied seed germination levels following each treatment and found that greater concentrations than 0.5% solution calcium hypochlorite and longer contact times reduced seed germination and did not improve the decontamination levels (Sweet & Bolton, 1979). They concluded that if seeds cannot be decontaminated with hypochlorite, than efforts could be shifted to find more effective seeds rather than a better sterilizer (Sweet & Bolton, 1979).

Vinegar

Since the development of synthetic pesticides, pesticide seed treatments have been used almost exclusively to control seed-borne pathogens (Borgen & Nielsen, 2001). Now, many alternative seed-disinfectants are being sought for heightened cost-effectiveness, accessibility, and to reduce the use of pesticides. One scientific study showed that some key organic acids, such as acetic acid (vinegar), at concentrations of 2.5% or higher reduce seed-associated bacteria (Van der Wolf et al., 2008). The researchers also showed that only organic acid to reduce seed germination at this concentration was propionic acid (Van der Wolf et al., 2008). In another study, researchers conducted trails in fields, disinfecting seeds with acetic acid, and found the treatments reduced common bunt (*Tilletia tritici*) in winter wheat by 91.5-96.2% without negatively effecting the seed germination (Borgen & Nielsen, 2001).

Vinegar is commonly considered to be useful as a sanitizing agent for household cleaning and home gardening due to its acidic nature, with potential for use by farmers who can access vinegar from fermented products. White distilled vinegar is considered as an eco-friendly organic fungicide and herbicide (Mancini, 2012). Thus, vinegar can be carefully applied to seeds in order to sterilize them. One method known for sterilization of seeds or beans is the immersion of dried seeds for 10 to 15 minutes into a bowl consisting of 1 tablespoon of apple cider vinegar to 1 quart of drinkable water (Mancini, 2012). Following immersion, a thorough rinsing of seeds for 5 minutes and subsequent drying prevents permanent seed damage from prolonged vinegar acidity (Mancini, 2012). Placing dry seeds in a netting bag with a tie and label simplifies this process (Mancini, 2012). Use of 1 tablespoon of white distilled vinegar in this process will have the same affect as the apple cider vinegar (Stouffer, 1999).

Sanitizing combinations of white distilled (or apple cider) vinegar with hydrogen peroxide, followed by subsequent washing with water, has also been shown to be an affective method for cleaning fruits and vegetables (Stouffer, 1999). It is considered to be ten times as effective as either solution alone (Stouffer, 1999). Use of clean sprayers filled separately with vinegar and hydrogen peroxide (never mixed) simplifies the cleaning process (Stouffer, 1999). Fruits and vegetables were sprayed first with vinegar, then immediately sprayed with hydrogen peroxide, shortly followed by a water rinse (Stouffer, 1999). The order of the vinegar or hydrogen peroxide application did not matter and neither is toxic in the small amounts remaining on washed products (Stouffer, 1999). Such methods could be applied to seed sterilization as affective bacterial killing agents on the seed surface. Finally, a recipe for preventing cross contamination of gardening tools is soaking tools in a half and half solution of white vinegar (50% vinegar and 50% water), which acts as a fungicide to kill any plant contaminants on these tools over a short time period (Martina, 2015).

Saltwater

Soaking in salt water is an effective disinfectant for seeds and is beneficial in the control of seed-borne fungi. One of the first seed-borne fungus discovered was *Tilletia caries*, which causes a covered smut of wheat, as described by Jethro Tull in 1733 (Kolotelo et al., 2001). Tull found that farmers whose wheat seed had been salvaged from the ocean was free of this smut, and this lead to the conclusion that salt water disinfected the wheat seed through its brining action (Kolotelo et al., 2001).

In high concentrations, salt water can act as an effective antimicrobial (Matsko, 2016). This is due to the cytolysis (cell reputing) of many bacterial cells that occurs due to the highly concentrated salt water. This is characteristic of hypertonic (high solute) solutions, and bacteria that are unable to live in such conditions. A sufficient method to create a salt-water disinfectant consists of the following steps. Add a teaspoon of salt into a clean cup of warm water and mix until all the salt is dissolved in the water (Matsko, 2016). Regular cooking salt will be effective (Matsko, 2016).

No one method may be perfectly effective as a disinfectant for any given seed variety

The most effective preventative measures to control seed-borne diseases are to only plant health seeds in the first place, preventing contamination, and to choose disease-resistant varieties (Borgen, 2004). However, in many situations it is often critical to reduce the degree of pathogen inoculum on seeds in order to prevent the infection of other plants and the spread of disease in fields (Kolotelo et al., 2001). There is a large micro-flora associated with seeds, but their effects on seeds are largely unknown (Kolotelo et al., 2001). Thus, it is safest to disinfect seeds as a reasonable preventative measure.

Attempts to attain seeds that are completely free from active bacteria and fungi usually results in failure because seed disinfectants are either too strong and damage the seed or are too weak to fully treat the seed (Wilson, 1915). Additionally, microbes located within the seeds are not released until germination (Sweet & Bolton, 1979). A more severe treatment will kill bacteria within the seed, but also cause more damage to the embryo (Sweet & Bolton, 1979). Some disinfectants are more effective than others, such as the three simple solutions outlined above. However, it should be recognized that no single surface disinfectant is perfect under every condition and each should be critically considered (Wilson, 1915; Sweet & Bolton, 1979).

Resources Moving Forward

Seed handling guidebook. Although this resource was meant for tree seeds, its outlines and applications are useful for all species' seed treatments. Retrieved from: https://www.for.gov.bc.ca/hti/publications/misc/seed_handling_guidebook_hi.pdf

Natural crop protection applications for fighting pest and pathogens in the tropics: http://www.naturalcropprotection.margraf-verlag.de/overin.htm

Website full of organic treatments for seeds for the control of pests and pathogens in the tropics: http://www.oisat.org/control_methods/other_methods/seed_treatment.html

Research book on pesticide seed treatments: Gullino, M. L., & Munkvold, G. (Eds.). (2014). *Global Perspectives on the Health of Seeds and Plant Propagation Material* (Vol. 6). Springer.

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8.7 - Pesticide seed application

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Introduction to Pesticide Seed Treatment and Alternative Seed Treatments

Seed treatment – the application of insecticides, fungicides and/or other growth-promoting materials to seeds – is a rapidly expanding field for pre-harvest pathogen control, working effectively to kill and reduce pests and pathogens living directly on or within seeds as well as in the soils surrounding a treated seed (Mancini & Romanazzi, 2014; Taylor & Harman, 1990). Fungi and insect pathogens, including seed-borne pathogens, can infect a variety of seeds while also harboring disease and potentially transferring infection to the next seasons' crops (Munkvold, 2009, p.295). There are a variety of seeds vulnerable to many pathogens, including cereals and vegetable seeds, requiring sterilization and protection (Mathre, Johnston, & Grey, 2006; Mancini & Romanazzi, 2014). Pesticide seed treatments have been shown to prevent plant disease epidemics caused by seed-borne infections, while also reducing the amount of pesticides needed to manage disease (Mancini & Romanazzi, 2014). An effective seed treatment requires a relatively small amount of pesticides to treat a seed, and new systemic pesticides will eliminate the need for multiple foliar or field applications of pesticides later in the growing season (Mancini & Romanazzi, 2014; Taylor & Harman, 1990). Seed-borne pathogens are killed before they get into the field, saving money and resources.

Applications of fungicides are almost always effective (Mancini & Romanazzi, 2014). However, they can also have poor effects on their non-target environment as well as contribute to greater pathogen resistance (Mancini & Romanazzi, 2014). Furthermore, aggravated use of pesticides can pose a serious hazard to farmers applying these substances without advanced safety equipment. Although pesticide seed treatment was found to be a substantial solution to reduce overall pesticide use, alterative disease-reducing treatments to pesticide use have also been sought to completely eliminate synthetic pesticide use (Mancini & Romanazzi, 2014).

Although the main goal of this critical review is to point to the effectiveness of pesticide seed treatment, it also directs the reader to consider effective alternative treatments, including physical treatments and bio-pesticides and bio-control agents. These alternatives can be used with pesticide seed treatments or if pesticide seed treatments are not an option. Chapters on "Compost Teas" and "Surface Sterilization of Seeds" within this encyclopedia also provide more information on less-effective but beneficial technologies. Overall, modern pesticide seed treatments are a safe and affordable pest and pathogen preventative measures, leading to increased seedling survival, disease-free plants and higher yields (Taylor & Harman, 1990).

What is Pesticide Seed Treatment?

Pesticide seed treatments are specifically the application of a small amount of chemical agents to seeds in order to provide protection to seeds, at the time of planting and thereafter, against a broad range of pests and pathogens, while also helping with the establishment of healthy crops (Taylor & Harman, 1990). Plant pathogens can reduce the quantity and quality of seeds harvested for future planting seasons, and can also preserved in seed lots if they are seed-borne pathogens, leading to infection and disease in future crops (Mancini & Romanazzi, 2014). Thus, management of plant diseases is important as it directly impacts current yields, disease prevalence, and the quality of seeds that will be used for future yields (Mancini & Romanazzi, 2014).

Synthetic pesticides (fungicides, insecticides, etc.) for foliar use (i.e. pesticide leaf-spray) have some major drawbacks, as they are expensive and are typically not effective against viruses. Often foliar and soil spraying-pesticides are applied manually and in excess in regions with poor knowledge of sustainable pesticide management, posing a threat to human health and the environment. However, pesticide seed applications use less pesticide and can effectively reduce plant disease while also being much more affordable.

Modern pesticide seed application can greatly enhance crop disease-resistance while reducing the harmful effects of aggravated pesticide use on humans and the environment. Fungicides represent a variety of modern pesticide chemicals used to treat seeds. Modern fungicides used today for seed treatment are generally low in toxicity to plant and animal life and are applied in such low doses they have a minimized impact on the environment (Mathre, Johnston, & Grey, 2006). Doses of these modern fungicides can be as low as 1 gram of active ingredient per hectare (0.4 grams/acre), resulting in a cost per hectare that is usually less than $5 per hectare and often lower than $2.50 per hectare, making seed treatment one of the least expensive growing applications on farms (Mathre, Johnston, & Grey, 2006).

The seed and crop protection industries have rapidly expanded both insecticide and fungicide seed applications since the 1990s, while also aiming to reduce the harmful impacts of active ingredients (Munkvold, 2009; Elbert, Haas, Springer, Thielert, & Nauen, 2008). This has led to systemic seed treatments that fight disease during germination, emergence, and plant growth (Munkvold, 2009). While breeding crops for pathogen resistance is key, crop protection products, such as seed treatments, are also needed to address unanticipated agronomic challenges (Munkvold, 2009). Finally, modern seed treatments can be, and is often, more than a single coating of fungicide or insecticide, and can contain several layers of active ingredients, wetting agents, colorants, and bird/wildlife repellents (DeLiberto & Werner, 2016; Munkvold, 2009).

Insecticides Seed Treatment for Fighting Pests and Pathogens

This section outlines various insecticide seed treatments, the diseases they control, the chemicals used, and their systemic/non-systemic effects on preventing insect-related plant disease. Table 1.0 outlines various seed-applied insecticide chemicals that have become widespread in the past two decades, most notably the neonicotinoid chemicals. Insecticide seed treatments only became widespread with the introduction of neonicotinoid active ingredients, starting with imidacloprid in 1991 (Munkvold, 2009; Elbert et al., 2008). Prior to this some insecticides were approved but use was often limited and sometimes dangerous (Munkvold, 2009). Imidacloprid was first used as a seed treatment for maize in 1995 and was replaced by thiamethoxam in 1997 and clothianidin in 2003 (Munkvold, 2009). Since 2000, approximately 90% of the maize planted in the USA has been seed treated with either thiamethoxam or clothianidin (Munkvold, 2009). The increased use of pesticides seed treatment in crops like maize is prevalent, and this trend is occurring for many other crops, such as in sugarbeet in the United Kingdom (Munkvold, 2009). Sugarbeet insecticide seed treatment applications went from 0% in 1993 to 75% in 2002 in the area sown to sugarbeet, corresponding to a

95% drop in overall insecticide use in sugarbeets in the United Kingdom (Munkvold, 2009). This drop occurred because soil-applied insecticides were readily replaced by insecticide seed treatments (Munkvold, 2009). Now the same seed-applied insecticides (thiamethoxam or clothianidin) are also used on canola, soybean, and cottonseeds throughout North America (Munkvold, 2009).

Table 1: Modern Insecticides Approved for use as Seed Treatments (2009)

Active Ingredient	Chemical Family	Product	Manufacturer	Major Crops	Pest/Disease
Acetamiprid	Neonicotinoid		Nippon Soda, Inc.	[b]Many	[b]Systemic protection from sucking and chewing pests (aphids, thyasnoptera and lepidoptera)
Clothianidin	Neonicotinoid	Poncho	Bayer	Maize	[e]Systemic protection from suchking and chewing pests
Diazinon	Organothiophosphate	Various	Various	Numerous	[a]Non-systemic protection from soil-borne insects, such as seedcorn maggot
Imidacloprid	Neonicotinoid	Gaucho	Bayer	Maize, soybean, canola, sorghum	[a]Systemic protection from sucking and chewing pests (aphids, flea beetle, leafhopper and seedcorn maggots). Length of control depends on dosage
Fipronil	Phenylpyrazole	Regent	BASF	Maize, sunflower, cereals, rice, cotton, vegetables	[c]Systemic protection from lepidoptera (moths), orthopterous pests, and coleopterous larvae in soil
Thiamethoxam	Neonicotinoid	Cruiser	Syngenta Crop Protection	Maize, soybean, canola, sorghum	[a]Systemic protection from sucking and chewing pests (thrips, aphids, Hessian fly, flea beetles)
Thiodicarb	Carbamate	Aeris	Bayer	Cotton	[d]Non-systemic protection from *Helicoverpa armigera* (old world bollworm) and some seedling fungal diseases

Adapted from: Munkvold, 2009 and [a]Paulsrud et al., 2001; [a]Paulsrud et al., 2001; [b]Yao et al., 2006; [c]Hainzl & Casida, 1996; [d]Gunning et al., 1996; [e]Nauen et al., 2003

Insecticides seed treatments can be broad spectrum, meaning they are toxic to a variety of insects, or narrow spectrum, meaning they specifically target only a one or a few insect species. Seed-applied insecticides are used to control soil-borne insects, but these compound also have the systemic ability to control above ground leaf (foliar) and stem-feeding insects (Munkvold, 2009). The modern active ingredients mentioned in table 1.0 can provide broad-spectrum, long-lasting control of pests and diseases (Munkvold, 2009; Elbert et al., 2008). Pesticide seed treatments opened the door to more seed applications, going further than simple seed-dressings to include film coating, pelleting or multilayer coating (Elbert et al., 2008). Neonicotinoids are used for seed treatment in cotton, corn, cereals, sugar beet, oilseed rape and other crops to control against a broad range of plant disease from different orders (Coleoptera, Lepidoptera, Diptera, etc.) (Elbert et al., 2008).

Fungicides Seed Treatment for Fighting Pests and Pathogens

As in the previous section, this section outlines various fungicide seed treatments, the diseases controled, the chemicals employed, and the various modes of action of these treatments that prevent fungal-related plant disease. Table 2.0 outlines various seed-applied fungicidal chemicals that have also become widespread in the past two decades, as well as some older chemicals, such as Carboxin, which was introduced in the late1960s. Historically, fungicides were developed using dangerous sulfur, copper and mercury compounds, but the toxicity of these compounds resulted in the banning of these substances for health and environmental reasons (Mancini & Romanazzi, 2014). The use of mercury fungicides continued up until the 1970s, when concerns of their toxicity in humans and animals let to their expiration (Mathre, Johnston, & Grey, 2006). Now fungicide seed treatments protect seedlings from common soil-inhabiting fungi that often cause seed rots and damping-off diseases (Paulsrud et al., 2001).

Table 2: Modern Fungicides Commonly Used as Seed Treatments (2009)

Active Ingredient	Chemical Family	Product	Manufacturer	Major Crops	Pest/Disease	Year
Azoxystrobin	Strobilurin	Dynasty	Syngenta Crop Protection	Maize	[b]**Very broad-spectrum** protective or curative control of fungal pathogens from all four fungal taxonomic groups	2004
Carbendazim	Benz-imidazole	Derosal	BASF; Bayer Crop Science	Maize	[c]**Systemic protection** against range of Ascomycetes and Basidiomycetes spp.; corm and tuber decays; powdery mildews; fusarium wilt	1973
Carboxin	Anilide	Vitavax	Bayer CropScience	Cereals, peanuts	[a]**Systemic protection** against smuts and fair protection from seed rot, damping-off, and seed blights. Not broad-spectrum	1969
Difenoconazole	Triazole	Dividend	Syngenta Crop Protection	Cereals	[a]**Systemic protection** against common bunt and loose smut of wheat	1994
Fludioxonil	Phenyl-pyrazole	Maxim	Syngenta Crop Protection	Maize, canola, sorghum, soybean,	[a]**Non-systemic** protection against seed decay and damping-off fungi (i.e. Aspergillus) as well as seed-borne	1994

				peanuts, rice	wheat scab. Broad-spectrum	
Mefenoxam	Phenyl-amide	Apron XL	Syngenta Crop Protection	Many	[a]**Narrow-spectrum** systemic protection against only Pythium, Phytophthora, and downy mildews	1996
Metalaxyl	Phenyl-amide	Allegi-ance	Bayer CropScience	Many	[c]**Systemic protection** from potato late blight	1977
Prothioconazole	Triazole	Redigo, Lomb-ardor	Bayer CropScience	Cereals	[e]**Broad-spectrum** protection against a range of fungal disease	2007
Triadimenol	Triazole	Baytan	Bayer CropScience	Cotton, cereals	[a]**Systemic protection** from common bunt and loose smut of wheat. Can be formulated with other fungicides to broaden disease control	1981
Trifloxystrobin	Strobilurin	Trilex	Bayer CropScience	Mazie, soybean, cotton, peanuts, rice	[d]**Broad-spectrum** protection against a range of fungal diseases, including blight, mildew, and rust	1999
Triticonazole	Triazole	Charter	BASF	Cereals	[e]**Systemic protection** against a range of fungal disease	1992

Adapted from: Munkvold, 2009 and [a]Paulsrud et al., 2001; [b]Huston, Roberts, & Jewess, 1999; [c]Davidse et al., 1981; [d]Bartlett et al., 2002; [e]Morton & Staub, 2008

Because is environmental and health concerns, there was a need to find strong replacements that were effective and affordable, and Carboxin was the first modern systemic fungicide to act as a replacement *(*Mathre, Johnston, & Grey, 2006*)*. Carboxin was found to prevent loose smut in wheat and barley and to prevent common bunt in wheat (Mathre, Johnston, & Grey, 2006). This is impressive as loose smut pathogen can survive from one season to the next by living inside the seed embryo, so the fungicide had to penetrate into the developing seed and eliminate the pathogen (Mathre, Johnston, & Grey, 2006). Carboxin was effective in this regard (Mathre, Johnston, & Grey, 2006). Now fungicides can control various plant diseases, helping farmers produce grains (Mathre, Johnston, & Grey, 2006). Table 3.0 outlines the modes of action of many of the chemicals listed in table 2.0. Readers are directed to Mathre, Johnston, and Grey’s (2006) review, which outlines many applications of fungicidal seed treatments for fighting a variety of diseases that impact wheat and barley in a useful and concise summary.

Table 3: Modes of Action of Common Seed Treatment Fungicides

Fungicide	Mode of Action
Difenoconazole	Sterol biosynthesis inhibitor
Imazalil	Sterol biosynthesis inhibitor
Tebuconazole	Sterol biosynthesis inhibitor
Triadimenol	Sterol biosynthesis inhibitor
Triticonazole	Sterol biosynthesis inhibitor
Carboxin	Inhibits proper mitochondrial function in cells by disrupting complex II of Succinic dehydrogenase
Metalaxyl	Inhibits RNA synthesis in cells by disrupting incorporation of uridine into RNA
Fludioxonil	Impairs membrane-bound transport processes in cells by inhibiting the accumulation and incorporation of sugar groups into hyphal wall glucans
Thiabendazole	Binds to the protein tubulin, thus arresting nuclear division in cells by interfering with microtubule assembly
Captan	Nonspecific mode of action
Mancozeb	Nonspecific mode of action

Adapted from: (Mathre, Johnston, and Grey, 2006)

Like insecticides, fungicide seed treatments can be broad spectrum or narrow spectrum and there are various types of fungicides, including contact fungicides and systemic fungicides, in which the latter can destroy pathogens living within seed tissue (Mancini & Romanazzi, 2014). Successful seed treatment depends on the pathogen's location within the seed (Mancini & Romanazzi, 2014). Contact fungicides do not stop internal infections and are only effective in preventing fungal spores from growing on the seed surface (Mancini & Romanazzi, 2014). Cytotropic fungicides do penetrate the outer seed layers where some fungal infections can persist (Mancini & Romanazzi, 2014). Finally, other systemic fungicides can penetrate deep into the seed, protecting against early infection from airborne and soil-borne diseases, although these fungicides are more effective later in seed development (Mancini & Romanazzi, 2014). As such, based on the fungicide's purpose and the disease threats, farmers can select the appropriate fungicide for a particular seed treatment.

Protection of Seeds and Seedlings

Without seed treatment, it may be difficult to control for seed-borne or early season pests and diseases (Mancini & Romanazzi, 2014). Alternative treatments would have to be sought, and this could lead to the need for foliar pesticide spraying that is both harmful and expensive. Environmental stresses, including heavy rains, crusted soils, deep planting, cool soil, and very dry soils, led to ideal settings for even weak pathogens to contribute to plant population losses in young plants infected since germination and mal-equipped to survived extended such environmental stressors (Paulsrud et al., 2001).

Non-systemic fungicides or insecticides form a chemical barrier over the surface of the germinating seed preventing pests and pathogens from entering from systemic fungicides or insecticides protect the foliar parts from insects, diseases, and root rot (Paulsrud et al., 2001). Even a delay in infection can reduce plant losses due to stressors while early infection leads to more damage (Paulsrud et al., 2001). Some seed treatments last 10-14 days beyond planting, while other active ingredients can protect seedlings much longer if applied at the highest specified rate and given favorable environmental conditions (Paulsrud et al., 2001). Typically pesticide breakdown is most rapid in warm and moist conditions (Paulsrud et al., 2001). Finally, seed treatments can assist in plant-stand formation when seeds are planted in unfavorable soils or slow to germinate (Paulsrud et al., 2001; Mancini & Romanazzi, 2014).

Specific Types of Seed Treatments

Seed coating includes any process that for the addition of materials to seeds, but pesticide seed treatment itself has many forms, and seed coating can refer to seeds that have been dressed with dry powder, coated, or pelleted (Taylor & Harman, 1990). Seed dressing is when a dry formulation or a wet liquid formulation of this powder is applied to seeds and this method can be applied at the farm level (Taylor & Harman, 1990). However, these materials do not adhere well to the seed surface and active ingredients may be lost, therefore seed dressings are best applied in the form of a slurry (Taylor & Harman, 1990; Sharma, Singh, Sharma, Kumar, & Sharma, 2015). Seed coating is a formulation used with a special binders that enhance adherence of the active ingredient to the seed, increasing the seed size and shape (Taylor & Harman, 1990). Adhesives used for seed coating include methyl cellulose, dextran, gum Arabic, and vegetable oils (Taylor & Harman, 1990). Finally, seed pelleting an advanced seed treatment, changing the seed size and weight with the addition of multiple inert fillers/adhesives that also work to enhance seed growth and protection (Taylor & Harman, 1990). Seed coating and pelleting usually require treatment application machinery and, therefore, can be more expensive (Taylor & Harman, 1990; Paulsrud et al., 2001). Seed coating and pelleting has been reviewed (Taylor & Harman, 1990) and are not discussed further in this chapter.

In order for the safe application of insecticide/fungicide seed treatments, or combinations of active ingredients to seed treatments, ensure the composition of the seed treatment is thoroughly understood. The quality of the final seed treatment will depend on the treatment mixture, processing conditions, the application rate of the formulation, and the equipment available (Paulsrud et al., 2001). Seed treatments can be applied to true seeds (corn, wheat, soybean, all which have a seed coat and embryo conformation) or to vegetative propagation materials (including bulbs, corms, or tubers), such as potato seed pieces (Paulsrud et al., 2001). All pesticide seed treatment active ingredients and additives are applied to the seed stage.

Advantages and Disadvantages of Pesticide Seed Treatment

Seed treatments have many important benefits, as outlined in the above sections, but they also pose some risks that should be considered. As many of the advantages of seed treatment are mentioned above, this section will outline some of the risks and disadvantages to seed treatment to offer a critical approach.

Advantages

Seed treatments are very effective are preventing seed-borne pathogens, such as smut or bunt, by protecting seeds and attacking these pathogens when they are weak during their seed-borne phase (Paulsrud et al., 2001). Seedlings are generally more vulnerable to disease then mature plants, so the timing of seed treatment is optimal (Paulsrud et al., 2001). It should be noted that seed treatments, in protecting against pathogens and insects, can also ensure uniform stand establishment of crops, as is done for maize in many parts of the USA (Paulsrud et al., 2001). Seed treatments can also suppress root rots in some crops (Paulsrud et al., 2001). Finally, as mentioned in previous sections, new systemic seed treatments provide an alternative to traditional broadcast pesticide sprays for early-season foliar diseases (Paulsrud et al., 2001).

Disadvantages

The risks of pesticide seed treatments revolve around human, environment, and food supply exposure to pesticides. Accidental exposure to workers who produce and apply seed treatment poses a constant risk of seed treatments (Paulsrud et al., 2001). Contamination of food supplies via accidental mixing of treated seed with finished foods is also a risk (Paulsrud et al., 2001). Treated seeds are intended for planting and can be harmful if ingested. Accidental poisoning is also a concern for livestock, as treated seed can look like food to animals, and some seed treatments may require grazing restrictions (Paulsrud et al., 2001).

The treated seed itself has a limited active ingredient capacity and duration of protection (Paulsrud et al., 2001). The treatment is limited to how much active ingredient will stick to the seed, which is why seed-coatings can help (Paulsrud et al., 2001). Still, there is a short duration of protection because of the small amount of ingredient applied, the dilution of the chemical as the plant grows, and its natural breakdown (Paulsrud et al., 2001). At high-doses, a few treatments can partially cause plant-toxicity, or phytotoxicity, damaging tender seed tissue and possibly leading to lower germination and stunting, although generally treatment phytotoxicity is low (Paulsrud et al., 2001).

On a macro-level, an increase of chemical inputs in seed treatments can have the negative effects of increased pathogen resistance as well as the spreading of active ingredients to non-target organisms in the environment (Mancini & Romanazzi, 2014). Furthermore, pesticide seed treatments have been shown to significantly impact the plant rhizosphere's (root system) fungal and bacterial communities, although the consequences of these effects must be further studied and taken in context (Nettles et al., 2016). Finally, workers can be exposed to the active ingredients of pesticides when applying seed treatments.

Seed Treatment as Part of Integrated Pest Management

Combining the use of synthetic pesticides and organic or ecological approaches is called Integrated Pest Management (IPM). The goal is IPM is to maximize crop productivity while minimizing the damages caused by pests and pathogens, while also using the practical resources available and minimizing environmental damages. IPM also aims to reduce pesticide residues from entering the food supply chain and environment, encouraging natural methods for pest control (Paulsrud et al., 2001; Elbert et al., 2008). Seed treatment is thus an integral part of IPM (Paulsrud et al., 2001). Pesticide seed treatment can control pests while reducing pesticide use per hectare, operator expose to pesticides, and can fit well into IPM programs (Elbert et al., 2008). Seed treatment can then be used in combination with biological mechanism to further control pests with IPM.

To implement IPM, identify the pests of interest and consider integrated synthetic and biological options needed to effectively manage the pest. This encyclopedia can direct the reader to other biological methods in this chapter outlined below as well as chapters on “Compost Teas” and “Surface Sterilization of Seeds” and that can be blended with the pesticide seed treatments discusses above for IPM. IPM calls for an integration of pesticide seed treatments with alternative methods for pest and pathogen control.

Supplemental Seed Treatment Additives

Seed treatment products often contain a variety of additives to supplement the active ingredient, such as seed treatments with enhanced adhesive coatings in the pelleted form (Elbert et al., 2008; Paulsrud et al., 2001). If important additives are not in the initial seed treatment then they can be added to any pretreatment mixing tank before seed coating (Paulsrud et al., 2001). Be aware of the potential for redundant additives already supplied in the initial formulation in order to conserve resources (Paulsrud et al., 2001). Colorants are also a useful additive, often used to distinguish treated seeds from food grain for animals and to ensure uniformity in treatment coverage on seeds (Paulsrud et al., 2001). A specific colourant, Anthraquinone, has been shown to selectively repel birds from eating seeds treated with it, resulting from a learned avoidance of seeds treated with Anthraquinone by Avian species (DeLiberto & Werner, 2016). Anthraquinone is a common dye and a safe chemical repellent, deterring many wild birds, as well as mammals, from consuming treated seeds (DeLiberto & Werner, 2016).

Summary

In general, insecticide and fungicide seed treatments can eradicate or reduce seed-borne pathogens and are more reliable than the proposed alternative treatments, such as physical treatment, or biological controls (Mancini & Romanazzi, 2014). Despite this, alternative treatments are still often effective and sometime as effective as chemical treatments, especially physical treatments (Mancini & Romanazzi, 2014). Chemical seed treatments with insecticides and fungicides, along with alternative seed treatments, can improve crop stand quality and increase crop yields through protection and disinfection from seed-borne, and later airborne and soil-borne, pathogens (Mancini & Romanazzi, 2014).

Resources Moving Forward

FAO on integrated pest management: http://www.fao.org/agriculture/crops/core-themes/theme/pests/ipm/en/

FAO on chemical controls for seed storage: http://www.fao.org/docrep/t1838e/T1838E1g.htm#Chemical%20control%20techniques

Website on Pesticide Environmental Stewardship: https://pesticidestewardship.org/pollinator-protection/seed-treatment-concerns/

Excellent research book of many aspects of seed treatments: Gullino, M. L., & Munkvold, G. (Eds.). (2014). *Global Perspectives on the Health of Seeds and Plant Propagation Material* (Vol. 6). Springer.

Excellent outline of many pests and pathogens that seed treatments can prevent, as well as the many active ingredients in seed treatments that prevent infections: Paulsrud, B. E., Martin, D., Babadoost, M., Malvick, D., Weinzierl, R., Lindholm, D. C., ... & Maynard, R. (2001). Oregon pesticide applicator training manual. *Seed treatment. University of Illinois Board of Trustees, Urbana*.

Queensland Government Website on Integrated Pest Management: http://ipmguidelinesforgrains.com.au/ipm-information/chemical-control/seed-dressings-treatments/

OMAFRA: http://www.omafra.gov.on.ca/english/crops/insects/ipm.html

USDA: http://www.ipmcenters.org/

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8.8a,b - Manure tea field spraying and seed application

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Compost "Teas" can Prevent Disease

Compost teas - an umbrella term that includes manure teas - are preventative measures: they reduce the possibility of plant infection from occurring. Preventative measures contrast with curative measures, with the latter aiming to address plant diseases as they occur within a field. Although the benefits of preventatives measure are not directly seen, these measures can save money and resources over time. Preventative measures can decrease the probability of pathogenesis in a field, reducing the need for insecticides to control plant epidemics that could have been controlled by preventative treatment in the first place.

Compost tea may reduce the need for multiple field applications of fungicides or bactericides later in the growing season. Aggravated use of pesticides is often damaging to the local environment and poses a health hazard to farmers using these applications without advanced safety equipment. Subsistence farmers interested in conserving crop health can consider compost teas as a safe preventative measure, although these teas are generally considered to be less effective than commercial pesticides.

Compost or Manure "Tea" Mechanism to Reducing Pathogenesis

Compost or manure "teas" - composed of compost, manures, and other organic materials - are organic approaches to reducing pathogens, most notably fungi and bacteria. There are multiple beneficial mechanisms that allow these teas to reduce pathogenesis of crops.

First, compost teas contain a variety of beneficial microbes in the compost or manure that outcompete pathogenic microbes for nutrients secreted by plants in both the roots and leaves (Ingham & Alms, 2003; Scheuerell, 2004). Plant exudates, both from roots and leaves, help grow disease-suppressing bacteria and fungi in the compost tea, fighting off pathogens (Ingham & Alms, 2003; Scheuerell & Mahaffee, 2002). Unfortunately pesticides and inorganic fertilizers can kill the beneficial microbes, leaving plant exudates for the disease causing microbes (Ingham & Alms, 2003).

Second, compost teas contain soluble nutrients that feed beneficial microbes within the teas themselves and also feed the plants after application of the "tea" (Ingham & Alms, 2003; Scheuerell, 2004). High nutrient concentrations promote beneficial microbe growth, plant resiliency, and increase retention of nutrients in the soil around the plants, reducing fertilizer demands (Ingham & Alms, 2003). Because of these mechanisms, compost teas are often sprayed onto the soil or used as a leaf spray (foliar).

Methods of Compost Tea Production and Application

Compost tea is produced by mixing compost (or manure in manure teas) with water and culturing for a defined period (Scheuerell, 2004). There are two major methods for producing these teas: actively aerating (aerated compost tea, ACT) or not (non-aerated compost tea, NCT) (Scheuerell, 2004). Finally, teas are made with or without additives that are intended to increase microbial population densities during production (Scheuerell, 2004). These are a number of other parameters besides the role of aeration that impact compost tea production and their suppressive properties (Scheuerell & Mahaffee, 2002). These include choice of compost feedstock, compost age, water ratio, fermentation time, added nutrients, temperature and pH, and these are outlined in table 1 (Scheuerell & Mahaffee, 2002). Each of these properties influences the suppressive capabilities of compost teas (Scheuerell & Mahaffee, 2002). Simple procedures/recipes can be found on wikihow (http://www.wikihow.com/Make-Manure-Tea).

A variety of parameters to consider for application are dilution ratio, equipment, timing, and rates of application (Scheuerell & Mahaffee, 2002). Application to soils and/or plants can be done with spray equipment and all types of irrigation systems, if useful (Steven J. Scheuerell). The application system determines the need for filtering compost tea and it should be noted that some filters could reduce microbial populations (Scheuerell, 2004). It should be noted that the research reflects that there is no one ideal compost tea and application factor for all host-pathogen systems (Scheuerell & Mahaffee, 2002).

Table 1: Compost tea production and application parameters that influence beneficial microbes or compounds efficacy in the tea.

Fermentation Parameters	**Variables to consider**
Fermentation vessel	Size, model, manufacturer
Compost	Feedstock, age, % moisture, available nutrients, microbial analysis, volume and density used
Water Source	Volume, initial and final temperature
Nutrient additives	Volume, initial and final temperature
Dissolved oxygen	Stirring, agitation, and/or aeration
Fermentation duration	Storage method if not immediately used
Application Parameters	**Variables to consider**
Filtration	Filter mesh size
Dilution ratio	Water source and optimal ratio for field
Adjuvants	Nutrients, UV stabilizers, microorganisms, surfactants
Application equipment	Nozzle and pressure
Application	Rate, time of day, weather, time between applications

Adopted from Scheuerell (2004).

In summary, these are several methods for producing compost or manure teas to choose from, depending on the scale of production and available financial resources for buying brewing equipment or constructing a homemade brewer (ATTRA, 1998). Methods include the Bucket-Bubbler, Tough, and Commercial Tea Brewer Methods (ATTRA, 1998). Two methods, found at ATTRA, are listed here and can be further researched if needed at ATTRA (ATTRA, 1998).

First, the Bucket-Fermentation Method: compost tea is made by immersing a burlap sack filled with compost into a tank with occasional stirring for 7-10 days, resulting in a compost water extract rather than a “brewed” compost tea (ATTRA, 1998). This is a hundreds of years old method for making basic watery compost tea (ATTRA, 1998).

Second, the Commercial Tea Brewers: These brewers contain a compost leachate basket with drainage holes placed in a tank with water and microbial food sources (ATTRA, 1998). A pump also supplies oxygen to aerate the compost tea while brewing in the tank (ATTRA, 1998). Although this method may be too expensive for a subsistence farmer, it may be affordable for a community.

Aerated and Non-aerated Compost Tea

As mentioned, the two major methods for producing compost teas are aerated compost tea (ACT) or non-aerated compost tea (NCT). This parameter is especially important because producing compost tea with or without aeration and nutrient additives was shown to affect total bacterial population counts as well as bacterial metabolically activity (Scheuerell, 2004). The main distinction between NCT and ACT is that NCT uses greater quantities of compost than ACT, usually without separate nutrient additives, and can be produced from several days to several weeks (Scheuerell, 2004). In contrast, ACT is aerated and uses composts, water, and nutrient additives to significantly increase microbial populations over a 12-36 hour period (Scheuerell, 2004). Compost is supplied aeration through technologies such as an aquarium pump (Lanthier & Advising, 2007). The higher oxygen supply stimulates growth of aerobic microbe populations that assist in compost tea disease suppression and nutrient supply, and these microbes may not survive low oxygen conditions (Lanthier & Advising, 2007).

Most research has focused on the plant disease control properties of compost tea, with most studies pointing to the efficacy of NCT as compared to ACT (Scheuerell, 2004). This review paper outlines the number of NCT studies that showed disease suppressive properties compared to ACT studies (Scheuerell & Mahaffee, 2002).

Case Studies

There are multiple examples in the literature to support the claims that both NCT and ACT can be effective in disease suppression (Scheuerell & Mahaffee, 2002; Martin, 2014; Haggag & Saber, 2007; Al-Dahmani, Abbasi, Miller, & Hoitink, 2003). Due to the volume of studies that reflect this, examples are outlined in table 2. Supposedly, like NCT, increasing the populations of both the total and active bacteria in ACT will generally lead to heightened plant disease suppression (Scheuerell, 2004). In one study, NCT used for seed sterilization prevented pea seeds from “damping-off” caused by the microbe *Pythium ultimum* and also helped the plant to grow after germination (Scheuerell & Mahaffee, 2002). Although less research has been conducted on soil-borne disease suppression (as compared to foliar disease suppression) with compost teas, this is an often-practiced technique used by organic farmers (Scheuerell & Mahaffee, 2002).

Table 2: Use of Compost Teas for Soil and Foliar Disease Suppression: Studies with Positive and Negative Results

Disease Suppressed; Pathogen Species	Compost Tea Used; Study Author	Result: Positive (disease suppression) or Negative (ineffective supression)
Late blight of potato, tomato; *Phytopthora infestans*	Horse compost extract; Weltzein (1990)	Positive
Gray mold on beans, strawberries; *Botrytis cinerea*	Cattle compost extract; Weltzein (1990)	Positive
Fusarium wilt; *Fusarium oxysporum*	Bark-compost extract; Kai *et al.*, 1990.	Positive
Apple scab; *Venturia conidia*	Spent mushroom compost extract; Cronin and Andrews (1996)	Positive
Ginseng; *Alternaria panax*	Spent mushroom compost; Yohalem *et al.,* 1994.	Negative
Strawberry; *Botrytis cinerea*	Cattle manure compost; Welke (1999)	Negative
Apple; *Venturia inaequalis*	Spent mushroom compost; Andrews (1993)	Negative
Apple; *Venturia inaequalis*	Cattle manure compost; Andrews (1993)	Negative

*Adapted from: Organic Seed Treatment Notes (*http://www.growseed.org/seedtreatments.html*) and* Scheuerell & Mahaffee, 2002*:*

Critical Analysis and Summary

Use and application of compost teas in practice are rapidly expanding and outpacing the capacity for traditional scientific research to document the effects of these teas (Scheuerell, 2004). As with many biotechnologies, compost teas are not the single solution to complex problems, such as unsustainable farming, and often their efficacy is limited compared to commercial pesticides (Scheuerell, 2004). However, these teas may be integrated into organic farming systems as a carrier of plant nutrients and beneficial microbes to manage diseases, especially when pesticides use is not a possible solution. Subsistence farmers should be informed of how compost teas may impact their production systems (Scheuerell, 2004)

As some microbes in manure teas can be human pathogens, these "teas" must be used with caution. Microbes in compost teas are thought to be the most importance factor assisting in plant disease suppression despite a limited understanding of the microbes that provide this protection (Scheuerell & Mahaffee, 2002). This limit in knowledge, along with a lack of reporting standards, likely contributes to the variability in compost tea research findings (Scheuerell & Mahaffee, 2002).

Resources Moving Forward

ATTRA Sustainable Agriculture link is a quick guide to a variety of compost tea production systems. Retrieved from: https://attra.ncat.org/attra-pub/viewhtml.php?id=125

ATTRA notes on compost teas. Retrieved from: https://attra.ncat.org/attra-pub/summaries/summary.php?pub=125

Notes for compost teas and other pathogen treatments seen here: http://www.growseed.org/seedtreatments.html

Compost Tea: Principles and Prospects For Plant Disease Control: good literature on ACT and NCT with tables. Retrieved from: http://www.tandfonline.com/doi/pdf/10.1080/1065657X.2002.10702095

Outline of compost teas titled: Compost tea and its impact on plant diseases. Retrieved from: http://crophealth.com/wp/wp-content/uploads/2012/04/CropHealthcom-Sustainable-Compost-Tea-and-plant-diseases-2007-BCOrganicGrower-COABC.pdf

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8.10 - Push-pull intercropping to reduce flying insects

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The Problem:

Cereal crops such as maize and sorghum are often targeted by various flying insect species that utilize the leaves to lay their eggs, leaving behind a major pest once the eggs reach the larvae stage of development. The larvae quickly shred through the leaves burrowing into the stems (gaining the name stem borers) resulting in severe yield losses up to 80% and increased danger of lodging (Khan et al., 2008). Use of chemical pesticides is often not an option for subsistence farmers due to the cost, lack of supply and access to appropriate information.

Push-Pull system: How it works

Despite these concerns, the Push-Pull companion cropping system, offers a promising strategy for simultaneously targeting these pests as well as striga weed (Khan et al., 2014). By integrating a repellant companion crop (the push) and an attractive trap companion crop (the pull) the push-pull system can help redirect and terminate the life cycles of both Striga and stem borer populations. The most successful system uses two plant varieties, Desmodium (push plant) and Napier grass (pull plant). The sprawling perennial legume Desmodium has been found to release a leaf volatile repellant to moths and other flying insect species in the air as well as various phytochemicals into the soil that cause the initial germination and then death of Striga seeds (Van den Berg and Van Hamburg, 2015). On the other hand, the fast-growing Napier grass has been observed to be an attractive sink crop, drawing the adult flying insects to lay their eggs on the grass instead of the main cereal crop (Van den Berg and Hamburg, 2015). In addition to this redirection, the eggs, upon reaching the larvae stage and subsequently burrowing into the plant, become trapped and die within the sticky sap produced within the Napier grass stems (Khan et al., 2000). Napier grass has been observed to be effective trap plant for the *Chilo partellus* (Lepidoptera: Crambidae) and *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) insect species. To best utilize these capabilities, the push crop is planted between the main cereal crop and the pull variety bordering the main plot. Studies have found that fields which implemented this cropping method showed 18 times lower Striga and 6 times lower stemborer levels than the control fields (Midega et al., 2015).

Other Benefits:

Aside from combating pests, Desmodium and Napier grass offer other soil, animal and financial benefits. For instance, Desmodium can be used for animal fodder and green manure, with studies linking its consumption to greater milk production in livestock (Khan et al., 2016). Also as a legume it can be used as a cover crop to add nitrogen to the soil while improving soil structure and preventing erosion (FAO, 2016) Napier grass can also be used for forage and is noted for its fast growth and high nutrient content (FAO, 2006; Rambau et al., 2016). It too can be used to prevent soil erosion particularly on hillside farmland (FAO, 2006). Excess cuttings from these varieties can be sold to neighbouring farmers as forage or for further propagation.

Requirements*:

Plant	**Desmodium**	**Napier Grass**
Push-Pull Role	Push	Pull
Main Varieties	*D. uncinatum* (Silverleaf D.) *D. intortum* (Greenleaf D.)	French Cameroon Kakamega I, II & III Banana grass
Rainfall Requirements	>875 mm required, some varieties can tolerate up to 3475 mm through with an increased vulnerability to pests and disease.	>1000 mm required though around 1500 mm is preferable.
Soil Requirements	Grow between range of pH 5.0-7.0, though 5.5-6.5 is best. Does not tolerate salinity.	Grows best in deep, fertile soils. No evidence of salinity tolerance.
Temperature Requirements	Minimum temperature ~15˚C, with ideal growing temperatures ~ 25-30˚C.	Minimum temperature ~ 15˚C, with ideal growing temperatures ~ 25-40˚C.
Flood Tolerance	Somewhat tolerant, but not to be relied on.	It does not tolerate flooding.
Drought Tolerance	Poor, but wilts less readily in fertile soils.	Survives drought well if its deep root system has been adequately established.
Response to Fire	Can recover from moderate fires once well established.	Will produce new growth afterwards.
Pests	Aphids, the amnemus weevil, and herbivorous bister beetles.	No major pests have been recorded as a concern; pests are attracted to the crop but few survive to adulthood.
Toxicity	None recorded.	While the presence of oxalates has been found, no toxicity was experienced.
Diseases	Susceptible to little-leaf disease.	Head smut disease and Napier grass stunt disease are concerns.
Altitude Response	Has been seen to grow from sea level up to 2400 m in Kenya.	Grows from sea-level to 2000 m.

*Source: (FAO, 2017)

Field Prep and Planting:

Proper land preparation is important factor in integrating push-pull system into pre-existing cropping systems. Napier Grass and Desmodium are both perennial companion crops, thus a thorough investment into full land preparation can translate to these varieties thriving for many years. A complete ploughing with subsequent disc-harrowing of the field and then drilling during the seeding stage is recommended (FAO, 2017). For Napier Grass, plant in furrows ~15 cm deep, covering with ~7.5cm of soil to start and adding more in as the plant grows (FAO, 2017). If available, first adding 2 handfuls of manure to the furrows is recommended to improve plant growth. The pull border should be planted at a distance of at least 1 m from the main cereal crop to prevent shading (Khan et al., 2001). Further, it is best to wait 12 weeks after sowing the main cereal crop before planting this boarder crop (FAO, 2006). Napier Grass while available in seed form is most commonly propagated from cuttings, splits or the whole stem. If planting from stem pieces, choose a piece with at least 3 nodes, one of which should remain exposed while the others are covered in soil (FAO, 2017).

Desmodium can be planted from cuttings or seed. Due to the small size of the desmodium seeds it is important that the soil be finely broken up (mixing the soil with finer soil or sand can help this process) before drill planting (CTA, 2007). Utilizing desmodium cuttings with a minimum of 2 internodes can be a quicker and easier mode of establishment provided the soil is sufficiently moist. The desmodium planting material should be placed in a 1-2 cm deep furrow ~30 cm away on either side from the closest cereal row (CTA, 2007; Khan et al., 2008).

Harvesting for Fodder:

As rule of thumb Napier grass is best harvested when it reaches 1 m of height and is a rich green colour (FAO, 2006). Once the grass surpasses this height and reaches maturity the colour will begin to turn first to a pale green and then a yellow-green---a sign that the nutrient content and digestibility is decreasing (FAO, 2006; Rambau et al., 2016). One study in Kenya found that with good weather it tolerated defoliation every 6-8 weeks (FAO, 2006).

Challenges:

While various research and farm trials have shown that the push-pull cropping system can reduce yield losses and create new financial opportunities for farmers, challenges remain in farmers' integration and acceptance of it. Arguably, the initial cost, labour and material requirements are the greatest barriers to uptake. Desmodium and napier grass seeds are not always readable available or feasible for plot requirements. Plant cuttings which are often a quicker and more reliable way to propagate these varieties are also difficult to obtain, especially as proper storage and transport of these materials are generally unavailable (Turano et al., 2016). Much of current push-pull discourse suggests farmers buy them from neighbouring farms, which can be a limiting factor based on the present prevalence of push-pull farm systems. While the number of push-pull systems are increasing, the density of farms have not yet reached a level to ensure a steady supply to interested farmers.

Then, for those able to obtain the needed materials the setup of the push-pull plot can be intimidating as well. The plot requires various spacing, planting and maintenance practices to meet the needs of each variety, thus interested farmers will need to be properly informed and likely assisted in its construction (CGIAR, 2005). However, once properly instructed concerning the push-pull system, some studies have found that local farmers can make effective teachers for other farmers in their region, thus increasing local acceptance of the technology (Amudavi et al., 2009). It should also be noted that the high initial labour and material inputs decrease substantially in the following seasons as the push and pull companion crops are perennials (Khan et al., 2008). After the first year, the main remaining labour requirement is the maintenance of the companion crop lines to prevent undesired spread. Therefore, the first season is largely one of investment as the benefits of the system are not very evident till the second or third cropping season.

Napier grass and Desmodium plants while providing useful services, can be constrained by factors such as disease and nutrient deficiency. Herbivorous beetles are a concern for desmodium production while Napier grass is susceptible to both Head smut and Napier grass stunt disease---all of which have been linked to a significant decrease in yield (Lebesa et al., 2012; Asudi et al., 2015; FAO, 2017). Attention should be paid that napier grass is not planted too close to the main crop as competition for light and nutrients could become a problem (Sekiya et al., 2015). Napier grass does require a fair amount of water and nutrients from the soil which could be difficult to obtain in arid soils (FAO, 2017).

Other Companion Crop Opportunities for Pest Management:

Companion Crop(s)	Pest(s) Effectively Targeted	Reference
Basil (*Ocimum basilicum* L.)	Aphids (Aphis fabae) Hornworm (*Manduca quinquemaculata* (Haworth)) Thrips (*Thysanoptera*)	Beizhou et al. (2011) Parolin et al. (2015)
Basil, Sacred (*Ocimum sanctum* L.)	Cabbage webworm (*Hellula undalis* Fabricius) Flea beetle (*Phyllotrera sinuate*)	Beizhou et al. (2011)
Marigold, African (*Tagetes erecta*)	Green Peach aphid (*Myzus persicae* Sulzer)	Ben Issa et al. (2016)
Marigold, French (*Tagetes patula nana* L.)	Cabbage aphid (*Brevicoryne brassicae* L.) Flea beetles (*Phyllotreta*) Green Peach aphid (*Myzus persicae* Sulzer)	Jankowska et al. 2009 Ben Issa et al. (2016)
Marigold, Pot (*Calendula officinalis* L.)	Cabbage aphid (*Brevicoryne brassicae* L.) Flea beetles (*Phyllotreta*)	Jankowska et al. (2009)
Rosemary (*Rosmarinus officinalis*)	Green Peach aphid (*Myzus persicae* Sulzer)	Ben Issa et al. (2016)
Spider Plant (*Gynandropsis gynandra*) & Coriander (*Coriandrum sativum*)	Flowerbud Thrips (*Megalurothrips sjostedti* Trybom) Western Flower Thrips (*Frankliniella occidentalis* [Pergande])	Waiganjo et al. (2007)
Sudan Grass (*Sorghum sudanensis*)	Stem borers ((*Chilo partellus* (Lepidoptera: Crambidae) and *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae))	Khan et al. (2000)

Future Opportunities for Companion Cropping and Plant Bioinsecticides:

There remains a lot to be understood concerning companion crop interactions in regards to nutrient competition, pest management and yield effects. While current scientific research around physically integrating a diversity of companion plants remains limited, inquiry is increasing around the use of plant extracts or oils as bioinsecticides. Neem, Lemongrass and Rosemary oil are a few of many observed to have significant effects in managing and deterring pests (Kianmatee and Ranamukhaarachchi, 2007; Ben Issa et al., 2016). Thus, improving farmer understanding and access to plant oil extraction technologies could offer a viable solution to pest management and economic opportunity. Another area that companion crop interactions could be explored is in deterrence or trap mechanisms in local indigenous landraces. One study in Kenya found that local spider plant (*Gynandropsis gynandra*) in combination with green mulch and coriander was more effective at reducing Thrip prevalence and damage in snap bean than the conventional pesticide (Waiganjo et al., 2007).

Further Practical Resources and Useful Reading:

1). The CTA Practical Guide Series, No. 2: How to control Striga and stemborer in maize
https://publications.cta.int/media/publications/downloads/1361_PDF.pdf

2). A primer on Planting and Managing 'Push-Pull' Fields for Stemborer and Striga Weed Control in Maize
http://www.push-pull.net/step_step.pdf

3). Companion Planting & Botanical Pesticides: Concepts & Resources
https://attra.ncat.org/attra-pub/viewhtml.php?id=72#2

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8.11 - Replenishing food of wild animals to prevent crop damage

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Introduction

Growing global populations put an increasing pressure on wildlife, and habitat loss is one of the major stresses. Humans and wildlife are now living in closer contact than ever before and human-wildlife conflicts are a major source of strain for both subsistence farmers and animal species. Crop-raiding is a significant problem affecting farmers; animals such as elephants (*Loxodonta africana*), wild boars (*Sus scrofa*), non-human primates, bears (*Ursidae*), and rhinoceroses (*Rhinocerotidae*) can be common culprits of crop-raiding. Not only does this pose a major threat to food sources and income for farmers, but it can also endanger wildlife. Human-elephant conflict is considered one of the top three threats to species survival (Gross et al. 2016).

Wildlife can be a huge cause of financial losses, and their management is not an easy task. The problem of wildlife raids has been found to be exacerbated during the dry season when seasonal food shortages occur (Mwangi et al. 2016). One Kenyan village perceived their poverty was because of crop damage from wildlife. To protect crops, farmers may have little option but to continually guard their livestock and crops. This daytime task often falls on children, who then cannot attend school (Mwangi et al. 2016). Other options used to manage wildlife included poisoning and shooting them.

Solutions for protecting crops from wildlife in non-lethal ways are not universal. There are many ways to dissuade wild animals from damaging crops or killing livestock. Possible solutions may include planting less desirable crops, providing an alternative food source of wildlife, installing barriers or using deterrents.

Planting less desirable crops

One way to prevent wildlife from crop-raiding is to plant crops that are low-conflict or that can be used symbiotically by farmers and animals. Certain crops are very desirable to different species; maize (*Zea mays*) is a very attractive crop to African elephants and wild boars (Gross et al. 2016). A study by Gross et al. (2016) tested alternative crops to see if they would be subjected to the same level of trampling and crop-raiding by elephants that maize was. Crops that contained essential oils (ginger, *Zingiber officinale* and lemongrass, *Cymbopogon citratus*) or had a strong scent (garlic, *Allium sativum* and onions, *Allium cepa*) were used as alternatives. Researchers found that lemongrass and ginger were good quality and harvestable at the end of their growing season. Ginger survived tramping much better than lemongrass did (Include this or no?). The study also found it would be ineffective to intercrop undesirable crops with desirable ones. However, elephants are extremely sensitive to chili peppers (*Capsicum* species) so bordering crops with chili pepper plants may be an exception.

Mentha species have also been shown to be left undamaged by wildlife, as has tobacco (*Nicotiana*) and turmeric (*Curcuma longa*) (Thapa 2010). Wheat (*Triticum* ssp.) and barley (*Hordeum vulgare*) are much less attractive to wild boars than maize (Schley et al. 2008). Tea (*Camellia sinensis*) has also been shown to be unattractive to wildlife, and is an economically important crop globally (Hockings & Sousa 2012).

Methods of grazing and preferences should be considered when selecting alternative crop species. For example, elephants prefer to graze on material growing that is 100-200 centimetres in height (Mwangi et al. 2016). Shorter-growing crops would be less desirable. Tall crops like maize also offer hiding places for wild boars and other wildlife (Schley et al. 2008). Wildlife may feel more vulnerable without cover and be less inclined to crop-raid.

Cashews *(Anacardium occidentalis*) are an example of a cash crop that benefits both humans and wildlife, particularly chimpanzees (*Pan troglodytes verus*). While humans have an economic interest in harvesting the cashew nuts, chimpanzees are primarily interested in the fruit which is unprofitable to humans. Chimpanzees remove the nuts from the fruit as they eat, making harvesting the nuts easier for humans (Hockings & Sousa 2012).

Planting an alternative food source for wildlife

It is important to address why wildlife are trying to access crops and livestock. One possibility is that habitats have become depleted and fragmented, forcing animals to look elsewhere. Another opinion is that crops are nutritionally superior and more favourable than wild food due to their spatial density and foraging ease (Watve et al. 2016).

Replenishing food sources for wildlife may still not be enough to dissuade wildlife from targeting farms since they are a source of high-density nutrition. Supplemental feeding is often used for game species to alter behaviour and locations (Felton et al. 2016). This often leads to increases in population densities and a decreased foraging range (Cooper et al. 2006). A study done on wild boars in Luxembourg found that supplemental feeding did not lead to a decrease in crop damage except in rare circumstances (Schley et al. 2008).

Wild places could be restored to provide natural food sources if they have been depleted, combined with other management practises to dissuade animals from entering farmland. Wildlife corridors are an option to connect fragmented habitat.

Deterrents

Scaring devices and loud noises have also been shown to be very effective deterrents, at least initially. Wildlife can quickly become desensitized to scaring devices like loud noises. (Thapa 2010). Early-warning systems (such as cowbells strung up) can help farmers anticipate the arrival of some wildlife species. Watch towers remain consistently effective and are especially useful when encountering potentially dangerous animals like rhinoceroses and elephants (Thapa 2010).

Dogs have been used successfully for thousands of years as guardian animals. However, in the tropics they are much less effective especially in areas with large predatory mammals (Wong et al. 2015). They also have a low rate of adoption because of some religions believe them to be unclean. However, barking dogs may be a good substitute for human noise-making, allowing farmers to be more productive and children to attend school. The effectiveness of dogs may depend on the offending wildlife species, and the risk of harm they pose to dogs.

Full-strength ammonia has been shown to deter sun bears (*Helarctos malayanus*), so ammonia-soaked fabric placed around crops can help ward off bears when required (Wong et al. 2015). This may also deter other animals who rely on their sense of smell, including elephants.

Barriers

Barriers are used to restrict access to crops in the forms of fences or ditches. Living fences can be cultivated and be very effective at keeping out wildlife. *Ipomoea* species are recommended for keeping out smaller animals, and *Euphorbia* species for larger wildlife, including elephants and rhinoceroses. *Euphorbia* species are covered in thick thorns (Thapa 2010). These species will grow very densely and make it impossible to pass, thus making them a very effective solution. Drawbacks include a long duration to grow the fence, and eventual plant death. These are less effective with burrowing animals such as wild boars.

Interestingly, barbed wire fences were found to be very ineffective with all animal species (Thapa 2010). These can be damaged and destroyed and require maintenance. Electric fences often do not work as well and require constant maintenance. It has been observed that primates often navigate across them, and elephants have been known to knock trees onto them to cross (Mwangi et al. 2016).

Chili fences have been used with good success. These are constructed by applying chili grease (from *Capsicum* spp.) and engine oil on rope fences surrounding the property. A compound in the chili grease causes an unpleasant odour which dissuades animals, like elephants, from entry. One study by Sitati et al. (2006) found that a 1.4 km rope fence prevented elephants from crop raiding for a period of weeks. However, the elephants eventually travelled to the ends of the fence and walked around (Sitati et al. 2006). The same study found that a farm fully fenced with chili ropes was able to deter elephants for at least two years, despite numerous attempts at crop raiding. Chili grease should be applied at least once a week to remain effective.

Trenches can be an effective solution when regularly maintained for smaller wildlife; they are less effective with elephants. When the trenches become filled with leaves and debris, they are not as useful (Sitati et al. 2006)

Critical Analysis

Changing cropping systems may not be a viable long-term solution; after a while, wildlife may grow accustomed to the new crop and begin eating it as well. This was shown in a village where sugarcane cultivation was recommended due to a high conflict with wild boars. After a few years, the boars began to eat the new crop (Thapa 2010). For subsistence farmers, planting alternative crops may not be as practical if markets are not easily accessible to sell them. This would depend on the crop and its usefulness as a staple food crop. Some alternative crops may require irrigation systems which may not be in place in remote villages (Thapa 2010).

Many problems can arise from supplemental feeding of wildlife, including alteration of population genetics or demography of the species (Felton et al. 2017). This can have a ripple effect on the surrounding forest environment. It has found to be an inefficient way of preventing crop-raiding. It can also result in nutritional imbalances in wildlife which can lead to declining health of the local population, and possibly put them at risk (Felton et al. 2017). If food is supplemented to wildlife, the targeted species should be offered food sources that closely resemble their natural diets. This would most likely be most effective when used in conjunction with deterrents.

The use of chili grease may be cost prohibitive for subsistence farmers unless peppers are grown locally. This may present a business opportunity if agronomic conditions are suitable for chili farming. Deterring wildlife may also shift them to neighbouring farms that are unprotected.

Finally, effective defense of cropland may increase the usage of land for agriculture. While this may benefit humans, it reduces natural foraging habitat for wildlife and will eventually exacerbate the issue in the future and create further problems for wildlife. Proper land stewardship is essential.

Resources for NGOs

Chili seeds can be purchased online from Alibaba.com, (**Access online** at: https://www.alibaba.com/showroom/hot-pepper-seeds.html)
Where to get seeds for aromatic herbs and trample-resistant varieties

How to build chili fences: (**Access online** at: http://www.resolv.org/site-BiodiversityWildlifeSolutions/files/2014/12/HEC-Chilli-Fence-Manual-World-Animal-Protection-2015.pdf)

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Chapter 9 - Post harvest

9.2 - Seed drying

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INTRODUCTION:

The Food and Agricultural Organization (FAO) of the United Nations estimates that post-harvest crop losses in sub-Saharan Africa amount to 8% of the total annual cereal yield (Kaminski & Christiaensen, 2014). These foods also provide nourishment to pests including fungi, insects, and rodents which lead to post-harvest losses (Kaminski & Christianensen, 2014). Seed drying is a vital skill for farmers to possess, as seed moisture content and incidence of infestation/disease are positively correlated (Bam et al., 2007). Wet grain leads to fungal molds and is more palatable to pests. The moisture content of the air, also known as the relative humidity, is a combination of the air's temperature and moisture content (FAO, 2016). In order for seeds to lose moisture, they must have a higher moisture content than the air around them, which makes it especially difficult to dry grain in the humid tropics (FAO, 2016). Seed size/porosity and wind speed are also important factors in determining the drying capacity of a grain. The intent behind writing this paper is to provide subsistence farmers with a toolkit to evaluate different seed drying methods according to their specific needs and capacities.

METHODS:

This section will provide a brief overview of different indigenous practices. Indigenous populations have long understood the importance of seed drying for food security (Taruvinga, Mejia, & Alvarez, 2014). Whilst indigenous drying practices can be sufficient in providing some communities with year-round access to grain, population growth and climate change are undermining the viability of these systems within certain contexts (Mrema et al., 2011). Population growth lends itself to land scarcity, which can cause farmers to reduce crop rotations, given their finite resources (Mrema et al, 2011). What results from this reduction in biodiversity is an increased incidence of pests/fungi which often prefer specific host plants (Mrema et al, 2011). Equally important, the increase in average global temperature is conducive to fungi and pests (Taruvinga et al, 2014). Indigenous post-harvest drying methods can be grouped into four categories: field drying, open air drying, semi-open storage drying, and heated air drying (Taruvinga et al, 2014).

With respect to field drying, crops can remain in the field following grain maturation for up to 5 days, as a pre-harvest drying method (Taruvinga et al, 2014). Open air drying often consists of leaving grains on wooden structures where they are directly exposed to the sun and wind (Taruvinga et al, 2014); although, grains are also frequently hung from trees/poles. These methods are often used in very hot/humid environments, as well as with recently-harvested grain (Taruvinga et al, 2014).

The third method, semi-open storage drying, involves the construction of "cribs", which generally consist of a combination of timber, reeds, and bamboo (Taruvinga et al, 2014). The cribs are supported by a foundation of stone or wood with baffles, to protect grain from rodents (Taruvinga et al, 2014); ideally, the crib should be located at least 90 cm from the ground (Taruvinga et al, 2014). The semi-open method is employed to dry both threshed and unthreshed grain (Taruvinga et al, 2014); whilst unthreshed grain is limited in its drying capacity by the protective case which surrounds it, but is better fortified against potential predators (Taruvinga et al, 2014).

A fourth option for drying seeds is by means of heated air from fire (Sutherland & Ghaly, 1982). Whilst fuel may not be abundant, subsistence farmers can overcome this problem by placing grain in close proximity or above the cooking area. The heated air increases the relative air humidity, thus lowering the EMC (Mreme et al, 2011). It is important that heated air-dried seeds are stirred regularly, to avoid damage and/or under-dehydration of seeds (Taruvinga et al, 2014). Only after seeds reach an acceptable moisture content, can they be stored in *bancos* (Taruvinga et al, 2014). This indigenous concept involves crafting a container using mud or woven branches, bamboo, and grass as a method of insulating seeds from EMC (Taruvinga et al, 2014).

PRACTICE:

The optimal drying method and duration of a given grain is contingent on the climatic conditions, as well as the structure of the grain itself (Kozanoglu et al., 2012). It should be noted within the parameters of constant relative humidity that an increase of 10 °C in temperature will cause an approximate 0.5 °C decrease in EMC (Mrema et al, 2011); it has been theorized that this decrease in EMC is the result of increased water pressure within the seed, lending to higher moisture mobility (Barozzo, Mujumdar, & Freire, 2014). Being that grains differ in their EMC at a constant temperature/relative humidity, one cannot adopt a homogenous approach toward grain drying. As Table 1 shows, there is significant variation in EMC between crops when analyzed at 27 °C and 70% relative humidity (FAO, 2016). In fact, the EMC of groundnuts is half that of maize, despite being dried under the same climatic conditions (FAO, 2016). In addition to the discrepancies in drying capacity, seeds also vary in their optimal storage moisture content. Table 2 shows the maximum moisture content recommended by FAO for short and long term storage of different grains. Close examination of this chart shows that there is more variation between crops than between drying durations (Mrema et al, 2011).

Although porosity and seed size do not directly affect the EMC, they do have an impact on the rate of drying; through their effects on surface area and diffusion can catalyze the drying process, or cause a major lag in it, leaving the crops vulnerable to disease/infestation (Kozanoglu et al, 2012). Drying occurs on the grain surface and hence a greater seed surface to volume ratio results in faster drying of grain (Kozanoglu et al, 2012). Due to the large surface area ratio found in smaller cereal grains, the initial rate of drying is must faster than large grain (Kozanoglu et al, 2012). Although the larger grains are at an initial disadvantage, they typically surpass the drying rate of smaller seeds (Kozanoglu et al, 2012). This phenomena can be explained by the relatively high porosity found within larger seeds. Once an adequate amount of moisture has been depleted from seeds, pores catalyze the drying process, as they become conduits for airflow, and in doing so, increase the surface area to which air is exposed (Kozanoglu et al, 2012). Figure 1 shows a simple formula which farmers can use to determine moisture content of their dried grains, using only a scale and calculator. Once informed of their grain's moisture content, a farmer can begin to consider the different factors which influence drying technique and duration.

APPLICATION OF DRYING METHODS:

As crops differ in their chemical compositions, they also differ in their relative vulnerabilities to different threats. Table 3 summarizes the strengths and weaknesses of maize, beans, groundnuts, and rice; all of which are grown in Africa. Maize, for instance, is less likely to require heated-air drying than beans, based on its ability to dry in the field, as well as its superior resistance to insects and pathogens. Good management strategies should also consider the effects of different drying practices on the overall quality of the seed. Over drying and exposure to high temperatures can have an adverse impact on the quality of a seed, as well as its germination rate. Excessive temperatures can lead to an increase in internal air pressure of a seed, and lead to external damage (FAO, 2016). Furthermore, essential proteins, sugars, and glutens can be altered by extreme temperatures, leading to nutrient deficiencies in the seeds (FAO, 2016). The standard safe seed drying temperature for oilseed grains is 43 °C (FAO, 2016); although, Tables 4 and 5 exemplify the drastic variation in heat tolerance of different grains (Sutherland & Ghaly, 1982). Overheating can also affect flavor and color of the products which will reduce their market price (Sutherland & Ghaly, 1982).

External factors that may influence the drying capacity of seeds, as well as their quality, include the cleanliness of seeds as well as the material on which they are dried. One study comparing the effectiveness of corrugated iron, cement, and wooden surfaces in promoting cowpea germination found that wood was superior for preventing pest infestation, and also had the highest rate of germination between the three (Ugwu et al., 1999). It has been suggested that the cleanliness of grain is an important determinant in the drying rate, given that these particles situate themselves within pores, and prevent full aeration (FAO, 2016). Rigorous cleaning should be undertaken in order to prevent this phenomenon, as well as reduce the risk of seed contamination (Kozanoglu et al, 2012). Caution should be taken during the cleaning process, as moisture-depleted seeds are more susceptible to compaction, which can limit porosity (Kozanoglu et al, 2012). Hopefully by now the reader has concluded that seed drying requires a complex management program as it is influenced by multiple factors. Figure 2 compares temperature with germination rate, insect activity, and fungal presence, in order to determine the safe drying temperature for most grain seeds (Mrema et al, 2011).

CRITICAL EVALUATION:

While heated air drying can have a critical impact on poverty reduction, it is important that farmers do not over rely on this method. Farmers may be incentivized to over-use heat drying, because it lends itself to quick drying, and therefore, readily available products to sell at market. While one could debate the finite nature of fuel resources, it can be said that population pressure will continue to increase demand for them, and lead to scarcity (as it already has in countries such as Ghana which suffer from significant deforestation). It is important to utilize other indigenous methods when possible, not only for their eco-benefits, but also to ensure their survival.

EFFECTS OF DRYING ON PROFIT/PRODUCTION;

Different methods of seed drying can affect production through their labor and resource requirements. While in-field seed drying can increase available drying time, it also hinders the ability of farmers to engage in crop rotation, as growing seasons for staple crops are often finite (Taruvinga et al, 2014). Heat-drying seeds can be time consuming, as the temperature must be monitored and seeds must be constantly stirred. Semi-open grain storage can be labor intensive, as cribs must be built to house the grain. It seems reasonable to suggest that there is a positive correlation between initial seed moisture content and required labor inputs in the drying process. That being said, farmers choose to grow lower maintenance crops (in terms of drying) such as maize, rather than focus on growing the components of a balanced diet. Although there are no simple answers in the world of seed drying, one thing is certain: <u>improved access to drying resources is a crucial component in bringing about food security.</u> Seed drying allows farmers to maintain grain reserves throughout the year, which serves a two fold purpose: not only do farmers maintain a buffer against famine, they also receive a higher market value for grain during non-growing seasons.

ADDITIONAL RESOURCES:

https://www.ag.ndsu.edu/graindrying/documents/eb35.pdfhttps://www.ag.ndsu.edu/graindrying/documents/eb35.pdf

http://www.fao.org/3/a-i3769e.pdf\

http://www.fao.org/docrep/015/i2433e/i2433e10.pdf

http://www.fao.org/docrep/T1838E/T1838E00.htmlhttps://www.fao.org/docrep/015/i2433/i/i2433e.pdf

https://www.fao.org/docrep/015/i2433/i/i2433e.pdf

Appendix

Table 1: Equilibrium moisture content (EMC) values at 27°C and 70% relative humidity. Retrieved from http://www.fao.org/docrep/015/i2433e/i2433e.pdf

crop	EMC(%)
maize	13.5
wheat	13.5
sorghum	13.5
millet	16
paddy	15
rice	13
cowpeas	15
peas	15
groundnuts (shelled)	7
copra	7

Table 2: Maximum moisture content of seeds. Retrieved from: https://www.ag.ndsu.edu/graindrying/documents/eb35.pdf

crop	short term storage (< 6 months)	long term storage (> 6 months)
barley	13%	12%
maize	15.5%	13.5%
durum	13.5%	12.5%
edible beans	14%	12%
flaxseed	9%	7%
millet	10%	9%
oats	13%	12%
rye	13%	12%
sorghum	13.5%	13%
soybean	13%	11%
confectionary sunflower	10%	9%
oil sunflower	10%	8%
wheat	13.5%	12.5%

M2 = 100 - [W1 (100 - M1)/W2]
W1 = weight of undried grain (kg)
W2 = weight of dried grain (kg)
M1 = moisture content of undried grain (%)
M2 = moisture content of dried grain (%)

Figure 1: Equation for determining moisture content of dried seeds. Retrieved from: http://www.fao.org/docrep/015/i2433e/i2433e.pdf

Table 3: Recommended drying practices of different crops. Retrieved from:http://www.fao.org/docrep/015/i2433e/i2433e.pdf

Grain	Advantages	Disadvantages	Drying Recommendations
rice		• Cracks occur in grain if drying occurs over prolonged period	• Thresh immediately after harvest, and dry immediately after that
groundnuts		• Susceptibility to mold • Overexposure to the sun can affect kernel quality	• Dry rapidly to stop the development of mold
maize	• Can remain in field post-maturation to promote pre-harvest drying • Can be threshed or not		• Dry unthreshed (to create barrier for disease/pest destruction), and then unthresh and further dry
beans		• Susceptible to insects/pathogens • Over drying can limit capacity to thresh	• Must be dried both pre and post threshing

Table 4: Impact of drying temperature on germination rates of sunflower seeds. Retrieved from:http://www.sciencedirect.com.subzero.lib.uoguelph.ca/science/article/pii/0022474X82900029

Bed temp (°C)	Moisture content (% w.b.)	Germination % (3 days/7 days)		FFA % oleic acid	PV (m-equiv/kg)	Photometric colour C (equation 4) Before heat bleach	After heat bleach
Control	11.6	55 (47–61)	78 (74–80)*	0.75	—	0.25	1.49
30	5.1	67	83	0.68	—	0.38	0.29
40	3.8	64	78	0.71	—	0.50	0.47
50	3.0	42	60	0.77	—	0.47	0.49
60	2.3	61	81	0.63	—	0.26	0.14
65	2.0	50	81	0.60	—	0.50	0.93
70	1.6	0	0	0.62	—	0.66	0.50
80	1.2	0	0	0.65	—	0.31	1.18
Control	14.2	61 (58–63)	68 (66–71)	1.32	6.23	0.84	2.33
30	6.0	62	74	0.96	6.93	0.35	0.64
40	4.5	66	79	0.87	8.45	0.22	1.00
50	3.0	61	69	0.97	8.55	0.52	1.53
60	2.5	61	68	0.84	7.57	0.30	0.73
65	2.1	9	36	0.73	5.82	0.72	0.38
70	1.7	0	0	0.75	6.10	0.19	0.63
80	1.3	0	0	1.42	6.29	0.68	11.26
Control	15.7	71 (68–72)	75 (69–79)	1.75	6.58	0.62	1.21
30	5.9	68	70	1.92	9.10	1.28	0.70
40	4.0	71	80	1.63	9.59	0.18	0.74
50	3.0	64	68	1.64	8.65	0.34	0.69
55	2.6	58	66	1.50	6.64	—	—
60	2.3	57	61	1.66	9.51	0.39	0.93
65	2.0	2	3	1.47	5.27	0.44	1.20
70	1.6	0	0	1.47	7.86	0.44	1.12
80	1.3	0	0	1.72	7.67	0.71	7.98

* The numbers in brackets indicate the range of the 3 control values.

Table 5: impact of drying temperature on germination rate of rapeseeds. Retrieved from: http://www.sciencedirect.com.subzero.lib.uoguelph.ca/science/article/pii/0022474X82900029

Bed temp (°C)	Moisture content (% w.b.)	Germination %			FFA % oleic acid	Photometric colour C (equation 4)	
		3 days	7 days	10 days		Before heat bleach	After heat bleach
Control	12.0	84 (79–91)	89 (86–93)	90 (88–93)†	0.46	5.48	5.09
40	3.7	84	91	91	0.42	3.58	1.00
50	2.9	76	93	93	0.33	3.40	1.10
60	2.1	84	94	94	0.34	4.07	1.00
65	1.9	66*	85*	88*	0.40	3.33	1.85
70	1.5	27*	75*	76*	0.39	2.94	1.73
75	1.2	0	0	0	0.33	3.23	3.69
Control	14.1	84 (80–89)	90 (88–93)	91 (89–93)	0.46	5.22	5.97
40	3.7	92	95	96	0.39	3.29	0.57
50	2.7	82	90	91	0.37	3.69	0.62
60	2.2	79	91	92	0.32	3.23	1.09
65	1.9	72*	84*	85*	0.35	2.75	2.07
70	1.6	10*	29*	34*	0.32	2.46	1.13
Control	16.1	81 (76–88)	91 (89–93)	92 (89–95)	0.49	6.48	7.29
40	4.8	85	90	92	—	—	—
50	3.0	89	94	94	—	—	—
60	2.1	76	91	91	0.32	3.33	0.61
65	1.8	69*	87*	88*	0.32	2.61	0.92
70	1.4	1*	31*	37*	0.28	3.14	1.61

* Weak seedlings.
† The numbers in brackets indicate the range of the 3 control values.

Figure 2: Optimal seed drying conditions. Retrieved from:
https://www.fao.org/docrep/015/i2433e/i2433e.pdf

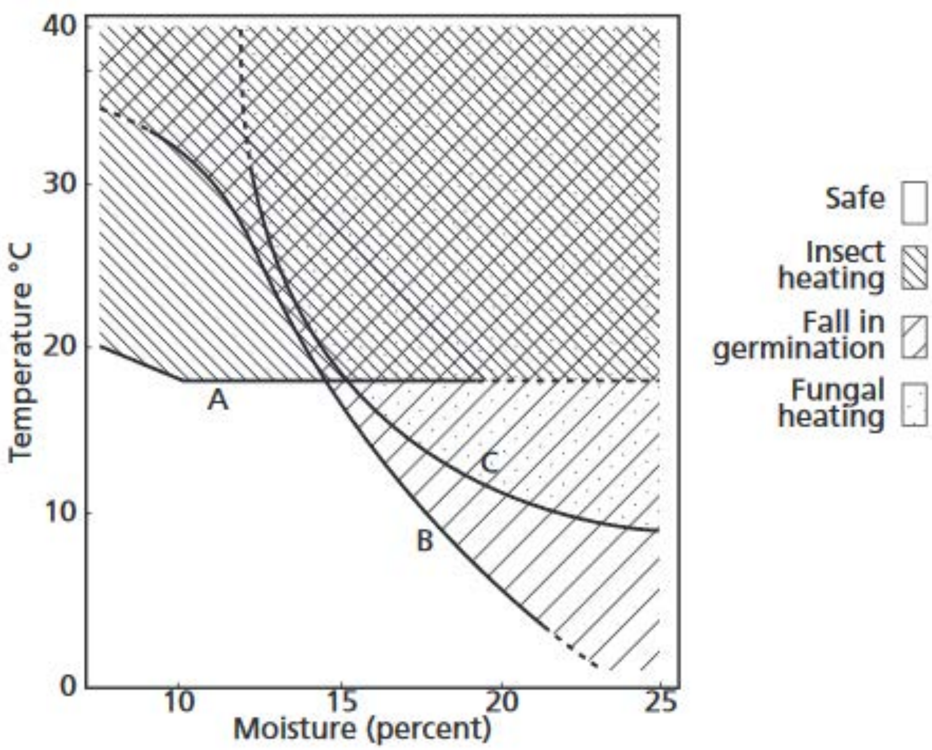

Table 6: “Approximate” allowable storage time (days) for cereal grains. Replicated using information from https://www.ag.ndsu.edu/graindrying/documents/eb35.pdf

Moisture Content (%)	30°	40°	50°	60°	70°	80°
14	*	*	*	*	200	140
15	*	*	*	240	125	70
16	*	*	230	120	70	40
17	*	280	130	75	45	20
18	*	200	90	50	30	15
19	*	140	70	35	20	10
20	*	90	50	25	14	7
22	190	60	30	15	8	3
24	130	40	15	10	6	2
26	90	35	12	8	5	2
28	70	30	10	7	4	2
30	60	25	5	5	3	1

*Approximate storage time exceeds 300 days. The columns are categorized according to storage temperature, and the rows according to moisture content of seeds after drying.
https://www.ag.ndsu.edu/graindrying/documents/eb35.pdf
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9.3 - Neem to combat pests during grain storage and in the field

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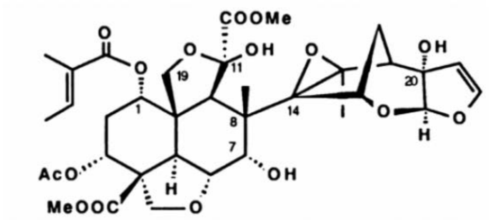
Introduction

Neem (*Azadirachta indica*) is a fast growing, drought tolerant deciduous, evergreen tree of Indo-Malay origin but now widely grown throughout the tropics and subtropics including in Africa (World Agroforestry Centre, 2011). Neem leaves and fruit have been in use since pre-history for a variety of purposes including ethnobotanical, medicinal, cultural and agricultural (Jamir, 1999; Harbant, & Mohamed, 2012). The plant or its extracts can be used as a multi-functional natural pesticide, for example as a seed coating to maintaining food quality during storage (Nisar, 2009), as a spray on field crops (Baidoo, 2012), and even as an adjunct prophylactic (preventative medicine) in aquaculture (Kumar, 2013). Neem can be used as an effect biopesticide in tropical vegetable gardens (e.g. kale and cabbage in Thailand) which often use large amounts of commercial pesticides (Tran 2003). The functionality of neem is due to some 35 active ingredients, among which are anti-feedants, deterrents, growth and reproduction limiting (sterility) compounds. Azadirachtin (Fig.1), a complex terpenoid, is widely considered to be the most active insecticidal ingredient (Schmutterer, 1990). While the seeds have the highest concentration of azadirachtin, the fruit, leaves and bark also contain the compound (Bramachari, 2004).



(A) $C_{35}H_{44}O_{16}$

Figure 1. Azadirachtin (Hummel, 2012)

Use of Neem as a Field Spray

Neem extracts can be used as a bio-pesticide spray for field crops. Bramachari reported that neem has been found to be effective against 413 different species of insects in 16 different insect orders including beetles, caterpillars, aphids, leafhoppers, leaf miners, psyllids, thrips, mealy bugs and whiteflies. Research has shown some efficacy in application to mite species (*V. jacobsoni*) that commonly infest honey bee hives (Melathopoulos et al., 2000). Baidoo (2012) found that neem extract significantly reduced the population of cabbage pests, and increased cabbage weight (*See Critical Analysis).*

Neem is particularly effective at the juvenile insect stage, as it disrupts a common insect hormone ecdysone, preventing moulting. As a result, the larvae remain in an immature stage and die (Bramachari, 2005). Therefore, the extract works best on the second generation of insects and a delayed response in the field is a common observation, and this should be explained to farmers in advance to prevent disappointment (Schmutterer 1990). Similarily, food products which require a high visual quality or do not recover from insect feeding might not be best suited for neem compounds (Schmutterer 1990).

Use of Neem to Prevent Food Storage Losses

The pesticidal property of azadirachtin means an extract of the seed or pulverized seed powder can be applied to jute bags for storage of grain, and can serve doubly as an insect deterrent; alternatively neem leaves are sometimes directly added to grain storage bags (Melathopoulous, 2000, Brahmachari 2004).

Possible Benefits

The neem tree is exceptionally hardy – suitable growing conditions include those that experience >400 mm rainfall, extended drought and poor soil, including saline (salty) soils (Schmutterer 1990). Obara (2004) describes the potential of Kenyan neem trees as a supply of excellent quality carving wood. It is considered highly desirable for this purpose as it is easy to work with has an aesthetically pleasing grain. While this is a benefit on the side of productivity, it should be considered that in areas of limited wood supply, these trees might need protection from poachers (Obara, 2004).

Extract of the neem tree has the potential to reduce reliance on commercial pesticides. Neem extract has the potential to be a low cost, long-term solution that may reverse conventional income flow from farmer to input manufacturer (Tran, 2003). Neem has potential as a small-medium local business enterprise, and the reader is encouraged to read Tran (2003) who has explored this subject. There may be significant market demand for the product in the future given the wealth of research and possible applications of neem compounds, including as a treatment for dengue fever, as a contraceptive and analgesic, and for rheumatism (Bramachari, 2004).

In terms of environmental impact, neem has been reported to disturb aquatic life at lower rates than many synthetic pesticides since it degrades rather quickly (36-48 hrs) following application if exposed to sunlight (Scott, 2003). While aquatic invertebrates were unharmed at full agricultural applicable concentrations of neem, some benthic (bottom feeding) populations were disturbed (Scott, 2003).

Critical Analysis

Tree propagation time: Neem is propagated from seeds (see below). It is estimated that approximately 10 years (minimum) of growth is required for a tree to produce ~10 kg of fruit, of which only a portion is neem kernel (Schmutterer 1990). Development projects may find this to be outside of their project timelines. Therefore, trees must be locally pre-existing or a long-term plantation program must be implemented. There may also be regulations on importing neem seed if not locally available (see below).

Spraying frequency: Schmutterer (1990) states that neem compounds are generally less effective in the short-term than synthetic commercial alternatives. While ecologically beneficial, the relatively short half-life of 36-48 hours is a practical challenge, meaning that the compound will need reapplication every 5-7 days. However, it is noted that some conventional pesticides also have similar application requirements (Schmutterer 1990).

Impact on plant growth: While Baidoo (2012) noticed increased cabbage weight as a result of neem spraying, Egho (2011) noted delayed development of the cowpea plant at 5% neem extract concentration.

Impact on human health: Though neem extracts are generally considered to be safe by advocates, Bramachari (2004) found that there were some human health concerns related to neem application. Toxicity in mammals from neem has been reported at relatively high dosages (Bramachari, 2004). Long-term controlled studies do not appear to have been conducted, and hence the possible effects of prolonged exposure to low doses of neem extract are not clear. As with any effective pesticide, safety equipment is preferable, but according to Raizada (2001), this may not be necessary after the neem extract has dried.

Environmental impact: As neem is a wide spectrum pesticide (Bramachari), it may harm beneficial insects. Prolonged over-spraying of neem extract may also lead to insect resistance, and hence neem

should be incorporated into integrated pest management (IPM) programs that promote good ecology to reduce pests (e.g. crop rotations) (Appropriate Technology, 2006).
Patent rights: An ongoing legal battle exists between W. R. Grace & Co. and advocate Jeremy Rifkin. W.R. Grace has patented a method of extracting an active ingredient from neem for use in commercial pesticides, whereas Rifkin contends that the traditional use of neem means that such a technology cannot be patented (Wolfgang, 1995).

How to make the extract: Small-Scale Production *(*Neem Foundation*)*

Preparing Neem Kernel Extract: The process for making a neem kernel extract is relatively simple. Following harvesting, neem kernels are ground, then the powder is usually gathered in a simple muslin cloth pouch and soaked overnight in water. The next morning, the pouch is squeezed to remove as much of the extract as possible. The ratio for an effective concentration of compounds is 50 g of neem kernel to 1 L of water. To increase surface area and decrease the time necessary for extraction, the outer coat of the neem kernel is removed, and the kernel is pounded gently. Some reports indicate that the outer coat is an effective addition to fertilizer. If the means do not exist locally to remove the seed coat, the ratio of the extract from (intact) neem kernels should be increased to 75 g per 1 L of water. The age of the neem kernels after harvesting is important; the seeds should be at least 3 months in age, and no older than 8 months to assure maximum azadirachtin content. For purposes of application onto leaves, an emulsifier is usually added, such as soap oil, soap cake powder, sandovit, or teepol, which are sometimes sold commercially. An emulsifier assists the active compounds in sticking to the leaves that will receive application.

Preparing Neem Leaf Extract: The concentrations of the active compounds are highest in neem kernels, but they are also present in the leaves (Bramachari, 2004). It is estimated that for 1 ha of land, nearly 80 kg of leaves would be required which is substantial. For practical purposes, it is therefore suggested that neem leaf extract should be applied to seedlings in nurseries and kitchen gardens. The process of making the leaf extract is nearly the same as producing the seed extract: the leaves are soaked overnight, then the next day the leaves are ground and the extract is filtered: 1 kg of green neem leaf is required per 5 L of water. As above, an emulsifier is added to facilitate better adhesion to applied leaf surfaces.

How to Spray Neem Extract or Commercial Neem Oil

As the active compounds break down fastest in extended bright light, the compound should be applied in the evening or very early morning. During high temperatures, the frequency of spraying should be increased. Since the compound is washed away by water, daily spraying is recommended in the rainy season. As insects lay eggs on the underside of the leaves, it is important to spray neem extract on the underside of the leaves. Optimally, each acre of land can be sprayed with approximately 60 L of ready-to-use solution (see below).

As an alternative, neem oil can be purchased commercially. To apply onto crops or seeds, 30 ml of neem oil is added to 1 L of water, along with an emulsifier. The resultant product needs to be mixed thoroughly and applied before oil droplets start floating on the water surface. Backpack sprayers have been found to be more effective than hand sprayers as they often have a built-in mixing agitation technology.

Further Information

Sources of seed and information on propagating neem trees

The trees are typically planted from seed. In India, there are commercial suppliers of neem seed including JDG Seeds which sell neem seeds for $1.10 USD per kg. Please refer to the Tree Seed Supplier Directory on the website of the World Agroforestry Center for local suppliers of neem seeds.

The Neem Foundation states that: “The seeds should be as fresh as possible as older seeds often do not germinate. Provided that only a few trees are to be planted, and there is sufficient moisture available, with minimum weeds, the seeds may be sown directly into the ground. Two to three seeds are placed together about 1 cm deep in loose soil. After germination, only the strongest plant should be retained. When planting a large number, it is advisable to cultivate young plants first in pots, trays or plastic bags. After 3 months, they should be transplanted into the ground. When using bags or pots care should be taken that the plants are not allowed to develop to a stage where the taproot has pierced the bottom and has to be shortened before transplantation. This weakens the trees and substantially slows their growth.”

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9.4 – Low oxygen (hermetic) grain storage bags

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Introduction

Though often overlooked, effective and affordable food storage technology desperately needs implementation in the developing world to protect from a wide variety of pests such as insects, rodents, and fungi.

Hermetically Sealed Technology

Principles

Hermetically Sealed Technology (HST) has been proven to be highly effective at preserving grains in many studies. A HST, when properly sealed and maintained, prevents the exchange of oxygen and moisture between the outside atmosphere and the stored grain (IRRI, 2004). This lack of oxygen creates an *anaerobic* environment; pests which rely on an *aerobic* environment, like fungal molds and insects are effectively controlled without the use of pesticides or other inputs, which are often out of reach for subsistence farmers (Kamanula et al., 2011).

HSTs have been found to be effective for storage of rice, cocoa beans, coffee, corn, dates, flour, millet, sorghum, sugar and wheat amongst others (GrainPro Inc., 2013). HSTs maintain flavor and aroma, prevent rancidity in foods such as peanuts, control insects and rodents, reduce fungal growth, and maintain harvest weight effectively (GrainPro Inc., 2013). Importantly, HSTs have been found to maintain seed viability for extended periods (FAO, 2011).

In a comparison with commonly used woven polypropylene bags (WPG), hermetic grain bags (HGB) were found to cause 99.5% mortality within 60 days of some common Sub-Saharan African maize pests that were artificially placed in the bags (Ognakossan 2013). In the same study, loss of grain was between 0.5-6% using HGB compared to 19-27% in WPG. Moisture rates were also maintained in the hermetic grain bags while moisture losses occurred in the WPG.

In an economic analysis of maize storage technologies in Kenya, Kimenju and De Groote (2010) presented the results of six-month crop storage loss trials in comparing metal silos, HSTs, a common pesticide and a standard woven polypropylene bag as control. Standard polypropylene bags were found to have the highest loss (24%), compared to the HST (6.3%), and metal silos (0.5-1.7%). While metal silos are perhaps a more effective means of storage in-place, they are not portable and not practical financially for a subsistence farmer (World Bank, 2011). Kimenju and De Groote (2010) noted that metal silos would take in excess of ten years to recoup the investment, whereas HSTs have the benefit of a relatively low initial investment and high return-on-investment. In fact, hermetic sacks are being bartered in some communities throughout Africa, as they are viewed as a high value commodity (FAO, 2011). An HST, effectively implemented, benefits farmers by allowing them to control when they sell their grain, and preventing the surplus at the end of the harvest which diminishes commodity prices for all farmers (Kimenju and DeGroote, 2010).

The World Bank does note that construction of mud silos in areas that do not traditionally use them has been effective (World Bank, 2011). For example, in northern Ghana 1,000 mud silos were commissioned by the Ministry of Food and Agriculture and associated organizations. It was found that in these areas, mud silos were effective in increasing effective crop storage time and preventing pest access, accounting for only 6.5 percent of losses over the study period as compared to jute bags and traditional granary structures (World Bank, 2011). However, construction of these silos requires the availability of suitable timber, which is sparse, and maintenance of the silos in the long term casts doubt over the ability of these silos to continue to offer such benefits (World Bank, 2011). Also, food security issues have encouraged individuals to store grain in their homes (often in the bedroom), and HSTs are more suitable for this (World Bank, 2011).

Critical Analysis

Grain needs to be suitably dried before being hermetically stored. Weinburg (2008) found that it is possible to store higher moisture content grain in HST, however losses do occur; it is still preferable, where possible, to dry grain adequately. Therefore, high humidity climates might find limited use if no effective method for drying foods can be practiced. The International Rice Research Institute (IRRI) estimates that to effectively reduce spoilage of foods inside HSTs, grains need to be dried to less than 12-14% moisture content depending on species (IRRI, 2010).

An HST needs to be kept protected, as any punctures leading to air leakage will minimize the benefits of the technology. To protect the bag, manufacturers recommend placing the HST into an existing type of storage such as a jute bag or woven polypropylene bag. To check for leaks, manufacturers suggest gently fill the bag with air, tying the bag shut, and placing a light book or hand on top, while observing the bag to check for air loss.

The Cowpea Bag

A variant of the HST is the Purdue Improved Cowpea Storage bag, which is a triple layer bag. It includes an outer protective layer and has been found to be quite effective in the protection of cowpea from a number of insects. Purdue maintains an extensive library of videos and information on their cowpea bag.

Purchase

The International Rice Research Institute (IRRI) co-developed one of the leading HST technologies with GrainPro Inc. GrainPro maintains an international distribution network, which is easily accessed through their site.

Large commercial systems cost about $100-130 per tonne, with an expected product life-cycle of at least ten years. Smaller scale 'Super Bags' cost approximately $1-2 depending on the volume of order and shipping destination. If protected from physical damage, they have been confirmed to last six growing seasons or more.

The cowpea bag can be purchased by visiting the Purdue website and consulting region specific dealers.

Practical tips

The International Rice Research Institute recommends that the grain should be dried to 12-14% moisture content. The HST should be placed inside an existing woven polypropylene bag or jute bag to provide protection. After the HST is filled with dried grain, excess air should be removed. The top of the bag should be twisted and folded into two, then tied with an elastic band or tape. The protective outer bag should also be closed. A very helpful and beautifully illustrated PDF is available through Purdue with many tips and basics

.

Further Information
The International Rice Research Institute has excellent information on grain storage (http://www.knowledgebank.irri.org/rkb/grain-storage-systems.html), and detailed information on hermetic storage including practical tips (http://www.knowledgebank.irri.org/rkb/grain-storage-systems/hermetic-storage-systems.html)

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9.7 – Simple clay pot cooler to prevent spoilage

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Introduction

It is estimated that between $200-300 million dollars (USD) worth of produce perish each year due to lack of adequate storage infrastructure (Chaurasia, 2005). The reduction of food spoilage is critical to ensuring that developing markets can remain competitive (Tomada, 1992).

The pot-in-pot (PiP) storage system is a promising method of providing portable, affordable refrigeration to parts of the world without electricity (Mittal, 2006). The pot is used to preserve vegetarian food in India (Date, 2012), and has been analyzed for its heat transfer properties, with a recorded decrease in temperature of 10.4˚C lower than ambient temperature in low humidity environments (Aimiuwu, 1992). Variations of this technology have been reported in West Africa (Aimiuwu, 2008), India (Date, 2012), and the Middle East (Mittal, 2006). The technology has been reported to be highly effective for storage of various fruits and vegetables including tomatoes, Guavas, Rocket (A leafy green), Okra and Carrots (Longmone 2003; Chaurasia et al. 2005; Odesola and Onyebuchi, 2009)

The technology is simple. A smaller pot is placed in a larger pot; the empty space between the pots is then filled with sand. Water is added to saturate the sand - as the water evaporates, it draws heat along with it, cooling the air and contents of the inner pot (Mittal, 2006). The PiP is based on the well-known principle of evaporative cooling. Just as the human body sweats during exposure to heat or while exercising to cool itself, the PIP slowly evaporates water contained in the outer pot, drawing heat with it, to effectively cool the air of the inner pot (Mittal, 2006).

Sand acts as an insulator, reducing the amount of water needed to reach the desired temperature (Mittal, 2006). A damp cloth is sometimes put over top of the inner pot. The outer pot should be highly porous and importantly, not glazed. A glazed pot will not allow water to effectively escape the vessel. Conversely, some trials have suggested that the inner pot be glazed or otherwise water-tight so as to prevent the entrance of moisture. This is especially important if the water is not potable.

Possible Benefits

A PiP system is based on revived indigenous knowledge which is easily transferrable, not patented, and extremely low-cost (around $1 per pot). Outer pots could be decorated as a form of branding and designed to be stackable. Many cultures already make and use pots and have sand available.

Critical Analysis

A PiP system would work best in high temperature, low humidity climates. As the humidity rises, the capacity of the water to evaporate, and thereby cool the contents of the second pot, is diminished. Additionally, high temperature and low humidity areas could be prone to drought, and a PiP system requires a constant, though relatively little supply of water. Saltwater could also be used. Unintended sealing of PiPs might trap plant-derived ethylene gas, a hormone which triggers ripening (Barry, 2007); in this situation, the produce could be placed in an ethylene adsorbent bag placed within the PiP. PiPs add shipping weight and bulk and would not likely be carried to market by hand. One might build a larger, semi-permanent structure on a small trailer which could be unloaded or loaded. One such (non-mobile) structure built of double walled brick was found to reduce ambient temperature inside the chamber by up to 14˚C while reducing shrinkage by 15-70% (Chaurasia, 2005).

Further Information

Pots based on this system (known as zeer pots) can be purchased by visiting Practical Action or by phoning +44 (0) 1926 634400. There are also detailed instructions available for local construction.

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9.15 - High efficiency cook stoves and pot skirts

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Introduction

Humans have been cooking food for at least 250,000 years, with some anthropological evidence dating the use of fire in cooking to 1.2 million years ago (Wrangham, 2003). Historically, cooking food has been a laborious endeavor, requiring the gathering of fuel in the form of wood and maintenance of equipment (Wrangham, 2003). Globally, a continued reliance on fuel woods is thought to be associated with deforestation, or at least forest degradation (Adeoye, 2011; Htun, 2013). As fuel wood becomes unavailable, some common substitutions for cooking fuel are crop residues and animal dung, which are crucial agricultural inputs for a subsistence farmer.

Most often, wood gathering has been relegated to children and women in particular, taking up a large proportion of their time (FAO, n.d.). Sexual assault often occurs as females collect fuelwood so minimizing the number of trips improves security (FAO, n.d.)

In many cultures, cooking indoors is a matter of practicality due to weather. Indoor cooking results in measurable impacts on the short term and long term health of women caused by the normal products of combustion including particulate matter (smoke) and noxious by-products such as benzene (C_6H_6) and carbon monoxide (CO). Naehler (2007) found that smoke from burnt wood suppresses the immune system. Some of the most commonly implicated illnesses are eye and lung irritations and associated pneumonias (Ochieng, 2013). Person (2012) estimates that globally, women and children are exposed to an average daily median of five hours of indoor air pollution where indoor cooking fires are commonplace. This exposure has been associated with approximately 1.5 million deaths in children <5 years of age, caused by acute respiratory infections related to indoor smoke, ostensibly from "inefficient" cooking stoves (Person 2012). This does not take into qualitative discomfort of coughing or runny nose or associated exposure to heightened room temperatures (Person, 2012).

Increasing the efficiency of cooking - thereby reducing pollution, fuel use, and time spent cooking is critical to improving social and economic outcomes. Recognizing this, many small-scale projects have emerged in various countries with products to meet this challenge. There are important misconceptions, however, about which cooking stove models improve either fuel efficiency or negative health effects (see below). Table 1 below evaluates a few promising cook stoves. One widely used stove is the 'upesi jiko' (Swahili for "quick stove"), which has been described by the United Nations as a "local solution to a global problem" (UNEP, n.d.) The distribution of this stove had a measurable effect in reducing fuel use and cook time, as well as visible smoke in the homes and associated eye irritation (Foote, 2013). The cost is approximately $2 USD for a single unit stove, and an additional $3 USD for a more permanent installation (Foote, 2013), though it should be noted that research indicated a high variability in stove design, price, efficiency, and health effects.

Table 1. Summary of selected improved cook stoves.
All Data, unless otherwise noted, is from Lit Review on Stoves (Berkeley). Rated on a five unit scale, 5 being best.

Design	*Efficiency*	*Health*	*Cost (USD)*	*Notes*
Traditional Three Stone Fire	*	*	*Free (high fuel cost)*	*A wide variability in efficiency. Tends to emit high levels of particulate matter (e.g. Smoke)*
Stovetec Rocket Stove (Aprovecho Research Centre) http://www.aprovecho.org	****	****	*$$-$$$$$ ($15-$1000)*	*Multiple models available ranging from residential to institutional multi-pot model.*
ONIL Stove (http://www.helpsintl.org)	*****	*****	*$$$$ ($150)*	*Expensive, non-mobile installation. Stove is vented outdoors.*
Upesi Jiko (Kenya Jiko)	***	**	$ ($2-5)	*Can usually be built locally, with possible benefits to local industry. Foote (2013) Found that Upsei Jiko did not significantly reduce rates of pneumonia, though the model tested did not vent outdoors. Carbon monoxide levels tested* **higher** *in* **charcoal** *Upsei Jiko as compared to a traditional three-stone fire.*
Greenway Smart Stove (http://grameeninfra.blogspot.ca/p/home.html)	****	****	*$$$ ($23.50)*	*First stoves are now on the market. Design is promising and has received near universal praise, but no studies could be found to corroborate claims.*

Understanding Engineering Principles of Healthy, High-Efficiency Stoves *(Adapted from Aprovecho Technical Manual)*

Though there is a wide variance in available products, many of the general engineering principles are similar. The information provided below is intended to inform the reader of the characteristics and misconceptions of what defines a high-quality stove, which need not be expensive.

Efficiency

There is an apparent misconception about what makes a cook stove efficient: cook stove efficiency is not only about converting fuel into heat but also about transferring the heat to the pot. For example, a three-stone fire is considered quite effective at turning wood into heat, known as combustion (70-90% efficient), but its inefficiency comes from only 10-40% of the released heat reaching the pot. Improving the efficiency of heat transfer is now thought to be more critical for human health by reducing emissions.

Insulation around the fire itself should ideally be made of lightweight, semi-porous, heat resistant materials. Insulation with a porous material helps to maintain airflow and temperature, encouraging a more complete combustion that reduces smoke and other toxic byproducts. Many commercial Jiko stoves use a ceramic liner for this purpose – some models have an insulative brick chimney.

Airflow is critically important to ensure efficient combustion. For this reason, a grate is often used under the space where combustion (fire) occurs to allow airflow to the fuel from all sides. A draft is important as well; closed box type stoves should have an access door and chimney that are roughly the same size to help maintain a steady draft. Insufficient airflow will result in more smoke and charcoal, but an excess of air will keep fire temperature low. A method of controlling airflow would be helpful, to adjust as necessary according to task.

Venting is the use of a chimney to evacuate smoke to the outdoors. Venting has been shown to have superior health benefits, but is usually costly than a simple intervention as it requires installation.

Critical Analysis

Wood reduction: Barnes (1993) estimated that approximately 300-600 kg of wood per family per year was saved, at a value of $15-84 (1993 USD) with the use of more efficient cook stoves, depending on location and materials used. For families that survive on $1-2 per day, these savings are substantial.

Human health: Research is ongoing to determine the health effects of using an improved cook stove. The issue is complex, not least because so many different models exist. Generally, it seems logical that most stoves, when used properly and maintained, will emit less carbon monoxide and other toxic gases. However, in 2010, the University of California-Berkeley evaluated 50 different models of improved cooking stoves in laboratory tests. The Berkeley study found that even poorly designed stoves can reduce fuel use compared to a three-stone fire, but may increase emissions of carbon monoxide perhaps because the improved stoves use charcoal (MacCarty, 2010). Ochieng (2013) found that a homemade rocket mud stove does produce less carbon monoxide than a three-stone fire, but still emits above World Health Organization guidelines, which is "unlikely to lead to appreciable health benefits."

While Harris (2011) found a 26% decrease in reported lower respiratory tract clinic visits in Santa Avelina, Guatemala, after the implementation of ONIL brand efficient stoves in 90% of households, Foote (2013) found that Jiko stoves are not effective in preventing respiratory diseases in children. Foote cited one of the main reasons for this observation was that combined use of Jiko with more traditional methods continues to prevail in households. The reasons for this are not explicitly stated, however Barnes (1993) attributes the prevailing use of traditional stoves over efficient stoves to a number of reasons, including perceived protection from insects provided by smoke, better and more efficient accommodation of pan sizes, waste heat as heating the home, and in some cases the wider variance of acceptable fuels in traditional stoves. Barnes also notes that cash expenditures are often non-existent in construction of traditional stoves, As a result, it is suggested that deployment of this technology would need to be highly region specific, taking into account the reasons traditional stoves are used. Interestingly, Barnes (1993) believes that the best market for new stove technology deployment will be urban and peri-urban, where fuel woods are already scarce and people already purchase both fuel and stoves.

Improved stoves for profit and jobs: More cost-effective cook stoves can enable post harvest processing and value addition of goods such as converting grains into flat bread or dry, roasted snacks. Stove building can also create a source of local employment (Ingwe, 2008). However, Wawire (2010) noted mixed results in Jiko stove making as an enterprise. While economically successful and sustainable, individuals cited relatively heavy time commitments needed to make the stoves and the tedious nature of the work as being among the factors influencing negative perception of the industry.

Constraints to adoption

In addition to the above discussion, there are several constraints to adoption of improved cook stoves. For example, Foote (2013) found that despite market subsidization and market promotion in the region studied, less than 20% of households owned a stove. Some high-efficiency stoves, such as the ONIL brand, are in the price range of $150 each and are therefore most likely out of reach for many families (http://www.helpsintl.org/programs/stove.php). Of interest is the effect of the local *perception* of fuel shortages as compared to scientifically predicted shortages. For example, if a local population does not perceive an imminent wood shortage, Barnes (1993) showed it might not adopt jiko stoves as easily. The reader is encouraged to read a more recent article which has integrated potential constraints to adoption of improved cook stoves into a cost-benefit analysis for different stove types, including capital costs, costs of repair and fuel, time savings, health and environmental benefits (Jeuland and Pattanayak, 2012).

One critical issue is that improved stoves typically only accommodate one pot, whereas a three-stone fire can accommodate several pans at once while also keeping other food warm through proximity.

There are cultural reasons why an improved cooking stove may not be adopted. For example, a traditional Punjab dish in India is Kadhi, which uses chickpea flour and buttermilk or yoghurt to produce a creamy dish eaten with pakoras, roti or boiled rice. Rocket stoves are most often designed with the fastest water boiling time as benchmark. Yet in this instance, the boiling of a liquid is not desired because the milky stew would scald (Barnes, 1993) -- few stoves have an option to “turn down the heat” once the fuel has been inserted aside from removing some of the fuel. Other cuisines seek to ‘slow cook’ food to increase flavor. In addition, some cultures use clay pots with rounded bottoms to cook food – a stove with a flat heating surface would be inefficient and possibly unsafe for heating this kind of pot. Many stove models can be adjusted to have ‘open’ access points that allow a rounded pot to sit comfortably – a skirt around the pot or a chimney would be necessary to ensure adequate airflow. Therefore, adjustments to an introduced stove, or additional technology may be needed according to cooking preferences. Ultimately, field-testing the stoves *in situ* will be of critical importance in determining efficacy prior to large-scale projects.

Pot Skirts

An appropriate technology would in this case be one that is adaptable and expandable to a given situation. To this end, one of the most inexpensive and simple interventions in cooking in the developing world may be the pot skirt. A pot skirt wraps around a pot to seal any gaps around the pot relative to the fuel source below, thus improving heat transfer. In fact, pot skirts have been found to increase fuel efficiency of rocket stoves by 20% (MacCarty, 2010). A pot skirt can also be used in conjunction with a jiko stove or traditional three-stone fire. An advantage of an effective pot skirt is that it can be adapted to a variety of sizes of pan or pot.

Currently, affordable pot skirts are not for sale, however the Haiti rocket stove project has full instructions on how to construct a relatively efficient stove and accompanying pot skirt.

Further Information

The Gaia Movement has insturctions on *How to Build a Jiko Stove*. ***Also see*** *How to build a rocket stove* **.**

Aprovecho, an NGO based out of Oregon, has high quality, open access information on the design and improvement of cook stoves, with information in Spanish and Italian in addition to English. Visit the website or contact info@aprovecho.org 541-767-0287

Purchasing information:

In Kenya, through mPesa, which delivers to 20+ locations around East Africa http://kenyacharcoal.blogspot.ca/2009/12/buy-energy-saving-jiko-and-plant-52.html) Contact Teddy via email at teddykinyanjui@hotmail.com

A highly polished line of advanced products is available through Colorado State university (http://www.envirofit.org/products/?pid=4)

For ONIL stoves http://www.helpsintl.org/programs/stove.php

Further Sites of Interest:

http://newswatch.nationalgeographic.com/2012/06/18/clean-cookstoves-must-be-rethought-so-they-actually-get-used-in-developing-world/

http://www.cleancookstoves.org/

http://www.povertyactionlab.org/

http://www.zentg.com/stovetec/

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9.16 - Pressure Cooker to reduce cooking fuel

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Introduction

Pressure cookers are well known to many as a stove-top implement which decreases cooking time. They are essentially a sealed cooking pot that maintains a pressure of about 15 pounds per square inch (psi) internally. This pressure increases the boiling point of water, which increases the internal temperature of the pot. There is a pressure release valve to ensure safety. Pressure cookers require approximately 50% of the energy necessary to cook rice as compared to conventional stove-top cooking (Das, 2006). They also save approximately 50% in cooking time (Das, 2006; Sinha, 1991). In India, van Elsland (2011) found that owning a pressure cooker benefitted the most food-insecure families the greatest, as there tends to be a correlation between fuel availability, either for purchase or harvest, and food insecurity. It was also found that in the context of this study, 35% of families had to skip a meal due to fuel shortages.

Practicality and Food Safety

Globally, hundreds of millions of poor people live in high altitudes including in Central America, East Africa and South Asia. The USDA (2011) notes that at altitudes above 2,500 feet (762 meters) the atmosphere becomes much drier on average, such that uncovered food will evaporate water quickly and dry the meal out. Pressure cookers are excellent at retaining moisture in foods so long as the heat is reduced once pressure is reached (Pokharel, 2004). In terms of food safety, higher altitudes limit the ability of heated water in destroying pathogens (USDA, 2011). While water boils at around 100°C (212°F) at sea level, with every 500ft (152 meters) increase in elevation, water boils at approximately 1°F lower. At 5000ft (1524 meters), food will require approximately 25% more cooking time than sea level to compensate; a food thermometer is recommended by the USDA as the only reliable way to determine if food has reached a safe internal temperature (160°F or 71°C). Hence, increasing the ambient pressure of food through the use of a pressure cooker will have significant benefits at high altitudes.

High Altitude Benefits

Pokharel (2004) conducted research on a variety of cooking methods in the Banepa and Dhulikhel municipalities of Nepal. These municipalities are approximately 5,000 feet (1524 meters) above sea level and have an average household family size of 6.2, making them a good case study for the efficiency of pressure cookers at high altitude. At this altitude, a pressure cooker on a liquid propane stove was able to cook rice in 9.7 minutes, compared to 27.7 minutes using a Karahi (open top pan with curved sides) and traditional fuel wood stove. In a system efficiency test, pressure cookers were found to be more efficient than all other implements on every stove-type at this altitude (Pokharel, 2004). While no data could be found, it would be of great interest to determine the combined effectiveness of a high-efficiency stove with a pressure cooker particularly in a high-altitude environment.

Hence, in places where high altitude communities exist such as Ethiopia, Nepal and Bolivia, a pressure cooker can be considered an essential tool which will save time, fuel and labour while reducing deforestation. In Nepal, a savings of over 55% in energy required to cook food was found, most likely due to its high altitude in cooking (Shaligram, 2002).

A possible benefit of using a pressure cooker is the resulting acceptability of some foods that are nutritious and/or suitable for production, consumption and profitability, but which struggle due to cooking constraints. One example of this is bambara groundnut, an indigenous legume in Sub-Saharan Africa which has an exceptional nutritional profile while being drought tolerant. Prior to African colonization, bambara may have been as important to Africa as a protein source as soybeans are to China, and could once again become a mainstay of local diets; however one of the primary constraints is the size of the bean, which is quite large. Hence, bambara requires substantial cooking time, and would require substantially more cooking time at high altitudes.

Where to purchase

While models developed in the past were sometimes dangerous, advancements in technology have reduced risk considerably. A modern pressure cooker will be constructed of stainless steel (18/10 grade) and will have a robust safety valve, as well as secondary fail-safe mechanisms such as a latch to hold the lid in case of valve failure. Some pressure cookers currently on the market are made of aluminum; while these devices are substantially lighter and possibly more affordable, extra care should be taken to determine that these devices are safe since aluminum is fairly soft metal and could fail if not of a high quality construction.

In Africa, a household pressure cooker can be purchased for approximately $7-10 USD. A link is provided, but may be out of date by publication.

Pokharel (2004) priced rice cookers in the Banepa region of Nepal at 300 rupees, which is approximately $3.50 USD.

Constraints to Development

Pressure cookers require more initial investment than a typical pan of similar size. The gasket or sealing ring on the lid requires special care, including cleaning and occasional lubrication, and will require replacement if visible wear or warping occurs. Some models do not require a gasket or sealing ring. Pokharel (2004) estimated the average life-time of a pressure cooker to be 5 years, with a 50 rupee maintenance cost over the course of the product life-cycle.

Pressure cookers accomplish much the same task as boiling, therefore foods that are meant to be baked or fried will be unsuitable. Certain foods are not well suited to pressure cooking. Typically these foods froth in excess and block the steam vent. Oatmeal is an example of a food that has this trait. To compensate for this, many cookers suggest filling the pot only 1/3 full when using foods that tend to froth. For other foods, a pressure cooker should not be filled beyond 50% capacity to allow for adequate room for food expansion and pressure buildup. Some manufacturers suggest using a teaspoon of oil in the cooking water to keep the frothing down, however users are encouraged to follow manufacturer directions.

Cooking with a pressure cooker may require overcoming fear concerning perceived hazards. It may also require some learning, especially at the beginning, as many foods will become overcooked quickly. Once started, there is no way to check the consistency of food once cooking has begun without first allowing pressure to escape, which essentially stops the cooking process. Usually a model will include instructions, but the foods listed might not be local foods or may not be in the local language, so instructional use may be needed.

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9.19/9.20 - Value addition ideas (revision pending)

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Introduction

There are more than 725 million chronically undernourished people in the world who don not have enough to eat to sustain a healthy life. In some countries people are using up to 80% of their income just to buy food (CARE, World Hunger 2016). Most of these people are subsistence farmers who farm what they can to barely feed their families.. These farmers mostly grow raw commodity crops, which fetch a poor market price. One simple poverty reduction solution is to “add value” prior to the final sale of the farm products. *Value addition* is a secondary process that involves changing the original product into something manufactured. One example would be to shell and roast peanuts, which would be sold at a local or international market.

Unfortunately, in many poor countries, farmers are failing to capture most of this value. In fact, the amount of agricultural product that is actually processed is around 30% in poor countries, compared to the average of 98% in the United States (Kornawa, 2011). The coffee exporters of Ethiopia are a perfect example of how much of the value is not being captured. They sell their beans raw and unprocessed to many international markets. A third party company that operates outside the country then processes this coffee. The processed coffee subsequently re-enters the economy as a different product, sold for a higher price (Kakonge, 2016).

The best way to help a poor developing nation is to encourage entrepreneurs to take the risk of starting a small business venture and experiment with different ideas to create value, and for subsistence farmers to improve upon their crops by innovating a more processed good that can be sold for a much higher price. For example, Aubierge Djossinou is a Chilli farmer in Kenya, who has learned to turn his peppers into powder. Djossinou was able to send his children to school and buy household needs with the sales from his value added product. Djossinou sold to different consumers including restaurants and shop owners (The Organic Farmer, Case Study, 2015).

Benefits of Adding Value

Value addition in Africa has been shown to provide 26 times more benefit to the community than by just selling materials in their natural raw state (Proudly Made in Africa, 2014). Economic growth is the most powerful way to improve living standards in poor countries. A case study was done by the *Department For International Development* (DFID, UK) and found that a 10% increase in average income correlated to a 20-30% reduction in poverty. Growth generates cycles of prosperity, investment, employment opportunities and provide incentives to send children to school (DFID, Growth). A farmer with more money can invest in better tools, better seeds and provide better nutrition for his/her family. The farmers can invest in practices that make farming easier, or more productive such as mechanization, which can be used to reduce the amount of labour spent weeding, or ploughing the fields. The *Food and Agriculture Organization* (FAO) conducted a study on how time was spent by people in poor nations and found that around 60-80% of a woman’s time is spent on the farm doing farm chores (FAO Article, 2011). Mechanisation or additional livestock would reduce the labour requirements freeing up time for women to do other activities more beneficial (FAO-Farm Power and Mechanization, 2006).

Professional packaging and labeling are a simple but cost effective means of improving profit, and contribute to brand recognition and advertising. It has been shown that there is a strong correlation between advertising and increased profit from sales (Artemenko, 2014). Packaging and labeling can potentially be outsourced to a local entrepreneur in a local city, if the farmers do not know how to do it themselves.

Challenges

As many subsistence farmers lack formal education or access to services to help entrepreneurs, the concept and benefits of value addition are difficult to share. Hundreds of studies have been conducted on education attainment and income.

The studies all seem to agree that schooling increases an individual's earnings by around 10% (Hanushek and Wößmann 2007). Disseminating information to farmers about value addition is crucial to foster economic growth and entrepreneurship. Furthermore, many smallholder farmers lack the capital or financial aid required to make initial investments into value addition. Access to financial investment is the biggest constraint to sustainable development. It is estimated that entrepreneurs in emerging economies are underfinanced, and there is a lack of investment in these entrepreneurs. Cumulatively, they need $2 trillion in financing to grow effectively (UNCTAD, 2015). A possible solution to this problem is micro financing, which consists of loans typically in the range of $50-$200 USD, to help jumpstart innovation or entrepreneurship within the community. The NGO, Kiva, for example uses crowd funding to micro finance loans (Kiva.org, 2016).

Many poor countries also have poor policy, which make it difficult or undesirable to start a business venture. Average Incomes in countries with a high level of corruption are about a third of those in countries without corruption (World Bank, 2016). In corrupt economies, there is a vast wealth divide between the rich and the poor, and many monopolies and oligopolies exist because of poor market policy. There is also very little incentive to innovate because of a weak enforcement of property rights. This also turns a lot of foreign investors away because they cannot trust that their investment will be protected (Elvin Mirzayev, 2015).

Value Addition Ideas

There are many cheap and effective ways of adding value to commodities. For example fruits can be converted into jams, vegetables into packaged consumer products, or legumes in salted or unsalted butters or snacks. Jams in sub-Saharan Africa can be made from many indigenous fruits such as pineapples, mangos, bananas and other citrus fruits (Iwuoha, 2013). The farmer needs jars, a heat source and sugar to create jam. The fruits need to be diced and cooked over a heat source with sugar. The jam is then cooled and jarred for preservation (Old Farmer's Almanac, 2016).

If a farmer grows vegetables, they can wash and package their produce in a plastic wrap with a creative label. Legumes such as peanuts or canola can be converted into cooking oil, or just roasted and salted as a snack.

To make peanut oil, the peanuts are removed from their shells, skinned, soaked and cleaned in hot water, blended or mushed into a paste, allowed to settle for 24 hours. Scrape the oil off the paste and jar it (How To Make Peanut Oil, iFoodTV). There is a hand crank peanut oil press that can be bought for $120 from a company called AGICO and delivered to any country. The manual oil press can be used for any type of legume and is very simple to use (Peanut Oil Press, AGICO). Additionally, Table 1a) shows different processing ideas for a few crops commonly grown around the world.

Table 1A. Value addition ideas

Raw Commodity	Value Addition	Tool(s) Needed	Raw Commodity	Value Addition	Tool(s) Needed
Corn	Popcorn/ Flour	Stove	Apples	Apple Sauce	Oven
Wheat	Bread/ Flour	Oven	Pumpkin	Pumpkin Seeds	Oven
Cassava	Cassava Flour	Mortar Pestle	Millet	Millet Bread	Mortar Pestle, Oven
Sugar Cane	Refined Sugar	Cane Shredder, Boiler	Barley	Flour	Mortar Pestle
Rice	Rice Paper	Pan and Oil	Pineapple	Juice	Juicer
Potatoes	Potato Chips	Oven	Rapeseed	Oil	Peanut Oil Press
Soybeans	Tofu	Pot and Strainer	Strawberries	Jam	Oven, Jars
Tomatoes	Tomato Juice	Juice Press	Cabbage	Pickled Cabbage	Barrels, Vinegar
Bananas	Dried Chips	Oven	Peanuts	Oil, roasted/salted snack	Peanut Oil Press
Oranges	Illness Remedies (Rind)	Knife			
Oats	Oat Flour	Mortar Pestle			
Sorghum	Flour	Mortar Pestle			
Grapes	Sun Protection				
Sunflower	Salted/roasted Seeds	Oven			
Coconut	Moisturizer				

Additional Resource for Further Reading:

Labeling and Packaging:

Alibaba.com is a great online site that connects entrepreneurs with suppliers to purchase the packaging and custom labeling that they need https://www.alibaba.com/

CCL.com is a labeling company that produces labels for anything; boxes, bags, tubes etc. https://ccllabel.com/

Mechanisation: South Africa Retailers

1) Heads Tractor
2) Tractor Kingdom Zar
3) Farmworld

Micro-financing:

Kiva.org is a great micro-financing loaner that uses crowd funding to reach the borrowers goals. Has a historical 97% repayment rate. https://www.kiva.org/

Whole Planet Foundation.org is a micro-finance institution that works through donations, and every donation is given to a farmer, then repaid and given to a different farmer. https://www.wholeplanetfoundation.org/about/

Farmer Cooperatives:

There is a website that has a lot information about farmer cooperatives. Website: http://12.000.scripts.mit.edu/mission2014/solutions/small-farm-cooperatives

An Article written by Dr. Chiyoge B. Sifa explains the importance of farmer co-ops in the development of the local economy: http://www.un.org/esa/socdev/documents/2014/coopsegm/Sifa--Coops%20and%20agric%20dev.pdf

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Chapter 10 - Human nutrition

10.1/10.2 - Improving iron absorption

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Introduction

Iron deficiency and related cases of anaemia constitute a global health risk of epidemic proportions. Iron deficiency reduces individuals' work capacities, negatively affecting their ability to make a living and, in cases where it is widespread, severely hampering national economic development. This is especially apparent in developing countries (WHO, N.D). This chapter outlines a simple, low-cost set of practices for enhancing people's abilities to absorb iron, with the goal of reducing the prevalence of iron deficiency. It is recommended that people increaes their ascorbic acid (vitamin C) intake around mealtimes, while simultaneously reducing caffeine intake.

Role of Iron in the Body

Iron is an essential element for most organisms and is critical to a number of human bodily functions. It is required for hemoglobin, the protein found in red blood cells that carries oxygen from the lungs to rest of the body (FAO & WHO, 2002). Iron can be classified under two primary subtypes:

- Heme Iron: primarily found in blood and muscles (meat) and is more easily absorbed by humans than the non-heme iron found in plants.
- Non-Heme Iron: found primarily in non-meat sources (plants and carbohydrates) and is not as easily absorbed by humans as heme iron (Hurrell & Egli, 2010).

Consequences of Iron Deficiency

Anaemia is a condition where a deficiency in hemoglobin prevents red blood cells from providing adequate amounts of oxygen to the body (UNICEF & WHO, 1999). This can decrease an individual's ability to work, contributes to overall poor health, and can lead to death over time. Physical symptoms include fatigue, shortness of breath, feelings of irritability, dizziness, headaches, and feeling cold, among others. Iron deficiency is responsible for approximately half of the cases of anaemia in developing countries. The other half of cases are generally attributable to disease, blood loss, and other nutrient deficiencies (Abbaspour et. al, 2014). Iron plays a crucial role in hemoglobin and red blood cell functionality (FAO & WHO, 2002), making proper intake and absorption important in reducing incidents of anaemia.

Who is most at risk for anaemia?

Anaemia affects approximately 1.62 billion people globally (WHO, 2008). Low iron intake and absorption, rapid growth, pregnancy and menstruation are the primary causes of iron deficiency (Abbaspour et. al, 2014) relevant to this chapter. Correspondingly, growing children, pregnant and menstruating women are highly vulnerable to iron deficiency and related cases of anaemia (Abbaspour et. al, 2014; CDC, 2015). Iron deficiency is the leading single-nutrient deficiency among children and infants (Zlotkin et. al, 2003), presenting a challenge to solve a significant worldwide problem. *Table 1* illustrates the prevalence of anaemia among subgroups globally, and specifically in Africa and India. The table displays a clear trend that anaemia rates in India and Africa, proportional to population, are considerably higher than the global standard.

Table 1: Estimated anaemia prevalence among select subgroups in select geographic regions

Region	**Subgroup**	**Estimated Number of Persons with Anaemia**	**Estimated Proportion of Subgroup Population**
Global	Pre-school Age Children *(0 – 4.99 years)*	293 000 000	47.4%
	Pregnant Women *(no age range defined)*	56 000 000	41.8%
	Non-Pregnant Women *(15 – 49.99 years)*	468 000 000	30.2%
India	Pre-school Age Children *(0.50 – 2.99 years)*	89 090 000	74.3%
	Pregnant Women *(15 – 49.99 years)*	12 799 000	49.7%
	Non-Pregnant Women of Reproductive Age *(15 – 49.99 years)*	134 495 000	52%
Africa	Pre-school Age Children *(0 – 4.99 years)*	83 500 000	67.6%
	Pregnant Women *(no age range defined)*	17 200 000	57.1%
	Non-Pregnant Women *(15 – 49.99 years)*	69 900 000	47.5%

*Table 1 was compiled using data from the World Health Organization's *Worldwide Prevalence of Anaemia 1993 – 2005 (http://apps.who.int/iris/bitstream/10665/43894/1/9789241596657_eng.pdf)*

The Effect of Caffeine on Iron Absorption

Caffeine does not have a marked effect on heme iron absorption, but it impinges on the body's ability to absorb non-heme iron significantly. As discussed, heme iron is typically found in meat, while non-meat foods provide non-heme iron (Hurrell & Egli, 2010). Many diets in developing countries are based around grains and/or vegetables, often comprising relatively little – if any – meat. In some cases this is the result of a lack of availability, and in others is a matter of culture and/or religious choice. Considering that subsistence farmers in developing countries, and in many African countries specifically, rely primarily on non-heme iron, impaired absorption is highly problematic.

Effect of Citrus on Iron Absorption

Citrus fruits are rich in ascorbic acid (vitamin C), which significantly improves the body's ability to absorb iron. Ascorbic acid is the *most potent* enhancer for humans when it comes to non-heme iron absorption (FAO & WHO, 2001). It exists in a number of fruits, making it an excellent option for improving iron bioavailability from grain and vegetable based diets.

Description of Practice: Reducing Caffeine and Adding Citrus

A simple and cost-effective method to help mitigate iron-absorption impairment is to limit caffeine intake. It must be noted that it is beyond the scope of this chapter to comment on the potential overall effects, both positive and negative, of completely eliminating caffeine from one's diet. As a best practice, nutritional experts recommend limiting caffeine intake, specifically around meal times.

Tea and coffee are popular dietary sources of caffeine. In addition to caffeine, tea and coffee contain tannins that have also been observed as major inhibitors to iron absorption (Aldrian et. al, 1997). To avoid caffeine and tannin inhibition, one should allow a two-hour window between main meals and consumption of coffee or tea (FAO & WHO, 2001).

Nutritional experts second primary recommendation is to increase ascorbic acid consumption, particularly by pairing it with non-heme iron sources to enhance absorption. As noted, citrus fruits are an excellent source of ascorbic acid, and represent a natural, low-cost intervention to boost non-heme iron absorption.

A variety of different citrus fruits can be used for enhancing iron absorption. Individuals' choices may be based on local availability, cultural preferences, or environmental factors (for example, soil type). When feasible, it may be advisable for subsistence farmers to plant multiple types of citrus fruit to better mitigate the risks posed by disease, pests, fungi and drought. The following table outlines approximate ascorbic acid content values for a number of citrus fruits:

Table 2: Ascorbic acid content in citrus fruits

Food and Quantity	**Milligrams (mg) per serving**	**Percent (%) Daily Value**
Orange juice – 2/5 cup (100 g)	50	83
Orange fruit – 1 medium (100 g)	71	118
Grapefruit juice – 2/5 cup (100 g)	38	63
Grapefruit – 1 small (100 g)	34.4	57
Lime juice – 2/5 cup (100 g)	29.1	49
Lime fruit – 1.5 2" fruits (100 g)	30	50
Lemon juice – 2/5 cup (100 g)	38.7	65
Lemon fruit – 2 large (100 g)	53	88

*Table 2 provides approximate values, calculated using data from the USDA Agricultural Research Service's *Food Composition Databases (https://ndb.nal.usda.gov/ndb/search/list)*

From the table, it can be deduced that the most potent source of dietary ascorbic acid is in consuming raw, whole oranges. Juicing is generally not recommended because, except in the case of grapefruit, it appears to lessen the ascorbic acid content gram-for-gram, and may be more labour intensive than eating the fruit whole.

It is worth noting here that adding lemon and lime to foods is already a traditional practice in many cultures. Because ascorbic acid is water-soluble and destroyed by heat (U.S Department of Health and Human Services, 2016) however, it is best that citrus be added to meals *after* the food has been cooked; for example, adding lemon zest to the top of a plated meal, as opposed to during the cooking process. This simple practice can be promoted where it is already common, and encouraged where it is not.

Additional Practices: Iron Fortification and Adding Meat to Vegetarian Meals

In addition to enhancing the body's ability to absorb iron, it can be beneficial to increase overall iron intake when feasible. Nutritional experts recommend adding small amounts of meat to meals (FAO & WHO, 2001) when available and culturally appropriate, and fortifying other foods with iron as best practices.

The iron-related benefits of adding small amounts of meat to otherwise vegetarian meals is two-fold. Meats are rich in heme iron that is resistant to the impairing effects of tannin and caffeine, providing a more bioavailable source to the body. Furthermore, heme iron also enhances the body's ability to absorb non-heme iron (WHO, 1999), indirectly improving iron bioavailability from non-meat sources. The following table outlines the iron content of a number of raw meats and meat products:

Table 3: Iron content in meats and meat products

Food and Quantity	Milligrams (mg) per serving
Chicken (meat, skin, giblets and neck) raw – 100g	1.31
Beef (grass-fed, ground) raw – 100g	1.99
Catfish (channel, wild) raw – 100g	0.30
Tilapia, raw – 100g	0.56
Brown Egg – 2 large, 100g	1.44

*Table 3 provides approximate values, calculated using data from the USDA Agricultural Research Service's *Food Composition Databases 28 (https://ndb.nal.usda.gov/ndb/search/list)*

It is important to note that *Table 3* was constructed using data on commercially available meats in the United States, and therefore may not reflect the iron content of locally available foods. A full analysis of iron content in meat is beyond the scope of this chapter, but this data suggests generally that red meat is the most potent provider of iron, followed by eggs and chicken. Based on this information, further research ought to look into the viability of raising chickens for egg harvest as a sustainable source of heme iron.

Where adding meat and/or meat products are not feasible or culturally appropriate, an alternative method of fortifying foods with iron can be beneficial. Iron fortification is beyond the scope of this chapter, but it should be noted that a number of low-cost, accessible options are being developed in this area (see *Food Fortification* and *Sprinkles, p. 140* in *Micronutrients, Macro Impact: The story of vitamins and a hungry world.* Obtained from http://www.sightandlife.org/fileadmin/data/Books/Micronutrients_Macro_Impact.pdf).

Benefits of Enhanced Iron Absorption

Enhancing iron absorption through the reduction of caffeine and addition of ascorbic acid has a number of tangible benefits. As an essential micronutrient (CDC, 2015), better iron absorption can contribute to increased physical and mental development in children, and to higher development levels for future generations (WHO, N.D). In addition, improving iron absorption can allow for higher work productivity by allowing more oxygen to reach the muscles from the lungs. This can allow people to work longer and harder without tiring, and generally enjoy life to a fuller extent (WHO, N.D). Finally, by enhancing cognitive/labour capacity and morale, these benefits can manifest in higher yields and profits for subsistence farmers.

Critical Analysis

Coffee and tea are two primary sources of caffeine, and may be staple beverages in many areas and to certain groups. With this in mind, it may be unrealistic and unwelcome to recommend complete elimination of these beverages from local diets. It is important to remember that we ought not make recommendations to people that we would not personally follow. Furthermore, as previously mentioned, it is beyond the scope of this article to assess the overall effects, whether positive or negative, of caffeine elimination. Beyond the personal health effects, there is also the potential that farmers in certain locales rely on coffee/tea as cash crops. Recommending that locals eliminate caffeine in their diets may have the unwanted effect of alienating these farmers, and potentially affect their livelihoods. For these reasons, it is imperative that we recommend a *targeted reduction* in caffeine consumption around mealtimes as opposed to complete dietary elimination.

In regards to the recommendation that meat be added to meals to increase iron intake, it is important to consider individual local contexts. Beyond the issues of livestock and fish availability, many people adhere to vegetarian diets based on cultural and/or religious beliefs. Many practitioners of Hinduism and Buddhism, for example, abstain from meat consumption entirely. In these cases, incorporating meat into the diet is simply not feasible, and therefore should not be recommended as an intervention option.

Further Reading

For further reading on this topic, see the following resources:

1. World Health Organization: Micronutrient Deficiencies. http://www.who.int/nutrition/topics/ida/en/
2. United States Department of Agriculture: USDA Food Composition Databases. https://ndb.nal.usda.gov/ndb/search/list
3. Center for Disease Control: Micronutrient Facts. http://www.cdc.gov/immpact/micronutrients/index.html
4. Food and Agriculture Organization of the United Nations: Humani Vitamin and Mineral Requirements. ftp://ftp.fao.org/docrep/fao/004/y2809e/y2809e00.pdf

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11. U.S Department of Health and Human Services: National Institutes of Health (February, 2016). Vitamin C Fact Sheet for Health Professionals. Retrieved November 23rd, 2016, from https://ods.od.nih.gov/factsheets/VitaminC-HealthProfessional/#en6.
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10.3 - Reducing vitamin A deficiencies by eating colorful foods and leafy greens

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Health Issues Resulting from Vitamin A Deficiencies

In 2013, 29 percent of children aged 6 to 59 months were vitamin A deficient, nearly one in three (UNICEF, 2016). VAD is caused by a diet that is insufficient in vitamin A, a necessary micronutrient that is needed to maintain the body's physiological functions, leading to adverse health affects (WHO, 2009). A diet that is chronically lacking in vitamin A can lead to low tissue concentrations of vitamin A and the failure of normal human development, metabolism, and a properly functioning immune system. (WHO, 2009; NIH, 2016). Vitamin A is needed in sustained small amounts or it can be administered in high does supplements to those in critical states, if needed (UNICEF, 2007). However, insufficient levels the vitamin A in periods of life with high metabolic demands (infancy, childhood, and pregnancy) can greatly impair cell functioning and vision processes (WHO, 2009). This is why VAD is the leading cause of preventable blindness in children, as well as a major contributor to childhood mortality under 5 years of age (UNICEF, 2007). Chronic VAD can lead to conditions such as childhood blindness, xeropthalmia, anaemia, and increased susceptibility to infectious diseases due to weakened immunity (WHO, 2009).

Vitamin A is also necessary for the healthy development of the fetus during pregnancy, as well as for the health of the mother, who requires the nutrient in excess to sustain fetus growth (WHO, 2011; NIH, 2016). Unfortunately, about 19 million pregnant women are impacted by VAD, and the majority of these women are from Sub-Saharan Africa and South-Asia (UNICEF, 2007). The WHO also estimates that 9.8 million pregnant women have xerophthalmia, the most common indicator of VAD, as a result of VAD (NIH, 2016). Human immunodeficiency virus (HIV) affects pregnant women and children through the mother-to-child transmission of the disease, and is a risk factor for VAD (WHO, 2011). Mother-to-child HIV transmission is the primary route for child HIV, with 1000 new cases occurring worldwide each day (WHO, 2011). Thus, HIV positive women should be included in interventions that aim to address VAD (WHO, 2011). It must be noted that vitamin A supplementation is not a WHO-recommended intervention to prevent mother-to-child transmission of HIV – but rather that HIV and pregnancy are risk factors for VAD (WHO, 2011). Because the greatest prevalence and severity of VAD complications are in young children and pregnant women, these groups carry the greatest burden of disease and require specific attention in alleviating VAD in South-Asia, Sub-Saharan Africa, and beyond.

Absorption of Vitamin A

Understanding how different forms of vitamin A impact their absorbance into the body is of great importance in order to address VAD. Two forms of vitamin A meet dietary needs: preformed vitamin A (retinol) and pro-vitamin carotenoid (i.e. β-carotene) sources (FAO/WHO, 2002). Preformed Vitamin A is found almost exclusively in the fat-storage cells of animal foods, such as the milk, beef, eggs, and fish (FAO/WHO, 2002). The pro-vitamin carotenoid form is found in vegetables and fruits, but this form is held in more complex lipid matrix structures within these plants cells, impacting the bioavailability of this form (FAO/WHO, 2002). The form of vitamin A great influences uptake: about 90 percent of ingested preformed vitamin A is absorbed into human metabolism, whereas pro-vitamin A carotenoid absorption greatly depends on the plant source and the amount of fats consumed in the person's diet (FAO/WHO, 2002). The amount of vitamin A obtained from plant sources depends on the conversion factor of the pro-vitamin A carotenoid plant source, and this reflects the bioefficacy of the organism's carotenoids (de Pee & Bloem, 2007). Vitamin A is a fat-soluble compound, meaning that fats assist in the uptake of both forms of vitamin A into human metabolism (FAO/WHO, 2002). It is important to note that a diet of less than 5-10 grams of fat daily can greatly reduce the absorption of these metabolites (FAO/WHO, 2002). Increasing the amounts of fats consumed in one's diet is likely to increase vitamin A uptake. However, this is not the only hurdle. As vitamin A is fat-soluble, its absorption is poor when diseases that prevent healthy fat uptake, such as chronic diarrhea, impact peoples' livelihoods (Merck Manuel, 2016; NIH, 2016). Chronic VAD frequently coexists with infectious diseases, leading to less vitamin A absorption into the body (WHO, 2009). Indeed, populations that acquire vitamin A from pro-vitamin carotenoid sources and lack adequate fat intake face a very high risk of VAD (FAO/WHO, 2002).

It is important to understand the different forms of vitamin A provide alternate levels of Retinol Equivalence (RE), the amount of compound that can be converted into preformed vitamin A (retinol) and absorbed adequately (FAO/WHO, 2002, NIH). A joint FAO/WHO Expert Group in 1967 introduced the concept of Retinol Equivalence (RE) and showed the relationship among the different forms of vitamin A, shown in table 1.1 (FAO/WHO, 2002). This table outlines the concept of the retinol equivalence (RE), with one RE being equal to 1 μg retinol, as a convention for comparing food sources of vitamin A. What can be seen in this table is that the absorption of carotenoids and their bioconversion to vitamin A (retinol) is less efficient than preformed vitamin A, which is already supplied in an adequate form (FAO/WHO, 2002). These conversion factors help to understand that bioefficacy of carotenoids and why preformed vitamin A is so advantageous.

Table 1: The Retinol Equivalence (RE) of Different Vitamin A forms

Vitamin A Form/Source	**Retinol Equivalence (RE)**
1 μg retinol	= 1 RE
1 μg b-carotene (less effective)	= 0.167 μg RE
1 μg other pro-vitamin A carotenoids (least effective)	= 0.084 μg RE

Adapted from FAO/WHO, 2002, *Human vitamin and mineral requirements. Chapter 7.*

Access to High Levels of Vitamin A through Orange-Yellow Fruits and Vegetables

In regions endemic for VAD, such as South-Asia and sub-Saharan Africa, shortages of vitamin A-rich foods correlates with the highest incidences of childhood infection (FAO/WHO, 2002). The prevalence of VAD in South Asian and Sub-Saharan African countries is the result of a number of factors, including insufficient access to proper dietary nutrients, economic constraints, and poor absorption of vitamin A (Akhtar et al., 2013). The situation is further complicated by low sources of preformed vitamin A (FAO/WHO, 2002).

In South Asia and sub-Saharan Africa where VAD is most prevalent, vegetable sources contribute up to 80% or more of the available supply of retinol equivalents (FAO/WHO, 2002). Seasonal food availability can result in changes and also scarcity of plant sources high in pro-vitamin A carotenoids and this availability influence the prevalence of VAD (FAO/WHO, 2002). For example, one should consider the scarcity of orange fruits in hot arid months in regions endemic for VAD (FAO/WHO, 2002). Thus, there is a need to balance vitamin A availability and need throughout the year in countries that experience dry seasons and limited resources. In order to address VAD using accessible interventions, it is important to use the materials that are readily available to the public. Table 1.2 outlines some household interventions to help reduce VAD (de Pee & Bloem, 2007).

Table 2: Optimizing Vitamin A Absorption and Intake Using Natural Food Sources

Optimization Technique/Intervention	**Natural Sources that Improve Vitamin A Uptake**
1. Consume more different possible food sources	Increase diet variability and accessibility of vitamin A-rich foods through diverse Homestead Food Production (HFP)
2. Give preference to foods with high vitamin A content and consider their bio-efficacy	Consume more of the following vitamin A-rich foods: - More vitamin A-rich animal foods (eggs, liver, fish, dairy products) - Use red palm oil - More red, orange, and yellow fruits - Produce orange-yellow varieties of crops
3. Increase the bioavailability of pro-vitamin A carotenoids	Increase bioavailability in the following ways: - Consume 3-5g of fat per meal - Cut, grind and homogenize the plant's lipid-matrix when preparing vegetables - Limit heating during preparation
4. Maximize Vitamin A Obtained from a food group	Maximize Vitamin A Obtained by: - Consuming fruits when fully matured - Give preference to fresh fruits and vegetables - Optimize storage to minimize carotenoid loss

Adapted from: de Pee & Bloem. 2007. *Int. J. Vitam. Nutr. Res.*, 77 (3), 182-192.

Foods that include a rich source of preformed vitamin A, such as fish, beef, and milk products, are sometimes not readily accessible in the regions endemic with VAD. Pro-vitamin A carotenoids are sometimes more accessible in these regions. They are found in yellow vegetables, orange-yellow non-citrus fruits, and leafy green vegetables (FAO/WHO, 2002). These orange-yellow vegetables and fruits can sometimes be more easily accessible and supported in regions endemic with VAD. A comprehensive list of orange-yellow products available in endemic areas can be found in table 1.3, along with their corresponding IU values. Red palm oil is also especially rich in pro-vitamin A carotenoids (FAO/WHO, 2002). From these results it can be seen that carefully cooking certain items such as sweet potato and carrots increases the IU of these items. This shows how cooking (but not too much heating) may break down plant matrixes and increase uptake of carotenoids into human metabolism. Indigenous plants in Africa and South Asia also produce many fruits, vegetables and leafy greens with many micronutrients, often including pro-vitamin A carotenoids (FAO/WHO, 2002).

Table 3: Orange-Coloured Fruits and Vegetables that are High in Vitamin A

Yellow-Orange Fruit or Vegetable Nutrition per 100 grams	**Vitamin (IU)**
High IU Vegetables	
Spices, chili powder	29,650
Sweet potato (cooked, baked in skin, flesh, without salt)	19,218
Carrots (cooked, boiled, drained, without salt)	17,033
Carrots (raw)	16,706
Sweet potato (raw)	14,187
Pumpkins (raw)	8,513
Red hot chili peppers (raw)	952
Tomatoes (red, ripe, raw)	833
High IU Fruits	
Cantaloupe Melons (raw)	3382
Apricots (raw)	1926
Mango (raw)	1082
Papayas (raw)	950
Watermelon (raw)	569
Red Palm Oil (Extra Virgin, Organics Overseas Inc.)	60,571

Source: USDA Food Composition Databases

Access to Vitamin A Through Leafy Greens

Pro-vitamin A carotenoids can also be found in green leafy vegetables, such as spinach, amaranth, and various other sources (FAO/WHO, 2002). The majority of the literature supports the consumption of eating dark green leafy vegetables to manage and prevent VAD (Müller & Krawinkel, 2005). A comprehensive list of pro-vitamin A carotenoid-rich leafy greens is seen in table 1.4, along with their corresponding IU values. It is important to recognize that although it may appear as though the leafy greens are very high in Vitamin A IU, 100 grams of leafy greens requires a lot of leafs, whereas for fruits and vegetables 100 grams may be one large carrot or mango. From these results it can be seen that cooking certain items such as Spinach, Collards, and mustard greens increases the IU of these items. Again, this shows how careful cooking may break down the matrixes and increase uptake of carotenoids into human metabolism. However, overcooking can damage the vitamin A content of the meal (de Pee & Bloem, 2007).

Table 4: Important Leafy Greens Sources High in Vitamin A IU Values, Cooked and Raw

Leafy Greens Nutrition per 100 grams	**Vitamin A (IU)**
Kale (cooked, boiled, drained, without salt)	13,621
Kale (raw)	9,990
Mustard greens (cooked, boiled, drained, without salt)	12,370
Mustard greens (raw)	3,024
Spinach (cooked, boiled, drained, without salt)	10,481
Spinach (raw)	9,377
Collard greens (cooked, boiled, drained, without salt) (*Brassica oleracea*)	7,600
Collard greens (raw)	5,019
Other High Vitamin A Leafy Greens (per 100 grams)	
Amaranth leaves (cooked, boiled, drained, without salt)	2,770
African spinach (Malabar spinach) (cooked)	1,158

Source: USDA Food Composition Databases

Many of these varieties of leafy greens are important sources of micronutrients to sub-Saharan Africa. For example, leafy greens such as Amaranth are eaten across the continent (NRC, 2006). To visualize why leafy greens would have a high content of carotenoids that often give an orange or red color, one can imagine leaves during the fall season in the northern hemisphere, as these leaves turn from green to orange-yellow pigments before falling to the ground. The potential of these leafy green products to aid in alleviating micronutrient deficiencies merits greater scientific attention.

Short Term and Long Term Interventions to Address VAD

Children need additional vitamin A because of high metabolic demands during growth, especially between 6-59 months old (UNICEF, 2016). VAD is a major contributor to child mortality under five in many high priority countries (UNICEF, 2007). To compensate for these needs in regions lacking in reliable vitamin A-rich food sources throughout the year, three specific interventions to improving vitamin A status are possible. These interventions are supplementation, fortification, and homestead food production/dietary diversification.

1. Supplementation: High supplement coverage, defined by the WHO's UNICEF supplement project, is the administration of two high dose vitamin A supplements, provide in small capsules, spread over 4-6 months (UNICEF, 2007). This coverage is the principle strategy to eliminate VAD because of its feasibility as well as its ability to ensure adequate biological supply of vitamin A. This coverage can simultaneously eliminate VAD in endemic regions while reducing childhood mortality under five by approximately 23 percent because of enhanced resistance to disease (UNICEF, 2016). It can also reduce mortality in babies younger than 6 months by 21 percent (Bhutta, Darmstadt, Hasan, Haws, 2005; Bhutta et al., 2008). Currently, the delivery of these supplements occurs through various national immunization or health days as well as routine health services. However, there are concerns that integrating supplementation into routine health services has not yet provided full coverage and so outreach initiatives must continue, such as delivery of supplements through outreach campaigns (UNICEF, 2007). Finally, the WHO recommends immediate supplementation for women in the post-partum period, and this should be coupled with the child's first immunization (UNICEF, 2007).

2. Food fortification: Two high-dose supplementations of vitamin A capsules is the principle strategy to fight VAD and it is the most effective (UNICEF, 2007). However, food-based approaches, including food fortification and dietary diversification to eat foods rich in vitamin A are increasingly feasible options (UNICEF, 2007). When foods are fortified or bio-fortified to address micronutrient deficiencies as public health initiatives, foods such as sugar, cereals, fats, and oils are enriched with certain vitamins or minerals (FAO/WHO, 2002). Food fortification of local staple crops in regions is the especially beneficial. Food fortification requires a significant amount of technological capital, distribution, and political commitment to reach VAD-affected areas and to be effective over the long time span needed to address micronutrient deficiencies (UNICEF, 2007).

3. Homestead food production/dietary diversification: In order to have a sustained source of vitamin A in endemic regions for VAD, sustainable community-based solutions are essential. An example of dietary diversification, Homestead food production (HFP) - increasing vitamin A-rich cultivar production and consumption - is generally successful in increasing vitamin A intake in regions with limited access to dietary diversity (de Pee & Bloem, 2007). Introducing vitamin A-rich cultivars and improving breeds through the interventions outlined in this book will create lasting solutions for communities, especially those that are the most remote (de Pee & Bloem, 2007). Dietary diversification is especially successful when coupled with nutrition education (de Pee & Bloem, 2007). Although progress has been made, these three major interventions have not solved the problem in priority countries, such as South Asian countries, because of poor governmental support and supervision (Akhtar et al., 2013). Impacts can be maximized when all of these interventions are supported together.

Critical Analysis

To those interested in addressing VAD, it is important to take a critical lens on the information provided here in order to ensure solutions are properly implemented. First, one should recognize that the only specific symptoms for VAD are ocular deficiencies, such as xerophthalmia and night blindness, whereas the many non-specific symptoms of VAD, including increased mortality, anaemia, and stunted growth, could be the result of other key nutrient deficiencies such as iron, zinc, or proteins (FAO/WHO, 2002). Next, a study published by the lancet showed that increased leafy green vegetable intake did not significantly improve vitamin A status in the sample population, although more recent studies published by the same author have concluded that although less beneficial than orange fruits and vegetables, leafy greens can assist in combating VAD (de Pee, West, Hautvast, Karyadi, 1995; de Pee & Bloem, 2007). Remember getting to 100 grams requires a lot green leaves. Finally, excess vitamin A consumption is toxic (Merck Manuel, 2016). Overconsumption can result in liver damage, dry skin, and weaker bones, among other concerns. However, most people recover when supplementation is discontinued (Merck Manuel, 2016; FAO/WHO, 2002). Taking 10 times the recommended daily allowance for months can cause toxicity, and smaller doses can cause toxicity in infants in weeks, while a very high dose could lead to fast-acting toxicity in infants (Merck Manuel, 2016). However, toxicity rarely occurs from ingestion of either form of vitamin A from food sources, other than high consumption of liver products (FAO/WHO, 2002).

Table 5: Estimated mean requirement and safe level of intake for vitamin A

Age group	Mean requirement µg RE/day	Recommended safe intake µg RE/day
Infants and children		
0-6 months	400	375
7-12 months	400	400
1-3 years	450	400
4-6 years	500	450
7-years	600	500
Adolescents, 10-18 years	330-400	600
Adults		
Females,19-65 years	600	500
Males, 19-65 years	600	600
65+	300	600
Pregnant women	370	800
Lactating women	450	850

Source: FAO

Cultural Relativity

Culture plays an important role in the foods consumed in certain regions. Good source of vitamin A, including the orange-yellow fruits and vegetables, can at times be restricted due to culturally related factors, such as food taboos (FAO/WHO, 2002). In many traditional cultures, certain foods are prescribed during illness and childbirth, influencing the nutrition that individuals experience at unique times (FAO/WHO, 2002). Furthermore, culture impacts foods freely consumed by children and pregnant women (FAO/WHO, 2002).

An example of how cultural factors can impact initiatives that reduce VAD is the case of Golden Rice (GR). GR is genetically modified rice that is concentrated with pro-vitamin A carotenoids as a public health initiative to address VAD (Al-Babili & Beyer 2005). The name GR comes from the yellow colour of the grains visible during milling and resulting from the substantial carotenoid concentration (Al-Babili & Beyer 2005). However, yellow rice is associated with disease in rice in some countries, leading some farmers to refuse to plant these cultivars. Although GR and its overall impacts are still being researched and considered, cultural acceptance of interventions must be considered (Al-Babili & Beyer 2005).

More Resources and Moving Forward

Excellent report on WHO world supplementation progress as of February 2016:
https://data.unicef.org/wp-content/uploads/2016/04/VAS-brochure-web-final_253.pdf

UNICEF's Report on a decade of progress in reducing VAD:

https://www.unicef.org/publications/files/Vitamin_A_Supplementation.pdf

The IRRI is developing rice, the staple food of more than half the world's population, to alleviate micronutrient malnutrition: http://irri.org/our-impact/making-rice-healthier

The Micronutrient Initiative is a worldwide project to address micronutrient deficiencies such as VAD: http://www.micronutrient.org

Book on food based approaches to combating micronutrient deficiencies: http://www.cabi.org.subzero.lib.uoguelph.ca/cabebooks/ebook/20103380332

FAO's Statistics on good Fruits and Vegetables to Eat: http://www.fao.org/wairdocs/other/ai215e/AI215E08.htm

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10.5 - Amaranth leaves as a source of protein and nutrients

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Background

Amaranth is a genus of plant that has the potential to solve nutrient deficiencies in developing nations (National Research Council, 2006). It is eaten both as a leafy green vegetable and for its grain, and is grown in around 50 countries (National Research Council, 2006). Amaranth is considered an under-utilized crop, and is largely unknown by the western world (Alemayehu, 2015). This is a shame considering that amaranth helps feed and nourish many people living in developing nations today (National Research Council, 2006).

One of the most distinguishing qualities of amaranth vegetable is its high protein composition (Alemayehu, 2015). The protein score of amaranth (as defined by WHO) is 74, which is higher than most commercial crops (wheat: 47, rice: 69, soya bean: 68-89 and maize: 35). Amaranth also contains a very balanced amino acid composition which is close to the levels recommended by FAO/WHO for a healthy human diet (Alemayehu, 2015). It is high in the essential amino acids histidine and lysine, as well as the non-essential amino acid arginine (Alemayehu, 2015).

Amaranth vegetable contains high levels of vitamins and minerals (Onyango *et al* 2012). The two vitamins that appear in the highest quantities in amaranth are vitamin A and vitamin C. Amaranth also contains high levels of important minerals such as iron, calcium and phosphorus (Onyango *et al* 2012). Lastly, amaranth has significant levels of antioxidants due to the presence of flavonoids (Amaranth: Future-Food, 2009). All in all, the nutritional value of amaranth is considered higher than wheat, maize, soya bean and milk (Alemayehu, 2015).

In addition to nutrient quality, amaranth is also highly regarded because of its ability to grow under a number of adverse growing conditions (Alemayehu, 2015). Amaranth is a crop that matures very quickly, leaves can be harvested as early as 3 weeks after planting. This is a key characteristic for amaranth to have, because it can alleviate hunger by acting as a supplemental food source in the time between harvests of longer-growing crops (National Research Council, 2006). This period, when food is the most scarce, is often referred to as the “lean season” and it contributes considerably to hardship and hunger (USAID, 2015).

There are about 60 species of amaranth worldwide (USDA, 2016). All are annuals which produce small seeds. Most of these species consist of weeds which are not cultivated. The subset of this species which is cultivated can be divided into three groups: ornamental amaranths which are grown for their beauty, vegetable amaranths which are grown for their foliage and grain amaranths which are grown for their seeds (USDA, 2016). There are currently 18 species of amaranth which can be used to produce food available at the World Vegetable Centre (AVGRIS, 2016). For a description of five of the most common species used for food see Table 1 in Appendix 1.

Other Benefits

Amaranth plants have many additional uses. For example, it can be sold in the local market, making it a cash crop (FAO, 2006). Amaranth is also used as a traditional medicine for conditions like tape worms, high blood pressure, and urinary and throat infections (Alemayehu, 2015). It can be used as a highly nutritious animal feed (Amaranth: Future-Food, 2009), as a type of firewood, or as a dye for the colours red, green and yellow. Amaranth can also be used as a cover crop and can be intercropped with taller plants like banana, cassava and trees because it is shade-tolerant (National Research Council, 2006).

Besides the many uses of vegetable amaranth, amaranth grain can be used as a nutritious food source (National Research Council, 2006). Amaranth plants will produce a very large amount of seed which can either be used for planting, or can be used as a grain. This grain is often parched and milled into flour in a process similar to most cereals (National Research Council, 2006). Grain amaranth has significantly higher amounts of certain minerals including calcium, iron, phosphorus, potassium and zinc (USDA, 2016). However, its protein content is lower and is only about 11-12% (Amaranth: Future-Food, 2009).

Growing Amaranth

Amaranth does well in hot, humid environment (National Research Council, 2006). They can tolerate a range of temperatures between 22-40˚C. Amaranth can be grown in upland areas, as most species can survive in altitudes up to 800 m (National Research Council, 2006). The nitrogen requirements of amaranth are about 40 kg/ha (Onyango *et al* 2012). The use of either livestock manure, or legumes in preceding crop rotations should provide enough nitrogen to the soil (Alemayehu, 2015). If these nitrogen-boosting practices are not available, nitrogen fertilizer will substantially boost yields (National Research Council, 2006). The pH of the soil should be around 5.5-7.5 however some cultivars will tolerate a higher and more alkaline pH. Amaranth thrives in a variety of soil textures but will do best in sandy, well-drained soil with a high organic content (National Research Council, 2006). Amaranth can survive on as little as 200 mm of rain in a year, making it very drought tolerant (Grosz-Heilman *et al* 1990). Despite this drought tolerance, irrigation immediately after planting is advantageous (OMAFRA, 2012).

Amaranth is normally grown from direct seeding (National Research Council, 2006). The seeds are broadcasted and then covered with a tiny layer of soil (National Research Council, 2006). The soil covering should be about 1-2 cm thick and the seeds should be planted at a rate of 2.2 kg/ha (Myers, 2000). The seedlings are normally grown in nursery beds and then are transplanted one they are big enough (National Research Council, 2006). Within a month (in warm weather and high rainfall within 3 weeks) the plants are large enough to either be eaten or transplanted. Once amaranth is mature, they are a very easy vegetable to grow and require very little attention (National Research Council, 2006).

Amaranth has very large yields and can be harvested several times in one growing season (National Research Council, 2006). The entire plant can be harvested and eaten, but it is more common for just the young shoots and leaves to be picked. On a 10 m squared plot as much as 30-60 kg of vegetable has been produced. One way to keep amaranth plants producing leaves instead of going to flower is by repeated pruning and pinching of the plants as well as keeping the plants thoroughly watered (National Research Council, 2006).

Seed yields are much more variable and are highly dependent on cultivar and environmental conditions (Alemayehu, 2015). For dry land, seed yields between 450-700 kg/ha are reasonable while on land that gets high levels of rainfall or is irrigated, a seed yield of between 900-2000 kg/ha is reasonable (Alemayehu, 2015).

Cooking Amaranth

Amaranth leaves have a soft texture with a very mild flavour, similar to artichoke, and no trace of bitterness (National Research Council, 2006). The leaves are first boiled and then are often put into soups and stews or pushed through a sieve and served as a puree. The leaves and stems should only be boiled for a few minutes in order to reduce nutrient losses. The leaves should turn an emerald green colour after boiling. It is important to note that the colour of the water that the amaranth is boiled in should turn a dark colour. This darkened water should be tossed away and should not be consumed because it contains compounds which interfere with our ability to utilize nutrients. Young leaves will contain less of these compounds which is why it is important to harvest amaranth early and regularly (National Research Council, 2006).

Amaranth grain also has a variety of uses (Mburu *et al*. 2012). These include being popped, or toasted. Amaranth flour can be used to make tortillas, cookies and bread among other things (Mburu *et al*. 2012).

Potential Problems

There may be issues with the acceptability of amaranth, which may hinder its incorporation into the diets of people who are not accustomed to it (Elbien, 2013). Katherine Lorenz has been introducing amaranth into the diets of the people living in rural Oaxaca, a state in Mexico (Elbien, 2013). Lorenz found that there was a very low adoption rate when amaranth was being introduced as a staple crop for local consumption. Even though its nutritional benefits were being promoted, many farmers still opted to stick to their local diets. Lorenz found that the best way to promote this crop was to promote it as a cash crop. Once the locals realized they could sell it for money, there were higher instances of amaranth being grown, and farmers were therefore more likely to eat it (Elbien, 2013).

Don Lotter, who was involved in projects to introduce amaranth into San Juan Comalapa, Guatemala also speculates that a big problem in amaranth adoption rates is advertisement (Lotter, 2005). He suggests that without massive advertising campaigns, amaranth has a poor chance of becoming a staple food for local peoples (Lotter, 2005).

These kinds of integration projects also take time (Puente, 2016). For example, Puente, an organization that promotes amaranth consumption in areas of Mexico, took 11 years (from 2003-2014) to get 15% of targeted families to adopt amaranth into their diets. In this organization, adoption into diets is categorized by amaranth being eaten 2-3 times a week. However, with ongoing persistence, this adoption rate number is projected to be closer to 50% by 2017 (Puente, 2016).

Although amaranth does not have any major diseases associated with it, it does still have several minor growth inhibiting issues (Alemayehu, 2015). The major fungal diseases associated with amaranth are damping-off fungal disease of seedlings, and cankers. In order to reduce the instances of damping-off, seedbeds must be well drained and ideally located in sunny areas (National Research Council, 2006). Various fungicides have also been proven effective against these diseases (National Research Council, 2006). Currently, there are not any fungicides labelled for use on amaranth, therefore, diseases have to be managed through proper site selection (Center for Crop Diversification, 2011).

Amaranth also has several pests associated with it (National Research Council, 2006). Leaf-chewing insects often pose a serious threat (National Research Council, 2006). Despite being susceptible to insects, amaranth is considered very resistant to nematodes (Alemayehu, 2015). Amaranth can be an effective means of controlling nematode populations when it is placed in crop rotations with plants that are more susceptible to nematodes (Alemayehu, 2015).

Practical Resources

An amaranth production guide from the Agriculture, Forestry and Fisheries department for the Republic of South Africa can be found at:
http://www.nda.agric.za/docs/Brochures/Amaranthus.pdf

An amaranth production guide from the World Vegetable Center can be found at:
http://203.64.245.61/web_crops/indigenous/Grow_Amaranthus.pdf

A guide on saving amaranth seed from the World Vegetable Center can be found at:
http://203.64.245.61/web_crops/indigenous/amaranth_seed.pdf

The following website are some suppliers of amaranth seed:

A supplier of amaranth seed located in India is Raj Foods International which can be found at:
http://www.rajfoods.co.in/products/amaranth-seeds.html

A supplier for *Amaranthus hybridus* seed for areas in South Africa is the company Organic Seeds which can be found at: http://www.organicseed.co.za/62-amaranth

A supplier of several different amaranth species is the U.S. National Plant Germplasm System which can be found at:
https://npgsweb.ars-grin.gov/gringlobal/search.aspx

West Coast Seeds supplies the species *Amaranthus tricolor* as well as several other species and can be found at here:
https://www.westcoastseeds.com/shop/vegetable-seeds/amaranth-seeds/red-leaf-amaranth-seeds/

Further Reading

Information about the Amaranth: Future-Food Project can be found at:
http://www.amaranth-future-food.net/Amaranth.asp

More information about grain amaranth published by the Jefferson institute can be found at:
http://amaranthinstitute.org/sites/default/files/docs/Amaranth_crop_guide.pdf

Information about the value of amaranth seed oil on the international market can be found at:
http://www.marketsandmarkets.com/PressReleases/amaranth-seed-oil.asp

The nutritional value of boiled amaranth leaves from the United States Department of Agriculture can be found at:
https://ndb.nal.usda.gov/ndb/foods/show/2817?manu=&fgcd=&ds=

Information about Puente, an organization that promotes amaranth growth in areas of Mexico can be found at:
http://www.puentemexico.org/content/mission-and-values

For more information about the varieties of seed available at the World Vegetable Centre see:
http://203.64.245.49/AVGRIS/search/characterization/amaranthus

For more information on growing amaranth and on different species of amaranth see the following paper: http://ageconsearch.umn.edu/bitstream/121422/2/AAE%20No.90003.pdf

For more information about amaranth see the following book chapter in the book Lost Crops of Africa: Volume 2: Vegetables, available at https://www.nap.edu/read/11763/chapter/3

Table 1: Characteristics of some of the most common types of amaranth used for food regularly (National Research Council, 2006).

Species	**Range**	**Additional Information**
Amaranthus cruentus	Western Africa	• Often called blood amaranth • The white-seeded form is used for grain and the black-seeded form is for vegetable • This species can grow at higher altitudes (up to 2000 m)
Amaranthus dubius	Africa, the Caribbean, parts of Indonesia, the Andean region of South America and throughout the Himalayas	• Its broad, rigid leaves are a dark green colour • This species is fast growing, high yielding and has a high palatability
Amaranthus hybridus	South-western United States, China, Indonesia, Malaysia, Mexico, Thailand, the Philippines, Nepal, and the Caribbean	• Size and colour vary • Very resistant to moisture stress • Has very large seed yields
Amaranthus blitum (also known as *Amaranthus lividus*)	Africa, Greece and Taiwan	• Well adapted to temperate climates • The leaves are very popular because they are sweet and have a sweet taste
Amaranthus tricolor	East Asia, China and India	• A large number of cultivars have been developed in India • One of the most developed vegetable forms of amaranth • Some varieties are bred as ornamentals • They can survive in arid environments

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10.6 - Cucurbit seeds as a source of protein and nutrients

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Introduction

Today, approximately half of the world's population lives on less than $2USD per day (WHO, NMH, & NHD, 2012). One of the most pressing challenges faced by this demographic is malnutrition. According to the WHO et al., a strong correlation exists between instances of underweight children and absolute poverty (2002). Mothers and children tend to be most affected by under nutrition. This malnutrition tends to occur when a lack of protein or energy is compounded with a micronutrient deficiency such as iodine, iron, or vitamin A (Haddad et al., 2014). Undernutrition is a multifaceted issue, encompassing a combination of inadequate diet and frequent infection, leading to further deficiencies in micronutrients (WHO et al., 2012). WHO et al. estimates that 27% (168 million) of children under five years old and 27-51% of women of reproductive age are underweight (2002). These statistics represent those who are categorized as severely underweight. However, the fatal risks associated with under nutrition are not limited to this demographic; even mild under nutrition can put an individual at an increased risk of dying from ensuing illness or infection (Haddad et al., 2014). According to the WHO et al., approximately 50-70% of the burden of diarrhoea, measles, malaria, and lower respiratory infections in childhood is attributed to under nutrition (2002).

As depicted in Table 1 below, protein related deficiencies prevail worldwide especially in the case of children under the age of five, contributing to conditions such as stunting and wasting. Lack of dietary protein tends to be a consequence of food insecurity due to factors such as crop failure from drought, disease, or pests (Guilbert, 2003). Iron deficiencies are also a prominent issue worldwide, effecting primarily women of reproductive age and children (Haddad et al., 2014). Iron is vital to numerous bodily processes such as carrying oxygen from the lungs to other tissues via red blood cells (UNICEF, WHO, & The World Bank, 2012). Lack of Iodine is another predominant nutritional issue worldwide effecting 28% of the population (Black et al., 2013). Iodine is essential in regulating thyroid hormones, insufficient iodine can result in difficulty swallowing or breathing (Haddad et al., 2014; World Health Organization & Food and Agriculture Organization of The United Nations, 2004).

Table 1: Illustrating the prevalence of nutrient deficiencies worldwide (Black et al., 2013; "Haddad et al., 2014;UNICEF et al., 2012).

	Baseline Year	Baseline status
Stunting (Children <5 years)	2012	162 million
Iron (Haemoglobin <110 g/L)	2011	29%
Wasting	2012	8%
Vitamin A (<0-70 µg/L)	2013	
Iodine (UIC <100 µg/L)	2013	28%

Potential of Cucurbitaceae Seeds

The Cucurbitaceae family represents a promising solution to reducing undernourishment worldwide. Egusi (*Colocynthis citrullus* L.) and pepita (*Cucurbita pepo*) are two underutilized species within this family whose seeds represent an excellent source of protein and micronutrients. Although seeds of legumes and pulses are typically looked towards as sources of high quality protein, the seeds of the cucurbit family are often overlooked. As illustrated in Tables 2 and 3, both egusi and pepita significantly contribute to fulfilling the daily nutritional requirements, especially in case of protein, fat, iron, and zinc.

Table 2: Daily Recommended Nutrient Requirements (*Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate*, 2005; Haddad et al., 2014; Ross, Taylor, Yaktine, & Valle, 2011)

	Protein (g)	Fat (g)	Carbs (g)	Iron (mg)	Zinc (mg)	Vitamin A (IU)	Folate (ug)
Infant	11	30	60-90	11	3	400	80
Child	13-19	30	130	10	5	400	200
Female	46		130	18	8	700	400
Male	56		130	8	11	900	400

Table 3: Nutrient Composition of Select Cucurbitaceae Species (Akobundu et al., 1982; Achu et al., 2005)

Cucurbitaceae Species	**Energy (Kcal)**	**Protein (g)**	**Fat (g)**	**Carbs (g)**	**Iron (mg)**	**Zinc (mg)**	**Vitamin A (IU)**	**Folate (ug)**
Melon Seed (Egusi)	557	28.3	47	15.3	7.3	10.24	0	58
Pumpkin Seed (Pepita)	559	30.23	49	10.7	8.82	7.81	16	58

Colocynthis citrullus L. (Egusi) produces bitter flavoured melon-type fruits similar to a cantaloupe (Akobundu et al., 1982). Egusi is a tendril climbing annual which is known to be tolerant of drought, humid environments, and depleted soils (Okoli, 1984). Grown widely in West Africa, this crop occupies an important role in the diet and culture of many ethnic groups (Okoli, 1984). Due to widespread popularity in various regions throughout Africa, Egusi seeds are relatively inexpensive and readily available making them excellent for diffusion to other countries (Achu et al., 2005). The seeds contain 24.8% protein (60% in defatted flour) and are rich in the essential amino acids: arginine, tryptophan, and methionine (Akobundu et al., 1982). Amino acids are the building block of protein, incorporating all nine essential amino acids is vital to maintaining a complete diet. In the case of Egusi seed, this would mean combining a food high in lysine such as soybeans (or other legume grain) into meals (Achu et al., 2005). The addition of lysine increases the availability of protein from the seeds (Akobundu et al., 1982). Lack of protein in a diet can be extremely problematic, leading to conditions such as wasting or stunting (WHO et al., 2002). Egusi seeds hold significant potential in providing a high protein food source and improving food security.

Defatted Egusi seeds can be ground up into flour, increasing available protein, calcium, thiamin, and niacin (Akobundu et al., 1982). The increased calcium availability in the flour has been found to be especially beneficial in regions where milk consumption is low (Akobundu et al., 1982). Utilizing Egusi in the form of flour not only has added nutritional benefits but could also increase adoption rates since flour is a popular cooking commodity in various cultures. In another method of preparation the seeds are soaked, boiled, blackened with charcoal. Then the seeds are wrapped in banana leaves for fermentation, producing a food seasoner known as "ogiri-isi", which can be added to soups, providing flavour and thickening properties (Okoli, 1984). Alternatively, the seeds can be roasted like peanuts and consumed as a snack type food (Okoli, 1984). All of these additional processing methods enrich nutritional value by increasing protein and mineral availability and extend shelf life (Stevenson et al., 2007).

Cucurbita pepo contains eight groups of cultivars commonly grown for consumption, which includes pumpkin, scallop, acorn, crookneck, straightneck, vegetable marrow, cocozelle, and zucchini (Paris, 1989). These cultivated forms are domesticates of wild forms originating from North-eastern Mexico and Texas (Paris, 1989). Pepita seeds typically refer to roasted pumpkin seeds, traditionally consumed in Latin America (Lira & Caballero, 2002). These seeds are high in oil, protein, tocopherols, and carbohydrates (Achu et al. 2005). The oil is composed primarily of polyunsaturated fatty acids, providing a high source of energy (Noor Raihana et al., 2015). Pumpkin seeds are also rich in tocopherols, also known as vitamin E, which is a fat-soluble antioxidant important for protection against toxins and eye disorders such as cataracts (World Health Organization & Food and Agriculture Organization of The United Nations, 2004). The meat of the pumpkin can also be consumed, providing a substantial dietary source of both vitamin C and A (Noor Raihana, Marikkar, Amin, & Shuhaimi, 2015). Similarly to egusi seeds, the high protein and unsaturated oils make pepita a valuable dietary protein source and high value cooking oil. Pumpkin seed oil colour tends to vary from dark green to brown and can be stored for longer periods of time since it is highly unsaturated (Stevenson et al., 2007).

Challenges

Although egusi seeds hold promising potential as a dietary protein source, they are high in phytic acid, reducing the availability of minerals (Enujiugha & Ayodele-Oni 2003). However, high phytate levels can be reduced through further processing such as heating or soaking (Enujiugha & Ayodele-Oni 2003). Another aspect of egusi nutritional content which should be taken into consideration is that it is relatively low in histidine, an essential amino acid for infants (Akobundu et al., 1982). Flour and oils are utilized worldwide in various culinary practices, however, the oil and flour processed from egusi and pumpkin seeds may vary in taste or colour reducing the likelihood of adoption. In order for pumpkin seeds to be consumed they must first be de-shelled; there are machines available to perform this task in larger quantities but they tend to be quite expensive. De-shelling by hand can be extremely time consuming which may deter adoption. An additional challenge is that egusi is relatively susceptible to root-knot nematodes which pose a substantial challenge to maintaining yields. The growing region may influence the crop losses associated with this pest, as will access to extension services. In order for the potential of cucurbit seeds as a protein source to be utilized, there needs to be more research and funding. Unfortunately, research funding tends to be predominantly Western led, who may not receive the same degree of benefits from the expansion of this protein source.

Further Reading:
http://www.wikihow.com/Shell-Pumpkin-Seeds - Provides steps and associated graphics detailing how to de-shell pumpkin seeds

Pumpkin Extension Manuals:
http://extension.psu.edu/business/ag-alternatives/horticulture/melons-and-pumpkins/pumpkin-production
http://www.infonet-biovision.org/PlantHealth/Crops/Pumpkin

Egusi Extension Manuals:
https://www.nap.edu/read/11763/chapter/10#170

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10.7A - Legumes and seeds as folate sources for pregnant women

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Folate Deficiency

This chapter will outline how folate deficiency can be detrimental to one's health, while also outlining various sources of folate found in many seeds and legumes grown throughout the developing world. Folate deficiency (FD) results from a reduced intake of folate – a generic term that encompasses both naturally occurring food folate as well as folic acid (NIH, 2016). FD can also occur due to heightened folate demands during pregnancy or because of impaired absorption occurring from mal-absorption disorders (Merck Manuel, 2016). Folate is a water soluble-B vitamin complex that is naturally available in foods while also frequently enriched in foods or provided as food supplements (NIH, 2016). Folic acid is the term used for the fully oxidized form of the vitamin complex used in dietary supplements and in fortified foods (NIH, 2016).

Folate deficiency is thought to contribute to the prevalence of many major diseases and severe birth defects (Basset, Quinlivan, Gregory, & Hanson, 2005). To help understand the common causes of folate deficiency, they are listed on the table 1. Inadequate intake can be the result of diseases that impacts absorption, use of various drugs, of simply inadequate dietary intake (Merck Manuel, 2016).

Table 1: Causes of Folate Deficiency

Cause of Folate Deficiency	**Source of the Cause**
Inadequate intake	- Lack of raw green vegetables in diet - Lack of enriched grains in diet - Chronic alcoholism
Impaired absorption	- Mal-absorption syndromes or acquired folate mal-absorption - Anticonvulsant intake - Celiac disease
Inadequate utilization	- Anticonvulsant intake - Drug intake that prevent folate use (folate antagonists) - Alcoholism
Increased demand	- Pregnancy and lactation - Infancy
Increased excretion	- Hemodialysis

Adapted from: *Merck Manuel, Folate (Folic Acid), Causes of Folate Deficiency*

Health Issues Resulting from Folate Deficiencies

Folate deficiency is associated with multiple cancers, cardiovascular disease, and Neural Tube Defects (NTDs) (Basset et al., 2005; NIH, 2016). Folate is a critical factor for the synthesis of the components of DNA, namely for the synthesis of purines and pyrimidines, as well as for the development of the fetal nervous system, red blood cells, and other cellular components (Merck Manuel, 2016). Furthermore, folate is important during phases of rapid cell growth, such as during fetal development, due to heightened cellular demands (NIH, 2016). Because this vitamin complex is an imperative cofactor for the synthesis of DNA precursors, one can see the range of adverse health effects that can occur in FD individuals. This section will briefly discuss the adverse health outcome resulting from FD starting with NTDs – a severe defect due to FD during pregnancy.

NTDs result in dangerous malformations that occur during fetal development, including various malformations of the spine (spina bifida), skull, and brain (anencephaly) in a newborn following a folate deficient pregnancy (NIH, 2016; Merck Manuel, 2016). NTDs are a failure for the neural tube to close at the upper or lower end between days 21 to 28 of post-conception pregnancy (NIH, 2016). As such, NTDs should be of concern for all pregnant women. Women lacking in folate intake are at risk of having children with NTDs, along with other complications such as low birth weight and early delivery (NIH, 2016). However, multiple clinical trails have clearly shown that a substantial proportion of NTDs can be easily addressed by taking folic acid pre-conceptionally (NIH, 2016). This evidence has led to required food fortification programs that have reduced by NTD rates by 25%-30% in the USA, and researchers believe this rate could be reduced even more if access inequalities are addressed (NIH, 2016). Risk of NTD is not always dependent solely on folate status, but rather a combination of other factors, such as obesity and low intake of other key nutrients, that may affect NTD risk (NIH, 2016).

While the relationship between FD and NTD is well established, the implications if FD in other major diseases are less certain. FD has been inversely associated with risk of multiple cancers (including colorectal, pancreatic, and more) as folate may influence the development of cancers due to its importance in DNA replication and cell division (NIH, 2016). However, further research is needed due to the high uncertainties around the role of folate in carcinogenesis, cardiovascular disease, and many health issues (NIH, 2016). What is certain is that folate is a key micronutrient for metabolism and many bodily processes (NIH, 2016).

Absorption of Folate and Folic Acid

As can be discerned in table 1, FD in isolation is not as common as its coexistence with multiple other nutrition deficiencies associated with mal-absorptive disorders, drug intake, and poor diet (NIH, 2016). Considering the causes of poor folate uptake into the human body, the following groups are considered at heightened risk of FD: 1. People with alcohol dependence, as alcohol interferes with folate absorption and accelerates its breakdown (NIH, 2016). 2. Women of childbearing age, as FD increases the risk of NTDs, and these women should obtain 400 micrograms/day of folic acid (NIH, 2016; WHO, 2012). 3. Pregnant women, as the demands for folate intake increase due to the growing fetus's need for cellular division and DNA synthesis (NIH, 2016). These women require 600 micrograms/day. 4. People with mal-absorptive or digestive-tract disorders, as these medical conditions can lower the natural folate absorption into the body (NIH, 2016). Generally, poor absorption of folate and increased demands predispose people to the greatest risk of FD. Additionally, prolonged cooking destroys folate and can predispose people to inadequate intake (Merck Manuel, 2016). This is important information for subsistence farmers and those without access to enriched gains who may meet folate dietary needs through local raw green vegetables, legumes, and intake of seeds.

Natural Sources of Folate and Folate Fortification/Supplementation

Consumption of a diversity of foods and vegetables is key to providing adequate supply of folate, among other vitamins and minerals. Beans and dark green vegetables are some of the foods with the highest natural folate concentrations (NIH, 2016). Many of the leafy greens are also high in iron, folate, and vitamin A. Natural folate can be found in beans and dark green leafy vegetables such as spinach, turnips, and seaweed. Folate can also be found in nuts, seeds, diary/egg products and meats, (NIH, 2016). Some of these products can be seen from table 2. The benefits of legume consumption for folate are further outlined in table 4.

Many countries (U.S., Canada, South Africa, Chile) have now established folic acid fortification programs, mainly enriching breads, cereals, flours, and other grain products with folic acid (NIH, 2016). The highest amounts of folate are now found among folic acid-enriched cereals (USDA, 2017). The U.S. Food and Drug Administration's fortification program has aimed to increased folic acid intake by 100 micrograms per day (NIH, 2016). As such, folic acid supplementation is an effective disease-prevention measure for helping to addressing folate deficiency on a large scale. It should also be noted that the National Institute of Health reports that folic acid is more bioavailable (85% availability) than folates naturally present in foods, which are said to have 50% bioavailability and requiring higher intake (NIH, 2016).

Table 2: Foods and Vegetables High in Folate

Foods High in Folate Nutrition	**Folate (μg) per 100 grams**
Pinto Beans (*Phaseolus vulgaris*): mature seeds, raw	525
Lentils (*Lens culinaris*): raw	479
Chicken (capons, giblets, cooked, simmered)	414
Egg (whole, dried)	119
Vegetables High in Folate	
Radish (oriental, dried)	295
Turnip greens (raw)	194
Turnip greens (cooked, boiled, drained, no salt)	118
Spinach (raw)	194
Spinach (cooked, boiled, drained, no salt)	146
Seaweed (kelp, raw)	180
Kale (raw)	141
Parsley (fresh)	152

Source: USDA Nutritional Database

Eat Seeds and Legumes for Higher Natural Folate and Mineral Nutrition

In general, the seeds of fruits and vegetables are very high in iron, zinc, folate and other minerals (USDA, 2017-a). The seed's outermost layer, known as the pericarp, contains the highest concentration of minerals, helping to strengthen this protective outer layer of the seed. This means that the pericarps of fruit and vegetable seeds are generally the area of the seed highest in mineral content. Seeds are often referred to as nutrient "sinks" because seeds accumulate nutrients for long-term storage from their parent plants (Zhang et al., 2007). The amount of folate in seeds is significant, as seen in table 1.3.

Seeds can also provide the necessary protein and fat content needed to fight many micronutrient deficiencies, as fat intake is important for micronutrient absorption (Wickens, 1995; FAO/WHO, 2002). Pumpkin and squash seeds kernels can provide more than 30 grams of protein per 100 grams of seeds (USDA, 2017-b).

Table 3: Seeds of Fruits and Vegetables that are High in Folate

Fruit or Vegetable Seeds Nutrition	**Folate (µg) per 100 grams**
Sunflower seed kernels (dried)	227
Acorns (dried)	115
Chestnuts (dried)	110
Lotus seeds (dried)	104
Sesame seeds (whole, dried)	97
Watermelon seed kernels (dried)	58
Pumpkin and Squash seed kernels (dried)	58

Source: USDA Nutritional Database

As such, seed of fruits and vegetables should be considered in malnutrition interventions by relief organizations, in addition to the possible fortification of staple crops. Seeds and legumes keep for a long period of time, acting as a reliable food source throughout the year in drought-stricken regions. Considering the seeds of local fruits and vegetables as well as legume pulses (legume grains) may be an advantageous folate/nutrition source, especially give that pulses and seeds can be stored and keep over the dry season, when other crops are not available.

Legumes also contain an outer layer "coating" structure that is high in minerals and folate. For example, the red layer surrounding kidney beans is good source of minerals, including folate. The high folate content of various legumes can be seen in table 4. From table 4, analysis of the species name of Kidney, Pinto and Black beans shows that many frequently consumed beans are in fact the same species, *Phaseolus vulgaris*, also known as "the common bean." *Phaseolus vulgaris* exists in various varieties. Table 4 shows that although the legume species is the same, nutritional concentrations can differ between varieties, even if their pulses look similar.

Table 4: Legumes Folate Nutrition (*legumes are also high in and other nutrients/minerals)

Legumes Species High in Folate	**Folate (μg) per 100 grams**
Cowpea (*Vigna unguiculata subsp. Unguiculata*): common, mature seeds, raw	633
Mung bean (*Vigna radiata*): mature seeds, raw	625
Chickpea (*Cicer arietinum*): garbanzo beans, bengal gram, mature seeds, raw	557
Pinto beans (*Phaseolus vulgaris*): raw	525
Lentils (*Lens culinaris*): raw	479
Pigeon pea (*Cajanus cajan*): red gram, raw	456
Black beans (*Phaseolus vulgaris*): mature seeds, raw	444
Broadbeans/Fava beans (*Vicia faba*): mature seeds, raw	423
Kidney beans (*Phaseolus vulgaris*): red, raw	394
Peanuts (*Arachis hypogaea*): Spanish, raw	240
Soybean (*Glycine max*): green, raw	165

Source: USDA Nutritional Database

Despite the natural sources of folate, many products may not be the staple crops of a particular region. Furthermore, the strong enrichment programs that exist in some nations may not exist in others. Therefore, when addressing FD in regions endemic with FD, it is important to increase folate intake by promoting food choices or enriched staple crops that are accessible for each particular region.

Critical Analysis of Folate Deficiencies and Supplementation Guidelines

Folic acid supplementation can address anemia but not the potentially permanent neurological damage that can result from vitamin B12 deficiency (NIH, 2016). As such, it is important to beware the affects of masking affect that folate supplementation can have in covering up vitamin B12 deficiency (NIH, 2016). Folate should not be consumed over the recommended upper limits due to possible health risks (NIH, 2016).

As part of a micronutrient deficiency supplementation program, the WHO recommends iron and folic acid supplementation in menstruating women in areas of high anemia prevalence. It is recommended that the supplemental dose of folate be seven times the 400 micrograms daily recommended dose to improve red call folate concentrations and reduce the risk of NTDs in menstruating women (WHO, 2011). Also note that as the neural tube closes by the 28th day of pregnancy, folic acid supplementation after this day will not prevent NTDs (WHO, 2012).

More Resources Moving Forward

National Institute of Health Office of Dietary Supplements: https://ods.od.nih.gov/factsheets/Folate-HealthProfessional/

Merck Manuel Professional Version Folate Information: http://www.merckmanuals.com/en-ca/professional/nutritional-disorders/vitamin-deficiency,-dependency,-and-toxicity/folate

Scientific Book on the health benefits of eating seeds and nuts:
Preedy V. R., Watson R. W., Patel V.B. (2011). *Nuts and Seeds in Health and Disease Prevention.* Academic Press. London, UK.

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10.7B - Small grains for mineral nutrition

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Small Whole Grains have High Mineral and Nutrient Content

This chapter is meant to inform subsistence farmers as well as governmental, and non-governmental organizations (NGOs) about the advantages of small grains as a source of high-quality nutrition. Small grains maximize surface area of the seed coat – the part of the seedling with the highest mineral density – and have the unique ability to keep for long periods of time. This chapter will outline the benefits of consuming small grain cereals as well as small grain legumes (pulses) and provide a critical analysis of these grains to ensure quality and proper knowledge transfer. Because of the advantages of small grains, the main point of this chapter is that these grains should be promoted.

Consumption of any small whole-grain is advantageous, whether it is a small whole cereal grain or the pulses (small dried seed-grains) of legume crops. There is a diversity of nutritional small grains, including lentils (a pulse), sorghum, quinoa, teff, fonio, and many more. Both cereal grains and pulses are high in minerals, energy, protein, and other nutritional factors. This chapter will outline small whole grains cereals followed by an outline of small whole grain pulses with a further analysis of their advantages. This is followed by a critical analysis at the end of this chapter.

Small Whole Grains and Whole-Grain Cereals

Whole-grains cereals are rich in many nutrients, condensed within their endosperm, germ and protective bran (the coating of the grain) (Slavin, 2004). All three components – endosperm, germ, and bran - are preserved and eaten in whole grains (Slavin, 2004). This is in contrast to refined-grains, whose embryo and protective components (the bran) are removed in processing, leaving only the endosperm (Slavin, 2004). Refined-grains generally have lower nutritional content compared to whole-grains, as it is the grain coat of whole grains that supplies the most concentrated source of minerals and beneficial phytochemicals (Dayakar *et al.*, 2016; Slavin, 2004). These seed-coat nutrients are what are needed in addressing malnutrition. Although the refining of grains typically removes the grain seed coat and reduces nutritional content, small whole grains (such as Finger Millets) are generally eaten whole, providing a more nutritious meal to the consumer (Slavin, 2004; Tripathi & Platel, 2010). This is the key advantage of small whole grains in addressing micronutrient deficiencies compared to other refined grains.

Millet grains are small-seeded whole grains that have high nutritional quality and can provide numerous health benefits (Saleh, Zhang, Chen, & Shen, 2013; Krishnan, Dharmaraj, & Malleshi, 2012; Slavin, 2004). Millet grains are important in many developing countries due to their suitability as a sustainable staple crop in regions throughout Africa and Southern Asia (Saleh et al., 2013). There are many different millets species and varieties, including the very important Pearl Millet (*Pennisetum glaucum*) and Finger Millet (*Eleusine coracana*) (Saleh et al., 2013). The last world total production tally of millet grains saw an annual production of 762712 metric tons, making it the sixth cereal crop in terms of world production, with the top producer India creating 43.85% of this total (Saleh et al., 2013). One example of the utility of millet grains is seen in the nutritional and livelihood security they provide in dry rural regions of India due to their drought-resistance and high temperature tolerance (Saleh et al., 2013).

Finger Millet is an especially notable source of many minerals, containing high amounts of iron and zinc, as well the richest source of calcium among the cereals (Krishnan et al., 2012). It's overall mineral content is 2.7%, distinctly higher than 1.5% mineral content in wheat and 0.6% mineral content in rice (Krishnan et al., 2012). Data outlining the nutrition benefits of finger millet and other small whole-grain cereals can be seen in table 1.1 and 1.2. Millet crops are generally as high or higher in protein and carbohydrate nutrition as maize, rice, and wheat (Saleh et al., 2013). Due to this high nutritional content and drought-resistance, Finger Millets can be used for combating micronutrient deficiencies in more arid regions (Krishnan et al., 2012).

Table 1.1: Millet Grains Nutritional and Mineral Compositions Compared to Fine Cereals (per 100 grams)

Food Grain	**Energy (kcal/ 100 g)**	**Carbohydrates (g/ 100 g)**	**Protein (g/ 100 g)**	**Fat (g/ 100 g)**
Pearl Millet[a]	**363**	67.0	11.8	4.8
Maize[a]	358	**73.0**	9.2	4.6
Sorghum	349	72.6	10.4	1.9
Wheat (whole)	346	71.2	11.8	1.5
Rice (raw, milled)	345	78.2	6.8	0.5
Little Millet	341	67.0	7.7	**4.7**
Foxtail Millet	331	60.9	**12.3**	4.3
Finger Millet	328	72.0	7.3	1.3
Kodo Millet	309	65.9	8.3	1.4
Barnyard Millet	307	65.5	6.2	2.2

Adapted from: *Dayakar et al., 2016: Nutritional and Health Benefits of Millets.* [a]Row adapted from Saleh et al., 2013

Tables 1.1 and 1.2 include an extensive amount on information comparing millets as well as refined grains to show that their nutritional values of energy, carbohydrates and proteins are variable but somewhat similar. However, table 1.2 also shows that millets can have much higher essential mineral content than refined grains (rice and wheat) and are seemingly more nutritious than rice.

Table 1.2: Millet Grains Nutritional and Mineral Compositions Compared to Fine Cereals (per 100 grams)

Food Grain	**Mineral Matter (g/ 100 g)**	**Calcium (mg/ 100 g)**	**Phosphorous (mg/ 100 g)**	**Iron (mg/ 100 g)**	**Crude fiber (g/ 100 g)**
Sorghum	1.6	25	222	4.1	1.6
Wheat (whole)	1.5	41	306	5.3	1.2
Rice (raw, milled)	0.6	10	160	0.7	0.2
Little Millet	1.5	17	220	**9.3**	7.6
Foxtail Millet	3.3	31	**290**	2.8	8.0
Finger Millet	2.7	**344**	283	3.9	3.6
Kodo Millet	2.6	27	188	0.5	9.0
Barnyard Millet	**4.4**	20	280	5.0	**9.8**
Pearl Millet[a]	-	42	-	42	2.3
Maize[a]	-	26	-	2.7	2.8

Adapted from: *Dayakar et al., 2016: Nutritional and Health Benefits of Millets.* [a]Row adapted from Saleh et al., 2013

Table 1.3: Unique Grains Nutritional and Mineral Compositions (per 100 grams)

Food Grains	**Carbohydrates (g/ 100 g)**	**Protein (g/ 100 g)**	**Fat (g/ 100 g)**	**Energy (kcal/ 100 g)**
Quinoa (*Chenopodium quinoa Willd.*): cooked	21.30	4.4	1.92	120
Teff (*Eragrostis tef (Zuccagni) Trotter*): cooked	19.86	3.87	0.65	101

Adapted from: USDA Nutritional Database Food Search

Another advantage of millet grains is that they represent a cheaper option in comparison to the cereals, explaining why they are staple crops in many poorer parts of Southern Asia and Africa (Tripathi & Platel, 2010). As mentioned, millet grains also remain more productive under arid conditions than cereals (Saleh et al., 2013). Drought-tolerant millet grains can provide high mineral and nutritional contents that can benefit human nutrition while providing food security in a sustainable and reliable way (Saleh et al., 2013).

Small Grain Pulses have High Protein and Mineral Content

Pulses are the small grains of legumes. Legumes are unique plants in that they can fix nitrogen through a symbiotic relationship, ultimately resulting in higher protein content compared to other crops. Because pulses contain a seed coat similar to whole-grain cereals, pulses are also very high in mineral content. More information on legumes and pulses can be found at in this encyclopedia under the title: Legumes & Pulses to Reduce Protein and Mineral Deficiencies.

Table 1.3: Nutritional Compositions of Pulses (grams per 100 grams)

Pulse	**Variety**	**Caloric (kcal/100 g sample)**	**Protein (g/100 g sample)**	**Fat (g/100 g sample)**	**Fiber (g/100 g sample)**	**Carbohydrates by difference (g/100 g sample)**
Pea	Cowpea (*Vigna unguiculata subsp. Unguiculata*): common, mature seeds, raw	336	23.5	1.26	10.6	60.03
	Pigeon pea (*Cajanus cajan*): red gram, raw	343	21.7	1.49	15.0	62.78
Bean	Pinto beans (*Phaseolus vulgaris*): raw	347	21.42	1.23	15.5	62.55
	Mung bean (*Vigna radiata*): mature seeds, raw	347	23.86	1.15	16.3	62.62
	Black beans (*Phaseolus vulgaris*): mature seeds, raw	341	21.6	1.42	15.5	62.36
	Fava beans (*Vicia faba*): mature seeds, raw	341	26.12	1.53	25.0	58.29
	Kidney beans (*Phaseolus vulgaris*): red, raw	337	22.53	1.06	15.2	61.29
Lentil	Lentils (*Lens	352	24.63	1.06	10.7	63.35

	culinaris): raw					
Peanuts	Peanuts (*Arachis hypogaea*): Spanish, raw	570	26.15	49.60	9.5	15.83
Soybean	Soybean (*Glycine max*): green, raw	147	12.95	6.8	4.2	11.05
Chickpea	Chickpea (*Cicer arietinum*): garbanzo beans, bengal gram, mature seeds, raw	378	20.47	6.04	12.2	62.95

Source: USDA Nutritional Database Food Search

Tables 1.3 and 1.4 include information that shows how diverse and advantageous legumes are for nutrition. Legumes are high in energy, protein, and very high in many minerals, as seen in these two tables. Some legumes (i.e. peanuts) can be very high in fats as well.

Table 1.4: Mineral Compositions of Pulses (grams per 100 grams)

Pulse	Variety	Magnesium (mg)	Calcium (mg)	Phosphorous (mg)	Iron (mg)	Potassium (mg)
Pea	Cowpea (*Vigna unguiculata subsp. Unguiculata*): common, mature seeds, raw	184	110	424	8.27	1112
	Pigeon pea (*Cajanus cajan*): red gram, raw	183	130	367	5.23	1392
Bean	Pinto beans (*Phaseolus vulgaris*): raw	176	113	411	5.07	1393
	Mung bean (*Vigna radiata*): mature seeds, raw	189	132	367	6.74	1246
	Black beans (*Phaseolus vulgaris*): mature seeds, raw	171	123	352	5.02	1483
	Broadbeans/Fava beans (*Vicia faba*): mature seeds, raw	192	103	421	6.70	1062
	Kidney beans (*Phaseolus vulgaris*): red, raw	138	83	406	6.69	1359
Lentil	Lentils (*Lens culinaris*): raw	47	35	281	6.51	677

Peanuts	Peanuts (*Arachis hypogaea*): Spanish, raw	188	106	388	3.91	744
Soybean	Soybean (*Glycine max*): green, raw	65	197	194	3.55	620
Chickpea	Chickpea (*Cicer arietinum*): garbanzo beans, bengal gram, mature seeds, raw	79	57	252	4.31	718

Source: USDA Nutritional Database Food Search

Supplementation and Fortification Interventions using Small Whole Grains

A possible intervention to improve nutritional health is to fortify millets (or millet flours) with mineral supplements. This could help address the malnutrition in sub-Saharan Africa and Southern Asia, as millets are staple crops in these regions due to their drought-resistant properties (Tripathi & Platel, 2010). In fact, one study done at the Central Food Technological Research Institute (CSIR) in India found that Finger Millet (*Eleucine coracana*) flour could effectively be used as a vehicle for zinc fortification (Tripathi & Platel, 2010). Further research should be done to assess if similar results can be achieved with other micronutrients, such as the essential vitamins and minerals outlined in the Human Nutrition chapters of this encyclopedia. Millets crops are cheaper in comparison to cereals crops, and thus are used by many populations in poverty (Tripathi & Platel, 2010). As such, fortifying millets with vitamin and mineral supplements could help numerous people living below the poverty line.

Finally, addressing nutrient deficiencies through bio-fortification by genetically engineering crops to produce higher concentrations of vitamins and minerals could be a solution in areas where the infrastructure for supplementation or food fortification is not possible (Basset et al., 2005; Nestel, Bouis, Meenakshi, & Pfeiffer, 2006). It could also reduce the costs of food fortification each year.

Critical Analysis of Small Whole Grains

Although millet grains are highly beneficial for nutrition, the conditions in which they are consumed are important. One study showed that the treatment of millets in cooking and preparing could greatly decrease the total micronutrient levels, but also increase the bio-accessibility of calcium, iron, and zinc in finger millet (Krishnan et al., 2012). For example, the study shows that native Finger Millet had total iron levels of 13.1 mg/100g before any treatment, whereas once the millet was expanded its iron concentration lowered to 5.5 mg/100g (Krishnan et al., 2012). However, under the same treatment conditions, the Finger Millet showed the bio-accessibility of iron goes from 1.16 to 2.7 mg/ 100g (Krishnan et al., 2012). It should be noted from this that the treatment of millet grains could influence the bio-accessibility of the rich micronutrient content housed within these crops.

Beneficial Seeds and Nuts in Africa

Africa is home to a wide variety of seeds and nuts that are highly concentrated in minerals and nutrients. Local varieties of crops should be explored to help address mineral deficiencies in rural regions. Egusi is a melon-like crop that is part of the watermelon family and is known for its large white seeds (NRC, 2006). Indeed, these seeds are used in a variety of meals through West Africa (NRC, 2006). Often the seed coat is removed and the seeds are then eaten or crushed into a powder and added to soups (NRC, 2006). Through the use of highly mineral-concentrated seeds from different melons, including the various varieties of Egusi grown throughout Africa, heightened intake of micronutrients could be achieved in rural and remote regions. For more information, readers are directed to the “Lost Crops of Africa” (NRC, 2006).

More Resources Moving Forward

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10.8 - Legumes/pulses to reduce protein and mineral deficiencies

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Introduction to Legumes and Pulses

Legumes, known for their podded fruits and unique flower structure, consist of many staple crops of the bean and pea family that are mainly grown for their grain seed, which is called a pulse (Graham & Vance, 2003). Legumes include chickpeas, beans, lentils, peanuts, and more podded plants (Messina, 1999). Legumes also play an important role in traditional diets in many regions of the world (Messina, 1999). Legumes play an essential role in global soil nitrogen levels as most legumes have symbiotic nitrogen-fixing bacteria that grow in root structures called nodules and 'fix-nitrogen' from the air (Herridge, Peoples, & Boddey, 2008). As such, legumes are important for crop rotation, soil health, and high in protein content.

Pulses simply refer to the dried grain seed of any particular legume and are separate from leguminous oil seeds by their lower fat content in comparison (WHO/FAO, 2007). Pulses are an important source of energy, dietary protein, fibre, minerals and vitamins required for healthy livelihoods (Boye, Zare, & Pletch, 2010). Pulses are a vital source of dietary protein for a large portion of the world's population, especially in regions where consumption of animal protein is limited by scarcity or self-imposed by cultural and religious factors (Boye et al., 2010). Nutritionally, pulses contain high amounts of protein (18-32%) and essential amino acids that might not be readily available, gaining pulses recent attention for their potential to fight malnutrition and disease (Boye et al., 2010).

The diets of subsistence level farmers in Africa and South Asia usually contain an adequate supply of carbohydrates through readily accessible grain products (maize, rice, etc.) but are often low in protein content (Broughton et al., 2003). Good supply of dietary proteins are often found in animal products, but scarcity of these products can prevent adequate protein intake (Broughton et al., 2003). Legumes are a notable solution to a lack of protein access, as legumes can provide the protein necessary for a health diet when other sources are unavailable (Broughton et al., 2003). In fact, dietary proteins are mainly acquired from legumes/pulses in many parts of the world (Broughton et al., 2003). By complementing other foods that are a primary source of carbohydrates, legumes that provide dietary proteins fulfill many human nutritional needs (Broughton et al., 2003).

Often a mono-carbohydrate diet of a single cereal grain is indicative of a population that is malnourished because cereals lacks the protein, vitamins, and minerals required for a healthy diet (Boye et al., 2010). However, pulses are normally high in protein, vitamin, and mineral composition. Cereals provide adequate carbohydrates but lack in protein, whereas pulses often provide adequate protein but lack in carbohydrates (Boye et al., 2010). Complementing locally grown grains with pulses and blending the different nutritional advantages of these crops could potentially address protein malnutrition problems worldwide (Boye et al., 2010). Legumes and cereal combinations in cultural diets have been key to survival of many peoples, and these combinations in cultural foods can be around the globe (FAO, 2016). Often, a diverse diet that includes various legumes, cereals, fruits, and vegetables, each providing its unique nutrient supply, provides the best chance for adequate nutrition in all required nutrients for human health.

Of vital importance, pulses are an important source of dietary minerals, with the potential to provide all 15 essential minerals required in a human diet if consuming adequate and diverse amounts (Wang et al., 2003). It should be noted that the mineral concentrations of minerals key to human metabolism (Fe, Zn, Ca, etc.) are low compared to animal food products (Wang et al., 2003).

The Common Bean: A Case Study

The common bean (*Phaseolus vulgaris L.*) is the most widely directly consumed grain legume in humans (Broughton et al., 2003). Global production exceeds 23 million metric tonnes and is twice that of the chickpea, the second most important grain legume (Broughton et al., 2003). The common bean represents half the grain legumes consumed globally, despite having lower than standard yields and sub-optimal seed quality (Broughton et al., 2003). It is the primary source of protein for humans in Mexico and Brazil (Broughton et al., 2003). Countries in Africa, such as Rwanda and Burundi, have reported that average national consumption of beans is greater than 40 kg per person per year, providing the second most important source of protein and third most important source of calories within these nations (Broughton et al., 2003). The high protein and mineral content of beans, especially in Fe and Zn, is important in areas with a high prevalence of micronutrient deficiencies, and should be complemented with starchy grains such as maize or root crops (Broughton et al., 2003). Beans are a major staple crop of eastern and southern Africa, often grown by resource-poor farmers (Broughton et al., 2003).

Legumes are High in Protein Content

As pulses are a rich source of protein, they contain high amounts of essential amino acids, including lysine, aspartic acid, and arginine (Boye et al., 2010). Pulses provide a well-balanced amino acid intake when paired with cereals and other foods rich in tryptophan and amino acids containing sulfur, as these metabolites are less prevalent in pulses (Boye et al., 2010). Table 1.1 shows that pulses are very high in protein content and as contain significant amounts of caloric energy, while some pulses are also rich in fats. In addition to their nutritional properties, pulse proteins provide water holding and fat binding functional properties that are also beneficial (Boye et al., 2010). Finally, fava beans are notable, and included in table 1.1 due to their drought resistance.

Table 1.1: Legumes Vary Significantly in Caloric, Protein, and Fat Content

Pulse	**Caloric (kcal/100 g sample)**	**Protein (g/100 g sample)**	**Fat (g/100 g sample)**
Cowpea (*Vigna unguiculata subsp. unguiculata*): common, mature seed, raw	336	23.53	1.26
Pigeon pea (*Cajanus cajan*): red gram, mature seed, raw	343	21.70	1.49
Lentils (*Lens culinaris*):	352	24.63	1.06

raw			
Soybean (*Glycine max*): green, raw	147	12.95	6.80
Beans (*Phaseolus vulgaris*): kidney, all types, mature seeds, raw	333	23.56	0.83
Peanuts (all types, raw)	567	25.80	49.24
Chickpea (*Cicer arietinum*): Bengal gram, mature seeds, raw	378	20.47	6.04
Fava Bean (*Vicia faba*): Mature seeds, raw	341	26.12	1.53

Source: USDA Nutritional Database

Table 1
Proximate composition of various pulses.

Pulse	Variety	Composition (g/100 g of sample)					Reference
		Protein[a]	Fat	Fibre	Ash	Carbohydrate	
Pea	Pigeon	19.39	3.24[e]	5.56[c]	4.05	–	Nwokolo (1987)
	Cowpea	22.53	1.60[e]	5.33[c]	3.81	–	Nwokolo (1987)
	Lencolen	34.7	2.4	4.25	3.93	54.72	El-Adawy, Rahma, El-Bedawey, and El-Beltagy (2003)
Chickpea	Garbanzo beans	19.30	6.04	17.4[b]	2.48	60.65	USDA
	Kabuli (Iraq)	23.6	4.9	4.4	3.1	–	Sosulski and Gadan (1988)
	Kabuli (India)	20.6	6.6	3.0	3.5	–	Sosulski and Gadan (1988)
	Kabuli (Canada)	22.1	6.5	7.8	2.6	–	Sosulski and Gadan (1988)
	Desi (India)	18.4	5.8	6.2	3.4	–	Sosulski and Gadan (1988)
	Desi (Canada)	25.1	6.1	8.4	2.8	–	Sosulski and Gadan (1988)
	Surutato	21.7	5.6	4.3[d]	3.0	65.4	Fernandez and Berry (1988)
	Surutato	26.2	6.0	5.5[c]	2.8	59.5	Ulloa, Valencia, and Garcia (1988)
	Kabuli	29.0	6.0	6.0	3.0	–	Viveros, Brenes, Elices, Arija, and Canales (2001)
	Desi	25.0	4.5	9.0	3.2	–	Viveros et al. (2001)
Lentil	Giza	27.5	1.16	–	4.03	63.4	El-Nahry, Mourad, Abdel Khalik, and Bassily (1980)
	Family 91	26.7	1.24	–	3.41	64.6	El-Nahry et al. (1980)
	Pakistani	26.4	1.25	–	1.46	64.5	El-Nahry et al. (1980)
	Giza 9	31.4	1.15	6.75	4.16	56.53	El-Adawy et al. (2003)
Bean	Kidney	23.58	0.83	24.9	3.83	60.01	USDA
	Red kidney	16.89	1.64[e]	30.34	1.14	–	Sell, Liuecke, Taylor, and Hamner (1949)
	V.C 2010	26.40	1.75	6.15	4.50	61.20	El-Adawy et al. (2003)

[a] Nx6.25.
[b] Total dietary.
[c] Crude.
[d] Acid detergent.
[e] Ether extract.

Legumes Complement Cereals that are low in Protein and Essential Amino Acids

Proteins in legumes such as beans can be predominantly stored as the protein phaseolin, a key indicator of the quality of bean seeds (Broughton et al., 2003). Phaseolin and many proteins in the legume family are deficient in amino acids that contain sulfur, including methionine (Broughton et al., 2003). The proteins contained in the seeds of cereals often contain these sulfur-containing amino acids, but are themselves deficient in other essential amino acids that are highly concentrated in pulses (Broughton et al., 2003). This is why a combined consumption of cereals and legumes can prevent nutritional deficiencies (Broughton et al., 2003). A balanced diet that provides all the essential nutrients occurs when cereals and legumes are consumed in a portion ratio of 2-cereal portions for every 1-legume portion (Broughton et al., 2003). As legume yields are often low, increased legume production to fulfill this nutritional ratio would benefit millions of malnourished people worldwide (Broughton et al., 2003).

Table 1.2 shows that pulses are high in amino acids that are not as prevalent in cereals, notably lysine and arginine, in which lysine is an essential amino acid. This table also shows how methionine levels (a sulfur-containing amino acid) are lower in pulses and must be obtained from alternative foods such as cereals.

Table 1.2: Amino Acid (Lysine, Arginine, and Methionine) Content in Legumes

Pulses	**Lysine (g/100g sample)**	**Arginine (g/100g sample)**	**Methionine (g/100g sample)**	**Tryptophan (g/100g sample)**
Peas, green, mature seeds, raw (*Pisum sativum*)	1.772	2.188	0.251	0.275
Lentils, raw (*Lens culinaris*)	1.720	1.903	0.210	0.221
Chickpea, mature seeds, raw (*Cicer arietinum*)	1.377	1.939	0.270	0.200
Beans, kidney, mature seeds, raw (*Phaseolus vulgaris*)	0.239	0.228	0.044	0.279
Soybean, green, raw (*Glycine max*)	0.775	1.042	0.157	0.157
Fava Bean, mature seeds, raw (*Vicia faba*)	1.671	2.411	0.213	0.247

Source: USDA Nutritional Database Food Search
Nutrient values and weights are for edible portion

Table 2
Amino acid content of various legumes.

Amino acid	Pea *Pisum sativum*		Chickpea *Cicer arietinum*		Lentil *Lens culinaris*		Bean *Phaseolus lunatus*		Soy *Glycine max*	
	Ref.[A]	Ref.[B]	Ref.[C]	Ref.[D]	Ref.[E]	Ref.[F]	Ref.[G]	Ref.[H]	Ref.[I]	Ref.[J]
Essential AA										
Isoleucine	3.33	3.89	0.36	4.1	5.06	9.58	0.54	5.3	1.94	2.28
Leucine	6.58	7.84	0.48	7.0	8.09	15.86	0.72	9.0	3.26	4.10
Lysine	6.84	6.25	0.91	7.7	5.69	12.64	0.83	7.7	2.69	3.23
Methionine	1.03	1.60[d]	0.12	1.6	1.18	1.63	0.23	1.3	0.61	0.80
Phenylalanie	4.19	5.17	0.42	5.9	5.55	10.64	0.69	6.0	2.16	2.66
Threonine	3.59	4.46	0.06	3.6	5.62	7.57	0.26	4.9	1.62	1.67
Tryptophan	0.94	0.61		1.1	ND	ND			0.50	
Valine	3.89	5.11	0.38	3.6	7.24	11.64	0.65	5.9	2.06	2.38
Arginine[a]	6.84	7.93	0.48	10.3	9.10	14.04	0.42	6.9	3.17	3.77
Histidine[a]	2.52	2.33	0.24	3.4	6.84	3.95	0.30	3.2	1.15	1.36
Non-essential AA										
Alanine	4.27	4.83	0.26	4.4	21.32	39.81	0.30	4.7	1.79	2.27
Aspartic acid	10.68	11.16[b]	0.58	11.4	11.17[b]	26.10[b]	1.36	12.0	4.79	6.09[b]
Cystine	1.55	0.35		1.3	0.44	0.39		1.1	0.70	0.86
Glutamic acid	16.92	18.46[c]	1.67	17.3	24.22[c]	42.27[c]	1.88	15.1	7.66	9.39[c]
Glycine	4.32	4.82	0.26	4.1	10.22	12.66	0.43	4.2	1.77	2.20
Proline	3.76	4.64	0.24	4.6	8.88	11.36	0.38	4.7	2.04	2.93
Serine	4.79	5.71	0.12	4.9	11.20	15.60	0.61	7.2	1.92	3.08
Tyrosine	3.16	3.34	0.19	3.7	5.05	7.53	0.45	3.4	1.53	1.75

[a] Conditionally essential.
[b] Aspartic acid + asparagine.
[c] Glutamic acid + glutamine.
[d] Methionine + cysteine.
[A] Unit: g AA per 16 g N (Leterme, Monmart, & Baudart, 1990).
[B] Unit: g/100 g protein (Khattab, Arntfield, & Nyachoti, 2009).
[C] Unit: g/100 g of wet sample (Candela, Astiasaran, & Bello, 1997).
[D] Unit: g/16 g N (Alajaji & El-Adawy, 2006).
[E] Unit: mg/g dry weight basis (Rozan, Yu-Haey, & Lambein, 2001).
[F] Unit: g/16 g N on dry weight basis (Evans & Boulter, 1974).
[G] Unit: percentage of total weight on dry basis (Kovalenko, Rippke, & Hurbugh, 2006).
[H] Unit: percentage on dry weight basis (Karr-Lilienthal, Grieshop, Spears, & Fahey, 2005).

Minerals are Highly Concentrated in Legumes and the Seed Coat of Cereals

Cereals are often consumed as an energy source while legumes provide micronutrients for human nutrition (Broughton et al., 2003). Legumes are a much greater source of micronutrients when compared to cereals because of their higher natural abundance of minerals and because many cereals have their seed coat remove prior to eating (Broughton et al., 2003). Polishing of cereals and removing the seed coat, also known as the bran, reduces the mineral content as these coatings contain a significant amount of minerals, giving this coating its rigid structure (Broughton et al., 2003). Conversely, many pulses are consumed whole, without the removal of the their outer layers, conserving their mineral content (Broughton et al., 2003). For example, beans supply high levels of iron, phosphorus, magnesium, and moderate levels of zinc, calcium and other minerals (Broughton et al., 2003). Beans often provide 10-20% of the adult requirement for many nutrients for those with restricted dietary consumption, defined as 15-20 kg/year (Broughton et al., 2003). Therefore, legume consumption in combination with cereals should be considered in addressing micronutrient deficiencies worldwide (Broughton et al., 2003).

Increasing the seed mineral density of grain legumes (pulses) is of interest, as these foods can contain all 15 essential minerals require in human nutrition (Wang et al., 2003). However, some mineral deficiencies, notably Fe and Zn deficiency, can still be prevalence in regions where legumes provide a considerable portion of the human diet (Wang et al., 2003). One possible solution is smaller pulses, or legume-seeds. Smaller seeds have a higher seed coat surface area in comparison to the seed volume. As the seed coat is the part of the seed that has the highest concentration of minerals, consumption of smaller seeds would mean more mineral intake per volume of pulses consumed. Additionally, research to understand how minerals move into has grained increased interest in order to optimize mineral-uptake conditions (Wang et al., 2003).

Antinutrients, Diet Composition, and Nutrient Bioavailability/Digestibility

Pulses seeds contain some undesirable "antinutrients" that interfere with normal protein digestibility and uptake of micronutrients (Boye et al., 2010). For example, phytic acid and trypsin inhibitors are antinutrients in some pulses that reduce micronutrient uptake and protein digestibility, respectively (Campos-Vega, Loarca-Piña, & Oomah, 2010; Welch & Graham, 2004). There are numerous other antinutrients in plant-foods that can impair human nutrition, but there are also many nutrients that increase of vitamins and minerals uptake and stimulate nutrition (Welch & Graham, 2004). Additionally, antinutrients may have some beneficial properties for human health, complicating the literature (Campos-Vega et al., 2010; Welch & Graham, 2004). Most legumes are mainly composed of proteins that are highly digestible and have high protein content (Boye et al., 2010).

The composition of one's diet is highly important in determining the bioavailability of nutrients found in plant foods (Welch & Graham, 2004). Plant food processing and preparation techniques can influence the amount of bioavailable micronutrients, sometime reducing the nutrient uptake (Welch & Graham, 2004). An example of this is combining foods rich in animal proteins (e.g. beef, poultry) with plant foods that have high antinutrient concentrations (e.g. phytic acid), which can lower the uptake of Fe and Zn from the meal (Welch & Graham, 2004).

Resources Moving Forward

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Chapter 11 – Livestock, poultry and fish

11.1 - Vetch fodder in the dry season

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Introduction

Extended seasonal drought in sub-tropical areas of the world pose many challenges for subsistence farmers. It is estimated that each dry season, approximately 450 million people globally have an inadequate food supply in the sub-tropics (Small & Raizada 2016). These periods of drought are often extended and have serious consequences for both crops and livestock. The dry season can last for months. Without adequate food sources, livestock can become unprofitable and may be sold or slaughtered for the family's consumption. Livestock play a critical role in subsistence farming. Livestock can provide offspring to eat or sell, milk, eggs, or manure to improve soils and provide a nitrogen source. Therefore, it is important that farmers can sustain their livestock through periods of scarcity. Alternative fodder sources during the dry season may be the difference between the family's health or malnutrition.

Two vetch species, common vetch (*Vicia sativa)* and hairy vetch (*Vicia villosa*), are potential crops to feed livestock during the dry season. Vetch is a very drought-tolerant legume that is a good option for grazing or making high quality hay. As a legume, vetch has the added benefits of having low nitrogen requirements and replenishes the soil. Vetch thrives in a variety of soils and is most commonly grown as a fodder source in the Mediterranean basin (their centre of origin) and western Asia. Vetch is accepted by a wide range of livestock species and is a highly nutritious fodder (Frame 2005). Vetch is a good source of protein and minerals (Frame 2005).

Description

Common vetch and hairy vetch are annual legumes that can climb up to four feet if intercropped with cereals (Verhallen et al. 2012). If grown in pure stands, vetch has a sprawling growth pattern. Vetch has a shallow root system that primarily occupies the first 20 cm of the soil. Vetch can fix nitrogen in the soil and improve growing conditions for other crops; growing hairy vetch before a cereal crop can provide nearly all the required nitrogen to the following crop (Verhallen et al. 2012). When nodes are well-developed, hairy vetch can deposit as much as 110 kilograms of nitrogen per hectare when left ungrazed (University of Missouri Extension, 2012). Common vetch can fix up to 100 kilograms of nitrogen per hectare (Velazquez-Beltran et al. 2002). Grazing will reduce this amount significantly, but still offer benefits to the soil (Ball 2001). Hairy vetch can also improve the availability of potassium to future crops. Vetch grows vigorously and will prevent weeds from growing (Verhallen et al. 2012).

Growth Information

Vetch is a hardy crop that grows best in conditions ranging from 8 to 19 °C and can grow under many soil conditions (Heuze et al. 2015). It prefers sandy, well drained soils (Verhallen et al. 2012) but can survive in very marginal conditions. A soil pH around 6-7 is preferable; vetch will not grow under very acidic conditions (Frame, 2005). Vetch grows vigorously once established, and even seedlings emerge at a rapid rate. It is important that vetch is established before the dry season begins as the crop will fail if it experiences a drought during its establishment (Frame 2005). Remarkably, both hairy and common vetch require only 300 mm of precipitation annually, but hairy vetch is better adapted to prolonged drought once established (Sustainable Agriculture Research and Education 2012).

Once vetch is above 6 inches, it may begin to be grazed (UME 2012). However, vetch cannot tolerate close grazing shorter than 3 inches during its peak flowering (Verhallen et al. 2012) (UME 2012). Cattle may be tolerable to graze during this time due to morphological features preventing close grazing (sheep and goats can graze much closer to the soil than cattle).

The main limitation to growth is phosphorous (Frame 2005). The recommended rate of fertilization is applying 100 kg of manure per hectare (International Livestock Research Institute 2013).

Cropping System

Vetch intercrops very well with cereals, particularly oats (International Livestock Research Institute 2013). In one study in Mexico, fields grown on subsistence farms with various levels of vetch in oat fields yielded 20% higher on average than compared to pure oat stands (Velázquez-Beltrán et al. 2002). Vetch helps prevent oats from lodging, and vetch flowers earlier than when grown in a pure stand (Paul et al. 2013).

Oats and vetch should be seeded at a 3:1 ratio, respectively. Oats should ideally be seeded at 90 kg/ha and vetch seeded at 30 kg/ha. They can be seeded in rows 15 centimeters apart, or broadcasted (Bezabih et al. 2016).

Uses and processing

Vetch and vetch-oat combinations can be grazed as pasture or dried as hay. Hairy vetch may be better suited to haying than pasture. If used for hay, hairy vetch should be cut during its early bloom stage (Ball 2001). When intercropped with oats, the crops should be harvested when the vetch is blooming and oats are at the milky-dough stage for best quality (Velázquez-Beltrán et al. 2002). However, in a study this was shown to be unrealistic for many subsistence farmers for a variety of reasons. The crop was cut later in the season and still yielded high quality hay (Velázquez-Beltrán et al. 2002). However, hay cut later in the season will have lower crude protein content and higher fibre content which may not be as beneficial but should still be significantly higher in protein than oats alone.

Vetch-oat fodder can be dried for hay within 48 hours under ideal sunny conditions (Bezabih et al. 2016). During drying, fodder should be turned once a day. Fodder is dry when a handful snaps rather than bends. Good fodder remains green and should not be sun bleached for maximum nutrient retention. Fodder can also be fed by cutting in the morning and feeding in the afternoon, allowing it to wilt slightly (Bezabih et al. 2016).

Post harvest storage conditions should offer protection from rain; moisture can encourage mould growth and nutrient leaching. Hay should ideally be stored off the ground for air circulation, preventing dampness and rot (Martinson & Peterson 2017). Wood slats raised a few inches off the ground by bricks would be a good solution for this.

Animal Nutrition

Vetch is comparable to other legumes like alfalfa from a nutritional standpoint (UME 2012). Vetch is widely accepted by several livestock species. It has also been reported that combining legumes with grass hay increases voluntary consumption as well an increases protein content (Velazquez-Beltran et al. 2002). Vetch is a good source of protein and minerals (Frame, n. d.).

There has been some anecdotal evidence that suggests vetch has a “flushing effect” on the reproductive status of livestock (ICARDA 2015); specifically, it has been thought to increase the amount of ewes that go into estrus shortly after having access to grazing vetch during the mating season. This is contrasted to ewes being grazed on stubble. This observation may suggest that a higher nutrition profile from vetch affects the ewe's ability to carry offspring, and can also affect the quality of oocytes (ICARDA 2015). From a practical standpoint, having a higher birth rate in a flock increases the amount of offspring to sell, and a higher income can improve the nutritional status of the household (ICARDA 2015).

Another study found that feeding forage legumes, like vetch, to cattle in Africa resulted in a higher output of milk production than feeding corn stover (Paul et al. 2013).

Recommended feeding:

Sheep and goats should be fed 1 kg per animal daily of oat-vetch fodder, or 300 g of hay (Bezabih et al. 2016). This may be supplemented with other feed that can be locally sourced.

The recommended amount for cattle depends on the availability other supplemental feed sources. If cattle have access cereal residues, they should be fed 4 kg/animal/day of fodder or 1.5 kg/animal/day of hay in addition to 3.5 kg/animal/day of cereal residues. If they have access to cereal and legume residues, they should be fed 3 kg/animal/day of oat-vetch fodder or 1/animal/day kg of hay in addition to 4 kg/animal/day of cereal and legume residues. If they have access to grass pasture, cattle should be fed 2.5 kg/animal/day of fodder or 0.6 kg/animal/day of hay in addition to 6 kg/animal/day of grass. If the cattle have access to grazing grass and crop residues, they should receive 2.5 kg/animal/day of fodder or 0.7 kg/animal/day of hay in addition to available supplementation (Bezabih et al. 2016).

Practical Information and Evaluation

Adoption rates of improved forages by smallholder African farmers are low (Paul et al. 2013). In one study, Kenyan farmers ranked common vetch as their preferred forage legume compared to silverleaf desmodium (*Desmodium uncinatum*), lablab (*Lablab purpureus*), and burgundy bean (*Macroptilium bracteatum*). Vetch was aso a more cost-effective option (Paul et al. 2013). In central Mexico, vetch-oat combinations were regarded as being an "excellent" or "very good" forage choice by 90% of farmers, and no farmers thought it was a bad forage combination (Velázquez-Beltrán et al. 2002). Farmers thought it was a good forage because the animals enjoyed it and did not waste feed; furthermore it improved the visual condition of the animals and was high yielding (Velázquez-Beltrán et al. 2002).

Some of the main concerns farmers in Mexico had with common vetch were that it spoils if it lodges and that its development rate was not always consistent with that of oats. Lodging can be remedied by an appropriate planting density with oats (Velázquez-Beltrán et al. 2002).

There have been some reported incidences of cyanide poisoning of cattle fed exclusively common vetch (Suter 2002). This was one isolated incident in Australia, and no other cases have been reported. Hairy vetch has been known to occasionally cause dermal issues in cattle when fed for prolonged periods (Cassida 2013). To prevent the likelihood of illness, vetch should be intercropped with oats to reduce concentrations of toxins (Suter 2002). If vetch is grazed or cut frequently enough to prevent development of seedheads, the risk should be removed (Heuze et al. 2016).

In North America, vetch is viewed as a weed that can be notoriously hard to control (particularly tufted vetch, *Vicia cracca* which grows as a perennial). To prevent weediness or uncontrollable growth in future crops, an annual variety may be easier to control. Hairy vetch can be controlled by 2,4D and dicamba if required (Verhallen et al. 2012). Desiccants are also very effective at killing hairy vetch (Ball 2001). Clopyralid is an effective way of controlling vetch species (Cowborough 2005).

Resources for NGOs

Potential vetch species for use:
Vicia sativa (common vetch) does well in most soils, but will not tolerate poorly drained soils or acidic soils. It can be used for pastures or for haying. It is not tolerant of frost or heavy grazing. If using as hay, it should be harvested after three months (ILRI 2013).

Vicia sativa ssp. Amphicarpa (underground vetch) performs better than other types of vetch in cold, dry areas and tolerates heavy grazing. Another benefit to underground vetch is that it produces both aerial and underground seed pods to increase chances of re-establishment and survival (Moneim & Elias 2003).

Vicia villosa (hairy vetch) is better suited to feeding as hay than as pasture. When grazed in a pasture, it can occasionally cause dermatitis or neurological problems in livestock (Cassida 2013). Hairy vetch is more cold hardy than common vetch. Hairy vetch is also more tolerant of poorly-drained soils and has a preference for sandy soils (Frame, n. d.). Hairy vetch can be broadcasted at a rate of 25 kg per hectare (Verhallen et al. 2012).

Vicia dasycarpa (grazing vetch) does well in heavy clay soils and is very ideal for grazing and baling. Seed at a rate of 50 kg per hectare in pure stands, or 25 kg per hectare when combined with 30 kg of cereal (Advance Seed 2017).

Where to access seeds:

•The International Centre for Agricultural Research in the Dry Areas (ICARDA) has over 6000 accessions of vetch that may be requested. Different qualities can be requested for specific areas. (**Access at**: <http://www.icarda.cgiar.org/research-sub/biodiversity-and-its-utilization>.)

•Alibaba.com also has a large selection of vetch seeds. (**Access at**: <http://www.alibaba.com/trade/search?fsb=y&IndexArea=product_en&CatId=&SearchText=vetch+seeds>.)

•Hairy vetch is widely available for sale in North America. Seeds can be found on Amazon.com (**Access at**: <https://www.amazon.com/s/ref=nb_sb_noss?url=search-alias%3Dlawngarden&field-keywords=hairy+vetch>) or other seed companies.
(**Access at**: <http://www.victoryseeds.com/vicia-sativa_hairy-vetch.html) (**Access at**: <https://www.smithseed.com/seed/cover-crops/cover-crops/vetch>.)

•Grazing vetch is available from the South African company Advance Seed. (**Access at**: <http://www.advanceseed.com/site/page?view=grazing_vetch>.)

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11.2 - Selection of dry season weeds as fodder

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Introduction

Subtropical subsistence farmers face an annual extended seasonal drought that may lead to a period of hunger, affecting nearly 600 million people across the globe (Small & Raizada 2016). One of the most concerning issues with extended dry periods globally is the inability to maintain livestock at a productive level. Livestock offer many benefits to a household: they can provide meat, fibres, eggs, milk, and draft power. If markets are accessible, they can be locations for selling offspring for income. Livestock are an important factor in easing poverty. However, it is difficult for livestock to remain productive in the extended dry season without good quality forage. Providing feed can cost up to 70% of production expenses of animal products in developing countries, and it is often of poor nutritional value (Paul et al 2013).

By making use of native weeds that are adapted to drought conditions, there is an opportunity to provide good quality nutrition to livestock to ensure they remain productive and support the household (Small & Raizada 2016). However, this is a novel and potentially risky idea and should be approached with caution. Weeds can be an underutilized resource to assist in cropping systems; they are opportunistic and adapted to the local growing conditions during the dry season. By taking advantage of their growth, weeds have the potential to be cultivated in pure stands or intercropped with cereals for a source of fodder. Cultivating wild plants can also help reduce the pathogen load on future crops by increasing biodiversity within the cropping system, as well as suppressing other undesired weeds and nematodes (Small & Raizada, 2016).

Qualities to Consider

One study asked African subsistence farmers to list the most important qualities they required in forage legumes (Paul et al. 2016). The top two qualities, regardless of location, were nutrition content and yield. Other top qualities included improving soil fertility, erosion control, seed production, and palatability. The perceived importance depended on location. When evaluating locally-growing weeds, some factors to consider are:

Ability to set and collect seed. The candidate species should be able to set seed that can be collected for use in a trial or for cultivation.

Palatability and lack of toxicity. The candidate species needs to be accepted by livestock and not be harmful. Observe what species livestock graze on during the dry season over a long duration.

Nitrogen-fixing capabilities. One of the most advantageous uses of legumes is their ability to convert atmospheric nitrogen into organic fertilizer through a symbiotic relationship with bacteria in their root nodules. The presence of nodules can be determined by examining plant roots and looking for small spheres with a magnifying glass. Symbiotic nitrogen fixation reduces the need for synthetic fertilizers, improves soil structure and deposits nitrogen for future crops or intercrops. More soil nitrogen creates higher yields for current and future crops (Navas et al. 2011). Legumes also increase soil organic matter and prevent soil erosion. Nitrogen-fixing properties of legumes decrease under drought conditions, therefore the nitrogen deposition in the soil may be lower than expected. This can be partially overcome by selecting for drought-tolerant species, such as vetch (Small & Raizada, 2016).

Dormancy period. Some seeds require a period of time under certain conditions before the seeds will germinate. Ideally a plant should have a short dormancy period in order to grow when required.

Grazing and cutting tolerance. Different plant species have different tolerances for grazing. Some species are very resistant to heavy grazing and close cutting; these are suitable for livestock species that browse closely to the ground like sheep. Cattle do not have the upper cleft lip that sheep do, and therefore cannot graze as closely.

Lack of competition with main crops. A risk in cultivating weedy species is that the plants may grow unchecked and be difficult to manage in the next crop rotation. Species should be researched to ensure they can be easily controlled to prevent harming future crop yields. Methods of control include chemical control by herbicide application, and physical control by means of ploughing under. Many smallholder farmers will not have access to herbicides.

Establishing a trial:

1. *Observe livestock grazing during the dry season.* The first step in selecting a species as a candidate is to observe which plants livestock eat during the dry season. This must be an extended period of observation to ensure consistency of palatability and lack of acute or long-term toxic effects.
2. *Obtain seeds from selected plant species.* To cultivate the weedy species as a crop, seeds must be collected and must be viable. Collected seeds can be planted out to determine the rate of germination. This would be important for evaluating the ease of cultivation. Ideally plants would have a low dormancy period in order to grow when required.
3. *Establish a weight-gain trial to determine benefits for livestock.* If possible, design a trial to establish whether there is a nutritional benefit when the candidate species is used as fodder. The trial should be composed of a control group and a test group: one group of livestock (the control group) should be fed the traditional dry season diet. The test group should be fed a modified diet, either the traditional diet supplemented with the candidate species, or solely the candidate species. Total amount of fodder between the two groups should be held relatively constant to ensure than any weight gain is not due to differences in food amounts. A way of assessing body condition should be established. A simple way to do so would be to compare body conditions of individual livestock at the beginning of the season with a body condition chart. (Please see the section “Resources for NGOs” for links to charts.) At the end of the season, each animal should then be re-evaluated and the scores should be averaged to determine whether the candidate weed species has a positive effect. A better and more accurate way of assessing this is by using a weight scale, where livestock are weighed before and after the trial. Other ways to assess changes in body condition would be differences in production. Milk production amounts could be measured, for milking species, or backfat thickness if animals are slaughtered during the dry season. If a trial is possible, it is highly recommended.
4. *Introduce the species into a small trial.* A small trial should be conducted to introduce the candidate species into a cropping system to ensure it is compatible. An example of this might be a small plot planted in the weed species during the dry season, followed by a traditional crop once the dry season has passed. This will investigate whether the candidate species is prone to “weediness” in subsequent crops; i.e. whether the growth of the candidate species can be controlled and will not grow unchecked beyond its cultivation. Another issue to note would be potential allelopathy, a phenomenon that occurs when a plant species produces toxins to inhibit the growth of another species in the same proximity. Since weeds are highly competitive, any survival mechanisms that damage crops must be ruled out before a weed can be considered to

be a candidate crop.

5. *Optimize agronomic conditions for the candidate species.* Once it has been determined that a candidate species is both edible for livestock and not harmful to staple crops, refinement of cropping systems can be undertaken. A weed species can be grown in pure stands as a rotation crop or intercropped, depending on potential benefits or risks. To be successful, a dry season weed rotation crop must fit into the crop calendar and not interfere with the sowing of the subsequent staple crop. Potentially, the dry season crop could be relay cropped, sown as an intercrop prior to harvesting of the previous staple crop, to take advantage of residual moisture prior to the onset of the dry season.

   Alternatively, leguminous weeds can offer benefits to cereals if intercropped and create a high-quality forage. One study in Nigeria found that the ideal planting ratio for forage legumes to cereals was a 2:2 ratio, compared to 3:1 and 1:3 ratios (Mohammed et al. 2015). This may be a good general rule of thumb to adopt. Some common cropping systems may have different ratios; for example, oat to vetch planting yields best at a 3:1 ratio, but for novel cropping systems it may be ideal to begin with a 2:2 ratio and adapt as needed in subsequent seasons (Bezabih et al. 2016). There may be nutritional benefits of intercropping. Offering livestock multiple plant species may provide a wider range of nutrients, or a dilution of toxins or damaging nutrients in some species. For example, a specific plant may cause excess calcium levels in some livestock species. Intercropping such a plant with a low-oxalate crop would reduce the amount of calcium intake, hopefully below harmful levels while increasing the amount of feed and nutrition available.

   To determine how to optimize agronomic conditions, trials should be conducted involving test and control plots. Differences between plots to note would include fodder and grain yield of both the dry season crop as well as all crops in the entire cropping system.

Critical Analysis

The main issues associated with this strategy are possible toxicity to livestock and humans, the potential difficulty of collecting viable seeds, the weedy persistence of the candidate species beyond its intended agronomic season, and possible allelopathic properties associated with the candidate species. If it is possible, an internet search of the candidate species may aid in understanding any of these risks. If it is not possible, establishing trials and observing results will help evaluate whether the candidate weed is a desirable option.

African subsistence farmers typically have a low rate of adoption for improved forages (Paul et al. 2013). The associated risks of using weedy species as fodder may be undesirable. However, there is a great need for innovation to mitigate the stress of extended dry periods on both humans and livestock. The cultivation of wild plants can also assist in global efforts to increase biodiversity in agricultural landscapes, as well as begin a domestication process to yield new crop species (Small & Raizada 2016). There is also the potential for business creation for smallholders selling seeds within their community. Cleaned seeds and chemically treated seed may assist in germination rates and could add value to the product, if they can be acquired.

Resources for NGOs

A review of the use of drought-tolerant leguminous weeds as fodder is available online. (**Access at**: https://agricultureandfoodsecurity.biomedcentral.com/articles/10.1186/s40066-017-0096-6)

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the International Centre for Agricultural Research in Dry Areas (ICARDA) are organizations with initiatives to develop drought-tolerant crops. (**Access at**: <http://www.icarda.cgiar.org/research-sub/biodiversity-and-its-utilization>.) (**Access at**: http://www.icrisat.org/>)

Body Condition Charts:

Beef Cattle: (**Access at**: https://pubs.ext.vt.edu/400/400-795/400-795_pdf.pdf)
Dairy Cattle: (**Access at**: http://www.omafra.gov.on.ca/english/livestock/dairy/facts/00-109.htm)
Goats: (**Access at**: http://www2.luresext.edu/goats/research/BCS_factsheet.pdf)
Sheep: (**Access at**: http://www.ablamb.ca/images/documents/resources/health/bcs-sheep.pdf)

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11.3 - Fish in rice paddies as a mid-season protein source

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Introduction

Smallholder farmers are often hungry during mid-season prior to the crop harvest. Farming fish within rice paddies can help to alleviate this hunger and provide a valuable source of protein to smallholder households as well as organic fertilizer and other agronomic benefits for rice production. Believed to have originated in China approximately 1700 years ago (Guo, 2001), the practice of farming fish within rice paddies is still most widely observed in Asia (Halwart and Gupta, 2004). The following chapter will provide basic instructions regarding its implementation, benefits and constraints, and will provide further resources to help get started.

Implementation of rice-fish farming systems

There are two primary methods of production within rice-fish farming, namely concurrent production (characterized by the simultaneous cultivation of fish and rice within the same paddy), and rotational production (when fish and rice are grown at different times) (Halwart and Gupta, 2004). The chapter will focus primarily on concurrent production, as it is most commonly practiced (FAO, n.d.), and is considered the most efficient of the two systems in terms of water resource usage (Frei and Becker, 2005). That being said, depending on the land, growing season(s), and irrigation structure it is possible in some cases that rotational production may be more appropriate, and in some aspects more productive - please consult the additional resources provided at the end of the chapter.

Selection and preparation of land

When determining what land to use for rice-fish farming, two of the most important factors to consider are water and soil (Sollows, 2001a). In cases where the land is not evenly elevated, the selection of higher-lying land may result in a shortage of water as it will flow downwards (Sollows, 2001a). Therefore, in these cases farmers should select comparatively low-lying land (Miah et al., 2011). Yet lower-lying land is more vulnerable to flooding, therefore it is important for farmers to evaluate their ability to control flooding when selecting a location (Sollows, 2001a). Regardless, it is critical that the land selected be above maximum flood level if possible (Sollows, 2001a). Loamy or clay-based soil is ideal for rice-fish systems as it has a high water-holding capacity (Miah et al., 2011). In the event that only sandy soil is available, the farmer may have to apply manure heavily throughout the season to ensure water retention (Sollows, 2001a). An additional factor to consider is proximity of the land to the farmer’s home, as this may reduce overall time spent maintaining the paddy (Sollows, 2001a).

Generally speaking, there are four major adaptations that must be made to the rice paddy to implement concurrent rice-fish production; the creation of a refuge, the increase in height of surrounding dikes (or bunds), and the provision of screens and drains (Halwart and Gupta, 2004).

A refuge can take several forms, such as trenches, sumps or pits, and ponds. The purpose of the refuge in rice-fish system is to provide a deeper area for the fish, where they can retreat to during points in the season if/when the water level in the paddy becomes too low or dries up (Figure 1). Additionally, the refuge can be used to contain fish for further propagation as the rice is harvested, as well as to increase the convenience of harvesting the fish themselves (Halwart and Gupta, 2004). To provide fish access to the entire paddy, trenches (or canals) should be created throughout and/or around the periphery of the paddy, connecting back to the central refuge (pond, pit, or trench) (Miah et al., 2011; Bocek, n.d.). Though structure and placement of the refuge may vary, most sources recommend that the refuge be approximately 50 cm deep and 1 m wide (Halwart and Gupta, 2004; Miah et al., 2011; Bocek, n.d.), providing the fish with a sanctuary 25-30 cm below paddy level. Altogether the fish refuge(s) should only take up 5-10% of the paddy area, as to maximize rice production (Miah et al., 2011; Bocek, n.d.).

Additionally, the dikes (or bunds), or in other words the embankments surrounding the paddy, must be raised higher than they would be for solely rice culture, in order to prevent fish from escaping. Recommended dike height is between 40 centimetres (Halwart and Gupta, 2004; Bocek, n.d.) and 60 centimetres (Miah et al., 2011), and width between 40 and 50 centimeters (Halwart, 2004; Bocek, n.d.). They also must be strong enough to hold water (and prevent flooding), therefore the use of good quality clay is recommended (Bocek, n.d.).

Finally screens and (if possible) drains should be added. As the water level in the paddy must vary at different points in the season, there must be a way for water to move in and out of the paddy. In regular rice culture, farmers would create a temporary gap in the dike to allow its passage. In rice-fish culture, screens must be used to cover these openings, to prevent fish from escaping (and predatory fish or animals from entering the paddy) (Halwart and Gupta, 2004). Recommended materials to use are bamboo slats, baskets, or pieces of fish net (Halwart and Gupta, 2004). Instead of making temporary breaches in the dikes (which in rice-fish culture are larger and harder to repair) to facilitate water flow, it is highly recommended that farmers create a more permanent drain system by inserting a drain (made potentially of a bamboo tube or chute, hollow log, or pipe) (Halwart and Gupta, 2004; Sollows, 2001b). These drain pipes would require screens, as discussed above. Please refer to Figure 1 for a visual aid regarding alterations to the paddy necessary for rice-fish.

Maintenance of rice-fish systems

There are many variations within rice-fish farming systems, according to the geographical location and associated growing season, land structure, and farmers' desired use of the fish (i.e. to sell as fingerlings, consume or sell as matured fish, etc.). As such, the following few paragraphs will provide only generalized tips for rice-fish production and the reader is encouraged to explore the more situation-specific information provided in the additional resources.

To withstand the environment of the rice paddy, fish species selected should be able to tolerate shallow water, high temperatures, low oxygen levels and high turbidity (Hora and Pillay, 1962). Those most commonly recommended are cyprinids and tilapias, most specifically the common carp, silver barb, and Nile tilapia (Halwart and Gupta, 2004; Sollows, 2001c), although research suggests that most major freshwater species can be farmed successfully (Halwart and Gupta, 2004). The choice of species is most likely to depend on regional preferences as well as access to seed, which is highly dependent on the availability of hatchery and nursery technologies (which may pose difficulties in many rural areas in the Global South) (Halwart and Gupta, 2004).

In terms of stocking, because the growing season of fish is often (but not always) limited to that of rice, usually 100 to 150 days (Halwart and Gupta, 2004), it is best to stock the fish as early as possible in order to maximize the growing season (Sollows, 2001c). Yet, it is important to make sure that the safety of the newly transplanted rice crop is not threatened in the process. While it is possible to stock small hatchlings directly after transplanting of the rice, it is safest to wait until 2 to 3 rice tillers have appeared (usually 1 to 3 weeks after transplanting or 4 to 6 weeks after direct seeding) to release fish stocks, especially in the case of large fish (Sollows and Cruz, 2001). When releasing the fish from transport bags into the paddy, the bag should be submerged in the paddy until the water temperature inside the bag is the same as that of the paddy before releasing the fish (Sollows, 2001c).

It is recommended that farmers culture 2 or more fish species, as then there will less competition for food amongst the fish (as different species eat different foods) (Sollows and Cruz, 2001). It is advised that fish be stocked in the paddy at a density of 3000/ha, at which level the organic materials found in the paddy should provide sufficient food for the fish (Sollows and Cruz, 2001). At higher levels, additional feed will likely be necessary (Sollows and Cruz, 2001). Although the harvesting process varies greatly across field type, production type, and geographical location, fish are often harvested approximately a few days to a week before or after the rice has been harvested (paddy has been drained) (Miah et al., 2011; Bocek, n.d.). In terms of rice varieties, there is no knowledge of any variety that does not work with fish (Sollows and Cruz, 2001), and hence the use of local and preferred varieties should be fine. That being said, rice varieties with certain qualities are often preferred, such as those which are deep water-tolerant or that tiller rapidly (allowing fish to be stocked earlier) (Sollows and Cruz, 2001).

Benefits and constraints to adoption

Unfortunately, while it has been well documented that rice-fish farming can have widespread economic, agricultural, ecological and nutritional benefits, the practice is often underestimated and undervalued by policy-makers and development practitioners alike (Halwart and Gupta, 2004; Halwart 2006).

Food security and nutrition benefits

A primary benefit of rice-fish farming is its potential effects on food security and nutrition. As noted in the Introduction, many farm households experience increased hunger in the mid-season (sometimes referred to as the hungry season) as this period is commonly the interim between the new harvest and the depletion of food stores from the previous one (Prein and Ahmed, 2000). Practicing rice-fish farming can reduce household stress during this period as small fish can be consumed to ensure adequate food supply until the harvest. In addition to providing sustenance in times of extreme scarcity, rice-fish farming can have an important effect on household nutrition (Halwart, 2006). The consumption of fish (often eaten whole) can provide households with critical micronutrients not sufficiently found in rice, such as calcium, iron, zinc, vitamin A, as well as some fatty acids and amino acids (Halwart, 2006).

Agricultural, ecological, and economic benefits

There are many agricultural, ecological, and economic benefits to rice-fish farming. It is estimated that rice yields are increased by approximately 10% (Sollows and Cruz, 2001; Halwart and Gupta, 2004). Fish feed on weeds and many insects, greatly reducing the presence of weeds, as well as the need for both insecticides and pesticides (Halwart, 2006). Additionally, the excrement of the fish, as well as decomposition of dead fish provides nutrients to the paddy soil, which act as a natural fertilizer (Halwart and Gupta, 2004). Also, the movement of fish releases nutrients from the soil and encourages uptake by the plant (Halwart and Gupta, 2004). As a final notable benefit, studies show that rice-fish fields are better able to produce and conserve nitrogen, and fish grazing keeps pH levels lower and decreases the volatilization of ammonia (a process which can cause extreme losses in nitrogen) (Halwart and Gupta, 2004). The associated decrease in use of chemical insecticides, pesticides and fertilizers can significantly help to increase biodiversity and ecosystem health (Halwart and Gupta, 2004).

There are significant economic gains which can be observed through the practice of rice-fish farming, both at the household and macro-economic level. Research reveals that increases in net income on rice-fish farms, due to savings on pesticides and earnings on fish sales, are 7 to 65% higher than on rice monoculture farms (Halwart and Gupta, 2004). The increased practice of rice-fish farming could also have other beneficial effects on the economy, as the increased demand for labour, hatcheries and nurseries, and transportation of fish seed (amongst other forms of related employment) can contribute to national income (Halwart and Gupta, 2004).

Constraints to adoption

It is important to mention a few important constraints surrounding the implementation and practice of rice-fish farming. Firstly, the preparation of land as well as farming itself is more labour-intensive than rice monoculture (Halwart and Gupta, 2004). Although purely speculative, it is possible that if a farm household is not able to afford additional labourers, the increase in labour may fall on women and children. This could result in negative societal impacts such as lower school attendance levels and related negative future livelihood impacts.

Additionally, farmers may be resistant to adopt rice-fish farming as it restricts the use of pesticides, which they may be accustomed to using. In the event that pesticides or nitrogen rich fertilizers are applied (or accidentally enter the paddy with the flood water), due to the associated increase in the concentration of ammonia (poisonous to fish in its unionized form), death of the fish could occur (Halwart and Gupta, 2004; Sollows 2011d). This could cause a significant and devastating shock to farm household income, and fear of such an occurrence may lower adoption levels.

Additional Resources

The resources below provide detailed descriptions of rice-fish farming practices across countries, climates, and land structures, as well as more detailed information on rice and fish species, and the benefits constraints of rice-fish culture:

Additional practical instructions for rice-fish paddy adaptations and practice:

http://teca.fao.org/read/8732

http://pubs.iclarm.net/resource_centre/CSISA-Training-manual-rice-fish.pdf

Additional research and case studies of rice-fish practices around the world:
http://www.auburn.edu/~clinedj/Spanish%20Publications%20Website/publications/English%20WHAP/GT8%20Rice_Fish.pdf

http://www.fao.org/3/a-a0823e.pdf

http://www.fao.org/docrep/005/Y1187E/y1187e00.htm#TopOfPage

Curriculum for farmer field school on rice-fish culture:

http://teca.fao.org/sites/default/files/technology_files/ba0031e01.pdf

Handout for the use of NGO partners, agricultural extension officers, and other relevant actors:

http://teca.fao.org/sites/default/files/technology_files/ba0031e03.pdf

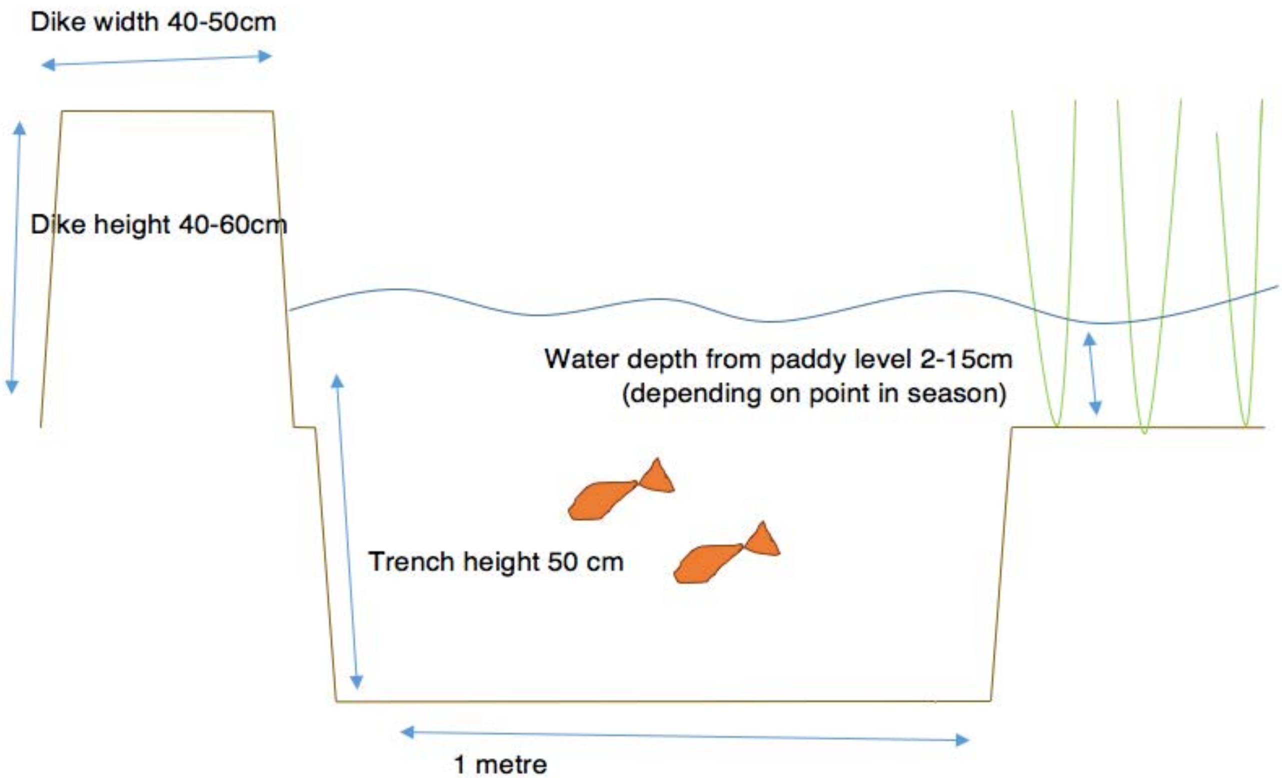

Figure 1. Dimensions for the construction of rice-fish paddy alterations. Adapted from (Halwart and Gupta, 2004; Miah et al., 2011; Bocek, n.d.),

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Chapter 12 – Crop breeding

Chapter 13 – Natural disasters