

Chapter 5

Crop nutrition

Combining ecosystem processes and judicious use of mineral fertilizer forms the basis of a sustainable crop nutrition system that produces more while using fewer external inputs.

To achieve the higher productivity needed to meet current and future demand, agriculture must, literally, return to its roots by rediscovering the importance of healthy soil, drawing on natural sources of crop nutrition and using mineral fertilizer wisely.

The over-use of mineral fertilizer in agricultural production has carried significant costs to the environment, including the acidification of soil, the contamination of water, and increased emissions of potent greenhouse gases. More targeted and sparing use of fertilizer would save farmers money and help to ensure that nutrients reach crops and do not pollute air, soil and waterways.

The impact of mineral fertilizer on the environment is a question of management: how much is applied compared to the amount exported with crops, and the method and timing of applications. In other words, it is the efficiency of fertilizer use, especially of nitrogen (N) and phosphorus (P), which determines if this aspect of soil fertility management is a boon for crops or a negative for the environment.

Experience indicates that higher and more sustainable yields are achieved when crop nutrients come from a mix of mineral fertilizer and organic sources, such as animal manure and trees and shrubs which, in dryer climates, can pump up from the subsoil nutrients that would otherwise never reach crops. Crop nutrition can be enhanced by other biological associations – for example, between plant roots and soil mycorrhizae. In “Save and Grow”, that combination of ecosystem processes and judicious use of mineral fertilizer forms the basis of a sustainable crop nutrition system that produces more while using fewer external inputs¹.

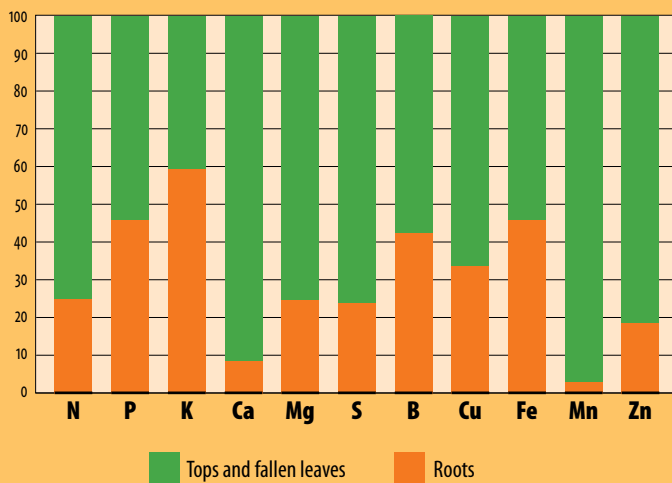
Cassava can grow and produce reasonable yields on soils where many other crops would fail. It is highly tolerant of soils with low levels of phosphorus and can generally grow even with no application of P-fertilizer. That is because cassava has formed a mutually beneficial association with a group of soil fungi called “vesicular-arbuscular mycorrhizae”^{2, 3}. Present in practically all natural soils, mycorrhizae penetrate the cassava root and feed on the sugars it produces. In exchange, the fungi’s long filaments transport phosphorus and micronutrients to the root from a greater volume of the surrounding soil than the root alone could reach. That symbiotic association allows cassava to absorb sufficient phosphorus for healthy growth.

Most of the nutrients absorbed by cassava during growth are found in the plant tops⁴. Returning stems and leaves to the soil – both as leaf litter and as mulch after the root harvest – enriches the soil with new organic matter, and some of the nutrients are re-used by the next crop (Figure 21). In fact, when the plant tops are recycled, fewer soil nutrients are exported in the root harvest than in the harvest of most other crops^{5,6} – a root yield of 15 tonnes per ha removes only about 30 kg of nitrogen, 20 kg of potassium (K) and just 3.5 kg of phosphorus⁷⁻⁹. There is little danger of phosphorus depletion, therefore, even after

many years of continuous cassava production on the same land¹⁰.

Cassava can also be grown on very acid and low-fertility soils because it tolerates low pH and the associated high levels of exchangeable aluminium. While the yields of crops such as maize and rice are usually affected strongly when the soil pH is below 5 and aluminium saturation is above 50 percent, cassava yields are normally not affected until the soil pH is below 4.2 and aluminium saturation is above 80 percent. For that reason, cassava may not require large amounts of lime in acid soils, where other crops would not grow without them.

Figure 21 **Distribution of nutrients in 12-month-old unfertilized cassava, Colombia (%)**



Source: Annex Table 5.1

Mineral fertilizer

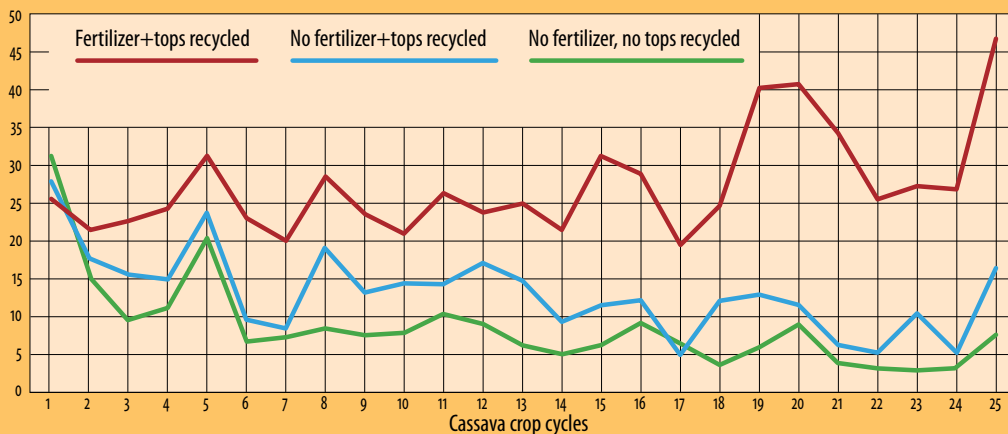
Its ability to produce on low-fertility soils has given rise to the misconception that cassava does not require, nor even respond to, the application of mineral fertilizer. In fact, the results of extensive trials reviewed by FAO have shown that many cassava varieties respond very well to fertilization¹¹. If anything, cassava's need for fertilizer is increasing as traditional means of maintaining soil fertility – such as intercropping and the mulching of plant residues – are abandoned under more intensive production systems.

When root yields are high, and residues are not returned to the soil, the harvest removes large amounts of nitrogen and potassium. To sustain both yields and soil fertility, cassava would require annual per hectare applications estimated at 50 to 100 kg of nitrogen, 65 to 80 kg of potassium and 10 to 20 kg of phosphorus, depending on the soil's native fertility and the desired yield levels.

Results from 19 long-term fertility trials, conducted over 4 to 36 years of continuous cassava cropping on the same plots, indicate that the main nutrient constraint was lack of K in 12 trials, of N in five trials and of P in only two trials. In Thailand, high root yields of up to 40 tonnes per ha were maintained when adequate amounts of mineral fertilizer (100 kg N + 22 kg P + 83 kg K) were applied annually and plant foliage was returned to the soil before each new planting. When no fertilizer was applied and plant tops were removed from the field, per hectare yields declined sharply, from 30 tonnes in the first year to about 7 tonnes after six years, owing to nutrient depletion, especially of potassium (Figure 22). Similar results have been witnessed on a wide range of different soils in Colombia, India, Indonesia, Malaysia, Thailand and Viet Nam⁹.

Cassava yields in Africa could be increased markedly if farmers had access to mineral fertilizer at a reasonable price. In the Democratic Republic of the Congo, the use of improved, pest- and disease-resistant varieties, in combination with appropriate rates of mineral fertilizer,

Figure 22 Effect of mineral fertilizer and crop residue management on cassava root yields over 25 crop cycles, Thailand (t/ha)



Source: Howeler, R.H. 2012. Effect of cassava production on soil fertility and the long-term fertilizer requirements to maintain high yields.

In R.H. Howeler, ed. *The cassava handbook – A reference manual based on the Asian regional cassava training course, held in Thailand*. Cali, Colombia, CIAT. pp. 411-428.

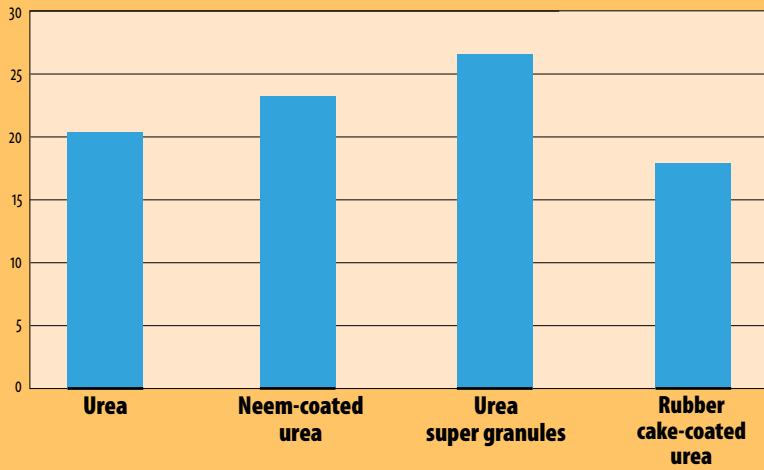
led to increases in cassava root yields – of 30 to 160 percent – as well as in stem yields, important for production of high quality planting material. In the west of the country, per hectare cassava yields increased from 12 to 25 tonnes with moderate applications of N-P-K fertilizer, and reached more than 40 tonnes with higher application rates¹². (However, fertilizer costs in sub-Saharan Africa remain high. Where using fertilizer on cassava is not economical, the crop may benefit from the residues of fertilizer applied to other crops of higher economic value, such as maize and soybean¹³.)

Initially, cassava should be fertilized with equal amounts of N, phosphorus pentoxide (P_2O_5) and potassium oxide (K_2O) at a rate of 500 kg to 800 kg per ha of a compound fertilizer such as 15-15-15 or 16-16-16. However, if the crop is grown continuously for many years on the same land, the N-P-K balance will need to be modified to compensate for the corresponding removal of each nutrient in the root harvest. That can be done by using fertilizers with a ratio of N, P_2O_5 and K_2O of about 2:1:3, such as 15-7-20, or any compound fertilizer that is high in K and N, and relatively low in P. Farmers should follow local fertilizer recommendations based on experimental results obtained with the crop or on the results of simple fertilizer trials conducted in their own fields with the help of an agronomist or extension worker.

Soluble fertilizers – such as urea, single- and triple-superphosphate, di-ammonium phosphate, potassium chloride and potassium sulphate – and most compound fertilizers should be applied either when the stakes are planted or, preferably, about one month later, when the roots have emerged. Phosphorus should be applied at or shortly after planting. N and K are best applied in split doses, one half at or shortly after planting, and the rest at 2 to 3 months after planting, when cassava reaches its maximum growth rate.

Most mineral fertilizers dissolve rather rapidly in soil water. They should be applied in short bands, dug with a hoe, 20-30 cm long and 4-5 cm deep at a distance of about 5-10 cm from the cassava stake or plant. After application, the fertilizers should be covered with soil to prevent volatilization of N and losses of nutrients through runoff and erosion. The roots of the plant will grow towards the fertilizer band in order to take up the nutrients dissolved in the soil solution. Localized application helps to avoid fertilizing weeds that may grow nearby.

Figure 23 **Effect of four sources of nitrogen on cassava root yield, India (t/ha)**



Source: Annex Table 5.2

To reduce economically wasteful and environmentally harmful losses of fertilizer nutrients, “Save and Grow” farming systems seek to maximize fertilizer use efficiency. Trials in India have shown how the supply of nitrogen fertilizer to cassava can be optimized by using urea compressed into supergranules or urea prills coated with cake made from neem seed oil (Figure 23)¹⁴. Both technologies slow considerably the nitrification of the urea, reducing losses to the air and to surface water runoff, and ensuring a continuous supply of nitrogen to match the requirements of the crop at different stages of growth. In trials, the neem-coated urea produced average root yield increases of 27 percent¹⁵.

Less soluble fertilizers, such as rock phosphate, lime, gypsum, sulphur and organic compost and manure, are usually broadcast over the entire field and incorporated before planting, in order to achieve good contact with the soil and enhance the rate at which they dissolve or decompose. In reduced or zero tillage systems, they should be applied at the bottom of the planting holes at the time of planting.



Fast-growing groundnuts protect soil from erosion and provide cassava with a source of nitrogen

*In Viet Nam, alley cropping with the leguminous tree *Leucaena leucocephala* (at right) increased yields – but it may not be as effective in the humid tropics*

Organic sources of nutrients

While mineral fertilizer can help to boost yields, alone it cannot sustain crop production in the long-term on degraded land¹⁶. Farmers need to maintain and improve soil quality and health using a number of other “Save and Grow” measures, such as conservation tillage, intercropping, green manuring, mulching crop residues and cover crops, alley cropping, and applying animal manure or compost (see also Chapter 2, *Farming systems*).

Intercropping with grain legumes, which fix atmospheric nitrogen, make some N available to the cassava crop. Although biological fixation cannot meet all of cassava’s nitrogen needs, it has some benefits. In Nigeria, after two years of cassava-soybean intercropping, incorporation of soybean residues led to yield increases of 10 to 23 percent¹⁷.

Research at two locations in the Democratic Republic of the Congo found that planting four rows of groundnuts between widely spaced rows of cassava also boosted root yields. But higher yields still were obtained in both locations with the application of 17-17-17 compound fertilizer at the rate of 150 kg per ha, divided evenly between the cassava and the intercrop.

The fertilizer treatment produced the highest net benefits in one location during the first year, while intercropping with groundnuts and without fertilizer produced the highest net benefit in the second year. Despite its high price in the region, mineral fertilizer was the treatment most preferred by farmers¹⁹.

Alley cropping with deep-rooting and fast-growing leguminous trees may be an effective means of improving soil fertility and yields, where mineral fertilizer is



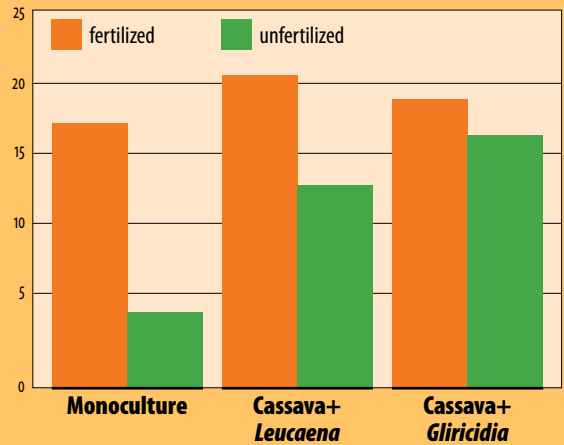
not available. In a long-term soil improvement experiment in southern Viet Nam, alley cropping with two leguminous tree species, *Leucaena leucocephala* and *Gliricidia sepium*, had a marked and consistent long-term beneficial effect on cassava grown in alleys 4 m wide, both when cassava was fertilized and when it was not fertilized. During the 16th year of continuous cropping on the same plots, fertilizer application alone boosted root yields from 4.8 tonnes to 17.4 tonnes per ha, while alley cropping with *Leucaena* and without fertilizer increased yields to 13.4 tonnes. Combining *Leucaena* with fertilizer achieved yields of more than 20 tonnes (Figure 24).

However, the benefit of alley cropping is limited in the humid tropics, which are dominated by large areas of low-fertility ferralsols. The alley cropping of trees in such areas does not automatically lead to higher cassava yields – a review of experiments in the humid zone of West and Central Africa revealed that, in the majority of trials, it had either no effect or a negative effect on cassava root growth¹⁹. Those results were probably due to the fact that, in more humid climates, the tree roots tend to remain in the upper levels of the soil, where they compete strongly with cassava.

Green manuring – the practice of growing a grain- or forage legume for some months, then mulching the residues prior to planting the cassava crop – also improves soil fertility, especially levels of nitrogen. Combinations of cassava with legumes have a definite biological advantage over monocropping because the area by time occupancy of the land is higher. That biological advantage decreases, however, with the duration of the legume crop, which should not exceed 90 days²⁰.

Many green manure species have been tested, both in Colombia and Thailand, to measure their effect on cassava²¹. Green manures used in Colombia include native weeds, cowpeas, groundnuts, pigeon peas, velvet beans (*Mucuna pruriens*), jack-beans (*Canavalia ensiformis*), the perennial forage legume *Zornia latifolia* and tropical kudzu (*Pueraria phaseoloides*). The grain legumes were harvested after four months and the forages were cut after six months, before being incorporated

Figure 24 Effect of alley crops on cassava root yield, Viet Nam (t/ha)



Source: Annex Table 5.3



Tithonia diversifolia, a wild sunflower found throughout the tropics, makes nutrient-rich, high-quality mulch

into the soil. Cassava was planted one month afterward, in plots with and without mineral fertilizer.

Although root production increased most markedly with the application of fertilizer, incorporation of green manures helped to boost yields when no fertilizer was applied. Groundnuts were among the most beneficial green manure crops, but *Zornia latifolia* and kudzu were also very effective, especially in the presence of fertilizers.

On very sandy soils in Colombia, the mulching of native weeds – tall grasses and creeping legumes – proved to be the best method of fertilization, in the absence of mineral fertilizer. The application of 3 to 4 tonnes of dry mulch per ha led to yield increases similar to those produced by the application of 500 kg of 15-15-15 mineral fertilizer^{21, 22}. Trials conducted in Thailand showed that several green manures, especially sunn hemp (*Crotalaria juncea*), also increased cassava yields²¹.

Another approach is to plant the green manure at the same time as the cassava, but in between the cassava rows, similar to an intercrop. The fast-growing green manures are pulled out 2 or 3 months after planting, and mulched between the rows. The manure crops *Canavalia ensiformis* and *Crotalaria juncea* have proven particularly effective in increasing cassava root yields.

Material for organic soil cover can also be collected off-site. Some species, such as *Tithonia diversifolia*, a wild sunflower found growing along roadsides throughout the tropics, make high-quality mulch. *Tithonia* is particularly high in N and K, although its nutrient content varies according to where it grows. In East Africa, the usual practice is to cut and chop leaves and soft twigs into small pieces, before the plant flowers, and spread them evenly over the soil surface²³.

At two sites in the Democratic Republic of the Congo, Kiduma and Mbuela, incorporating into the soil 2.5 tonnes per ha of dry matter of *Tithonia diversifolia* and *Chromolaena odorata* before cassava was planted produced very marked increases in yields, similar to those obtained with the application of low to moderate levels of N-P-K compound fertilizers²⁴. When they were applied in combination with low or moderate levels of fertilizer, cassava yields increased even beyond those obtained with higher fertilizer rates.

Tithonia was more effective in increasing cassava yields than *Chromolaena* in Kiduma, but not in Mbuela, owing to the much lower nutrient content of *Tithonia* collected at the latter site. Application of mineral fertilizer at low, moderate and high levels increased cassava

yields significantly at both sites, and fertilizer residues remaining in the soil benefited the following cassava crop (Figure 25).

Despite the high cost of fertilizer, the net economic benefits increased with fertilizer application, up to the highest rate in Kiduma and up to a moderate rate in Mbuela. However, the cost-benefit ratio and marginal rate of return were highest for *Tithonia*. In areas where mineral fertilizer is not available or is too costly, therefore, cassava yields can be markedly improved by incorporating locally available vegetation, such as *Tithonia* or *Chromolaena*.

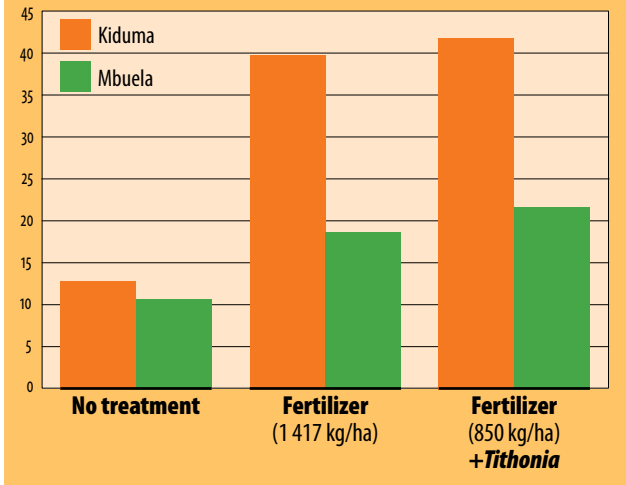
However, they may not always be available, and are cumbersome to collect and transport at the high rates of application used in the Congolese experiments. In addition, *Tithonia* can easily become a weed in the field where it has been applied as green manure, and *Chromolaena odorata* is a favoured breeding site of the African grasshopper *Zonocerus variegatus*, a major pest of cassava in West Africa.

So, while green manure can definitely play an important role in maintaining soil fertility and improving cassava yields, the practice and the green manure species selected need to be adapted to the conditions of the growing area. Since cassava has a long growth cycle, farmers may be reluctant to use part of that year for green manure production. In many cases, they will prefer to invest in mineral fertilizer.

Animal manure and compost are used by smallholder farmers around the world to increase crop production. Among the various types, chicken manure tends to have the highest nutrient content. Manure and compost are both good sources of organic matter which, when incorporated into the soil, improve its structure and aggregate stability, and enhance water holding and cation exchange capacity. They also facilitate the below-ground biological activity of earthworms, bacteria and fungi, and supply a wide range of nutrients, including secondary and micro-nutrients.

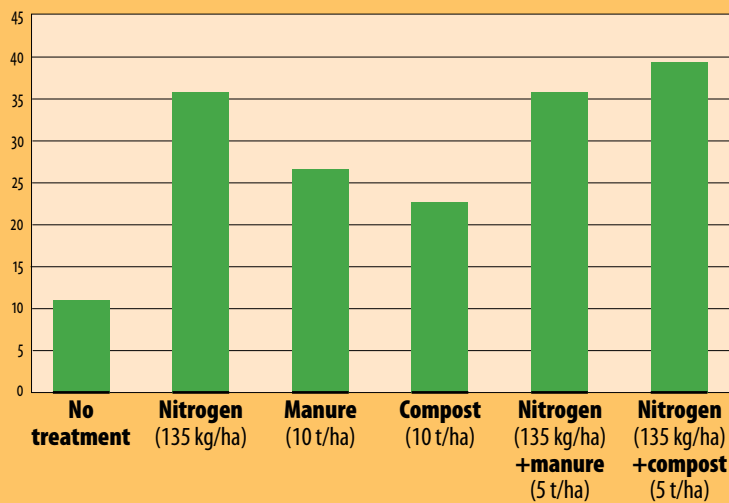
An IITA-led research programme on agricultural development in the humid tropics is investigating the potential benefits to soil

Figure 25 **Effect of mineral fertilizer and green manure on cassava root yield at two sites in DR Congo (t/ha)**



Source: Annex Table 5.4

Figure 26 **Effect of mineral and organic fertilizers on cassava fresh root yield, Indonesia (t/ha)**



Source: Annex Table 5.6

fertility of livestock integration with cassava production. Livestock integration will add value to green manure species and cassava leaves when they are used as feed, which in turn will increase returns of animal manure to fields and crop yields¹⁶.

Trials indicate that combining about 3 to 5 tonnes of manure or compost per ha with mineral fertilizer that contains the right balance of N, P and K is often the most effective means of increasing yields and maintaining the soil's productive capacity. The fertilizers supply the bulk of the macro-nutrients needed by the

plants, while the organic sources provide secondary and micro-nutrients – which are only needed in very small quantities – and improve the soil's physical condition.

In trials in Indonesia and Viet Nam, a combination of compost or farmyard manure – five tonnes per ha in both cases – with judicious selection and use of mineral fertilizers – nitrogen and potassium in Viet Nam (Annex table 5.5), and only nitrogen in Indonesia (Figure 26) – produced high crop yields and the highest net income.

The main drawback to organic sources of nutrients is that they contain relatively low levels of nitrogen, phosphorus and potassium – it takes one tonne of animal manure or compost to supply the same amount of the major nutrients as 50 kg of a compound fertilizer (Annex table 5.7). For small-scale farmers in isolated rural areas, the lack of roads, transport and on-farm machinery may make the collection and application of several tonnes of manure or compost cumbersome and expensive, if not impossible.

Controlling soil erosion

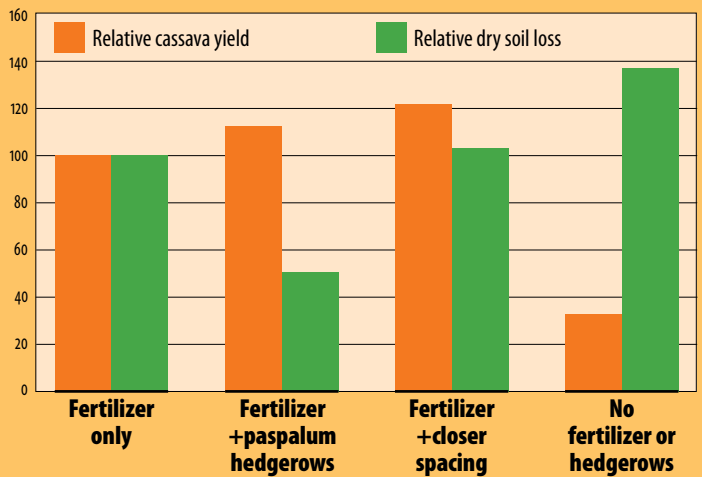
Because the topmost soil layer is the most fertile, control of soil erosion is essential for sustainable soil fertility management. Removal of topsoil causes the loss not only of available or exchangeable nutrients, but the total amounts of nutrients in the organic and mineral fraction²⁵.

Growing cassava tends to cause more soil losses to erosion than growing most other crops, especially where farmers do not use cover crops or mulches to protect the soil from the direct impact of rain, sun and wind during the first 2 to 3 months of growth¹⁰. In addition, cassava is often grown on sandy or sandy-loam soils that have low aggregate stability, and on slopes that are already eroded, partly because cassava is one of few crops that can produce reasonably well on exposed subsoils.

“Save and Grow” practices can reduce runoff and erosion significantly, while helping to increase cassava yields. One option is minimum or zero tillage (see Chapter 2, *Farming systems*), which protects the soil from erosion, slows the decomposition of organic matter and maintains soil aggregate stability and internal drainage. A study in Colombia found that a combination of minimum tillage and grass-legume mixtures in rotation enhanced microbial soil activity, which resulted in significant binding of soil particles, thereby increasing aggregation and reducing soil erosion²⁶. Zero tillage is most effective in a well-aggregated soil with an adequate level of organic matter.

If the land is prepared using conventional tillage, ploughing and ridging on slopes needs to be done along the contour, rather than up-and-down the slope, and contours should be planted with hedgerows of grasses or shrub- or tree-legumes in order to slow runoff and trap eroded sediments. Cassava stakes should be planted through mulch (such as crop residues, grasses or leguminous tree prunings), and intercrops should be grown as a soil cover between the cassava rows.

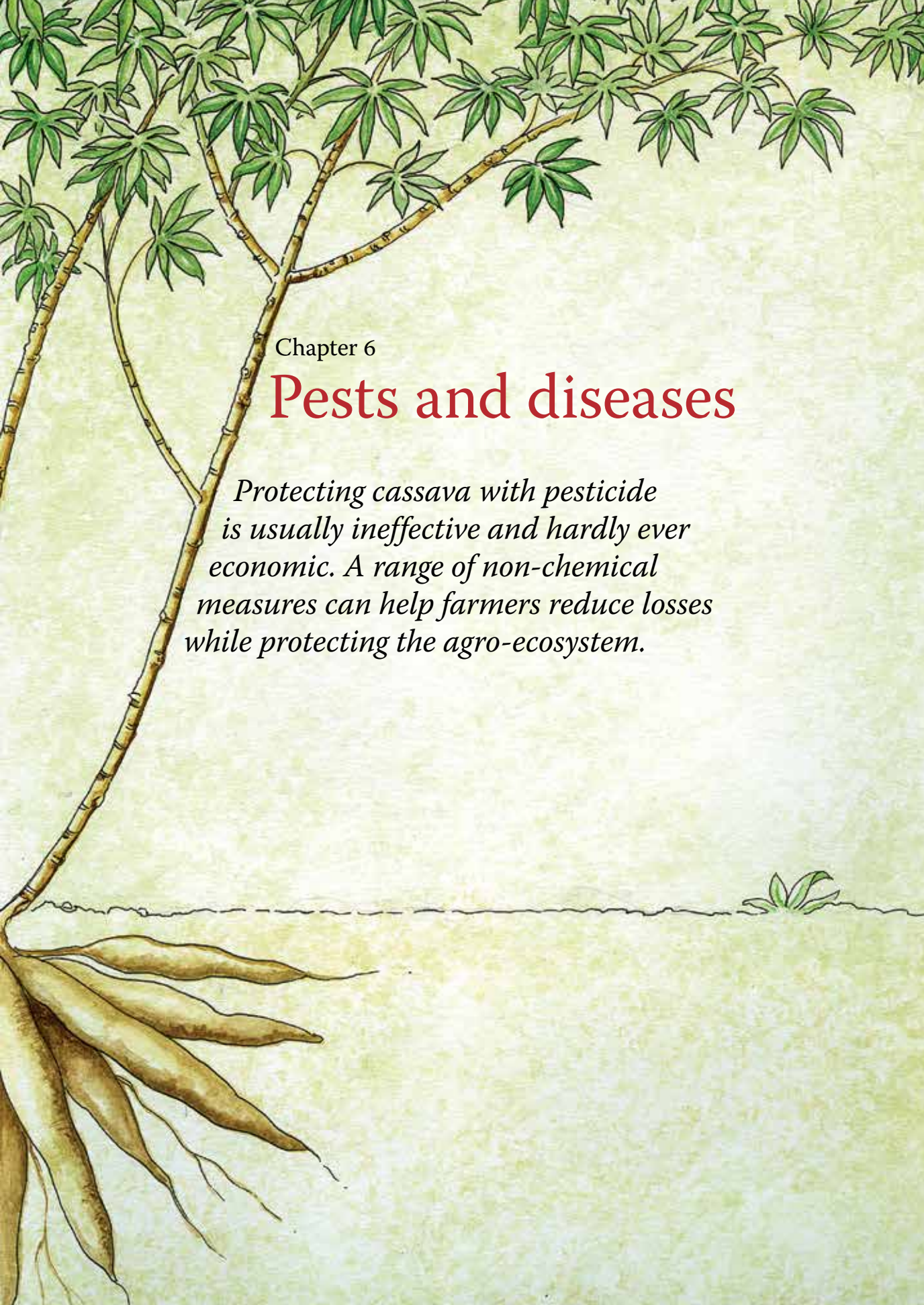
Figure 27 Effect of soil conservation practices on cassava root yield and dry soil loss due to erosion, Viet Nam (%)



Source: Annex Table 5.8

Studies in Colombia and in several Asian countries have shown that among the practices most effective in controlling erosion are: planting contour hedgerows of vetiver grass, *Tephrosia candida* or *Paspalum atratum*; planting cassava on contour ridges; and planting *Leucaena leucocephala* or *Gliricidia sepium* along the contour in alley cropping systems (Figure 27). The benefit of all of those measures is enhanced by applying mineral fertilizer to the cassava, because it leads to faster soil coverage by the plant canopy.

Most erosion control practices have advantages and disadvantages, and trade-offs need to be made. It is important to involve farmers directly in testing and selecting the practices most suited to their soil and climate, their socio-economic conditions and their traditions.



Chapter 6

Pests and diseases

Protecting cassava with pesticide is usually ineffective and hardly ever economic. A range of non-chemical measures can help farmers reduce losses while protecting the agro-ecosystem.

The first line of defence against crop pests and diseases is a healthy agro-ecosystem. Because synthetic insecticide, fungicide and herbicide disrupt the natural crop ecosystem balance, “Save and Grow” seeks to minimize their use to the extent possible. It promotes instead integrated pest management (or IPM), a crop protection strategy that aims at enhancing the biological processes and crop-associated biodiversity that underpin production¹.

Crop losses to insects are kept to an acceptable minimum by deploying resistant varieties, conserving and encouraging biological control agents, and managing crop nutrient levels to reduce insect reproduction. Diseases are controlled through the use of clean planting material, crop rotations to suppress pathogens, and elimination of infected host plants. Effective weed management entails timely manual weeding and the use of surface mulches to suppress weed growth.

When necessary, low-risk selective pesticides may be used for targeted control, in the right quantity and at the right time. Since all pesticides are potentially toxic to people and the environment, the products employed must be locally registered and approved, and carry clear instructions on their safe handling and use.

Like all major crops, cassava is vulnerable to pests and diseases that can cause heavy yield losses. Their impact is most serious in Africa. Until recently, Asia had few serious pest and disease problems, but this may be changing as the crop is grown more intensively over larger areas and planted throughout the year for industrial processing.

When pest or disease management measures become necessary, a strategy of non-chemical control should be considered before any decision is taken to use pesticide. Since cassava is a long-season crop, and exposed to pests and diseases for an extended period, pesticide is usually ineffective and hardly ever economic. That is why insecticide, for example, should be used only in short-term, localized applications in “hot spots” where the pest is first observed, and only when the pest is in its early stage of development.

A range of non-chemical measures can help farmers reduce losses to pests and diseases while protecting the agro-ecosystem²⁻⁷. First, planting material should be of varieties with tolerance or resistance to the most important cassava diseases and pests, and taken from mother plants that are free of disease symptoms and signs of pest attacks. As an extra precaution, stakes can be soaked in hot water to kill pests or disease-causing organisms that might be present. In extreme

cases, soaking stakes in a solution of fungicide and insecticide may be necessary. However, farmers who do so must have received training in the correct use of pesticide and, in selecting chemicals, should follow the recommendations of local plant protection specialists. Ecosystem-based practices, such as mulching, planting hedges and intercropping, can provide refuges for natural enemies of insect pests. Building up soil organic matter increases pest-regulating populations early in the cropping cycle.

During crop growth, applying adequate amounts of mineral fertilizer or manure to the crop can enhance its resistance or tolerance. Insecticide should not be applied to the leaves of the growing cassava plant, as it may kill natural biological control agents that help to keep some major pests and diseases under control. For example, insecticide kills cassava mites' natural enemies – phytoseiid mite predators – before killing the mites themselves. When natural predators are eliminated, the result is an increase in the pest population, to which farmers may respond with increased use of pesticide, thereby perpetuating and worsening the cycle of pest damage. Biopesticides, such as extract of neem seed oil, are recommended for controlling whiteflies, mealybugs and variegated grasshoppers. Whitefly and mealybug numbers can also be reduced with sticky traps and by spraying plants with soapy water.

Control of major cassava diseases

Although the largest number of cassava diseases is found in Latin America and the Caribbean, the plant's centre of origin, many of them are now also found in sub-Saharan Africa and Asia. Some have evolved separately in Africa and Asia, and have not yet arrived in the Americas.

Bacterial blight is one of the most widespread and serious of the cassava diseases. Caused by the proteobacterium *Xanthomonas axonopodis* pv. *manihotis*, it is transmitted mainly by infected planting material or infected farm tools. It can also be spread from one plant to another by rain splash, and by the movement of people, machines or animals from infected fields to healthy fields. The bacterium infects first the leaves, which turn brown in large patches and eventually

die, then the vascular tissues of the petioles and woody stems.

The effect of bacterial blight on yields varies according to factors such as location, variety, weather patterns, planting time and the quality of planting material. In 1974, the disease caused losses of 50 percent in large plantations in Brazil. Bacterial blight can also threaten food security by reducing the production of cassava leaves, which are an important source of vegetable protein in Central Africa.

Although potentially devastating, bacterial blight can be controlled effectively with “Save and Grow” practices. They include:

- ▶ Use varieties with good tolerance (many tolerant, high-yielding varieties are now available)
- ▶ Use healthy planting material from disease-free plants or plants derived from meristem culture, rooted buds or shoots
- ▶ Before planting, treat stakes by soaking them in hot water at 50°C for about 50 minutes. In extreme cases, and on the advice of local plant protection specialists, stakes may be soaked for 10 minutes in a solution of cupric fungicides
- ▶ Plant at the end of rainy periods
- ▶ After using tools in blight-infected plots, sterilize them in hot water or in a dilute solution of a disinfectant, such as sodium hypochlorite
- ▶ Ensure that the plants are adequately fertilized, especially with potassium
- ▶ Uproot and burn any diseased plants and infected crop residues
- ▶ Intercrop cassava with other species to reduce plant-to-plant dissemination of bacterial blight caused by rain-splash (fast growing crops such as maize will also reduce dissemination by wind)
- ▶ To prevent the carry-over of the disease in the soil, rotate cassava with other crops, or leave the field in fallow for at least six months between cassava crops.

Viral diseases are usually transmitted through the use of infected planting material. In addition, whiteflies – mainly of the species *Bemisia tabaci* – are vectors for viruses that cause cassava mosaic disease (CMD) and cassava brown streak disease (CBSD).



Misshapen leaves, lack of chlorophyll, mottling and wilting: symptoms of cassava mosaic disease

Cassava mosaic disease is endemic in sub-Saharan Africa. Common symptoms include misshapen leaves, chlorosis, mottling and mosaic. Plants suffer stunting and general decline, and the more severe the symptoms, the lower the root yield. In the mid-1990s, an unusually severe form of CMD caused yield losses of 80 to 100 percent in parts of Kenya and Uganda. CMD is also the most serious cassava disease in India and Sri Lanka, where it can lead to root losses of up to 90 percent in traditional varieties⁸.

Cassava brown streak disease causes corky necrosis in roots that renders them unfit for consumption. The disease has been responsible for total crop failures in parts of Africa's Great Lakes region. In 2011, FAO warned that none of the cassava varieties grown by farmers in the region seemed to be resistant to CBSD. Even plants produced from clean planting material can become infected through the transmission of the virus by *B. tabaci* whiteflies from infected plants in neighbouring plots. Because the symptoms of CBSD may not be evident on the cassava leaves or stems, farmers may not be aware that their crops are infected until they harvest the roots. The lack of above-ground symptoms makes the use of disease-infected planting material more likely.

Two key recommendations for control of both CMD and CBSD are strict enforcement of quarantine procedures during international exchange of cassava germplasm, and cultural practices, especially the use of resistant or tolerant cultivars and virus-free planting material.

A major effort has been made to produce and distribute CMD- and CBSD-free planting material in the Great Lakes region. January 2012 saw the release in the United Republic of Tanzania of four high-yielding cassava varieties, bred through marker-assisted selection, that are resistant to CMD and tolerant to CBSD.

A decade of intensive research at Kerala's Central Tuber Crops Research Institute identified a Nigerian variety and the wild species, *Manihot caerulescens*, as resistant to both the Indian and Sri Lankan mosaic viruses. Researchers have used those two donor parents and crossed them with high-yielding local varieties to produce several promising lines resistant to CMD, one of which has become popular in the industrial cassava belts of Tamil Nadu⁹.

Root rots occur mainly in poorly drained soils during very intense rainy periods, and are common in Africa, Asia and Latin America. They are caused by a wide range of fungal and bacterial pathogens,

and lead to loss of leaves, dieback in stems and shoots, and root deterioration, either as the crop grows or during post-harvest storage. Farm tools and plant residues left in fields post-harvest are often contaminated with disease-causing fungi and are sources of spores that infect new plants.

In trials in Colombia's Amazon region, smallholder farmers eliminated cassava root rot using simple "Save and Grow" practices. They planted stakes taken only from healthy mother plants, used a mixture of ashes and dry leaves as a soil amendment and fertilizer during planting, and intercropped cassava with cowpeas³. Other cultural practices that control root rots include:

- ▶ If no disease-free planting material is available, immerse stakes in hot water for around 50 minutes
- ▶ Plant on light-textured, moderately deep soils with good internal drainage
- ▶ Improve drainage by reducing tillage and using surface mulches
- ▶ Rotate cassava with cereals or grasses
- ▶ Uproot and burn diseased plants

An effective biological control for root rot is immersion of the stakes in a suspension of *Trichoderma viride*, a fast-growing species of soil fungus that parasitizes the vegetative tissue of other soil-borne fungi^{3,10}. In experiments in Nigeria, two groups of stored cassava roots were inoculated with four pathogenic fungi. One group was also inoculated with a culture filtrate of *T. viride*. Over a period of three weeks, the group without *T. viride* suffered an incidence of rot ranging from 20 to 44 percent; in the group inoculated with the biocontrol agent, there was a drastic reduction in the range and number of the target fungi, with the incidence of rot ranging from zero to 3 percent after three weeks. Inoculation with *T. viride* rendered unnecessary repeated spraying with synthetic fungicide¹¹.

Control of major insect pests

Around 200 species of arthropod pests have been reported on cassava. Of these, some are specific to the crop, while others attack other crops as well. The greatest diversity of cassava insect pests is found in Latin America, where they have co-evolved with the crop. However, cassava pest problems are not necessarily more serious

in Latin America – many harmful insects are kept under control by predators and parasitoids, which have co-evolved over the centuries^{4, 5}.

Whiteflies feed directly on young cassava leaves and are also a virus vector, making them probably the most damaging insect pest in all cassava-producing regions. In Latin America, 11 whitefly species have been reported on cassava, including *Aleurotrachelus socialis*, *A. aepim* and *Trialeurodes variabilis*, which cause most damage. The whitefly *Bemisia tabaci*, the vector of cassava mosaic disease and cassava brown streak disease, is found in most of sub-Saharan Africa and now in India. It is also present in Latin America, but does not feed on cassava. Another species, *Aleurodicus disperses*, or spiralling whitefly, is found in India, Lao PDR and Thailand, as well as in Africa, and can cause serious damage and yield losses.

Although many farmers use insecticides to control whitefly infestations, spraying is usually ineffective – *A. socialis* whiteflies, for example, double their numbers in less than five days. Not spraying insecticide, on the other hand, allows biological control by the whitefly's

natural enemies, which include many species of parasitoids, predators and entomopathogens.

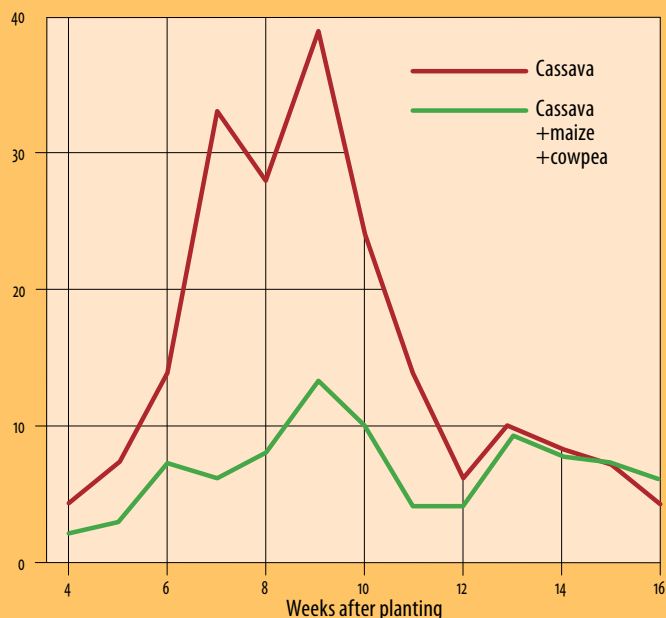
A two-year experiment in Cameroon found that intercropping cassava with maize and cowpeas was associated with a drop of 50 percent in the adult whitefly population and a 20 percent reduction in the incidence of cassava mosaic disease (Figure 28)¹². Research in Colombia suggests that intercropping with cowpeas depresses cassava leaf growth, making the plant less appetizing to whiteflies. Less vigorous growth did not affect root yields – in fact, yield losses were only 13 percent in the cassava/cowpea system, but as high as 65 percent in the monoculture¹³.

Other recommended control measures include imposing a “closed season”, when no cassava can be present in the field, in order to break the whitefly's



Bemisia tabaci transmits serious viral diseases to cassava plants

Figure 28 Mean number of adult whiteflies on cassava leaves, Cameroon



Source: Adapted from Fondong, V.N., Thresh, J.M. & Zok, S. 2002. Spatial and temporal spread of cassava mosaic virus disease in cassava grown alone and when intercropped with maize and/or cowpea. *J. Phytopathology*, 150: 365-374.

development cycle (although, this may not be as effective with some species, such as *B. tabaci*, that have multiple hosts). Recent trials in Colombia indicate that planting different cassava varieties in the same field may reduce herbivore load and increase yields in zones subject to heavy *T. variabilis* attacks¹⁴.

Mealybugs feed on cassava stems, petioles and leaves, and inject a toxin that causes leaf curling, slow shoot growth and eventual leaf withering. Yield loss in infested plants can be up to 60 percent of the roots and 100 percent of the leaves. Of the approximately 15 species of mealybug that attack cassava plants, two – *Phenacoccus herrini* and *P. manihoti* – cause major damage to cassava in Latin America.

In the early 1970s, *P. manihoti* was accidentally introduced into sub-Saharan Africa, where it had no natural enemies, and spread rapidly throughout the region's cassava growing areas. The mealybug population was brought under control by the introduction of several natural enemies from South America. The most effective predator was *Anagyrus lopezi*, a tiny wasp: the female wasp lays its eggs in the mealybug and the growing larvae kill their host.

P. manihoti was recently introduced inadvertently into Thailand and within a year it had spread throughout the country. At its peak, in May 2009, it affected 230 000 ha of Thai cassava-growing land. The outbreak devastated the 2010 cassava harvest, which fell to 22.7 million tonnes, from a record of 30 million tonnes the year before.

How Thai authorities and farmers responded to the 2009 mealybug outbreak provides an excellent example of the effectiveness of biological pest control. To avoid new outbreaks, farmers were advised not to plant cassava in the late rainy season and early dry season, and to soak stakes in an insecticide solution before planting. They were also warned to avoid spraying insecticides on the plants themselves – experience had shown that spraying provoked the pest's resurgence.

To control outbreaks, researchers identified several native predators and parasites but concluded they were unable to effectively reduce the mealybug population. They suggested the use of *Anagyrus lopezi*, the wasp that had successfully controlled the mealybug in Africa in the 1970s. In September 2009, some 500 adults of *A. lopezi* were hand-carried to Bangkok from IITA's Biological Control Centre in Benin.

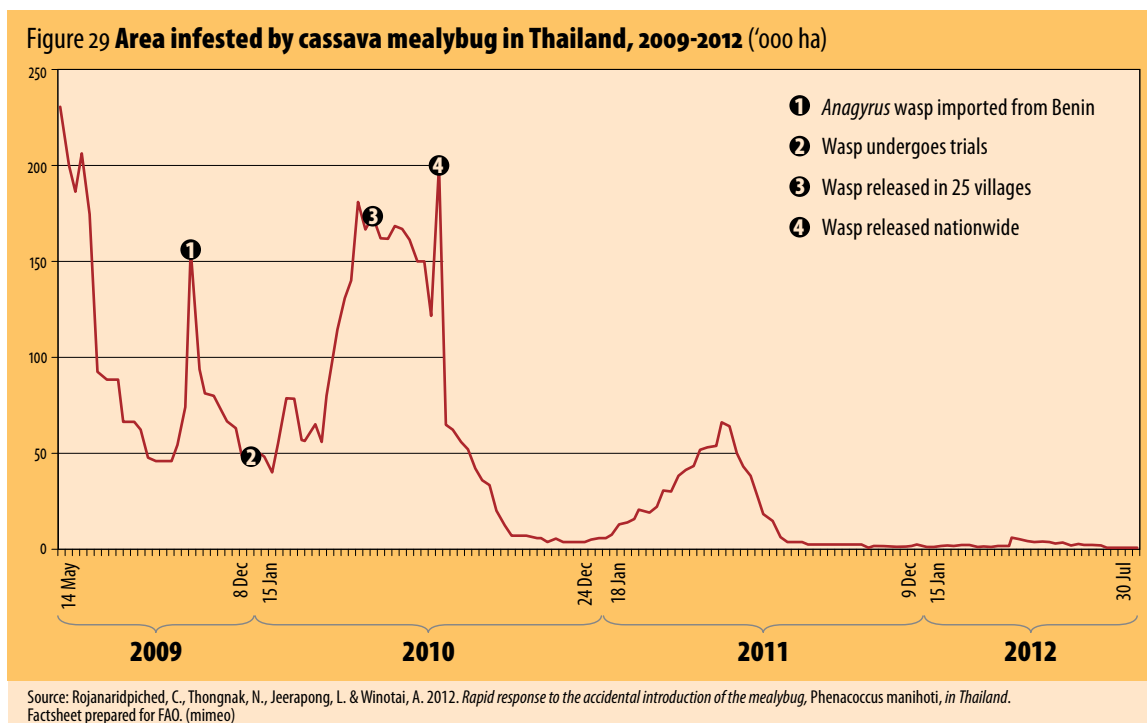
After quarantine laboratory tests and field trials, the government began large-scale multiplication and distribution of the wasp. By May 2012, almost 3 million pairs of *A. lopezi* had been released throughout



Mealybugs have devastated cassava fields in sub-Saharan Africa and Thailand



Natural enemy of cassava mealybugs – the tiny wasp Anagyrus lopezi



the infested cassava area. The biological control campaign was highly successful – the infested area was reduced to 170 000 ha in 2010, to 64 000 ha in 2011 and just 3 300 ha in 2012 (Figure 29)¹⁵.

Current recommendations for the control of cassava mealybugs include:

- ▶ Conserve the population of natural enemies by not spraying synthetic pesticide
- ▶ If necessary, treat planting material with a solution using a locally registered and recommended insecticide
- ▶ Monitor cassava plantations every 2 to 4 weeks to detect focal points of infestation
- ▶ Remove and burn the infested parts of plants
- ▶ Avoid the movement of planting material from one region to another
- ▶ Minimize the movement of planting material from infested to non-infested fields

Cassava mites are an important insect pest in all producing regions. The cassava green mite, *Mononychellus tanajoa*, causes the most damage to cassava in Latin America and sub-Saharan Africa, especially

in lowland areas with a prolonged dry season. It feeds on the underside of young leaves, which become white-yellow, deformed and smaller. The mite can cause root yield losses of up to 80 percent. Another green mite species, *M. mcgregori*, was recently reported in Cambodia, China and Viet Nam. Although it may not be as aggressive as *M. tanajoa*, it could cause serious damage owing to the lack of primary natural enemies.

The introduction of green mites on cassava imported from Latin America in the early 1970s devastated Africa's cassava production. To bring the mite under control, entomologists at IITA and CIAT first identified its area of origin in South America and its natural enemy, another mite, from Brazil. The Brazilian mites survived in Africa but their diffusion was very slow.

The solution was another predatory mite, *Tetranychus aripo*, which spread rapidly in African farmer's fields and did not have a voracious appetite for green mites – an advantage, since it allows enough green mites to survive and prevent the predatory mites from dying out. As well as reducing the damage caused by green mites throughout Africa, *T. aripo* has contributed substantially to the science of biological control and to the knowledge of how mites work in complex food systems¹⁶.

Many species of red spider mites have been observed on cassava in all three cassava-producing regions. It is the most prevalent dry season pest of cassava in Asia, where the most common species are *Tetranychus urticae* and *T. kanzawai*. Yield losses range from 18 to almost 50 percent. Red mites feed mainly on the underside of leaves, but attack old leaves at the base of the plant, causing considerable webbing. Further research is urgently needed to identify the most effective natural enemies of red spider mites.

Current recommendations for the control of cassava mites include:

- ▶ Plant resistant or tolerant varieties, if available
- ▶ In endemic areas, treat stakes with a recommended, locally approved insecticide
- ▶ Promote good establishment by planting early in the wet season
- ▶ Apply adequate and well-balanced fertilizers to improve plant vigour
- ▶ Apply foliar sprays with water at high pressure to reduce mite populations
- ▶ Strictly enforce quarantine regulations



Other natural enemies of insect pests worth protecting: Coccinellidae beetles (top) and the African lacewing

Other important pests that are found only in Latin America are the cassava hornworm, burrowing bugs, leaf-cutter ants, shoot flies and fruit flies. Great care needs to be taken to avoid accidentally introducing those pests from Latin America to Africa and Asia, where they have no natural enemies and could, therefore, do great damage. A newly identified menace in Asia – found in Cambodia, Lao PDR, the Philippines, Thailand and Viet Nam – is witches' broom disease, which is thought to be caused by a phytoplasma.

Some cassava pests and diseases have also been accidentally introduced on other plant species closely related to cassava, such as *Jatropha curcas*, which is used as “living fences” in Asia and has become popular recently as a source of biofuel. Special care must be taken in moving vegetative planting material of related species between countries, and large *Jatropha* plantations should not be located in cassava growing regions.

Weed management

Compared to many other crops, the initial growth of cassava is slow. That, combined with the wide spacing between planted stakes, gives weeds a chance to emerge and compete for sunlight, water and nutrients.

In the first four months after planting, cassava can easily be overwhelmed by competition from narrow-leaf grassy weeds and from broad-leaf weeds, which include many leguminous plants. In East Africa, weeds are often a more serious production constraint than insect pests or diseases and can reduce yields by about 50 percent¹⁷. In Nigeria, farmers spend more time on weeding than on any other aspect of crop production¹⁸.

Once the cassava canopy has closed, it will shade out most weeds and keep the field almost completely weed-free^{19, 20}. Six to eight months after planting, when cassava starts to shed many leaves (especially during the dry season), weeds may reappear, but this generally does not seriously affect yields. Excessive late weed growth may make harvesting more difficult, but can also protect the soil from erosion if post-harvest rains are heavy.

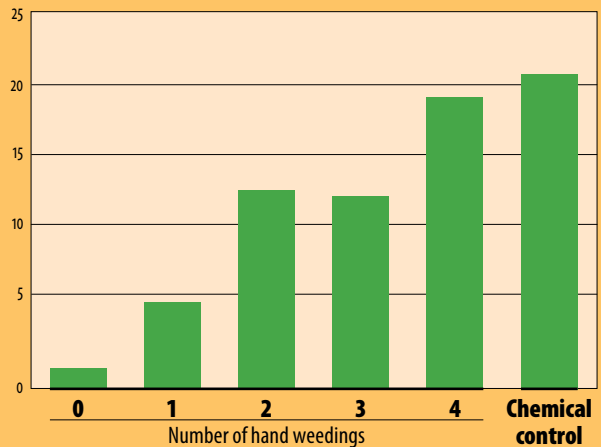
“Save and Grow” cultural practices can provide an effective defence against weeds. While cultural controls may not be 100 percent effective, they do help in reducing weed competition, and thus the need for mechanical or chemical weeding²¹. Cultural control begins with selection of high-quality planting material from varieties with vigorous early growth and tolerance or resistance to important diseases and pests. High planting density and the correct type and rate of fertilizer, applied in short bands next to the planted stakes, can stimulate early crop growth and rapid canopy closure. Planting in the dry season under drip irrigation can also encourage the growth of cassava but not that of weeds.

To prevent weed emergence, the soil should be covered with a thick layer of mulch, such as rice straw or maize residues. Another “Save and Grow” recommendation is to intercrop cassava with fast-growing plants, such as melons, squash, pumpkins, common beans, groundnuts, soybeans, mungbeans and cowpeas. As those are short-duration crops, they can be harvested after about 3 to 4 months, when the cassava canopy closes and weeds are shaded out. While intercrops may reduce cassava root yields, they markedly reduce weed growth, and offer an eco-friendly – and less expensive – alternative to spraying with herbicides. A study in Nigeria of legume cover crops in a mixed cassava/maize system reported significant improvements in cassava root yields when velvet beans were grown to suppress weeds¹⁸.

Many smallholder cassava farmers use mechanical control measures. Most commonly, they remove weeds by hoeing, starting about 15 days after planting, or after emergence if the cassava is planted horizontally. Research in Colombia (Figure 30) found that with hand-weeding at 15, 30, 60 and 120 days after planting, cassava root yields were 18 tonnes per ha, only 8 percent less than those obtained when weeds were controlled with herbicides. When weeds were not controlled at all, yields fell to just 1.4 tonnes.

Weeds growing between the rows can also be incorporated into the soil using an oxen- or buffalo-drawn cultivator or, where

Figure 30 Effect of hand weeding on fresh cassava root yield 280 days after planting, Colombia (t/ha)



Source: Annex Table 6.1

available, tractors equipped with cultivator blades. In the absence of both machinery and draught animals, farmers in Thailand use a manually-drawn cultivator, known as a “poor man’s plough”. In Viet Nam, farmers use a contraption made from the handlebar and front wheel of a bicycle, with a cultivator blade attached behind the wheel. This operation is usually followed by hand weeding with a hoe between the plants in the row.

On larger farms or when labour is unavailable or is too expensive, weeds are often controlled with herbicides. Many herbicides are highly toxic and, being water soluble and persistent in the environment, can be washed away to contaminate ground and surface water. Farmers need to exercise care in the choice of the herbicide to be used and follow the advice of local plant protection specialists.

Pre-emergence herbicides do not kill existing weeds. Instead, they prevent weed seeds in the soil from emerging or, at least, reduce their rate of growth. Pre-emergence herbicides are either incorporated into the soil before planting or applied on the soil surface with a knapsack sprayer immediately after planting. Pre-emergence herbicides that are selective for cassava can be applied over the vertically planted stakes without affecting cassava sprouting or yield.

The application of pre-emergence herbicides can maintain a cassava field almost weed-free for 6 to 8 weeks after planting. Farmers may apply a mixture of two herbicides – one that controls the grassy weeds and one the broad-leaf weeds. A lower dosage is recommended on light-textured soils, while a higher dosage may be needed in heavy soils, such as loamy clays. Special care needs to be taken when cassava is grown in association with other crops, because the pre-emergence herbicides normally used for cassava may harm the intercrop.

At about two months after planting, weeds may need to be controlled again to reduce competition with cassava. This is usually done by hoeing or using an animal- or tractor-mounted cultivator, depending on the height of the growing cassava plants and the extent of canopy closure. When most of the weeds are grassy species, it is also possible to apply a selective post-emergence herbicide, which kills grasses but does not affect the cassava plant. Post-emergence herbicides can be used about 4 to 5 months after planting, when some bottom leaves start to drop off. They should only be applied on windless days and with a nozzle shield to prevent spray from reaching the cassava stems or leaves.