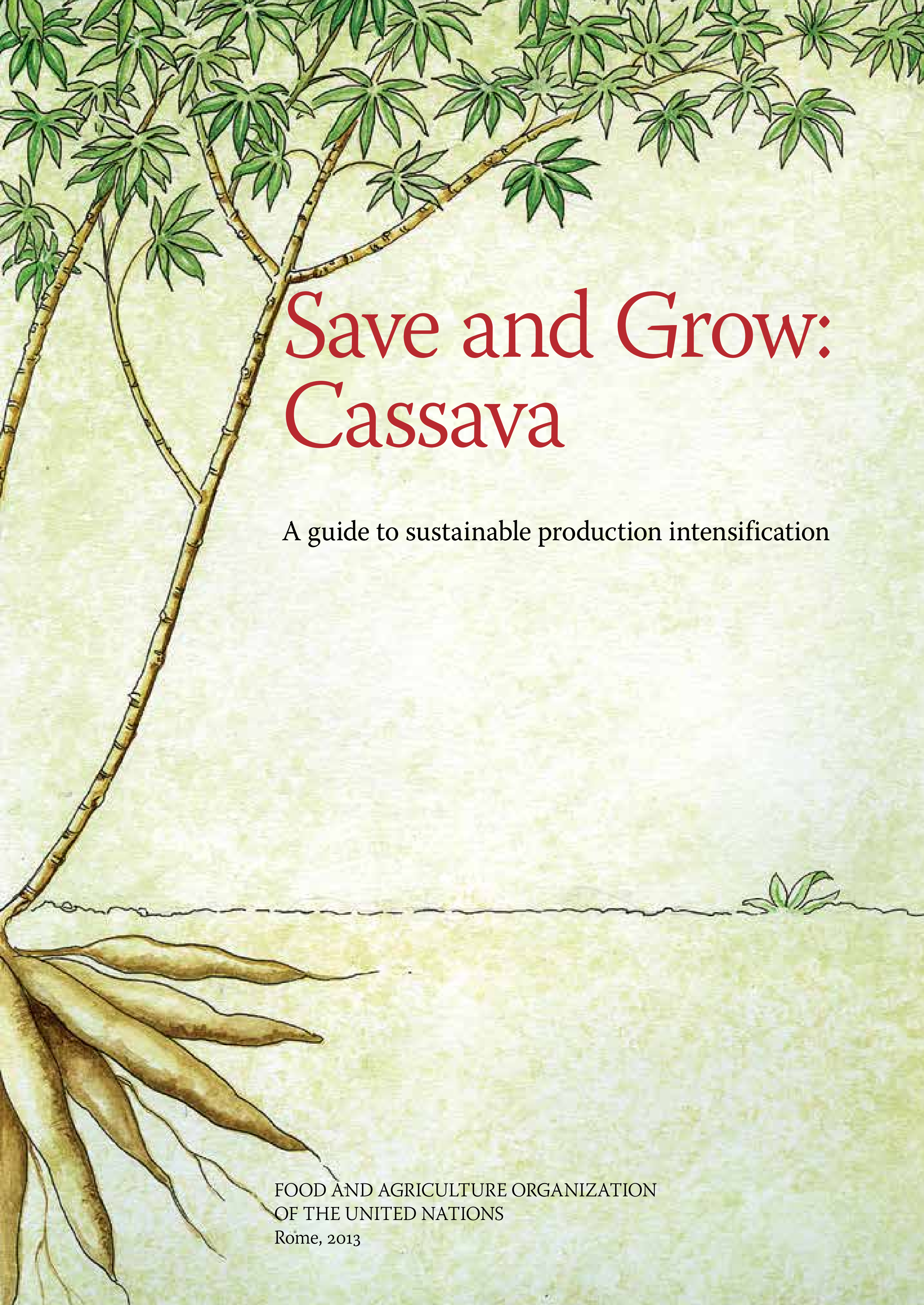
SAVE AND GROW

Cassava

A GUIDE TO SUSTAINABLE PRODUCTION INTENSIFICATION



Save and Grow: Cassava

A guide to sustainable production intensification

FOOD AND AGRICULTURE ORGANIZATION
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Foreword

Cassava is a tropical root crop, originally from Amazonia, that provides the staple food of an estimated 800 million people worldwide. Grown almost exclusively by low-income, smallholder farmers, it is one of the few staple crops that can be produced efficiently on a small scale, without the need for mechanization or purchased inputs, and in marginal areas with poor soils and unpredictable rainfall.

Since 2000, the world's annual cassava production has increased by an estimated 100 million tonnes, driven in Asia by demand for dried cassava and starch for use in livestock feed and industrial applications, and in Africa by expanding urban markets for cassava food products. There is great potential for further production increases – under optimal conditions, cassava yields can reach 80 tonnes per hectare, compared to the current world average yield of just 12.8 tonnes.

Booming demand offers millions of cassava growers in tropical countries the opportunity to intensify production, earn higher incomes and boost the food supply where it is most needed. But how smallholder cassava growers choose to improve productivity should be of major concern to policymakers. The Green Revolution in cereal production, based on genetically uniform varieties and intensive use of irrigation and agrochemicals, has taken a heavy toll on agriculture's natural resource base, jeopardizing future productivity. In moving from traditional, low-input to more intensive cultivation, small-scale cassava growers should not make the same mistakes.

Sustainable intensification of cassava production is the subject of this guide, the first in a series to the practical application of FAO's "Save and Grow" model of agriculture to specific smallholder crops and farming systems. Endorsed by FAO in 2010, "Save and Grow" is an ecosystem approach to agriculture that aims at improving productivity while conserving natural resources. It promotes practices that can help the world's half a billion smallholder farm families to produce more from the same area of land while enhancing natural capital and ecosystem services.

Drawing on two decades of research findings and on-farm experiences in Africa, Asia, Latin America and the Caribbean, the guide presents an eco-friendly approach to managing cassava more intensively. Many recommended practices combine traditional knowledge with modern technologies that are adapted to the needs of small-scale producers. They include: minimizing tillage to protect soil health, optimizing timing and methods of planting, and using biological control agents to counter pests and diseases. The guide shows how well-balanced applications of mineral fertilizer, in combination with intercropping, crop rotation, mulching, manure and compost, can make a cassava-based farming system not only more productive and profitable, but also more sustainable.

The adoption of "Save and Grow" agriculture will require significant improvements in the provision of extension, inputs and production credit to small-scale producers. Moreover, FAO recognizes that improved productivity may not bring about sustainable, long-term development outcomes: a major effort is needed to integrate smallholders into higher levels of value addition. Transforming cassava into a multipurpose subsector that generates income, diversifies economies and ensures food for all will require political commitment, investment, institutional support and a demand-driven approach to technology development.

This guide will be a valuable resource for policymakers in assessing how a dynamic cassava sector can help them to achieve their goals of poverty alleviation, economic development and food security, and of practical use to agricultural researchers, technicians and other professionals in preparing programmes for sustainable cassava production intensification.

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Contents

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Overview

1. Cassava, a 21st century crop

The "food of the poor" has become a multipurpose crop that responds to the priorities of developing countries, to trends in the global economy and to the challenge of climate change.

Long regarded as unsuitable for intensification, cassava has grown dramatically in importance in world agriculture. The 2012 harvest reached record levels, thanks to expansion of global trade in cassava products and strong growth of output in Africa. Production is intensifying worldwide. In the years ahead, cassava will see a shift to monocropping, higher-yielding genotypes, and greater use of irrigation and agrochemicals. But intensification carries great risks, including upsurges in pests and diseases, and depletion of soil nutrients. This guide shows how FAO's "Save and Grow" farming approach can help developing countries to avoid the risks of unsustainable intensification, while realizing cassava's potential for producing higher yields, alleviating rural poverty and contributing to national economic development.

2. Farming systems

Many smallholder cassava growers already practise three key "Save and Grow" recommendations: reduced or zero tillage, soil surface cover and crop diversification.

Planting cassava without prior tillage in degraded soils may produce lower yields in the initial years; once soil health is restored, however, untilled land can produce high yields at a lower cost to the farmer and the farm's natural resources. Mulch and cover crops help to reduce weed infestations and create soil conditions that improve productivity. Growing cassava in associations, sequences and rotations increases net income per unit area of land, and reduces the risk of crop failure. Intercropping with grain legumes can produce higher incomes than monocropping, and supplies food for the household. Protective hedgerows reduce soil erosion, while rotating cassava with legumes and cereals helps to restore soil health and yields.

3. Varieties and planting material

The full potential of cassava will not be realized until production constraints are mitigated in higher-yielding varieties, and cassava growers have access to disease-free planting material.

The time is right for the genome-wide characterization of cassava genetic diversity, to fill gaps in landrace collections, and to create natural reserves to safeguard wild relatives. The harmonization of passport and evaluation data on genebank accessions should be a priority. Breeding should focus on developing varieties that are well-adapted to specific agro-ecologies, cropping systems and end-uses, and produce good yields with minimal need for agrochemicals and irrigation. The routine multiplication and distribution of disease-free planting material of improved varieties are essential for sustainable intensification. While few countries have formal seed systems for cassava, a 3-tier community-based system pioneered in Africa, involving NGOs and farmer associations, has helped ensure that improved varieties and healthy planting material are adopted by cassava growers.

4. Water management

Once established, cassava can grow in areas that receive just 400 mm of average annual rainfall. But much higher yields can be obtained with higher levels of water supply.

Optimizing rainfed cassava production requires careful attention to planting dates, planting methods and planting positions, and soil management practices that help to conserve water. Although it can grow in areas with 400 mm of rainfall a year, maximum root yields in Thailand were correlated with rainfall totalling about 1 700 mm. Cassava responds well to irrigation – full surface irrigation has doubled the root yield obtained without irrigation; drip irrigation can produce about the same yield as surface irrigation using 50 percent less water. In Nigeria, root yields increased sixfold when the quantity of water supplied by supplementary drip irrigation was equal to that of the season's rainfall. Supplemental irrigation that increased the total water supply by 20 percent almost doubled root yields.

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.

Although cassava produces reasonable yields on poor soils, many varieties perform better with fertilization. Yields in Africa, especially, could be markedly improved if farmers had access to mineral fertilizer at a reasonable price. Farmers can improve soil fertility with other "Save and Grow" measures. Intercropping grain legumes, and mulching the residues of legumes and native weeds, boosts root yields. When combined with fertilizer, both alley cropping with deep-rooting leguminous trees and the use of organic compost or farmyard manure produce higher crop yields and net incomes. Options to reduce the loss of soil nutrients to erosion include zero tillage, which maintains soil aggregate stability and internal drainage, contour hedgerows of vetiver grass, and the application of mineral fertilizer, which leads to faster soil coverage by the plant canopy.

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.

Growers should use planting material of varieties with tolerance or resistance to major pests and diseases, as well as ecosystem-based practices, such as mulching, maintaining soil organic matter, and planting intercrops to provide a habitat for pest predators. Biopesticides, sticky traps and soapy water can help control many insect pests. Plant health strategies should encourage natural biological agents – the mass release of a tiny wasp defeated serious outbreaks of cassava mealybug in Africa and Asia. To prevent weeds overwhelming young plants, farmers should use optimum planting densities and fertilization, and varieties with vigorous early growth. Regular hand weeding can be as effective as weed control with herbicides. Farmers need to exercise care in the choice of the herbicides and should follow the advice of local plant protection specialists.

7. Harvest, post-harvest and value addition

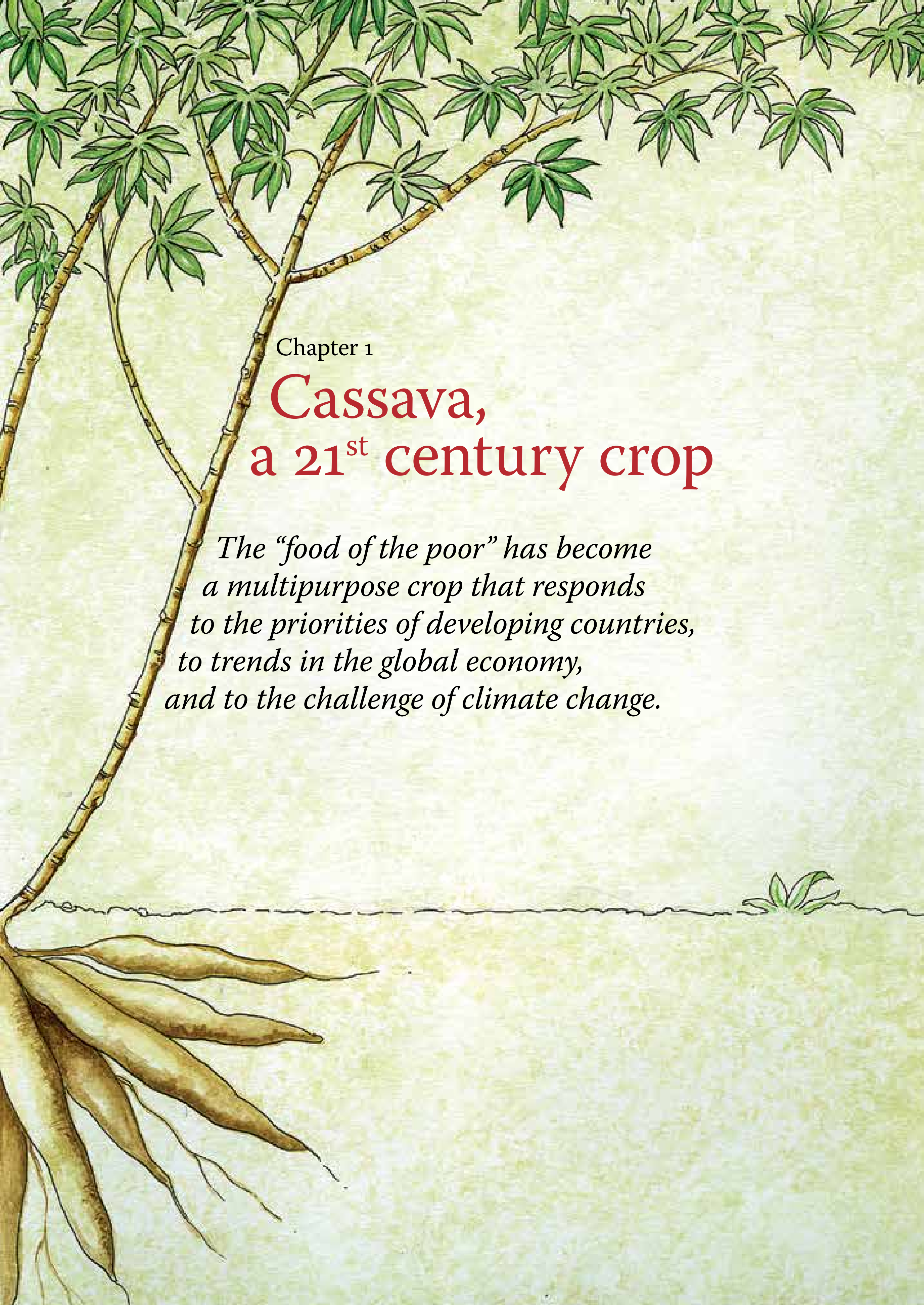
Food for the household, feed for livestock, and raw material for a wide array of value-added products, from coarse flour to high-tech starch gels – cassava is a truly multipurpose crop.

Harvested cassava roots are consumed directly by many farm households or fed to their livestock. Roots can be processed into granulated flour, or into high quality cassava flour which can be used as a substitute for some of the wheat flour in bread and confectionary. In Thailand and China, root starch goes into food products, plywood, paper and textiles, and is used as feedstock for production of sweeteners, fructose, alcohol and fuel ethanol. Two recent cassava mutations have starch properties that are highly valued by industry. The root is not the only useful part of the plant – young cassava leaves make a nutritious vegetable, and plant tops can be fed to cattle, buffaloes, pigs, chickens and silkworms.

8. The way forward

Governments need to encourage smallholders' participation in a sustainable cassava development agenda, and support research and extension approaches that "let farmers decide".

Farmer participatory research and farmer field schools have proven very effective in promoting sustainable natural resources management in smallholder production systems. Cassava growers may also require incentives, such as payments for environmental services, to adopt improved farming practices. Action is needed to make mineral fertilizer and other inputs more affordable to smallholders, and to provide them with quality, disease-free planting material. Investment in roads, storage and processing capacity in production zones will help cassava growers retain a bigger share of value-addition. Policies should promote private investment in cassava processing, and foster associations that link producers with processors, promote standards and share market information. While government subsidies may reduce farmers' exposure to price volatility, more sustainable options are available, such as crop insurance and supply contracts between food manufacturers and farmers' cooperatives.



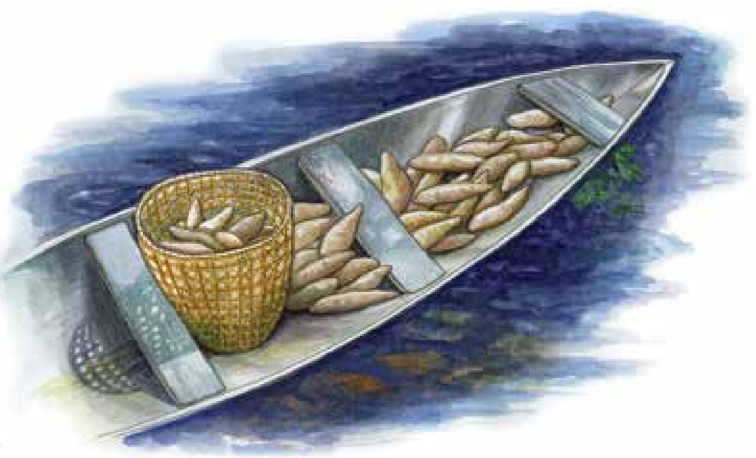
Chapter 1

Cassava, a 21st century crop

The "food of the poor" has become
a multipurpose crop that responds
to the priorities of developing countries,
to trends in the global economy,
and to the challenge of climate change.

Cassava (*Manihot esculenta* Crantz) is one of some 100 species of trees, shrubs and herbs of the genus *Manihot*, which is distributed from northern Argentina to the southern United States of America. While some studies indicate that cassava has multiple centres of origin, others suggest that the cultivated species originated on the southern edge of the Brazilian Amazon[1-4]. Botanically, cassava is a woody perennial shrub, which grows from 1 m to 5 m in height. It is believed to have been cultivated, mainly for its starchy roots, for 9 000 years, making it one of agriculture's oldest crops. In pre-Colombian times, it was grown in many parts of South America, Mesoamerica and the Caribbean islands.

Following the Spanish and Portuguese conquests, cassava was taken from Brazil to the Atlantic coast of Africa. By the 1800s it was being grown along Africa's east coast and in Southern Asia. Farming of cassava expanded considerably in the 20th century, when it emerged as an important food crop across sub-Saharan Africa and in India, Indonesia and the Philippines. Since it is sensitive to frost and has a growing season of nearly one year, cassava is cultivated almost exclusively in tropical and subtropical regions. It is grown today by millions of small-scale farmers in more than 100 countries, from American Samoa to Zambia, under a variety of local names: *mandioca* in Brazil, *yuca* in Honduras, *ketela pohon* in Indonesia, *mihogo* in Kenya, *akpu̲* in Nigeria and *sắn* in Viet Nam.



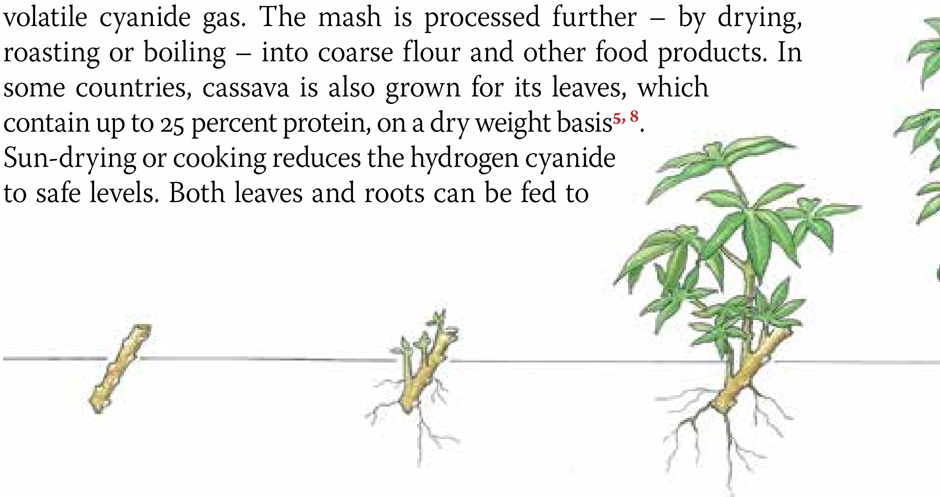
***Manihot esculenta* has characteristics** that make it highly attractive to smallholder farmers in isolated areas where soils are poor and rainfall is low or unpredictable. Since it is propagated from stem cuttings, planting material is low-cost and readily available. The plant is highly tolerant to acid soils, and has formed a symbiotic association with soil fungi that help its roots absorb phosphorus and micronutrients. To discourage herbivores, its leaves produce two glycosides which, when digested, produce highly toxic hydrogen cyanide. Since most of the soil nutrients absorbed during growth remain in the above-ground part

Studies suggest that cassava was first cultivated, as many as 9 000 years ago, on the southern edge of the Brazilian Amazon, where it is still grown today of the plant, recycling the plant tops helps to maintain soil fertility. Under drought stress, leaf production is reduced until the next rains. Thanks to its efficient use of water and soil nutrients, and tolerance to sporadic pest attacks, cassava growers, using few if any inputs, can expect reasonable harvests where other crops would fail.

Cassava roots are more than 60 percent water. However, their dry matter is very rich in carbohydrates, amounting to about 250 to 300 kg for every tonne of fresh roots. When the root is used as food, the best time to harvest is at about 8 to 10 months after planting; a longer growing period generally produces a higher starch yield. However, harvesting of some varieties can be "as needed", at any time between six months and two years. Those attributes have made cassava one of the world's most reliable food security crops.

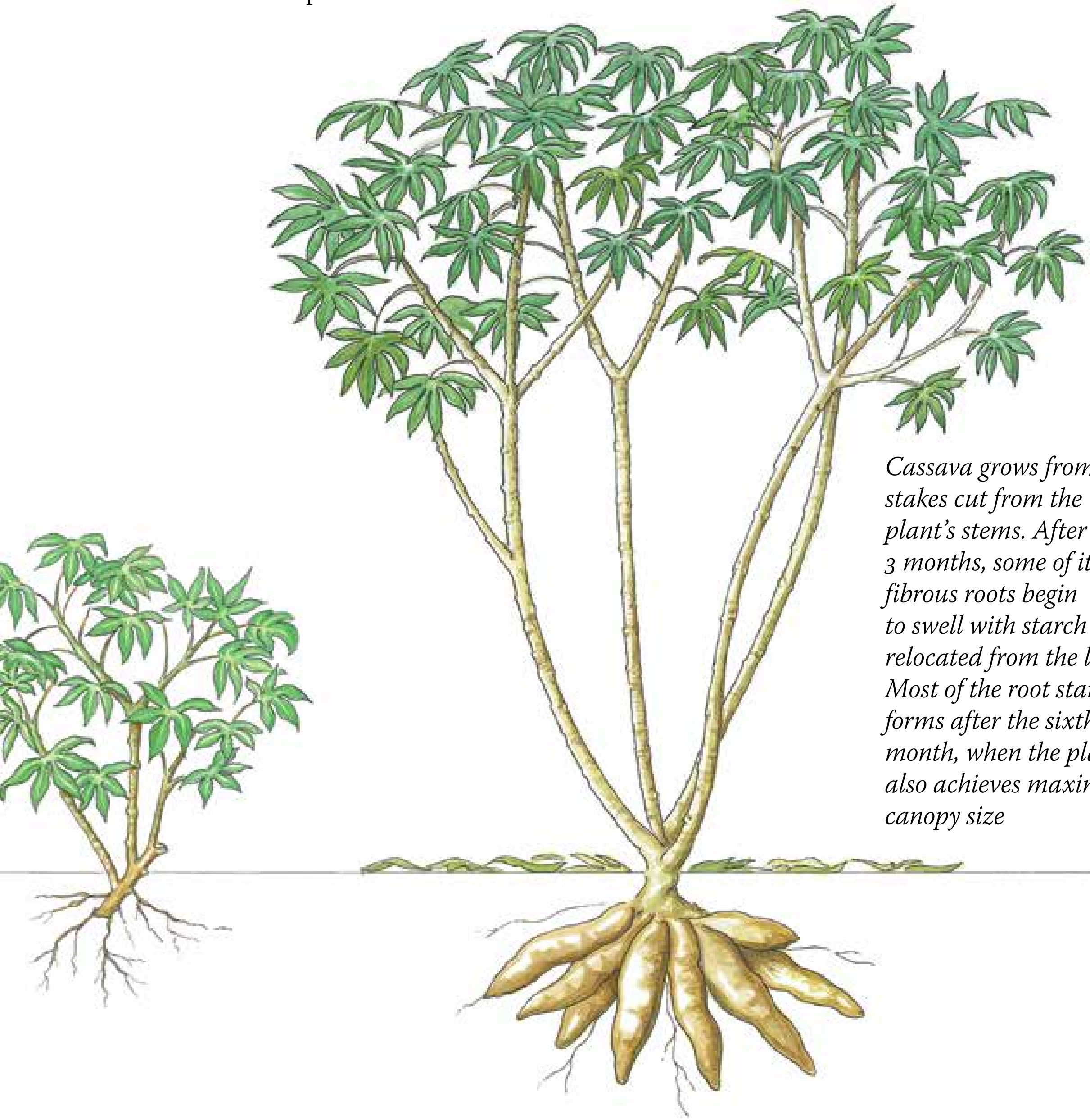
Thanks to its roots' high starch content, cassava is a rich source of dietary energy. Its energy yield per hectare is often very high, and potentially much higher than that of cereals[5]. In many countries of sub-Saharan Africa, it is the cheapest source of calories available. In addition, the roots contain significant amounts of vitamin C, thiamine, riboflavin and niacin[6].

Depending on the variety, they may also contain high levels of cyanogenic glycosides, especially in the outer layers[7]. Once harvested, therefore, cassava roots are peeled, then thoroughly cooked, or peeled, grated and soaked to induce fermentation in order to release the volatile cyanide gas. The mash is processed further – by drying, roasting or boiling – into coarse flour and other food products. In some countries, cassava is also grown for its leaves, which contain up to 25 percent protein, on a dry weight basis[5, 8]. Sun-drying or cooking reduces the hydrogen cyanide to safe levels. Both leaves and roots can be fed to



farm animals, while stems can be used as firewood and a substrate for growing mushrooms.

Cassava's versatility does not end there. Its root starch can also be used in a wide array of industries, including food manufacturing, pharmaceuticals, textiles, plywood, paper and adhesives, and as feedstock for the production of ethanol biofuel.



Cassava grows from stakes cut from the plant's stems. After 3 months, some of its fibrous roots begin to swell with starch relocated from the leaves. Most of the root starch forms after the sixth month, when the plant also achieves maximum canopy size

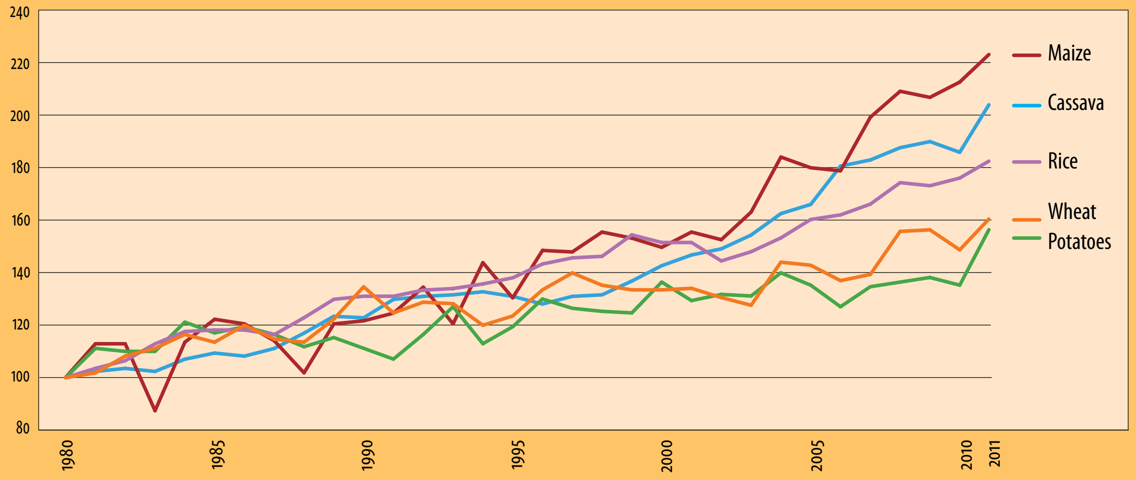
Among the family of staple food crops, cassava was long regarded as the least suited to intensification. Cassava stem cuttings are bulky and can easily transmit serious pests and diseases, and the plant's very low rate of vegetative multiplication retards the adoption of new, improved varieties. Unearthing cassava roots is labour-intensive, and the roots themselves are cumbersome to transport and highly perishable: they need to be processed within a few days of harvesting.

The Green Revolution approach to intensification, based on dwarf varieties and high inputs of agrochemicals and irrigation, dramatically boosted yields of wheat and rice, but it has proven inappropriate for cassava in rainfed areas. Partly because it is grown in developing countries, far less research and development has been devoted to cassava than to rice, maize and wheat[9].

But cassava's importance in agriculture has changed dramatically. Between 1980 and 2011, the global harvested area of cassava expanded by 44 percent, from 13.6 million to 19.6 million hectares, which was the biggest percentage increase among the world's five major food crops. In that same period, world cassava production more than doubled, from 124 million to 252 million tonnes[10].

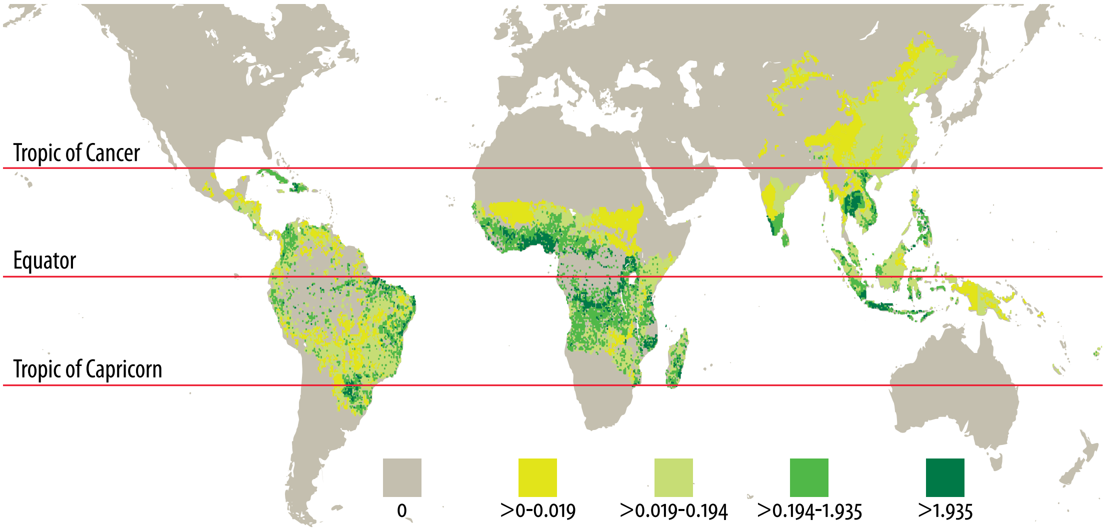
Over the past decade, growth in cassava production has accelerated (Figure 1). FAO estimates put the global harvest in 2012 at more than 280 million tonnes, representing a 60 percent increase since 2000 and an annual growth rate double that of the previous two decades[11]. Since 2000, the growth rate of cassava output in Africa has been equal to

Figure 1 **Growth in world production of major crops, 1980-2011** (index 1980=100)



Source: FAO. 2013. FAOSTAT statistical database (http://faostat.fao.org/).

Global cassava harvested area (ha/km^2)



Source: Adapted from Monfreda, C., Ramankutty, N. & Foley, J.A. 2008. Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. *Glob. Biogeochem. Cycles*, 22: 1-19.

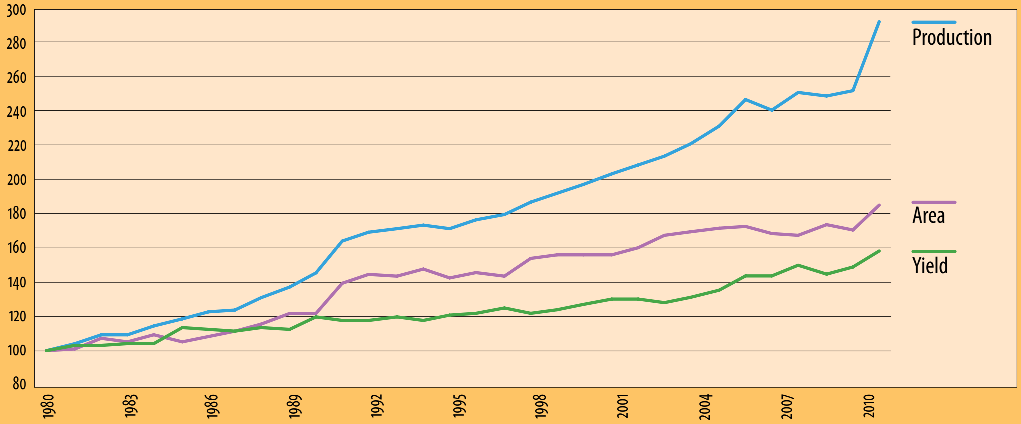
that of maize, while in South, Southeast and Eastern Asia the rate has been almost three times that of rice[10].

Another significant trend since the turn of the century is the higher productivity of cassava-based farming systems. Growth in production between 1980 and 2000 was due mainly to increases in the harvested area, of some 3.7 million ha; yields grew at an annual rate of just 0.6 percent. Since then, global average yields per hectare have increased by almost 1.8 percent a year, from 10.4 tonnes per ha in 2000 to 12.8 tonnes in 2011. While growth of cassava yields trailed well behind that of other major food crops in the period 1980-2000, the rate of increase over the past decade has exceeded that of potatoes, maize, rice and wheat[10].

Current average yields are still far lower than cassava's potential. A study by the International Center for Tropical Agriculture (CIAT) in the 1990s estimated conservatively that – with improved crop and soil management, and the use of higher yielding varieties more resistant to drought, pests and diseases – cassava could produce an average of 23.2 tonnes of roots per ha. On the current harvested area, that amounts to more than 450 million tonnes a year.

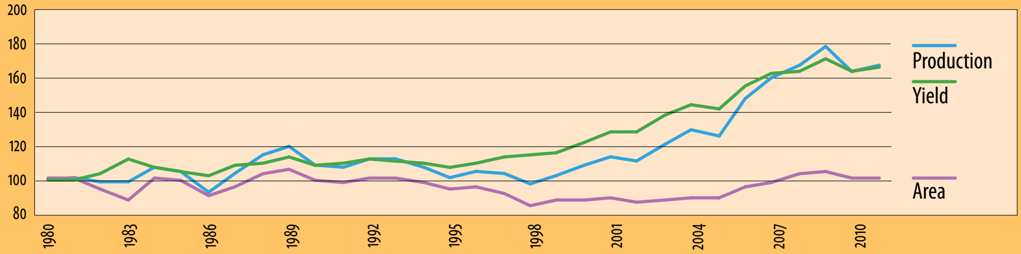
A review of developments in the world's cassava producing regions reveals that diverse factors are driving increases in output and that growers are responding to rising demand by intensifying production.

Figure 2 **Growth in cassava production, harvested area and yield in sub-Saharan Africa, 1980-2011** Index: 1980=100



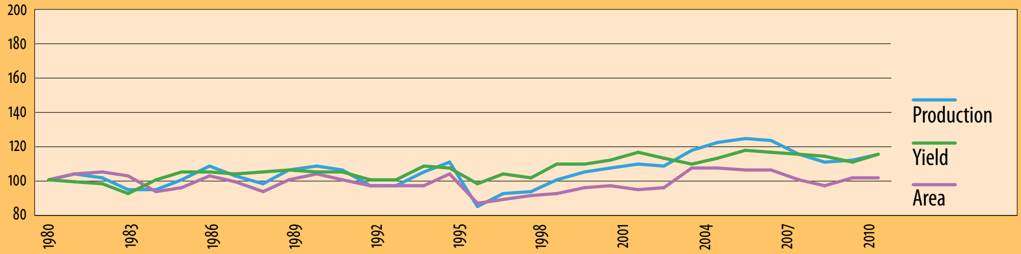
Source: Annex Tables 1.1, 1.2 and 1.3

Figure 3 **Growth in cassava production, harvested area and yield in Asia, 1980-2011** Index: 1980=100



Source: Annex Tables 1.1, 1.2 and 1.3

Figure 4 **Growth in cassava production, harvested area and yield in Latin America and the Caribbean, 1980-2011** Index: 1980=100



Source: Annex Tables 1.1, 1.2 and 1.3

Sub-Saharan Africa

Output of cassava has increased most markedly in sub-Saharan Africa, which harvested 140.9 million tonnes – more than half of the global harvest – in 2011. Between 1980 and 2000, production almost doubled, from 48.3 million to 95.3 million tonnes, thanks to a 56 percent increase in the harvested area and 25 percent growth in yields. Between 2000 to 2011, expansion of the harvested area slowed to 18 percent, but improvements in yields, from 8.6 tonnes to 10.8 tonnes per ha, boosted production by almost 50 percent (Figure 2).

Cassava in sub-Saharan Africa is grown mainly on small holdings by low-income farmers who make little or no use of external inputs. It is usually grown with other crops, such as maize, rice, legumes, melons, bananas and oil palm. It is still essentially a food crop – around 90 percent of harvested roots are destined for human consumption, while around 10 percent is semi-processed as on-farm animal feed[12].

Since 2000, cassava production has grown faster than the region's population, boosting the cassava food supply to almost 60 kg per capita per year. Africans' consumption of cassava is higher than that of any other staple food, including maize. Almost all of it is consumed as fresh roots or after processing into fermented flour products[13]. By some estimates, urban Nigerians consume cassava at the rate of 0.2 kg per day[14].

The biggest gains in cassava production since 2000 have been in West Africa, where output rose by 60 percent, from 47 million to 76 million tonnes. Productivity has increased as countries in the subregion recognized cassava's potential as an industrial crop that could help to diversify farmers' incomes, earn foreign exchange and generate jobs[12]. Growth in output was particularly strong in Nigeria and Ghana: in the space of 11 years, both countries boosted yields by 25 percent, to around 15 tonnes per ha[10].

Average yields in the rest of the region remain low, at around 10 tonnes. However, thanks to more intensive production – mainly through greater use of improved varieties, mineral fertilizer and other inputs – yields have increased substantially in some countries. For example, a government programme in Malawi for the rapid multiplication of disease-free, higher-yielding planting material led to a rapid increase in cassava cultivation nationwide[15]. Between 1990 and 2011, average yields rose from 2.3 tonnes per ha to 21.5 tonnes, and production from 144 000 to 4.2 million tonnes[10].

More recently, Rwanda has shown how intensification can produce spectacular results in a very short time. Since 2007, the country's food crop intensification programme has distributed to farmers 140 million stem cuttings of improved, disease-resistant varieties, and provided them with imported fertilizer and extension advice. As a result, yields rose from less than 6.5 tonnes in 2007 to 12.3 tonnes by 2011, and production more than tripled, from 780 000 to 2.5 million tonnes[16].

Sub-Saharan Africa lags behind global trends in the development of the cassava value chain. However, new uses for cassava are emerging: in commercial livestock feed, as a partial substitute for wheat flour in bread making and as an industrial raw material. In 2012, Nigeria made a strong entry into the global cassava trade when it secured an order to supply China with 1 million tonnes of dried cassava chips[10]; the government recently announced further sales to China of 3.3 million tonnes in 2013[17].

Asia

Cassava growers in Asia account for 30 percent of world production. Over the past three decades, their cassava output has grown by 66 percent, from 45.9 million tonnes in 1980 to 76.6 million tonnes in 2011. That growth was due almost entirely to more intensive cultivation – the harvested area in 1980 and 2011 was unchanged, at around 3.9 million ha, while average yields increased from 11.8 to 19.5 tonnes per ha in the same period (Figure 3).

As in Africa, cassava is mainly a smallholder crop that was once grown as a reserve in case of shortfalls in the rice harvest and as on-farm animal feed[18]. Today, most cassava is grown in the region to meet demand for dried cassava chips and cassava starch for use in commercial livestock feed and for industrial processing.

Thailand put cassava on the map of industrial uses in the 1980s, when it developed a thriving business exporting dried pellets to Europe for use in livestock feed. The country's impressive increase in cassava production, from 3.4 million tonnes in 1970 to more than 20 million tonnes in 1990, was achieved thanks to expansion of the harvested area, which grew almost seven times over; yields actually fell, from 15.3 tonnes to less than 14 tonnes per ha[10].

In the 1990s, Thailand launched a major programme for the dissemination to farmers of new, higher-yielding varieties, along with improved access to mineral fertilizer and extension. Between 1990 and

2009, Thai yields rose by almost two-thirds, the harvested area shrank by 10 percent, and production reached a record 30 million tonnes.

Since 2000, Asia's cassava production has increased by 55 percent, as more countries seek to enter lucrative export markets. The region's major customer is China. Between 2000 and 2009, China's annual imports of dried cassava grew from 256 000 tonnes to more than 6 million tonnes, while imports of cassava starch more than doubled, to 1.2 million tonnes[10].

Thailand dominates the export trade, shipping 6 million tonnes of dried cassava chips and starch, with a total value of US$1.5 billion, in 2010. However, it faces increasing competition. Viet Nam has more than quadrupled cassava production, from 2 million to 8.5 million tonnes[11] since 2000, and exported 1 million tonnes of dried cassava in 2010. Indonesian exports also grew, from 150 000 tonnes in 2000 to 1.4 million tonnes. In Cambodia, a fledgling export trade in dried cassava, amounting to 22 000 tonnes in 2011, was recently boosted by orders from China for 1 million tonnes[19].

An important new area of cassava utilization in Asia is as feedstock for the production of biofuel – one tonne of dried chips yields about 300 litres of 96 percent pure ethanol[13]. As countries seek to reduce both dependence on imported oil and greenhouse gas emissions, companies in China, Japan and the Republic of Korea are obtaining concessions for large-scale cassava plantations, mainly in Cambodia, Indonesia, Lao PDR and the Philippines, as a source of dried chips for ethanol production.

In a few countries, cassava remains first and foremost a food crop. Indonesia has the region's highest per capita cassava food supply, of 44 kg per year, well above the regional average of 6.7 kg. Cassava is also grown mainly for food in Kerala State, India, where farmers have achieved average root yields of 24 tonnes per ha, thanks to intensive production, often under irrigation[20].

Latin America and the Caribbean

Only 14 percent of the world's cassava, or some 34.3 million tonnes, is grown in Latin America and the Caribbean, where *Manihot esculenta* was domesticated. Between 1980 and 2011, the harvested area grew by less than 1 percent, to 2.6 million ha, while production increased by 15 percent, thanks to modest improvements in yields. Nevertheless, average annual growth in production since 2000 has been at twice the rate recorded in the previous two decades (Figure 4).

As in other tropical regions, cassava in the Americas is usually relegated to marginal areas with uncertain rainfall, acid soils, low native soil fertility, and difficult terrain. The inherent nature of cassava cultivation, especially the labour inputs required, makes it generally a smallholder crop, grown in farming systems that include other crops or animal components[21]. Production is dominated by Brazil, which harvested 24.4 million tonnes – almost three-quarters of the region's total output – in 2011, followed by Paraguay (2.4 million tonnes), Colombia (2.2 million tonnes) and Peru (1.1 million tonnes)[10].

Although consumption of cassava as food has declined over the past 50 years, with the massive movement of rural populations to urban areas, it remains an important staple food especially in Colombia and northeast Brazil. FAO estimates that, regionally, about half of cassava production is used as food and half as animal feed. Cassava consumption is being promoted in Brazil by policies aimed at substituting imported cereals with domestically produced cassava flour. The government has mandated the blending of 10 percent cassava flour with wheat flour in bread, an initiative that is estimated to absorb about half of the country's cassava output[11].

Cassava growers in Latin America and the Caribbean typically apply few inputs, and yields – averaging 12.9 tonnes per ha – are well below potential levels. However, there has been a significant shift, beginning in the 1990s, toward larger-scale, more intensive production, especially in Brazil. While most of Brazil's cassava continues to be grown in the dry northeast, where yields average around 11 tonnes per ha[21], intensive cultivation in the country's southern states – mainly to produce cassava flour and native starch for the food, cardboard and textile industries – has obtained yields of up to 40 tonnes[22].

Brazilian production of cassava starch, processed mainly in factories in the state of Paraná, is estimated at more than 500 000 tonnes in 2011[23]. Some 70 percent of the raw material is produced by smallholder farmers[24]. To ensure a year-round supply of raw material, cassava production is mechanized, with farmers frequently cultivating cassava as a monocrop using high levels of inputs[24]. Other countries in the region, notably Colombia, Paraguay and Venezuela, are also increasing their capacity to produce cassava starch. Compared to Asia, very little of the region's cassava output enters international trade. In fact, the biggest exporter is Costa Rica, which exported some 92 000 tonnes of dried cassava in 2010.

Although world cassava production reached record levels in 2012, for the 14th consecutive year, there remains ample room for further growth. World trade in cassava products saw a marked expansion in 2012, thanks to cassava's price advantage over maize as a source of starch. International prices of chips and starch have been remarkably stable, despite very strong demand. FAO expects continued increases in production in 2013 in sub-Saharan Africa[11].

Cassava's new status in agriculture is a major step forward toward realization of Global Cassava Development Strategy, adopted in 2001, after four years of consultations, by FAO, the International Fund for Agricultural Development (IFAD), public and private sector partners and 22 cassava-producing countries. The strategy recognized cassava's potential not only to meet food security needs, but also to provide an engine for rural industrial development and a source of higher incomes for producers, processors and traders[25].

If anything, growth in cassava production is likely to accelerate over the current decade. Once seen as the "food of the poor", cassava has emerged as a multipurpose crop for the 21st century – one that responds to the priorities of developing countries, to trends in the global economy and to the challenges of climate change. In brief:

Rural development. Policymakers in tropical countries are recognizing the huge potential of cassava to spur rural industrial development and raise rural incomes. They look to Thailand, where increases in yields over the past two decades have boosted smallholder earnings by an estimated US$650 million and lifted many cassava growers out of poverty. In southern Brazil, cassava is a multi-million dollar industrial crop, processed in factories that employ thousands of rural people[24]. It has been estimated that investments in cassava research and development in Africa could generate some of the highest gains in agricultural GDP[26].

Urban food security. A major driver of production increases will be high prices of cereals on world markets, which sparked global food price inflation in 2008. In Africa, persistent urban poverty has boosted the consumption of cassava food products as consumers seek cheaper sources of calories[12]. Among FAO's recommendations to governments for holding down food prices is processing cassava into products that are marketable as instant foods with a long shelf-life[27]. Cassava could also help improve the nutrition of low-income populations – new biofortified varieties produce roots that are rich in vitamin A, iron and zinc.

Import substitution. Many governments have, or are considering, mandatory blending of mostly imported wheat flour with domestically produced cassava flour in bread making. Nigeria recently raised its levy on wheat flour to 100 percent, and will use revenue for a cassava bread development fund[11]. It has also announced plans to substitute 10 percent of the maize in poultry feed with cassava grits, which will increase annual demand for cassava roots by 480 000 tonnes[28]. In East Africa, the animal feed industry is turning to cassava, as maize and wheat become increasingly unaffordable[29].

Renewable energy. Global output of bio-ethanol could reach 155 billion litres by 2020, up from around 100 billion litres in 2010. Cassava currently contributes to only a small part of production, but demand from China is growing rapidly following its decision to no longer use cereals to produce biofuel. Currently, 50 percent of China's ethanol is derived from cassava roots and sweet potatoes, and in 2012 it was expected to produce 780 million litres of ethanol from 6 million tonnes of dried cassava[13]. China plans to develop cassava varieties suitable for biomass energy production in colder and drier regions of the country's north[30].

New industrial uses. Worldwide, cassava is the second biggest source of starch, after maize, with production estimated at 8 million tonnes a year. However, tropical countries import each year some US$80 million worth of maize starch that could be replaced by starch from locally grown cassava[13]. In Thailand, which has earned some US$4 billion from starch exports since 2000, scientists are developing a variety with root starch that rivals premium "waxy" maize starch[31, 32]. A recent cassava mutation offers smaller root starch granules that reduce considerably the time and energy required for ethanol production[33].

Adaptation to climate change. Another factor that favours increased cassava production is the crop's potential to adapt well to climate change. A recent study of the impacts of climate change on major staple crops in Africa found that cassava was the least sensitive to the climatic conditions predicted in 2030, and that its suitability would actually increase in most of the 5.5 million sq km area surveyed.

Conversely, all other major food crops in the region, including maize, sorghum, millet, beans, potatoes and bananas, were expected to suffer largely negative impacts[34].

As market demand grows, traditional cassava cropping systems are being replaced worldwide by more intensive production. In the years ahead, the trend towards intensification – aimed at achieving higher yields on the same area of land – is expected to strengthen in all cassava-producing regions. The alternative, expanding the harvested area, is not feasible in most countries owing to a diminishing supply of arable land and the high labour requirements of cassava cultivation. Past experience has also demonstrated that opening up new areas for cassava can carry heavy environmental costs: in Thailand, expansion of the harvested area in the 1970s and 1980s led to massive deforestation[25].

Farmers, industry and policymakers are seeking solutions to constraints to cassava yield increases[9]. Smallholder producers in Brazil, India and Thailand have been highly successful in commercial production, obtaining yields of between 25 and 40 tonnes per ha, through more intensive farming. Although current African yields are less than half the global potential yield, root harvests of up to 40 tonnes have been obtained in on-farm trials[35]. In Nigeria, yields could reach 25 tonnes per ha and beyond with improved varieties, agronomic practices and crop management.

Rwanda plans to boost its cassava output in 2017 from the current 2.5 million tonnes to as much as 6.1 million tonnes, by disseminating higher-yielding varieties, training farmers in improved crop management, and encouraging increased use of mineral fertilizer, pesticide and irrigation[16]. Supported by international donors, other African countries – including Ghana and the Democratic Republic of the Congo – have made similar plans for the commercialization of cassava, in line with the African Union's Pan-Africa Cassava Initiative, which has identified *Manihot esculenta* as a key agricultural commodity, food security crop and "poverty fighter"[36].

The future of cassava is likely to see, therefore, a shift to increased monocropping on larger fields, the widespread adoption of higher-yielding genotypes that are more suited to industrialization, and higher rates of use of irrigation and agrochemicals.

In promoting programmes for intensified cassava production, policymakers should consider the lessons of the Green Revolution. Based on genetically uniform crop varieties and intensive use of tillage, irrigation, mineral fertilizer and pesticide, the Green Revolution model of agriculture produced a quantum leap in global cereal yields and average per capita food consumption. But those enormous gains in productivity were often accompanied by negative effects on agriculture's natural resource base, so serious that they jeopardize its productive potential in the future. In many countries, decades of intensive cropping have degraded fertile land and depleted groundwater, provoked pest upsurges, eroded biodiversity, and polluted air, soil and water[37].

Applying the same model to cassava production carries similar risks. A shift from traditional smallholder cassava farming systems – based on intercropping and periods of fallow to replenish soil nutrients[39] – to more intensive monocropping may simplify management and favour initially higher yields. Experience has shown, however, that it also increases the prevalence of pests and diseases, and accelerates the depletion of soil nutrient stocks[35, 38].

In southern Brazil, year-round demand for cassava for starch processing has led to continuous monocropping in the same field, overlapping planting dates, increasing use of genetically uniform varieties, and greater need for agrochemicals to maintain soil fertility and combat pests and diseases[24]. In Rwanda, higher cropping densities under intensification have created pest and disease pressure that is negatively affecting yields[16]. As warmer conditions start to favour intensive cassava production in new areas of Africa, Asia and South America, the risk of pest and disease problems is expected to increase[24].

Continuous cultivation of cassava – involving at least 10 years of production on the same piece of land with less than one year of fallow between crops – is already widespread in sub-Saharan Africa, especially in non-humid and highland zones[40]. In East Africa, agricultural landscapes have changed from traditional systems with an important fallow component to continuous cassava-based production[35].

With intensification, many of Africa's cassava growers have eliminated fallow periods altogether and are not compensating for nutrient losses by adopting soil fertility management techniques, such as cover crops and manure application. Declining levels of soil nutrients lead to falling yields, to the point where production becomes unprofitable[39].

In northeast Thailand, several years of cassava cultivation in upland areas led to a decline in soil fertility owing to erosion, tillage practices that removed soil cover, and the failure of farmers to incorporate residues in the soil[41]. In Colombia, yields of monocropped cassava dropped from 37 tonnes to 12 tonnes per ha over a period of nine years owing to soil degradation.

In Nigeria, research found that soil erosion increases when traditional mixed cropping is replaced by monoculture[42]. Moreover, traditional practices, found to be highly successful in reducing soil erosion under polyculture, are less effective when used in monoculture[42]. In trials in Viet Nam, monoculture of cassava produced yields of 19 tonnes, but resulted in severe, unsustainable soil losses to erosion of more than 100 tonnes per ha[43].

In 2010, FAO endorsed an ecosystem-based approach to crop production intensification, one that is both highly productive and environmentally sustainable[44]. Dubbed "Save and Grow", it calls for "greening" the Green Revolution through farming practices that draw on nature's contributions to crop growth, such as soil organic matter, water flow regulation, pollination and bio-control of insect pests and diseases. The key principles underpinning "Save and Grow" are:

- maintaining healthy soil to enhance crop nutrition
- cultivating a wider range of crop species and varieties in associations, rotations and sequences
- using well-adapted, high-yielding varieties and good quality seed
- efficient water management that produces more crops per drop
- preventative management of insect pests, diseases and weeds.

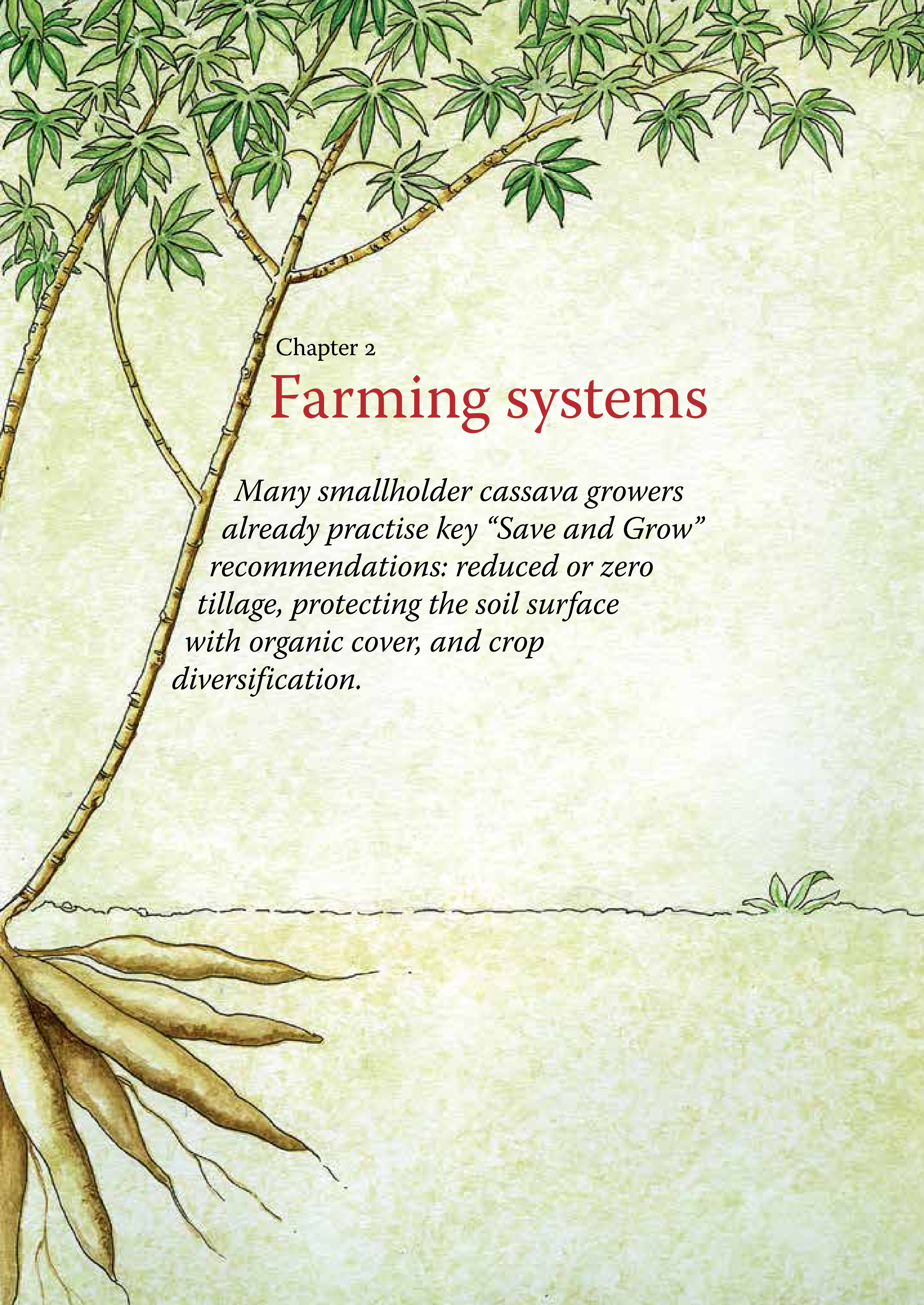
This eco-friendly model of agriculture encourages reduced or zero-tillage in order to boost yields while restoring soil health. It controls insect pests by protecting their natural enemies rather than by spraying crops indiscriminately with pesticide. It uses mineral fertilizer sparingly, in combination with organic sources of soil nutrients[37].

Supporting evidence from agricultural development projects in 57 developing countries has shown that more efficient use of water, reduced use of pesticide and improvements in soil health boost crop yields by around 80 percent[45]. Another study concluded that farming systems that conserve ecosystem services, through conservation tillage, crop diversification, legume intensification and biological pest control, perform just as well as high-input intensive systems[46, 47].

With "Save and Grow", tropical countries can avoid the risks of intensified cassava production

This guide shows how "Save and Grow" can help developing countries avoid the risks of unsustainable intensification, while realizing cassava's potential for producing higher yields, alleviating rural poverty and contributing to national economic development. It shows, for example, how growing cassava with groundnuts produces not only high root yields but also much higher income than monocropping; how a predatory wasp has been far more effective than insecticide in defeating devastating outbreaks of cassava mealybug; and how rotating cassava with beans and sorghum restored yields where mineral fertilizer alone had failed.

Chapters 2, 3, 4, 5 and 6 present a set of adoptable and adaptable ecosystem-based practices that have enhanced cassava productivity and can serve as the cornerstone of national and regional programmes. Chapter 7 explores post-harvest uses and value addition. Chapter 8 outlines policies that facilitate sustainable intensification of cassava production, and underlines the importance – when introducing new practices or technologies – of "letting farmers decide".



Chapter 2

Farming systems

Many smallholder cassava growers already practise key "Save and Grow" recommendations: reduced or zero tillage, protecting the soil surface with organic cover, and crop diversification.

In "Save and Grow", farming systems are founded on three key recommendations[1]. First, farmers should aim at protecting soil structure, soil organic matter and overall soil health by *limiting mechanical disturbance of the soil.* That means minimizing "conventional tillage", the practice of ploughing, harrowing or hoeing land before every crop and during crop growth. Instead, farmers are encouraged to practise conservation tillage, which excludes operations that invert the soil and bury crop residues. Common forms of conservation tillage are strip or minimum tillage, which disturbs only the portion of the soil that is to contain the seed row or planting hole, and zero tillage, in which ploughing or hoeing are eliminated.

Along with conservation tillage, FAO recommends *maintaining a protective organic cover on the soil surface*, i.e. using crops and mulches to reduce soil erosion, conserve soil water and nutrients, and suppress weeds. Organic soil cover not only improves soil's physical properties; it also encourages the proliferation of soil biota – including earthworms and beneficial protozoa, fungi and bacteria – that promote soil health and crop performance. In zero tillage systems, crops are planted directly through a mulch formed by the residues of previous crops or cover crops.

Third, farmers should *cultivate a wider range of plant species* in associations, sequences and rotations that may include trees, shrubs and pasture. Mixed cropping diversifies production, which helps farmers to reduce risk, respond to changes in market demand and adapt to external shocks, including climate change. Rotating or associating nutrient-demanding crops with soil-enriching legumes, and shallow-rooting crops with deep-rooting ones, maintains soil fertility and crop productivity and interrupts the transmission of crop-specific pests and diseases.

By improving levels of soil organic matter and biotic activity, reducing pest and disease pressure, reducing erosion and increasing the availability of crop water and nutrients, those three practices increase yields sustainably. They also lower production costs, mainly through savings on machinery, fossil fuel and external inputs such as irrigation, mineral fertilizer and pesticide.

To till or not to till?

Cassava needs a sufficiently loose-textured soil to facilitate initial root penetration and to allow for root thickening. It also succumbs easily to weed competition, excessive soil moisture and root rot. For those reasons, it is usually planted in soil that has been loosened and cleared of weeds by hoeing or ploughing. On degraded and unstructured soils, conventional tillage makes it easier to insert stakes in the ground and provides well-drained, aerated conditions for the root system[2, 3].

However, crop yields are a function not of tillage, but of soil conditions. Cassava stakes can also be planted, and can produce good yields, in soil that has not been tilled, provided that the soil is healthy, well structured and free of compaction[4]. Friable soils, high in organic matter, provide ideal conditions for zero-till cultivation[2]. A study of smallholder cassava production in East and West Africa found that cassava was more frequently planted on seedbeds without prior land preparation than any other staple crop, except rice. Where soils had poor physical properties, farmers planted it on manually prepared mounds or ridges[5].

Continuous conventional tillage, especially when done with heavy, tractor-mounted ploughs, harrows and rototillers, buries the soil's protective cover, kills soil biota, causes the rapid decomposition of organic matter, and degrades soil structure by pulverizing soil aggregates. Ploughing or hoeing the soil at the same depth, season after season, often leads to the formation of a hardpan, a compacted soil layer – usually found below the topsoil – that is difficult for water and roots to penetrate[6]. In such soils, some kind of mechanical loosening will be necessary for continued crop production, but at the cost of further soil degradation.

In that same soil, growing cassava without tillage may produce lower yields in the initial years. In the longer term, however, by reducing mineralization, erosion and water loss, helping to build up organic matter and maintaining soil aggregate stability and internal drainage, zero tillage promotes root functioning to the maximum possible extent. Once soil health is restored, untilled land can produce high yields and do so at a lower cost to both the farmer and the farming system's natural resource base[7-10].

Currently, land is prepared for cassava in many different ways and at different intensities. Small-scale farmers in Indonesia, Viet Nam and many African countries, or wherever land is too steep for any kind of mechanization, usually use a hoe to loosen soil in the area to be planted. Since manual land preparation is labour-intensive, many farmers prepare only the planting hole itself. While that is a form of reduced tillage, it can also result in low yields if weeds are not controlled.

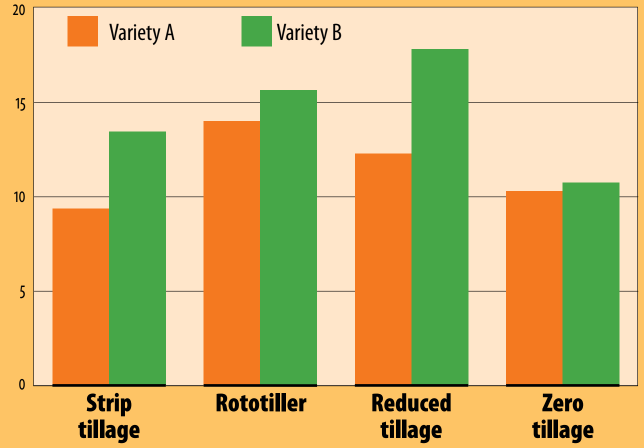
In regions where farmers cultivate larger areas of cassava, they traditionally plough the fields with oxen or water buffaloes, usually in one or two passes. In mountainous areas of Colombia, farmers use a pair of oxen pulling a simple reversible plough[11]. In Indonesia, they plough the field with oxen, and then create planting ridges by hand, using a short-handled hoe. In Kerala State, India, farmers hoe the soil, then make individual mounds for each cassava plant, a labour intensive approach requiring more than 30 days of labour per hectare.

In countries where cassava is grown intensively on larger areas, of from 2 to 5 ha, land is usually prepared by tractor using a mouldboard or disc plough, generally followed by the use of a disc harrow and sometimes a ridger. Alternatively, the soil is loosened and residues and weeds are incorporated with a rototiller. However, this method tends to pulverize the soil and can lead to serious erosion on sloping land.

Many cassava farmers in southern Brazil practise conservation tillage. They generally grow a cover crop, such as black oats (*Avena strigosa*) or wheat, during the winter months to protect the soil surface, increase soil organic matter and suppress weeds. In the spring, before the cereal crop matures, they crush it with a tractor-drawn rolling drum, or kill it with herbicides, then plant cassava stakes with a mechanized planter directly through the mulch of the crop's residues. In Paraguay, farmers practise hand-planting of cassava without tillage using black oats or leguminous shrubs as a winter cover crop[12].

Many experiments have attempted to determine the best method of land preparation for cassava and the effectiveness of conservation tillage alternatives[11, 13]. However, evidence of the effect of different tillage options on yields is not conclusive: the results of trials in Africa, Asia and Latin America vary from year to year and from place to place. On a gentle slope in Colombia, reduced tillage – involving the preparation by hoe of the planting holes only – resulted in the highest yields of one variety, while the use of a tractor-mounted rototiller

Figure 5 **Effect of tillage system on cassava root yield, Colombia** (t/ha)



Source: Annex Table 2.1

produced the highest yields of another variety (Figure 5). Both zero tillage and strip preparation with a hoe or rototiller produced significantly lower yields. But other trials in the same area – which compared zero tillage, ploughing with oxen, and strip tillage – found that zero tillage produced the highest yields as well as the lowest rates of soil erosion.

In a three-year experiment on a 25 percent slope in Hainan Province, China, the highest yields, of 26 tonnes per ha, were obtained by conventional ploughing and disking. Reduced tillage of the planting holes produced slightly lower per hectare yields, of 24.6 tonnes, while zero tillage and strip preparation produced lower yields still, of around 22.8 tonnes. However, zero and reduced tillage also resulted in the lowest rate of soil erosion, which was a major problem on the steep slopes[14].

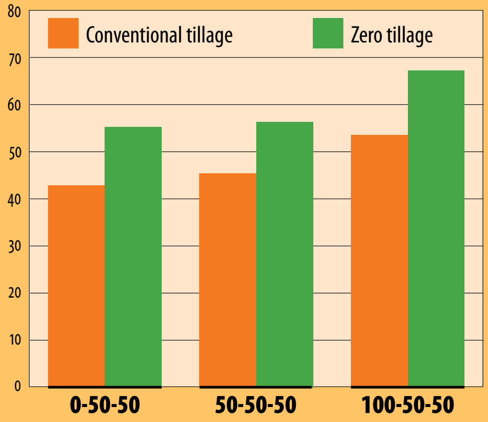
In Brazil, average cassava yields over four years of trials were 18.2 tonnes per ha on zero-tilled plots, significantly lower than the 24.7 tonnes obtained with conventional tillage[15]. However, in clay soil that had been previously planted with winter maize under zero tillage for four years, there were no significant differences between zero tillage and conventional tillage yields[16].

In a land preparation trial conducted for four consecutive years in Thailand, the standard practice – ploughing twice with a 3-disc plough followed by a 7-disc harrow – produced the highest yields, while zero tillage consistently produced the lowest yields[3]. In another Thai experiment, however, tillage did not result in significant yield differences. Using a subsoiler followed by a chisel plough, researchers obtained an average root yield of some 22 tonnes per ha, compared to 20 tonnes when the land was not tilled and weeds were controlled with herbicide[17].

Also in Thailand, with nitrogen fertilizer applied at the rate of 100 kg per ha, the fresh root yield of cassava grown under zero tillage reached 67 tonnes, significantly higher than the 53 tonnes obtained using conventional tillage (Figure 6). In the second year, average yields from the unprepared plots fell to 49 tonnes, slightly less than the conventional tillage yield that year of 54 tonnes[17].

A study in Nigeria found that yields under conventional ridge tillage were up to 46 percent higher than those obtained in untilled fields[18], although zero tillage was practised by the majority of local farmers. However, the trial beds were planted at the height of the rainy season in June, when levels of soil moisture were higher and soil temperatures lower, which delayed the emergence of plants in the zero-tilled plots and led to a substantial number of rotten stems[18]. In fact, when planted at the onset of the rainy season, in March, cassava emergence was higher under zero tillage[19]. Other trials in Cameroon and Nigeria have found that cassava yields were not affected by tillage[18, 20]; in the Democratic Republic of the Congo, yields were higher in untilled than tilled oxisols, and similar in sandy loam soil, provided the field was mulched[2].

Figure 6 **Effect of tillage system and fertilizer* on cassava root yield, Thailand** (t/ha)

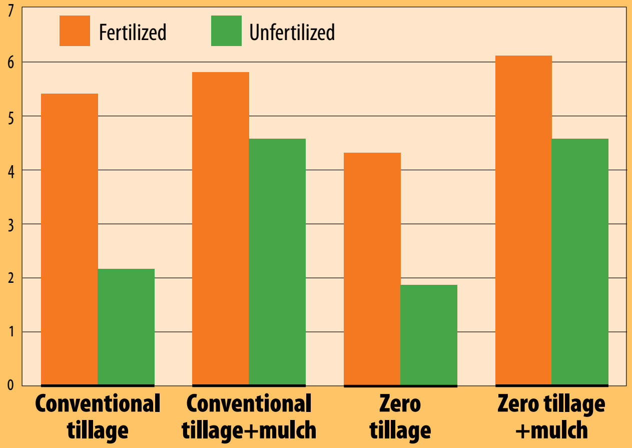


* N-P_2O_5-K_2O in kg/ha

Source: Annex Table 2.2

Finally, a recent study of an 8-year experiment in sandy loam soil in Colombia concluded that zero tillage was more effective in building up soil nutrients and conserving the soil's physical properties and, when combined with mulching of residues, produced the highest root yields, with or without mineral fertilizer (Figure 7). Weighing up the costs and benefits, the study concluded that zero tillage compared favourably with conventional tillage and, in the long term, was "an optimum system" for cassava production[21].

Figure 7 **Cassava yield response to surface plant mulch, fertilizer and tillage, Colombia** (t/ha)



Source: Annex Table 2.3

Based on the evidence presented, no single method of land preparation can be described as "best for cassava". As a general conclusion, it can be inferred that the effects of tillage on cassava yield are variable from year to year and that the benefits of zero tillage in terms of erosion control are usually positive. Research also indicates that some land preparation is necessary in areas with heavy, poorly drained soils or where soils are already badly degraded. However, even in those cases, the need for tillage can be reduced through practices that improve soil structure, organic matter content and drainage, such as mulching[2].

Cassava growers should be encouraged to adopt minimum tillage and, ideally, zero tillage, especially on well-aggregated, friable soils with an adequate level of organic matter. Since yields do not depend on tillage *per se*, but on soil health, it is also recommended that, in tillage trials, changes in soil structure and organic matter under a zero-till regime be monitored closely, as those factors are likely to have a long-term positive impact on cassava yields and are good indicators of sustainability.

Even where conservation tillage produces lower yields, it offers farmers economic advantages: reduced spending on the fuel and equipment needed for conventional tillage, and – since it reduces soil erosion, conserves soil moisture and helps maintain soil health – the opportunity to produce cassava more intensively and sustainably, without the need for high levels of external inputs[22]. Conservation tillage will also be important as an alternative to conventional tillage in cassava-growing areas affected by climate change. Where rainfall is reduced, it will help to conserve soil moisture; where rainfall increases, it will help reduce soil erosion and improve soil structure, allowing better internal drainage[23].

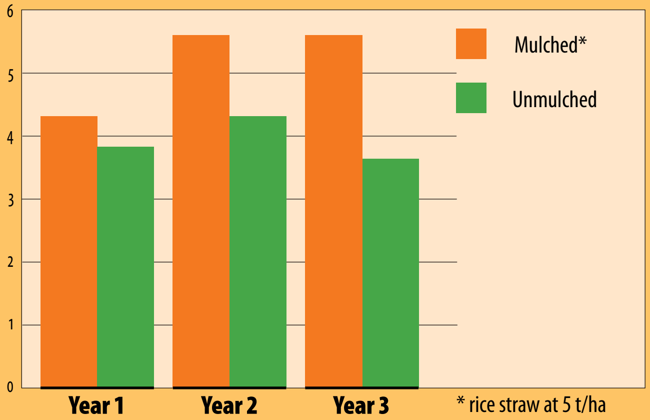
Cover crops and mulching

Maintaining a continuous ground cover is another basic "Save and Grow" practice that is also essential for reaping the full benefits of conservation tillage. Ground cover is especially important in cassava production – because the initial growth of cassava is slow, the soil is exposed to the direct impact of rain during the first 2 to 3 months of its growth cycle, and the wide spacing between planted stakes favours the emergence of weeds. To protect the soil surface, reduce runoff and erosion, and inhibit weed growth, "Save and Grow" recommendations include covering the soil surface with mulch, such as crop residues, or growing cover crops (also called "live mulch") during fallow periods or during cassava establishment. Mulching seedbeds is recommended especially when growing cassava on slopes prone to soil erosion. Cassava stakes can be planted directly through the mulch cover, with little or no land preparation[24].

Mulch cover also serves as an insulating layer that reduces diurnal temperature variations and water evaporation, even during periods of prolonged drought. It increases the soil organic matter content and provides a favourable environment for soil micro-organisms and below-ground fauna. By improving physical soil conditions – reduced soil temperatures, higher levels of moisture, increased water infiltration capacity and lower evaporation – it favours higher yields[16].

In a 3-year trial in the Democratic Republic of the Congo, the application of 5 tonnes of rice straw on late season cassava led to an increase in soil pH, organic carbon content, total nitrogen, soil-available phosphorus and soil exchangeable cations. Mulched cassava plants produced more and bigger storage roots than unmulched plants, and the dry storage root yield increased each year, from an average of 4.3 tonnes to 5.6 tonnes per ha, irrespective of the cultivar used. In the first, second and third year, yields were 17 percent, 28 percent and 58 percent higher, respectively, than those of unmulched cassava (Figure 8)[25].

Figure 8 **Effect of mulching on dry root yield of late season cassava, Democratic Republic of the Congo** (t/ha)



* rice straw at 5 t/ha

Source: Annex Table 2.4

Growing cover crops between cassava cropping cycles is regarded mainly as a soil improvement practice (see Chapter 5, *Crop nutrition*). However, it can also help reduce weed infestations. Fast-growing legumes smother many unwanted weeds that normally proliferate during cassava establishment and after the cassava harvest, thus providing weed control that is less labour-intensive than manual weeding and less expensive than spraying with herbicides (see also Chapter 6, *Pests and diseases*).

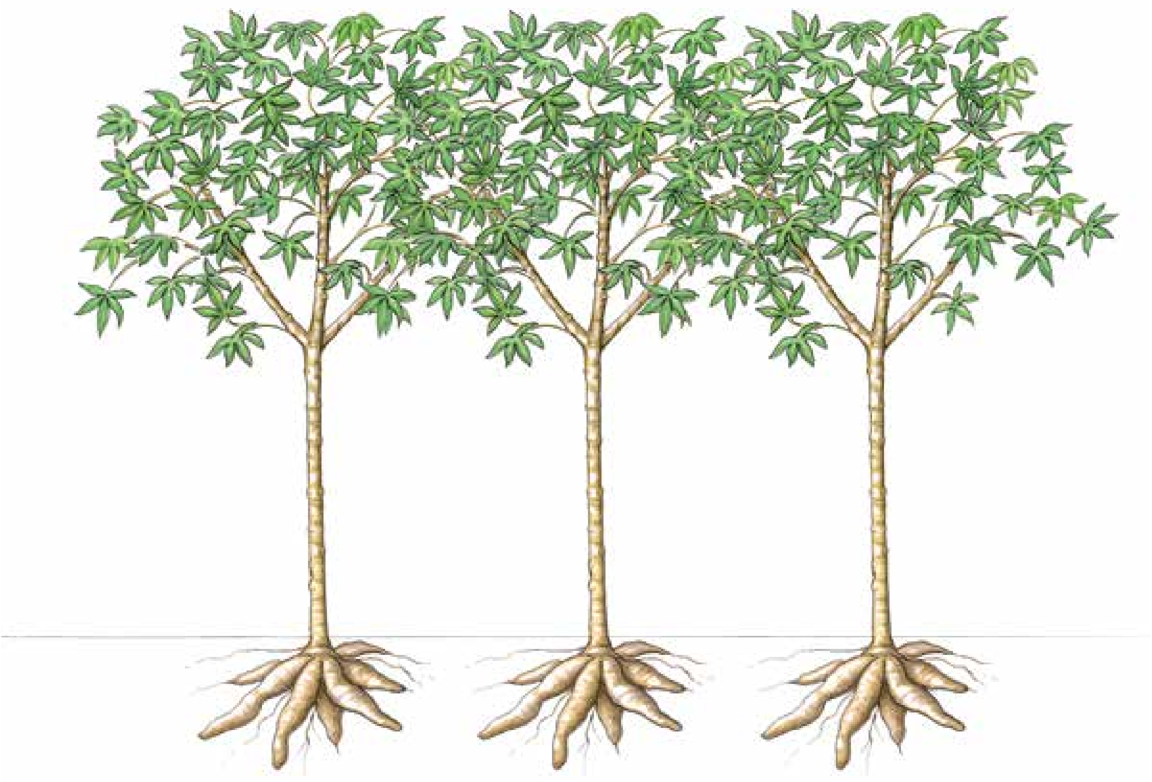
Trials have found that while perennial legumes are more effective for soil protection than commonly intercropped grain legumes, such as beans and cowpeas, highly productive perennials, such as stylo (*Stylosanthes guianensis*) competed strongly with cassava for nutrients and reduced root yields considerably. However, with less aggressive legumes, such as pintoi groundnuts (*Arachis pintoi*), the yield loss was less serious[26].

Mixed cropping

Although cassava is widely grown as a monocrop in Thailand and southern Brazil, intercropping is practised by smallholder cassava farmers in many parts of the tropics. Subsistence growers, or those with very limited areas of land, generally plant the space between cassava rows with early maturing crops, such as maize, upland rice and various types of grain legumes, including common beans, cowpeas, mungbeans and groundnuts. The practice has many benefits – it protects the soil from the direct impact of rain, reduces soil erosion from runoff, and limits weed growth during the early stages of cassava development.

Intercropping also produces crops that can be harvested at different times during the year, increases total net income per unit area of land, and reduces the risk of total crop failure. In south-western Nigeria, for example, maize and cassava are often planted in the first of two annual rainy seasons; the maize is harvested during a short break in the rains, after which the cassava continues alone. Since the two crops have different pest and disease complexes and growth requirements, one may survive even if the other fails. Some farmers even plant a second maize crop – cassava is less risky and the maize, if it succeeds, provides a bonus[27].

When grown as a monocrop, cassava is usually planted with spacing of 1 m, making 10 000 plants per hectare



Growing cassava with short-duration grain legumes has an added advantage: it supplies both carbohydrates and protein, which provide the foundation of a healthy diet for the farming household. It has been estimated that one hectare of cassava intercropped with black common beans (*Phaseolus* spp.) can produce around 10 tonnes of fresh cassava roots with 30 percent starch and 600 kg of beans with 28 percent protein – enough to meet the annual requirements of five adults and leaving a surplus of about 6 tonnes of cassava for use as animal feed or for sale[2].

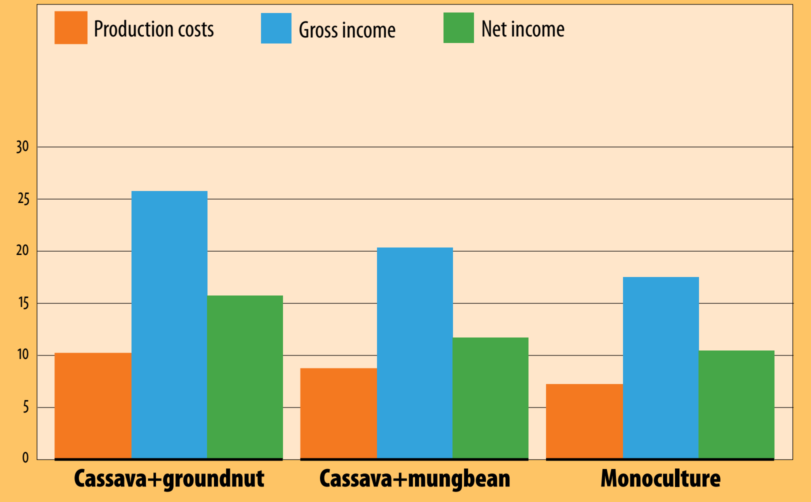
In many parts of Africa, cassava is grown with a wide range of other crops, either in a regular pattern or an irregular mixture of various crops that are continuously harvested and replanted as space becomes available. In West Africa, farmers often plant from 5 to 10 cassava stakes along the edge of large mounds, and plant crops such as maize, beans and melons in the middle of the mounds.

In Indonesia, upland rice is grown between the cassava rows, while maize is grown between the cassava plants in the rows themselves. Once the rice and maize are harvested, at about four months after planting, the inter-row space is replanted with grain legumes, such as soybeans and groundnuts. In some areas, the long rainy season allows the planting of a fourth intercrop, such as mungbeans, after the grain legumes have been harvested. That very intensive intercropping allows the production of up to five crops a year on a very small area of land.

Trials in Viet Nam showed that cassava intercropped with groundnuts (*Arachis hypogaea*) produced not only high root yields, of 30.7 tonnes per ha, but also much higher income than monocropping

In Indonesia, farmers plant cassava along with faster growing crops, such as maize and rice. After the cereal harvest, they plant groundnuts

Figure 9 **Production costs and income of three intercropping trials with cassava, Viet Nam** (million dong)



Source: Annex Table 2.5

(Figure 9). At 32 tonnes per ha, monoculture yields were slightly better than those of the cassava/groundnut system and production costs were almost 30 percent lower. However, the high commercial value of the groundnut yield, of 1.5 tonnes per ha, resulted in a total net income 50 percent higher than that of the monoculture.

In the Democratic Republic of the Congo, planting cassava with spacing of 2 m between rows and 0.5 m within the row (instead of the usual 1 m x 1 m) allowed for two successive legume intercrops, of groundnuts and climbing beans. The crop arrangement did not affect the cassava root yield, and the extra income generated from legume sales amounted to almost US$1 000 per ha[28]. In India, intercropping with banana produced higher cassava root yields, while the highest net return was obtained by combining cassava with french beans or cowpeas[29].

In northeast Thailand, dairy farmers have developed a "food-feed" system of cassava intercropped with cowpeas. The cowpea crop produces up to 2.4 tonnes of fodder per ha, which is fed along with dried cassava leaves to their cows. While the system produces generally lower root yields, compared with monocropping, researchers found that it increased land use efficiency and resulted in higher economic returns[30].

Intercropping requires careful selection of the crops – and the most suitable varieties of each crop – to be planted, careful timing of planting, good fertilization, and optimum plant densities and distribution. In Nigeria, the success of maize/cassava combinations depends on the time and the rate of recovery of the cassava after the maize harvest. Research found that cassava root yields dropped from 31.6 tonnes per ha to less than 20 tonnes with high densities of maize planting and maize yields that exceeded 3.5 tonnes[27]. In trials in Thailand, planting cowpeas (*Vigna unguiculata*) and sword beans (*Canavalia gladiata*) at the same time as cassava, over a period of four years, resulted in lower yields than when cassava was grown alone. However, moving the planting date three weeks after that of cassava reduced competition during cassava's early growth stages, which allowed it to establish better and produce root yields exceeding those of the monocrop[31].

The effectiveness of intercrops in reducing soil erosion depends on whether they have been able to produce enough foliage in time to protect the soil surface from rainfall. That may explain why experience with intercropping as a means of soil erosion control is mixed. Intercropping with groundnuts, pumpkins, squash or sweet corn was judged not very effective in Thailand, but growing cassava along with maize in Viet Nam and with mungbeans in Thailand was "quite effective"[32].

More consistent results in reducing soil erosion have been achieved by planting cassava with protective hedgerows, or "live barriers", a low-cost alternative to engineered soil conservation options such as contour bunds or bench terraces[33]. Hedgerows filter and slow the rate of runoff and can be created using various recommended grasses, perennial legumes and other plants, or established naturally from native grasses and other species left as unhoed or unploughed strips in the field[2, 34]. Farmers in several Asian countries protect their fields with hedgerows of vetiver grass (*Vetiveria zizanioides*), the shrub *Tephrosia candida*, the grass *Paspalum atratum* and closely-spaced pineapple. Vetiver grass, especially, is recommended for reducing severe erosion of already degraded land.

An added advantage of planting hedgerows is that, when pruned regularly, they provide *in situ* mulch, which makes these systems particularly effective in reducing erosion and less laborious than carrying mulch from elsewhere. Pineapples can be harvested and sold, while paspalum and other grasses can be cut and fed to cattle and buffaloes.

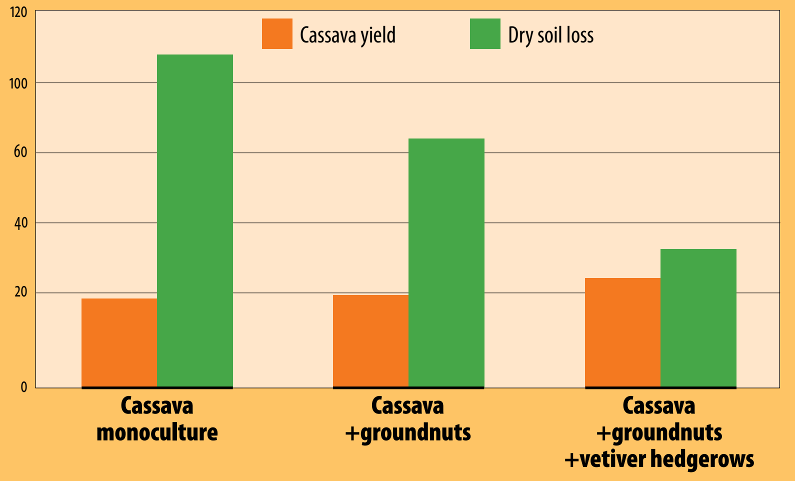
In trials in Viet Nam, monoculture of cassava without hedgerows produced yields of 19 tonnes per ha, but resulted in severe soil losses of more than 100 tonnes per ha. Intercropped with groundnuts, cassava root yields were slightly higher and soil losses fell to 65 tonnes, a big improvement but unsustainable in the long term. Cassava grown with groundnuts and vetiver hedgerows recorded the highest root yields, of 23.7 tonnes, the lowest soil losses, of 32 tonnes, and the highest net income of all the treatments tested (Figure 10).

In Thailand, intercropping cassava with cowpea (above) results in generally lower root yields, but enough cattle fodder to produce higher net income

Another type of intercropping is agroforestry, in which trees and perennial shrubs are grown along with crops. In India, cassava is grown under mature coconut palms and rubber trees[35]. Cassava may also be planted in alleyways between rows of deep-rooting and fast-growing leguminous trees, such as *Leucaena leucocephala* and *Gliricidia sepium*. The foliage is cut back regularly and the prunings are either incorporated into the soil of the alleys or – in a zero-till system – applied as mulch before the cassava is planted.

Since the trees fix large amounts of atmospheric nitrogen and their roots draw nutrients from deeper soil layers, the decomposition of prunings fertilizes the alley soil and boosts the yield of alley crops. In dryer climates, trees are deeper-rooting and thus compete less for water and nutrients than other intercrops. In agroforestry systems with cassava, leaf cuttings from the forage legume *Flemingia macrophylla* were found to have a particularly positive effect on root yield[36]. In Benin, a combination of mineral fertilizer and the application of 3 tonnes per ha of pigeon pea (*Cajanus cajan*) mulch led to significant root yield increases[37].

Figure 10 **Yield and dry soil loss in response to crop management treatments, Viet Nam** (t/ha)

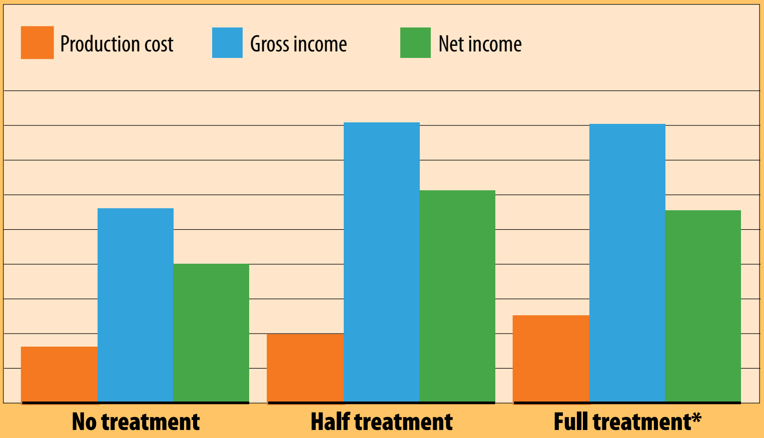


Source: Annex Table 2.6

While cassava is rarely rotated with cereals in cassava-growing areas with poor soils and unpredictable rainfall, it is a common practice in cereal-growing areas in parts of Africa, where cassava's ample litter falls and post-harvest residues are used by farmers to maintain soil fertility. Maize yields benefit substantially from the nitrogen released by the decomposition of green, leafy cassava biomass[38].

In marginal areas where cassava is the main crop, it can be rotated with grain legumes, such as beans, groundnuts, mungbeans, cowpeas and soybeans, which fix atmospheric nitrogen and make it available to the successive cassava crop. In India, sequential cropping of cassava and cowpeas improved soil fertility to the point where applications of manure and mineral fertilizer could be reduced by 50 percent, with no yield loss. Thanks to savings on external inputs, income from the cowpea-cassava sequential cropping system exceeded that of production using full fertilizer treatments (Figure 11)[39].

Figure 11 **Cost and benefit of sequential cropping with cassava and cowpea, India** ('000 Rs/ha)

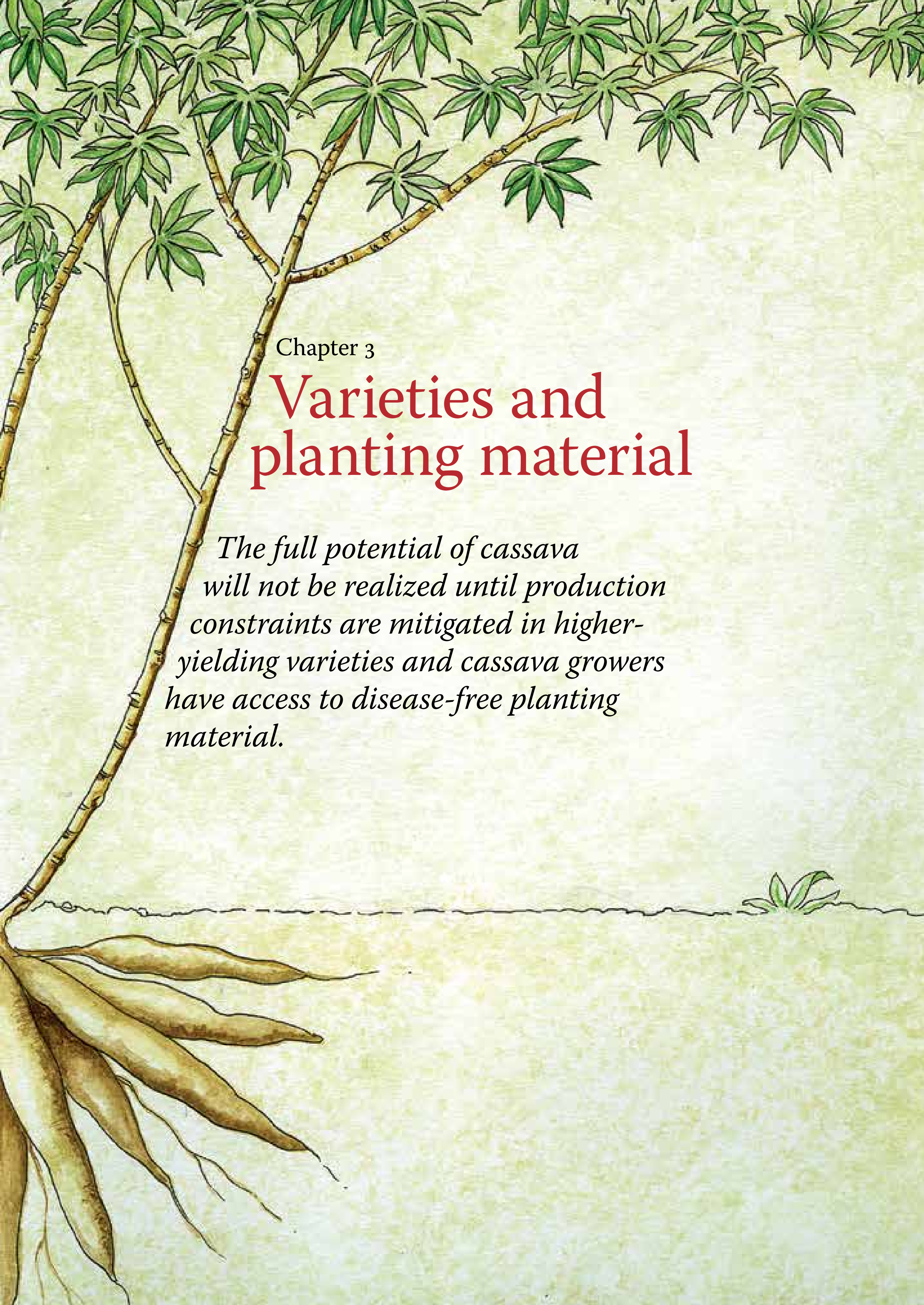


* Full treatment= 26 kg/ha P + 25 tonnes/ha farmyard manure

Source: Annex Table 2.7

A study in Colombia found that yields of monocropped, unfertilized cassava dropped from 37 tonnes to 12 tonnes per ha over a period of nine years. While moderate use, thereafter, of fertilizer had no positive effect on productivity, a rotational scheme – using sunn hemp (*Crotalaria juncea*), maize, cassava, common beans, sorghum and cassava again – restored yields to 30 tonnes. Researchers concluded that soil nutrients were not deficient, but that the cassava had been unable to make use of them owing to biological soil degradation following years of continuous cassava production[40]. In Thailand, a long-term experiment showed that rotating cassava yearly with groundnuts, followed by pigeon peas in the same year, contributed to a steady increase in cassava root yields, while yields under continuous cassava monocropping tended to decrease[31].

Many smallholder cassava production systems already incorporate, to varying degrees, the three key "Save and Grow" practices of minimizing soil disturbance, using organic soil cover and improving system resilience through crop diversification and cropping sequences. Those practices provide the foundation for sustainable intensification of cassava production. However, they need to be supported by four additional "Save and Grow" practices: the use of well-adapted, high-yielding varieties and good quality planting material; efficient management of water resources; enhanced crop nutrition based on judicious use of mineral fertilizer combined with organic manures; and integrated management of insect pests, diseases and weeds. Those practices are described in the following chapters.



Chapter 3

Varieties and planting material

The full potential of cassava will not be realized until production constraints are mitigated in higher-yielding varieties and cassava growers have access to disease-free planting material.

Farming systems based on “Save and Grow” will use crops and varieties that are better adapted to ecologically based production than those bred for high-input agriculture. More limited use of external inputs will require plants that are more productive, use nutrients and water more efficiently, have greater resistance to insect pests and diseases, and are more tolerant to drought, flood, frost and higher temperatures.

Varieties will need to be adapted to less favoured areas and production systems, produce food with higher nutritional value and desirable organoleptic properties, and help improve the provision of ecosystem services. Sustainable intensification will also require adaptation to climate change – greater genetic diversity will improve adaptability, while increased resistance to biotic and abiotic stresses will improve the resilience of cropping systems.

Farmers will need the means and opportunity to deploy those materials in their production systems. That is why the management of plant genetic resources, development of crops and varieties, and the timely distribution of high quality seed are essential contributions to sustainable intensification[1].

Among the world’s major staple food crops, cassava is well-known for its ability to produce reasonable yields on poor soils, in areas with low or erratic rainfall, and without agrochemicals and other external inputs. Those “hardy” traits have made cassava highly suitable for low-input, small-scale agriculture, while its inherent potentials have placed it among the crops most suitable for resource-poor farming in the tropics and neotropics under 21st century climate change scenarios.

However, cassava’s full potential will not be realized until some critical production constraints are mitigated in higher-yielding, well-adapted varieties. For example, cassava is susceptible to waterlogging, to low temperatures at high elevations, and to a wide spectrum of mutable pests and diseases that can seriously affect yields. Climate change models indicate that it will be affected more by biotic constraints than drought and high temperatures[2].

With the growing importance worldwide of cassava as a source of food, animal feed and industrial feedstock, there is increasing demand for cultivars with specific characteristics and adaptation to different ecologies. Niche varieties need to be developed and deployed to cater to increasingly diverse and competing end uses. In Africa, new varieties will be needed as cultivation expands into dry savannah, semi-arid and subtropical zones and the shift towards market-oriented production accelerates[3].

The system that will provide high-yielding and adapted cassava varieties to smallholders has three parts: genetic resources conservation and distribution, variety development, and the production and delivery to farmers of high quality, healthy planting material.

Conserving the cassava genepool

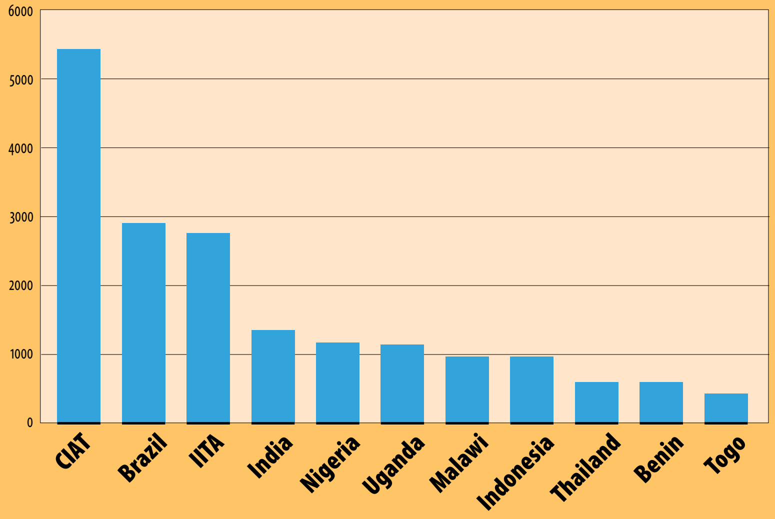
The genus *Manihot* consists of the cultivated species, *Manihot esculenta*, and – depending on the taxonomic classification used – from 70 to 100 wild species[4]. Both wild relatives and traditional cultivars, or landraces, developed by farmers over centuries are the primary sources of genes and gene combinations for new varieties[4].

In the early 1970s, CIAT launched a major initiative to collect and conserve cassava landraces. Today, CIAT's collection at Cali, in Colombia, is the world's largest, containing about 5 500 landrace accessions. The collection is maintained in a tissue culture laboratory, and a back-up *in vitro* collection is held at the International Potato Center in Lima. CIAT has created a "core collection" of about 630 accessions that represents the wide genetic diversity found in the main collection and is used for intensive characterization and genetic analysis. A duplicate of the core collection is maintained in Thailand, both *in vitro* and in the field.

The International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria, also has an important cassava genebank of some 2 800 accessions, collected mainly in West Africa. The largest national collection, of 2 900 accessions, is held by the Brazilian Agricultural Research Corporation. Other major collections, totalling 7 200 accessions, are held by Benin, India, Indonesia, Malawi, Nigeria, Thailand, Togo and Uganda (Figure 12). Most other cassava-growing countries have established a genebank of local landraces and improved varieties, although little documentation is available on many national collections[4].

Over the past two decades, biotechnologists and molecular breeders have used genebank accessions to determine which genes control specific traits, and in 1997 the first genetic map of cassava was announced[5]. With the decreasing cost of molecular biology and biotechnology, the time is right to begin the genome-wide characterization

Figure 12 **Major collections of cassava germplasm** (number of accessions)



Source: Annex Table 3.1

of cassava genetic diversity and to fill gaps in germplasm collections before valuable diversity is lost[6].

Further collection of landraces needs to be carried out as farmers abandon their traditional cultivars for improved varieties. For example, CIAT's genebank has limited representation from Central America and no accessions from Suriname or French Guiana[6]. According to FAO's *Second report on the state of the world's plant genetic resources for food and agriculture*, priority countries for collecting in the Americas are the Plurinational State of Bolivia, Brazil, Colombia, Haiti, Nicaragua, Peru and the Bolivarian Republic of Venezuela; in Africa, collecting needs to focus on the Democratic Republic of the Congo, Mozambique, Uganda and the United Republic of Tanzania. Strategies for on-farm conservation and management of landraces also need to be developed to complement *ex situ* conservation[4].

Wild relatives of cultivated cassava could make an important contribution to the development of varieties suitable for sustainable intensification under low-input regimes. However, wild *Manihot* species have been poorly collected and poorly characterized and evaluated, and many populations are threatened in their native habitats[6]. Land clearing in Brazil has been most extensive in areas that are the natural habitats of seven wild *Manihot* species which could be a valuable resource for future breeding of cassava for semi-arid environments. Deforestation of the Amazon Basin threatens forest species of *Manihot*, and urbanization and agricultural expansion are reducing the habitats of wild relatives native to Mesoamerica. Action is urgently needed, therefore, to realize long-standing proposals to create *in situ* reserves for wild *Manihot*[4].

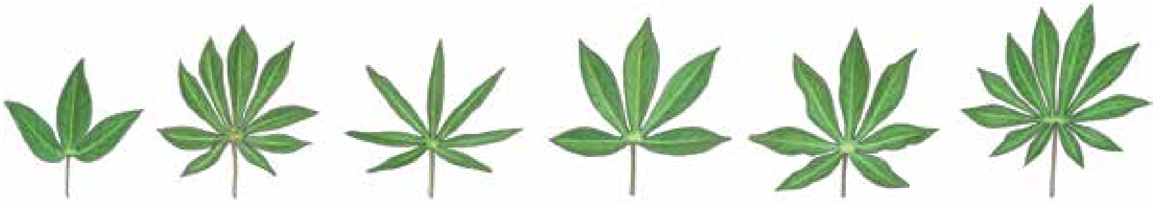
The harmonization of passport and evaluation data on genebank accessions should also be a priority. Molecular biology tools, underpinned by robust information technology, would contribute to more efficient data generation and dissemination, and facilitate global genotyping of cassava accessions. Data should be made publicly available through searchable databases in order to facilitate the acquisition of germplasm that could be used to augment locally available heritable variations for the genetic improvement of the crop.

That is a major undertaking, and will require the active collaboration of CIAT, IITA, national programmes – particularly in the main producing countries and the crop's centres of genetic diversity – and the advanced laboratories that work on cassava. Through multilateral mechanisms, especially the International Treaty on Plant Genetic Resources for Food and Agriculture, FAO can provide a much-needed neutral platform for synergistic cooperation.

Breeding improved varieties

Early introductions of cassava from Latin America to Africa and Asia represented a narrow genetic base, which limited the diversity available to farmers for selection of new varieties. In Thailand, for example, a single clone – Rayong 1 – was grown on 90 percent of the entire cassava-cultivated area until the 1990s[7]. The availability of superior varieties with combinations of many useful traits has improved remarkably in recent decades, as researchers at CIAT, IITA and several national breeding programmes have exploited the wide genetic diversity available in genebanks.

The breeding and distribution of higher-yielding varieties with resistance or tolerance to biotic and abiotic stresses have contributed to substantial increases in cassava yields and to overall production – especially in Asia – over the past 30 years. It is estimated that improved



Cassava plants have 3 to 11 smooth or winding leaf lobes, arranged spirally around the stem

varieties are planted on 55 percent of Asia's total cassava farming area. In Africa, the rate of adoption is lower, and in fact yields there are also much lower. In order to close the yield gap, therefore, the dissemination and adoption of improved varieties need to be promoted worldwide.

Higher yield and improved root quality are the most common breeding objectives, but others also receive breeders' attention, including resistance to insect pests and diseases, and tolerance to drought, waterlogging, low and high temperatures, high soil acidity and low soil phosphorus[8-11]. While some genebank accessions have been released directly as new varieties, most are used in crossing programmes to produce new varieties that combine high yield potential with other beneficial traits.

The CIAT breeding programme has released clones with better resistance to cassava bacterial blight, super-elongation disease, white flies and thrips, and tolerance to root rot caused by *Phytophthora* water moulds. It has also developed cold-tolerant varieties that produce well in areas up to 1 800 m above sea level, such as the tropical Andes and the East African highlands, and works with national programmes to develop varieties adapted to the seasonally cool subtropics of China, Brazil and Paraguay.

More than half a million sexual seeds produced by CIAT have been distributed to national breeding programmes in Asia, which use them to make selections or to cross the best selections with their own promising lines. At least 50 improved varieties containing some Latin American germplasm supplied by CIAT have been released in Asia.

Cassava roots are conical, cylindrical or irregular, and coloured cream, yellow and light to dark brown

CIAT has also supplied India's Central Tuber Crops Research Institute with tissue culture plants of lines with high levels of resistance to the Indian and Sri Lankan cassava mosaic virus.

In four decades of work on cassava genetic improvement, IITA has produced more than 400 improved varieties with traits such as resistance to cassava mosaic disease (CMD), bacterial blight and green spider mites. The varieties have been released throughout sub-Saharan Africa, and are estimated to have doubled cassava yields in some countries. IITA's scientists identified three different sources of CMD resistance – the wild "cassava tree" (*Manihot glaziovii*), found in Brazil, and two Nigerian landraces. Some 40 varieties resistant to CMD have been released in Nigeria, 36 in the United Republic of Tanzania, 30 in the Democratic Republic of the Congo and 14 in Malawi. The disease is now considered largely under control in areas where the resistant varieties are planted.

Research at both CIAT and IITA has also focused on improving the nutritional value of cassava by increasing its vitamin A, iron and zinc content. Through breeding, scientists have been able to double the content of carotenoids, a precursor of vitamin A, in cassava roots[12]. Cassava biofortified with vitamin A has been released in several countries, including the Democratic Republic of the Congo and Nigeria.

The cassava genepool has already been extensively tapped to produce income-generating technologies for farmers worldwide[6]. Great scope exists for further improvements, as the rapid development of molecular technologies deepens our understanding of the structure and behaviour of the cassava genome, and the costs of sequencing and molecular marker development decline.

With climate change threatening crop production in many parts of the world, breeding efforts will focus increasingly on "stacking" multiple traits in elite varieties. There should also be greater focus on developing varieties for niche agro-ecologies and – since almost all breeding is done in monoculture fields – for specific intercropping systems, rather than for wide adaptation. That is because low-income smallholders living in isolated areas with suboptimal soil conditions need "smarter", locally adapted varieties that can produce very good yields with minimal use of agrochemicals or irrigation.

National programmes should be encouraged, therefore, to introduce the outputs of the pre-breeding activities of CIAT and IITA into their own breeding programmes that use landraces and other farmer-preferred genotypes as parents. Until now, the focus has been on evaluating breeding lines from the CGIAR centres for wide adaptations; that work must now be complemented by introgressing traits from locally adapted materials.

There are promising examples of cassava breeding for specific industries and uses. Scientists at CIAT have identified a cassava mutation with root starch containing zero or near-zero amylose[13], which has extremely useful applications in industry[14]. That "waxy starch" characteristic is now being incorporated into high-yielding commercial varieties by the Thai Tapioca Development Institute[15]. CIAT has also identified an induced mutation that has starch granules one-third the normal size, with a rough outer surface. The starch is expected to be useful to the fuel-ethanol industry, as it requires less time and energy to convert the starch into sugar, the first stage in fermentation for ethanol production[16].

Other on-going work at CIAT and partner organizations include the routine application of molecular tools in cassava genetic improvement. For instance, a number of molecular markers for tracing the inheritance of resistance to whiteflies, green mites and bacterial blight are at varying stages of validation.

Molecular markers associated with a specific gene for resistance to cassava mosaic disease are being used to select for resistance to this devastating disease. High-yielding, locally adapted cassava varieties resistant to CMD have been developed by CIAT as a precautionary measure against the real possibility of the virus's appearing on the American continent. The use of molecular markers is also making the trans-continental transfer of cassava germplasm possible. Latin American cassava genotypes have been successfully introduced into African cassava breeding programmes as the markers provided an efficient means for deploying only those genotypes with resistance to CMD.

Following the first demonstration of successful genetic transformation in cassava in 1996, a number of transgenic genotypes with improved resistance to viruses and abiotic stress, reduced levels of cyanogenic glycoside content, better nutritional qualities and modified starch yield and characteristics have been developed[17]. Initially, the capacity for developing cassava transgenes was restricted to a few advanced laboratories in the United States of America and Europe. However, cassava can now be genetically transformed in a number of laboratories in Asia and Africa as well. The wide applicability of this potentially useful means of producing “designer varieties” with novel traits is enhanced by the continued development of genotype-independent protocols for genetic transformation in cassava.

While there are a few cases of controlled trials of transgenic cassava genotypes, none has been officially released anywhere in the world. In addition to the technical challenges, intellectual property rights and biosafety issues will need to be addressed before genetic transformation can become a method of choice for cassava improvement. Recognizing those constraints, CIAT is investigating the production of non-transgenic herbicide-resistant varieties that would reduce the labour cost of weeding, which currently accounts for 20 to 40 percent of production costs, and could greatly facilitate the adoption of reduced-tillage practices[6].

Farmer participation in variety trials and the choice of selection criteria (known as participatory plant breeding, or PPB), needs to become a key step in the development of new varieties. Farmers’ criteria must inform all stages of selection, and trials in farmers’ fields should begin as early as possible in the selection process. National programmes should incorporate PPB principles into the development and deployment of improved cassava varieties, especially with the increasing demand for niche cultivars suited to particular environments, cropping systems or end-uses. Agricultural extension services in many countries will need to be substantially upgraded to ensure that smallholder farmers reap the full benefits of improved cassava varieties.

Planting material

The use of high quality planting materials that maintain genetic purity and are free of diseases and pathogens is crucial in cassava production. With vegetatively propagated crops, diseases and pests can build up over several generations of propagation, a problem that is negligible with botanic seeds. In addition, cassava stem cuttings are perishable, bulky and cumbersome to transport, and require considerable storage space. As cassava under subsistence agriculture is typically harvested piecemeal over a period of one year or more, storage of stakes until the next planting is logistically challenging.

As a result, many farmers do not save cassava stems for planting and frequently source cuttings from neighbours or in local markets; under such conditions, assuring the quality of planting material is practically impossible.

Effective systems for routine multiplication and distribution of disease-free planting material of improved varieties is essential for sustainable intensification. Among major cassava producers, Thailand has been the most successful in disseminating improved varieties to its cassava farmers. In 1994, the Thai Government established a special programme for the rapid multiplication and distribution of new varieties with high yield potential, high harvest index, high root starch content and early harvestability. The programme involved the country's Department of Agriculture and Kasetsart University's Faculty of Agriculture, which supplied the basic planting material, and the Department of Agricultural Extension and the Thai Tapioca Development Institute, which multiplied and distributed it. By 2000, almost 90 percent of Thailand's cassava area was planted to the recommended cultivars, compared to less than 10 percent a decade earlier[7, 18].

Although several protocols have been developed for the rapid multiplication of cassava, and could be scaled up for the dedicated production of material that meets quality standards[19], very few countries have a formal seed system for cassava multiplication. Efforts to involve the private sector have made little progress, owing mainly to the plant's low multiplication rate, compared to that of cereals – while one cassava stake can produce in a year enough stems for 10 new stakes, a maize seed can yield 300 new seeds three months after planting.

Stakes cut from healthy stems free of pests and diseases have a higher rate of sprouting and produce higher root yields

In India, the indiscriminate use of infected planting material, the non-availability of resistant varieties and the lack of commercial interest in supplying healthy planting material have resulted in the widespread incidence of cassava mosaic disease. The country's Central Tuber Crops Research Institute has developed procedures for multiplying virus-free cassava meristems *in vitro*. However, no private firms have adopted the technology in order to supply farmers with virus-free cassava plants on a large scale, as they have done for other high-value horticultural crops, such as banana and potatoes[20].

To increase the efficiency of cassava stem production, IITA and Nigeria's National Root Crops Research Institute have developed a rapid multiplication technology, which involves cutting cassava stems into stakes with 2 or 3 nodes, rather than the usual 5 to 7. With efficient field management, cassava stems can be harvested twice a year, at 6 and 12 months after planting, yielding around 50 times more stems than were used for planting[21]. A study in 2010 found that one-third of cassava farmers in Akwa Ibom State, Nigeria, were using the technology to multiply stems of improved varieties, which they sold to other farmers; their average earnings from sales were US$750 a year[22].

In the absence of a national cassava seed system, cassava development programmes in a number of African countries have used a 3-tier community-based system of rapid multiplication to supply farmers with improved, healthy planting material[23]. At the top level, material from breeders is multiplied under optimal agronomic conditions on research stations and government farms to produce disease-free foundation seed. The secondary level involves further multiplication on 2 ha farms often run by farmer groups, community organizations and NGOs. Certified material is then distributed to tertiary multiplication sites, which are the main and most readily accessible source of stems[24]. In several countries, the approach includes the distribution of "seed vouchers", which allow low-income farmers to buy stems at subsidized prices.

It is estimated that more than 300 000 households in western Kenya and 80 percent of small-scale cassava farmers in Uganda are growing improved varieties multiplied and distributed through the system[23]. The African Technology Uptake and Up-scaling Support Initiative (TUUSI) has called on the region's policymakers to promote the 3-tier approach more widely and to encourage the formal seed sector to become involved in the certification, multiplication and distribution of high quality planting material. TUUSI also recommends the participation of NGOs and farmer associations as the best means of ensuring that research outputs are adopted by the largest number of cassava growers[23].

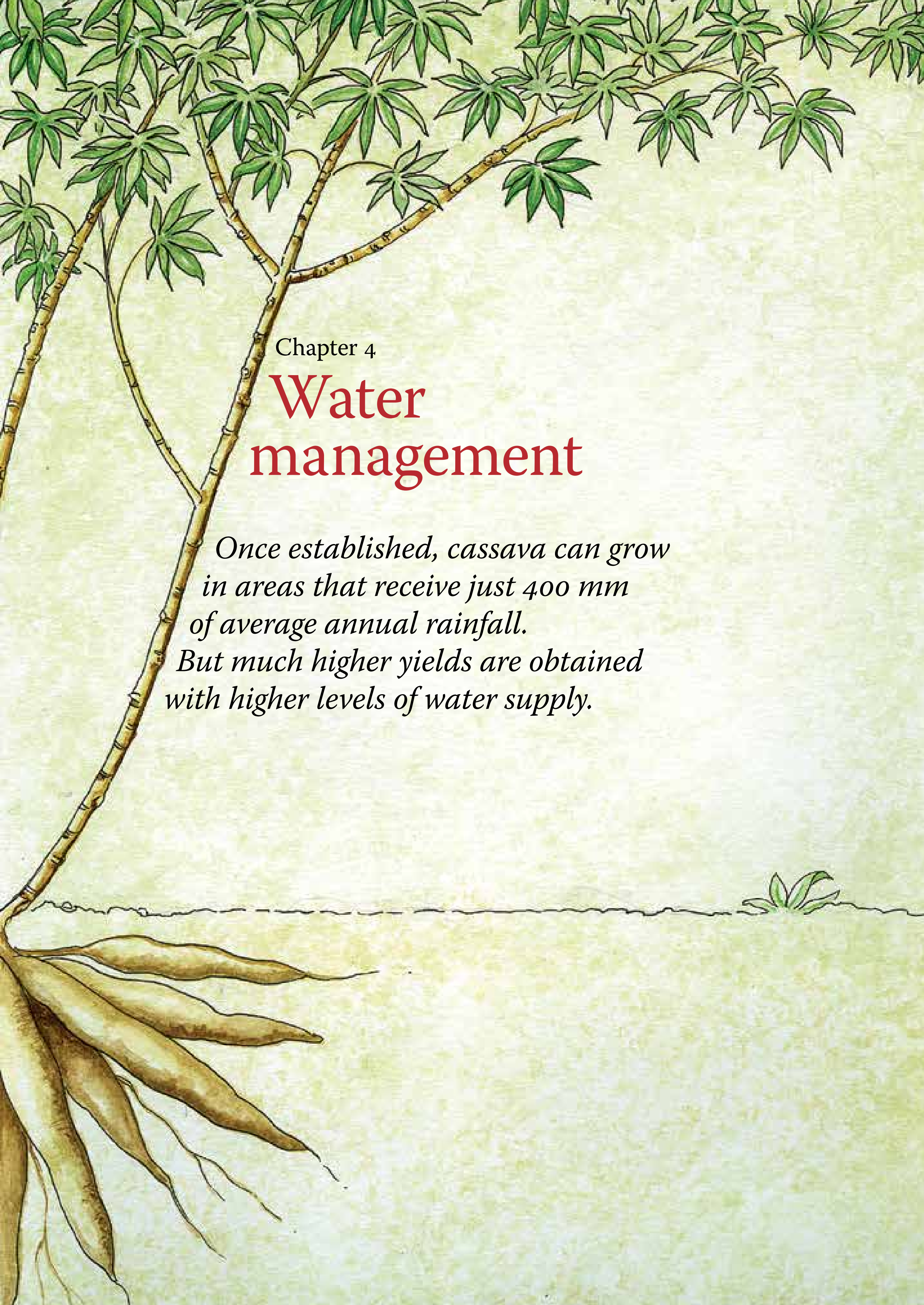
A high level of grassroots participation in multiplication was achieved by the Great Lakes Cassava Initiative, managed by Catholic Relief Services and supported by the Bill & Melinda Gates Foundation. Implemented in six countries of East and Central Africa, the initiative involved 10 agricultural research institutes, 53 local NGOs and some 3 000 farmer groups. It established a network of 6 500 small multiplication plots, averaging 0.3 ha, each serving around 350 local farmers, and helped disseminate a total of 33.6 million stems. The initiative also put in place a low-cost quality management protocol, based on visual assessment, to evaluate varietal purity and score for pests and diseases[25].

The use of poor-quality planting material will remain one of the major causes of low cassava yields, especially in Latin America and Africa, for some time to come. In the absence of efficient systems of multiplication and distribution, farmers can help to improve the situation using some simple local practices:

- *Cut stems* from vigorous plants which are 8 to 12 months old, show no symptoms of pests or diseases, are growing in fertile soil, and produce high root yields. The long, straight primary stems of late-branching varieties are the most suitable.
- *Store cut stems* in an upright position in the shade, with the base of the stems resting on soil that has been loosened with a hoe and is watered regularly. Stems that have been stored for no more than 5 days before being cut into stakes will sprout more quickly.
- *Cut stems into stakes* 20 cm long, each with 5 to 7 nodes, immediately prior to planting. The diameter of the stakes should be at least 3 cm, while the diameter of the pith should be less than half the diameter of the stem.
- *Before planting*, soak the stakes for 5 to 10 minutes in hot water to kill pests or disease-causing organisms that might be present. Getting the right water temperature is also simple – mix equal amounts of boiling and cold water[26].

To ensure high yields, the stakes' mother plants should have been adequately fertilized. Cassava plants grown in soil with low levels of nitrogen, phosphorus and potassium produce stakes that are also low in those nutrients, and are also low in starch, reducing sugars and total sugars. In turn, plants grown from stakes with a lower nutrient content have a lower rate of sprouting, produce fewer stems and have lower root yields (Annex table 3.2)[27].

Even within a uniformly fertilized field, some plants grow better and produce more roots than others. Farmers can increase the size of their next cassava harvest by cutting the stems to be used as planting material only from plants with high root yields. This simple practice will markedly increase production, especially when using traditional varieties that may be susceptible to pests and diseases.



Chapter 4

Water management

Once established, cassava can grow in areas that receive just 400 mm of average annual rainfall. But much higher yields are obtained with higher levels of water supply.

The sole source of water for around 80 percent of the world's farmland is rainfall. Rainfed crop production accounts for as much as 60 percent of global agricultural output and is the source of livelihoods and food security for millions of the world's poorest farmers. Irrigated agriculture, with its higher cropping intensities and higher average yields, produces up to three times more from the same unit area of land.

Both rainfed and irrigated agriculture face major challenges. As competition for increasingly scarce water resources intensifies, irrigation is under growing pressure to produce "more crops from fewer drops" and to reduce its negative environmental impacts, including soil salinization and nitrate contamination of drinking water. Greater use of water-saving precision technologies, such as drip and micro-irrigation, will make an important contribution to sustainable intensification.

Climate change poses grave risks to rainfed agricultural production. Scenarios indicate a decline of some 30 percent or more in runoff from rainfall over large areas of sub-Saharan Africa, South Asia and Latin America by 2050. As water flows become more variable and uncertain, and the incidence of droughts and floods increases, crop yields are projected to decline in many developing countries[1].

Nevertheless, a comprehensive assessment of water management in agriculture has found that the greatest potential for yield increases is in rainfed areas[2]. But realizing that potential will require implementation of key "Save and Grow" recommendations: the use of improved, drought-tolerant varieties, widespread adoption of conservation tillage, mulching and other soil improvement practices, the reversal of land degradation, and adding an irrigation component to rainfed cultivation through rainwater harvesting and supplemental irrigation[2].

Unlike most other food crops, cassava does not have a critical period during which adequate soil moisture is essential for flowering and seed production. It also has several defence mechanisms that help it to conserve water, and its roots can grow to great depths to access subsoil moisture reserves[3]. As a result, cassava can withstand relatively prolonged periods of drought[4].

However, the crop is very sensitive to soil water deficit during the first three months after planting. Stakes will only sprout and grow well when the temperature is above 15°C and the soil moisture content is at least 30 percent of field capacity[5]. Water stress at any time in that early period reduces significantly the growth of roots and shoots, which impairs subsequent development of the storage roots, even if the drought stress is alleviated later[6, 7].

Once established, cassava can grow in very dry areas – such as northeast Brazil – that receive just 400 mm of average annual rainfall[3]. In southern India, the crop's water requirement is put at from 400 to 750 mm for a 300-day production cycle. But higher yields have been obtained with much higher levels of water supply. Research in Thailand found that maximum root yields were correlated with rainfall totalling about 1 700 mm during the 4th to 11th month after planting[8].

Cassava also responds well to irrigation. In trials in Nigeria, root yields increased sixfold when the quantity of water supplied by supplementary drip irrigation matched that of the season's rainfall[9]. However, cassava is also susceptible to *excess* water – if the soil becomes water-logged, sprouting and early growth is affected and yields fall.

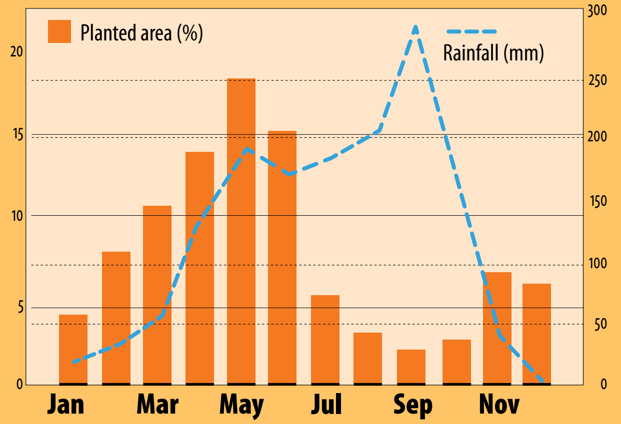
Rainfed production

In most parts of the world, cassava is almost exclusively a rainfed crop. Optimizing rainfed cassava production requires, therefore, careful attention to planting dates, the use of planting methods and planting positions that make the most of available soil moisture, and soil management practices that help to conserve water.

Cassava can be planted throughout the year if rainfall is evenly distributed, but not during periods of heavy rains or drought[10]. In areas with only one rainy season per year, farmers usually plant as soon as the rains start – generally around April-May in the northern tropics and October-November in the southern tropics. A survey in Thailand in 1975 found that almost 50 percent of the cassava crop was planted in the period April to June (Figure 13).

Once well-established, young plants will grow deeper roots as the topsoil begins to dry out with the arrival of the dry season. In Andhra Pradesh State, India, farmers plant cassava in well-watered nursery beds, before the onset of the 5-month rainy season, in order to induce sprouting and root development. When the rains start, the rooted stakes are transplanted to the field. If the early rains do not persist and some of the transplanted stakes die, they are replaced by newly sprouted stakes from the nursery beds. Using this approach, farmers can make optimum use of the short wet season without the need for irrigation.

Figure 13 **Rainfall and area of cassava planted each month in Thailand**



Source: Adapted from Sinthuprama, S. 1980. Cassava planting systems in Asia. In E.J. Weber, J.C. Toro and M. Graham (eds.). *Cassava cultural practices.* Proc. of a Workshop, held in Salvador, Bahia, Brazil. March 18-21, 1980. pp. 50-53.

In southern Nigeria, planting usually takes place between March and April, at the onset of the rainy season, although later planting – in June, at the peak of the rains, with harvesting 10 months later during the long dry season – produces higher profit margins[11]. Delaying planting beyond June in southern Nigeria can lead to drastic yield reductions, of up to 60 percent (Figure 14)[12].

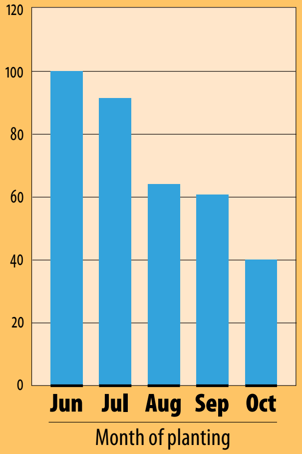
In areas with two relatively short rainy seasons per year, cassava can be planted in the early or middle part of either rainy season and harvested after 10 to 14 months, preferably during the dry season, when the root starch content is highest. In Kerala State, India, cassava is usually planted in April-May, with the start of the southwest monsoon, and in September-October, when the northeast monsoon arrives. However, some farmers plant short-duration cassava in lowland paddy fields in February, after the rice has been harvested, and the soil is still wet. The crop benefits from the remaining soil moisture during the dry months that follow, and is harvested after eight months, before the land is used again for rice.

Planting early in the rainy season will generally produce the highest yields because the plants have adequate soil moisture during the most critical part of their growth cycle. However, research has shown that yields can vary according to the variety used, the soil type, the plant's age at harvest, and the rainfall intensity and distribution during any particular year.

In Thailand, planting in June produced average root yields of almost 40 tonnes per ha, compared to 27 tonnes when planting was in September, the month with the heaviest rainfall, and 22 tonnes in October, the beginning of the dry season (Figure 15)[10].

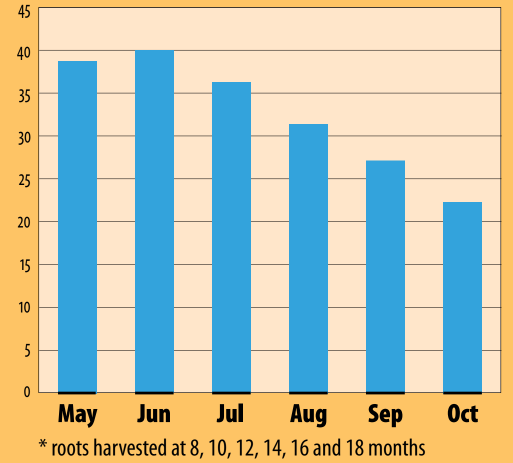
However, later research at the same location in Thailand, using four improved Rayong varieties, showed that the highest average yield was obtained by planting in August to November; planting either

Figure 14 **Effect of planting date on root yield of late season cassava, Nigeria** (%)



Source: Annex Table 4.1

Figure 15 **Effects of time of planting on average cassava root yield*, Thailand** (t/ha)



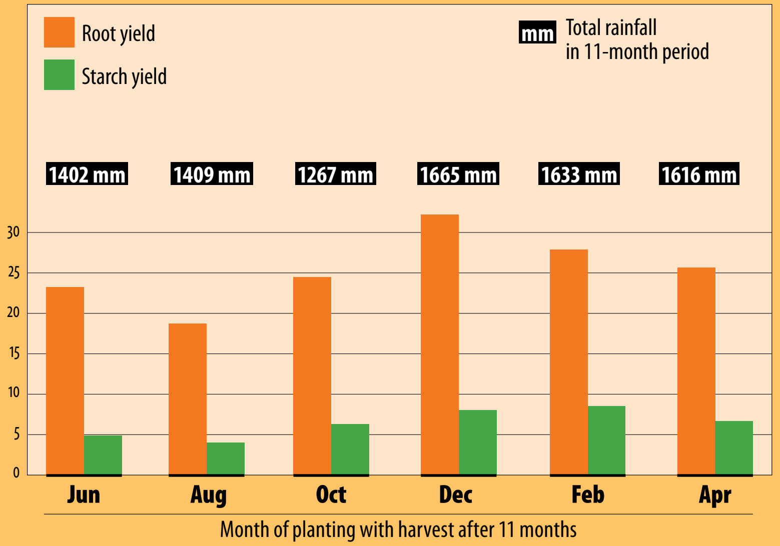
* roots harvested at 8, 10, 12, 14, 16 and 18 months

Source: Annex Table 4.2

early, in April-May, or late, in December-March, produced much lower yields. A more recent experiment conducted over three consecutive years produced a different result again. The highest root yields were obtained when cassava was planted in December, in the early dry season, and harvested after 11 months, in November (Figure 16)[8].

The explanation: in the location used for the trials, rain falls occasionally during the dry season and provides enough soil moisture to produce 90 percent of the potential plant stand. Planting even later in the dry season, in February, resulted in lower root yields but higher starch content. By plotting root yield and starch content against rainfall during specific periods of the growth cycle, it was found that root yields were best correlated with total rainfall during the 4th to 11th month (March to October), while starch content was best correlated to rainfall during the 6th to 9th month (July to October), after planting[8].

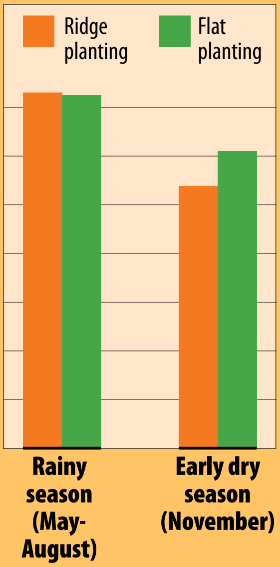
Figure 16 **Effect of different planting dates and average rainfall on cassava root and starch yield, Thailand** (t/ha)



Source: Annex Table 4.3

Planting methods need to be tailored to soil moisture conditions under rainfed production. When the soil is not well drained and too wet owing to heavy rains, it is better to plant stakes on the top of ridges or mounds to keep the roots above the standing water. That will also reduce root rots. However, where cassava is planted during dry periods in Thailand, the rates of stake sprouting and plant survival are significantly higher when cassava stakes are planted on the flat, owing mainly to the slightly higher soil moisture content in the top 30 cm of soil (Figure 17)[13].

Figure 17 **Effect of planting method on cassava plant survival in rainy and dry season, Thailand** ('000/ha)

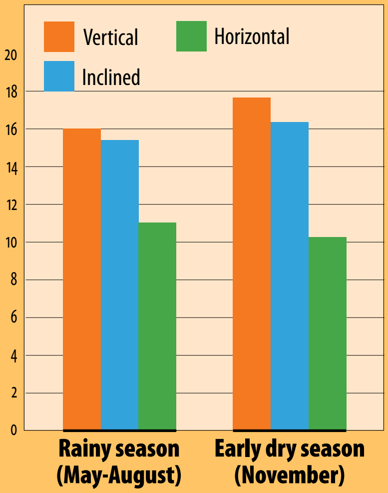


Source: Annex Table 4.4

Similarly, stakes should be planted at a shallow depth, of 5 to 10 cm, in heavy and wet soils, but slightly deeper in light-textured and dry soils to avoid surface heat and lack of moisture. In Thailand, planting stakes vertically or inclined at a 45 degree angle produced significantly higher yields and root starch contents than horizontal planting (Figure 18). The yield gap was even more pronounced when the stakes were planted early in the dry season and at shallow depths, because of hot, dry conditions close to the soil surface. With horizontal planting, sprouting was markedly delayed and the plant stand was reduced[13].

If the first rains are intense, the risk of waterlogging is greatest in shallow soils, and also in poorly drained soils where the subsoil has been compacted by heavy machinery. The risk of waterlogging can be reduced with zero tillage, which improves internal drainage (see Chapter 2, *Farming systems*). Where tillage is practised, soil should be prepared when it is not too dry or too wet – which reduces the number of ploughing and harrowing passes required – and, if necessary, a subsoiler can be used to break up the compacted layer.

Figure 18 **Effect of stake planting position on cassava root yield in rainy and dry season, Thailand** (t/ha)



Source: Annex Table 4.4

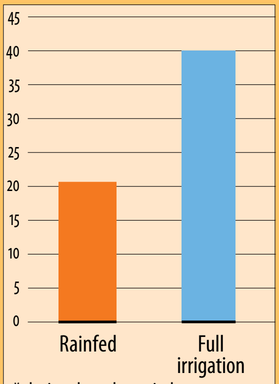
Sometimes, it may be better to delay planting to the latter part of the rainy season, but no later than about two months before the onset of the dry season. Planting towards the end, rather than at the beginning, of the rainy season usually results in lower yields, but it has some advantages: less weed competition and – if the crop is harvested in the off-season – the possibility of higher market prices. Another advantage is that the late planting of cassava does not coincide with other major agricultural activities, so there is less competition for labour.

Irrigated production

When it is planted towards the end of the rainy season, or when the rainy season is very short, cassava benefits from supplemental irrigation during rainless periods. On land that is flat, or nearly flat, this can be done by flood or furrow irrigation, but on sloping land it may be more practical to use overhead sprinklers or a rotating water cannon.

Research in India found that during periods of drought, yields increased with increasing amounts of surface irrigation water applied. Full irrigation, at 100 percent of crop water requirements, doubled the root yield obtained without irrigation. It also increased slightly the

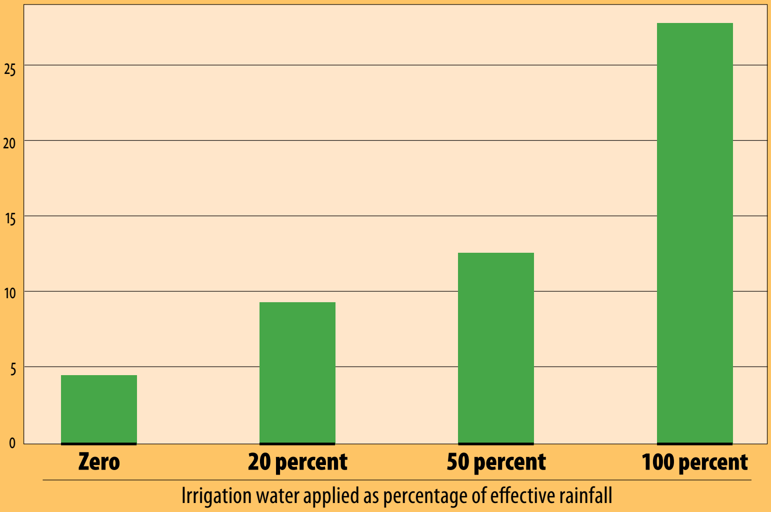
Figure 19 **Effect of supplemental irrigation* on cassava root yield, India** (t/ha)



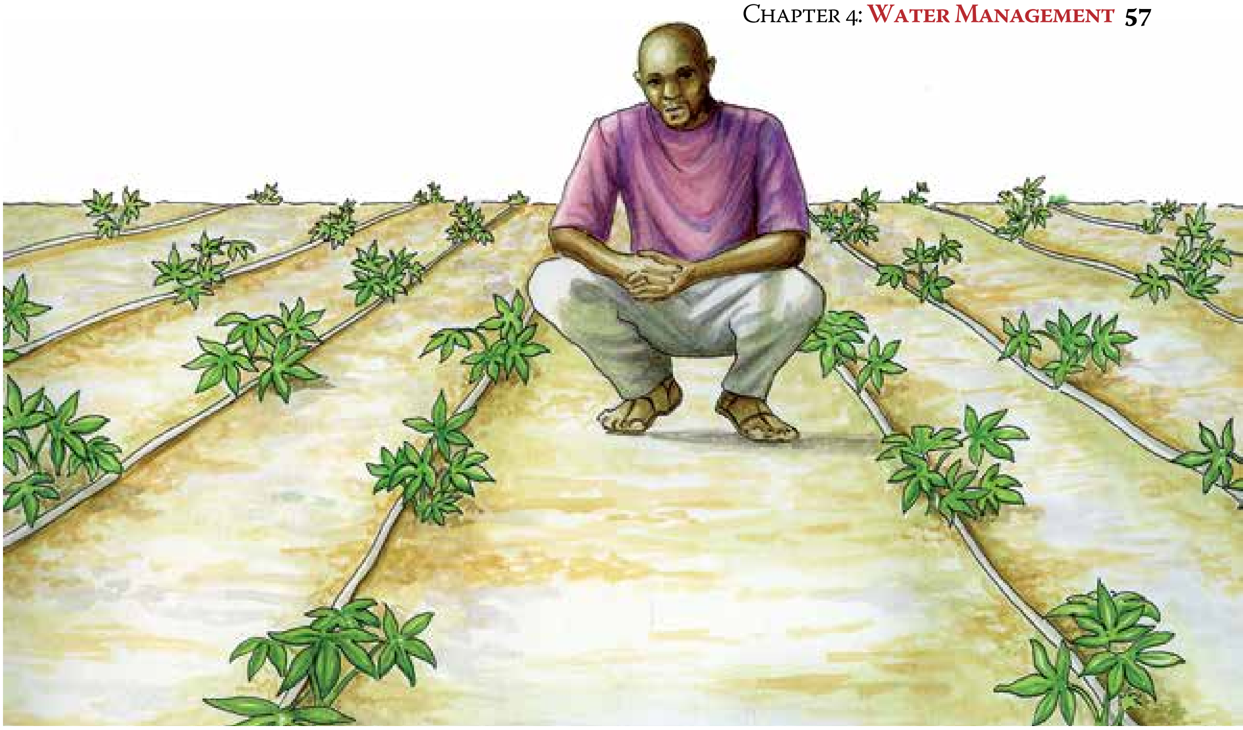
* during drought periods (more than 7 days without rain)

Source: Annex Table 4.5

Figure 20 **Effect of supplemental drip irrigation on cassava root yield, Nigeria** (t/ha)



Source: Annex Table 4.7

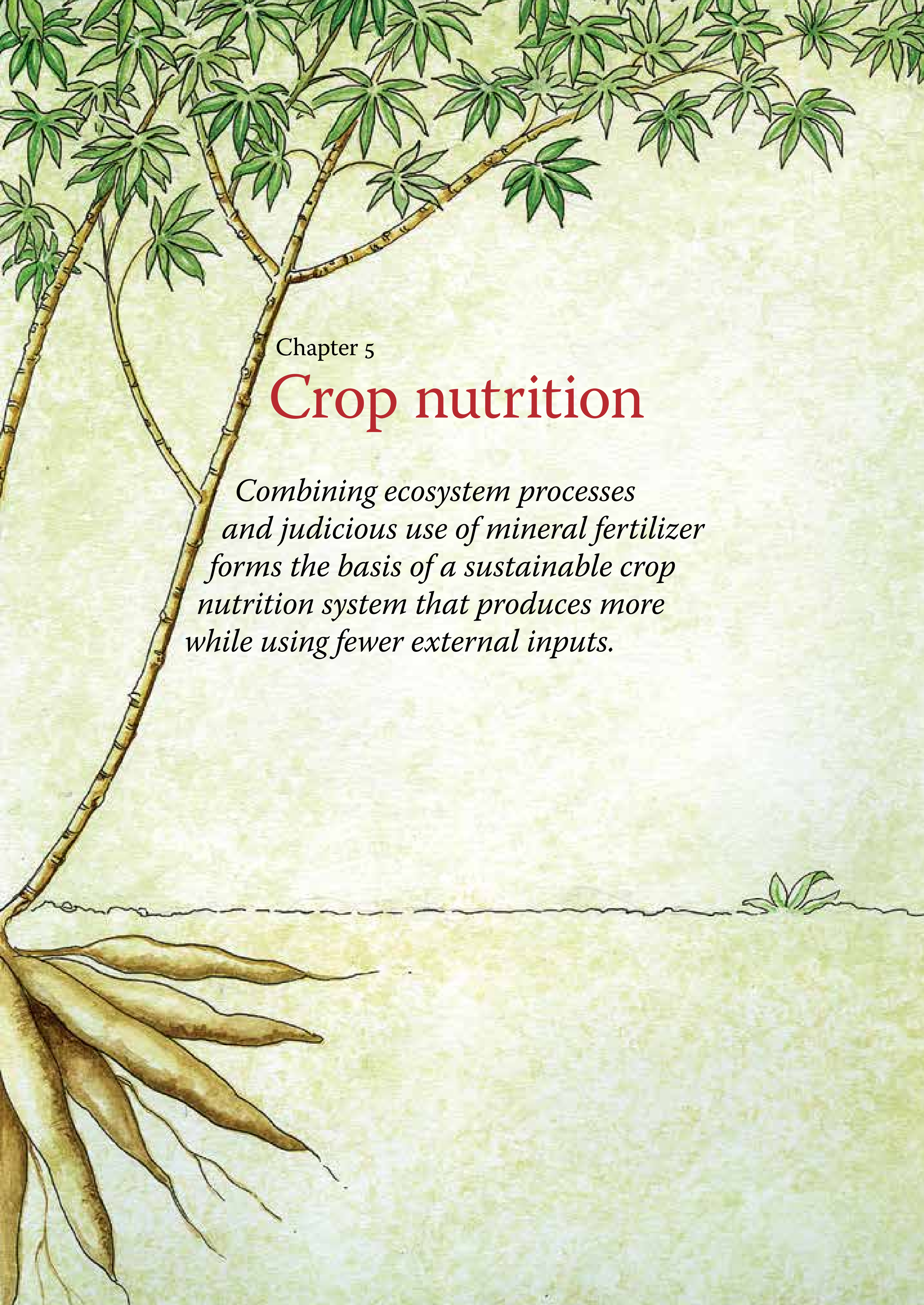


starch content of roots and markedly reduced the hydrogen cyanide content (Figure 19)[14].

More effective, in terms of water use efficiency, is drip irrigation which, by providing small and frequent water applications, saves water while maintaining soil moisture at a level that is highly favourable to crop growth (it also allows the farmer to water the cassava plants but not the weeds). In trials in the very dry zone of Tamil Nadu, India, drip irrigation of cassava produced about the same yields as those obtained with flood irrigation – around 60 tonnes per ha – using 50 percent less water. When the water applied through drip irrigation was equal to that used in flood irrigation, yields continued to increase substantially, to 67.3 tonnes (Annex table 4.6)[15].

With drip irrigation, researchers in Nigeria increased root yields from 4.6 to 28 tonnes

Similar results were reported from experiments in south-western Nigeria. With 730 mm of effective rainfall during the growing season, rainfed cassava produced root yields of less than 5 tonnes per ha. In plots under supplemental drip irrigation, yields rose sharply with increasing levels of water applied. At 100 percent of rainfall, drip irrigation produced yields of 28.1 tonnes, equal to total water use efficiency of 18.8 kg per ha per mm, compared to 6.2 kg without irrigation (Figure 20). Yield increases at lower application rates were also significant – supplemental irrigation that boosted the total water supply by 20 percent almost doubled root yields[9].



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.

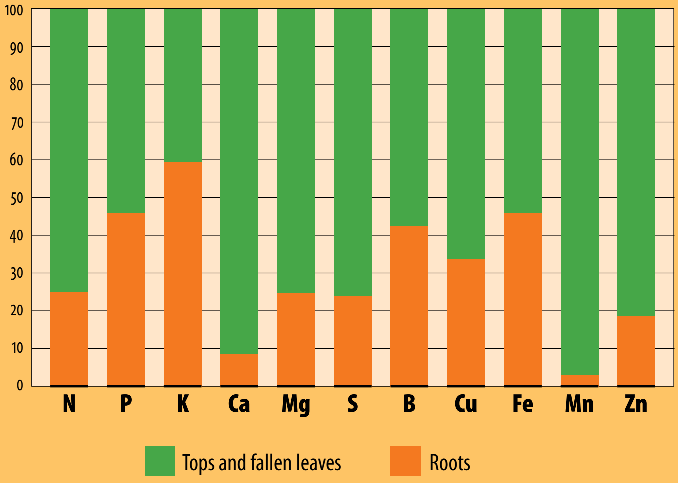
Experience indicates that higher and more sustainable yields are achieved when crop nutrients come from a mix of mineral fertilizer and organic sources, such as animal manure and trees and shrubs which, in dryer climates, can pump up from the subsoil nutrients that would otherwise never reach crops. 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 inputs[1].

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 tops[4]. 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 phosphorus[7-9]. There is little danger of phosphorus depletion, therefore, even after many years of continuous cassava production on the same land[10].

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

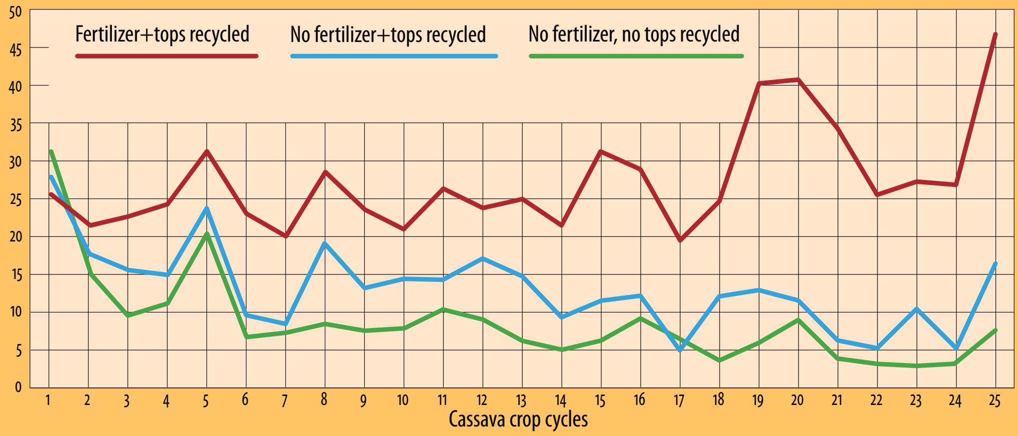
Its ability to produce on low-fertility soils has given rise to the misconception that cassava does not require, nor even respond to, the application of mineral fertilizer. In fact, the results of extensive trials reviewed by FAO have shown that many cassava varieties respond very well to fertilization[11]. 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 Nam[9].

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.

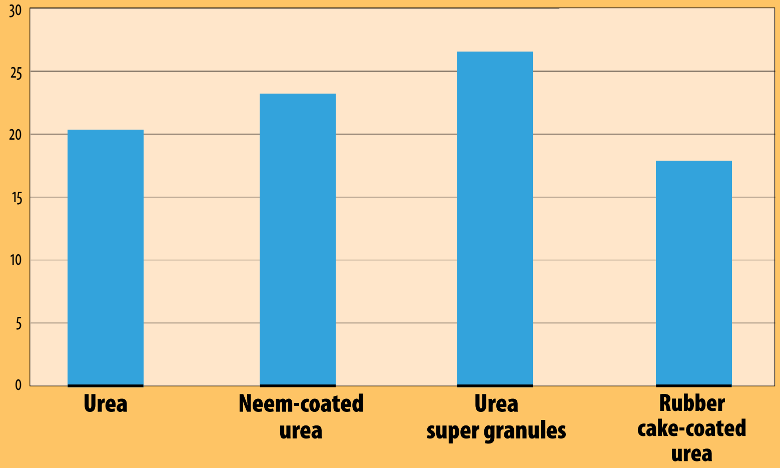
led to increases in cassava root yields – of 30 to 160 percent – as well as in stem yields, important for production of high quality planting material. In the west of the country, per hectare cassava yields increased from 12 to 25 tonnes with moderate applications of N-P-K fertilizer, and reached more than 40 tonnes with higher application rates[12]. (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 soybean[13].)

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.

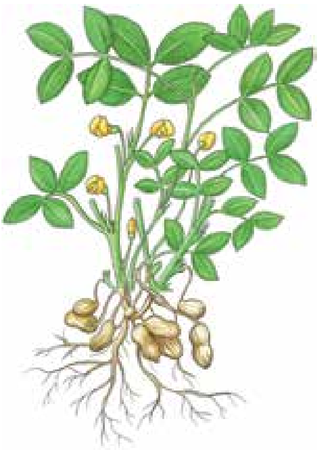
Figure 23 **Effect of four sources of nitrogen on cassava root yield, India** (t/ha)



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 percent[15].

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

Organic sources of nutrients

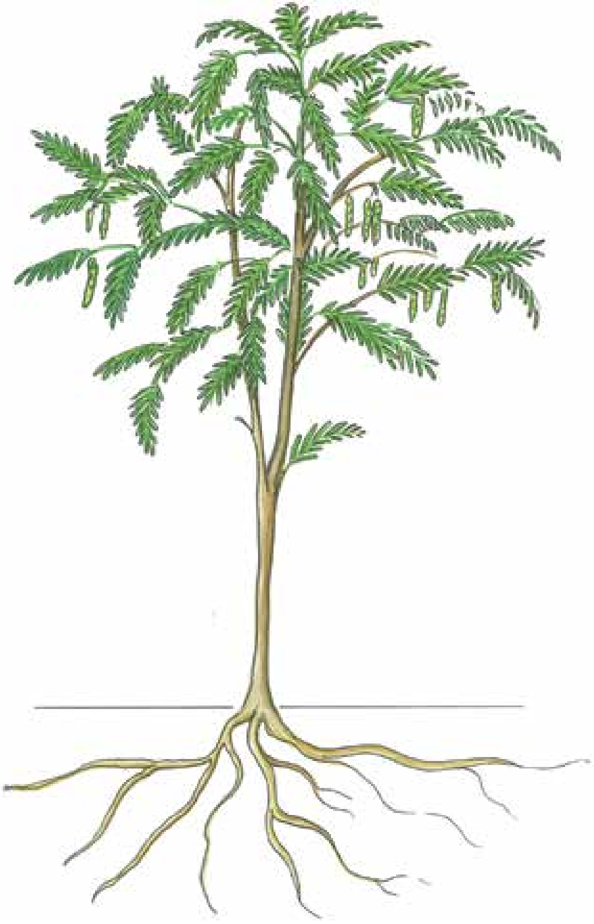
While mineral fertilizer can help to boost yields, alone it cannot sustain crop production in the long-term on degraded land[16]. Farmers need to maintain and improve soil quality and health using a number of other "Save and Grow" measures, such as conservation tillage, intercropping, green manuring, 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 percent[17].

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.

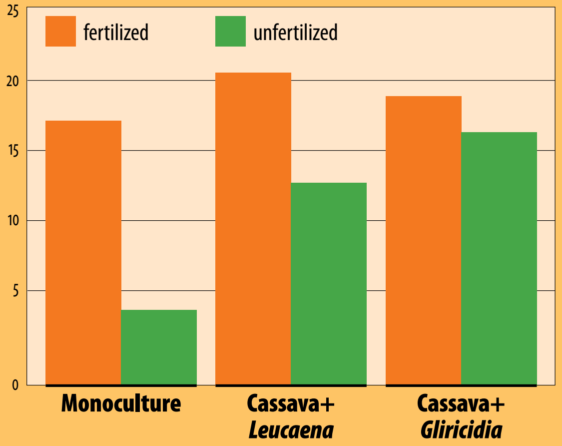
The fertilizer treatment produced the highest net benefits in one location during the first year, while intercropping with groundnuts and without fertilizer produced the highest net benefit in the second year. Despite its high price in the region, mineral fertilizer was the treatment most preferred by farmers[19].

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



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*

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



Source: Annex Table 5.3

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 growth[19]. 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 days[20].

Many green manure species have been tested, both in Colombia and Thailand, to measure their effect on cassava[21]. 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

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 yields[21].

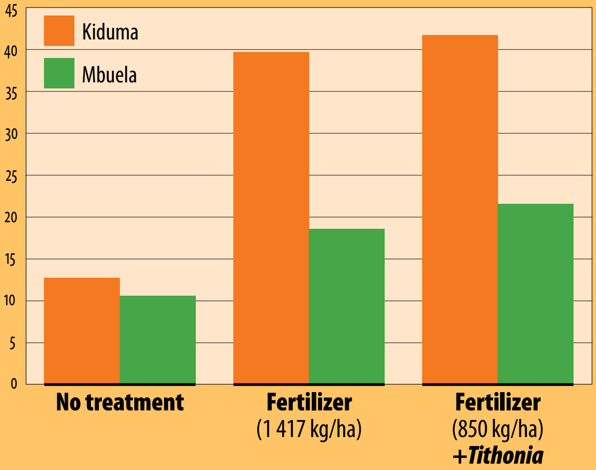
Another approach is to plant the green manure at the same time as the cassava, but in between the cassava rows, similar to an intercrop. The fast-growing green manures are pulled out 2 or 3 months after planting, and mulched between the rows. The manure crops *Canavalia ensiformis* and *Crotalaria juncea* 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 surface[23].

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 fertilizers[24]. 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).

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

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*.

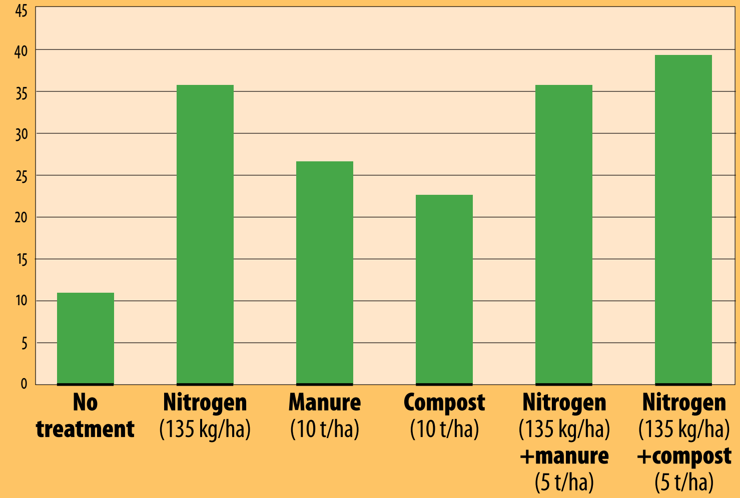
However, they may not always be available, and are cumbersome to collect and transport at the high rates of application used in the Congolese experiments. In addition, *Tithonia* can easily become a weed in the field where it has been applied as green manure, and *Chromolaena odorata* is a favoured breeding 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 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 yields[16].

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 micronutrients – 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.

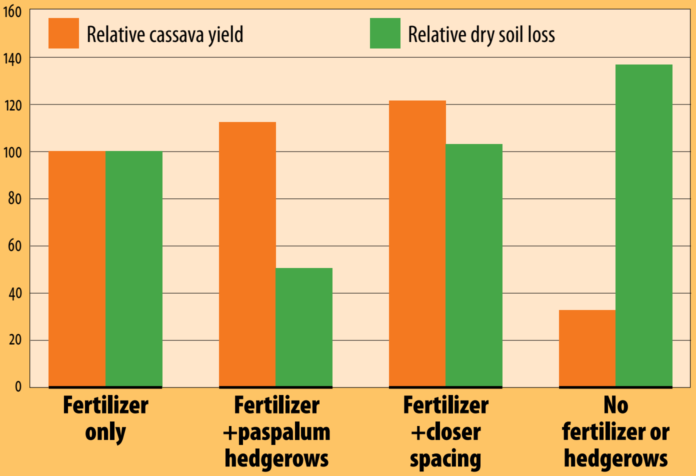
Controlling soil erosion

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 fraction[25].

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 growth[10]. 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 erosion[26]. Zero tillage is most effective in a well-aggregated soil with an adequate level of organic matter.

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

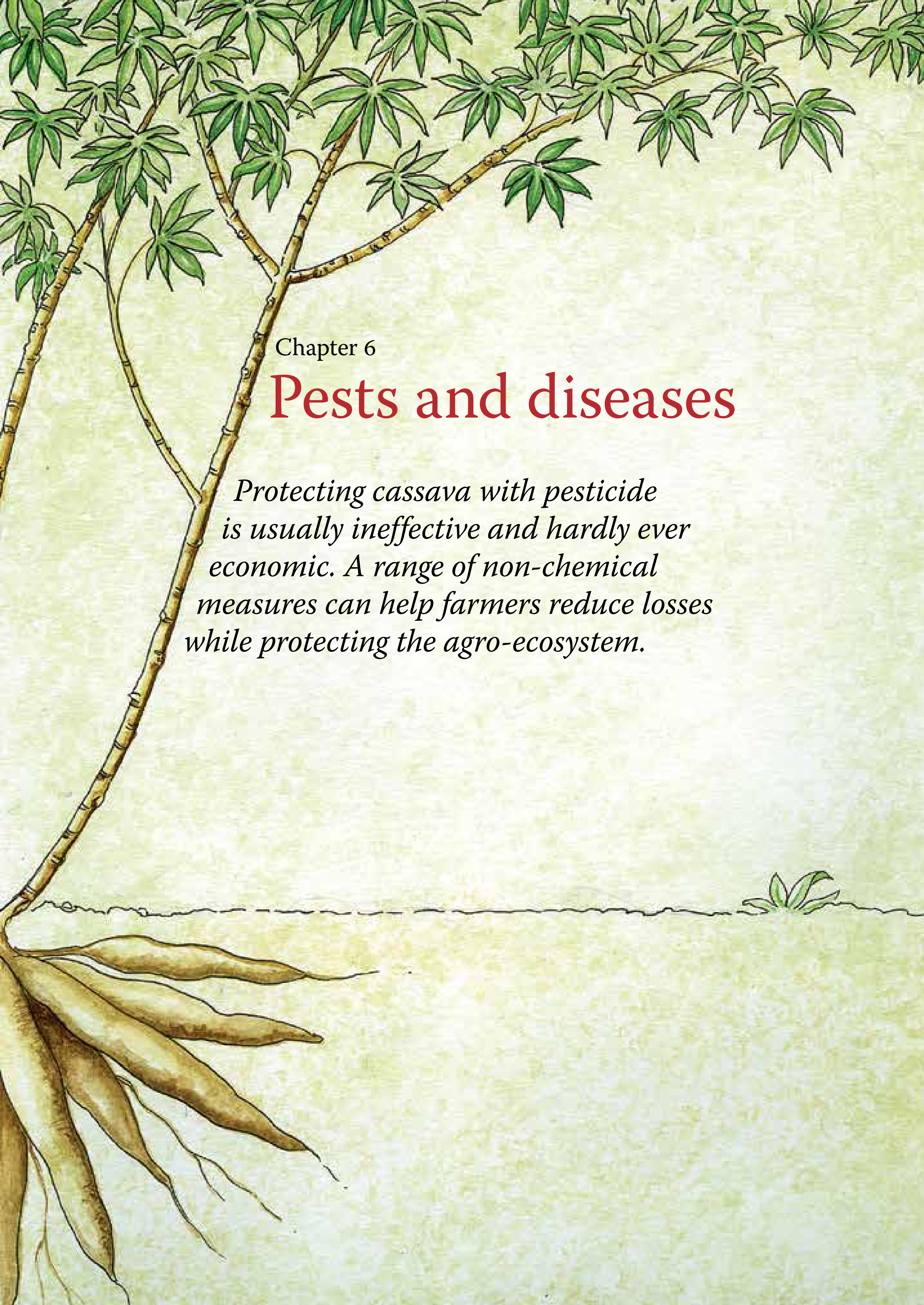


Source: Annex Table 5.8

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.

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 production[1].

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-ecosystem[2-7]. 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.

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

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).

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 varieties[8].

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 Nadu[9].

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 cowpeas[3]. 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 fungicide[11].

Control of major insect pests

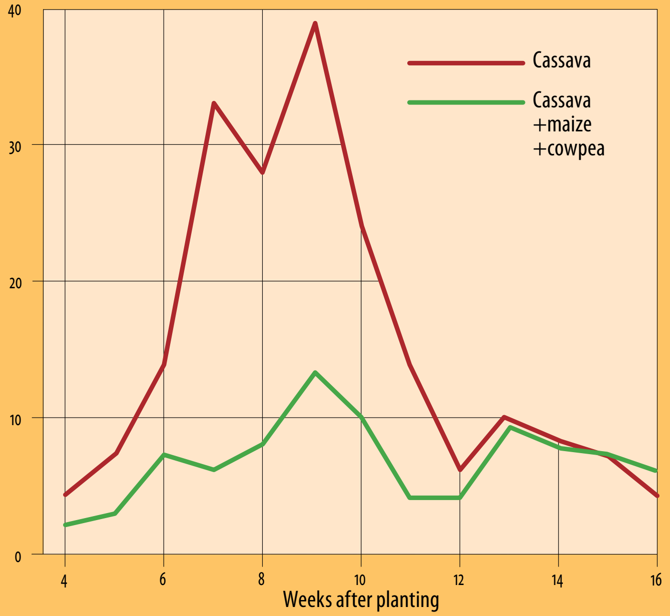
Around 200 species of arthropod pests have been reported on cassava. Of these, some are specific to the crop, while others attack other crops as well. The greatest diversity of cassava insect pests is found in Latin America, where they have co-evolved with the crop. However, cassava pest problems are 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].

Bemisia tabaci *transmits serious viral diseases to cassava plants*

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.

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.

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 monoculture[13].

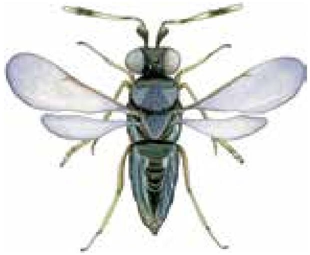
Other recommended control measures include imposing a "closed season", when no cassava can be present in the field, in order to break the whitefly's development cycle (although, this may not be as effective with some species, such as *B. tabaci*, that have multiple hosts). Recent trials in Colombia indicate that planting different cassava varieties in the same field may reduce herbivore load and increase yields in zones subject to heavy *T. variabilis* attacks[14].

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.

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

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.



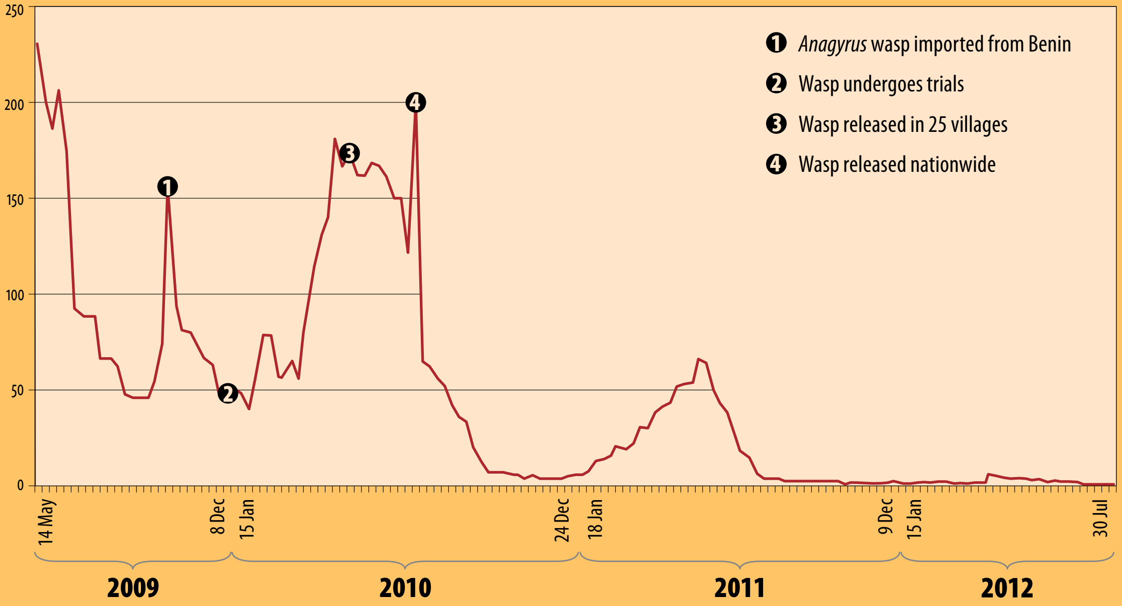
Natural enemy of cassava mealybugs – the tiny wasp Anagyrus lopezi

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

Figure 29 **Area infested by cassava mealybug in Thailand, 2009-2012** ('000 ha)



Source: Rojanaridpiched, C., Thongnak, N., Jeerapong, L. & Winotai, A. 2012. *Rapid response to the accidental introduction of the mealybug,* Phenacoccus manihoti, *in Thailand*. Factsheet prepared for FAO. (mimeo)

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.

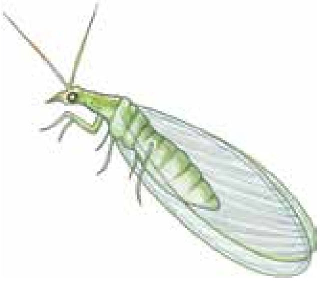
The introduction of green mites on cassava imported from Latin America in the early 1970s devastated Africa's cassava production. To bring the mite under control, entomologists at IITA and CIAT first identified its area of origin in South America and its natural enemy, another mite, from Brazil. The 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 systems[16].

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.

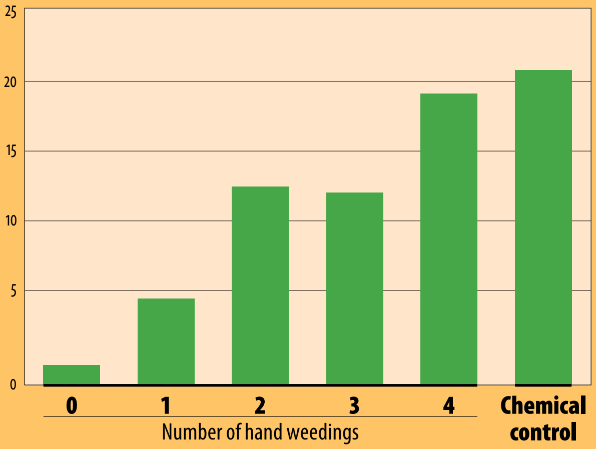
In the first four months after planting, cassava can easily be overwhelmed by competition from narrow-leaf grassy weeds and from broad-leaf weeds, which include many leguminous plants. In East Africa, weeds are often a more serious production constraint than insect pests or diseases and can reduce yields by about 50 percent[17]. In Nigeria, farmers spend more time on weeding than on any other aspect of crop production[18].

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 weeding[21]. 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 weeds[18].

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



Source: Annex Table 6.1

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.

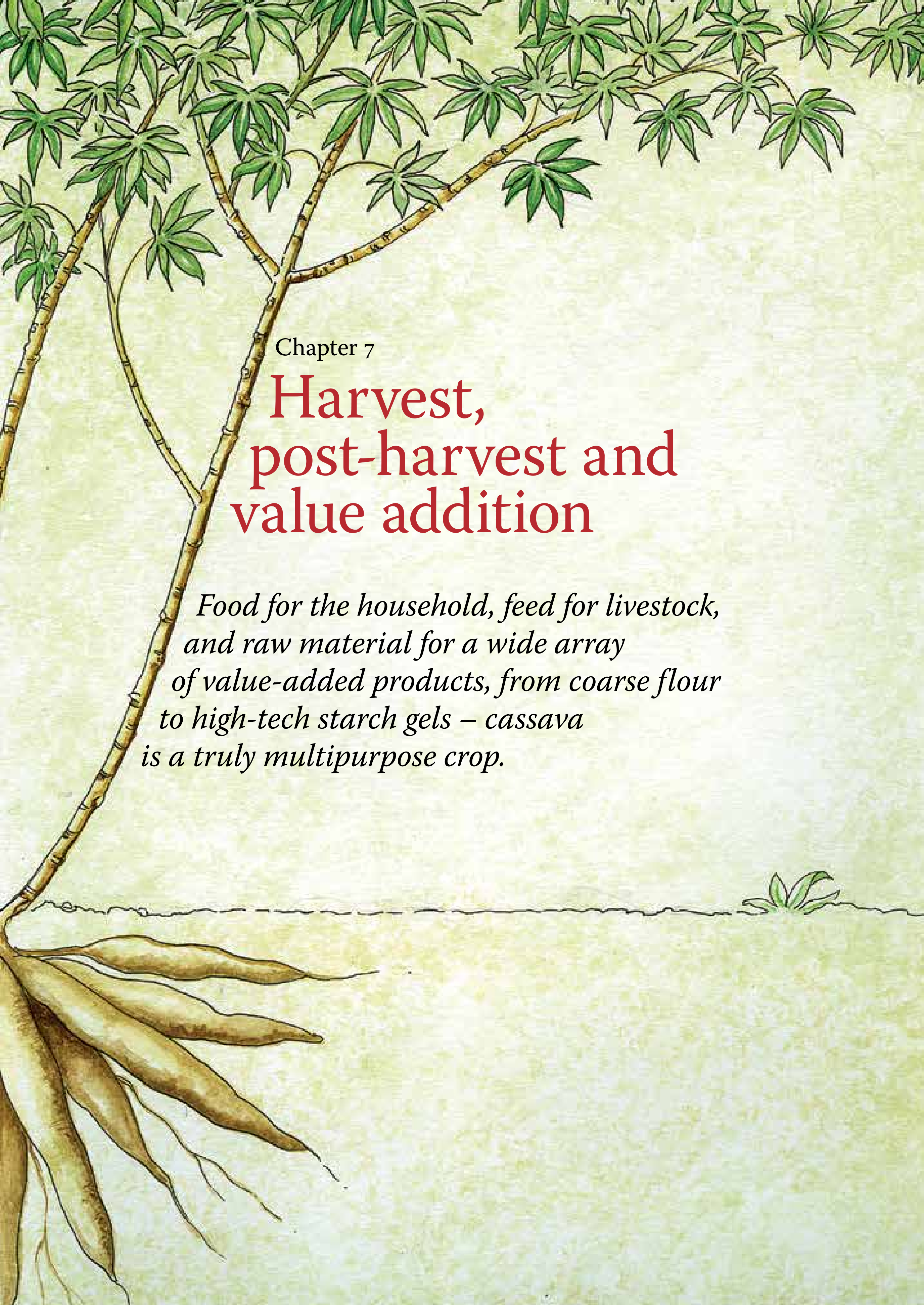
Weeds growing between the rows can also be incorporated into the soil using an oxen- or buffalo-drawn cultivator or, where available, tractors equipped with cultivator blades. In the absence of both machinery and draught animals, farmers in Thailand use a manually-drawn cultivator, known as a "poor man's 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.



Chapter 7

Harvest, post-harvest and value addition

Food for the household, feed for livestock, and raw material for a wide array of value-added products, from coarse flour to high-tech starch gels – cassava is a truly multipurpose crop.

One of the major positive attributes of cassava is that it does not have a specific harvesting period. Roots may be harvested any time between six months and two years after planting. During periods of food shortage, they can be harvested whenever needed, often one plant – or even one root – at a time. For human consumption, harvesting usually takes place at about 8 to 10 months; for industrial uses, a longer growing period generally produces a higher root and starch yield. Once harvested, roots can be consumed directly by the farm household, fed to livestock or sold for processing into a wide array of value-added products, ranging from coarse flour to high-tech modified starch gels.

The root is not the only part of the plant that can be put to good use. In Africa, cassava leaves are cooked as a vegetable. In many countries, the green part of the upper stem, including leaves and petioles, are fed to cattle and buffaloes, while the leaf-blades are fed to pigs and chickens. In China, Thailand and Viet Nam, fresh leaves are used for raising silkworms. Stumps are burned as fuelwood, and woody stems are ground-up and used as a substrate for growing mushrooms.

Bringing home the harvest. Worldwide, cassava growers produced more than 280 million tonnes of fresh roots in 2012

Harvesting roots and plant tops

Cassava roots are generally harvested by cutting off the stems about 20 cm above ground, then lifting the whole root system out of the ground by pulling on the stump. If the soil is too hard or the roots are too deep, it may be necessary to dig around the roots with a hoe, spade or pick to remove the soil, avoiding damage to the roots in the process.

To harvest their cassava, Thai farmers have developed a metal tool that is attached to a pole and used as a lever. It works best in loose or light-textured soils. In heavier soils, which can become very hard in the dry season, a harvesting blade attached to a tractor is sometimes used. The blade cuts through the soil just below the roots and the forward movement of the tractor pushes the root clumps to the surface. The roots are then cut from the stump and placed in baskets or sacks for transport.

The harvest of large cassava fields is often done by middlemen who employ teams of workers and use trucks to transport the roots to markets or processing plants. In Viet Nam, roots are often carried home in two baskets hanging on a shoulder pole; in Lao PDR, farmers use bamboo shoulder baskets. In China, the harvested roots are generally transported in a wagon attached to a 2-wheel tractor, while in Thailand, many farmers use a small agricultural truck.

After the root harvest, plant tops are often left to dry on the ground and later incorporated in the soil to help maintain its fertility (see Chapter 5, *Crop nutrition*). However, farmers can greatly increase the total amount of cassava foliage available for feeding to animals by cutting the green tops every 2.5 to 3 months during the plant's growth cycle. After each pruning, the remaining stems will sprout again and produce another crop of leaves within 2 to 3 months. For maximum foliage production, cassava stakes should be planted with closer spacing, of about 60 x 60 cm.

Young leaves harvested at regular intervals during the cassava growth cycle tend to have a higher protein and lower fibre content than those collected at the final root harvest, when plants are normally 11 to 12 months old. The younger leaves are more palatable and provide a higher quality feed. Similarly, leaf meal containing only leaf-blades has a higher protein and lower fibre content than meal that also contains petioles and green stems.

In an experiment in Thailand, total dry leaf yield was 710 kg per ha when leaves were harvested only at the time of root harvest, at 11.5 months after planting (Annex table 7.1). But the yield increased to 2.6 tonnes when leaves were cut five times during the same period. The total leaf protein yield also increased, from 170 kg with only one leaf harvest to 650 kg, similar to a good crop of soybeans[1, 2]. However, as the frequency of leaf cutting increased, the final root yield dropped, from around 40 tonnes per ha when leaves were harvested only at the time of the root harvest, to less than 25 tonnes when leaves were harvested a total of five times[2]. Depending on the cost of labour and the relative prices of fresh roots and dry leaves, this system may or may not be economic.

Harvesting the plant tops 4 or 5 times during a one-year growth cycle also removes a large amount of nutrients – especially nitrogen – from the field, and would not be sustainable without the application of large amounts of mineral fertilizer to maintain soil fertility.

Post-harvest uses and value addition

Food for direct consumption

Young cassava leaves are regularly picked and cooked for human consumption in several African countries, notably Cameroon, the Democratic Republic of the Congo, Liberia and the United Republic of Tanzania. The tender leaves contain up to 25 percent protein, on a dry matter basis, and are a valuable source of iron, calcium, and vitamins A and C[3]. The essential amino acid content of cassava leaf protein is similar to that found in a hen's egg. The market value of cassava leaves in areas where they are consumed is often higher than that of the roots, indicating that their sale contributes significantly to farm household incomes[4].

In Central Africa, tender young cassava leaves are regularly picked and cooked as a protein-rich vegetable

Cassava leaves are prepared by removing the hard petioles, then pounding the blades and young petioles with a pestle and mortar, and boiling the resulting pulp for about 30 to 60 minutes. That process eliminates cyanogens and makes the leaves safe to eat. However, prolonged boiling also results in considerable loss of vitamin C[5].

Cassava roots deteriorate rapidly and must be processed within a few days of harvesting. In many parts of Brazil, fresh roots are grated and the liquid, which contains much of the roots' cyanide content, is pressed out. The semi-dry mash is then roasted to produce *farinha*, a coarse flour that is spread on many Brazilian dishes. In Africa, grated roots are fermented before being roasted on a hot plate to produce a granulated flour called *gari*, or sun-dried and milled into flour, which is mixed with water to produce a stiff dough called *fufu*.

Steaming is used in Côte d'Ivoire and Benin to make another granulated cassava product, called *attiéké*. In the Democratic Republic of the Congo, pounded cassava flesh is wrapped in banana leaves and steamed for several hours to make cassava bread or sticks, called *chickwangue* or *kwanga*, which are served with soups, stews and sauces.

In Indonesia, peeled roots are sliced lengthwise then sun-dried. The dry chunks, called *gaplek*, are then stored or sold in market stalls. When needed, *gaplek* is pounded into flour, which is swirled around with a little water to produce small granules the size of rice grains. The granules, called *tiwul*, are steamed, either separately or together with rice, and eaten as a "rice extender" when there is not enough rice to feed the family. Another popular snack in Indonesia, called *krepek*, is made by washing peeled roots and thinly slicing them with a hand- or electric slicer. The slices are placed in cold water, drained and then fried in hot oil for a few minutes. Once cooked, they are covered with a mixture of hot or sweet spices and sold in small plastic bags by hawkers or in local markets.

High quality cassava flour (HQCF) is cassava flour that has not been fermented and can be used as an alternative to wheat flour and other starches in bread and confectionary. The processing of cassava roots into HQCF involves peeling, washing, grating, pressing, disintegration, sifting, drying, milling, screening, packaging and storage.

Although markets for unfermented high quality cassava flour are emerging in sub-Saharan Africa, the challenge is linking them to large numbers of small-scale growers whose output is highly variable in quality. Where the value chain is relatively well established (for example, in Nigeria and Ghana), artificial dryers capable of processing 1 to 3 tonnes of HQCF per day could help to locate intermediary processing closer to the sources of fresh cassava roots. Processors could also provide intermediate bulking, aggregation and transportation services, and ensure acceptable quality of products to be delivered to the end-use market[6].

Native starch is extracted from cassava roots in some countries, mainly in Asia, and used in food products. If properly extracted, cassava starch is pure white, with low levels of fat and proteins and a non-cereal taste, which is desirable in many food products[7]. Starch extraction can be done at almost any scale – in backyard artisanal production units and large-scale fully mechanized factories. Many artisanal starch production units still operate in Cambodia, India, Indonesia and Viet Nam. In backyard processing, cassava roots are hand-peeled, washed, grated and mixed with water. The starch water is passed through a cloth sieve to remove the fibre, and the suspended starch is then left to settle in tanks or flow channels. After the surface liquid is siphoned off, the wet starch is collected, crushed and spread out on bamboo mats or on concrete floors for sun-drying. In artisanal production systems, daily starch output ranges from 50 to 60 kg of starch per worker, while semi-mechanized processing can yield up to 10 tonnes a day[8].

In some parts of Colombia, wet starch is left to ferment for a few days before being sun-dried. This produces sour starch, which is the main ingredient in buns called *pan de bono*. In Tamil Nadu State, India, wet starch is collected, crushed and then shaken on a hemp cloth to form small starch balls, which are sieved and steamed for a few minutes to form tapioca pearls. In Indonesia, cassava starch is mixed with shrimp paste, food colouring and water and then extruded and thinly sliced by hand. The slices are steamed on bamboo screens for 5 to 15 minutes, after which they are sun-dried on a patio floor for half a day, producing hard chips known as *krupuk*. When deep-fried, *krupuk* swell into brittle soft crackers, which are a popular snack that accompanies almost every meal.

Starch extraction produces a considerable quantity of useful residues. Root peelings can be recycled as fertilizer and animal feed. Once dried, the discarded fibre can be sold as flocculent to the mining industry, while low-density starch lost during sedimentation is used as pig feed[8].

Industrial uses

In countries such as Thailand and China, much of the native cassava starch is further processed to make a range of modified starches, for incorporation in food products or use as feedstock for production of sweeteners, fructose, alcohol and monosodium glutamate. Along with high quality cassava flour, modified starch is also used in the manufacture of plywood, paper and textiles.

In fully mechanized starch factories in China and Thailand, cassava roots are thoroughly washed, then cut and rasped, after which the mash is mixed with water several times to release the starch granules. The “starch milk” – the water containing suspended granules – is then separated from the pulp, after which the granules are separated from the water by sedimentation or in a centrifuge. At that point, the starch requires solar or artificial drying to remove moisture before being milled, sifted and packed into 50 kg bags or one-tonne sacks. In modern, fully mechanized starch extraction plants, daily output is as high as 300 tonnes[8].

Increasingly, cassava is also being used for production of fuel ethanol. Fresh roots or dried chips are cleaned, washed, crushed and mixed with water, heated with liquefying enzymes, then cooled with other enzymes, which convert the starch to sugars. The sugars are fermented with yeast to produce ethanol, which is concentrated through distillation and finally dehydrated in a molecular sieve to produce 99.5 percent pure anhydrous ethanol. It can be blended with gasoline to produce "gasohol" with 10 percent, 20 percent or even 85 percent ethanol. Cassava-based fuel ethanol factories are now operating, or are under construction, in Cambodia, China, Colombia, Thailand and Viet Nam. Conversion to ethanol will become one of the major uses of cassava fresh roots and dry chips in the future, especially in China[9].

Two recent cassava mutations could expand considerably cassava's use in industrial applications[7]. The first, an induced mutation, has very small starch granules which offer a faster rate of hydrolysis – thus reducing the cost of producing ethanol or sweeteners – than other major starches. The second, a spontaneous mutation, produces an amylose-free "waxy" starch that has great advantages when used in frozen foods. Gels made from the starch have excellent water retention during defrosting, a highly desirable characteristic for the food industry.

Animal feed

Both the roots and leaves of the cassava plant can be used as on-farm animal feed or as an ingredient in commercial animal feed. Because of their high cyanide content, however, fresh roots or leaves can be fed to animals only in very small quantities. Cassava roots are chipped or sliced, while leaves are chopped into small pieces. Before being fed to animals, the cassava pieces are spread out on a floor overnight in order to release some of the cyanide by evaporation. The root chips and leaf pieces can also be sun-dried to 12 to 14 percent moisture content, then stored for future use. Alternatively, the chopped pieces of roots and leaves can be packed tightly in plastic bags or air-tight containers and fermented to make silage (*see p.96*). Both sun-drying and ensiling will release most of the cyanide, making those products safe as feed for pigs, cattle, buffaloes and chickens.

Dried cassava chips are produced by first washing, or at least slightly cleaning, the roots in a rotary drum to remove soil and some of the outer skin. The roots are then chipped and spread out on a concrete floor for sun-drying, and turned regularly with a rake to promote uniform drying. Normally it takes up to four days of sun-drying to make dried chips with about 12 to 14 percent moisture content.

In Viet Nam, cassava roots are often roughly peeled and sliced by hand before sun-drying in courtyards or along roadsides. In Thailand, many farmers take their cassava to drying yards, where the roots are first dumped into the hopper of a diesel-powered chipping machine. The chipped roots are then spread over large concrete floors for sun-drying and turned over regularly by a vehicle with a large rake. After two or three days of drying, the chips are piled up by a grader and loaded in bulk onto trucks. Some are further processed into pellets, mainly for export.

Although the need for rapid chipping and drying adds to the complexity of production, small farmers in Asia and their marketing partners, who provide cassava chips for the animal feed export industry, have shown that with adequate infrastructure, smallholder produce can be dried locally and reach market chains with relatively low losses[10].

Chips are usually sold directly or milled into a powder that can be mixed with other ingredients – such as soybean meal, full-fat soybeans, fishmeal or other protein sources – to make a nutritious animal feed that is usually supplemented with methionine, vitamins and minerals. When the diet is well-balanced, in terms of energy and protein, the performance of pigs is very similar to that obtained with a diet based on maize or broken rice. Cassava meal is highly digestible and naturally contaminated with lactic acid bacteria and yeast, which improve the micro-flora in the digestive tract of animals. At low levels, hydrogen cyanide in cassava feed increases the efficiency of an enzyme, lactoperoxidase, which is a natural antibiotic that kills mycotoxins in the animal's body and milk. Animals raised on cassava diets have generally good health, good disease resistance and a low mortality rate. They require few if any antibiotics in their feed[11].

Dry cassava leaf meal (also known as "cassava hay") is usually obtained by cutting the plant tops at 2.5 to 3-month intervals during the cassava growth cycle. The best quality foliage meal contains a large proportion of leaves and only very young stems, and is obtained from plants or shoots that are less than three months old. After harvesting, the foliage is chopped and spread out on a concrete floor for sun-drying. The moisture content needs to be reduced from about

70 percent to 12 to 14 percent so that the foliage can be milled and stored.

Owing to its high fibre content, cassava foliage meal is suitable mainly for ruminants. Research has shown how supplementation with 1 to 2 kg of cassava hay per animal per day increases the milk yields of dairy cows and boosts levels of thiocyanate in the milk, which may enhance milk quality and storability. Condensed tannins in the foliage meal also reduces gastro-intestinal nematodes, indicating that the meal may act as an anti-helminthic agent[12]. For non-ruminants, dry cassava foliage meal is best limited to 6 to 8 percent of the feed for growing pigs and to less than 6 percent of that for broilers. In broilers, the inclusion of cassava foliage meal is useful mainly as a natural pigmenter – the high content of xanthophyll pigments (500-600 mg/kg) improves the pigmentation of skin in broilers and that of egg yolks[13].

Leaf silage is made by mixing chopped leaves with 0.5 percent salt and 5 to 10 percent cassava root meal or rice bran, and then placing the mixture in large plastic bags or air-tight containers. The leaves are compacted to expel all air and the bags are sealed. Under these anaerobic conditions, the leaves start to ferment, resulting in a sharp drop in pH, as well as in cyanide content. After about 90 days of fermentation, the silage is ready to be fed to animals, usually pigs and cattle. The silage can be stored in tightly sealed bags for at least five months without spoiling. The ensiled leaves contain about 21 percent crude protein and 12 percent crude fibre. They also contain 200 ppm hydrogen cyanide, compared to more than 700 ppm before ensiling. In experiments conducted in Viet Nam, a diet containing 15 percent ensiled cassava leaves improved the daily weight gain of pigs and reduced their feed cost by 25 percent[14].

Chapter 8

The way forward

Governments need to encourage smallholders' participation in a sustainable cassava development agenda, and support research and extension approaches that "let farmers decide".

This guide has presented a range of science-based "Save and Grow" farming practices that will contribute to the sustainable intensification of cassava production. They provide the basis for competitive, profitable production systems that boost productivity per unit of input, while protecting and nurturing the agro-ecosystem.

However, those recommendations will have little impact unless they are incorporated in large-scale agricultural development programmes and are widely adopted by farmers. For that to happen, governments will need to make policies that encourage the participation of all stakeholders, and particularly smallholder producers, in a sustainable cassava development agenda. Successful adoption of "Save and Grow" will also depend on farmers' understanding of agro-ecosystem functions and on their capacity to make wise technology choices. That will require significant strengthening of extension services and innovative approaches to the transfer of knowledge and technologies[1].

Policies for sustainable intensification

Smallholder farmers raise crops and livestock primarily to feed their families and to earn enough income from sales to cover expenses, such as education and health care. They often have a short planning horizon, focused on satisfying their immediate needs, rather than ensuring the long-term sustainability of their farming enterprise. Farmers need to become aware that some of their current practices jeopardize their natural resource base and, with it, their future productivity, income, livelihood and food security.

Locally, negative impacts of unsustainable crop production include the erosion, compaction and nutrient depletion of soil, the loss of natural habitats and natural enemies of pests, and the risks posed to farmers' health by the excessive use of pesticide. Other farming practices have off-farm impacts which, while not harming the farmer directly, are nevertheless of serious concern to society at large. Those "negative externalities" range from nitrate pollution of waterways and flooding of downstream areas, to pesticide residues in food and the greenhouse gas emissions responsible for climate change.

Like most people, farmers are usually reluctant to spend time and money solving problems that do not directly affect them. The challenge facing cassava-producing countries, therefore, is to set policies and create an institutional environment that facilitate sustainable intensification of cassava production, while expanding market opportunities for small-scale cassava growers.

Policymakers should begin with an analysis of the current state of the cassava subsector. In most countries, cassava production is still labour-intensive and largely subsistence-oriented, with low levels of technology uptake, high production and post-harvest losses, and weak linkages to markets.

Transforming the subsector, in a way that ensures food security, income generation and economic diversification, requires the identification of profitable value chains and market preferences, strategies for reducing price variability on the demand side, and options for enhancing the quality, volume and reliability of production on the supply side. Improving market access and competitiveness will require vertical and horizontal coordination, strategic market-led research, and mechanisms for stimulating innovation and sharing knowledge, including farmers' practical know-how. As policymakers encourage higher levels of value addition, a major effort will be needed to integrate small-scale growers into the cassava marketing chain.

While there is no "one-size-fits-all" set of recommendations, it is possible to identify the key features of enabling policies and institutions for sustainable intensification of smallholder cassava production.

Promote "Save and Grow" farming approaches and practices. Cassava growers should be encouraged to phase out slash-and-burn production, and cultivate smaller areas of flat and more fertile land nearer to their homes, transport and markets. Continuous production on the same land will help to reduce forest clearing, the annual burning of vegetation (which emits large amounts of carbon dioxide into the atmosphere), and the drudgery of carrying heavy loads of cassava roots over long distances. The steeper land can be returned to forest vegetation or used for perennial fruit trees, rubber or coffee.

To be sustainable, however, intensive systems of cassava production need to use good quality planting material and ecosystem-based approaches to soil fertility management and to insect pest, disease and weed control. In many countries, low-input cassava production systems already incorporate key "Save and Grow" practices, such as reduced or zero tillage, the use of cover crops and mulches, and mixed cropping. Extension and advisory services – organized by the public sector, the private sector or NGOs – will be crucial in improving those practices by ensuring access to relevant external knowledge and linking it to the wealth of knowledge held by smallholders themselves. Participatory extension approaches will be needed to support farmers in testing and adapting technologies. New channels of communication, including radio, mobile phones and the Internet, can help to reduce the transaction costs of extension.

Cassava growers may also need incentives – for example, payments for environmental services – to adopt new farming practices and to manage other ecosystem services besides food production, such as soil conservation and protection of biodiversity. Adoption of integrated pest management can be promoted by removing "perverse subsidies" on synthetic pesticides, regulating their sale, and providing incentives for local production of biopesticides and insectaries for natural predators.

Facilitate improvements in the input supply chain. Disposable household income is too low to allow many small-scale farmers to move from low-input/low-output production to more intensive cultivation of cassava. Action is needed, therefore, to make improved planting material, mineral fertilizer and other inputs more affordable to smallholders. Governments should encourage private investment in the production of inputs, and establish credit lines to enable private suppliers to organize bulk procurements that ensure the availability of inputs in time for planting. Where necessary, the quality of inputs should be routinely tested to prevent the sale of bogus products. To avoid the inappropriate use, wastage and negative environmental impacts of mineral fertilizer, its distribution should be accompanied by training and extension advice.

Institutions that facilitate participation – such as farmer groups, community organizations and development NGOs – can also help to reduce the transaction costs of accessing input markets, while "smart subsidy" voucher schemes could be introduced to allow smallholders to purchase fertilizer and planting material at below-market prices. Although subsidies are attractive to smallholders, they can create dependency; in the long-term, group-based revolving credit funds will be a more sustainable source of financing. Once cassava growers see how fertilizer and improved varieties can help to increase their yields and income, they will want to buy more – and will have the financial means to do so. That, in turn, stimulates competition, which lowers prices and makes inputs more affordable.

Control pest and disease threats with resistant varieties and strict quarantine regulations. As cassava production is intensified, continual cropping risks provoking an upsurge in pests and diseases, which are already one of the most serious constraints to increased productivity. Rather than resorting to chemical pesticide, cassava intensification programmes should promote integrated pest management, which draws on resistant cultivars, biological control agents, bio-pesticides and habitat management to protect crops, conserve biodiversity and safeguard the environment and human health. All germplasm and varieties deployed should be resistant to the predominant pathogen populations present in each specific country, agro-ecozone and farming system. In the absence of a formal seed supply, quality planting material should be made available to growers through community systems of multiplication and distribution.

With increased international movement and exchange of cassava germplasm, improved phytosanitary measures will be needed to ensure that planting material is free of pests and diseases. Sensitive and robust detection and diagnostic methods to prevent the movement of pathogens are essential for improving quarantine security and bringing national phytosanitary regulations into line with international trade conventions and protocols. The transfer of cassava germplasm should be carefully planned in consultation with quarantine authorities and should be in amounts that allow adequate testing. Cassava germplasm should only be moved as seed, pathogen-tested *in vitro* material, or as cuttings from re-established pathogen-tested *in vitro* material that has been grown under containment[2].

Support cassava research and technology development. Applied agricultural research can facilitate the transformation of cassava cropping systems by helping to develop varieties with disease- and pest-resistance and more desirable commercial traits, water-efficient irrigation technologies, and appropriate farm machinery, especially for land preparation, planting and harvesting. Policies should help to foster public-private partnerships for technology development, and link them to markets in order to facilitate the up-scaling of successful innovations. For example, Thailand's Tapioca Development Institute, which was set up with government funding but operates as an independent non-profit organization, is working with CIAT and Kasetsart University to breed "waxy" starch cassava varieties adapted to Thai growing conditions. The Latin American and Caribbean Consortium to Support Cassava Research and Development (CLAYUCA) is a regional network of public and private entities that plans and coordinates research for the cassava subsector. Acting as a facilitator of public/private alliances, CLAYUCA fosters sustainable cassava production intensification and improved access to elite genetic material. Among recent achievements is a small-scale, low-cost technology, easily operated and managed by smallholder farmers, for local production of ethanol from cassava.

Improve rural infrastructure. Good physical infrastructure is essential for the smooth operation of the cassava value chain, especially considering the need to process the roots within 48 hours of harvesting. The poor state of rural roads in many countries not only limits farmers' access to inputs and financial services – it also severely restricts their access to markets. The lack of storage and processing infrastructure leads to high post-harvest losses, undermines market development and discourages all stakeholders in the value chain from producing and supplying quality-differentiated products with desirable market traits.

Investment in road networks and in warehousing and processing capacity in production zones will help to link small-scale cassava farmers and processors to growth markets for intermediate cassava products that have a longer shelf life. It will also contribute to price stabilization, reduction of post-harvest losses and lower transaction costs. With appropriate technology and equipment, community-level processing plants could produce high quality cassava flour, grits and chips for rural and urban-based industries, allowing cassava growers to retain a bigger share of the value-addition. There is a need to develop models for community-level bulking and grading that can assure regular supply to potentially large urban markets. Since mechanical drying powered by fossil fuels has often proven to be uneconomic in isolated rural areas, processing power based on a combination of solar energy, fossil fuel and biomass sources should be considered.

Develop value chains and markets in order to boost demand and increase returns to producers. Initially, those markets will be local ones for fresh roots or leaves, or small-scale processors of fermented flour or low-quality starch. As markets develop and demand grows, farmers have an incentive to grow more by intensifying production. An increased supply of raw material provides an incentive to processors to expand capacity and modernize their factories, which stimulates further production increases, driving an upward spiral of rural development. Examples of successful market development include the rapid growth in Thailand of the production of dried cassava chips and, more recently, of fuel ethanol for domestic markets and export.

Governments should promote private investment in cassava processing plants, and foster associations that link cassava growers and processors, such as the Thai Tapioca Starch Association and Nigeria's Cassava Market and Trade Development Corporation. Cassava industry stakeholders may need assistance in initiating industry-wide or activity-specific associations that can help enterprises of different sizes to work together. An active industry association can foster cooperation among value chain participants, promote grading standards, share market information, and lobby governments to support cassava subsector development. Industry clusters – market-driven, private sector-oriented groups or enterprises – can be formed around such associations to define the measures and activities needed to improve productivity and to make the value chain work efficiently.

Planners will need to link support to the cassava subsector with action to develop associated industries. For example, development of cassava as a feed resource should exploit complementarities with livestock and poultry enterprises; increasing output of high quality cassava flour will require the strengthening of links with the bakery industry.

Reduce farmers' exposure to price volatility. For people whose livelihood depends mainly on agriculture, volatility in output prices means fluctuations in income and greater risk. Guaranteeing farmers a reasonable price for their crops will encourage them to invest in production. One approach is subsidies, such as the Thai Government's national "pledging scheme", which set aside in 2012 some US$1.43 billion for purchasing roots from cassava growers[3]. More sustainable approaches include contract farming, which helps to reduce the transaction costs of input supply and output marketing by aggregating small parcels of farmland. Large scale processors not only ensure an agreed price to farmers but also provide technical services in return for growers' commitment to deliver all or a significant portion of production. In the Philippines, for example, one of the country's leading food manufacturers offers supply contracts to farmers' cooperatives that can consolidate at least 20 ha of land for cassava production. It provides start-up technical advice, a guaranteed floor price, and a marketing agreement that covers product quality, volumes and a delivery schedule[4].

Governments in developing countries should foster greater availability of crop insurance which, while it does not eliminate risk, does mitigate losses caused by adverse weather and similar events, thus improving risk-bearing capacity and encouraging investment in production. While common in industrialized countries, crop insurance is very limited in the developing world and particularly so for smallholder crops such as cassava.

Letting farmers decide

Farmers will need to be convinced that "Save and Grow" practices are better than those they are using already and – very importantly – that they have short-term economic benefits. Not all recommended practices are equally useful, nor are they universally applicable. Farmers are interested only in those practices that fit well with their cropping systems and ways of farming. Practices that may have been effective during trials on experimental stations may not perform nearly as well under farmers' local conditions.

Since most technologies have advantages and disadvantages, trade-offs need to be made. That can best be done by farmers themselves, rather than by researchers or extensionists. It is important, therefore, that cassava growers be involved in all stages of agricultural research and technology development, and are empowered to test and validate, in their own fields, practices aimed at improving the sustainability of cassava production. By shifting the extension paradigm from "teaching" to "learning", two methodologies – farmer participatory research (FPR) and farmer field schools (FFS) – have proven highly effective in incorporating sustainable natural resource management into smallholder production systems.

Farmer participatory research emerged in the 1990s in response to the failure of top-down agricultural research to deliver significant improvements in the well-being of low-income farmers in risk-prone environments. The difference between FPR and the more traditional "technology transfer" approach is that extension workers do not promote or recommend any particular practice or technology. Instead, they provide a menu of options that farmers can test in simple trials in their own fields, with help from research or extension staff[5].

CIAT has used farmer participatory research extensively in Asia for the development and transfer of cassava production technologies. Its FPR programme involved farmers in 99 villages in China, Thailand and Viet Nam, who conducted more than 1 150 trials, mostly of improved varieties, fertilization, erosion control, plant spacing, green manuring and the use of cassava roots and leaves as animal feed.

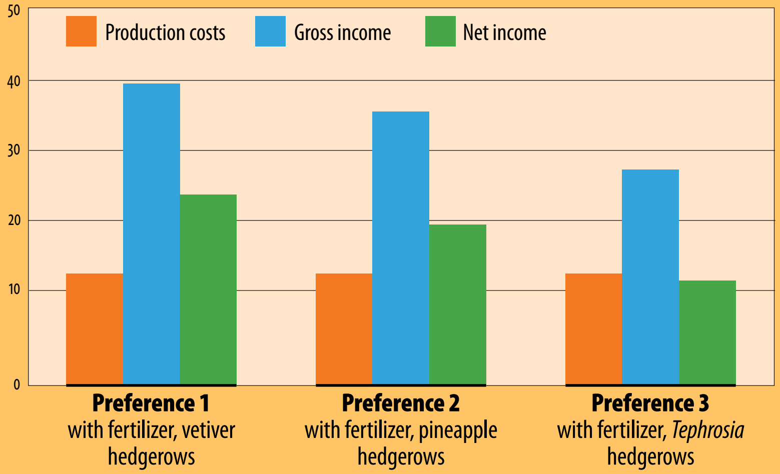
With FPR, members of a farmers' group, or farmers in a particular village or district, first diagnose the main problems encountered in cassava production and, with assistance from research and extension staff, consider possible solutions. From this diagnosis, they decide on specific topics for their trials. Whenever possible, the farmers visit experimental stations or other villages to view similar trials, or confer with farmers who have already adopted the practices being tested.

They then select 3 to 5 alternative treatments, along with one traditional practice, to test in simple, unreplicated FPR trials in their own fields. If all farmers in the area use the same treatments in one type of trial, each trial can be considered a replication, and the results can be averaged over those replications. That improves confidence in the results obtained.

The next step is for the farmers to design and conduct the trials, with help from research or extension staff. The farmers manage the trials themselves, while staff may visit occasionally to discuss progress and help solve problems. Finally, at harvest time, all farmers in the area, and from neighbouring areas if possible, are invited to a field day where they view the trials and discuss the results. During the field day, staff present the average results of the various types of trials, as well as the production costs, gross income and net income of each treatment. Based on this information, farmers can select those varieties or practices that they consider most suited to their own conditions.

The FPR approach has been highly successful. An independent impact assessment in 2003 found that, in Thailand, all of the farmers who had directly participated in trials had adopted improved varieties, 98 percent the use of mineral fertilizer, and 80 percent soil conservation practices to control erosion. In Viet Nam, the adoption rates were

Figure 31 **Farmer preferred cassava management options with groundnut intercrop in Viet Nam** (million dong)



Source: Annex Table 8.1

82 percent, 80 percent and 71 percent, respectively[6]. In one province of Viet Nam, improved technologies and agronomic practices boosted average per hectare root yields from 8.5 tonnes in 1994, when the trials began, to 36 tonnes in 2003. The Vietnamese trials, and Asian trials in general, have shown clearly that farmers prefer treatments which produce both sustainable yields and the highest net income (Figure 31).

Farmer field schools encourage a process of group-based learning, and were originally developed by FAO in the late 1980s to promote integrated pest management in Asian rice fields. At field schools, farmers are able to deepen their knowledge of agro-ecosystem processes, and test and validate practices that control pests and diseases and improve the sustainability of crop yields.

The application of FFS to cassava began in Africa in the late 1990s. The spread of new strains of the viruses causing cassava mosaic disease and, more recently, cassava brown streak disease, has served as an entry point for promoting IPM and eco-friendly production. Field schools link up with programmes that distribute disease-tolerant cassava varieties and test them in multiplication fields. This learning-by-doing approach provides the opportunity for farmers to develop strategies to manage disease problems more effectively, while improving their cassava production practices.

In the Democratic Republic of the Congo, an FAO project trained facilitators to assist 30 field schools in Kinshasa province, where yields of cassava had been declining owing to pest attacks, diseases and soil nutrient depletion. Through training in the use of healthy planting material, mulching and intercropping, the field schools helped farmers achieve yield increases of up to 250 percent[7].

In Gabon, pest and disease pressure, the lack of improved varieties, and the use of inefficient farming methods kept smallholder cassava root yields below 8 tonnes per ha. Through field schools, some 750 growers improved their skills in the selection of healthy planting material. Many began using higher-yielding varieties with resistance to cassava mosaic disease, as well as improved practices, such as avoiding cultivation on wet soils and planting stakes along the contours of sloping land in order to limit damage from root rot. They also learned the importance of regular weeding, eliminating diseased plants, planting in rows and optimizing planting densities.

An evaluation in 2012 found that, thanks mainly to the use of high-yielding varieties, integrated pest management and resource-conserving cultivation practices, the farmers had increased their cassava yields threefold. In one province, yields reached 30 tonnes per hectare[8].

Annex tables

Chapter 1: Cassava, a 21st century crop

Table 1.1 Harvested area of cassava (million ha)

	1980	1990	2000	2011
Sub-Saharan Africa	7.05	8.59	11.01	13.05
Asia	3.89	3.85	3.40	3.91
Latin America/Caribbean	2.65	2.75	2.54	2.67

Source: FAO. 2013. FAOSTAT statistical data base (http://faostat.fao.org)

Table 1.2 Cassava production (million tonnes)

	1980	1990	2000	2011
Sub-Saharan Africa	48.34	70.26	95.34	140.97
Asia	45.94	49.79	49.46	76.68
Latin America/Caribbean	29.70	32.21	31.30	34.36

Source: FAO. 2013. FAOSTAT statistical data base (http://faostat.fao.org)

Table 1.3 Average cassava yields (tonnes/ha)

	1980	1990	2000	2011
Sub-Saharan Africa	6.85	8.18	8.66	10.80
Asia	11.82	12.92	14.53	19.60
Latin America/Caribbean	11.23	11.72	12.34	12.88

Source: FAO. 2013. FAOSTAT statistical data base (http://faostat.fao.org)

Chapter 2: Farming systems

Table 2.1 Effect of method of land preparation on the yield of two cassava varieties in Mondomito, Cauca, Colombia in 1981/82

Tillage treatment	*Cassava root yield (t/ha)*	
	CMC 92	*MCol 113*
Without preparation	10.8	10.4
Hand preparation of planting holes	17.9	12.3
Preparation with oxen-drawn plough	16	11.6
Oxen-drawn plough followed by ridging	15	10
Preparation with tractor-mounted rototiller	15.7	14.1
Rototilling followed by ridging	16.8	10.9
1 m wide strips prepared with hoe, alternated with 1 m wide unprepared strips	12.2	9.7
1 m wide strips prepared with rototiller, alternated with 1 m wide unprepared strips	13.5	9.5
LSD 5%	4	1.8

Source: Howeler, R.H., Ezumah, H.C. & Midmore, D.J. 1993. Tillage systems for root and tuber crops in the tropics. *Soil Tillage Res.*, 27: 211-240.

Table 2.2 Effect of tillage system and nitrogen application rate in the first year on cassava root yield, Khon Kaen, Thailand, 2000/01 (tonnes/ha)

*Fertilizer rate**	*Tillage system*	
	Conventional tillage	*No tillage*
0-50-50	42.7	55.13
50-50-50	44.94	56.06
100-50-50	53.69	67
Average	47.13	59.38

* N-P_2O_5-K_2O in kg/ha

Source: Adapted from Jongruaysup, S., Treloges, V. & Chuenrung, C. 2003. Minimum tillage for cassava production in Khon Kaen Province, Thailand. *Songklanakarin J. Sci. Technol.*, 25(2): 191-197.

Table 2.3 Average responses of cassava top biomass, yield and root dry matter content (8 years) on dry weight basis to surface plant mulch, fertilizer and tillage in sandy loam soils, northern Colombia

*Treatment**	*Fertilization*			*No fertilization*		
	Root yield (t/ha)	*Top biomass (t/ha)*	*Root dry matter (%)*	*Root yield (t/ha)*	*Top biomass (t/ha)*	*Root dry matter (%)*
CT	5.51	3.18	30.2	2.19	1.43	30.1
CT+mulch	5.92	3.98	30.9	4.66	2.93	30.6
NT	4.42	2.77	29.5	1.93	1.43	29.2
NT+mulch	6.11	3.85	31	4.66	2.95	30.4
Mean	5.49	3.45	30.4	3.36	2.19	30.1

* CT = conventional tillage; NT = no tillage

Source: Adapted from Cadavid, L.F., El-Sharkawy, M.A., Acosta, A. & Sánchez, T. 1998. Long-term effects of mulch, fertilization and tillage on cassava grown in sandy soils in northern Colombia. *Field Crops Res.*, 57: 45-56.

Table 2.4 Effect of mulching on dry storage yield of late season cassava, Democratic Republic of the Congo (t/ha)

Cultivar	1981-82		1982-83		1983-84	
	*Mulch**	*No mulch*	*Mulch**	*No mulch*	*Mulch**	*No mulch*
Mpelolongi	4.7	4	6.2	4.7	6.1	3.4
30085/28	5.3	4.4	6.7	5	6.8	4.7
2864	4.8	4.2	7.1	5.2	6.8	4.5
30122/2	3.7	3.6	4.5	3.9	4.7	3.1
30555/3	3.7	3.2	5.2	3.7	4.9	3.2
30010/10	3.4	3.7	4	3.1	4.4	2.8
Means	4.3	3.8	5.6	4.3	5.6	3.6

* Rice straw at 5 t/ha

Source: Adapted from Lutaladio, N., Wahua, T. & Hahn, S. 1992. Effects of mulch on soil properties and on the performance of late season cassava (*Manihot esculenta* Crantz) on an acid ultisol in southwestern Zaire. *Tropicultura*, 10(1): 20-26.

Table 2.5 Average results of three FPR intercropping trials conducted by farmers in Suoi Rao and Son Binh villages, Chau Duc district, Ba Ria-Vung Tau, Viet Nam in 2001/02

Treatment	*Cassava yield (t/ha)*	*Starch content (%)*	*Inter-crop yield (t/ha)*	*Gross income*	*Production costs*	*Net income*	*Farmers' preference (%)*
				(million dong/ha)			
C + groundnut intercrop	30.74	27.66	1.483	25.81	10.07	15.73	48
C + mungbean intercrop	29.81	26.66	0.57	20.38	8.64	11.74	42
C + soybean intercrop	34.54	27.5	0	19.00	8.62	10.38	6
C + maize intercrop	21.00	24.30	3.64	15.56	8.59	6.90	35
Cassava monoculture	31.88	27.93	-	17.53	7.12	10.42	29

Source: Adapted from Nguyen, H.H., Tran, T.D., Nguyen, T.S., Tran, C.K., Tuan, V.V. & Tong, Q.A. 2008. The FPR cassava project and its impact in South Viet Nam. *In* R.H. Howeler, ed. *Integrated cassava-based cropping systems in Asia. Working with farmers to enhance adoption of more sustainable production practices.* Proceedings of a Workshop on the Nippon Foundation Cassava Project in Thailand, Viet Nam and China, held in Thai Nguyen, Viet Nam. Oct. 27-31, 2003. pp. 140-156.

Table 2.6 Effect of various crop management treatments on soil loss due to erosion and the yield of cassava and intercropped groundnut, as well as the gross and net income in an FPR erosion control trial conducted by six farmers in Kieu Tung village of Thanh Ba district, Phu Tho province, Viet Nam in 1997 (3rd year)

Treatment*	*Dry soil loss (t/ha)*	*Yield (t/ha)*	
		Cassava	*Groundnut*
C monoculture with fertilizer, no hedgerows	106.1	19.17	-
C+G, no fertilizer, no hedgerows	103.9	13.08	0.7
C+G, with fertilizer, no hedgerows	64.8	19.23	0.97
C+G, with fertilizer, *Tephrosia* hedgerows	40.1	14.67	0.85
C+G, with fertilizer, pineapple hedgerows	32.2	19.39	0.97
C+G, with fertilizer, vetiver hedgerows	32	23.71	0.85
C monocult., with fertilizer, *Tephrosia* hedgerows	32.5	23.33	-

* C = cassava; G = groundnut; fertilizers = 60 kg N + 40 P_2O_5 + 120 K_2O/ha; all plots received 10 t/ha pig manure

Source: Adapted from Howeler, R.H. 2001. The use of farmer participatory research (FPR) in the Nippon Foundation Project: Improving the sustainability of cassava-based cropping systems in Asia. *In* R.H. Howeler & S.L. Tan, eds. *Cassava's potential in Asia in the 21st Century: Present situation and future research and development needs.* Proc. 6th Regional Workshop, held in Ho Chi Minh city, Viet Nam. Feb. 21-25, 2000. pp. 461-489.

Table 2.7 Economics of sequential cropping with cassava and vegetable cowpea, Tamil Nadu, India

Treatment*	Cassava root yield (t/ha)	Production cost ('000 Rs/ha)	Gross income ('000 Rs/ha)	Net returns ('000 Rs/ha)
No treatment	26.9	16.04	56.24	40.19
Half treatment	41.2	19.60	80.90	61.30
Full treatment	40.9	24.94	80.73	55.79

* Full treatment = 26 kg/ha P + 25 tonnes/ha farmyard manure

Source: Adapted from Tamil Nadu Agricultural University (TNAU). 2002. *Report to Quinquennial Review Team – Tuber crops (1997-98 to 2001-02)*. Coimbatore Centre, AICRP on tuber crops (other than potato). Dept. of Vegetable Crops, Horticultural College and Research Institute, TNAU Coimbatore. pp. 34-35.

Chapter 3: Varieties and planting material

Table 3.1 Major collections of cassava germplasm

Location	Number of accessions	Type of accession* (%)				
		WS	LR	BL	AC	OT
CIAT	5436	1	87	11	0	1
Brazil	2889	0	0	0	0	100
IITA	2756	0	28	47	0	25
India	1327	0	0	0	0	100
Nigeria	1174	0	0	0	0	100
Uganda	1136	0	4	89	7	0
Malawi	978	0	22	72	6	0
Indonesia	954	0	0	0	100	0
Thailand	609	0	0	100	0	0
Benin	600	0	100	0	0	0
Togo	435	0	100	0	0	0
Other	14148	6	26	3	14	51

* WS = wild species; LR = landraces/old cultivars; BL = research materials/breeding lines; AC = advanced cultivars; OT = others (type unknown or a mixture of two or more types)

Source: Adapted from FAO. 2010. *The second report on the state of the world's plant genetic resources for food and agriculture.* Rome.

Table 3.2 Effect of N, P and K fertilization of mother plants of cassava used for production of planting material on the root and stem yield of the subsequent crop

Fertilization of mother plants (kg/ha)*	Sprouting (%)	Fresh root and stem yields (t/ha)			
		Unfertilized		Fertilized**	
N P K		Roots	Stems	Roots	Stems
0 0 0	85	13.5	2.02	19.1	4.49
0 100 100	97	17.5	2.63	25.6	3.64
100 0 100	98	14.9	2.98	23.5	4.38
100 100 0	77	15.8	2.25	24.7	4.53
100 100 100	97	24.2	3.10	30.2	6.22

* Rates are in kg/ha of N, P and K

** Application at planting of 50 kg N, 43 kg P and 83 kg K/ha

Source: Adapted from Lopez, J. & El-Sharkawy, M.A. 1995. Increasing crop productivity in cassava by fertilizing production of planting material. *Field Crops Res.*, 44: 151-157.

Chapter 4: Water management

Table 4.1 Effect of delayed planting on root yield of late season cassava in southern Nigeria

Month of planting	*Root yield (dry weight, t/ha)*	*Percent of June planting yield*
June	10.81	100
July	9.72	90
August	6.91	64
September	6.70	62
October	4.48	41

Source: Adapted from International Institute of Tropical Agriculture (IITA). 1977. *Annual Report for 1977.* Ibadan, Nigeria.

Table 4.2 Effect of time of planting and age at harvest on yield (t/ha) in Thailand (1976-78)

	8 months	*10 months*	*12 months*	*14 months*	*16 months*	*18 months*	*Average*
May	20.27	26.98	36.49	42.46	49.52	57.06	38.76
Jun	22.15	27.73	36.51	47.31	51.93	53.36	39.83
Jul	19.82	29.07	35.07	40.74	44.05	48.51	36.21
Aug	14.46	22.96	29.14	38.62	39.57	43.68	31.41
Sep	12.25	17.64	28.65	32.48	34.59	36.26	26.98
Oct	8.16	16.69	22.17	23.95	29.52	32.61	22.18

Source: Adapted from Sinthuprama, S. 1980. Cassava planting systems in Asia. *In* E.J. Weber, J.C. Toro & M. Graham, eds. *Cassava cultural practices*. Proc. of a Workshop, held in Salvador, Bahia, Brazil. March 18-21, 1980. pp. 50-53.

Table 4.3 Effect of different planting dates, and the average rainfall received, on cassava growth and yield when cassava, cv. Rayong 90, was grown for three consecutive cycles at Rayong Field Crops Research Center in Thailand from 1994 to 1998

*Month of planting**	*Total rainfall** (mm)*	*Canopy cover*** (%)*	*Final plant stand (%)*	*Root yield (t/ha)*	*Starch content (%)*	*Starch yield (t/ha)*
June	1402	77.3	97	23.32	21.27	4.96
August	1409	55.0	97	18.92	22.33	4.22
October	1267	55.0	91	24.56	25.73	6.32
December	1665	82.0	90	32.18	25.07	8.07
February	1633	89.2	88	27.92	30.35	8.47
April	1616	87.8	87	25.67	26.13	6.71

* Roots were harvested after 11 months

** Rainfall received during the 11-month growth cycle

*** Percent canopy cover averaged over all months of the growth cycle

Source: Adapted from Howeler, R.H. 2001. Cassava agronomy research in Asia: Has it benefited cassava farmers? *In* R.H. Howeler & S.L. Tan, eds. *Cassava's potential in Asia in the 21st Century: Present situation and future research and development needs.* Proc. 6th regional workshop, held in Ho Chi Minh city, Viet Nam. Feb 21-25, 2000. pp. 345-382.

Table 4.4 Effect of planting method, stake position, stake length, and planting depth on cassava yield, planted in both the rainy and dry season at Rayong Field Crops Research Center, Thailand

Treatment	*Rainy season (May-August)*			*Early dry season (November)*		
	*No. plants survived ('000/ha)**	*Root yield (t/ha)*	*Starch content (%)*	*No. plants survived ('000/ha)**	*Root yield (t/ha)*	*Starch content (%)*
Planting method **Ridge**	14.57	14.98	16.64	10.69	14.69	18.63
Planting method **No ridge**	14.43	13.47	16.66	12.09	14.96	18.65
Stake position **Vertical**	14.87	16.04	17.03	13.04	17.74	19.04
Stake position **Inclined**	14.89	15.46	17.14	11.99	16.40	18.68
Stake position **Horizontal**	13.74	11.08	15.85	9.31	10.32	18.17
Stake length **(20 cm)**	14.55	14.52	16.67	10.58	14.53	18.51
Stake length **(25 cm)**	14.41	13.54	16.69	13.02	15.41	18.87
Planting depth **(5-10 cm)**	14.43	13.90	16.61	9.74	13.14	18.21
Planting depth **(15 cm)**	14.56	14.43	16.73	12.71	16.17	18.97

Data are the average of three years, 1987-1989

* Out of a total of 15 625 stakes/ha planted

Source: Adapted from Tongglum, A., Vichukit, V., Jantawat, S., Sittibusaya, C., Tiraporn, C., Sinthuprama, S. & Howeler, R.H. 1992. Recent progress in cassava agronomy research in Thailand. *In* R.H. Howeler, ed. *Cassava breeding, agronomy and utilization research in Asia.* Proc. 3rd regional workshop, held in Malang, Indonesia. Oct. 22-27, 1990. pp. 199-223.

Table 4.5 Effect of supplemental flood irrigation on the average root yield, and starch and HCN contents of cassava planted at CTCRI, Trivandrum, India, 1982-1985

*Level of irrigation**	*Fresh root yield (t/ha)*	*Starch content (% on dry wt. basis)*	*HCN (ppm on fresh wt. basis)*
IW/CPE = 0 (rainfed)	20.8	72.7	55
IW/CPE = 0.25	24.5	72.9	41
IW/CPE = 0.50	30.8	74.5	41
IW/CPE = 0.75	34.8	75.2	33
IW/CPE = 1.0	39.7	75	22
C.D. (0.05)	4.8		

* Irrigation during drought periods (more than 7 days without rains); IW = irrigation water in mm; CPE = cumulative pan evaporation in mm.

Source: Adapted from Nayar, T.V.R., Mohankumar, B. & Pillai, N.G. 1985. Productivity of cassava under rainfed and irrigated conditions. *J. Root Crops*, 11(1-2): 37-44.

Table 4.6 Effect of flood and drip irrigation on the fresh root yield of cassava grown for three consecutive years on sandy loam soils in Bhavanisagar, Tamil Nadu, India (t/ha)

*Irrigation method/level**	*1996/1907*	*1998*	*1999/2000*
Flood irrigation, 5 cm at 0.60 IW/CPE	48.5	59.8	45.8
Drip irrigation at 100% of flood irrigation	57.6	67.3	51.2
Drip irrigation at 75% of flood irrigation	53.9	64.6	50.4
Drip irrigation at 50% of flood irrigation	51.6	62.2	46.2

* IW = irrigation water in mm; CPE = cumulative pan evaporation in mm.

Source: Adapted from Manickasundaram, P., Selvaraj, P.K., Krishnamoorthi, V.V. & Gnanamurthy, P. 2002. Drip irrigation and fertilization studies in tapioca. *Madras Agric. J.*, 89(7-9): 466-468.

Table 4.7 Effect of different amounts of supplemental drip irrigation on the tuber yield of cassava grown for two years at the Federal University of Technology in Akure, Nigeria

Level of drip irrigation (% of available soil water)	*Dry root yield (t/ha)**		*Total water supplied by irrigation as % of water used*	
	2006/07	*2007/08*	*2006/07*	*2007/08*
0	4.66	2.98	0	0
25	8.53	6.43	14.83	17.85
50	13.10	9.20	34.33	40.65
100	28.15	15.36	51.11	61.72

* For a 9-month growth cycle, during which period total rainfall was 872 and 795 mm in 2006/07 and 2007/08, respectively

Source: Adapted from Odubanjo, O.O., Olufayo, A.A. & Oguntunde, P.G. 2011. Water use, growth, and yield of drip irrigated cassava in a humid tropical environment. *Soil Water Res.*, 6(1): 10-20.

Chapter 5: Crop nutrition

Table 5.1 Nutrient distribution in 12-month-old cassava, cv. M Ven 77, grown without fertilization in Carimagua, Colombia (kg/ha)

	N	*P*	*K*	*Ca*	*Mg*	*S*	*B*	*Cu*	*Fe*	*Mn*	*Zn*
Roots	30.3	7.5	54.9	5.4	6.5	3.3	0.08	0.02	0.38	0.02	0.1
Plant tops	69.1	7.4	33.6	37.4	16.2	8.2	0.07	0.03	0.45	0.33	0.26
Fallen leaves	23.7	1.5	4	24.7	4	2.5	0.04	0.01	0	0.37	0.18

Source: Adapted from Howeler, R.H. 1985. Mineral nutrition and fertilization of cassava. *In* J.H. Cock & J.A. Reyes, eds. *Cassava: Research, production and utilization.* UNDP-CIAT Cassava Program. Cali, Colombia. pp. 249-320.

Table 5.2 Effect of four sources of nitrogen on the yield and quality attributes of cassava, cv. Sree Visakham, grown at the College of Agriculture, Trivandrum, India, 1989-1991

	Number of roots/plant	*Root yield (t/ha)*	*HCN content (ppm, fresh weight basis)*	*Total dry matter (t/ha)*
Urea	5.1	19.95	47.4	10.52
Neem-coated urea	5.8	22.59	46.8	12.13
Urea super-granule	5.9	25.65	48.4	13.97
Rubber cake-coated urea	4.9	17.76	48.2	10.4

Source: Vinod, G.S. & Nair, V.M. 1992. Effect of slow release nitrogenous fertilizers on the growth and yield of cassava. *J. Root Crops* (Special issue), 17: 123-125.

Table 5.3 Effect of planting intercrops, green manures and alley crops, with or without fertilizers, on cassava and intercrop yields, as well as the gross and net income obtained when cassava, KM 60, was grown for the 16th consecutive year at Hung Loc Agricultural Research Center in Dongnai, Viet Nam in 2007/08

	Root yield (t/ha)		*Starch content (%)*		*Gross income (million d/ha)*		*Production costs (million d/ha)*		*Net income (million d/ha)*	
*Treatment**	*with fertilizer*	*without fertilizer*	*with fertilizer*	*without fertilizer*	*with fertilizer*	*without fertilizer*	*with fertilizer*	*without fertilizer*	*with fertilizer*	*without fertilizer*
C monoculture	17.44	4.81	23.28	21.28	20.41	5.63	6.01	3.80	14.40	1.83
C+pigeon pea GM	15.62	6.75	23.6	21.7	18.28	7.90	8.11	5.90	10.17	2.00
C+*Mucuna* GM	17.82	8.56	24.45	22.35	20.85	10.02	8.11	5.90	12.74	4.12
C+groundnut IC	20.41	8.62	25.35	24.08	24.82	10.09	8.11	5.90	16.72	4.19
C+cowpea IC	19.44	7.44	24.92	22.65	22.75	8.71	8.11	5.90	14.64	2.81
C+*Crotalaria* GM	18.75	8.5	24.95	21.72	21.94	9.95	8.11	5.90	13.83	4.05
C+*Leucaena* AC	20.68	13.39	25.52	24.4	24.20	15.67	7.71	5.50	16.49	10.17
C+*Gliricidia* AC	19.3	16.75	26.32	24.95	22.58	19.60	7.71	5.50	14.87	14.10
Average	18.68	9.35	24.8	22.89	21.98	10.94	7.75	5.54	14.23	5.40

* C = cassava; GM = green manure;
IC = intercrop; AC = alley crop

Source: Nguyen Huu Hy, personal communication.

Table 5.4 Effect of application of various rates of chemical fertilizer and incorporation of the green manure species *Tithonia diversifolia* and *Chromolaena odorata* on cassava fresh root yields (t/ha) during two cropping cycles at two sites in the Bas-Congo region of DR Congo

Green manures	*Fertilizer rate* (kg/ha)*	*First crop*		*Second crop*	
		Kiduma	*Mbuela*	*Kiduma*	*Mbuela*
None	0	12.7	10.5	10.1	5.4
None	283	23.7	14.9	14.9	7.4
None	850	31.4	19.6	17.6	9
None	1,417	39.6	18.6	33.1	18
Tithonia	0	32.8	18.1	12.7	6.4
Tithonia	283	37.6	23.5	17.8	8.7
Tithonia	850	41.5	21.7	20.2	8.2
Chromolaena	0	19.9	18.2	12.2	7.3
Chromolaena	283	29.5	21.1	18.4	8.5
Chromolaena	850	35.2	23.4	18.6	9

* Fertilizer = 17-17-17 as N-P_2O_5- K_2O

Source: Adapted from Pypers, P., Sanginga, J.M., Kasereka, B., Walangululu, M. & Vanlauwe, B. 2011. Increased productivity through integrated soil fertility management in cassava-legume intercropping systems in the highlands of Sud-Kivu, DR Congo. *Field Crops Res*., 120: 76-85.

Table 5.5 Effect of the application of farm-yard manure (FYM) and chemical fertilizers on cassava yield and economic benefit at Thai Nguyen University of Agriculture and Forestry in Thai Nguyen province of Viet Nam, in 2001 (2nd year)

Treatment	*Cassava root yield (t/ha)*	*Harvest Index*	*Gross income*	*Fertilizer costs*	*Production costs*	*Net income*
			('000 dong/ha)			
No fertilizers, no FYM	3.25	0.39	1,625	0	2,800	-1,175
5 t FYM/ha	7.79	0.49	3,895	500	3,300	595
10 t FYM/ha	10.02	0.52	5,010	1,000	3,800	1,210
15 t FYM/ha	13.11	0.52	6,555	1,500	4,300	2,255
80 N+80 K_2O/ha, no FYM	15.47	0.5	7,735	680	3,580	4,155
80 N+80 K_2O/ha + 5 t FYM/ha	17.98	0.48	8,990	1,180	4,080	4,910
80 N+80 K_2O/ha + 10 t FYM/ha	18.7	0.49	9,350	1,680	4,580	4,770
80 N+80 K_2O/ha + 15 t FYM/ha	18.5	0.48	9,250	2,180	5,080	4,170

Source: Adapted from Nguyen The Dang, personal communication, 2002.

Table 5.6 Effect of various fertilizer combinations on the fresh root yields of cassava, cv. Faroka, and on the grain yield of intercropped maize, as well as gross and net income when grown in Jatikerto Station in Malang, East Java, Indonesia, in 2005/06 (2nd year)

Treatment $N-P_2O_5-K_2O$ (kg/ha)	*Organic (t/ha)*	*Cassava yield (t/ha)*	*Maize yield (t/ha)*	*Gross income*	*Fertilizer costs*	*Production costs*	*Net income*	*Farmers' preference*
				(mil. Rp/ha)				
0-0-0	0	10.96	1.1	4.72	0	4.1	0.62	
135-0-0	0	35.6	1.93	13.52	0.45	7.01	6.51	2
135-50-0	0	36.8	2.07	14.05	0.69	7.37	6.68	3
135-50-100	0	37.47	2.1	14.3	1.27	8.02	6.28	4
0-0-0	10 manure	26.53	1.66	10.32	2	7.65	2.67	
0-0-0	10 compost	22.67	1.63	9.05	1	6.27	2.78	
135-0-0	5 manure	35.63	2.26	13.89	1.45	8.01	5.88	1
135-0-0	5 compost	39.33	1.97	14.75	0.95	7.88	6.87	5
135-50-0	5 compost	39.07	1.87	14.56	1.19	8.1	6.46	
135-0-0	5 sugar mud	33.73	1.67	12.63	0.95	7.32	5.31	

Source: Adapted from Utomo, W.H., Marjuki, W., Hartoyo, K., Suharjo Retnaningtyas, E., Santoso, D. & Wijaya, A. 2010. Enhancing the adoption of improved cassava production and utilization systems in Indonesia (The ACIAR Cassava Project in Indonesia). *In* R.H. Howeler, ed. *A new future for cassava in Asia: Its use as food, feed and fuel to benefit the poor.* Proc. 8th Regional Workshop, held in Vientiane, Lao PDR. Oct. 20-24, 2008. pp. 490-507.

Table 5.7 Average nutrient content of one tonne of various types of wet manure and compost as compared to 50 kg of 15-15-15 chemical fertilizers

	DM (%)	*N (kg)*	*P (kg)*	*K (kg)*
1 t cattle manure	32	5.9	2.6	5.4
1 t pig manure	40	8.2	5.5	5.5
1 t chicken manure	57	16.6	7.8	8.8
1 t sheep manure	35	10.5	2.2	9.4
1 t city garbage compost	71	6.9	3.3	6.1
50 kg 15-15-15 fertilizer	100	7.5	3.3	6.2

Source: Howeler, R.H. 2001. Cassava agronomy research in Asia: Has it benefited cassava farmers? *In* R.H. Howeler & S.L. Tan, eds. *Cassava's potential in Asia in the 21st Century: Present situation and future research and development needs.* Proc. 6th regional workshop, held in Ho Chi Minh city, Viet Nam. Feb. 21-25, 2000. pp. 345-382.

Table 5.8 Effect of various soil conservation practices on the average 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 Viet Nam from 1993 to 2003

Soil conservation practice	Relative cassava yield (%)		Relative dry soil loss (%)	
	Cassava monoculture	Cassava + groundnut	Cassava monoculture	Cassava + groundnut
With fertilizers; no hedgerows (check)	100	-	100	-
With fertilizers; vetiver grass hedgerows	113	115	48	51
With fertilizers; *Tephrosia candida* hedgerows	110	105	49	64
With fertilizers; *Flemingia macrophylla* hedgerows	103	109	51	62
With fertilizers; *Paspalum atratum* hedgerows	112	-	50	-
With fertilizers; *Leucaena leucocephala* hedgerows	110	-	69	-
With fertilizers; *Gliricidia sepium* hedgerows	107	-	71	-
With fertilizers; pineapple hedgerows	100	103	48	44
With fertilizers; vetiver + *Tephrosia* hedgerows	-	102	-	62
With fertilizers; contour ridging; no hedgerows	106	-	70	-
With fertilizers; closer spacing, no hedgerows	122	-	103	-
With fertilizers; groundnut intercrop; no hedgerows	106	100	81	100
With fertilizers; maize intercrop; no hedgerows	69	-	21	-
No fertilizers; no hedgerows	32	92	137	202

Source: Adapted from Howeler, R.H. 2008. Results, achievements and impact of the Nippon Foundation Cassava Project. *In* R.H. Howeler, ed. *Integrated cassava-based cropping systems in Asia. Working with farmers to enhance adoption of more sustainable production practices.* Proc. of a Workshop on the Nippon Foundation Cassava Project in Thailand, Viet Nam and China, held in Thai Nguyen, Viet Nam, Oct. 27-31, 2003. pp. 161-209.

Chapter 6: Pests and diseases

Table 6.1 Effect of hand weeding at different times and frequencies on the fresh root yield of cassava, cv. CMC 39, at 280 days after planting at CIAT, Cali, Colombia

No. of hand weedings*	Frequency of hand weeding (days)					Fresh cassava root yield (t/ha)	Yield as % of maximum yield***
4 +	15	30	60	120	UH**	18.0	86
3 +		30	60	120	UH	16.0	76
2+			60	120	UH	11.0	52
1+				120	UH	7.0	33
4	15	30	60	120		19.5	92
3	15	30	60			12.9	61
2	15	30				13.3	63
1	15					5.8	28
2		30	60			16.3	77
2	15	45				15.4	73
0	Chemical weed check					21.1	100
0	Weedy check					1.4	7

* + = additional weedings

** UH = until harvest, as needed

*** Percentage of the yield of cassava weeded with herbicides

Source: Doll, J.D. & Piedrahita, C.W. 1978. *Methods of weed control.* Cali, Colombia, CIAT.

Chapter 7: Harvest, post-harvest and value addition

Table 7.1 Average effect of the number and timing of leaf cutting on the total dry leaf and protein yields, root yield and starch content of two cassava varieties, as well as gross and net income obtained in an experiment at TTDI Center in Huay Bong, Thailand

*No. of leaf cuts**					*Total dry leaf yield (t/ha)*	*Protein content (%)*	*Total leaf protein yield (t/ha)*	*Fresh root yield (t/ha)*	*Root starch content (%)*	*Gross income*			*Production costs*	*Net income*
										Leaves	*Roots*	*Total*		
1	2	3	4	5						('000 B/ha)				
				X	0.71	24.46	0.17	39.89	19.58	4.15	45.43	49.58	24.3	25.28
X				X	1.5	25.16	0.38	39.91	20.15	9.02	46.01	55.04	30.68	24.35
X	X			X	1.99	25.21	0.5	27.02	21.1	11.92	31.59	43.51	32.53	10.99
X	X	X		X	2.56	25.13	0.64	28.6	19.75	15.34	32.53	47.88	36.78	11.09
X	X	X	X	X	2.57	25.28	0.65	24.46	18.19	15.56	27.2	42.76	40.07	2.7
Average					1.87	25.05	0.47	31.97	19.75	11.2	36.55	47.75	32.87	14.88

* Cuts no. 1, 2, 3, 4 and 5 correspond to leaf cuttings at 2.5, 5, 7, 9 and 11 MAP, respectively, with the last cut at time of root harvest

Source: Adapted from Howeler, R.H. 2012. Cassava leaf production for animal feeding. *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. 626-648.

Chapter 8: The way forward

Table 8.1 Effect of various crop management treatments on soil loss due to erosion and the yield of cassava and intercropped groundnut, as well as the gross and net income in an FPR erosion control trial conducted by six farmers in Kieu Tung village of Thanh Ba district, Phu Tho province, Viet Nam in 1997 (3rd year)

*Treatment**	*Gross income*	*Production costs*	*Net income*	*Farmers' ranking*
	(mil. dong/ha)			
C monoculture with fertilizer, no hedgerows	9.58	3.72	5.86	6
C+G, no fertilizer, no hedgerows	10.04	5.13	4.91	5
C+G, with fertilizer, no hedgerows	14.47	5.95	8.52	-
C+G, with fertilizer, *Tephrosia* hedgerows	11.58	5.95	5.63	3
C+G, with fertilizer, pineapple hedgerows	14.55	5.95	8.6	2
C+G, with fertilizer, vetiver hedgerows	16.1	5.95	10.15	1
C monocult. with fertilizer, *Tephrosia* hedgerows	11.66	4.54	7.12	4

* C = cassava; G = groundnuts; fertilizers = 60 kg N + 40 P_2O_5 + 120 K_2O/ha; all plots received 10 t/ha pig manure

Source: Adapted from Howeler, R.H. 2001. The use of farmer participatory research (FPR) in the Nippon Foundation Project: Improving the sustainability of cassava-based cropping systems in Asia. *In* R.H. Howeler & S.L. Tan, eds. *Cassava's potential in Asia in the 21st Century: Present situation and future research and development needs.* Proc. 6th Regional Workshop, held in Ho Chi Minh city, Viet Nam. Feb. 21-25, 2000. pp. 461-489.

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Abbreviations

CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture
CBSD	cassava brown streak disease
CMD	cassava mosaic disease
CTCRI	Central
FAO	Food and Agriculture Organization of the United Nations
FFS	farmer field school
FPR	farmer participatory research
GDP	gross domestic product
ha	hectare
IFAD	International Fund for Agricultural Development
IITA	International Institute of Tropical Agriculture
IPM	integrated pest management
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
K	potassium
K_2O	potassium oxide
N	nitrogen
NGOs	non-governmental organizations
P	phosphorus
P_2O_5	phosphorus pentoxide
t	tonne
TUUSI	Technology Uptake and Upscaling Support Initiative

This guide is the first on the practical application of FAO's "Save and Grow" model of agriculture to specific smallholder crops and farming systems. It comes as cassava production intensifies worldwide, and growers shift from traditional cultivation practices to monocropping, higher-yielding genotypes, and greater use of agrochemicals. Intensification carries great risks, including soil nutrient depletion and upsurges in pests and diseases. The guide shows how ecosystem-based "Save and Grow" approaches and practices can help tropical developing countries to avoid the risks of unsustainable intensification, while realizing cassava's potential for producing higher yields, alleviating hunger and rural poverty, and contributing to national economic development.

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