

Integrated Blast and Weed Management and Microdosing in Finger Millet

A HOPE Project Manual for Increasing Finger Millet Productivity

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Preface

More than one third of the 800 million people in sub-Saharan Africa (SSA) continue to be food insecure. There has been a number of projects attempting to address the food insecurity in SSA and the project "Harnessing Opportunities for Productivity Enhancement (HOPE)" for Sorghum and Millets is one such project that is being implemented by ICRISAT and its partners. The project aims at increasing the productivity of sorghum and millets in order to improve household incomes and food security for 110,000 households in SSA. The value chain approach to the research and development strategy employed by ICRISAT scientists and their collaborators in this project is to improve the demand for sorghum and millet products, which will in turn stimulate demand or increased adoption for sorghum and millet technologies.

Finger millet (*Eleucine coracana* (L.) Gaertn.), an important food cereal in SSA, exhibits very low yields mainly due to finger millet blast (*Magnaporthe grisea*) and weed infestation, among other constraints. Finger millet is produced in poor soils with limited use of organic and/or inorganic fertilizer, and this contributes to the low production that farmers experience. In order to improve finger millet productivity, farmers have to adopt appropriate and cost effective methods to control blast and weeds in finger millet and also to apply some modest minimal levels of fertilizer (microdosing). Therefore, the HOPE project has produced this handbook on "Integrated blast and weed management and microdosing" that can be used by extension agents and lead farmers in training other farmers. The manual has information on identification, epidemiology and management of blast disease, weed management and integrated cultural weed control practices. Further, the manual also contains guidelines on application of small doses of fertilizer in finger millet production. The user manual, in English, has also been translated in two local languages in ESA, namely, Amharic for Ethiopia and Swahili for East Africa.

Literature review of past work on finger millet and information generated from stakeholders' workshops have been the main sources of information contained in the user manual. The authors are very grateful to Dr Andrew Mgonja for carrying out the literature search and for preparing the manual. The authors are also indebted to ICRISAT's editorial staff, especially Ms Lydia Flynn and her team and Dr Dave Harris for editing the manuscript and preparing it for publication. The authors register their appreciation to the Bill & Melinda Gates Foundation (BMGF) for financing the HOPE project and, by extension, this manual. The authors are indebted to each and everyone who was involved in one way or the other in making this manual a reality.

Part 1: Integrated Blast Management in Finger Millet

Introduction

Finger millet is a staple food for millions of resource poor people in the semi-arid regions of Africa and Asia. In eastern Africa, it is cultivated in the lake regions of Kenya, Uganda, Tanzania and Rwanda, and in Ethiopia. In Kenya, the crop is grown in western, Nyanza and eastern regions; in Tanzania it is mainly grown in Singida, Arusha, Mbeya, Rukwa and Kilimanjaro regions, and in Uganda it is grown in the eastern and northern regions. In Rwanda, it grows in semi-arid hilly areas. Finger millet grows well in altitudes from sea level to 2,400 m in a variety of soil types ranging from poor to fertile but well drained.

A number of constraints limit finger millet production and productivity; key among them is blast disease, lack of improved varieties and poor crop husbandry. An average yield of 750 kg/ha in Africa is low and is attributed to the above constraints. Blast is the most destructive disease of finger millet because of its aggressiveness. In East Africa, losses exceeding 80% have been reported in bad years. Finger millet blast is caused by the fungus *Magnaporthe grisea* (*anamorph Pyricularia grisea*). In addition to finger millet, this fungus can also attack a number of other species of grasses and sedges. The pathogen attacks all stages of crop development (vegetative and productive stages). Blast isolates causing leaf, neck and head blast (Annex 1) on finger millet are genetically similar suggesting the role of the same strains in different types of blast.

Finger millet blast management should employ low cost technologies as finger millet farmers are resource poor. This manual will describe finger millet blast disease (causal organism, epidemiology, factors favoring infection, disease distribution, host ranges, life cycle, damage and the economic importance) and management methods. The main methods include cultural control and these include use of disease free seeds, proper seeding rates, proper weeding, preventing blast propagule dissemination, crop rotation, intercropping and straw management. Chemical control is another blast management method and includes field spraying with a fungicide and seed dressing. The best and cost effective control method, however, is use of integrated control methods including use of resistant varieties and other cultural practices.

Finger Millet Blast Disease

Blast characteristics and identification

Healthy (disease-free) finger millet.

Finger millet blast is characterized by the appearance of lesions on the leaves, nodes and heads. On the leaves, lesions are typically spindle-shaped, wide in the center and pointed toward either end. Large lesions usually develop a greyish center, with a brown margin on older lesions. Under blast disease-conducive conditions, lesions on the leaves of susceptible lines expand rapidly and tend to coalesce, leading to complete drying of infected leaves. Resistant plants may develop minute brown specks, indicative of a hypersensitive reaction. When the area between the leaf blade and leaf sheath (leaf collar) is infected, the collar turns brown and dies. This is called collar rot, which leads to death of the whole leaf above it. Besides attacking the leaves, the fungus may also attack the neck causing neck rot. When a neck is infected, all parts above the infected node may die (Sreenivasaprasad 2004). When this occurs, yield losses may be large

Neck blast.

Leaf blast.

Head blast.

because grain formation is inhibited and/or formed grains may be shriveled. In such cases yield losses may be as high as 90% (Ekwamu 1991).

Causal organism

Finger millet blast is caused by the fungus *Magnaporthe grisea* (*anamorph Pyricularia grisea*). In addition to finger millet, this fungus attacks a number of other species of grasses and sedges. Despite this apparently broad host range, any particular strain infects only a limited number of host species.

Blast genotypes show limited genetic diversity (Takan et al. 2003). Genotypes prevalent in some countries of East Africa express considerable variation in pathogen aggressiveness on a single variety as well as on all susceptible varieties. No isolate shows clear cut differences in expression on the host, suggesting the role of quantitative resistance. Isolates causing leaf, neck and head blast on finger millet are genetically similar suggesting the role of same strains in different types of blast, hence the host resistance identified should be effective against all expressions of blast in general (Takan et al. 2004).

M. grisea isolates from weed hosts are in general genetically similar and aggressive as those from finger millet, and in most cases belong to the same genetic groups. Weed blast isolates are capable of infecting finger millet, thus confirming the view that weeds serve as inoculum sources for finger millet blast (Takan et al. 2004). Seeds are also a primary source of inoculum causing seedling blast.

Epidemiology

Conidia (asexual spores) infect the plant under conditions of high humidity. They germinate by rapid growth of a hyphal element called a *germ tube*. The tip of the elongating germ tube enlarges and forms a dome-shaped, melanized infection structure called the *appressorium*. Enormous turgor pressure builds within the appressorium leading to penetration of the plant cuticle by the *penetration peg*, which enters the underlying epidermal cells (Hayden 1999). Once inside, invading hyphae swell and fill the cells. Hyphae penetrate the neighboring epidermal or parenchymal cells and rapidly form a colony.

Sporulation occurs in the grey area of the lesion, under conditions of high relative humidity. Conidia are produced on conidiophores that usually project through the stomata, though extrusion through the epidermal cell wall can also occur. Conidia are usually released at night or early morning. Conidium formation reaches a peak period three to eight days after appearance of lesions and may continue for as long as twenty days. Spores are released by dew or rain and are carried in the air to other plants. Spore production is a continuous process as long as conditions are favorable. The air borne spores, called conidia, land on finger millet leaves and germinate entering the leaf through the stomata into the epidermis. The fungus grows in there and produces lesions 4-5 days later. New conidia are produced soon after the 6^{th} day after spore germination (Yaegashi and Nishihara 1976). Distribution of the disease in the field is usually relative to the amount of disease propagule in the seed lots.

Factors favoring infection

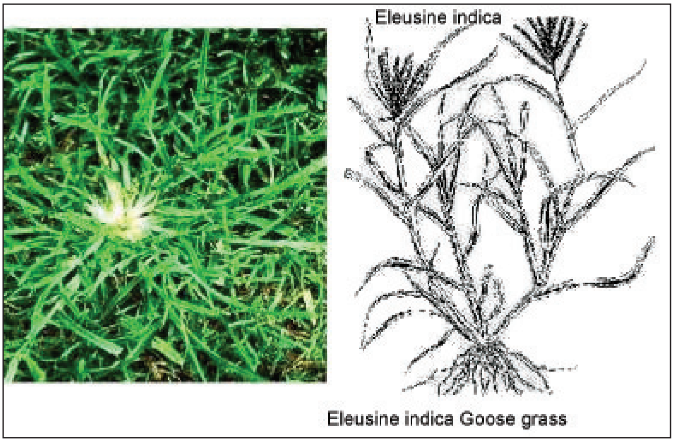
Blast infection is favored by cloudy skies, frequent rain and drizzles, which support accumulation of dew on leaves for a long time. In the tropics, blast spores are present in the air throughout the year, thus favoring continuous development of the disease. The fungus also establishes better in soils with high levels of nitrogen. (Sreenivasaprasad et al. 2006, Hayden 1999). The rate of sporulation increases with increasing relative humidity (90% or higher) and for pathogen germination, the optimum temperature should be 25-28°C.

Host range

The fungus has a wide host range, but the most common alternate hosts are mostly grass weeds such as *Eleusine indica*, *Eleusine Africana*, *Digitaria* spp., *Setaria* spp. and *Doctylocterium* spp. These serve as primary sources of inoculum. Other grains that sustain finger millet blast are volunteer upland rice plants (Sreenivasprasad et al. 2005).

Economic importance

Blast is the most destructive disease of finger millet because of its aggressiveness. In East Africa, grain yield losses exceeding 80% have been reported in some years. Grain quality is also affected because of poor grain filling.



Alternate host for finger millet blast.

Disease Management

Finger millet blast disease can be managed through cultural methods, use of resistant varieties and also chemical control measures. However, while the individual measures can be applied, integration of the components of the different control measures seems to give the highest benefits.

Cultural control

Use of disease free seeds

Diseased seed are primary sources of blast inoculum that can infect the subsequent crop. Most finger millet growing communities use their own saved seed from the previous harvest. This should not pose any problem of loss of seedling vigor as finger millet is a self-pollinated crop. However, where there is no seed selection, the farmer's seed may be contaminated with blast disease propagules. It is important to avoid contaminated seed by selecting ear heads that are free of disease and treating seed with a fungicide to kill disease propagules. Where possible, farmers can purchase certified seed from reputable seed dealers.

Planting time and soil fertility management

Manipulation of planting time and fertilizer application have been found useful in blast management. Sowing seeds with the onset of the rainy season helps to avoid early infection of seedlings. This is because, by the time enough inoculum accumulates in the air, the plants will have passed the sensitive periods for blast infection, which is between seed germination and plant tillering.

Excessive use of fertilizer is discouraged as it increases the incidence of blast. Heavy doses of nitrogen fertilizers cause lush crop growth rendering it susceptible to blast attack. A combination of organic and microdosing of inorganic fertilizer at ¼ of the recommended rate is both economical and can minimize blast infection. If animal manure is available, it should be used instead of nitrogen fertilizers. The rate of 5-10 t /ha animal manure is recommended. Nitrogen should be applied in small increments and not as one big dose.

Seeding rates

High plant density, coming from high seeding rate, enhances blast development and establishment due to dew accumulation on leaves. Seeding is therefore recommended to be done in rows and at the recommended spacing of 40×10 cm or 30×15 cm so as to allow an open space between the rows. This permits aeration and reduces dew accumulation.

Weed management

It is recommended to weed finger millet two to three times a season in order to maintain a weed free field. Weeds compete with the crop and weaken it for easy infection by blast. A dense population of weeds creates a good micro-environment for development of blast due to increased humidity around the crop plants (Berkowitz 1988). Proper weeding to eliminate alternate blast pathogen host weeds will reduce disease levels.

Propagule dissemination control

Avoid working in the field when it is raining or when there is a lot of dew. Inoculum in the form of conidia sticks to clothes when they are wet and can be moved to other finger millet fields where they can initiate infection. Avoid use of same field tools in blast and non-blast infected fields to prevent blast propagule dissemination. It is advised to wash all field tools after using them in a blast infected field.

Practice crop rotation

Crop rotation is aimed at including in the cropping system, crops that are not infected by finger millet blast and at such intervals that reduce disease propagules in the field (Barberi and Co Cascio 2001). The following system is suggested:

Finger Millet - Groundnuts - Maize
Finger Millet - Chickpea - Wheat
Finger Millet - Cowpea/Pigeonpea - Sorghum

Intercropping

Finger millet can be intercropped with cowpea, groundnuts and pigeonpea (Buhler 2002). The reasons for intercropping are the same as those given for crop rotation.

Field hygiene

Finger millet straw from diseased plants should either be ploughed deep under so that blast propagules are unable to germinate or it should be collected and burnt (Horowitz et al. 1983). Do not thresh or winnow finger millet from diseased plants in the field, so as to avoid disease propagules being blown long distances that can infect crops in other fields.

Use of resistant varieties

Planting varieties resistant to finger millet blast is the most practical and economical way of controlling finger millet blast (Lenné 2005). In eastern Africa improved varieties have been identified with low blast levels and good agronomic traits (grain yields 1.5-3.0 t ha^{-1}). These varieties include (Mgonja et al. 2007a, 2007b):

KNE 688	Gulu E
KNE 814	SX8
KNE 1149	SEC 915
P 224 (Pese 1)	KNE 409
Seremi 1 and 2 (U 15)	KNE 1098

Variety U15.

Variety P224.

Among these, P 224 (Pese1) and Seremi 2 have been released in Uganda, U15 and P224 released in Tanzania in 2012, KNE 409 and 1098 released in Ethiopia and P 224 released in Kenya.

Chemical control

Systemic fungicides such as pyroquilon and tricyclazone are possible chemicals for controlling the disease. Benlate has also been tried on finger millet and was found to reduce leaf blast by 28% on young millet and head blast by 38%.

Finger millet seed can be treated with Trycyclozole at 1g/kg seed to kill disease propagules as they germinate in the soil around roots. Such a treatment eliminates disease infection through roots.

Chemical blast control, though effective to a reasonable level, is a very expensive option for the resource poor farmer. Cultural control methods are the best options.

Summary of key messages

- There are various control methods for finger millet and these include cultural, chemical and the use of resistant varieties
- Usefulness of any one method depends on the economic and social conditions of the farmers
- Integrating the different finger millet blast-disease control options offers the most benefits.
- The use of resistant varieties is the most basic and economic control method and can be integrated with cultural methods as well as chemical control.

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Part 2: Microdosing in Finger Millet

Introduction

Finger millet (*Eleusine coracana* L. Gaertn) is an important minor millet grown in eastern and southern Africa, southern Asia and central America. Finger millet, with Ethiopia as its center of origin, is a food eaten mostly by the poor in the developing countries, but it is gaining in importance because of its usefulness as a nutritious food for young children and for diabetic patients.

Finger millet, as is the case with many cereal crops, has a number of constraints including frequent droughts, diseases (eg, blast) and unavailability of adequate essential nutrients such as Nitrogen (N), Phosphorus (P) and Potassium (K). Drought is the leading cause of food insecurity and human suffering in sub-Saharan Africa. Three-quarters of the world's severe droughts over the past 15 years have occurred in Africa. Over 34% of the population in Africa (about 230 million people, FAO 2004) live in arid and semi-arid environments.

Most soils in the dry tropics are coarse, sandy and fast-draining, and consequently have inadequate amounts of the much needed nutrients (N, P, K) for growth. The nutrients, therefore, require supplementation to improve the recurrent poor yields obtained by farmers.

Application of these nutrients, in the form of fertilizers, in the conventional way, may be risky, under the frequent droughts occurring in the dry tropics. Additionally, farmers in these regions are resource poor and cannot afford to purchase and use large amounts of fertilizers.

The combination of frequent droughts and endemic poverty make resource poor farmers dependent on natural soil fertility to produce their crops. This dependence on natural soil fertility has led to declining crop yields, necessitating farmers and scientists to collaborate in order to improve the soil fertility levels. As scientists strive to develop improved finger millet varieties that are efficient in water and nutrient utilization especially for the drought prone areas, a method of fertilizer application was developed that ensures use of essential nutrients within the crop zone under low moisture conditions. This method uses small amounts (micro-dose) of fertilizers applied at planting or after emergence of the crop to boost nutrient uptake and productivity.

This is a manual for training trainers (extension, lead farmers and farmer group leaders) who will in turn train other farmers on use of microdosing techniques in improved finger millet production. The manual begins with a brief on the extent and causes of soil fertility problem in crop production and the rationale for using microdosing techniques to improve the fertility of the soil. Next to be discussed are specific microdosing methods, fertilizer application rates and finally some recommendations for promoting and sustaining use of microdosing techniques among the majority of finger millet producers.

Microdosing in finger millet

There are efforts to improve finger millet's genetic potential to complement other crop management practices in improving yields. Results of studies conducted in Uganda indicate that yields of finger millet can more than triple, with application of correct amount and placement of fertilizer. To overcome drought and nutrient related constraints, in finger millet production, a more efficient fertilizer application method, microdosing, which uses a small amount of fertilizer to improve finger millet productivity has been developed. The specific microdosing technique employed in finger millet production depends on the type of finger millet sowing method.

What is microdosing?

Microdosing is application of small amounts of fertilizer to a sowing hole or beside a plant at the appropriate time for more efficient use of the fertilizer and available moisture by the plants in order to optimize yields (Annex 1). The fertilizer is placed in the root zone of finger millet to facilitate efficient uptake (Tabo et al. 2006, Twomlow et al. 2008). So the critical elements in microdosing are using a very small amount of suitable fertilizer, placing it in a strategic position for maximum use and timing the application to coincide with moisture availability in the soil.

Rationale for using microdosing method

- Most soils in sub-Saharan Africa are low in N and P because the soil parent material is low in these elements, declining soil organic matter and prolonged cropping without fertilizer application (Bationo 2008).
- Resource poor farmers have for a long time failed to use fertilizers because the recommendations involved large quantities that are unaffordable. Under their situation of limited cash, the cost of recommended amount of fertilizer and risk of crop failure due to drought, are too high to ignore.
- Nevertheless, although a majority of farmers in drought prone sub-Saharan Africa cannot afford the rates of fertilizer use recommendations,

they need to improve their crop productivity in order to improve food security in these drought prone areas that receive unreliable rains and have soils deficient in nitrogen and phosphorus.

- The fertilizer microdosing technique allows resource poor farmers to apply small, affordable and efficient amounts of fertilizer to their impoverished land for improved soil health and crop production.
- It has the potential to end the widespread hunger in drought prone areas of Africa where soils are depleted and smallholder farmers rarely produce enough to feed their own families.

The impact of microdosing

- Microdosed crops perform better under drought conditions, especially with early season moisture availability. They develop a large root system capable of absorbing water and required nutrients contained in the fertilizer that help to hasten crop maturity and escape late season drought.
- In Kenya, a system was initiated to supply small packs of seed and fertilizer to first-time and women buyers so as to create fertilizer demand. The initiative yielded good results because demand for additional farm inputs from agro-dealers was created (Blackie and Albright 2005).
- In Zimbabwe, a rate of 25 kg of ammonium nitrate (AN) per acre was introduced for microdosing in maize production. Most farmers obtained 30 to 50% yield increase – a production level that helped to end grain shortage in Zimbabwe in 2004 (Rusike et al. 2004, Mazvimavi et al. 2008, Mapfumo and Giller 2001).
- Malawi initiated a subsidized starter pack program to overcome famine by supplying packs of fertilizers to farmers for use in microdosing in maize production (Blackie and Mann 2005, Snapp et al. 2004). When the program was abandoned, Malawi got into the problem of food deficit again. Thereafter a new program called 'Smart subsidies' was started that enabled Malawi to produce surplus food (Denning et al. 2009).
- The 'Warrantage', system, practiced in Niger by using a combination of microdosing techniques and by delaying the sale of millet grain harvest by 10 months, by which time prices had increased by three times, enabled farmers to increase their income by 50 to 134%. During the grain-sale delay period they obtained inventory credit to purchase inputs for the next cropping season, using their grain as collateral. They repaid the credit after selling their produce (Pender et al. 2006).

Microdosing methods

There are three common microdosing methods in use, and one method currently under development. Timing of application with respect to soil moisture availability and placement of fertilizer relative to position of seed or plantlet is critical.

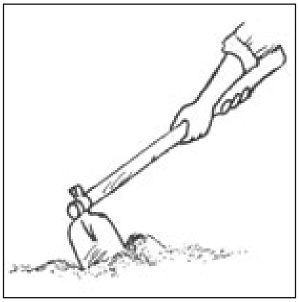
- Planting holes are dug, then fertilizer and seeds are placed into them and covered
- Fertilizer is placed 5 cm away from growing plantlets, to avoid the burning effect of fertilizer on the plantlets
- Appropriate amount of seed and fertilizer is mixed prior to seeding in moist soil conditions. Seeding under dry soil conditions leads to damage to the seeds or seedlings
- A new method, still under development, is by use of a tablet that is dropped in each planting hole; the tablet dissolves and slowly releases N and P, making them available for a longer period of time.

Microdosing based on method of sowing

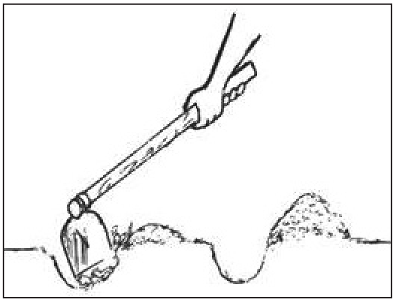
The method used in sowing finger millet influences the microdosing method to be used, especially fertilizer application technique.

- Seeding by drilling: Suitable amount of fertilizer and seed is mixed immediately before drilling in moist soil conditions.
- Spot sowing: Fertilizer is placed in the seeding hole.
- Broadcasting: Seed is mixed with fertilizer and then immediately broadcast and worked into moist soil by pulling twigs over it.
- Transplanting finger millet: Planting holes are dug and then appropriate fertilizer is placed in holes immediately followed by transplanting of the seedlings.
- Where rainfall is high as is the case in Uganda and some parts of Kenya, around Lake Victoria, delay of fertilizer application for 30-40 days after sowing is necessary. Under this system, the correct amount of fertilizer is spot placed 5 cm away from the target plantlet. Fertilizer can be applied in two to three equal doses starting at sowing, 30 days after sowing and at booting depending on moisture availability (Hove et al. 2006).

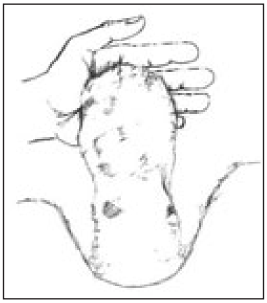
Microdosing techniques



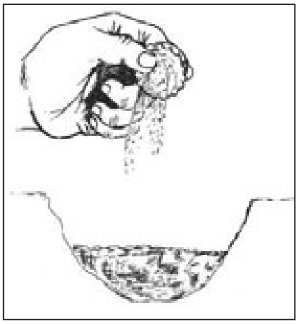
Checking soil moisture – the soil has to be moist enough.



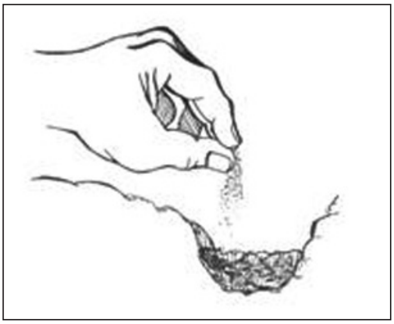
Digging sowing holes.



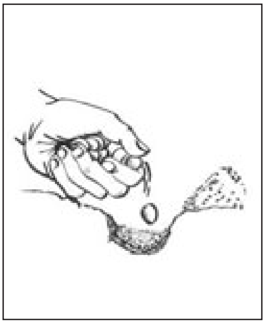
A handful of manure is dropped into each hole.



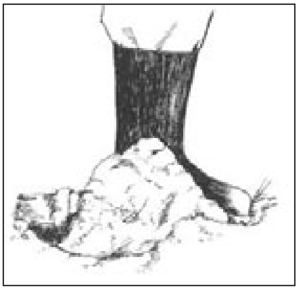
Fertilizer in one bottle cap dropped into the sowing hole.



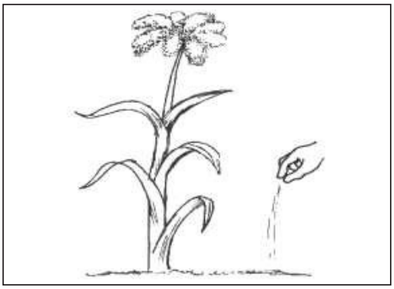
A three finger pinch of fertilizer is dropped into the sowing hole.



Seed is dropped into a hole with a handful of manure and a three-finger pinch or bottle cap full of fertilizer.



Covering the sowing hole after dropping manure, fertilizer and seed.



A three-finger pinch or one bottle cap full of fertilizer is dropped 5 cm away from the plant (top dressing).

Fertilizer microdosing rates

- In Niger, as little as 2 g of Di-ammonium Phosphate (18-15-0) per hole or 20 kg/ha or 6g of NPK (15-15-15) per hole or 60 kg/ha was used in microdosing applications. These fertilizer amounts doubled the crop yield.
- In Zimbabwe, microdosing is delayed to 30-40 days after sowing to avoid loss of fertilizers due to the heavy rains that fall in the early season periods. They use a bottle top to apply fertilizers at the rate of 60 kg/ha of ammonium nitrate (AN) or 75 kg/ha of calcium ammonium nitrate (CAN) or 50 kg/ha of Urea. The amounts used per hectare differed between fertilizer types due to their differing levels of N (Hove et al. 2006). AN has 34% N, CAN has 28% N and Urea has 46% N.
- Application should always be done on wet and weed free soil. Urea should be covered with soil after application to avoid volatilization (Hove et al. 2006).

Microdosing and use of organic manure

- Microdosing is best practiced in conjunction with application of manure such as kraal or compost manure. Combining mineral fertilizers with organic manure can substantially improve agronomic efficiency of nutrient use compared to same amount of nutrients applied through either source alone (Vanlauwe et al. 2001a).
- While mineral fertilizers are applied to supply the commonly deficient NPK in the drought prone areas of sub-Saharan Africa, organic manure supplies the minor nutrients lacking in mineral fertilizers.
- Several tons of organic manure would be needed to provide the NPK necessary for normal plant growth, which is not possible under the resource-poor farmers' environment.
- Manure has the ability to conserve soil moisture and improve soil structure and can also be micro-dosed by putting a handful of well decomposed manure in each planting hole prior to placing mineral fertilizer and seed.
- Application of micro-doses of manure together with mineral fertilizers to a planting hole increased sorghum yields 7.5 fold in Burkina Faso (Reij and Thiambiano 2003).
- Manure for microdosing is readily available as livestock rearing by smallholder farmers in sub-Saharan Africa for wealth accumulation, income generation, improvement of household nutrition and provision of manure is a common practice.

Policy and technical considerations to promote microdosing

- Current fertilizer prices in sub-Saharan Africa are higher than those in other countries due to low volume of fertilizer used, poor road infrastructure and inappropriate pricing policies coupled with lack of local fertilizer production. These constraints are potential intervention focal points for sub-Saharan countries in order to make fertilizer more affordable and accessible to resource poor farmers.
- Farmers, a majority of whom cannot afford current fertilizer prices, should be involved in policy formulation and fertilizer related technology development and evaluation in order to evolve effective capacities and motivation to use the microdosing system (ICRISAT/MAY 2000).
- Farmers are very receptive to any innovations that provide them with adequate food and income security. It is important that microdosing innovation in finger millet delivers the expected results within the first year of the farmers' participation in order to sustain their motivation (Twomlow et al. 2008).
- As seen in the case of Malawi and Niger, farmers prefer to buy fertilizers in affordable small packs for use within the cropping season. Fertilizer use by small farmers through the affordable small pack innovations should be extrapolated in the whole region with the support of respective governments and fertilizer companies. The 'Warrantage' system developed in Niger is worth trying in every country in the region.
- As good as it has proved to be, microdosing can only perform successfully if it is accompanied with good agronomic management practices that include good land preparation, use of improved seed, timely sowing, recommended plant spacing, proper maintenance of soil moisture, timely and effective weeding and effective control of insects and diseases.
- In order to maximize returns from microdosing using compost or farm yard manure, it is important to crop an area of land that suits the amount of manure and family labor available.
- Participatory engagement of all primary stakeholders is necessary at all stages of the microdosing process, starting from planning to implementation and adoption. It is the best way to create awareness and enhance farmers' capacity and sustain the use of microdosing innovations.
- Microdosing is done only when soil moisture is available.

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Part 3: Integrated Weed Management in Finger Millet

Introduction

Finger millet is an important minor millet grown in eastern and southern Africa, southern Asia and central America. It is a food mostly eaten by the poor, but, it is useful to persons with diabetes and growing children because of its medicinal nature and high nutritional value (rich in Ca, P and Fe). Grains are used to prepare cakes, pudding, sweets, and the germinated grain is malted for beer making and to feed to infants. It is also good for pregnant women, and is considered a nutritious food for adults of different ages. Finger millet also makes good fodder.

Finger millet is a short stature cereal growing up to 2 ft high at maturity. Under poor management conditions, weeds are enemy number one as competitors for light, nutrients and water. The millet crop fails completely without these important resources. Weeds that grow taller than finger millet compete heavily for light, rendering the crop unable to utilize its full potential in processing its own food. Consequently finger millet plants etiolate, produce small heads and become susceptible to lodging.

Weed management is one of the most expensive finger millet farming activity faced by farmers. Weeding normally takes up to 50% of all labor put into finger millet management and as a constraint it limits the area that a household can sow.

Weeds should and can be removed out of a finger millet field though the exercise is labor intensive and costly. There is no single best way of removing weeds from the field except to go for integrated weed management, which involves use of cultural and chemical weed control methods. Among the cultural methods, hand weeding is more common for resource poor farmers. It is usually undertaken by women and children resulting in drudgery and withdrawal of children from school during the weeding seasons. It is costly due to the time involved but, if done effectively, it can control weeds very well and increase farmers’ income.

Integrated Weed Management in Finger Millet

Integrated weed management is based on knowledge of the biological and ecological characteristics of weeds and understanding how their presence can be modulated by cultural practices. Based on this knowledge, the farmer must first build up a weed management strategy within a crop sequence, and then choose the best method of direct weed control during crop growing cycles. Besides this, it must be remembered that weed management is always strictly embedded in crop management itself. As such, the interactions between weed management and other cultural practices must be duly taken into account. For example, the inclusion of cover crops in a crop sequence is an interesting way to integrate weed management with nutrient management in low-external input systems, with additional benefits on other important agro-ecosystem properties (eg, soil fertility, soil moisture retention and biodiversity).

Integrated weed control is a systematic process that supports a balanced approach to managing crop production systems through effective, economical and environmentally-sound suppression of weeds (Buhler 2002). It is a concept that is providing solutions for weed resistance to herbicides and elimination of useful plants and insects.

What are weeds?

Weeds are plants for which we have not found use, and that have negative effects or influence on useful plants or crops we grow (Buhler 2002).

Classification of weeds

Weeds are classified on the basis of their mode of growth and time they take to mature.

Annual weeds

Complete their life cycle in one year. This means that the weeds germinate, grow and produce viable seed within one year.

Bi-annual weeds

They have a life span of two years from the time they germinate to production of viable seeds. They usually die with the maturity of their seeds.

Perennial weeds

These are weeds that live for two to many years and only produce seeds from the second year onwards.

Simple perennials

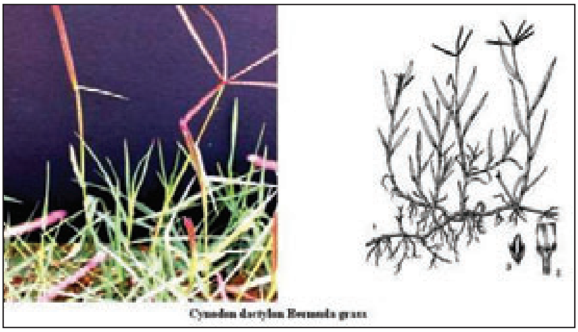
These are perennial weeds that propagate themselves through seeds only. Their root system is usually large and fleshy (eg, common dandelion *Taraxacum officinale*).

Bulbous perennials

These weeds reproduce by seeds and underground bulbs.

Creeping perennials

Reproduce by seeds, above ground stolons and below ground rhizomes. They are the most difficult perennial weeds to manage. A good example is Bermuda grass (*Cynodon dactylon*).



Weeds that affect finger millet, with stolons.

Weed dispersal

Weed seeds are not able to move on their own from place to place except through the help of wind, water, animals, humans, machinery, animal feed and crop seeds.

Wind Some weed seeds have cottony coverings and parachute like structures that enable them to float with the wind, eg, common dandelion.

Water Seeds of weeds growing along irrigation channels and ditches fall onto water and are carried to other fields. Weed seeds are also carried from one field to another by excess irrigation water during irrigation. Curly dock (*Rumex crispus*) pods have pontoons that help carry the floating seed on water.

Animals and humans Some weed species produce seeds with barbs, hooks, spines and rasps that cling to human clothes and animal fur. Common cocklebur (*Xanthium strumarium*) produces seeds that adhere tightly to


Weed seeds dispersed by wind.


Weed seeds dispersed by animals.

human clothes or animal fur. Black jack (*Bidens pilosa*) seeds have hooks that easily attach to human clothes.

Machinery Weed seeds are often dispersed by tillage and harvesting equipment and other field tools by attaching themselves to soils on them.

Crop seeds and fodder Any weed seed contained in crop seed is potentially capable of multiplying itself in the field to eventually cause harm to crops. At harvest time a lot of weed seeds remain with crop straw, which is eaten by livestock. Finally the weed seed goes back to the field either in mulch or animal manure.

Weed dormancy As discussed above, weed seeds travel great distances and unfortunately may remain dormant in soil and water for a number of years. Weed seeds are capable of surviving at a soil depth of 6 inches for several years. Efforts to get rid of weeds may not yield good results because dormant seeds become active time after time while new weed seeds are also being produced.

Impact of weeds on crops

Weeds interfere with crop plants in the following areas:

Water is often the primary factor that limits finger millet crop production. Weeds often require more water than crops and are more efficient at capturing available soil moisture.

Some perennial weeds develop deeper roots that spread wider than crop roots and compete severely with crop plants for water.

Nutrients Weeds and crop plants compete for limited supplies of nitrogen, phosphorus and potassium in the soil. Weeds are better competitors for nutrients than crops because of their more efficient root system and fast growth. They deprive the crop plants of essential nutrients. Plants become weak and give poor yields.

Light Light is used as it is captured without undergoing any storage for later use. Weeds, which grow faster than crops, develop large canopies that intercept light also needed by crops. Finger millet fails to manufacture the food it needs, becomes weak and produces a poor crop.

Allelopathy Some weed species produce certain chemicals or hormones that interfere with the growth of finger millet. Nut sedges and Johnson grass are known to produce allelopathic chemicals that inhibit growth of finger millet. Allelopathic chemicals may be produced by weeds as a fight against the competing crops around the weeds.

Crop quality Weeds are capable of producing a large number of seeds, which contaminate finger millet grain and by so doing reduce its quality.

Poisonous weeds Some weeds not only contaminate produce but they are also poisonous to humans. Poison ivy (*Toxicodendron radicans*) causes severe skin irritation (dermatitis) in humans.

Weeds harbor pests and diseases Weeds may serve as reservoirs for new and common invasive insect pests and diseases. *Eleusine indica* is a common weed that serves as an alternate host to finger millet blast. This and other weeds act as primary sources of inoculum for finger millet blast infection.

Weed management strategies

Weeds compete with crops for water, nutrients and light. If any of these factors, essential for plant growth, are limited, expected yields will be poor. In many agricultural systems around the world, competition from weeds is one of the major factors reducing crop yield and farmers' income (Berkowitz 1988). In developing countries, herbicides are rarely accessible at a reasonable cost, hence farmers often need to rely on alternative methods for weed management. In planning for weed management the following strategies should be considered:

- Identify the invasive weed species and study them well
- Develop an inventory for invasive weeds, the damage they cause and places where they are found

- Develop basic control strategies based on potential damage, effect of the control measure on environment and costs involved
- Consider a combination of control methods that take into account maintenance of soil moisture, structure, useful insects and environment as a whole
- Consider the effectiveness of the method/s used in terms of returns per unit cost of the measures.

There are three major weed control strategies - preventive, cultural and curative.

Preventive strategies

Preventive methods include weed seed dispersal control, crop rotation, cover crops (when used as green manures or mulches), tillage systems and seed bed preparation.

Control of weed seed dispersal

Weed seed dispersal methods have been discussed above but the methods to reduce such seed dispersal are discussed here.

Avoid heavy winds Heavy winds can be avoided by growing wind break trees on the side of the field where wind usually comes from.

Water To avoid dispersal of weed seeds by water all weeds along irrigation channels and ditches should be removed before they set seed.

Animals and humans Animals should be monitored to make sure they do not carry weed seeds in their fur from one field to another. People should avoid carrying weed seeds in and on their clothes.

Farm machinery and tools Once farm machinery and tools have been used they have to be cleaned of any weed seeds. This includes removing soil clogs off machines and washing them before going to another farm.

Crop seeds and fodder. The number of weed seeds in finger millet seed should be at the most minimum or none at all to avoid early establishment. Since fodder given to livestock can harbor many weed seeds, it should not be put back into the field raw. Instead it should be composted to rot well for use of weed seed free manure.

Crop rotation

Differentiation of crops grown over time on the same field is a well-known primary means of preventive weed control. Different crops obviously bring about different cultural practices, which act as a factor in disrupting the growing cycle of weeds and, as such, prevent selection of the flora towards increased abundance of problem species (Barbiri and Co Cascio 2001). In contrast, continuous cropping selects the weed flora by favoring those species that are more similar to the crop and tolerant to the direct weed control methods used (eg, herbicides) via repeated application of the same cultural practices year after year (Liebman and Dyck1993). When leguminous crops are included in a finger millet rotation, they trigger germination of *Striga* but are unable to support its continued growth. The *Striga* then dies. Similarly, when sweet potatoes or cowpeas are grown in a field after finger millet, most annual weeds get strangled.

Mulching

When mulch is used, it is left to decompose on soil surface. Weed suppression seems mostly to be the result of the physical effects of mulch, rather than to nutrient- or allelochemical-mediated effects (Froud 1983). In particular, weed suppression seems directly related to the amount of mulch applied, which influences light extinction through the mulch and consequently weed seed germination (Teasdale and Mohler 2000). Small-seeded weed species appear to be more sensitive than large-seeded species to physical effects of mulch.

Cover crops

Cover crop effects on weeds largely depend upon cover crop species and management, following finger millet and weed community composition. Weed suppression is exerted partly through resource competition (for light, nutrients and water) during the cover crop growing cycle. Interference with weeds, including competition, physical and allelopathic effects, is generally higher when crucifers are used as cover crops (Karlen et al. 1994). Interference from cover crops is related to their occupation of ecological niches otherwise available for weeds. This is mostly a result of the sequestration of soil nutrients (especially N), to the release of allelochemicals (eg, glucosynolates from crucifers) and to modifications of the soil microenvironment (Gallandt et al. 1999). An example of a highly weed suppressive cover crop is kale. In contrast, although direct weed suppression by legumes can be significant, their residual weed control effect is usually lower because the high quantity of N released from their residues after cover crop destruction stimulates weed emergence, especially when legumes are used as a green manure (Blum et al. 1997).

Tillage systems

The effect of primary tillage on weeds is mainly related to the type of implement used and to tillage depth. These factors considerably influence weed seed and propagule distribution over the soil profile and therefore they directly affect the number of weeds that can emerge in a field. Shallow cultivation by hand hoe leave weed propagules on the soil surface where they can easily germinate and grow when soil moisture is available.

However, mould board ploughing is very effective in reducing weed density and hence it is an important preventive method as a partially suppressive direct weed control method that reduces the labor needed for subsequent hand-weeding (Froud 1988).

Disturbance posed to weeds by tillage is dependent more on the type of implement than on tillage depth. Tools that do not invert the soil (eg, chisels) increase weed density and shift weed flora composition towards an increased presence of biennials, perennials and non-seasonal annuals. Most of these species are characterized by wind-dispersed seeds with reduced longevity and dormancy and are unable to emerge from deep soil layers (Zanin et al. 1997).

Seedbed preparation

Cultivation for seed bed preparation has two contrasting effects on weeds: (i) it eliminates the emerged vegetation resulting after primary tillage; and (ii) it stimulates weed seed germination and consequent seedling emergence, thanks to soil mixing and reallocation of seeds towards shallower soil layers. Together, these two effects can be exploited through application of the false (stale) seed bed technique, a preventive method with the specific aim of reducing weed emergence in the next crop cycle.

The false seed bed technique is a weed control technique that involves creating a seedbed some weeks before seed is due to be sown in order to stimulate as much as possible the emergence of weeds prior to sowing. Emerged weeds are then destroyed by the next cultivation or by application of a total herbicide (eg, glyphosate), the latter being useful especially where perennial weeds are present. At sowing time, the seed bank of those weed species able to emerge together with the crop is then already partially depleted and their emergence in the crop is reduced. Cultivation can be performed with any mechanical or hand tool. Application of the false seed bed technique can reduce weed emergence > 80% compared to standard seed bed preparation (van der Weide et al. 2002). Obviously, application of this technique implies that there should be enough time (at least 2 months) between ploughing and sowing of the next crop to allow weeds to emerge. For this method to be effective, the soil must have enough moisture to sustain weed-seed germination. Therefore, this method is useless where soil water availability is limited.

Cultural strategy

Cultural methods include crop sowing time and spatial arrangement, crop genotype choice, cover crops, intercropping, and crop fertilization.

Crop spatial arrangement

Sowing finger millet by drilling eliminates spaces where weeds can grow within the plant row. The only available space for weed growth will be between the rows where weeds can be removed by hand hoe in small farms. Increasing crop plant density increases its competitive ability with weeds but, at the detriment of yield because of higher intra-specific competition between finger millet plants.

Crop genotype choice

Different genotypes of the same crop possess traits that may vary in their abilities to compete against weeds. These traits are typically those related to faster seedling emergence, quick canopy establishment (Rasmussen and Rasmussen 2000), and higher growth rates in the early stages. Use of these genotypes can therefore reduce the need for direct weed control measures (eg, herbicides or cultivation).

Intercropping

Another cultural method for increasing crop competitive ability against weeds is intercropping, which increases the use of natural resources by the canopy and, compared to sole crops, often compete better with weeds for light, water and nutrients (Liebman and Dyck 1993). For example, compared to sole cropping, a finger millet green gram intercrop sown in a two row-by-one row layout decreased relative soil cover of weeds. The success of intercropping relies on optimizing the use of available light, water and nutrient resources by the intercrops while at the same time minimizing competition between them. In practice, this means optimizing intercrop spatial arrangement, relative plant densities and crop relative growth over time in any given environment (Ofori and Stern 1987).

Curative strategy

Curative methods include any chemical, physical (eg, mechanical and thermal) and biological methods used for direct weed control in an already established crop.

Physical weed control

In the physical weed control method, weeds are removed from the field or are frequently disturbed to cause their death or inability to produce seed. There are several ways this can be done; one way is to turn the soil well during cultivation so as to cover all weeds to deny them re-growth. The second way is to slash down all weeds so as to deplete their food reserves and cause their death. This can be done between the finger millet rows. The third way is to remove weeds by hand especially those growing very near the crop plants. This is possible where there is spot growth of weeds and is common for finger millet. The last, but not least, way is the use of hand hoe, which is a very common practice by resource poor farmers. It is the best way of removing weeds between the rows of finger millet. Any weeds found within the rows are removed by hand.

Soil thermo-heating

Soil thermo-heating is a preventive method that exploits heat to kill weed seeds and therefore reduce weed emergence.

High soil temperature (200°C), if lasting 20 to 30 seconds, is able to kill the reproduction structures of pests, diseases and weeds (Horowitz et al. 1983). Soil thermo-heating can be defined as a soil disinfection method that exploits the thermo-energy available through burning straw in the field. To increase the thermo-heating effect as much as possible, the soil surface must be smooth and must contain enough moisture to favor heat transfer down the profile, and to make reproductive structure of pests, diseases and weeds more sensitive to heat damage. For this reason, prior to thermo-heating enough straw has to be collected to cover the entire soil surface to a depth of 6 inches. The straw is then set on fire and should burn for at least 30 seconds to produce effective heat.

Chemical weed control

The control of weeds in growing crops by use of weedicides increases yields and ensures efficient use of irrigation, fertilizers and plant-protection measures, such as the spraying of insecticides and fungicides. The removal of weeds from the growing crops facilitates easy harvesting and gives high-quality produce without admixture with weed seeds. Chemical weed control can be carried out at times, situations and under conditions that make manual or mechanical weeding difficult. A great advantage of this method lies in the killing of weeds in the crop rows and within the rows. The chemical method is easier, less time-consuming and less costly than hand weeding (Hoglund et al. 1991).

It is important to understand the basics of herbicides and their use so as to integrate them in general weed management programs. Herbicides are classified according to their selectivity, mode of action and the time of application.

Pre-emergence herbicides

A pre-emergence herbicide is usually applied into the soil before finger millet is sown or after the crop is seeded, but before crop and weeds emerge. Crop seeds are sown deeper than the herbicide zone and weeds are controlled as they try to emerge. The advantage of these herbicides is that they control weeds early and well and minimize competition. However, pre-emergence herbicides are usually not effective in controlling perennial weeds and are also less effective under dry soil conditions. Many pre-emergence herbicides leave residues in the soil that may be detrimental to sensitive crops in a rotation. Examples of pre-emergence herbicides:

Pendimethalin (stomp) is applied at 3.3 kg product/ha 1 to 2 days after sowing crop seed; Oxadiazon at 2 kg product/ha is applied 1 to 2 days after sowing crop seed; Isoproturon at 1 kg product/ha is applied 1 to 2 days after sowing crop seed.

Post-emergence herbicides

These are herbicides applied after both the crop and weed seeds have emerged. Use of these herbicides has the following advantages: They are applied when the type and density of weeds have been observed; they usually do not leave any residues in the soil and are effective in the control of perennial weeds. However, these herbicides are only effective when weeds are young and lush. Any new flush of weeds coming out after the herbicide is applied are not controlled and application can be delayed under rainy and windy conditions.

Examples of post-emergence herbicides

2,4-D to kill broad-leaved weeds and annual grasses. It is usually applied 25-40 days after sowing finger millet. Applying it early can scorch crop plants and after 45 days it can reduce crop seed setting.

Roundup (glyphosate) is another post-emergence herbicide that kills all weeds unselectively and even crops too. It is best applied, therefore, before sowing finger millet to weedy fields. Crop sowing can then follow 7 days later.

Selective herbicides

These are herbicides that when applied, will kill weeds without harming the crop. It does not matter whether they are pre- or post-emergence herbicides. 2,4-D will kill broad-leaved weeds and annual grasses in a finger millet crop without causing harm to the crop itself.

Non-selective herbicides

These herbicides kill all plant life in a treated area. They can be pre- or post-emergence herbicides. Roundup is the best example for non-selective post-emergence herbicide.

Contact herbicides

Contact herbicides kill weeds or plant parts covered by herbicide during spraying and are directly toxic to living plant cells. They are effective against annual weeds and can also burn off tops of perennial crops, but not those that are underground such as rhizomes, corms, stolons or bulbs.

Systemic herbicides

These are herbicides absorbed by either the roots or the leaves and translocated to other parts of the plant. They act slowly and show effect a few days after they are applied. 2,4-D is a systemic and selective herbicide, whereas Roundup is systemic and non-selective.

How to increase effectiveness of herbicides

Age of weed

As a rule, weeds in the seedling stage are usually most susceptible to herbicides. Young weeds are growing actively and there is a great deal of movement of food and water throughout the plant. Systemic herbicides, once inside the plant, will be moving with these materials to the growing points.

With established perennial weeds, such as bermuda grass, treatment at early flower stage is usually more effective. This is because the root food reserves are expended and newly produced food along with herbicide is being moved back down to the root system to again build up reserves. With bermuda grass and other perennials, it is the root we must attack for control.

It is critical to follow herbicide label directions regarding stage of weed growth to obtain optimal control.

Nutrition

Herbicide injury to weeds is greatest when nutrient levels are high and the weeds are growing vigorously. Adequate fertility also improves weed control by increasing competition by the crop.

Cultivation

Chemical weed control is more effective in fields that are cultivated because more weed seeds are brought to the surface to germinate. With perennial weeds, cultivation lowers the root reserves making them more susceptible to herbicides.

Soil Organic Matter

Soils with high Organic Matter (OM) such as compost manure require higher rates of chemical than do sandy soils. This is because more of the chemical is bound to the soil colloids in high OM soils.

Soil texture

Higher herbicide rates are needed on silts and clays because they provide more surface area for chemical binding. Sandy soils require the lowest rates.

Soil moisture

For soil applied herbicides, even mechanically incorporated products, some moisture is required to place them in the soil solution for weed uptake. Soil herbicides generally work best in a warm, moist soil.

Residues in soil

Some chemicals, such as atrazine, persist in the soil in phytotoxic concentrations. The farmer must be aware of this if susceptible crops are to be planted subsequently.

Problems associated with use of herbicides

Injury to the crop

Herbicides should be applied at the right growth stage of the crop to avoid injury. When applied too early the crop is injured or even killed. And when too late, seed formation is affected negatively.

Occupational hazard

Herbicides, as a rule, are quite safe to use, having a low toxicity to man and animals. All precautions must be taken, however, to protect the applicator and persons who may come in contact with the chemical.

Resistant weeds

Weed populations contain a very small number of individual plants that are naturally able to withstand a particular herbicide (or herbicide group), which is registered to control the weed. This naturally occurring resistance is not due to weather conditions or application technique but is an inherent characteristic of the genetic makeup of the resistant plants (Hoglund 1991).

Because of their low frequency of occurrence, these resistant plants go undetected. The continual use of the same herbicide (or herbicide group) year after year allows them to set seed and multiply. Furthermore, by removing the susceptible weeds, there is more opportunity for the resistant strain to flourish.

It is important, therefore, to know the herbicide groups so that herbicides with different mechanisms of action can be selected as part of the strategy in preventing a build up of resistant weeds.

Managing resistance

- Rotate crops. This usually results in using a diversity of herbicides.
- Rotate herbicides with different modes of action.
- Use tank mixes that control the target weeds by different modes of action.
- Use short residual herbicides whenever possible. Use long term residual herbicides wisely and not continuously on the same field.
- Integrate herbicide use with other weed control strategies.
- Practice good sanitation practices to prevent movement of weed seed with soil, machinery, crop residue, etc.
- Use herbicides only when weeds are in the susceptible stage.
- Use herbicides only when weather and soil conditions are appropriate for effective control.
- Use Wipe-on technology where appropriate for weeds growing above the crop.
- Use band treatments over the row and cultivation between rows.

- Selective flaming or steam treatment may be appropriate in some situations (more research needed).
- Properly maintain application equipment and accurately calibrate them.
- Maximize competition from beneficial plants.

Safety measures with herbicides

- Keep pesticides out of the reach of children.
- Do not use the same sprayer for weed control and insect control applications. Mark one sprayer “WEEDS”.
- Use a low pressure regulator to help prevent spray “drift” onto desirable plants.
- Make applications in the cool of the day when there is little to no wind.
- Spray when no rain is forecast for 24 hours unless the product calls for watering-in.
- Dress properly: Protect eyes and skin, wear approved chemical resistant gloves and boots, and wear an approved respirator if possible.
- One of the greatest risks is handling the concentrate, so wear approved gloves and be sure to protect your eyes from splashing.
- Triple-rinse empty pesticide containers into your sprayer and dispose of containers properly.

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About ICRISAT

International Crops Research Institute for the Semi-Arid Tropics

ICRISAT is a member of the CGIAR Consortium

The **International Crops Research Institute for the Semi-Arid Tropics** (ICRISAT) is a non-profit, non-political organization that conducts agricultural research for development in Asia and sub-Saharan Africa with a wide array of partners throughout the world. Covering 6.5 million square kilometers of land in 55 countries, the semi-arid tropics have over 2 billion people, of whom 644 million are the poorest of the poor. ICRISAT innovations help the dryland poor move from poverty to prosperity by harnessing markets while managing risks – a strategy called Inclusive Market-Oriented Development (IMOD).

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