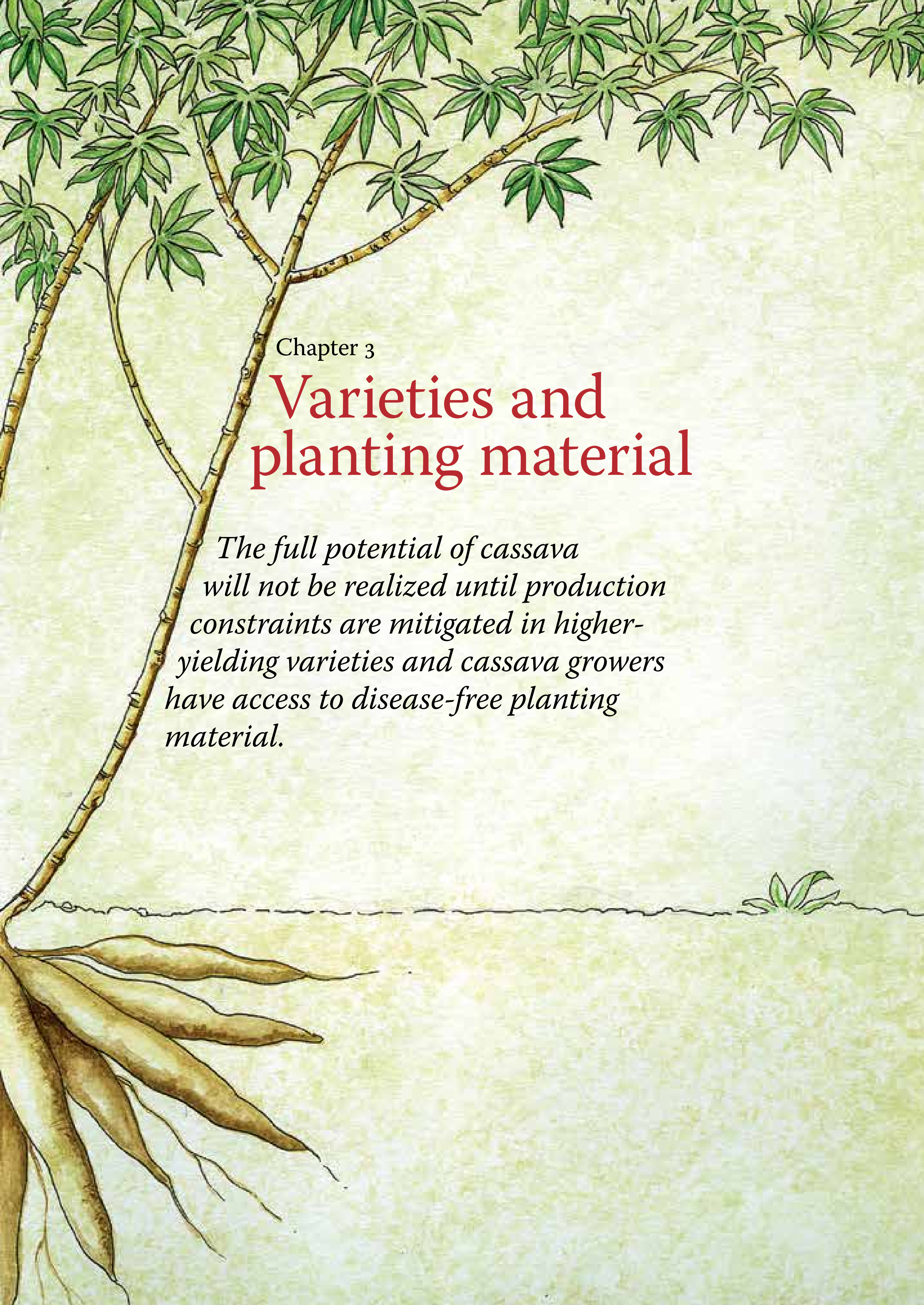


Chapter 3

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

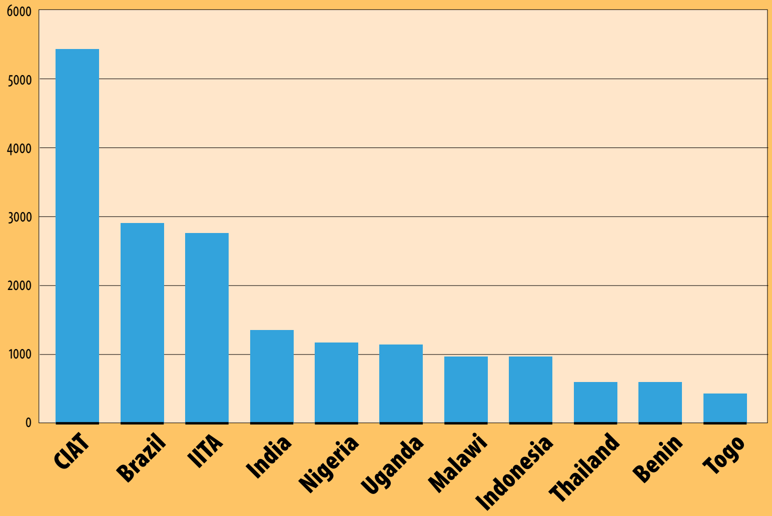
The genus *Manihot* consists of the cultivated species, *Manihot esculenta*, and – depending on the taxonomic classification used – from 70 to 100 wild species[4]. Both wild relatives and traditional cultivars, or landraces, developed by farmers over centuries are the primary sources of genes and gene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

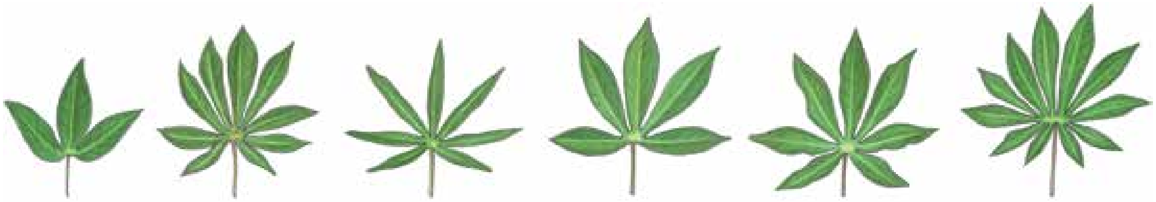
The harmonization of passport and evaluation data on genebank accessions should also be a priority. Molecular biology tools, underpinned by robust information technology, would contribute to more efficient data generation and dissemination, and facilitate global genotyping of cassava accessions. Data 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



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.

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

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].

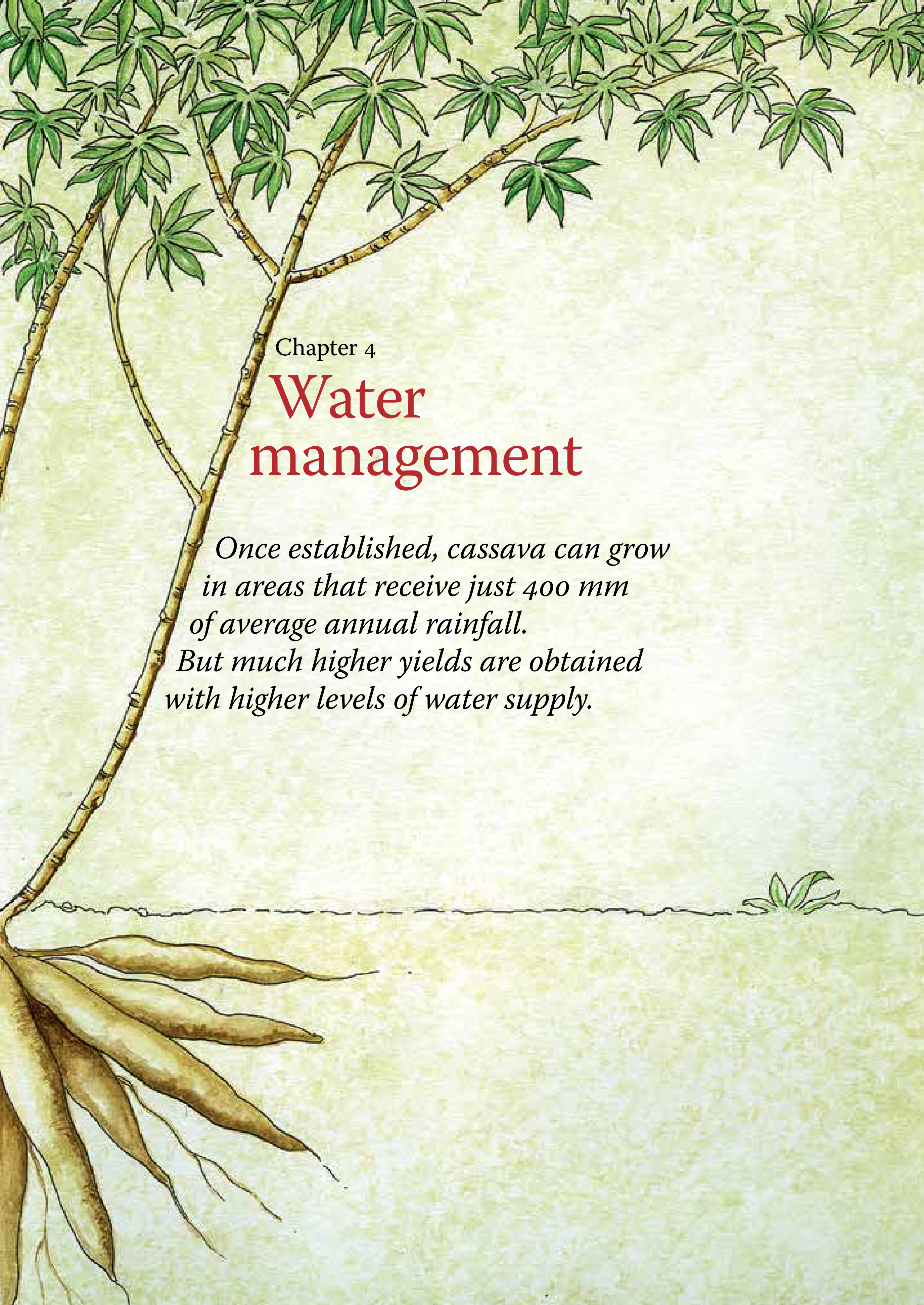
A high level of grassroots participation in multiplication was achieved by the Great Lakes Cassava Initiative, managed by Catholic Relief Services and supported by the Bill & Melinda Gates Foundation. Implemented in six countries of East and Central Africa, the initiative involved 10 agricultural research 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.

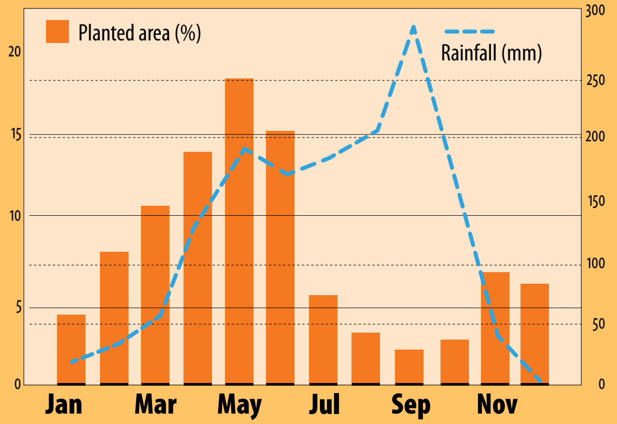
Cassava can be planted throughout the year if rainfall is evenly distributed, but not during periods of heavy rains or drought[10]. In areas with only one rainy season per year, farmers usually plant as soon as the rains start – generally around April-May in the northern tropics and October-November 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.

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.

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



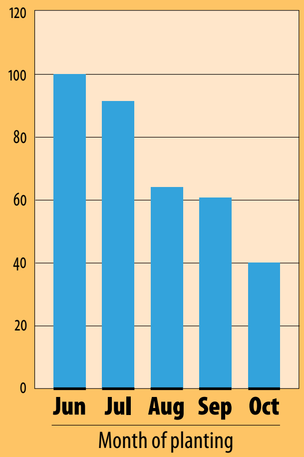
Source: Adapted from Sinthuprama, S. 1980. Cassava planting systems in Asia. In E.J. Weber, J.C. Toro and M. Graham (eds.). *Cassava cultural practices.* Proc. of a Workshop, held in Salvador, Bahia, Brazil. March 18-21, 1980. pp. 50-53.

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].

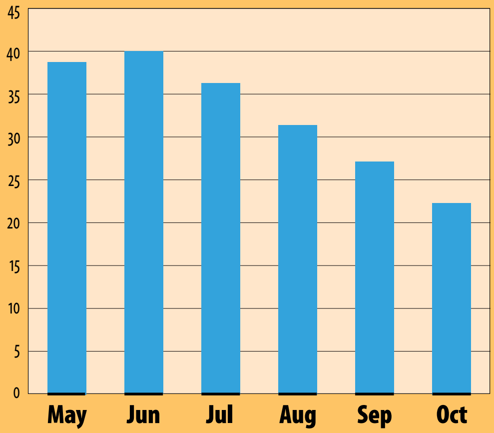
However, later research at the same location in Thailand, using four improved Rayong varieties, showed that the highest average yield was obtained by planting in August to November; planting either

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)



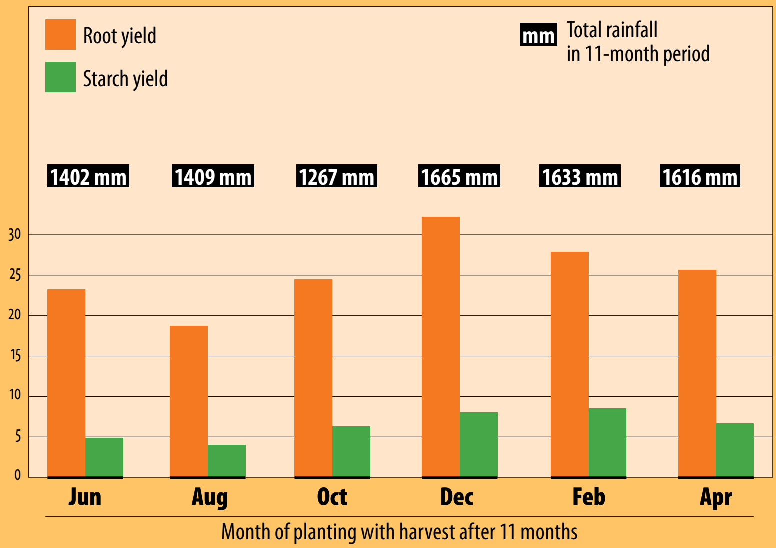
* roots harvested at 8, 10, 12, 14, 16 and 18 months

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

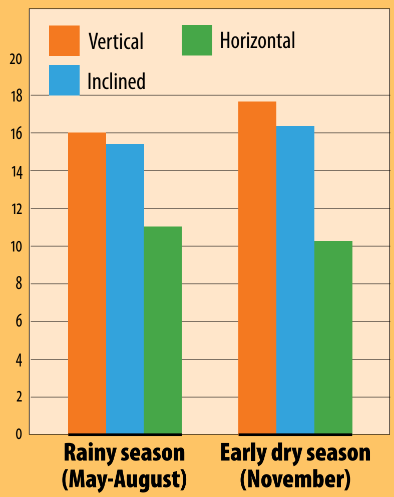
Planting methods need to be tailored to soil moisture conditions under rainfed production. When the soil is not well drained and too wet owing to heavy rains, it is better to plant stakes on the top of ridges or mounds to keep the roots above the standing water. That will also reduce root rots. However, 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].

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.

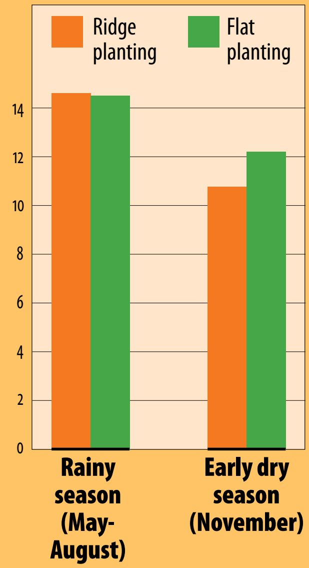
Sometimes, it may be better to delay planting to the latter part of the rainy season, but no later than about two months before the onset of the dry season. Planting towards the end, rather than at the beginning, of the rainy season usually results

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



Source: Annex Table 4.4

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



Source: Annex Table 4.4

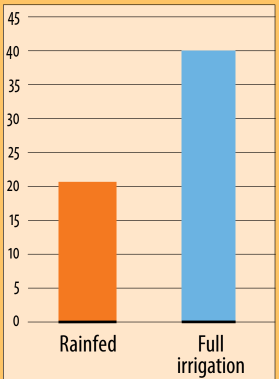
in lower yields, but it has some advantages: less weed competition and – if the crop is harvested in the off-season – the possibility of higher market prices. Another advantage is that the late planting of cassava does not coincide with other major agricultural activities, so there is less competition 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

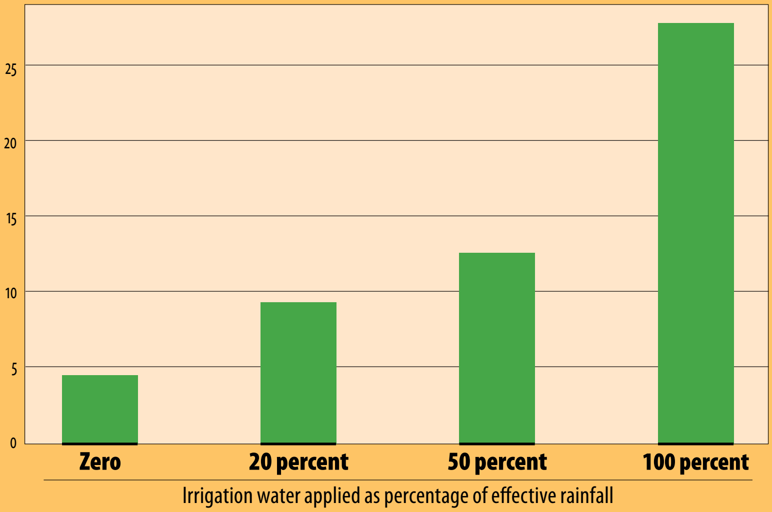
Figure 19 **Effect of supplemental irrigation* on cassava root yield, India** (t/ha)



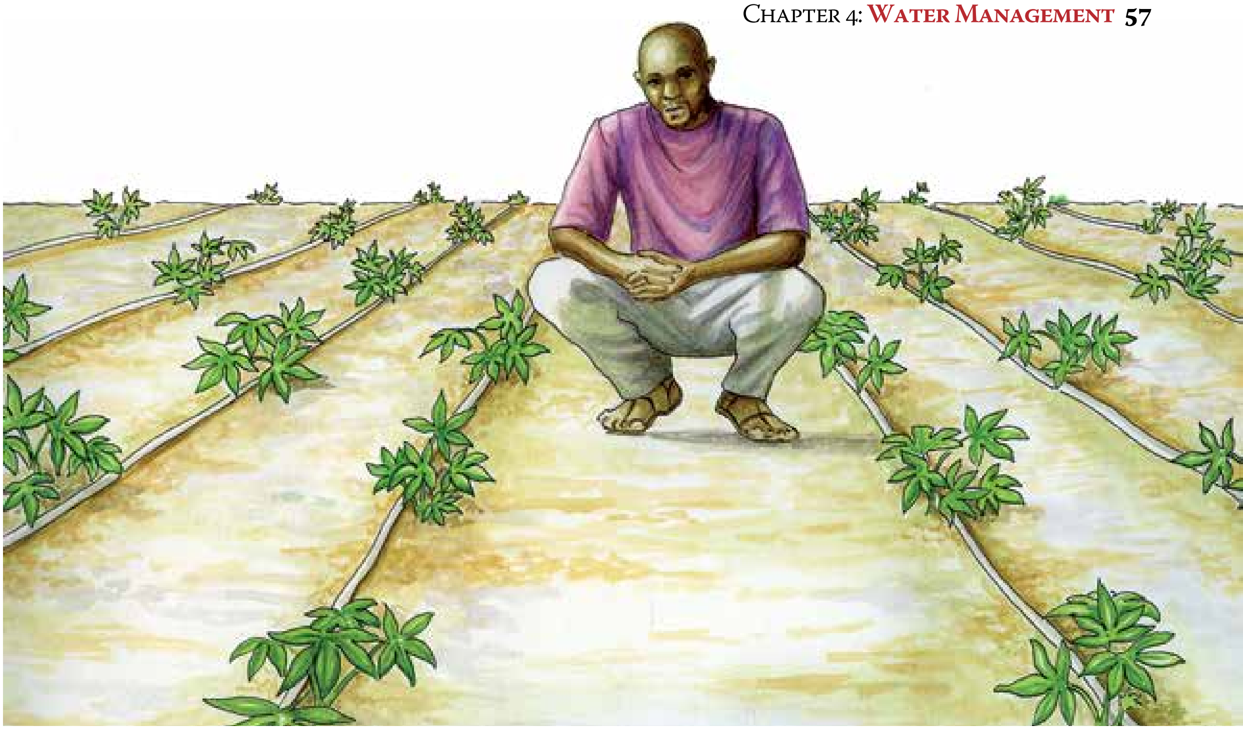
* during drought periods (more than 7 days without rain)

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].

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

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].

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].