Integrated crop management for cassava cultivation in Asia

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1 Introduction

Cassava is grown in tropical and subtropical areas of Africa, Asia and Latin America. In Africa and much of Latin America cassava is used mainly for direct human consumption, after boiling or processing. In Asia cassava has now become more of an industrial crop that is processed into a wide array of products, such as starch and many starch-derived products, modified starch, animal feed and bio-ethanol. Moreover, due to very high population pressure in Asia, the crop is grown mostly by smallholder farmers on very small plots of land and is often grown in the same field year after year. As a consequence, cassava production increases have to be achieved mainly by increasing yields rather than through area expansion. Obtaining high yields requires very careful crop and soil management to prevent soil degradation caused by nutrient depletion and erosion.

The demand for cassava in Asia is expected to grow in the years to come largely because of an increasing demand for animal feed, biofuels and multiple uses of starch. The livestock and poultry feed industry is growing rapidly as more animal protein is incorporated into the Asian diet. The rapid expansion of the biofuel industry in recent years is driven by the expectation of long-term declining reserves of fossil fuels, but perhaps more significantly by new policy developments aimed in part at reducing the carbon footprint of fuels, but also because of the power of farm lobbies in major producing countries to advocate for

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new markets for grains, especially maize. Starch is a commodity of continuing growth, and multiple crop sources can provide the raw material for most uses. Maize starch leads all sources, followed by that of cassava, with the latter having the greatest annual rate of increase. While there are certain to be significant year-to-year fluctuations, the cassava industry will see continuous growth, especially with the development of value-added cassava traits and products in Asia (Hershey, 2015). Increasing the quantity and quality of cassava products in response to growing demand will require careful and sustainable increases in cassava production. Expansion into newly cleared land is not a sustainable option, given the declining available land and negative environmental impacts. Science must focus on sustainable increased productivity per unit area to keep prices competitive in the marketplace, improve farmer income and protect the environment.

Cassava is better adapted to less favourable environments than most other major crops, especially in low-fertility and drought-prone areas. In Southeast Asia, upland soils are less fertile compared to the lowlands, and they are usually located in areas that are not supported by well-developed infrastructure, such as roads, markets, electricity, water supply and agricultural supply stores (Dierolf et al., 2001). However, most smallholder farmers and their families live and grow food crops on these marginal upland soils and in fragile environments, where manure and fertilizers are not commonly applied or are applied in insufficient amounts and at inappropriate application times. The crop is often considered the 'food of last resort' (Howeler and Aye, 2014).

Cassava extracts soil nutrients in proportion to the production that is removed from the field. In the absence of proper crop and soil management, cassava cultivation may lead to soil erosion and land degradation. Its ability to grow on already-depleted soils is one of its great attributes, but effective soil management and other sound crop management practices must also be in place to take advantage of the crop's efficiency. In addition, adverse environmental consequences of rapid commercialization of cassava are also apparent in fragile upland farming systems. The increase in cassava cultivation seen in Southeast Asia, particularly during the last decade in Cambodia, Laos and Myanmar, may have been in part a response to declining soil fertility and increasing soil erosion from other cropping systems that could not be sustained. This dynamic has had the unfortunate consequence that cassava is widely seen as a crop that causes soil depletion and erosion, even though these effects are often caused by other crop systems.

The fact that cassava is well adapted to adverse conditions is fully compatible with its cultivation in a sustainable manner, through the adoption of good agricultural practices (GAP). Under ideal conditions, maximum root yield of cassava can potentially be about 30 t/ha of dry roots, equivalent to 75–100 t/ha of fresh roots (Cock et al., 1979). However, the average cassava yields in Asia and throughout the world are much lower. The difference between average actual yields of farmers and potential yields – the so-called 'yield gap' – is still high for cassava in Asia. Some 20 years ago the economically achievable cassava yield in Asia was estimated at about 25 t/ha (Henry and Gottret, 1996), and this yield is already being achieved in a few countries. However, a recent review of the cassava research literature indicates that if all current constraints could be eliminated, the attainable yield in Asia could be as high as 46 t/ha (Howeler, 2014, unpublished). Appropriate crop management practices, including better land preparation, use of suitable high-yielding varieties and good quality planting materials, along with the correct plant populations, balanced fertilizer application, and effective weed and erosion control, will all be required to improve cassava yields.

2 Implementing GAP in cassava pre-harvesting

GAP include those practices that are technically feasible, economically viable, environmentally sustainable and socially acceptable.

The focus of GAP should be on the sustainable optimization of cultivation. This has also been defined as 'A sustainable agriculture is one that over the long term enhances environmental quality and the resource base on which agriculture depends; provides for basic human food and fibre needs; is economically viable; and enhances the quality of life for farmers and society as a whole' (American Society of Agronomy, 1989).

Key concerns for achieving sustainable cassava production include the crop's actual and perceived contributions to soil erosion and decline in soil fertility. Additionally, the environmental and economic sustainability of the cassava sector is under increasing pressure from the lack of high-yielding, adapted varieties for some agro-ecological conditions, inappropriate crop management, emerging pests and diseases, rising labour costs and the difficulty in mechanizing the smallholder production system, especially those located on sloping land.

Like for any other crop, cassava cultivation cannot focus solely on short-term profits, but must take into account long-term environmental sustainability for the overall success of the cassava value chains in Asia. Moving towards sustainable cassava cultivation will depend upon the wise use of limited natural resources (e.g. soil and water), but a goal of improved environmental quality without ensuring the viability of short-term returns to growers would also jeopardize production (Norman et al., 1997). Therefore, sustainable cassava cultivation emphasizes the efficient use of natural resources, so that production remains economically viable and socially acceptable while environmental quality is still maintained or improved.

Some common myths about cassava have contributed to reluctance by many governments to support cassava research and development, and have inhibited development and adoption of best practices:

Myth # 1: *Cassava does not need fertilizer.* It is true that cassava will tolerate low-fertility soil conditions, and still produce some yield where other crops would fail. Cassava is often cultivated on infertile soils by resource-poor farmers with little to no fertilizer or manure. In traditional systems, soil fertility may have been maintained by fallow periods, crop rotation, intercropping and other means. As pressure on land increased, these practices have tended to decline, but the alternative practices for maintaining soil fertility may not have been adopted because of the myth that cassava does not need fertilizers. However, cassava is often highly responsive to appropriate nutrient application. With application of optimum types and amounts of nutrients, the highest quantity and quality of cassava roots will be achieved.

Myth # 2: *Cassava cultivation degrades the soil.* Cassava is often cultivated on infertile or highly degraded soils; however, this is not necessarily because the crop has 'caused' this soil degradation. A relatively large amount of nutrients is removed from the soils when cassava roots are harvested from the field. Therefore, continuous planting of cassava on the same soil without adequate nutrient application will lead to soil nutrient depletion. Cassava is also often cultivated on sloping lands, again because it performs better under these conditions than alternative crops. However, due to its slow early growth and poor initial canopy formation, cassava creates conditions for soil erosion from rainfall, when cultivated without soil conservation measures, especially in light-textured soils. Therefore, cassava cultivation can result in serious soil erosion and degradation if the crop and soil are not properly managed.

The lack of promotion and adoption of GAP at the level of both agricultural officials and farmers has hampered the development of sustainable cassava systems. This chapter describes in detail the different elements of GAP. It includes every production step practiced by cassava producers, especially smallholder farmers, to increase cassava yields in profitable and sustainable ways. Further details on crop nutrient management are provided in 'Improving soil and nutrient management in cassava cultivation', 'Addressing nutritional disorders in cassava cultivation' and 'Nutrient sources and their application in cassava cultivation' by Howeler.

Major causes of low cassava yields in some parts of Southeast Asia are (Bellotti et. al., 2012; Howeler, 2001, 2014; Howeler and Aye, 2014):

- Lack of high-yielding and best-adapted varieties
- Low soil fertility and inadequate fertilizer or manure use
- Soil erosion when cassava is cultivated on sloping land
- Use of poor-quality planting materials
- Inappropriate agronomic practices, including land preparation and suboptimum plant populations
- Strong weed competition
- Pest and disease problems
- Inappropriate mixed cropping

2.1 Variety selection and production of planting materials

The use of suitable cassava varieties and good quality planting materials are essential for obtaining the stable high yield and quality of products that markets demand. Farmers in Southeast Asia grow a wide range of cassava varieties; the highest-yielding and best-adapted varieties vary from region to region, and according to end use. However, there are some varieties from China, Thailand and Vietnam that have demonstrated high yield potential across many parts of the region, though typically varieties perform best within specific agro-ecological zones. The names of the most popular released varieties and their main characteristics for industrial processing are described in 'Cassava cultivation in Asia' by Aye. Local testing for adaptation to specific agro-ecological and socio-economic conditions is essential to assure that the best varieties are used by farmers.

Cassava variety identity can only be assured when the source of the planting materials used is known and controlled, since many varieties may appear quite similar to each other. The choice of variety arises from a consensus, and sometimes compromises, among the expectations of farmers, consumers, cassava industries and traders. This can be achieved by inviting representatives of these various actors in the value chain to field days when on-farm variety trials are being harvested. This provides an opportunity to discuss the various features such as agronomic characteristics, resistance to major pests and diseases, and market requirements. For example, the variety Rayong 72 from Thailand is broadly popular because it has high yield and good plant architecture, is drought tolerant, has a relatively high starch content and is suitable for starch processing and animal feeding (after chipping and drying). It was tested among all the value chain actors before release and promotion.

Smallholder farmers usually produce their own cassava planting material. Farmers plant cuttings (also called 'stakes') taken from the stems of mother plants, for clonal propagation. This means that the new plants will have characteristics identical to those of the mother plants. But it will also increase the risk of disease or pest transmission to the next generation if the planting materials are not carefully selected to be free of those problems. Selecting quality planting materials of suitable cassava varieties is thus necessary to obtain high yield and root quality. Among many management factors, two key points stand out for obtaining the highest-quality planting materials, both of which can boost early season production and have lasting effects on yield potential: freedom from diseases and pests, and good physiological quality of the planting materials, including nutritional quality.

Good quality planting materials provide a certain degree of resilience against unfavourable conditions, such as early season lack of rain, low soil fertility, and pests and diseases. To ensure good quality planting materials the following guidelines are suggested:

1. *Variety:* Selected varieties must have good early rooting and high bud sprouting capacities. These capacities can be assessed from the percentage of sprouted plants at 15–20 days after planting.
2. *Age of the mother plant:* Planting materials should be cut from plants that are between 10 and 12 months old, when a good proportion of the stems are mature enough for rapid sprouting. Younger planting materials dry out easily and older planting materials tend to have delayed sprouting.
3. *Storing of stems:* Stems to be used as planting materials should be stored upright in the shade of trees or in buildings. Leaving the stems exposed in the open field will reduce their viability. In areas with danger of frost, the stems should be stored in trenches in the field or dug into hillsides, covered with straw and soil to protect against frost damage. Storage time should be as short as possible and preferably not more than two months after harvest.
4. *Part of the stem:* The cuttings should be taken from lignified stems that are not too old and not too young, that is, they are usually taken from the middle two-thirds of the stems of the mother plants (discarding older bottom and younger top of the plant). When the stems have sprouted or the ends have dried during storage, these parts should be eliminated before cutting the planting stakes.
5. *Size of the stems used as planting materials:* The most suitable stems are those with a diameter of the central pith equal to or less than 50% of the stem diameter. High-quality stem cuttings have a diameter between 1.5 and 2.0 cm.
6. *Length of the planting stakes:* Planting stakes should be about 20–25 cm long regardless of the planting positions used (i.e. vertical, horizontal or inclined).
7. *Number of nodes per planting stake:* The planting stakes should have between five and seven nodes. The number of nodes may vary depending on the varieties and on weather conditions during the growth of the mother plants.
8. *Cutting of stems into stakes and cutting angle:* The cutting of stems into stakes should be done with a sharp knife, machete, cleaver or lopper. Under favourable conditions, planting stakes that have been cut either transversely or bevelled may give good yields. But planting stakes that have been transversely cut will root more uniformly around the whole stem perimeter, resulting in a better root distribution. To prevent excessive drying and damage during transport, the cutting of stems into stakes is best done in the field and just before planting.

2.2 Land preparation

Land preparation is one of the most expensive and critical management operations, necessary for the success of cassava production. In general, land preparation involves ploughing, harrowing and levelling the ground to make it suitable for planting. Where cassava is traditionally grown as the first crop after clearing the land, no land preparation may be required, other than the removal of bushes, shrubs and vines, if planting is to be done by hand. When the first rains have softened the ground, farmers loosen the soil in individual planting holes with a hoe or sharp spade or planting stick, and proceed to plant the cassava stakes.

In fields where successive crops of cassava are grown, as soon as one cassava crop has been harvested, the land can be prepared again for the next planting. However, if cassava stems and leaves are left in the field, it is better to wait several weeks before these are incorporated into the soil in order to prevent their re-sprouting among the newly planted stakes. Cassava growers should understand the different tillage methods and equipment used for land preparation, and be able to select the most appropriate tools and practices for their situation. Methods of land preparation have a significant effect on cassava root yield but not on the root starch content (Jongruyasub et al., 2007).

Conservation tillage, including minimal and zero tillage, are possible solutions in land preparation to improve soil health. The aim of land preparation is to condition the soil with the best physical attributes for cassava to grow. Land preparation may produce a lighter structure, which makes planting by hand easier; it also incorporates plant residues, weeds and soil amendments such as basal fertilizers and manures. However, excessive land preparation using tractors, especially on wet soil, can lead to soil compaction or the formation of a hardpan, which reduces water infiltration and may lead to soil erosion. Depending on the crop's requirement, land topography and availability of resources, land preparation may be done manually with a hoe, animal traction or mechanized using a two-wheel or four-wheel tractor. Any land preparation method should consider the efficient use of soil and water resources, the effect on the environment and the expected economic returns on investment.

Land preparation is achieved by loosening the soil with a hoe or using bullocks or a tractor to plough, often followed by a harrow or rototiller to break up big soil clumps and smoothen out the soil surface. In most countries in Southeast Asia, however, cassava fields are very small, often located on steep slopes where the use of tractors is impossible. Farmers cultivating small areas, such as in Indonesia, Northern Vietnam and Northern Laos, often use only a hoe to loosen the whole area to be planted, or only the planting hole itself.

In areas of intermediate farm size, on flat or slightly sloping lands, such as in the Philippines, Indonesia, Southern India and the Ayeyarwady delta of Myanmar, farmers will often plough the fields with bullocks or buffaloes, usually one or two times, to loosen the soil and incorporate crop residues and weeds (Aye, 2012). In southern India and Myanmar ploughing may be followed by making mounds by hand to concentrate the most fertile topsoil for the planting of stakes. In high rainfall areas farmers may plant cassava on top of ridges to prevent waterlogging of the root system. These ridges are either made by hand, using hoes or are made with a tractor-mounted disk. Regardless of the soil type and moisture condition, most farmers in Cambodia, Thailand and South Vietnam, where slopes are not too steep, use a hired four-wheel tractor to prepare their land. In Thailand this is usually done with a three-disk plough followed by a seven-disk harrow and sometimes a ridger; however, some farmers use their own two-wheel tractor equipped with a small disk plough or a rotovator. Farmers prefer to plant cassava in well-prepared loose soil without any weeds, which facilitates vertical or inclined planting of stakes and reduces early weed competition (Howeler, 2014). Land preparation in smallholder systems is likely to change over time as technologies for small farm mechanization advance, and labour costs continue to rise. Mechanization is often used for the purpose of early land preparation to ensure timely planting.

When considering the choice of land preparation methods, it is important to have clearly defined short- and long-term objectives, and to monitor the resulting effects. Any tillage operation has more than one effect. For example, if the soil is tilled to decrease the soil ped (aggregate) sizes, weeds will be controlled and crop residues will be incorporated, but soil moisture may be lost. Tractor operators typically prefer to prepare the field in straight lines parallel to the roads or field borders, irrespective of slope direction, or they prefer driving up and down the slope rather than along the contour. These kinds of land preparation could exacerbate soil erosion, especially on sloping land with sandy soils. On sloping land, it is important to plough along the contour to reduce erosion. Conventional mouldboard or disk ploughing can also create a 'plough sole', or a compacted layer, at 15–20 cm depth, restricting root growth, drainage and nutrient penetration. Compacted layers can be broken by using a subsoiler, but this is a very energy-intensive, that is, expensive, process (Watananonta et al., 2006).

2.3 Planting methods

Three methods, that is, horizontal, inclined (slanted) and vertical, are commonly used for planting cassava stakes. In the case of the vertical or inclined method about half of the stake is pushed into the soil while the other half remains above the ground. With horizontal planting the stakes are placed in a shallow trench about 2–5 cm deep and covered with soil. With the vertical or inclined method, the cassava stakes sprout more quickly than with the horizontal method, but the vertical method tends to produce deeper roots which are more difficult to harvest in clayey soils. Planting vertically or slanted generally produces higher yields than planting horizontally (CIAT, 1979), particularly during periods of drought. Vertical planting is most suitable for sandy soils and under conditions of limited rainfall (Tongglum et al., 1992); it results in higher sprouting rates and root yields compared to horizontal planting, as shown in Table 1. Most mechanical planters are designed to plant stems horizontally. They open a furrow, drop in the stake and cover it with soil (Ospina et al., 2007). More recent designs also allow vertical planting (Fig. 1).

Figure 1 Cassava vertical planting machine.

Table 1 Effect of stake position, stake length and planting depth on cassava yield (t/ha), planted in both the rainy and dry season at Rayong Field Crops Research Center, Thailand. Data are the average of three years, 1987–1989

	Rainy season (May–August)			Early dry season (November)		
Treatments	No. of plants survived ('000/ha)	Root yield (t/ha)	Starch content (%)	No. of plants survived ('000/ha)	Root yield (t/ha)	Starch content (%)
Method of planting						
Ridge	14.6	15.0	16.6	10.7	14.7	18.6
No ridge	14.4	13.5	16.7	12.1	15.0	18.6
F-test	NS[1]	NS	NS	**	NS	NS
Stake position						
Vertical	14.9	16.0	17.0	13.0	17.7	19.0
Inclined	14.9	15.5	17.1	12.0	16.4	18.7
Horizontal	13.7	11.1	15.8	9.3	10.3	18.2
F-test	**[2]	**	**	**	**	**
Stake length (cm)						
20	14.5	14.5	16.7	10.6	14.5	18.5
25	14.4	13.5	16.7	13.0	15.4	18.9
F-test	NS	*[3]	NS	**	NS	NS
Planting depth (cm)						
5–10	14.4	13.9	16.6	9.7	13.1	18.2
15	14.6	14.4	16.7	12.7	16.2	19.0
F-test	NS	NS	NS	**	**	**

No interaction between methods and treatments in all characters.
[1] NS = not significantly different.
[2, 3] Mean within a column separated by DMRT at 0.01% and 0.05%, respectively.
** = F-test highly significantly different;
Source: Tongglum et al., 1992, 2001.

2.4 Plant density and planting arrangement

Plant density (number of plants per hectare) will determine the quantity of planting material required for cassava cultivation and will influence management practices such as weeding; it will also impact the final yield and affect the quality of the resulting planting material (e.g. high density will tend to produce thinner stems). The goal is to have enough healthy and vigorous planting material at the time of the next planting. The best plant spacing of cassava will vary according to the branching habit of the variety, the fertility of the soil, climatic conditions and also whether the crop is grown in monoculture or in association with intercrops (Leihner, 1983). This can be summarized as follows:

- Under favourable climatic conditions and in fertile soil, cassava grown in monoculture can be planted at a population of about 10 000–12 000 plants per hectare, or at a spacing of about 100×100 cm to 90×90 cm.
- Under less favourable climatic conditions or in less fertile soil, the cassava plant population under monoculture should be increased to between 12 000 and 18 000 plants per hectare, corresponding to a spacing of about 90×90 cm to 75×75 cm.
- When cassava is intercropped and grown under favourable conditions, the inter-row spacing is widened and the inter-plant spacing is reduced to obtain a cassava plant population of about 8 000–10 000 plants per hectare.
- When cassava is intercropped and grown under less favourable conditions, the cassava plant population should be increased to about 10 000–12 000 plants per hectare, with the inter-row and inter-plant spacing adjusted according to the relative importance of cassava in comparison with the associated crop(s).
- Highly branching varieties will require wider spacing than semi-branched ones, which in turn require wider spacing than non-branching varieties.
- Whether the stakes are planted in a square or in a rectangular (wider inter-row and narrower inter-plant spacing) arrangement will not greatly affect yields as long as the optimum number of plants per hectare is being maintained.

2.5 The use of intercropping

Farmers plant cassava either as a sole crop in monoculture or in a mixed intercropping system. Mixed intercropping involves several crops grown together in the same space, using a random or specifically designed distribution. Each crop may be planted and harvested at various times according to its specific maturity characteristics. Generally, smallholder farmers prefer to grow two or more crops at the same time in the same field in a mixed intercropping system. Common intercrops with cassava in Asia include upland rice (*Oryza sativa* L.), maize (*Zea mays* L.) and legume crops such as peanut (*Arachis hypogaea*), cowpea (*Vigna unguiculata*) and mung bean (*Vigna radiata*). In China, especially in subtropical areas, farmers often prefer intercropping with watermelon or sweet potatoes. In other areas with plantation crops such as rubber, coconut or cashew, cassava is often intercropped for a few years between the rows of young trees, or in the case of coconut, among either the young or the old trees (Villamayor et al., 1992). Intercropping cassava with leguminous crops such as common bean (*Phaseolus vulgaris*), cowpea, mung bean and peanut is beneficial, as these legumes will provide the necessary proteins for the family and their livestock. In addition, the legumes fix nitrogen from the atmosphere, and cassava may benefit from this symbiosis. Because of the legumes' faster growth, they cover the ground and protect the soil from the direct impact of rainfall when the cassava canopy is not yet closed, reducing soil erosion. Early maturing food crops should be selected for intercropping with cassava in order to reduce the period of competition and to avoid excessive shading of the young cassava plants.

Intercropping systems vary markedly from country to country as well as among different regions within the same country, depending on the soil and climatic conditions, especially the length of the rainy and dry seasons. Intercropping has many advantages for smallholder farmers to reduce the risk of crop failure, to provide diversity of crops and to obtain food or income at different times of the year. Numerous experiments have been conducted to determine the best intercrops for cassava, as well as the best planting arrangements and relative time of planting (Leihner, 1983; Aye and Howeler, 2012).

Probably the most intensive intercropping systems are found in the wetter zones of West Java and southern Sumatra of Indonesia. Here, cassava is often intercropped with simultaneously planted upland rice between cassava rows and maize between plants within the cassava row. Once the upland rice and maize are harvested at about four months after planting, a short-duration grain legume, such as mung bean, soya bean, cowpea or peanut, is planted in the inter-row space previously occupied by rice. If rainfall permits, a fourth intercrop such as mung bean or peanut is planted in the space previously occupied by the harvested grain legume. In East Java, on the other hand, the dry season is longer and cassava can be intercropped by only one crop, usually maize. In South Vietnam, cassava is often intercropped with maize or planted among young rubber or cashew trees, while in north Vietnam, the crop is often intercropped with peanut or black bean (cowpea). In Guangxi province of China, cassava is often intercropped with maize, peanut, sweet potato or watermelon, while in Hainan province, the crop is often interplanted among young rubber trees or bananas. In Thailand, cassava is seldom intercropped because farmers cultivate larger cassava fields and do not have enough labour to manage more intensive intercropping, but the crop is sometimes planted for a few years among young rubber or coconut trees.

Intercropping normally reduces the yield of each crop, compared to their yields in monoculture, but the overall system is typically more economically productive, as well as having the other benefits already described. Competition between the crops can be reduced by modifications of the plant spacing or planting patterns of both crops, or by adjusting the relative time of planting, and the amounts of fertilizer applied to each crop to maximize yields. There are many alternative ways of planting cassava in intercropping systems. Tongglum et al. (2001) reported that intercropping cassava with peanut seems to have had a long-term beneficial effect on soil fertility and cassava yields in Rayong, Thailand. The most commonly used intercropping systems are shown in Table 2.

When smallholder farmers adopt intercropping cassava with other crops, a relatively small area of land may be sufficient to provide the family with their basic dietary needs, such as energy, proteins, minerals and vitamins.

Table 2 Intercropping systems with cassava in Asia

Country	Associated crops
Cambodia	Upland rice, maize, cashew nut, rubber
China	Maize, watermelon, sweet potato, peanut, rubber
East Timor	Maize, peanut, vegetables, banana
India	Maize, cowpea, vegetables, coconut
Indonesia	Upland rice, maize, soya bean, cowpea, mung bean, peanut, coconut, rubber
Laos	Upland rice, maize, Job’s tear, peanut
Myanmar	Maize, peanut, common bean, banana
Philippines	Maize, peanut, sweet potato
Thailand	Maize, rubber, coconut, cashew nut
Vietnam	Maize, upland rice, peanut, black bean, rubber, cashew nut, coffee, tea

Source: Aye and Howeler, 2012.

3 Implementing GAP for cassava crop health

3.1 Soil fertility and soil health

The effect of low soil fertility can be difficult to notice in cassava because the plants do not display clear deficiency symptoms of major nutrients (N, P, K). Growth and development will be slow and yield will be low if some nutrients are not present or are present in either inadequate or excessive amounts. Nutrient deficiencies can be corrected by applying balanced fertilizers. However, most smallholder farmers in Southeast Asia do not apply adequate amounts of fertilizers or manure on cassava. Cassava grows reasonably well and produces reasonable yields even in low-fertility soils that may be too infertile for other crops, or on soils that have been depleted by previous crops. However, cassava is also highly responsive to nutrient application (mineral and organic fertilizers).

High-yielding cassava varieties require more plant nutrients than traditional varieties, since the former have usually been selected, especially for responsiveness to favourable growing conditions. Application of the optimum type and amount of nutrients is critical to achieving the highest quantity and quality of cassava roots. Application of high rates of N may increase the cyanide concentration of the roots, while high rates of K may increase the starch and decrease the cyanide concentration. External nutrient sources must be used to fill the gap between the cassava crop's needs and the soil's indigenous supply. The nutrients removed when roots and/or plant tops are harvested must be replaced in the soil to maintain stable high yields. Additional nutrients may need to be added to account for removal of stems and leaves, if these are not reincorporated into the soil.

Soil organic matter (SOM) improves soil moisture and aeration and reduces nutrients from being leached down the soil profile. It can also act as a buffer against adverse environmental effects such as high temperature and drought. SOM can be maintained through mulching, which adds a protective layer of plant material on top of the soil between crop plants. Mulching can be achieved by allowing cassava stems and leaves to decompose on the soil surface, by manure application and by appropriate crop rotations or intercropping practices. Mulches can also be from decaying weeds, grass or compost, and have the following benefits:

- Protect the soil from erosion
- Reduce compaction from the impact of heavy rain
- Conserve soil moisture
- Prevent weed growth
- Maintain a more even soil temperature (reduces the extremes of either high or low temperatures)

3.2 Soil erosion control

Preventing erosion is a key aspect of maintaining soil health. Due to population pressure and scarcity of agricultural land in Asia, many smallholder farmers grow cassava on sloping lands. High rainfall and very intensive cropping on steep slopes can cause severe soil losses due to erosion, which tends to be more serious in Asia than in Africa or Latin America (Chorley, 1969; Milliman and Meade, 1983). Many cassava soils in Asia are light-textured, and are thus more susceptible to erosion, especially in Thailand, the Philippines, Vietnam and some parts of southern China. In those areas, the land-use systems should be designed to strengthen the soil's physical structure and avoid leaving the soil surface exposed to direct rainfall impact and wind at times of highest risk. Erosion results in deteriorating soil quality (physical and chemical characteristics), which in turn reduces cassava yields. The erosion process mainly removes SOM, and certain clay fractions, which provide soil water and nutrient holding capacity. If cassava is grown on steep or exposed lands, physical anti-erosion structures, such as contour hedgerows, bunds and grass strips, should be used.

Soil conservation techniques aim to reduce the amount and speed of runoff water by improving water infiltration into the soil. They also aim to protect the soil from direct rainfall impact by stimulating rapid early crop growth and canopy formation of cassava, or by including intercrops to cover the soil more quickly, while the cassava canopy develops. Contour cultivation with contour grass barriers or hedgerows also reduces the length or steepness of slopes in cassava fields by filtering out the soil sediments and depositing those above the hedgerows, this results in natural terrace formation.

Erosion control experiments using different crops grown on sloping land often show that cassava causes more soil loss by erosion than many other crops (Quintiliano et al., 1961; Margolis and Campos Filho, 1981; Putthacharoen et al., 1998). This is because cassava plants have to be widely spaced to reduce inter-plant competition, while initial plant growth is slow, leaving the soil surface between plants exposed to the direct impact of rain drops. This results in the disintegration of soil aggregates and the movement of the smaller soil particles downhill with the rainfall runoff. This is particularly serious when cassava is grown on light-textured soils that have little clay and organic matter to bind the aggregates together, or in heavier soils that have been compacted by the use of heavy machinery when the soil is too wet. This soil compaction leads to poor internal drainage, resulting in excessive overland runoff and soil erosion.

While cassava has intrinsic characteristics that may lead to serious soil erosion, research has shown that there are many simple agronomic and soil conservation practices that will markedly reduce erosion while often increasing yields. Numerous experiments, demonstration plots and Farmer Participatory Research (FPR) trials have been conducted in Thailand, Vietnam, China and Indonesia to determine the effect of these practices on cassava yields and soil loss due to erosion (Howeler, 2008, 2012j, 2014). Different sets of treatments were compared in these experiments and trials depending on the situation and preferences of farmers, with the most promising treatments repeated in many different experiments. The average relative yield and soil loss obtained for each treatment in these experiments or trials are shown in Tables 3 and 4 for Thailand and Vietnam, respectively. In both tables the relative yield and soil loss for each treatment in a specific experiment were determined in comparison with the yield and soil loss of a check treatment of either cassava monoculture or intercropped with peanut (the latter in Vietnam only), with application of a medium level of fertilizers but no hedgerows or other special cultural practices.

In both Vietnam and Thailand, one of the most effective agronomic practices, both in terms of increasing yields and decreasing erosion, was the application of fertilizers, as this markedly improved initial plant growth resulting in early canopy closure, thus reducing the area of bare soil exposed to the direct impact of raindrops. In Vietnam, the lack of fertilizer application reduced yields on average by 68% and increased erosion losses by 37%, compared with the fertilized check treatment, while in Thailand the lack of fertilizers decreased yields on average by 4% but increased soil losses by erosion (140%). Other very effective practices in Thailand include the planting of contour hedgerows of vetiver grass (*Vetiveria zizanioides*), while in Vietnam similar results were obtained with hedgerows

Table 3 Effect of various soil conservation practices on the average[1] relative cassava yield and dry soil loss due to erosion as determined from soil erosion control experiments, FPR demonstration plots and FPR trials conducted in Thailand from 1994 to 2003

	Soil conservation practices[2]	Relative cassava yield (%)	Relative dry soil loss (%)
1	With fertilizer; no hedgerows, no ridging, no intercrop (check)	100	100
2	With fertilizer; vetiver grass hedgerows, no ridging, no intercrop[4]	90 (25)	58 (25)
3	With fertilizer; lemon grass hedgerows, no ridging, no intercrop[4]	110 (14)	67 (15)
4	With fertilizer; sugarcane for chewing hedgerows, no intercrop	99 (12)	111 (14)
5	With fertilizer; *Paspalum atratum* hedgerows, no intercrop[4]	88 (7)	53 (7)
6	With fertilizer; *Panicum maximum* hedgerows, no intercrop	73 (3)	107 (4)
7	With fertilizer; *Brachiaria brizantha* hedgerows, no intercrop[3]	68 (3)	78 (2)
8	With fertilizer; *Brachiaria ruziziensis* hedgerows, no intercrop[3]	80 (2)	56 (2)
9	With fertilizer; elephant grass hedgerows, no intercrop	36 (2)	81 (2)
10	With fertilizer; *Leucaena leucocephala* hedgerows, no intercrop[3]	66 (2)	56 (2)
11	With fertilizer; *Gliricidia sepium* hedgerows, no intercrop[3]	65 (2)	48 (2)
12	With fertilizer; *Crotalaria juncea* hedgerows, no intercrop	75 (2)	89 (2)
13	With fertilizer; pigeon pea hedgerows, no intercrop	75 (2)	90 (2)
14	With fertilizer; contour ridging, no hedgerows, no intercrop[4]	108 (17)	69 (17)
15	With fertilizer; up and down ridging, no hedgerows, no intercrop	104 (20)	124 (20)
16	With fertilizer; closer spacing, no hedgerows, no intercrop[4]	116 (10)	88 (11)
17	With fertilizer; C + peanut intercrop	72 (11)	102 (12)
18	With fertilizer; C + pumpkin or squash intercrop	90 (13)	109 (15)
19	With fertilizer; C + sweet corn intercrop	97 (11)	110 (14)
20	With fertilizer; C + mung bean intercrop[3)]	74 (4)	41 (4)
21	No fertilizer; no hedgerows, no or up and down ridging	96 (9)	240 (10)

[1] Number in parentheses indicates the number of experiments/trials from which the average values were calculated.
[2] C = cassava.
[3]* = Promising soil conservation practices; [4]** = Most promising soil conservation practices;
Source: Howeler, 2008.

Table 4 Effect of various soil conservation practices on the average[1] relative cassava yield and dry soil loss due to erosion as determined from soil erosion control experiments, FPR demonstration plots and FPR trials conducted in Vietnam from 1993 to 2003

		Rel. cassava yield (%)		Rel. dry soil loss (%)	
	Soil conservation practices[2]	Cassava monoculture	Cassava + peanut	Cassava monoculture	Cassava + peanut
1	With fertilizer; no hedgerows (check)	100	–	100	–
2	With fertilizer; vetiver grass hedgerows[4]	113 (17)	115 (23)	48 (16)	51 (23)
3	With fertilizer; *Tephrosia candida* hedgerows[4]	110 (17)	105 (23)	49 (16)	64 (23)
4	With fertilizer; *Flemingia macrophylla* hedgerows[3]	103 (3)	109 (4)	51 (3)	62 (3)
5	With fertilizer; *Paspalum atratum* hedgerows[4]	112 (17)	–	50 (17)	–
6	With fertilizer; *Leucaena leucocephala* hedgerows[3]	110 (11)	–	69 (11)	–
7	With fertilizer; *Gliricidia sepium* hedgerows[3]	107 (11)	–	71 (11)	–
8	With fertilizer; pineapple hedgerows[3]	100 (8)	103 (9)	48 (8)	44 (9)
9	With fertilizer; vetiver + *Tephrosia* hedgerows	–	102 (7)	–	62 (7)
10	With fertilizer; contour ridging, no hedgerows[3]	106 (7)	–	70 (7)	–
11	With fertilizer; closer spacing, no hedgerows	122 (5)	–	103 (5)	–
12	With fertilizer; peanut intercrop, no hedgerows[3]	106 (11)	100	81 (11)	100
13	With fertilizer; maize intercrop, no hedgerows	69 (3)	–	21 (3)	–
14	No fertilizer; no hedgerows	32 (4)	92 (15)	137 (4)	202 (12)

[1] Number in parentheses indicates the number of experiments/trials from which the average values were calculated.
[2] IC = intercrop, HR = hedgerows.
[3] = Promising soil conservation practices
[4] = most promising soil conservation practices
Source: Howeler, 2008.

of paspalum grass (*Paspalum atratum*) or the legume shrub *Tephrosia candida*; the latter species grows best under subtropical conditions in northern Vietnam and southern China. These contour hedgerows, spaced between 6 and 20 m apart, depending on the slope, decreased soil losses on average by about 40–50% and either slightly decreased yields or actually increased yields by 10–13%.

Other very effective practices included the planting of cassava in alley cropping systems between contour hedgerows of *Leucaena leucocephala* or *Gliricidia sepium* (Nguyen Huu

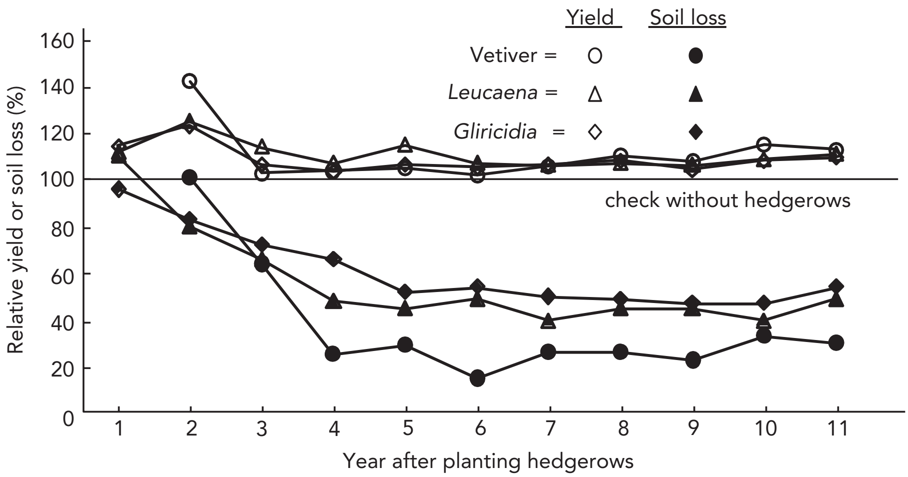

Figure 2 Trends in relative yield and relative soil loss by erosion when cassava was planted with contour hedgerows of vetiver grass, *Leucaena leucocephala* or *Gliricidia sepium* in comparison with the check without hedgerows during 11 consecutive years in Hung Loc Agric. Research Center in South Vietnam from 1997/98 to 2007/08. Source: Nguyen Huu Hy et al., 2010.

Hy et al., 2010) or with *Flemingia macrophylla* or elephant grass (*Pennisetum purpureum*) (Wani Hadi Utomo, pers. comm.; Wargiono et al., 1992, 1995, 1998, 2001; Howeler, 2014). In general, these contour hedgerows became more and more effective in reducing erosion over time, as shown in Fig. 2 (Nguyen Huu Hy et al., 2010; Howeler, 2012j, 2014). Other very effective practices are planting of cassava on contour ridges, planting at closer plant spacing and intercropping with peanut. The common practice of up and down land preparation and ridging slightly increased yields in Thailand, but also markedly increased soil loss by erosion (Howeler, 2008, 2014).

The method of land preparation can also have a significant effect on both cassava yield and soil loss by erosion, but this is not always consistent and will vary with the type of soil and the water content of the soil at the time of land preparation. Currently, many people recommend the practice of zero tillage to improve soil health and prevent soil compaction. This practice can be used for cassava production, but is most suitable in areas where cassava is planted by machine, as manual planting requires a well-prepared and loose soil in order to control weeds and facilitate the insertion of the cassava stakes. Also, most experiments have shown that the effect of zero tillage on yield and soil erosion is highly variable, but usually results in lower yields than when the soil is well prepared with a disk plough followed by harrowing and contour ridging. Table 5 shows that in one location in Thailand zero tillage resulted in low yields and high soil loss due to erosion, while in another nearby site the yield was relatively high and the soil loss was low. Long-term trials comparing zero tillage with conventional land preparation may be necessary to determine whether yields will increase after several years when soil tilth and nutrient availability may have improved as a result of zero tillage.

The data also shows that lack of fertilizer application consistently resulted in low yields and high levels of soil erosion. From these results it can be concluded that soil erosion can

Table 5 Effect of various tillage practices and fertilizer application on the average cassava yield and annual soil loss due to erosion when cassava was planted on 5–8% slope in Si Racha, Chonburi Province, and in Pluak Daeng, Rayong Province, Thailand

	Cassava yield (t/ha)		Dry soil loss (t/ha)	
Tillage treatment	Si Racha (1987–1988)	Pluak Daeng (1989–1990)	Si Racha (1987–1988)	Pluak Daeng (1989–1990)
1. Zero tillage, with fertilizer	28.5	17.0	49.8	10.7
2. Conventional tillage[1], with fertilizer	28.6	14.4	20.8	17.5
3. Conventional with contour ridging, with fertilizer	32.6	15.6	8.1	13.2
4. Conventional with up–down ridging, with fertilizer	29.4	16.1	23.6	19.8
5. Conventional tillage, no fertilizer	21.5	12.2	35.8	25.8

[1] Conventional tillage is ploughing with a three-disk plough followed by harrowing with a seven-disk harrow.
Source: Adapted from Jantawat et al., 1994.

be quite serious in cassava fields, but that many agronomic and soil conservation practices will both increase yields and reduce soil losses by erosion.

The increases in yield due to specific soil conservation practices, such as the planting of contour hedgerows, is likely to be small, ranging from 0 to 20%, as these hedgerows take up space in the field and may compete with cassava plants growing nearby. This competition can be minimized by the right choice and management of the hedgerow species. But if the crop is grown on slopes and is poorly managed, cassava yields are likely to decrease over time, due to the loss of top soil, which contains most of the organic matter, nutrients and beneficial microorganisms, as well as by gully formation, and by washing out plants, or the covering of small plants with eroded sediments.

However, contour ridging, fertilization and intercropping require more work and usually imply higher production costs. Hedgerows also require more work for establishment and maintenance and may reduce yields by occupying 10–20% of the land. Thus, farmers have to consider the trade-off between immediate costs and benefits versus long-term benefits of less erosion and improved fertility (Table 6).

3.3 Weed control

A 'weed' in a generic sense is an unwanted plant that causes damage to native or endemic vegetation or ecosystems, or to agricultural production. Weeds typically propagate prolifically. Depending on the species, they reproduce either through seeds, or by vegetative propagation (i.e. bulbs, rhizomes and root suckers, and stem fragments). Weeds compete with cassava for space, nutrients, light and water. Cassava grows slowly for the first three months and is generally not competitive with fast growing weeds during these early stages of growth. Cassava will suffer serious yield losses, or in extreme cases becomes completely eradicated, if the crop is not adequately weeded, especially during the early stages of its growth. The critical period for weeding is during the first two months after planting. Weed competition during the first 60 days after planting diminishes yields to approximately 50% of the weed-free control case (Villamayor, 1988). In less intensive cultivation systems, especially in Africa, farmers may prefer early branching varieties that

Table 6 Effect of various soil/crop management practices on erosion and yield, as well as on labour and monetary requirements, and long-term benefits in cassava-based cropping systems

Erosion control practice	Erosion control	Terrace formation	Effect on cassava yield	Labour requirement	Monetary cost	Long-term benefits	Main limitations
Minimum or zero tillage	++	–	–	+	––	+	Compaction, weeds
Mulching (carry-on)	++++	–	++	+++	+	++	Mulch availability, transport
Mulching (*in situ* production)	+++	–	++	++	+	++	Competition
Contour tillage	+++	+	+	+	+	++	
Contour ridging	+++	+	++	++	++	+	Not suitable on steep slopes
Leguminous tree hedgerows	++	++	+	+++	+	+++ [1]	Delay in benefits
Cut-and-carry grass strips	++	++	––	+++	+	+++ [1]	Competition, maintenance
Vetiver grass hedgerows	+++	+++	+	+	+	+++	Availability of planting materials
Natural grass strips	++	++	–	+	–	++	High maintenance costs
Cover cropping (live mulch)	++	–	–––	+++	++	+	Severe competition
Manure or fertilizer application	++++	–	+++	+	+++	+++	High cost
Intercropping	++	–	–	++	++	+++	Labour-intensive
Closer plant spacing	+++	–	+	+	+	++	

+ = effective, positive or high.
– = not effective, negative or low.
[1] = value added in terms of animal feed, staking material or fuel wood.
Source: Howeler, 2012j.

more quickly develop a canopy to provide some weed control. Yield reduction varies from 40% in early branching varieties to 70% in late- or non-branching varieties (IITA, 1990).

In general, cassava should be weeded 2–3 times during the first three months or until canopy closure. A field should be weed-free at planting, and first weeding is done about one month later. If pre- or post-emergence herbicides are used, the weeding schedule will vary. Weeding can be done by hoe, animal-drawn cultivator or hand tractor, but can also be done by a tractor-mounted cultivator, or with herbicides. In light-textured soils in Thailand, farmers sometimes use a 'poor man's plough', that is, a cultivator blade pulled by hand, between cassava rows for weed control. Weed control after four months of age for cassava may not increase root production. While hand weeding can be effective, safe and minimally damaging to the crop, it is also often the most expensive method.

Chemical weed control in cassava is of increasing interest to farmers as a component of improved production technology. Recommended pre-emergence herbicides (referring to the time of weed seed germination) should be applied right after planting (Table 7). Farmers should have pre-emergence herbicides applied and activated – by rainfall or irrigation – prior to the initiation of weed seed germination. Farmers want to have an 'active' chemical barrier present in the soil solution when the target weed seeds imbibe water. This is accomplished by applying pre-emergence herbicides early so that there is ample time for rainfall to occur.

To achieve pre-planting weed-free conditions, a broad-spectrum post-emergence herbicide such as Roundup® (glyphosate) should be applied at the rate of 4–5 l/ha about ten days before land preparation, or it may be applied in no-till or minimum till situations. Post-emergence 'burn-down' herbicides (e.g. Fluazifop) may be applied as soon as weeds begin to emerge after the pre-emergence herbicide treatment. For best results, post-emergence herbicides should be sprayed only when farmers are sure of having at least three hours of sunshine after spraying. They are basically non-selective, localized contact herbicides and should be sprayed with a shield over the spray nozzle to ensure that only the weeds receive the chemical. Post-emergence herbicides should not be applied on windy days as the spray may drift and damage the cassava plants. If the cassava field is infested with difficult-to-control weeds such as *Imperata* grass (*Imperata cylindrica*) and selective herbicides (Gesapax for *Imperata*) should be used. Systemic herbicides like glyphosate, Fusilade or Sarasota are absorbed and translocated throughout the plant and should be carefully applied with manufacturers' guidelines for each of the herbicides.

Weather conditions affect herbicide performance. Herbicides should not be applied soon after heavy rainfall, or before the likelihood of rain, as the chemicals may become diluted and become less effective. If herbicides are used, farmers should be well-informed and trained about their effective use, safety and precautions. However, environmental conditions can still impact the level of control.

Weed competition can also be reduced by adequate and early application of fertilizers to speed up canopy closure, by intercropping and by planting towards the end of the rainy season when weed growth is less vigorous. To prevent the fertilizer actually stimulating weed growth, the fertilizer should not be broadcast but be band applied near the cassava stake or plant. However, some agricultural practices can contribute to weed multiplication and propagation. For example, the use of cattle manure which has not properly decomposed can contribute to serious weed seed dispersal. Timely weeding and integrated weed control measures are encouraged for sustainable cassava production.

Table 7 Various herbicides used for the control of weeds in cassava

Technical name	Commercial name	Selectivity for cassava	Time of application	Dosage of CP/ha [1]	Type of weeds controlled
Diuron	Karmex	intermediate	Pre	2.0–3.0 kg	broadleaved
Alachlor	Lazo	high	Pre	3.0–4.0 lit	grasses
Fluometuron	Cotoran	intermediate	Pre	4.0–5.0 lit	broadleaved
Oxifluorfen	Goal	intermediate	Pre	2.0–4.0 lit	broadleaved/ grasses
Metribuzin	Sencor	intermediate	Pre	1.0–1.5 lit	grasses
Linuron	Afalon	intermediate	Pre	2.0–3.0 kg	broadleaved/ grasses
Trifluralin	Treflan	high	Ibp	2.5–3.5 lit	broadleaved/ grasses
Metolachlor	Dual	high	Pre	3.0–4.0 lit	grasses
	Karmex + Lazo	intermediate	Pre	1.0–1.5 + 1.5–2.0	broadleaved/ grasses
	Cotoran + Lazo	intermediate	Pre	1.0–2.5 + 1.5–2.0	broadleaved/ grasses
	Goal + Lazo	intermediate	Pre	1.0–2.0 + 1.5–2.0	broadleaved/ grasses
	Afalon + Lazo	intermediate	Pre	1.0–1.5 + 1.5–2.0	broadleaved/ grasses
	Karmex + Dual	intermediate	Pre	1.0–1.5 + 1.5–2.0	broadleaved/ grasses
	Cotoran + Dual	intermediate	Pre	1.0–2.5 + 1.5–2.0	broadleaved/ grasses
	Goal + Dual	intermediate	Pre	1.0–2.0 + 1.5–2.0	broadleaved/ grasses
	Afalon + Dual	intermediate	Pre	1.0–1.5 + 1.5–2.0	broadleaved/ grasses
Glyphosate	Roundup	not select.	Post	2.0–3.0 lit	broadleaved/ grasses
Glufosinate	Basta	not select.	Post	1.0–3.0 lit	broadleaved/ grasses
Fluazifop	Fusilade	high	Post	1.0–3.0 lit	grasses
Paraquat	Gramoxone	not select.	Post	2.0–3.0 lit.	broadleaved/ grasses

Ibp = Incorporated before planting; Pre = pre-emergence; Post = post-emergence; CP = commercial product
[1]Lower dosage for use in light-texture soils and higher dosage in heavy-texture soils.
Source: Calle, 2002.

3.4 Pest and disease control

Pests and diseases can threaten the sustainable production of cassava. Traditionally, farmers in Asia have paid little attention to the issue, since cassava in the past had not been severely affected by pests or diseases. However, cassava has begun to suffer from various pest and disease problems that can markedly reduce cassava yields (Bellotti et al., 2012), and effective preventative control has become necessary (see also 'Diseases affecting cassava' by Legg and 'Integrated pest/disease management in cassava cultivation' by Wykhuys).

Cassava used for industrial processing requires year-round production of roots, a practice which has aggravated pest and disease problems as there have to be cassava plants in the field throughout the year at different stages of development. The most important pests now found in Asia include whiteflies, mealybugs, red spider mites, scale insects, white grubs, termites and several pests attacking dried cassava during storage. The most important cassava diseases in Asia are Indian cassava mosaic disease and Sri Lankan cassava mosaic disease (SLCMD), cassava witches' broom disease, cassava bacterial blight (CBB) caused by *Xanthomonas axonopodis* pv *manihotis* (*Xam*), root rots (*Phytophthora* spp.), cassava anthracnose (*Glomerella manihotis*), brown leaf spot (*Cercospora henningsii*) and white leaf spot (*Phaeoramularia manihotis*).

Since the accidental introduction of the cassava mealybug *Phenacoccus manihoti* to Thailand in 2008, this pest has caused serious reductions in cassava growth and yields. Due to the lack of effective native biological control this cassava mealybug rapidly spread throughout Thailand and then into neighbouring countries, particularly to the cassava growing regions of Cambodia and Laos. Whitefly (*Aleurodicus dispersus*) and red spider mite (*Tetranychus* sp.) problems have also become more serious in Southeast Asia's cassava growing regions.

Concurrently, the previously unknown witches' broom disease has also spread in major cassava growing areas of Cambodia, Laos, Thailand, the Philippines and Vietnam with the first reported infestation in Thailand in early 1993 (Graziosi et. al., 2016). Witches' broom disease is transmitted mainly through the use of infected planting material of cassava; however, as there has been limited study on the disease in the past, there are no effective measures to control the disease once the plants are infected.

Recently, the outbreak of SLCMD in the Rattanak Kiri province of northeastern Cambodia (Wang et al., 2016) has caused a potentially serious threat to cassava production in Asia. The causal virus is transmitted by infected planting material as well as by the whitefly *Bemisia tabaci*, which has been found in both Vietnam and Thailand. CBB, root rots, cassava anthracnose, brown leaf spot and white leaf spot are also often seen on cassava in Asia. However, because cassava is a long-season crop that is exposed to these problems over a long period, it is hardly ever economic or effective to control pests and diseases through single control measures such as the application of pesticides; the use of resistant varieties should be the best method, especially for diseases. Integrated pest management is the most effective approach to manage pests and diseases, and may include a combination of resistant varieties and cultural practices, including mechanical, biological and chemical methods.

4 Implementing GAP in cassava post-harvesting

Harvesting cassava is time-consuming and physically arduous, especially under tropical weather conditions. The crop is traditionally harvested by cutting off the top (stems and leaves) about 20 cm from the soil surface and then pulling on the remaining stump of the

Figure 3 Cassava harvesting tool.

stem until the roots emerge from the soil. This may require some digging around the roots with a hoe, shovel or other tools. Some farmers still use a harvesting stick for harvesting cassava, but most use metal harvesting tools. A simple tool, invented by farmers in Thailand, consists of a metal plate with a notched cut out V-shape, which is welded onto a metal cylinder, and then attached to a wooden or metal pole (Fig. 3). The notched V of the metal plate is pulled around the stump and the attached pole is pulled up to function as a lever to more easily lift the stump with the attached roots out of the ground; normally this does not require additional digging of the soil. There are many variations of this harvesting tool, but all make use of the same concept – the power of leverage. In larger farms and commercial plantations, or in very hard clay soils, cassava is now often harvested by tractor-mounted harvesting tools that dig under the roots and lift the root clumps out of the soil and onto the soil surface. This is currently mainly practised in heavy clay soils in eastern Thailand, as these soils become too hard in the dry season to harvest the roots by hand. It is also practiced by a large commercial plantation in eastern Cambodia.

5 Adoption of GAP by farmers

While many management practices to control problems such as soil erosion have been recommended by researchers and extension agents, not enough of these practices have been adopted by farmers. This is mainly because most of the recommended practices require either additional labour or money, and benefits are usually accrued over the long-term, while most poor farmers are in desperate need of immediate income to feed their families.

Cramb and Nelson (1998) reported the results of a modelling exercise to predict the long-term effect of planting contour hedgerows in a relatively eroded soil in the Philippines on the long-term yield of maize and on net present value (NPV). In this example, the model predicts that when maize is grown in open fields without hedgerows, yields will decline markedly during the first few years. With hedgerows, yields will be lower initially, as hedgerows occupy space in the field, but maize yields with hedgerows will overtake those without hedgerows after two years and remain fairly constant at 2–3 t/ha for the next 25 years. However, the NPV for planting maize without hedgerows was higher than planting with hedgerows for the first five years. The NPV for the first two years was very low due to the high initial cost of establishing the hedgerows and the cost of maintenance and lower maize yields obtained. Thus, the farmer will not receive economic benefits from planting hedgerows until after five years. It is only after 10–15 years that farmers will reap substantial economic benefits from these soil conservation practices, but that is too long for most farmers with a short planning horizon, or with immediate needs for adequate income. This example shows the main dilemma in promoting soil conservation practices: most recommended practices were selected by researchers because they are effective in controlling erosion, but few consider whether poor farmers can actually bear the economic burden of adopting these practices. If they cannot, governments may have to provide some incentives, since part of the benefits of better erosion control are reaped off-site by people living downstream or in the cities – benefits sometimes referred to as *ecosystem services*.

Another problem in the transfer of soil conservation technologies is that many soil erosion control trials were conducted on experiment stations under optimum and uniform conditions. These conditions seldom correspond with those faced by farmers living in mountainous areas with heterogeneous soils, topography and climates, and with economic opportunities that vary markedly from place to place depending on distance to roads and markets.

Many practices that seemed very effective in controlling erosion, and may have economic benefits under the conditions of the experiment station, may be rejected by farmers simply because they are not effective or not appropriate under the farmer's specific biophysical and socio-economic conditions. For that reason it is more effective to present farmers with a range of options, from which they can select those that they consider useful, and let them try out some of these options in simple trials on their own fields. In this way farmers can observe and decide which is the most effective and useful practice for their own conditions. This Farmer Participatory Research (FPR) methodology is particularly useful for developing and disseminating technologies such as erosion control practices that are highly site-specific and where there are many trade-offs between costs and benefits. Only farmers themselves can decide about the costs they can bear and risks they can take now in order to obtain benefits sometime in the future.

FPR has been conducted in over 100 villages in the cassava growing regions of China, Indonesia, Thailand and Vietnam from 1994 to 2003 (Howeler, 2008, 2012k, 2014). Table 8 shows an example of a simple FPR erosion control trial conducted by six farmers having adjacent plots on a uniform slope of 35–45%.

During the third year of cropping, some erosion control practices, such as intercropping with peanut, application of fertilizers and contour hedgerows of vetiver grass or *Tephrosia candida* reduced soil loss to about one-third, while doubling gross and net income. These were the practices most farmers selected as most useful for their particular conditions. Farmers selected a combination of practices, such as new high-yielding varieties, better fertilization and intercropping with peanut, which increased income, in combination with contour ridging and contour hedgerows that mainly reduced erosion, so as to obtain both short-term and long-term benefits.

Table 8 Effect of various crop management treatments on the yield of cassava and intercropped peanut as well as the gross and net income and soil loss due to erosion in an FPR erosion control trial conducted by six farmers in Kieu Tung Village of Thanh Ba District, Phu Tho Province, Vietnam, in 1997 (3rd year)

			Yield (t/ha)		Gross income[2]	Product costs	Net income	
Treatment[1]	Slope (%)	Dry soil loss (t/ha)	Cassava	Peanut[1]	(mil. dong/ha)			Farmers ranking
C monocult., with fertilizer, no hedgerows	40.5	106.1	19.17	–	9.58	3.72	5.86	6
C + P, no fertilizer, no hedgerows	45.0	103.9	13.08	0.70	10.04	5.13	4.91	5
C + P, with fertilizer, no hedgerows	42.7	64.8	19.23	0.97	14.47	5.95	8.52	–
C + P, with fertilizer, *Tephrosia* hedgerows	39.7	40.1	14.67	0.85	11.58	5.95	5.63	3
C + P, with fertilizer, pineapple hedgerows	32.2	32.2	19.39	0.97	14.55	5.95	8.60	2
C + P, with fertilizer, vetiver hedgerows	37.7	32.0	23.71	0.85	16.10	5.95	10.15	1
C monocult, with fert., *Tephrosia* hedgerows	40.0	32.5	23.33	–	11.66	4.54	7.12	4

[1] Fertilizers = 60 kg N+40 kg P_2O_5, + 120 kg K_2O/ha; all plots received 10 t/ha pig manure.
[2] Prices: cassava (C) dong 500/kg fresh roots
peanut (P) 5000/kg dry pods
US$1 = approx. 13 000 dong
Source: Howeler, 2010c, Howeler et al., 2007.

Table 9 Extent of adoption (% of households)[1] of new technologies by participating and non-participating farmers (n = 767) in the cassava project in Thailand and Vietnam in 2003

Technologies	Thailand			Vietnam			Full sample		
	Partic. n = 109	Non-partic. n = 308	Total n = 417	Partic. n = 126	Non-partic. n = 224	Total n = 350	Partic. n = 235	Non-partic. n = 532	Total n = 767
New varieties									
100% improved varieties	100	88.0	91.1	50.0	38.8	42.9	73.2	67.3	69.1
75% improved varieties	0	11.7	8.6	5.6	6.7	6.3	3.0	9.6	7.6
50% improved varieties	0	0.3	0.2	26.2	18.3	21.1	14.0	7.9	9.8
25% improved varieties	0	0	0	4.0	5.4	4.9	2.1	2.3	2.2
No improved varieties	0	0	0	14.3	30.8	24.9	7.7	13.0	11.3
	100	100	100***[2]	100	100	100***[2]	100	100	100***[2]
Soil conservation practices									
Contour ridging	52	22	30***	35	31	33	43	26	31***
Hedgerows	60	10	23***	50	12	25***	54	11	24***
No soil conservation	21	72	59***	23	58	45***	22	67	53***
Intercropping	28	8	13***	79	49	59***	55	25	34***
Fertilization									
Chemical fertilizers	98	86	89***	85	86	86	91	86	87**
Farmyard or green manure	55	25	33***	74	60	65**	65	40	48***
No fertilizer	0	13	9***	12	8	9	6	11	9*

[1] Percentages may total more than 100% as households can adopt more than one type of technology simultaneously.
Significant differences between participants and non-participants. * $P<=0.10$; ** $P<=0.05$; *** $P<=0.01$.
[2] Level of significance refers to differences between participants and non-participants in terms of the category distribution, not to the level of adoption.
Source: Dalton et al., 2007.

Table 9 shows the results of a survey about the extent of adoption of various technologies that farmers in Thailand and Vietnam had tested in their FPR trials conducted between 1994 and 2003. The survey was conducted in four project sites each in Thailand and Vietnam as part of focus group discussions with farmers that had participated in the FPR trials and those that lived in villages nearby that had not participated in the project. The data shows that farmers mainly adopted the new varieties, followed by improved fertilizer use, while fewer farmers adopted soil conservation practices and significant numbers of farmers (only in Vietnam) adopted intercropping.

Among soil conservation practices, more farmers adopted contour ridging than contour hedgerows. There were highly significant differences in adoption rates between participating and non-participating farmers, indicating that FPR trials are highly conducive to the adoption of new technologies, especially of those technologies where the immediate benefits are not as clear. In 2015, 12 years after the project ended, many farmers in north Vietnam were still planting and promoting the planting of contour hedgerows of *Paspalum atratum* in their cassava fields, which serve both to reduce erosion on sloping land and as fodder to feed their cattle and water buffaloes.

6 Conclusion

Many of the current cassava cultivation systems have been developed and used for many decades. The world's annual cassava production has increased by an estimated 100 million tonnes since 2000, driven in Asia mainly by demand for starch and dried cassava for use in livestock feed, biofuels and other industrial applications. In Africa demand has been driven by expanding urban markets for cassava food products as a result of population increases and urbanization (FAO, 2013). Farmers have shown that these cultivation systems have some degree of sustainability. However, there is increasing pressure to produce still more cassava to accommodate a growing world population. At the same time, the adverse environmental consequences of rapid commercialization of cassava have also become apparent in some fragile upland farming systems. Furthermore, climate change is adding complexity to the situation by placing greater demands for new technologies that respond to various climate change challenges for cassava in Asia.

Cassava is more resilient than most crops in the face of multiple biotic and abiotic constraints since it can endure a number of pest and disease attacks or even periods of severe drought; however, it is very sensitive to excess water or flooding. Since the crop has no specific maturity period, there is no period of growth (after initial establishment) during which it is especially vulnerable to environmental stresses (Hershey et al., 2012). There is, therefore, great potential for further production increases in many tropical areas. Jarvis et al. (2012) reported that cassava is a highly resilient crop capable of resisting even the most severe consequences of climate change in the tropics and subtropics. Furthermore, cassava fresh root yields can potentially reach 75–80 tonnes per hectare (Cock et al., 1979), compared to the current world average yield of just 11.2 tonnes (FAOSTAT, 2016). The opportunities for increasing sustainable cassava production can only be achieved by using the best-adapted cassava varieties and implementing GAP in cassava cultivation. Cassava production also needs to be profitable with key focus on smallholder farmers. Farm labour scarcity and rising labour costs are some of the factors most responsible for driving various adaptations, including mechanization, in the cassava cultivation system. Ensuring the availability of a wide range of expertise to develop and implement sustainable cassava cultivation strategies is necessary.

7 Future trends

Despite the importance of cassava in food security and income generation in tropical and subtropical countries, most governments give low priority to cassava-related programmes and policies to direct cassava research and implement good agronomic practices for sustainable cassava cultivation. During the past several decades, international research organizations, especially CIAT and IITA, have been collaborating with many of the national agricultural research and extension institutions to conduct research on cassava breeding and evaluation of cassava germplasm, agronomic practices and soil management, cassava cropping systems, and utilization and marketing tools. However, there is still a strong need to further strengthen cassava research holistically. For instance, there could be better collaboration between cassava breeders and agronomist to develop goals and strategies to optimize the response of new varieties to improved agronomic practices. In addition, there exist great opportunities to achieve more widespread adoption of improved varieties and practices by researchers working together with extensionists to help farmers conduct their own research to develop the best practices for their own conditions.

Regarding future priority research areas, more emphasis should be placed on developing better-integrated methods of effective and profitable cassava intensification, the effective use of inputs and the conservation of natural resources in cassava cultivation systems with the primary goal of improving smallholder farmers' livelihoods while protecting the environment. There is still much to learn about the implementation of GAP in sustainable cassava cultivation. The current recommended agronomic practices will need to be adapted to the site-specific conditions of farmers' fields and farmers' requirements.

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