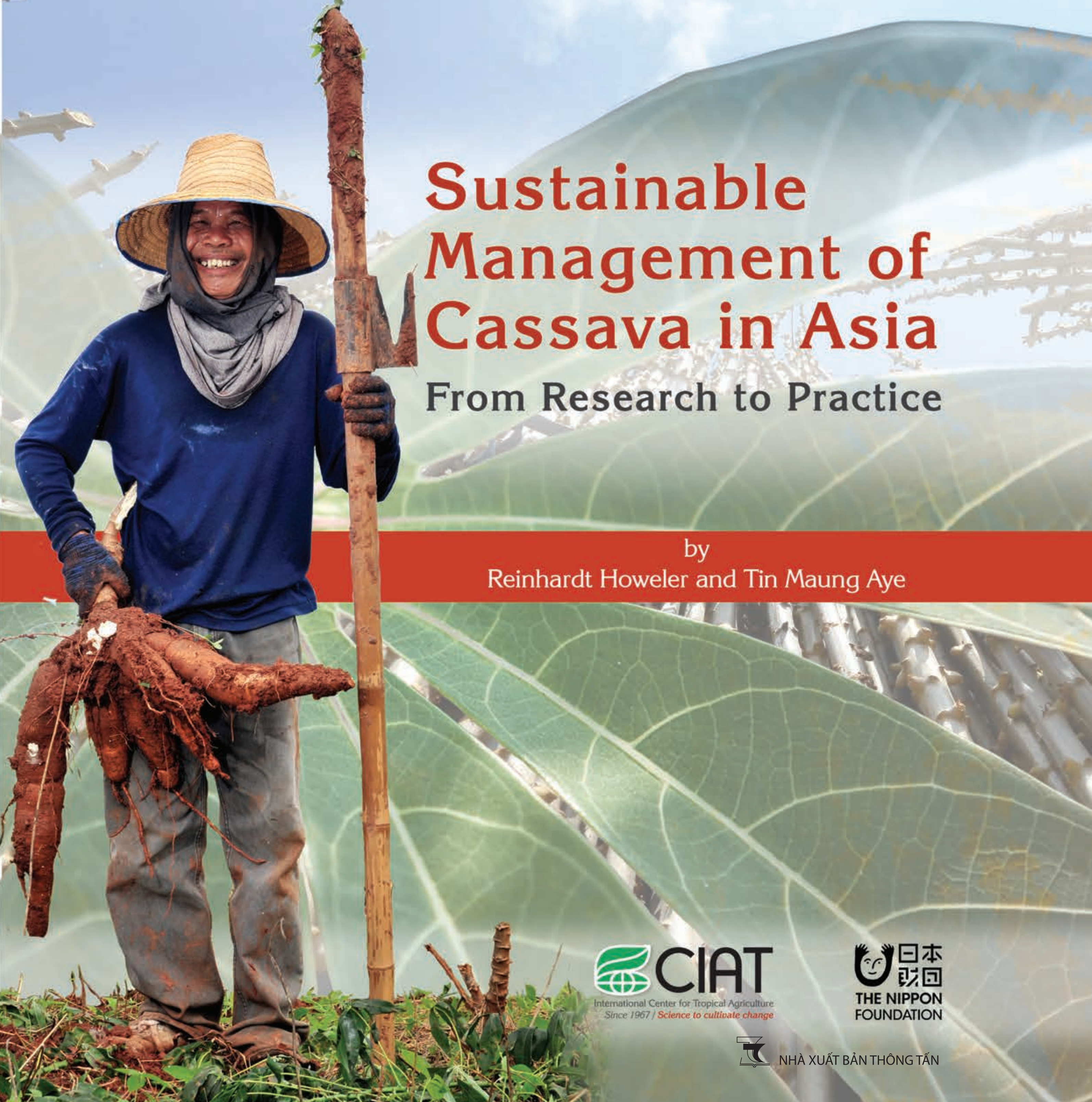

Sustainable Management of Cassava in Asia

From Research to Practice

by
Reinhardt Howeler and Tin Maung Aye

CIAT
International Center for Tropical Agriculture
Since 1967 / Science to cultivate change

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1. *Manihot esculenta*. 2. Variedades. 3. Deficiencias del suelo. 4. Manejo del suelo. 5. Siembra. 6. Cultivo intercalado. 7. Plagas de plantas. 8. Enfermedades de las plantas. 9. Necesidades de nutrientes. 10. Abonos NPK. 11. Oligoelementos. 12. Abonos orgánicos. 13. Estiércol. 14. Fertilidad del suelo. 15. Rendimiento. 16. Erosión del suelo. 17. Prácticas agrícolas. 18. Asia.

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FOREWORD

Cassava is one of the most popular crops in Asia's uplands for its flexibility in cropping systems, its ability to produce well in challenging conditions and for its multiple uses – providing food, animal feed, and income to support farming families. But although cassava has a reputation as an easy crop to grow, it requires good management in order to get good yields year after year, while protecting the soil and water resources.

The world of agriculture is changing quickly, and cassava is not immune to this change. On the one hand, the market for cassava and cassava products is growing in several Asian countries, with the potential to become more lucrative. Many new, higher yielding varieties are available for farmers to use, and their knowledge about crop and soil management has grown steadily.

Yet at the same time, pests and diseases are growing in importance and can often impact yields. Their control requires very good knowledge and careful integrated management practices. There are many options for managing soil preparation, planting density, weeds, and harvesting. The production of high-quality planting material (stakes or seed) is a kind of invisible benefit that is often not fully appreciated by growers, and understanding and implementing the inputs and practices that contribute to long-term optimized productivity is fundamental to a cassava farmer's success. For example, soil fertility management is the core practice for long-term success for many cassava farmers.

But the right combination of practices will be specific for each farm. Farmers who grow cassava often do not have easy access to good information on best management practices. In most countries, the extension systems for providing technical advice to cassava farmers are non-existent or not as well developed as for rice or maize, for example. The experts, charged with providing that advice – usually extension agents, sales representatives of companies providing inputs, such as fertilizer or pesticides, or the technical outreach staff of processing companies – typically work with many crops and many farmers, or may have a commercial interest in advice that motivates the purchase of specific products or services. Most technologies developed for cassava are designed to be environmentally friendly, that is, they do not rely on high inputs of chemicals or destructive practices. It is important that technologies that are disseminated and promoted take full advantage of this concern for the environment.

This book aims to provide well-founded and unbiased information on managing the cassava crop for maximum profitability and household well-being, while protecting the soil for long-term sustainability. It is based on the experience and research results from many decades, especially in Asia but also in Africa and Latin America. Much of the information was developed by the International Center for Tropical Agriculture (CIAT) – with headquarters in Cali, Colombia, and a regional office for Asia, previously in Bangkok, Thailand, and currently in Hanoi, Vietnam – and partner institutions throughout the region. These partners are mentioned throughout the manual in discussion of the relevant experiments or technologies. Many farmers themselves participated in developing research ideas and solutions through a process of Farmer Participatory Research (FPR). This has been a key part of assuring the practical relevance of the results.

The book is designed both for those who provide advice directly to farmers, as well as the teachers who train students to become extension agents, agronomists, or industry representatives. It can also serve to provide advice and information directly to well-informed farmers, who can understand some of the more technical information and apply it for their own needs and conditions. No manual can provide detailed advice at the individual farm level, but it will give good guidance for extension agents and others who work with farming communities to adjust and adapt to specific needs. We invite national partners to use this manual freely to develop additional material for local training and extension purposes.

The authors of this book, Drs. Reinhardt Howeler and Tin Maung Aye, have worked extensively with a broad range of partners, on experiment stations and on farmer fields across the region. The work summarized in this manual represents the best available advice from more than 50 years of combined research experience and work with farmers to understand their real-life challenges and opportunities.

This manual would not have been possible without the support of the Nippon Foundation. This support involved more than two decades of funding for research, training, and network development activities throughout Southeast Asia. CIAT gratefully acknowledges the key role of the Nippon Foundation, both in the research initiatives that developed the information included in this manual, and the support to write, translate, and produce it.

CIAT's Cassava Program is pleased to present this manual for use in managing cassava production systems that will optimize the short- and long-term benefits for farmers who grow the crop, while protecting the environment.

Clair Hershey

Leader, CIAT Cassava Program

PREFACE

Demand for cassava as a source of food, animal feed, starch, and many starch-derived products has been growing rapidly in Southeast Asia. This has created many opportunities for farmers growing the crop to increase their income and improve their livelihoods. But increasing their cassava production could come at environmental costs if farmers fail to manage their crop properly.

The International Center for Tropical Agriculture (CIAT), located in Cali, Colombia, near the crop's center of origin in Latin America, has the world mandate for conducting basic research on all aspects of cassava production. Since the establishment of the Cassava Program in 1972, CIAT has conducted intensive research to understand more about the crop and its impact on the surrounding environment. CIAT also maintains the world's largest collection of cassava varieties, presently containing over 6,000 accessions. Using this genetic diversity, plant breeders have produced many higher yielding and better adapted cassava varieties, while others have conducted research on pest and disease control and crop management improvement. Initially most of this research focused on Latin America, but in 1983 the CIAT-Asia Regional Office was established to facilitate greater interaction with cassava researchers in that region.

Although cassava in Asia was already changing from a subsistence food crop to an important industrial crop, the narrow genetic base of existing cassava varieties represented a limitation to increase the yield and starch content. With the aim of increasing the crop's genetic diversity in the region, the CIAT cassava breeder, Dr. Kazuo Kawano, introduced a number of promising in vitro clones and large numbers of sexual seed to Asia from CIAT's breeding program in Colombia. These lines were used to cross with well-adapted local clones to produce new and higher yielding cassava varieties with our partners in national programs. The best of these varieties have now been distributed across the whole region.

In addition, intensive research to develop more effective agronomic practices that would increase cassava yield while maintaining the productive capacity of the soil and reduce erosion, were started by agronomists in national programs in collaboration with CIAT. To enhance the adoption of these new varieties and technologies, researchers and extension workers in national institutions were encouraged to work together with farmers and help them test the new varieties and potentially useful technologies on their own fields in so-called Farmer Participatory Research (FPR) trials. With generous financial support from The Nippon Foundation in Japan, farmers in many countries in Asia conducted over one thousand FPR trials on their own fields and selected those varieties and practices that were most suitable for their own conditions. The wide-spread adoption of these varieties and practices resulted in steadily increasing cassava yields and improvements in farmers' income and livelihoods.

The successful wide uptake of improved cassava varieties and practices would not have been possible without the close collaboration between CIAT researchers and those from various national partner institutions. Their commitment to documenting the research process and experimental results is what has made this book, and other reference materials developed with support from The Nippon Foundation, possible.

The purpose of this book is to provide information about the results of the research in a clear format to help farmers improve their cassava yields while protecting the soil and the environment. It is intended as a source book for researchers, extension workers, NGO staff working on agricultural development, as well as large- and small-holder cassava farmers.

With generous financial support from The Nippon Foundation and institutional support provided by CIAT, the book offers a thorough reference on environmentally friendly cassava production practices. From a brief history of cassava and its importance in the region to detailed recommendations on soil and crop management, the book provides strong experimental evidence for various options from which to choose.

Holding the belief that solutions to the concerns raised in this book are site specific, depending on the local bio-physical and socio-economic situations, the book does not present a fixed package of recommendations but mainly different options available to farmers. The topics discussed include the various cassava-growing conditions and the crop's many uses, as well as the different varieties that are currently available and their attributes – from high yield and starch content, good eating quality, and resistance to certain pests or diseases.

The book also provides information about managing planting material, including care during the growing season, stem selection, and storage; about time and method of planting, weed control, integrated pest and disease management, intercropping and describes different harvesting methods and tools. It also provides detailed information on various erosion control measures as well as other methods to minimize the impact of cassava cultivation on the environment. There are also chapters on how to diagnose nutritional deficiencies and toxicities and how to prevent or overcome these problems by the application of chemical fertilizers, manures, or various biological methods for maintaining the productivity of the soil while increasing yield and starch content.

We would like to take this opportunity to thank our colleagues in the various national programs who collaborated in the many research and extension activities described in this book, as well as the many farmers who actually put the research results into practice; they taught us many aspects of practical cassava production. We hope that the lessons we learned, as described in this book, will be useful to others and will contribute to more sustainable cassava production throughout Asia, as well as in many other parts of the world.

Reinhardt Howeler and Tin Maung Aye

About the authors

Reinhardt Howeler was born in Indonesia but grew up in the Netherlands. After completing his undergraduate degree in Tropical Agriculture he immigrated to the US, where he continued his study, obtaining a PhD degree in soil chemistry from Cornell University. He joined CIAT in Cali, Colombia, in 1970, and the newly formed cassava program in 1972, conducting numerous greenhouse and field experiments to determine the nutritional requirements of the crop, and how to manage cassava without causing serious erosion. In 1986, he moved to the CIAT office in Bangkok, Thailand, where, during the following 23 years he worked closely with researchers, extension workers, and farmers in practically all cassava-growing countries in the region, to develop better soil and crop management practices, and enhance their adoption by using a Farmer Participatory Research (FPR) methodology. As a result, cassava yields in Asia increased substantially, which allowed for the rapid increase in industrial use of cassava, which in turn increased demand and farm-gate prices, and improved the incomes and livelihoods of many poor cassava farmers.

Tin Maung Aye was born and raised in Myanmar, where he obtained a BSc degree in Agriculture from the Institute of Agriculture in Yezin in 1984. After working as a research assistant for three years, he moved to Thailand, where he completed an MSc in Agricultural Systems at the Asian Institute of Technology (AIT) in Bangkok in 1994. After working in various positions at AIT, he joined Landcare Research Ltd. in New Zealand as a chemical analyst, and later worked as a research assistant at the Fertilizer and Lime Research Center at Massey University. He completed his PhD degree in Soil Science from Massey University in New Zealand in 2001. He has been working for the CIAT Cassava Program as a soil scientist and cassava agronomist since 2005, the first four years in Lao PDR, and since then mainly in Cambodia, Lao PDR, Vietnam, and Myanmar. He is now based at the CIAT-Asia Regional Office in Hanoi.

Throughout his career, he has been active in farming communities and professional organizations with the objective of assisting in poverty reduction and enhancement of agricultural sustainability in less favored upland areas of tropical Asia and the Pacific, particularly in Southeast Asia.

Contents

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The mention of any commercial product does not represent an endorsement of that particular product by the authors.When using chemical products, careful precautions need to be taken for their safe use. For further information about the use of chemical products, it is recommended to consult the local phytosanitary authorities.

CHAPTER 1

CASSAVA IN ASIA: HOW IS IT GROWN AND WHAT IS IT USED FOR?

Cassava has been grown by Latin America's indigenous populations for at least 4,000 years, and is still an important food crop today.

What is cassava and where is it grown?

Cassava is a starchy root crop and one of the most important food crops in many parts of the tropics. It can also be used for feeding animals, to produce starch, and even biofuel. The crop's scientific name is *Manihot esculenta* Crantz. It has its origin in Latin America, where it was grown for centuries by indigenous populations before the arrival of Europeans. Later, cassava was taken to Africa and Asia as a food security crop. Cassava is now the seventh most important food crop in the world – way behind wheat, maize, and rice, but slightly ahead of potato. In the past 30 years, the cassava-growing area has increased more quickly than that of any other major food crop.

In 2012, about 30% of all cassava in the world was produced in Asia, where the major producing countries are Thailand, Indonesia, Vietnam, India, China, and Cambodia. Yields in Asia are much higher than in the Americas and are almost double the average yield in Africa. India has by far the highest cassava yield in the world, at over 35 tons per hectare.

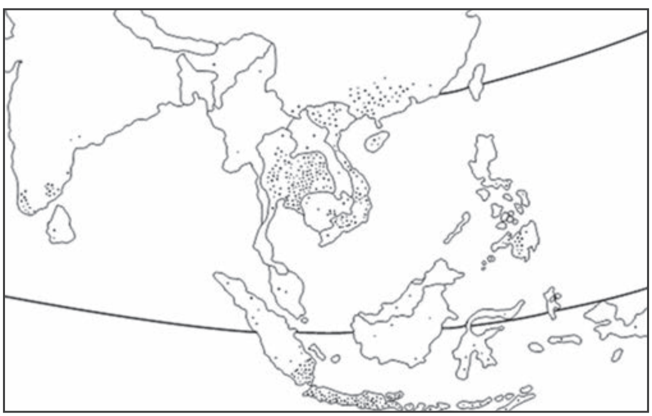


Figure 1-1. Cassava production zones in Asia in 2007. Each dot represents 10,000 ha of cassava.

Green cassava fields stand out in a parched landscape during the dry season in Thailand.

Poorly managed cassava cultivation can indeed lead to serious soil degradation resulting in low yields.

Conditions where cassava can grow successfully

Cassava has high yield potential and can be grown under a wide range of upland conditions, even on poor soils and in areas of low or unpredictable rainfall where many other crops would fail. In Southeast Asia, most smallholder farmers and their families live and grow food crops on marginal upland soils and in fragile environments, where manure and fertilizers are not commonly applied. Because cassava can grow on marginal land, in very poor soils and under drought conditions, it is often considered the "food of last resort." However, like other crops, cassava extracts soil nutrients, and its cultivation may lead to erosion and land degradation in the absence of proper crop and soil management. Its ability to grow on already-depleted soils is one of its great advantages, but this must be combined with effective soil management practices. This is a key message in this book.

In general, cassava grows best in areas where temperatures are between 25 and 29 °C. The crop will tolerate temperatures up to 38 °C, but growth stops when temperatures drop below 15 °C. The stems and roots are killed when the temperature drops below freezing.

Cassava is very drought tolerant, though the crop grows best when the soil is moist but not saturated with water. During long periods of drought, the fibrous root system will grow deeper into the soil to absorb water. Leaves will stop growing, and older leaves may drop off. Unlike other crops, cassava will not die because of drought, but will become more or less dormant until the rains return.

While cassava is tolerant of very acid and low-fertility soils, the crop does respond well to increased soil fertility. In very infertile soils, cassava may still produce 5–10 t/ha of roots, while other crops may not produce anything at all. But in more fertile soils, or with adequate fertilization, cassava can produce 30–40 t/ha. Thus, good soil management, including the use of chemical fertilizers in combination with organic sources of nutrients such as manures, will markedly increase cassava yields while maintaining or improving the productive capacity of the soil.

Two years later, after adoption of a new high-yielding variety, more balanced fertilization, and the planting of contour hedgerows for control of erosion, cassava yields tripled.

What is cassava used for?

Cassava roots can be a low-cost energy source for food or livestock feed on-farm. Alternatively, roots can be sold to generate income in support of farm households.

Cassava for human food

Cassava roots are a good source of carbohydrates and, when eaten with legumes, leafy greens, fish, or other sources of protein, can make for an adequate diet. Dry cassava leaves contain about 25–30% protein and, when the young leaves are cooked with spices, they make a delicious and nutritious vegetable. However, both cassava roots and leaves contain compounds that can release a chemical called hydrogen cyanide, which imparts a bitter taste and is toxic when consumed. The capacity of the roots or leaves to release hydrogen cyanide is known as the cyanogenic potential. Many preparations and processes reduce the cyanogenic potential to safe levels. For that reason, cassava roots and leaves should never be eaten fresh, but should be either cooked, dried, or ensiled before consumption, either by people or animals.

Cassava varieties used for human consumption are usually chosen for a combination of traits, for example, root color, absence of bitter taste, ease of peeling, quick cooking, texture, or good taste. The roots are usually harvested before the plants are ten months old, as older plants tend to have more starch and more fiber, making the roots dryer and harder to eat and digest. Most cassava in Asia is eaten after peeling, washing, cutting into chunks, and cooking, very similar to cooking potatoes. In some countries, especially Indonesia, the roots are often peeled, cut into pieces, and dried in the sun to produce cassava flour. In many countries, especially in Indonesia, India, and China, people can have a

Figura 1-2. Almost all parts of the plant can be used.

Boiled cassava is a favorite food for many minority groups living in mountainous areas of Lao People's Democratic Republic (Lao PDR).

banquet of a wide variety of dishes all made from cassava roots and leaves, including soups, stews, vegetables, rolls, and desserts.

Cassava for animal feeding

Ruminant animals, such as buffalos, cattle, and goats can digest large amounts of fiber, so they can eat cassava leaves together with the petioles and green upper stem. Non-ruminants, on the other hand, such as pigs and chickens, can only eat the leaf blades, and preferably only the young leaves, which have more protein and less fiber. Cassava-based diets, well formulated according to the type of animal and their stage of development, can be as efficient for animal production as maize-based diets.

Cassava roots are usually peeled and cooked, or chipped into small chunks or slices and sun-dried. While fresh roots will spoil in 3–4 days after harvest, the sun-dried root pieces can be stored for several months and used whenever needed. The dried chunks can be fed directly to cattle or pigs, but are often ground into a flour to be mixed with protein sources, such as cassava leaf meal, full-fat soybean, or fish meal, as well as salt, essential minerals and amino-acids, such as methionine, cystine, and lysine, for a more balanced diet.

Ensiled cassava leaves are fed to dairy cattle near Malang, East Java, Indonesia.

Both cut-up roots and leaves can also be fermented to produce silage that can be stored for many months. The cut-up unpeeled roots are mixed with 0.5% salt and placed in a large plastic bag. After pressing out the air, the bags are tied with a string. The roots will ferment in 8–9 weeks and the resulting silage can be fed to animals, especially ruminants. Cut-up leaves – either with or without petioles and green stems – can be mixed with 5 or 10% rice bran or cassava root meal and about 0.5% salt, put into air-tight plastic bags and left for 6–8 weeks. The resulting leaf silage will still have about 20–25% protein on a dry matter basis, while much of the hydrogen cyanide will have evaporated. This leaf silage can supplement soybean or fish meal as a protein source.

Cassava for processing

While cassava remains a very important food crop in Indonesia, East Timor, India, Lao PDR, and Myanmar, it is now mainly an industrial crop in Thailand, Malaysia, and Cambodia, and a major animal feed crop in Vietnam, China, and the Philippines. The roots are processed into dry chips – mostly for export to China – or the fresh roots are processed into native starch, modified starch, sago pearls (also called tapioca balls), ethanol, and a wide variety of starch-based products, including sorbitol, mono-sodium glutamate, medicines, and even biodegradable plastics. High-yielding varieties with high starch content are selected irrespective of taste, cooking quality, or cyanogenic potential. In general, varieties used for industrial processing have higher yields than those used for human consumption, but the sale price per kilogram may be considerably lower.

Cassava roots are now being used for production of fuel-ethanol in many countries in Asia.

Cropping systems in Asia

The cassava area in Asia tends to range from 0.2 to 0.8 hectares per family in China, Vietnam, Kerala state of India, and Java island of Indonesia, and from 2 to 3 hectares per family in Thailand.

In Wuming county of Guangxi province of China, cassava is the second most important upland crop.

The crop is often grown in association with maize, upland rice, and grain legumes, such as soybean, peanut, cowpea, or mungbean, in Indonesia; with peanut or black bean (cowpea) in North Vietnam; with peanut or watermelon in Guangxi province, and with rubber trees in Hainan province of China; and under coconut trees in the Philippines and Kerala state of India. The crop is primarily grown in monoculture in Thailand, Cambodia, Malaysia, and South Vietnam.

In many parts of Asia, cassava fields are small and often located on slopes above the rice paddies.

In many parts of Central and West Java, Indonesia, cassava is often intercropped with upland rice and maize, followed by peanut, cowpea, or mungbean.

How is cassava grown?

Cassava is vegetatively propagated by planting a 15–20 cm long stem cutting (also called a "stake"), cut from a mature and woody stem of an 8–18 month old mother plant. On average, each mother plant can produce about ten stem cuttings, so the multiplication rate of cassava is about 1 to 10, which is very low. That of maize is about 1 to 300.

After clearing the land and soil preparation, stem cuttings are planted by pushing them about 8–10 cm into the soil, either vertically or inclined; or they are buried horizontally in the soil at a depth of 5–8 cm. Once the stem cuttings are planted in moist soil, they will absorb water and the buds will sprout. When planted vertically or inclined, cuttings have to be planted with the buds facing upwards. This method results in faster sprouting, normally within 5–10 days. Only 1 or 2 buds near the upper end of the cutting normally sprout. When stakes are planted horizontally, the new shoots will only appear above the soil after about 15–30 days. Up to 4 or more buds may sprout, resulting in more stems per plant, but these stems may be thinner and produce poorer quality cuttings for replanting, so it is recommended to cut off the weaker stems and leave only two strong stems. Thicker and more mature stakes tend to sprout faster than thin or immature ones. The roots cannot be used as propagation material, because they have no buds from which sprouts can originate to develop a new plant.

After about two weeks, the stakes produce fibrous roots, which penetrate the soil to absorb water and soil nutrients. Young leaves open and start photosynthesizing, producing sugars and starch, which feed the plant's growth. Depending on the variety, the main stems may grow straight up or may fork into 2–3 branches. Cassava is a poor competitor with weeds or other crops growing nearby because of its slow early growth. Weeds grow faster and will seriously compete with cassava for light, water, and nutrients, resulting in reduced cassava growth and lower yields. It is, therefore, very important that the fields are weeded 2–3 times during the first 3–4 months before the cassava canopy closes over. At about three months after planting, some of the fibrous roots start filling with starch. These roots swell to become the tuberous or storage roots that will eventually be harvested.

Cassava yields are often low due to low soil fertility, inadequate fertilization, and serious erosion on sloping land.

What are the major problems that limit cassava yields?
Cassava is a hardy crop, yet, it can suffer from a host of disease and pest problems, and yield can also be seriously affected by weed competition. While plants may survive and produce some yield on poor or degraded soils, high yields are only obtained in fertile or well-fertilized soils, and only when the crop is well managed, weeds are controlled, and insect and disease problems are minimized.

Under ideal conditions, cassava yields can be as high as 100 t/ha. However, conditions are never ideal as soils vary from place to place and weather conditions change from year to year. Also, because good soils are usually reserved for more valuable crops, such as vegetables, fruits, and flowers, or more demanding crops, such as sugarcane, maize, and soybeans, cassava is almost never grown on those soils where it grows best. Still, in those areas where cassava is currently grown, yields could probably double if all current problems that limit yields could be eliminated.

According to a study conducted in the mid-1990s, some of the problems most seriously limiting cassava yields in Asia are soil-related problems, mainly low soil fertility, and soil erosion when the crop is grown on slopes. Most cassava in Asia is grown on soils that are moderately acid and of very low fertility, mainly lacking nitrogen and potassium, but in some areas also phosphorus, calcium, magnesium, and some micro-nutrients such as zinc. A much smaller proportion of cassava is grown on soils that are very acid and particularly low in phosphorus and potassium, while cassava is also sometimes grown in areas having limestone-derived or high-pH soils where the crop may suffer from micro-nutrient deficiencies.

When cassava is grown on slopes – even very gentle slopes – soil erosion can be a serious problem. This is because cassava is often grown on very sandy soils containing low levels of clay and organic matter, which normally bind the soil particles together to form aggregates. Without strong soil aggregates, raindrops falling on the soil will dislodge the separated particles and carry them down the slope with the runoff. Also, because cassava has to be planted at a rather wide spacing and the crop's early growth is slow, much bare soil between plants is exposed to the direct impact of falling raindrops during the first 2–3 months, until the crop canopy has closed. It is also necessary to keep the weeds under control during this time, which will further loosen the soil and make it even more susceptible to erosion. Thus, soil losses due to erosion are often more serious in cassava than in other crops grown under the same conditions. But there are many simple soil conservation and crop management practices that can be used to reduce soil erosion. These will be discussed in **Chapter 12.**

When too much water accumulates after several days of heavy rain, serious gully erosion can occur.

The main causes of low yield are:

- Lack of high-yielding and well-adapted varieties
- Low soil fertility and inadequate fertilizer or manure use
- Serious soil erosion when the crop is grown on sloping land
- Strong weed competition
- Outbreaks of pests and diseases
- Drought, mainly during the first 1–2 months after planting
- Use of poor quality planting material
- Waterlogging
- Inappropriate agronomic practices
- Inappropriate methods of intercropping

What can farmers do to reduce these limiting factors?
Farmers need to adapt their management practices to the climatic conditions, topography of the land, and the soil on which they farm, selecting the right crop or cropping system and the right varieties or the most effective cropping practices. Cassava varieties differ markedly in their tolerance to drought, to low or high temperatures, to different disease and pest problems and to soil acidity or low fertility. Plant breeders and agronomists have been working for many years to produce new high-yielding varieties that are tolerant or resistant to these problems, and to develop better, more efficient agronomic practices that will increase yields. Farmers can work with researchers or extension agents to determine which problems are most serious in limiting their cassava yields, and then conduct trials on their own fields to select the best varieties and management practices to solve their own specific problems.

Most cassava soils in Asia will be low in one or more nutrients that are likely to limit the yields obtained. To increase yields, it is therefore essential to determine which nutrients are most yield limiting and then apply those nutrients, either in the form of chemical fertilizers or animal manures. Ways to improve soil fertility and increase yields will be discussed in **Chapters 7** to **11**.

Weed competition can markedly reduce cassava yields.

White flies can cause major damage.

Competition from weeds can also seriously reduce cassava yields, but in most cassava fields in Asia, weeds are reasonably well controlled, mostly by hand weeding or by the use of herbicides. Still, farmers may be able to reduce the cost of weeding, or weed more efficiently, by following some of the recommendations discussed in **Chapters 4** and **5**.

There are also several pests and diseases affecting cassava in Asia, but until recently, most of these did not significantly reduce yields. However, during the past ten years, when cassava production in Asia intensified, new insect and disease problems have appeared, while other already existing problems have become more serious. Since many insects and diseases can be transmitted by the use of infected or infested planting materials, it is very important to use disease- and pest-free planting materials to plant the next crop. This will be discussed in more detail in **Chapter 6**.

In many countries, cassava is intercropped with other crops, or is planted among existing trees such as young rubber or mature coconut trees. Cassava yields tend to be reduced due to competition for light, water, or nutrients by the associated crops or trees, but this is usually compensated for by the additional value obtained from those crops. For details, see **Chapter 5**.

Witches' broom is a new disease that can seriously reduce cassava yields.

In some countries, cassava is planted between rows of young rubber trees.

CHAPTER 2

ARE BETTER VARIETIES AVAILABLE?

"Traditional cassava varieties" are the outcome of selection by generations of farmers. In some cases, they have been developed locally, and sometimes they are the result of trade among regions. These varieties will vary from region to region, and farmers may grow a wide range of varieties, selected for their high yields, good eating quality, ease of peeling, or other attributes, such as resistance to certain pests or diseases. Farmers are usually very keen to try new varieties that may increase their yield and income at no extra costs. However, when specific varieties are grown away from their adapted localities, they often fail. Very few varieties grow well across diverse agro-ecological conditions. Therefore, cassava varieties must be evaluated for the specific local soil and climatic conditions under which they will be planted, as well as for various end-uses, such as for human consumption, animal feeding, or industrial processing.

CIAT has a collection of over 6,000 different cassava varieties, grown and maintained in test tubes in the lab until they are tested in the field.

There are more than 6,000 cassava varieties in the germplasm collection of the International Center for Tropical Agriculture (CIAT) in Colombia. These varieties are available for use in the breeding programs of international and national research institutes. Cassava varieties are usually bred and selected for higher root yield and dry matter or starch content, resistance to specific diseases or pests, and for tolerance to drought, poor soils, or cool temperatures.

When cassava is used for human food, there may be a wide range of varieties grown for different dishes or different tastes. On Java island of Indonesia, farmers grow an especially large number of varieties bred and selected over the past 2–3 centuries, grown in a mosaic of different soils and climates. In contrast, in Thailand, where cassava is grown mainly for industrial processing, the range of varieties is limited. In fact, during the 1970s and 80s, about

To produce a new cassava variety, breeders have to place pollen from the male flower (on bottom) on the stigma of the female flower (on top), and then plant out the sexual seed produced to see how these plants perform in comparison with existing or other new varieties.

one million hectares of cassava were grown using a single variety: Rayong 1. Depending too much on a single variety is dangerous, as this variety could suddenly become susceptible to a new disease or pest problem. For that reason, Thai researchers developed, distributed, and promoted a range of higher yielding varieties. Presently, Rayong 1 is hard to find in Thailand as farmers have switched to new, higher yielding varieties. Cassava yields in Thailand have markedly increased, from 13–14 t/ha in 1995 to 23 t/ha in 2009. Data in **Table 2-1** show that new varieties played a major role in increasing yields in Thailand, but better crop management, especially the use of chemical fertilizers, better erosion control, and more intensive weeding, was almost equally important.

Since the mid-1970s, cassava breeders in national programs across Asia have developed improved varieties with specific characteristics, such as good taste, high yield, high starch or dry matter (DM) content, early maturity or early high yield. Others were selected for dual-purpose use, which means that they can be used for both eating and processing into starch or ethanol. Most new varieties have some genetic background from Latin America, as they were selected from crosses between local varieties and Latin American germplasm, introduced as sexual seed by CIAT cassava breeders, who worked closely with breeders in the various national cassava

Table 2-1. Change in cassava yields in Thailand between 1990 and 2009 as a result of the adoption of new varieties and better cultural practices.

Year	Cassava area under new varieties (%)	Cassava yield (t/ha)	Observation
1990	1.1	13.9	Almost no adoption of new varieties.
1995	13.0	13.0	Only some adoption of new varieties.
2003	97.8	19.3	Almost 100% adoption of new varieties and some improved agronomic practices.
2009	~99	22.7	No major change in varieties but major adoption of improved agronomic practices with 80% of cassava farmers using chemical fertilizers.

breeding programs in Asia. Being the center of origin of cassava, Latin America has a much wider genetic diversity than Asia. The introduction of this germplasm into Asia has allowed for more rapid improvement in many desired characteristics.

In the past, a large number of locally selected clones dominated many Asian countries. Most of these clones were so-called "sweet varieties" and were grown mainly for direct eating purposes. Generally, eating varieties have low to moderate dry matter and starch contents as well as a low cyanogenic potential. Some popular eating varieties are shown in **Table 2-2**.

Nowadays, there are several new varieties for eating and/or industrial purposes. Industrial varieties are bred and selected mainly for high yield and high starch content. However, most of these varieties have high cyanogenic potential and are therefore called "bitter varieties," due to their bitter taste even after cooking. The most popular industrial varieties are shown in **Table 2-3**.

Tables 2-2 and **2-3** show the names and the years that these varieties were released and their main characteristics. Farmers may be able to obtain planting material from these released varieties in their own country, with specific characteristics they like, and then compare them with varieties they have traditionally grown. Adoption of new, higher yielding varieties is likely to further increase cassava yields in many countries.

Several national cassava breeding programs in Asia also maintain large collections of different varieties in the field or in test tubes in the lab.

Researchers checking the growth and morphological characteristics of different varieties being tested in the field.

Table 2-2. Cassava varieties suitable for human consumption that have been grown or released in Asia, and their most important characteristics.

Country	Variety name	Year of release	Main characteristics
Cambodia	Damlong Kor	-	Good eating quality
	Damlong Mi	-	Good eating quality
China	Bread cassava	-	Low yield, high starch content, good eating quality
	SC 102	-	Low yield, high starch content, good eating quality
	SC 6068	1980	Low yield, high starch content, good eating quality
	SC 9 = yolk cassava	2005	High yield, high starch content, high β-carotene*, good eating quality
East Timor	Mantega	-	Good eating quality; high β-carotene
	Lesu	-	Good eating quality
	Ai Luka 2	2007	High yield, good eating quality
	Ai Luka 4 = Gading	2007	High yield, good eating quality
India	M4	-	Good eating quality, relatively low yield
	Sree Visakham	1977	High β-carotene, suitable under coconut
	Kalpaka	1996	Early bulking, good cooking quality
	Sree Jaya	1998	Early maturing, good cooking quality, suitable for rice-based rotation
	Sree Vijaya	1998	Early bulking, β-carotene, for rice-based rotation
	Sree Rekha	2000	High yield, β-carotene, for lowland and upland
	Sree Prabha	2000	High yield, β-carotene, for lowland and upland
	Vellayani Hraswa	2002	Early bulking, good cooking quality, for rice-based rotation

Continues

Continued

Country	Variety name	Year of release	Main characteristics
Indonesia	Adira 1	1978	High yield, good eating quality
	Malang 2	1992	High yield, sweet
	Darul Hidayah	1998	High yield, sweet, specific adaptation
	Litbang UK2	2012	High yield, high ethanol yield, early bulking, sweet
Malaysia	Medan	-	Popular old eating variety, good when steamed
	Sri Pontian	2003	Edible, for snack food
Philippines	Golden Yellow	-	Good eating quality, high β-carotene
	VC-2	1988	High yield, edible
	VC-3	1990	Dual purpose
	VC-4	1990	High yield, dual purpose
	PSB Cv-11	1995	Dual purpose
	PSB Cv-12	1995	Dual purpose
	PSB Cv-15	1999	Dual purpose
	NSIC Cv-48= R 72	2013	High yield, drought tolerant, dual purpose
Thailand	Hanatee	-	Relatively low yield, good eating quality
	Rayong 2	1984	Good eating quality, for snack food
Vietnam	Vinh Phu	-	Good eating quality
	Gon	-	Good eating quality
	Nep	-	Good eating quality, slightly sticky
	Ba Trang	-	Good eating quality, early bulking
	KM 95	1995	High yield, dual purpose
	KM 95-3	1998	High yield, dual purpose
	KM 98-7	1998	High yield, dual purpose
	KM 98-1	2005	High yield, dual purpose
	KM 140	2007	High yield, dual purpose, early bulking
	KM 98-5	2008	High yield, dual purpose, early bulking

*β-carotene: Beta-carotene converts into vitamin A in the human diet.

Table 2-3. Cassava varieties released in Asia suitable for processing, and their most important characteristics.

Country	Variety name	Year of release	Main characteristics
Cambodia	Damlong narrow leaf	-	High yield
	Malaysia = KU50	[1]	High yield, high starch content
China	SC 201	-	High yield, suitable for poor soils
	SC 205	-	High yield, suitable for high-fertility soils
	Nanzhi 188	1987	High yield, poor cold tolerance
	Nanzhi 199	1987	High yield, high starch content
	SC 124	1988	High yield, cold tolerant
	SC 8002	1994	High yield
	SC 8013	1994	High yield, typhoon resistant
	GR 891	1998	High yield, high starch content
	GR 911	1998	High yield
	SC 5	2002	High yield, typhoon resistant
	SC 6	2002	High starch content, typhoon resistant
	SC 7	2005	High yield
	SC 8	2005	High yield
	SC 10	2006	High yield, cold tolerant
	Gui Re 3	2006	High yield, high starch content
	Gui Re 4	2008	High yield
	SC 11 = MBra 900	2009	High yield
India	H-97	1971	High yield, high starch content
	H-165	1971	Early maturing, erect, suitable under coconut
	H-226	1971	High yield, high starch, suitable for processing
	Co-1 = ME-7	1976	High starch, CMD[2] tolerant, suitable for processing
	Sree Sahya	1977	High yield, drought tolerant
	Co-2	1985	Drought, CMD and root rot tolerant

Continues

Continued

Country	Variety name	Year of release	Main characteristics
India	Sree Prakash	1987	Early maturing, suitable for rice-based rotation
	Co-3	1992	CMD tolerant, good cooking quality, suitable for processing
	Nidhi	1993	Early maturing, for sandy soils along coast
	H-119	1995	Early maturing
	Sree Harsha	1996	High yield, high starch, drought tolerant, suitable for processing
	Co-4	2002	CMD tolerant, high starch content, erect
	Sree Padmanabha	2006	First CMD-resistant variety, drought tolerant
	Sree Athulya	2006	High yield, high starch, triploid, for processing
	Sree Apoorva	2006	High yield, high starch, triploid, for processing
Indonesia	Adira 2	1978	High yield, bitter
	Adira 4	1987	High yield, bitter
	Malang 1	1992	High yield, bitter
	UJ-3 = Thai = Rayong 60	2000	High yield, early bulking, very bitter
	UJ-5 = Kasetsart = KU 50	2000	High yield, high starch content
	Malang 4	2001	High yield, bitter
	Malang 6	2001	High yield, bitter
Malaysia	Black Twig	-	Commercial starch variety, highly adaptable
	Sri Kanji 1	2003	High yield, relatively high starch content
	Sri Kanji 2	2003	High yield, relatively high starch content
Philippines	Lakan	-	High yield
	VC-1	1986	High yield
	VC-3	1990	Dual purpose
	VC-4	1990	High yield, dual purpose
	VC-5	1990	High yield, bitter

Continues

Continued

Country	Variety name	Year of release	Main characteristics
Philippines	PSB Cv-11	1995	Dual purpose
	PSB Cv 12	1995	Dual purpose
	PSB Cv-15	1999	Dual purpose
	PSB Cv-19	2000	Mite resistant
	NSIC Cv-22=KU 50	2008	High yield, high starch content
	NSIC Cv-48=R72	2013	High yield, drought tolerant
Thailand	Rayong 1	-	High yield, rather low starch content
	Rayong 3	1983	High starch content, very branching
	Rayong 60	1987	High yield, early bulking, very bitter
	Sriracha 1	1991	High starch content
	Rayong 90	1991	High starch content, relatively high yield
	Kasetsart 50 (KU 50)	1992	High yield, high starch content
	Rayong 5	1994	Relatively high yield, high starch content
	Rayong 72	1999	High yield, drought tolerant
	Huay Bong 60	2003	High yield, high starch content
	Rayong 7	2005	High yield, high starch content
	Rayong 9	2005	High yield, high starch, high ethanol yield
	Huay Bong 80	2008	High yield, high starch content
	Rayong 11	2011	High starch content, high yield
	Rayong 86-13	2013	High starch content, high yield
Vietnam	La Tre = SC 205	-	High yield, mainly suitable for fertile soils
	KM 60=Rayong 60	1993	High yield, early bulking, very bitter
	KM 94=KU 50	1995	High yield, high starch content
	SM 937-26	1995	High yield, high starch content
	KM 95	1995	High yield, dual purpose
	KM 95-3	1998	High yield, dual purpose
	KM 98-7	1998	High yield, dual purpose
	KM 98-1	2005	High yield, dual purpose
	KM 140	2007	High yield, dual purpose, early bulking

Continues

Continued

Country	Variety name	Year of release	Main characteristics
Vietnam	KM 98-5[3)]	2008	High yield, dual purpose
	Sa21-12	2012	High yield, high starch content
	Sa06	2012	High yield, high starch content
	KM 419	2013	High yield, high starch content
	HL-S10	2013	High yield, early bulking
	HL-S11	2013	High yield, high starch content, early bulking
	KM 101	2013	High yield, early bulking

1) Introduced from Vietnam in the eastern provinces and from Thailand in the west, but never officially released.

2) CMD = Cassava Mosaic Disease.

3) KM 98-5 released in Tay Ninh and Dong Nai provinces.

Different varieties may have very distinct characteristics.

Farmers in Cambodia, testing new varieties in their fields in Farmer Participatory Research (FPR) variety trials.

CHAPTER 3

WHAT METHOD OF LAND PREPARATION IS BEST?

Farmers know from centuries of experience that crops grow better when the land is well prepared before planting: most competing vegetation is removed, the soil is loose enough for easy planting, and the surface is relatively smooth. In many cases this is achieved by loosening the soil with a hoe and incorporating or removing weeds, or using bullocks or a tractor to plow, often followed by a harrow or rototiller to break up big soil clods and smooth out the soil surface. This is still the most practical way of soil preparation used by farmers all over the world.

But research has shown that leaving crop residues on the soil surface and planting the seed without plowing and incorporating residues and weeds will increase the organic matter content of the soil, in turn improving the soil structure by enhancing aggregation, improving internal drainage, and protecting the soil from erosion. "Conservation tillage" or "zero tillage," as it is also known, also enhances biological activity in the soil, such as that of beneficial micro-organisms and earthworms.

Conservation tillage, as practiced in parts of Brazil, allows cassava planting in the mulch of the previous crop's residues without plowing.

In most countries in Asia, cassava fields are very small, often located on steep slopes where the use of tractors is impossible, and herbicides are either not available or too costly. In the near future most cassava in Asia will still be planted after some form of land preparation, but attempts should be made to prevent over-preparation of the soil, especially with heavy machinery and on very wet soil, as this will lead to soil compaction, which will impede drainage.

In an experiment conducted on a 25% slope on Hainan island of China, hand preparation of only planting holes resulted in similar yields as twice plowing and harrowing, but markedly reduced erosion. No tillage (zero tillage), followed by direct planting in small holes, reduced yields and slightly increased erosion. By contrast, large soil losses were observed when the field was plowed and harrowed twice before planting without ridges. Planting on contour ridges markedly reduced erosion and further increased yield.

In steep sloping areas, it is recommended to:

On steep slopes, minimum tillage by preparation of only the planting holes is probably the best option.

- Cut or uproot all competing vegetation; leave dead vegetation on the soil surface
- Loosen the soil with a hoe only in small planting holes of about 30x30 cm
- Plant one stake in each planting hole, either vertically, slanted or horizontally
- Apply a spoonful of chemical fertilizer, like 15-15-15 (if available), near each stake to enhance early growth and increase yields. A fertilizer labeled 15-15-15 contains 15% N, 15% P_2O_5, and 15% K_2O (see **Chapters 8** and **10** for more details).

Land preparation by plowing once or twice with oxen is practiced almost throughout Asia.

Farmers cultivating small areas, such as in Indonesia, Vietnam, and China, often use only a hoe to loosen the whole area to be planted, or only the planting hole itself. The latter is a form of minimum tillage that may well be very sustainable, but might result in strong competition from weeds, so weeding 2–3 times during the first 3–4 months before the cassava canopy closes is very important. See **Chapter 4** for more details.

In regions where farmers cultivate somewhat larger areas of cassava (0.5–2 ha), they will often plow the fields with bullocks or water buffaloes, usually only one or two passes. This is a common practice in Lampung province of Indonesia, North Vietnam, the Philippines, and Tamil Nadu state of India.

In areas of intermediate farm size, on flat or slightly sloping land, it is therefore recommended to prepare the land as follows:

- Plow the field with bullocks or water buffalos one or two times to loosen the soil and incorporate crop residues and weeds.
- On sloping land, plow along the contour to reduce erosion.
- Make contour ridges by hand using a hoe if labor is available; or use a moldboard plow pulled by cattle.
- Plant cassava stakes on top of the ridges.
- Apply a spoonful of chemical NPK-fertilizer, like 15-15-15 (if available), near each stake to enhance early growth and increase yields.

Plowing with a disk or moldboard plow is common when cassava is planted in larger fields.

Plowing with heavy machinery on wet soil may lead to serious soil compaction resulting in waterlogging.

In countries where cassava is grown in larger areas (2–5 ha), land is usually prepared by tractor using a moldboard or a disk plow, generally followed with a disk harrow and sometimes a ridger. Alternatively, the soil is loosened, and residues and weeds are incorporated with a rototiller, either tractor mounted or a self-propelled two-wheel hand tractor. The use of a tractor-mounted rototiller tends to pulverize the soil, which, when used on sloping land, can lead to serious soil erosion.

Plowing with tractors results in a loose and clean soil surface and high yields, but may cause severe erosion as well as formation of a "plow sole," or compacted layer at 15–20 cm depth. This compacted subsoil impedes free drainage, resulting in poor growth or root rot during the months of heavy rainfall. Moreover, the topsoil is rapidly saturated with water, which is followed by overland runoff and sometimes severe gully erosion.

To improve drainage, a "subsoiler" can be used to break the compacted subsoil.

Growing cassava on a compacted soil with poor drainage (in front) may result in very poor growth and low yields.

Regular use of a subsoiler will help to break the plow sole and improve internal drainage and plant growth during the height of the rainy season, and increase yields. The subsoiler is usually followed by either a 3-disk plow or 7-disk harrow to reduce weed competition and loosen the soil for easy planting.

Therefore, in areas where cassava fields are prepared by tractor-mounted equipment, it is recommended to prepare the land as follows:

- Apply systemic herbicides, like Glyphosate, to kill the weeds and volunteer cassava plants.
- Loosen the soil with a subsoiler to 40–50 cm depth to break up the plow sole; if a subsoiler is not available, use a chisel plow to loosen the soil to 20–30 cm depth.
- Loosen and smooth out the soil surface with a disk harrow (or rototiller on flat land).
- Make ridges along the contour or when cassava suffers from root rot or waterlogging during periods of heavy rain.
- Plant on top of ridges or on the flat.
- Prepare the land when the soil is moist, but do not enter the field with heavy machinery when the soil is very wet.
- Apply a spoonful of NPK-fertilizer, like 15-15-15 (if available), near each stake to enhance early growth and increase yields.

Making ridges or mounds by hand for planting cassava requires a lot of heavy work.

CHAPTER 4

WHEN TO PLANT AND HOW TO GROW CASSAVA

What is the best planting material and how to store it before the next planting?

To grow healthy plants and obtain high yields, it is important to start with good quality planting material. A new cassava crop is almost always started from stem cuttings, often called “stakes." Each plant is a “clone,” and therefore identical to the mother plant from which the stems were cut. In this way, a variety can remain stable, without changing its characteristics, for many years. Some cassava varieties also produce botanical seeds, but these seeds produce plants that are different from the mother plant, and are used mainly in breeding programs to develop new varieties. This discussion will cover only planting material derived from stems.


Using poor quality planting material (in front) will result in poor sprouting and low yields.

Stem cuttings are taken from the woody lower or middle part of the stems of mother plants that are between 8 and 18 months old. Stakes cut from the lower part of the stem are thicker and have more reserves of starch, sugars, and nutrients, allowing them to sprout and develop roots to absorb water and nutrients from the soil. Before cutting the stems, the mother plants should be carefully observed to make sure they are free of pests and diseases, to prevent infections being passed on to the next generation. Also, mother plants cultivated on fertile or well-fertilized soil, especially with potassium, should be selected, as stakes cut from these stems will have more starch, sugars, and nutrients to sprout faster, grow better, and produce higher yields. Finally, mother plants that produce above-average root yields will give higher yielding stakes. Farmers should harvest the mother plants first and observe the roots, before selecting the best plants for cutting stems to be used as planting material. This also reduces the chances to use stems that may be infected with virus diseases, such as frog skin or cassava brown streak disease, which only

Stakes are cut from the lower and middle part of the stem.

Roots evenly distributed around the stem will facilitate harvesting.

show symptoms in the roots, but no clear symptoms in the top growth.

It is important to cut the stems into stakes at the site of planting and not before they are to be transported. Cut stakes may dry out rapidly during transportation. A sharp knife, cleaver, lopper, or saw should be used for cutting the stems into planting stakes, so that planting tissue is not torn, splintered, or damaged. Stakes that have been cut at a 90° angle are able to root uniformly around the whole stem perimeter, resulting in better root distribution.

In many cases, cassava is harvested during the dry season, but cannot be replanted until the next wet season. In that case, stems needed for planting material will have to be stored for weeks or even months. The stems can be bundled with string and stored upright in the shade of trees, or in a well-ventilated storage room. Storing in the field under the sun is not recommended as the stems will dry out faster and lose their viability more quickly. For rather long-term storage, it is recommended to loosen the soil where the stems will be stored, and add some water occasionally to the soil during storage to keep the stems fresh. If the upper parts of the stems have sprouted during storage, these parts should be cut off and discarded.

In areas where planting material has to be stored during cold winters, the stems need to be stored in a protected spot, as stems will otherwise be killed by frost. In that case, the stems are best stored in or near the house or barn, or if that is not possible, they can be stored in trenches dug in the field or in the side of hills or embankments, and then covered with straw and soil. In those areas, it is also useful to plant varieties that are particularly cold tolerant, even though they may still be killed if subjected to frost.

In areas where there are serious pest or disease problems, it is advisable to soak the stakes for 15 minutes in a solution of insecticides and fungicides, which may also contain some necessary micro-nutrients, just before planting. This will be discussed in **Chapter 6**.

To select the best planting material and keep it fresh for as long as possible, it is recommended to:

- Cut stems used for planting material from mother plants that are 8–18 months old and that do not have any disease or pest symptoms.
- Use as planting material only the lower and middle part of the total stem, eliminating the immature (green) top parts.
- Cut stems from mother plants that are grown in fertile soil, or in soil that has been well fertilized, especially with potassium.
- Cut stems from mother plants that have produced above-average root yields.
- If it is necessary to store the stems until the next planting season, store the bundled stems in an upright position in the shade of trees or buildings. Loosen the soil slightly with a hoe before placing the bundles and keep the soil moist by occasional watering.
- Before cutting the stems into stakes, discard the upper parts of the stems if these have sprouted, as well as any part that has obviously dried out.
- Cut stems into stakes only at the field where they are to be planted and never before they are transported to the planting site.
- In areas with serious disease or pest problems, treat the stakes by soaking for 10–15 minutes in a solution containing insecticides, fungicides, and possibly micro-nutrients.

Cassava stems should be stored upright in the shade and cut into stakes just before planting in the field.

In areas with cold winters, cassava stems may be stored in trenches underground or dug into hillsides to protect against frost.

It is time to plant!

What are the optimum climatic and soil conditions for cassava?

Cassava can be grown under a wide range of climatic and soil conditions. Ideally, the soil temperature should be above 18 °C and annual rainfall should be above 1,000 mm. Cassava can grow well on well-drained sandy loam to clay loam soils, but will not tolerate excess water. The crop can be harvested more easily on lighter textured soils. Under favorable growing conditions, cassava can produce more than 30 t/ha of fresh roots after 11–12 months. Cassava can grow well in acid soils with pH levels as low as 4.0–4.5 and up to 80% aluminium saturation, but will not grow as well as some other crops in alkaline (high pH) or saline (salty) soils.

When is the best time to plant cassava?

While cassava is very drought tolerant and plants will seldom die during the dry season, the crop needs adequate soil moisture to sprout after planting, until stakes produce roots that can grow and absorb water from deeper down the soil profile. The highest rates of sprouting occur when the soil is moist for at least 2–3 weeks after planting. For that reason, it is advisable to plant cassava at the beginning of the rainy season so the crop can benefit from adequate soil moisture during the early part of the growth cycle.

However, planting during the height of the wet season is not recommended as the planted stakes may rot before they have sprouted, and plants may suffer from lack of oxygen if the roots are growing in waterlogged soils. High yields may also be obtained by planting cassava near the end of the wet season, so plants can become well established during the last months of rains, grow slowly during the dry season, and have an additional period of fast growth in the following wet season. This has the advantage that weed competition is less serious, as the cassava canopy is already well developed in the early part of the second wet season. Typically, starch content falls rapidly at the beginning of the rainy season as the starch reserves are mobilized for new leaf and stem growth. Harvest will need to be delayed until acceptable root starch contents are restored.

Thus, the best time to plant cassava is as follows:

- In areas with a tropical climate and only one long wet season, plant cassava at the start of the wet season and harvest during the middle of the dry season.
- In this case, cassava can also be planted towards the end of the wet season as long as there is enough soil moisture during the first two months of the crop cycle and cassava is harvested after at least 10–11 months of growth.
- In areas with a tropical climate and two short wet seasons, cassava can be planted at the start of either wet season.
- In areas with a temperate climate and cold winters, cassava is best planted in the early part of spring and harvested during the winter when starch contents are highest.

What is the best planting distance for cassava?
Where cassava is a subsistence crop, it tends to be planted randomly in whatever space is available, but where it has become a commercial crop, farmers aim to maximize yields and net income. In that case, cassava should be planted in straight rows, or in rows following the contour to reduce erosion on sloping land.

The best plant spacing will depend on the growth habit of the variety, the fertility of the soil and whether the crop is grown in monoculture or intercropped.

When cassava is grown as a sole crop in monoculture, the distance between rows can vary between 80 and 120 cm. This depends to some extent on the growth habit of the variety, with branching varieties needing wider spacing than non-branching erect varieties. The distance between rows also depends on the equipment or machinery being used to till the land. The distance between rows (inter-row spacing), and the distance between plants in the row (inter-plant spacing) may have to be adjusted to the wheelbase of a tractor.

When cassava is grown in association with other crops – usually called “intercropping” – the inter-row space can be about 100 cm to accommodate one or two rows of a short-duration intercrop, such as maize, upland rice, or a grain legume, such as common bean, soybean, peanut, cowpea, or mungbean. In some countries, the inter-row spacing is widened to 200 cm to allow the planting of 3–4 rows of intercrops. The best inter-row spacing will also depend on the relative value of cassava as compared to the intercrops. When farmers depend on the intercrops as an important source of food or income, they will plant a higher population of the intercrops and less cassava (see **Chapter 5**).

Once the inter-row spacing has been decided, the inter-plant spacing can be adjusted to maximize the yield of a specific variety, with branching varieties generally requiring more space than erect varieties. Inter-plant distances generally vary between 50 and 100 cm. When cassava is grown on a fertile soil under favorable weather conditions, plants grow bigger than when the same variety is grown on an infertile soil or under unfavorable weather conditions. For the latter, smaller plants should be planted at a closer spacing, or higher plant population, than those bigger plants growing under more favorable conditions. When plants are grown at a high plant density, each plant has less room and will suffer more from competition by its neighbors, leading to a lower yield per plant. But with more plants per hectare, yields can still be similar to those obtained with a wider spacing when the yield per plant is probably higher but the number of plants per hectare is smaller.

Case Study

Research conducted in three different locations in Thailand shows that the highest yield of Rayong 2, a tall, semi-branched variety, was obtained at a spacing of 100x66 cm, or a population of about 15,000 plants per hectare, while the same spacing also produced the highest yield of Rayong 3, which is a short, highly branched variety. But results obtained in India, on a relatively poor but well-fertilized soil, shown in **Figure 4-1**, indicate that the highest yield of a non-branching variety was obtained at a spacing of 75x75 cm, or almost 18,000 plants per hectare, while a semi-branched variety produced the highest yield at a spacing of 90x90 cm or about 12,000 plants per hectare. Most farmers like to plant at a spacing of about 80x80 cm or 15,625 plants per hectare.

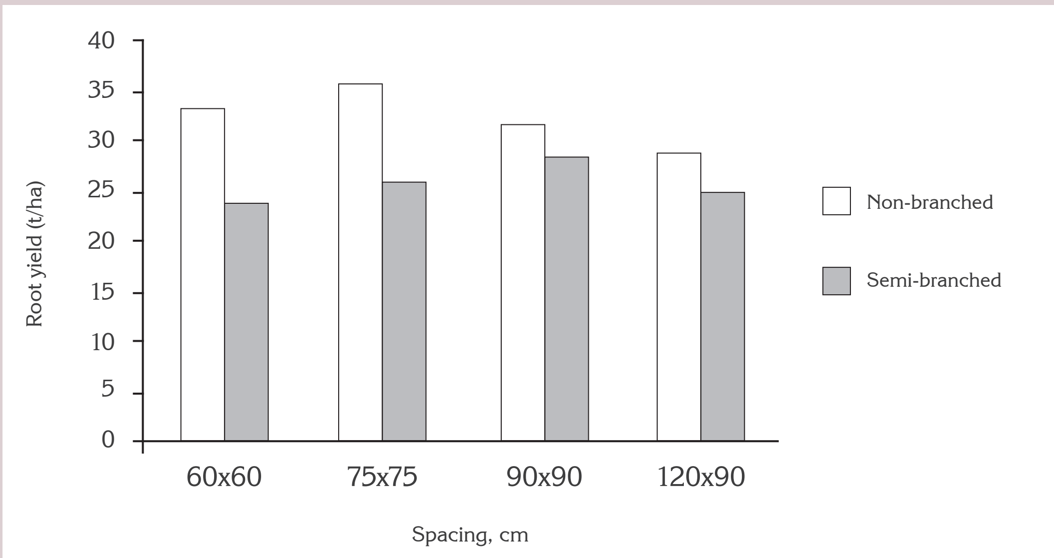


Figura 4-1. Effect of plant spacing on the root yield of non-branching and semi-branched cassava varieties grown at the Central Tuber Crops Research Institute (CTCRI), Kerala state of India in 1973.

In some countries, cassava is planted vertically by pushing the stakes 8–10 cm into the soil.

The best plant spacing of cassava will vary according to the branching habit of the variety, the fertility of the soil, and climatic conditions, and whether the crop is grown in monoculture or in association with intercrops. This can be summarized as follows:

- Under favorable climatic conditions and in fertile soil, cassava planted in monoculture can be planted at a population of about 10,000–12,000 plants per hectare, or a spacing of about 100x100 cm to 90x90 cm.
- Under less favorable climatic conditions or in less fertile soil, the cassava plant population under monoculture should be increased to between 12,000 to 18,000 plants per hectare, corresponding to a spacing of about 90x90 cm to 75x75 cm.
- When cassava is intercropped but grown under favorable conditions, the inter-row spacing is widened and the inter-plant spacing reduced to obtain a cassava plant population of about 8,000 to 10,000 plants per hectare.
- When cassava is intercropped and grown under less favorable conditions, the cassava plant population should be increased to about 10,000 to 12,000 plants per hectare, with the inter-row and inter-plant spacing adjusted according to the relative importance of cassava in comparison with the associated crop(s).
- Highly branching varieties will require a wider spacing than semi-branched varieties, which in turn require a wider spacing than non-branching varieties.

What is the best stake position for planting cassava?
If the soil is loose, stakes can be planted vertically or slanted, by pushing the lower part of the stake about 8–10 cm into the soil. Stakes can also be planted horizontally at 5–10 cm

depth by digging individual holes, or by making a long shallow furrow, laying the stakes down and covering with soil. The latter method is common in heavy clay soils or with zero- or minimum-tillage methods of land preparation. When the soil is well prepared and loose, planting vertically or inclined is faster than planting horizontally, but care should be taken that the buds on the stakes face upward; with horizontal planting, the position of the buds does not matter.

Recommendations with regard to planting position and ridging:

- In light textured sandy or sandy loam soil, cassava stakes can best be planted in a vertical or inclined position, especially when planting coincides with a dry period.
- In heavy clay soil, it is advised to plant horizontally, as the roots tend to grow closer to the soil surface, making harvesting easier.
- During the wet season, there is little difference in yield between vertical, inclined, or horizontal planting.
- When planting vertical or inclined, it is important to plant stakes with the buds facing upward.
- Planting on ridges is recommended during periods of heavy rainfall, but planting without ridges is better during dry periods as the ridged soil tends to dry out faster.

In other countries, farmers plant stakes horizontally by making individual planting holes or shallow trenches.

Is there a need to weed?
Cassava is a poor competitor and may suffer serious yield losses if the crop is not adequately weeded during the early stages of plant growth. In general, the crop should be weeded 2–3 times during the first three months or until canopy closure.

Weeding with a short-handled hoe in India.

Weeding with a long-handled hoe in Vietnam.

Weeding with a "poor man's plow" in Thailand.

Weeding with a "speed-weeder" made from bicycle parts in Vietnam.

Applying pre-emergence herbicides right after planting cassava in Thailand.

Weeding with a hand-tractor.

Weeding is most often done by hoe, by animal-drawn cultivator or hand tractor, but can also be done by a tractor-mounted cultivator or with herbicides. In light-textured soils in Thailand, farmers sometimes use a "poor man's plow," which is basically a cultivator blade pulled by hand between cassava rows. Weed competition can be reduced by adequate and early application of fertilizers to speed up canopy closure, by intercropping, and by planting towards the end of the rainy season when weed growth is less vigorous.

When herbicides are used, it is recommended to apply a pre-emergence herbicide such as Metolachlor at 1.5 kg active ingredient (a.i) per hectare immediately after planting, followed by once or twice hand weeding at one and two months after planting (MAP) or by spot application of Glyphosate, using a shield over the applicator to prevent damage to the cassava plants. Experiments in Vietnam showed that application of 2.4 l/ha of Dual (the commercial name of Metolachlor) increased cassava yields and net income as compared to hand weeding. Dual will mainly kill grasses, so for control of both grasses and broadleaved weeds, it is recommended to mix Dual with other herbicides as indicated in **Table 4-1**.

Table 4-1. Herbicides used for weed control in cassava under monocropping.

Technical name	Commercial name[1)]	Selectivity for cassava	Time of application[2)]	Dosage[3)] of commercial product/ha	Type of weeds controlled
Diuron	Karmex	Intermediate	Pre	2.0–3.0 kg	Broadleaved
Alachlor	Lazo	High	Pre	3.0–4.0 L	Grasses
Fluometuron	Cotoran	Intermediate	Pre	4.0–5.0 L	Broadleaved
Oxifluorfen	Goal	Intermediate	Pre	2.0–4.0 L	Broadleaved/grasses
Metribuzin	Sencor	Intermediate	Pre	1.0–1.5 L	Grasses
Linuron	Afalon	Intermediate	Pre	2.0–3.0 kg	Broadleaved/grasses
Trifluralina	Treflan	High	Ibp	2.5–3.5 L	Broadleaved/grasses
Metolachlor	Dual	High	Pre	3.0–4.0 L	Grasses
	Karmex + Lazo	Intermediate	Pre	1.0–1.5 + 1.5–2.0	Broadleaved/grasses
	Cotoran + Lazo	Intermediate	Pre	1.0–2.5 + 1.5–2.0	Broadleaved/grasses
	Goal + Lazo	Intermediate	Pre	1.0–2.0 + 1.5–2.0	Broadleaved/grasses
	Afalon + Lazo	Intermediate	Pre	1.0–1.5 + 1.5–2.0	Broadleaved/grasses
	Karmex + Dual	Intermediate	Pre	1.0–1.5 + 1.5–2.0	Broadleaved/grasses
	Cotoran + Dual	Intermediate	Pre	1.0–2.5 + 1.5–2.0	Broadleaved/grasses
	Goal + Dual	Intermediate	Pre	1.0–2.0 + 1.5–2.0	Broadleaved/grasses
	Afalon + Dual	Intermediate	Pre	1.0–1.5 + 1.5–2.0	Broadleaved/grasses
Glyphosate	Roundup	Not selective	Post	1.0–3.0 L	Broadleaved/grasses
Glufosinate	Basta	Not selective	Post	1.0–3.0 L	Broadleaved/grasses
Paraquat	Gramoxone	Not selective	Post	2.0–3.0 L	Broadleaved/grasses
Fluazifop	Fusilade	High	Post	1.0–3.0 L	Grasses
Sethxydim	Poast	High	Post	0.20–0.25 L	Grasses

1) Commercial names may vary between continents and countries.
2) Ibp = incorporated before planting; Pre = pre-emergence; Post = post-emergence.
3) Lower dosage for use in light-textured soils and higher dosage in heavy textured soils.

Applying too high a concentration of Diuron may lead to toxicity symptoms and slow growth.

Applying Glyphosate without a shield over the nozzle may lead to toxicity symptoms and slow growth.

The following weeding guidelines are recommended:

- Control weeds 2–4 times during the first three months of growth, starting at 2–4 weeks after planting.
- Weeds can be controlled by hand, using a hoe, by hand-pulled or tractor-mounted cultivator or by herbicides; or by any combination of these.
- If labor is scarce or expensive, it is recommended to apply pre-emergence herbicides right after planting, even right over the top of stakes planted vertically or inclined. Do not walk in the field for about 30 days after application in order not to damage the herbicide film on the soil surface.
- The pre-emergence herbicide application can be followed by once or twice hand weeding, followed by the application of a post-emergence herbicide at 4–5 months after planting. The post-emergence herbicide should be applied with a shield over the nozzle to prevent hitting the lower stems and leaves of cassava.
- Do not apply post-emergence herbicides on windy days as the spray may drift onto the cassava plants.

When and how to harvest cassava

Cassava can be harvested any time, but the roots are usually harvested between 6 and 18 months. Some early-maturing varieties can be harvested at 6–8 months after planting (MAP) for direct human consumption, but most industrial varieties are harvested between 10 and 12 MAP. **Table 4-2** indicates that root yields nearly tripled between 8 and 18 months and that starch contents increased substantially between 8 and 10 months. Harvesting cassava at about 18 months provides an income only every 18 months, but at a considerable saving in terms of production costs. Planting half of the field at the beginning and half at the end of the rainy season, and harvesting after 18 months, farmers will still have an income every year. Harvesting an early-maturing variety at 6–8 MAP, however, allows for double cropping cassava with a subsequent short-duration crop of rice, cowpea, sweet corn, or mungbeans.

Table 4-2. Average fresh root yield of Rayong 1 as affected by age at harvest when planted at Rayong Field Crops Research Center (RYFCRC), Thailand, in 1975–1979.

Age at harvest (months)	Fresh root yield (t/ha)	Dry root yield (t/ha)	Starch yield (t/ha)	Starch content (%)
8	16	6.4	2.3	14
10	23	8.3	4.8	21
12	31	10.7	5.9	19
14	38	13.1	7.4	20
16	42	15.0	8.7	21
18	45	16.4	9.2	20

Cassava is usually harvested by cutting off the plant tops at 20–30 cm above the ground and using the remaining stumps to pull up the roots. If the soil is hard, the roots can be lifted out of the ground with a long pointed metal bar inserted into the soil below the root clump and pushing the upper end of the bar down using a wooden block on the ground for better leverage. Or, cassava can be harvested using a special harvesting tool consisting of a metal plate with a large ‘V’ cut into one edge of the plate. The metal


Farmers in Thailand have developed three types of cassava harvesting tools to facilitate the root harvest.

plate is welded onto a 2-inch diameter piece of pipe into which a 2-inch wooden dowel of about 1.2–1.5 m length can be inserted. The roughly edged metal 'V' is pulled around the lower stem to grab the stump just above the ground after which the long end of the stick is lifted up to pull the whole root clump out of the ground. Roots can also be dug out with pick, hoe, or shovel. In areas where labor is expensive or the soil is too hard during the dry season, farmers can use a tractor-mounted cassava harvesting tool that loosens the soil and lifts up the roots for easy gathering by hand, as is often used in Thailand. In Malaysia, a more sophisticated cassava harvesting machine will dig the root clumps and deposit them in an attached wagon. After pulling up the root clumps, the individual roots are cut off from the stumps and packed in baskets or sacks for transportation to the house, drying floor, or starch factory. To prevent spoiling, fresh roots should be processed within 2–3 days after the harvest.



Various modifications of the Thai harvesting tools are now used in several countries in Asia.

Several types of tractor-mounted cassava harvesting tools are available in Thailand.

After lifting the root clumps out of the ground, the roots are cut off from the stumps and carried in baskets to the truck or trailer.

Concerning the harvest, the following can be recommended:

- Cassava used for human consumption is usually harvested at 6–10 months, while that used for processing is best harvested at 10–18 months after planting (MAP).
- Delaying the harvest to 18 MAP will greatly increase the root yield at minimal extra costs, while generally having little effect on the starch content.
- In areas with a long dry season, cassava is best harvested in the middle of the dry season, while in areas with a temperate climate, cassava is best harvested during the winter, when the starch content is highest.
- In light-textured or lose soils, the root clumps can often be lifted out of the ground by pulling on the lower stems, but in heavier or compacted soil, the harvest is much facilitated by using some simple harvesting tools or by the use of a tractor-mounted cassava harvester.

CHAPTER 5

IS INTERCROPPING A GOOD OPTION?

What is intercropping?

Intercropping can be defined as the planting of more than one crop on the same land at the same time. Intercropping has many advantages for smallholder upland farmers: to reduce the risk of crop failure, provide diversity of crops, and obtain food or income at different times of the year. Intercropping makes the best use of available farm land and labor and may reduce weed problems. In addition, intercrops may fix N and supply nutrients to the topsoil, and because of their faster growth, they cover the ground and protect the soil from the direct impact of rainfall when the cassava canopy is not yet closed, reducing soil erosion. However, intercrops need to be carefully managed to reduce competition with cassava for light, water, and nutrients. This is usually done through modifications of the plant spacing or planting pattern of both crops, by adjusting the relative time of planting, and by fertilizing each crop adequately to maximize yields.

In general, intercropping is practiced when land is limited and labor is abundant, but not on larger holdings or when labor is in short supply.

When smallholder farmers adopt intercropping cassava with other crops, a relatively small amount of land may be sufficient to provide the family with their basic dietary needs, such as energy, proteins, minerals, and vitamins. Cassava roots are a good source of carbohydrates to provide the necessary calories and, when intercropped with leguminous crops, such as common bean *(Phaseolus vulgaris)*, cowpea *(Vigna unguiculata)*, mungbean *(Vigna radiata)*, and peanut *(Arachis hypogaea)*, these legumes will provide the necessary proteins for the family and their livestock. In addition, the legumes may fix nitrogen (N) from the atmosphere, and

Intercropping cassava with peanut in Vietnam.

Cassava planted among mature coconut trees in Sri Lanka.

cassava may benefit from this symbiosis. Early-maturing food crops should be selected for intercropping with cassava in order to reduce the period of competition and to avoid excessive shading of the food crops.

Commonly used intercropping systems in Asia
Probably the most intensive intercropping systems are found in the wetter zones of West Java and Sumatra of Indonesia. Here, cassava is often intercropped with simultaneously planted upland rice between cassava rows and maize between plants in the cassava row. Once the upland rice and maize are harvested at about 4 months after planting, a short-duration grain legume, such as mungbean, soybean, cowpea, or peanut, are planted in the inter-row space previously occupied by rice. If rainfall permits, a fourth intercrop, such as mungbean or peanut, can be planted in the space previously occupied by the harvested grain legume. In East Java, on the other hand, the dry season is longer and cassava can be intercropped by only one crop, usually maize.

In South Vietnam, cassava is often intercropped with maize or planted among young rubber or cashew trees, while in North Vietnam, the crop is often intercropped with peanut or black bean (cowpea). In Guangxi province of China, cassava is often intercropped with maize, peanut, sweet potato, or watermelon, while in Hainan province, the crop is often interplanted among young rubber trees or bananas. In Thailand, cassava is only occasionally intercropped with maize or grain legumes due to lack of labor, but the crop is sometimes planted for a few years among young rubber or coconut trees.

Improvements in cassava intercropping systems
Several factors should be considered in the selection of crops and management practices to maximize the outputs of intercropping systems.

1. Plant type and/or growth habit

Cassava varieties may differ in their growth habits. Some have vigorous early growth and early branching, while others are more erect with medium-to-late branching. This may also vary with the fertility of the soil. In soils low in K, plants tend to be short and highly branched, while plants growing in soils high in N are tall and show vigorous early growth. To minimize the shading of low-growing grain legumes by cassava, the latter should have an erect and late-branching growth habit; but, to avoid the shading of cassava by fast-growing intercropped maize, the cassava variety should have a vigorous early growth with medium-to-late branching.

2. Relative time of planting

The greatest total yields are generally obtained when both intercrops and cassava are planted at the same time, or with a difference in planting date of only 1–2 weeks.

3. Planting density

In general, the optimum monocrop planting density can also be used when cassava is grown in association with other crops without causing a serious yield reduction of the associated crop. However, if the cassava variety is very vigorous, it may be necessary to reduce its planting density in order to maximize total yields. With late-branching and less vigorous cassava varieties, the best yields were achieved with an intermediate planting density of about 10,000 plants per hectare.

4. Planting pattern

The choice of planting arrangement of each crop is important in reducing competition and maximizing total yield. In many cases, a normal square planting arrangement of cassava with one row of grain legume or maize between cassava rows gives the maximum yield and income from both crops. However, to favor the growth of intercrops, a wider inter-row spacing of cassava and shorter interplant spacing within the row is often preferred. This arrangement may allow the planting

Intercropping cassava with upland rice and maize in Indonesia, with sweet corn in Thailand and with water melon in China.

of two or more rows of intercrops between cassava rows. In Indonesia, cassava is often planted with an inter-row spacing of 1.8–2.0 m and interplant spacing of 0.5 m, which allows the planting of 4–5 rows of upland rice or peanut planted between cassava rows, in addition to one hill of maize between cassava plants in the row. After the harvest of upland rice and maize, there is still enough light between cassava rows for planting a second intercrop of a short-duration grain legume. Alternatively, cassava can be planted in double rows spaced at 0.8x0.8 m in each double row, with 1.9–2.0 m between the centers of double rows. This will allow the planting of several rows of intercrops between each double row of cassava. By varying the inter-row and interplant spacing, a cassava planting density of about 10,000 plants/ha can be maintained. Within limits, whether cassava is planted in a square or rectangular planting pattern has little effect on cassava yields.

The spacing of the intercrops planted between the cassava rows depends on the growth habit of the crop. Most grain legumes should be planted at least 50–70 cm from the nearest cassava row to prevent excessive competition from cassava. Within the remaining inter-row space, 2–3 rows of legumes can be grown at 30–50 cm between rows. Intercropping cassava with common beans at CIAT in Colombia, the arrangement of three rows of beans (spaced at 30 cm between rows) planted between cassava rows (spaced at 1.8 m between rows) produced the highest total yield and income. However, in North Vietnam the planting of two rows of peanut between cassava rows, spaced at 1 m between rows, was most profitable.

5. Fertilization

Crops grown in association tend to cause less loss of nutrients through erosion and leaching but more loss of nutrients removed in the harvested products. Intercropping represents an intensification of the demand for nutrients, particularly when each associated crop is planted at its normal density. In this case, the removal of nutrients from the soil is higher than when cassava is grown in monoculture (**Table 5-1**).

Table 5-1. Removal of soil nutrients by the products (roots and grains) harvested in a cassava–mungbean intercropping system, compared to removal by cassava planted in monoculture.

	Nutrients removed (kg/ha)					
System	N	P	K	Ca	Mg	S
Cassava in monoculture	40	5	78	19	8	6
Cassava–mungbean intercropping	90	11	84	18	10	9

There is little or no information about the optimum rates and balance of N, P, and K fertilization for each crop in an intercropping system, because this is highly dependent on the fertility of the soil, on the nutritional requirements of each crop, their competitive interaction and growth duration. Whether most fertilizers should be applied to cassava or to the intercrop also depends on the expected income to be derived from each crop. In general, cassava should be fertilized as if it were planted in monoculture, generally requiring relatively high levels of N and K, while cereal crops require mostly N and P, and grain legumes P and K.

6. Weed control

Intercropping cassava tends to reduce the growth of weeds between cassava rows, but it also makes weeding by mechanical means more difficult. One hand-weeding with a hoe at 3–4 weeks after planting is often practiced, after which the canopy cover from both cassava and the intercrops will generally prevent further weed growth.

Weed competition can also be reduced by application of pre-emergence herbicides. However, some herbicides that are selective for cassava may not be selective for the intercrop. Thus, care should be taken in the selection and dosage of the appropriate herbicides, as shown in **Table 5-2.**

Table 5-2. Pre-emergence herbicides used for crops grown in association with cassava.

Product or mixture	Dosage[1] (kg a.i./ha)	Time of application	Selective for crops grown in association with cassava
Linuron + Fluorodifen	0.25–0.50 + 1.50–2.10	Post-planting	Common bean, cowpea, and mungbean
Linuron + Metolachlor	0.25–0.50 + 1.00–1.50	Post-planting	Common bean, cowpea, mungbean, peanut, and maize
Oxadiazon + Alachlor	0.25–0.50 + 1.44	1–2 weeks before or after planting	Cowpea, mungbean, peanut
Oxadiazon + Metolachlor	0.50–1.0 + 1.0	Post-planting	Common bean, cowpea, mungbean, peanut, and maize
Oxifluorfen	0.25–0.50	1–2 weeks before or after planting	Peanut

1) The doses indicated are used as follows: low doses on light-textured soils and high doses on heavy-textured soils. Quantities individually indicated for each product are combined to obtain the tank mix; dosages are expressed in kg of active ingredient/ha.

To maximize the yield, profitability and sustainability of cassava intercropping systems, the following can be recommended:

- Growing cassava in association with other crops is mostly practiced when land is scarce and labor is abundant; or in isolated areas where families grow most of their own food crops.

- To reduce the competition between cassava and the associated crops, cassava is best intercropped with short-duration crops such as maize, upland rice, peanut, cowpea, soybean, and mungbean, or with creeping crops like watermelon, squash, etc.

- Cassava can also be planted between young rubber, cashew, or banana trees, or under mature coconut trees as long as there is adequate light penetration.

- Highest total yields and income are usually obtained when cassava and the intercrop are planted at the same time, or within one or two weeks of each other.

- Plant spacing will depend on the branching habit of the cassava variety, with highly branching varieties needing a larger inter-row space than moderately branching or erect varieties.

- In areas with a long wet season, cassava can be intercropped sequentially with 2 or up to 3 other crops within a one-year period as long as the inter-row space is wide enough (usually 1.8–2.0 m) to allow enough light penetration between the cassava rows for the 2nd or 3rd intercrop to grow.

- In areas with a relatively short wet season, cassava can usually be intercropped with only one other crop, because a second intercrop would normally not produce well due to lack of soil moisture.

- In that case, cassava can be grown at a normal square planting arrangement, such as 1.0x1.0 m, with 1–2 rows of intercrops between cassava rows; or, to favor the intercrop, the inter-row space can be widened to allow for more rows of intercrops.

- Most grain legumes should be planted at least 50–70 cm from the nearest cassava row and with 30–50 cm between intercrop rows.

- To maximize total yield, both cassava and the intercrops should be adequately fertilized, with cassava receiving mostly N and K, intercropped cereals mostly N and P and the grain legumes mostly P and K.

- While the fast growth of most intercrops will reduce weed competition, it is usually necessary to do at least one hand weeding after which the canopy of both cassava and the intercrops will generally prevent further weed growth.

- Weeds can also be controlled by application of pre-emergence herbicides as long as the herbicides are selective for both cassava and the associated crop(s).

CHAPTER 6

HOW TO PREVENT SERIOUS PEST AND DISEASE PROBLEMS

Like other crops, cassava can suffer from serious pest and disease problems that reduce yields. But being a long-season crop that is exposed to these problems over a long period, it is hardly ever economic, nor effective, to control these problems through frequent applications of pesticides. Most pests and diseases can be kept under sufficient control through integrated pest and disease management (IPM). This may include the following:

- Plant cassava varieties with tolerance or resistance to the most important diseases and pests.
- Use high-quality planting material cut from mother plants that are free of pest and disease symptoms.
- As an extra precaution, treat the stakes with a mixture of fungicides and insecticides before planting.
- Apply adequate amounts of fertilizers or manures to stimulate vigorous growth, which enhances resistance or tolerance.
- Do not apply insecticides to the crop as these may kill the natural biological control agents that will keep some major pests and diseases under control. Pesticides should only be used as 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. Pesticides can be used to control soil-borne pests, such as termites, as this will not affect the natural enemies of foliar pests.

- To reduce soil-borne diseases, mainly root rots, rotate cassava with other crops, especially cereals or grasses.
- Monitor the crop regularly and pull out plants with symptoms of disease or pest problems. Burn infected plant residues after harvest.
- Prevent the movement of diseased or pest-infested planting material from infested to non-infested fields.
- Do not purchase planting material from unknown sources, as pests and diseases may be a risk.

Major cassava pests

The most important pests found in all three continents include whiteflies, mealybugs, green and red mites, scale insects, white grubs, termites, and several pests attacking dried cassava during storage. Other important pests that are found only, or mainly, in Latin America include cassava hornworm, burrowing bugs, leaf-cutter ants, shoot flies, fruit flies, and lace bugs. Great care should be taken to not accidentally introduce these pests from Latin America to Africa or Asia, where they can cause tremendous damage due to the absence of their natural enemies. For that reason, it is absolutely prohibited to take vegetative planting material from one continent to another – as well as from one country to another.

Some of the pests, as well as certain diseases, can also be accidentally introduced on other plant species, closely related to cassava, such as *Jatropha curcas*, used as fences in Asia and recently popularized for biofuel. Special care must be taken in the movement between countries of vegetative planting material of these related species, and that large *Jatropha* plantations are not located in cassava growing regions.

Whiteflies

Whiteflies are considered one of the most damaging agricultural pests, both as a direct feeder and a virus vector; they are probably the most damaging pest on cassava in all three continents. The whitefly species *Bemisia tabaci* is the vector of several serious virus diseases in Africa, and the vector of the Indian and Sri Lankan cassava mosaic viruses found mainly in India. Another species, *Aleurodicus dispersus* or spiraling whitefly, is found in several countries in Asia and Africa, where it can cause serious feeding damage and possible yield losses.

White flies are one of the most serious cassava pests.

Whiteflies have six life stages – the egg, four nymphal stages, and the adult. The three types of damage they can cause are:

- Direct damage – by piercing and sucking sap from the foliage, resulting in weakening and early wilting, yellowing, and necrosis of the lower cassava leaves.
- Indirect damage – by the accumulation of honeydew produced by the whiteflies, which serves as a substrate for the growth of black sooty mould on leaves, resulting in reduced photosynthesis.
- As a virus vector – by the transmission of plant viruses from one plant or crop to another. Over 40 diseases of crops are transmitted by whiteflies worldwide. The yield losses in cassava can be as high as 76% if the plants are seriously affected.

To control high populations of whiteflies, many farmers spray insecticides, but this is ineffective as some whitefly species can double their population in only 4.2 days. They can only be controlled with very frequent applications – this is uneconomical and disrupts the natural biological control process. To control whiteflies effectively, integrated pest management (IPM) must be implemented, including:

Cassava stakes are treated in a solution of insecticides, fungicides, and micro-nutrients before planting.

- Plant whitefly-resistant varieties.
- Enhance the function of natural enemies, among which are many species of parasitoids, predators, and entomopathogens. These techniques will be further developed in the future.
- Intercrop cassava with cowpea.
- Implement a "closed season" in which no cassava should be present in nearby fields in order to break the whitefly development cycle. This may not be as effective with whitefly species that have multiple hosts, such as *Bemisia tabaci*.
- Treat planting stakes by immersion for 7 to 10 minutes in a solution of 1 g of Thiamethoxam (Actara) per liter of water.
- Make foliar applications of Thiamethoxam at a high dose of 0.8 liter/ha or 0.6 liter/ha of Imidacloprid as a drench, but only on young plants (less than 6 months after planting) and when whitefly populations are still low.

Cassava mealybugs

Of the approximately 15 species of mealybugs attacking cassava plants, there are two species causing major damage to cassava in the Americas, i.e., *Phenacoccus herreni* and *Phenacoccus manihoti.* The latter species was inadvertently introduced into Africa in the early 1970s, where it spread rapidly throughout the cassava-growing regions of that continent. The same species was recently accidentally introduced into Thailand and within a year it had spread throughout the country and into neighboring Lao PDR and Cambodia, and later into Vietnam. It is now also reported in Indonesia.

Several other species of mealybugs have been identified in Asia, including *Phenacoccus gossypii, Phenacoccus* *grenadensis*, and *Phenacoccus jackbeardsleyi*. Shortly after initiating feeding, the young nymphs produce a white waxy material that forms a cover over the insects. These mealybugs cause two types of damage to cassava:

- Mechanical or direct damage caused by their sucking-feeding habits, resulting in leaf yellowing and defoliation.
- Indirect damage caused by the build-up of sooty mould on the leaf surface due to the mealybugs' excrements, resulting in reduced leaf photosynthesis.

Phenacoccus herreni is found mainly in northern South America, while *Phenacoccus manihoti* was first found in Paraguay, Bolivia, and southern Brazil, where it was causing little damage due to effective biological control. However, once it found its way into Africa, and later into Asia, where its natural enemies were not present, it multiplied quickly and spread fast and far. Only after the introduction into Africa of several biological control agents, mainly parasitoids and predators from their area of origin in southern South America, was it possible to bring the mealybug population under control. From this experience, it was found that the parasitoid *Anagyrus lopezi*, a tiny wasp, was the most effective in attacking the *Phenacoccus manihoti* mealybug. When the females of the *Anagyrus lopezi* wasp lay their eggs in the mealybug, the developing larvae of the parasite will kill their host in the process. Thus, when the same species of mealybug also arrived in Asia, Thai researchers quickly introduced *Anagyrus lopezi* from Africa, learned how to mass-rear the wasp, and distributed millions of wasps into their cassava fields with excellent results. The Thais also taught farmers how to soak planting stakes in a solution of 4 g Thiamethoxam in 20 liters of water for ten minutes before planting. This treatment kills the mealybugs present on the stakes and prevents any mealybug from feeding on emerging leaves for at least one month after planting.

There are several species of mealybugs that can do serious damage to cassava plants.

For the effective control of mealybugs, the following measures can be recommended:

- Treat cassava stakes in a solution of Thiamethoxam at 0.5–1 g/liter before planting.
- Minimize the movement of planting material from infested to non-infested fields.
- Avoid spraying of chemical pesticides to conserve the population of natural enemies.
- Monitor the cassava fields every 2–4 weeks to detect the focal points of infestation (hot spots).
- Remove the infested parts (apical buds) of the plants and burn these.
- Avoid the movement of planting material from one region to another.

Cassava mites

More than 40 species of mites have been reported feeding on cassava, of which the most important are the **green mites**, *Mononychellus tanajoa* and *Mononychellus caribbeanae*; and the **red mites**, *Tetranychus cinnabarinus, Tetranychus kanzawai*, and *Tetranychus urticae*. These can cause serious damage, especially in lowland areas with a prolonged dry season. The red spider mites, *Tetranychus* sp. are the most prevalent dry season pest in Asia. The most common species are *Tetranychus urticae* and *Tetranychus kanzawai.* However, the green mite has also been reported recently in Asia.

The cassava green mite prefers to feed on the underside of young leaves, which become white-yellow and may be deformed and smaller in size. This may result in defoliation, starting at the top of the plant. Once the rains come, green mite populations are markedly reduced and cassava sprouts new leaves again.

Red mite populations may build up to high levels when favorable environmental conditions exist, especially in the dry season. Depending on plant age and the duration of attack, the yield losses can be between 20 to 50%. Red mites initially attack the mature leaves at the lower part of the cassava plant, before moving to the upper leaves. The first symptoms generally occur at the base of the leaf and along the midribs, seen as yellow dots along the main leaf vein, eventually spreading over the whole leaf, which turns reddish, brown, or rusty in color. Severely infested leaves dry and drop off, and plants may die.

When confronted with heavy mite infestations in their cassava fields, many farmers start applying insecticides. However, this is not economic and may actually be counter-productive as even low doses of insecticides could kill the natural enemies before killing the mites. Mite damage is mainly controlled by the planting of resistant varieties. Further research is urgently needed to determine the most effective natural enemies of red spider mites, especially in Asia. But to be effective, moderate levels of host plant resistance should be combined with effective biological control. This is only possible as long as no chemical pesticides are used to control pests, such as whiteflies or mealybugs.

Over the past 30 years, many surveys have been conducted in 14 countries of the Americas to collect and evaluate potential natural enemies of the green spider mite. Of these, 87 are collected species of phytoseiids – these are mites feeding on mites. These were found to have the greatest potential for controlling mites. Some of these phytoseiid species were shipped from Colombia and Brazil, via quarantine in England, to Africa in 1993, where at least three species from Brazil became established and were successful in controlling the cassava green mite population enough to reduce their damage to non-economic levels.

Red mites (on top) are a common cassava pest during the dry season in Asia, but the green mites (on bottom) have now also been reported.

Similar research should be conducted for the control of the red spider mite in Asia.

Current recommendations for the control of cassava mites include:

- Plant resistant or tolerant varieties if available.
- Treat stakes before planting with Thiamethoxam in those areas where mites are a serious pest.
- Plant in the early wet season to enhance good establishment.
- Apply adequate and well-balanced fertilizers to improve plant vigor.
- Apply foliar sprays with water at high pressure to reduce mite populations.
- Apply only selective insecticides to protect natural enemy populations, as phytoseiid mite predators are very sensitive to even low dose applications of pesticides.
- Strictly enforce quarantine regulations.

Other pests that can be important locally include white grubs, scale insects, and termites.

Major cassava diseases

Until recently, Asia had few serious pest and disease problems, but this is changing as production of the crop is intensified and cassava is planted throughout the year for industrial processing. The following are the most important cassava diseases in Asia:

Indian and Sri Lankan cassava mosaic disease
The Indian cassava mosaic virus (ICMV) and Sri Lankan

cassava mosaic virus (SLCMV) are distinct begomoviruses, closely related to the virus that causes cassava mosaic disease (CMD) in Africa. There are several ICMV-tolerant cassava varieties, but many farmers in Kerala State of India prefer to plant their local varieties because of better eating quality. The recent introduction of lines resistant to CMD from CIAT, such as MNga-1 (developed by IITA in Nigeria) and other lines are now being used extensively in the Indian breeding program to produce ICMV-resistant varieties with other desirable characteristics.

Symptoms of Indian or Sri Lankan cassava mosaic disease.

The symptoms of these two diseases include chlorotic mottling of green leaves with leaf deformation, which may lead to leaf fall and severe stunting of plants. Leaves can also be reduced in size, twisted and deformed. Symptoms appear mainly during the wet season, making identification of diseased plants very difficult during the dry season. The disease is spread mainly through the use of infected planting material, as well as by the whitefly *Bemisia tabaci*.

Mosaic disease-resistant varieties (on the right side of the photo) are now being developed in India.

To effectively control the disease, the following practices are recommended:

- Plant field-tolerant cassava varieties such as H-97, H-165, and Sree Visakham.
- Select disease-free meristem-derived planting materials, followed by clonal multiplication with periodic screening and pulling out of newly infected plants.
- Select disease-free planting material before the beginning of the hot dry season.
- Multiply disease-free planting material on a large scale at higher altitudes, where whitefly populations are very low or non-existent.

- Plant stakes first in a nursery at close spacing before transplanting only plants without disease symptoms to the field to prevent the spread of the disease.

- Follow strict phytosanitary practices, such as timely harvesting, prompt destruction of crop residues and pulling out of self-sown plants and weeds that may harbor both the disease and its vector.

- Cultural practices, such as intercropping or a change of planting dates, should be further investigated to determine their effectiveness.

Cassava bacterial blight (CBB) is one of the most common cassava diseases, but high-yielding varieties with good CBB tolerance are now available.

Cassava bacterial blight (CBB)

This disease is wide-spread and can be serious during the rainy season. It is caused by the bacteria *Xanthomonas axonopodis* pv. *manihotis*. Symptoms of the disease are the presence of water-soaked, angular spots, and necrosis of leaves. The branches may partially or totally wilt and gum exudates may appear on the main stem or immature branches. There may be stem die-back and necrosis of some vascular strands of the stems and roots. The degree of plant damage varies depending on the degree of tolerance of the varieties and the growth stages of the plant.

The disease is transmitted mainly through the use of infected planting material, or the use of infested tools. The disease can also spread from one plant to another by rainfall splash, and by the movement of people, machines, or animals from infected fields to healthy fields. Fortunately, many high-yielding varieties with good tolerance to CBB are now available. Other measures to control the disease are:

- Use only healthy planting material from disease-free crops or plants derived from meristem culture, or rooted buds or shoots.

- Treat stakes by immersion for 10 minutes in a solution of cupric fungicides, such as copper oxychloride or Orthocide at 3–6 g/liter; or immersion in hot water (49 °C) for 49 minutes. This treatment does not seriously affect sprouting.

- Plant at the end of rainy periods.

- Sterilize tools in hot water or in a dilute solution of sodium hypochlorite after their use in CBB-infected plots.

- Apply fertilizers, especially potassium.

- Pull out and burn any diseased plants and infected crop residues.

- Intercrop cassava with other species to reduce plant-to-plant dissemination of CBB by rainfall splash; fast-growing crops, such as maize will also reduce dissemination by wind.

- Rotate cassava with other crops or leave the field in fallow for at least six months between cassava crops to prevent the carry-over of the disease in the soil.

Cassava root rots

This disease complex is widespread in all three continents, but is found mainly in heavy, poorly drained soils with high organic matter content, and during intense rainy periods. The disease can be caused by a wide range of fungal or bacterial pathogens that attack woody plants, such as cassava, and cause root deterioration, either as the crop grows or after harvest when roots are stored.

Root rots are commonly found in heavy or compacted soil and in areas with heavy rainfall.

The most common root rots are caused by a variety of species within the genus *Phytophthora*, especially *Phytophthora drechsleri.* The disease can attack both young and mature plants, causing sudden wilting, severe defoliation, and soft root rot. The infected roots exude a pungent, watery liquid, and they decompose completely.

The disease is best controlled by planting resistant varieties in combination with practices, such as:

- Plant preferably on light-textured, moderately deep soils with good internal drainage.
- If necessary, improve drainage by the use of a subsoiler.
- If the soil is rather clayey and flat, plant on top of ridges.
- Rotate cassava with cereals or grasses when more than 3% of plants show symptoms of root rot.
- Eradicate diseased plants by removing infected roots from the field and burning them.
- Select healthy planting material from disease-free mother plants.
- If no disease-free planting material is available, treat stakes with a solution of 0.3 g active ingredient of metalaxyl/liter, or immerse stakes before planting in hot (49 °C) water for 49 minutes.
- Use biological control by immersing stakes in a suspension of *Trichoderma harzianum* and *Trichoderma viride* at 2.5 x 10^8 spores/liter, followed by application of the same suspension in drench form.

Other methods of control of root rots, more suitable for smallholder farmers, include:

- Application of 200 g/plant of a 1:1 mixture of ash and dry leaves.

- Stake selection.
- Intercropping with cowpea *(Vigna unguiculata).*

These practices eliminated root rots in farmer participatory trials conducted in the Colombian Amazon region where root rots are a serious problem.

Witches' broom disease

Recently (2008) symptoms of a new disease have been observed on cassava in many Asian countries, especially in southern Vietnam, Thailand, Lao PDR, Cambodia, and the Philippines. Plants show excessive sprouting of small leaves having short petioles. If plants are infected early in the growth cycle, they remain small. Many different varieties are affected, but some more than others. In general, plants are dwarfed and show an exaggerated proliferation of buds, as well as shoots and small branches growing from a single stake. Sprouts have short internodes and many small leaves. The roots of affected plants are thinner and smaller with drastically reduced starch contents.

This disease is mainly transmitted by the use of stakes cut from infected plants. It may also be spread by insect vectors, but this is not yet confirmed. To prevent the disease from spreading, the following measures are recommended:

- Plant varieties that are resistant or that show tolerance to the disease.
- Use only healthy planting material cut from mother plants without any symptoms of the disease.
- Eliminate any diseased plants from the field.
- Rotate cassava with other crops to prevent the transmission of the disease from infected cassava crop residues left in the field.

Witches' broom disease is mainly spread by the use of infected planting material.

- Prevent the movement of planting material from areas where the disease is prevalent to other areas where the disease does not exist.
- Also, prevent the movement of planting material of related species such as *Jatropha*, which have a similar disease complex as cassava.

CHAPTER 7

DIAGNOSIS OF NUTRIENT DEFICIENCIES AND TOXICITIES

Like other crops, cassava needs three essential macro-nutrients to grow well: nitrogen (N), phosphorus (P), and potassium (K). These are called "macro-nutrients" because they need to be absorbed in rather large quantities to sustain normal growth. Besides these macro-nutrients, plants also need to take up three nutrients often called "secondary nutrients," as these are needed in fairly large quantities, but are rarely deficient in the soil. These "secondary nutrients" are calcium (Ca), magnesium (Mg), and sulphur (S). Finally, there are five essential nutrients that plants need in much smaller quantities; therefore, they are called "micro-nutrients." These are boron (B), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn).

"Hidden hunger"

If any of these essential nutrients are in short supply in the soil, most other crops, such as maize, rice, or soybeans, will show clear deficiency symptoms. But cassava may not show any clear deficiency symptoms, although plants remain shorter and weaker than normal, and root yields will be low. Cassava will show clear nutrient deficiency symptoms only for a few nutrients, or only when the deficiencies are very severe. This is called "hidden hunger," because plants may look normal but their yields are low due to the inadequate absorption of some essential nutrients. Since cassava is usually grown on low-fertility or degraded soils, it is very likely that one or more essential nutrients are not present in adequate amounts. Plants can also suffer from toxic elements when they are present in excessive amounts, so cassava yields may be depressed by both nutrient deficiencies and toxicities.

Only in a few varieties is N deficiency characterized by the lighter green color of leaves (in front).

N deficiency usually results in short plants (on left) without clear deficiency symptoms.

Common deficiencies are:

Nitrogen (N) deficiency

Cassava plants suffering from N deficiency may not show any visible deficiency symptoms, but are shorter and grow slower than normal. In some varieties and under severe N deficiency, leaves are slightly lighter green in color, the chlorosis being rather uniform throughout the plant. Severe N deficiency is usually observed in very sandy soils low in organic matter (OM), but may also be found in very acid soils that are high in OM, mainly due to a slow rate of organic matter decomposition and subsequent N mineralization.

Phosphorus (P) deficiency

Phosphorus-deficient plants seldom show clear deficiency symptoms; instead, cassava plants are shorter and less vigorous, have thinner stems, and smaller and narrower leaves than normal plants. Root yields can be seriously reduced by P deficiency. In extreme cases, plants have a few dark yellow or orange lower leaves, which later become necrotic, flaccid, and fall off. In the absence of clear deficiency symptoms, P deficiency is generally diagnosed through knowledge about the soil, or from soil or plant tissue analyses.

Plants suffering from P deficiency are usually short and spindly without clear deficiency symptoms, but under very severe deficiency, plants may have some yellow or orange lower leaves.

Potassium (K) deficiency

Potassium deficiency results in reduced plant height and vigor. Stem internodes are markedly reduced and the upper stem tends to become woody, resulting in a zigzag-shaped growth. In general, stems are thick and highly branched, producing a spreading growth form. Clear deficiency symptoms in leaves are seldom observed. In the field, K-deficient plants are seldom chlorotic (having a light green color), but upper leaves are small, and lower leaves may be yellow with dead tissue along the leaf borders. Some of this necrosis seems to be due to K-deficiency-induced diseases, mainly anthracnose. The edges of lower leaves may also curl up, similar to drought symptoms.

Potassium deficiency is particularly common in sandy soils with low potassium reserves, and especially in fields that have been cultivated with cassava for many years.

K-deficient plants are usually short with very short internodes and some yellowing and leaf necrosis of older leaves.

K-deficient plants have a prostrate (spreading) growth habit, with some chlorosis and curling of edges of lower leaves.

Ca deficiency affects mainly the growing points of tops and roots with curling down or necrosis of upper leaf tips.

Calcium (Ca) deficiency

Symptoms of Ca deficiency are seldom observed on cassava in the field, but in very acid soils with low levels of available Ca, the crop may respond to Ca applications. Ca deficiency reduces root growth, so plants are smaller and shorter, with a coarse and stubby root system. Under very severe Ca deficiency, the older leaves remain normal and green, while the tips of young leaves are curling downward and may be necrotic. Ca deficiency affects principally the growing points of both tops and roots.

Magnesium (Mg) deficiency

Unlike most other nutrient deficiencies, the symptoms of Mg deficiency are commonly seen in cassava fields and are easily recognizable. When Mg is lacking, the lower leaves of cassava become yellow along the borders and in between the veins, producing a “fish-bone” effect of green veins on a yellow background. This is called “interveinal” yellowing or “chlorosis.” The yellowing starts with the oldest leaves and moves up the plant, but leaves in the upper part of the plant do not show these symptoms. Plant height is generally not reduced and the leaves are not deformed. Mg deficiency is most common in very acid soils.

Mg-deficient plants show green veins on a yellow background (fish-bone effect) in the lower leaves.

Sulphur (S) deficiency

Sulphur deficiency in cassava is characterized by a uniform yellowing of upper leaves similar to that caused by N deficiency. Under severe conditions, the whole plant becomes uniformly chlorotic and leaves remain small.

S-deficient plants show yellowing of upper leaves.

Boron (B) deficiency

Symptoms of B deficiency in cassava are rarely seen in the field. Since B (like Ca) does not readily move within the plant, the symptoms of severe B deficiency are mostly seen in the growing points of roots and shoots. Under severe B deficiency conditions, plants remain short and the fibrous roots are thick and short. Leaves at the top of the plant are small, deformed, and dark green, while the internodes of the upper stem are very short. Sometimes the petioles and stem exude a brown gummy substance, which later changes into brown spots. When the deficiency is not severe, plants have small chlorotic spots on the leaves in the middle or lower part of the plant.

B deficiency. Small white spots on leaves in the middle part of the plant.

Under severe B deficiency conditions, plants are short with small upper leaves and a brown exudate on upper stem or petioles.

Fe deficiency is characterized by uniform yellow or white leaves, starting in the upper part of the plant.

Iron (Fe) deficiency

Iron-deficient cassava plants are characterized by uniform yellowing of all leaves without major deformation. Under severe conditions, upper leaves and petioles may become almost completely white. This problem is only found in alkaline or limestone-derived soils, or in spots of old termite hills present in acid soils. The symptoms are most pronounced during the dry season.

Zinc (Zn) deficiency

Cassava is very susceptible to Zn deficiency, especially at the early stages of growth. Symptoms of Zn deficiency appear as white spots or lines on young leaves. When very severe, the whole leaf becomes pale green to white, leaf lobes become smaller and narrower, and tend to point outward away from the stem. Often, lower leaves show necrotic white or brown spotting and the plant remains small and weak. Plants showing early symptoms of Zn deficiency may later recover by themselves once the fibrous root system is well established and roots become infected with mycorrhizal fungi in the soil. If the deficiency is severe, however, plants may either die or produce very low yields.

Zn-deficient plants have green or light-green upper leaves with white spots and necrotic lower leaves. The lobes of upper leaves may turn outward.

Other deficiencies that may occur, but that are not very common, are copper (Cu), and manganese (Mn) deficiency. Symptoms of copper (Cu) deficiency have been observed only in soils with very high levels of organic matter, such as peat soils. These deficiencies and their control will be briefly discussed in **Chapter 9**.

Common toxicities are:

Aluminum (Al) toxicity

This is characterized by small plants without any clear symptoms but with lower yields due to excessive absorption of this toxic element. This problem is generally observed only in very acid soils with a pH below 4.2 and is often associated with Ca deficiency.

Manganese (Mn) toxicity

This is characterized by yellow- or orange-colored lower leaves with purple-brown spots along the veins; these leaves will become flaccid and drop off. Manganese toxicity is only observed in some very acid soils or in very compacted soils with poor internal drainage, resulting in waterlogging.

Mn toxicity is characterized by a few yellow leaves with brown or purple spots along the veins of lower leaves.

Salinity toxicity

This is characterized by uniform yellowing of leaves, starting at lower leaves and moving up the plant. These symptoms are very similar to those of iron deficiency. Under very severe conditions, the upper or lower leaves will show border necrosis, and young plants may die. Symptoms are only observed in saline or alkaline soils. There are large varietal differences in tolerance to soil salinity and alkalinity.

Cassava plants growing in saline or alkaline soils often show yellowing of upper leaves and necrosis of lower leaves.

Boron (B) toxicity
This is characterized by necrotic spotting of lower leaves, especially along the edges of leaves. These symptoms are only observed when too much boron has been applied.

Since many of these symptoms are not very clear in cassava, the determination of which nutrient is in inadequate or toxic supply is not easy. In many cases, it needs to be confirmed by soil or plant tissue analysis done in specialized laboratories. These laboratories are not always close by and the interpretation of the results can be done only by experienced personnel. In that case, it may be easier to conduct very simple experiments on the farm with the help of researchers or extension workers. In these experiments, each plot receives all the necessary nutrients – mainly nitrogen, phosphorus, potassium, calcium, magnesium, and zinc – but in each plot one nutrient is left out. The nutrient that is left out from the plot with the lowest yield is the most yield-limiting nutrient and should be applied. Other missing nutrients that caused a yield reduction in the experiment may also need to be applied in order to increase yields.

CHAPTER 8

APPLICATION OF NPK FERTILIZERS: WHAT KIND, HOW MUCH, WHEN, AND WHERE?

Even though cassava performs better than most crops on acid and infertile soils, the crop is highly responsive to fertilizer application. Still, fertilizers or lime are seldom applied to the crop since many farmers believe cassava does not need good soil fertility and does not respond to fertilizers. However, thousands of fertilizer experiments conducted by the Food and Agriculture Organization of the United Nations (FAO) throughout the world between 1961 and 1977 indicate that cassava is as responsive to fertilizer applications as other crops, and that fertilizer application to cassava can be highly economically beneficial.

The fertilizer experiments conducted by FAO were mostly short-term trials. These indicate that in West Africa (Ghana) cassava responded mainly to potassium (K), in Latin America (Brazil) mainly to phosphorus (P), and in Asia (Indonesia) to nitrogen (N), followed by P. Also, in nearly 100 NPK cassava trials conducted in Thailand in the early 1980s, the crop responded mainly to N, followed by K and P. Similarly, many short-term NPK trials conducted in India indicate mainly a response to N with an occasional response to K and P.

Short-term responses to various applied nutrients depend largely on the original fertility of the soil as well as on the nutrient requirements of the crop. However, in long-term experiments, the response to particular nutrients may change over time, depending initially on the original fertility of the soil, but subsequently this will depend on which nutrients are being depleted most by the removal of the harvested products (see **Table 10-2** in **Chapter 10**).

Results of soil analyses are most useful to determine the short-term fertilizer recommendation for a specific site. But soil samples need to be analyzed in a specialized laboratory, and the results interpreted by an experienced technician who can make fertilizer recommendations based on the requirements of different crops. If no soil analysis results are available, and little is known about the characteristics of the soil, it is recommended to apply initially about equal amounts of N, P_2O_5, and K_2O, such as 500–600 kg/ha of a fertilizer like 15-15-15 or 16-16-16 (about 75–100 kg per ha of N, P_2O_5, and K_2O). Depending on the growth of the cassava plants, the yield levels obtained, and whether or not the crop residues are incorporated or removed, the levels of application of N and K should increase over time, while the level of P application can probably be reduced. When soils are particularly low in available P, or are known to be highly P-fixing, it may be necessary to initially apply as much as 100–200 kg P_2O_5/ha, but these levels should be drastically reduced in later years as the applied P tends to build up in the soil, which may reduce the uptake of some micro-nutrients, such as iron and zinc.

In the second year of planting at Jatikerto, near Malang, Indonesia, cassava responded very markedly to N application (in back). Note the light green color of leaves of N-deficient plants in front.

Nitrogen (N)

Some of the most dramatic responses to N have been obtained on sandy soils in Santa Catarina State of southern Brazil. There was a nearly linear response in two varieties up to levels of 150 kg N/ha. In this location, yields increased from 10 to 35 t/ha by N application to a soil with 89% sand and very little organic matter. For both varieties, highest yields were obtained with the split application of nitrogen, with 1/3 applied at 30, 60, and 90 days after planting.

A similar spectacular response to N was also observed in a clay soil with 1.2% OM in East Java, Indonesia (**Figure 8-1**). In this case, cassava was intercropped with maize, which competed strongly for the limited supply of N in the soil.

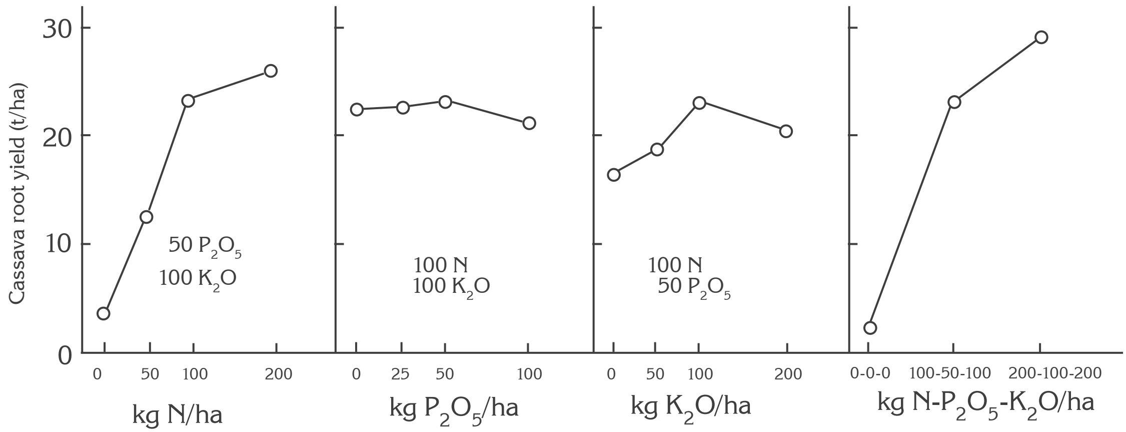


Figure 8-1. Response of cassava, cv. Faroka, to the annual application of various levels of N, P, and K during the 7th crop cycle in Jatikerto, East Java, Indonesia, in 1994/95.

In Kerala State of southern India, cassava responded principally to the application of N, with a recommended rate of 100 kg N/ha, half applied at planting and half at two months. Similarly, in Thailand, where cassava is generally grown on moderately acid and low OM soils, the crop responds mainly to application of 50–100 kg N/ha. In Nanning, in Guangxi Province of China, there was also a highly significant response to N, up to 200 kg N/ha in one variety (SC205), but only up to 50 kg N/ha in the other (SC201). Since SC201 is extremely vigorous, high N levels produced too much top growth at the expense of root production.

Thus, high N levels may produce too much top growth at the expense of root production. Application of high levels of N also stimulates production of the toxic compound hydrogen cyanide, while it may decrease the starch content and increase the susceptibility of the variety to some diseases, such as cassava bacterial blight. Thus, N rates must not only be adjusted to a particular soil, but also to the needs of a particular cassava variety. There are usually

With and without (in front) N application of two varieties at Guangxi Subtropical Crop Research Institute (GSCRI) in Nanning, Guangxi (on top), and at the Chinese Academy of Tropical Agricultural Sciences (CATAS) in Danzhou, Hainan, China (below).

no major differences between N sources, such as urea, ammonium nitrate, ammonium sulphate, and mono- or di-ammonium phosphate.

Since most N sources are highly soluble in the soil solution, they do not need to be in good contact with soil to dissolve. In contrast, they should be concentrated by band or spot application near each plant to prevent most weeds from benefiting from the fertilizer.

Based on these results, the following methods of N application are recommended:

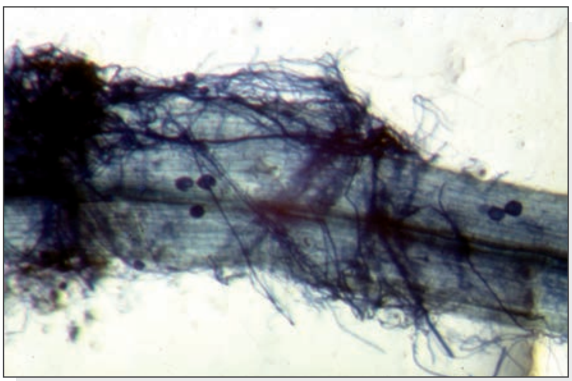
- In most soils, cassava root yields can be increased with the application of 80–120 kg N/ha, all applied at planting or at 30 days after planting.
- If leaves are regularly harvested during the growth cycle, or stems and leaves are removed at the time of root harvest, the rate of N application should increase to 120–200 kg N/ha.
- In sandy well-drained soils, apply N in two or more fractions, such as half at planting and half at 1–2 months after planting; or apply 1/3 of the total at planting, 1/3 at 30 days, and another 1/3 at 60 days after planting.
- There are usually no major differences between various sources of nitrogen, such as urea, ammonium sulphate, ammonium nitrate, or mono- or di-ammonium phosphate. The latter two sources also contain phosphorus.
- Most nitrogen fertilizers are highly soluble in the soil solution and should therefore be band applied in a hole or in a short furrow made with a hoe at the side of each stake or plant and then covered with soil.

- Do not leave N fertilizers on the soil surface, as part of the nitrogen will be lost by volatilization or be washed away by runoff water.

Phosphorus (P)

Under normal field conditions, cassava is more tolerant of low levels of phosphorus in the soil than most other crops, such as maize, rice, or soybean, so it can still grow well in some very poor P-deficient soils where other crops would need large P applications. This is because the small fibrous roots of cassava become infected with a beneficial fungus, called vesicular-arbuscular mycorrhizae (VAM), which produces many thin, thread-like filaments, which grow into the surrounding soil. These thin filaments, known as "hyphae," can absorb P more efficiently as they can explore a larger volume of soil than the uninfected roots. These fungi help cassava take up P even from very low-P soils.

In sterilized field plots, cassava grows very poorly due to P deficiency (in front), but when inoculated with mycorrhizal fungi, plants grow quite well (in back).



Once infected with mycorrhizal fungi, the small fibrous roots of cassava become covered with hyphae, which help the roots in the absorption of P and some micro-nutrients.

In a sterilized soil, cassava grows very poorly due to the absence of mycorrhizae (on left), but when inoculated with highly effective species of mycorrhizae, plants grow normally (on right).

In Asia, P deficiency is not usually the principal limiting factor for cassava production because most cassava is grown on soils that have enough available P, that is, P in a form that plants can take up. Nevertheless, significant responses to P application have been observed in Guangzhou (Guangdong), in Nanning (Guangxi) and on Hainan Island of China; in North and South Vietnam; and on Leyte Island of the Philippines. In low-P soils in Kerala State, India, significant initial responses to 100 kg P_2O_5/ha were reported, but these declined over time. The most economic rate of P application was found to be 45 kg P_2O_5 /ha. The greatest response to P application in Asia was observed in the Plain of Jars in Xieng Khouang Province of Lao PDR in soils with very low levels of available P.

Responses to P application depend not only on the level of available P in the soil, but also on the mycorrhizal population and the cassava variety used. Research in Colombia has shown that some varieties produced high yields of 40–50 t/ha without P application in a soil with very low levels of available P, but with a highly effective mycorrhizal population.

Without P application (in front) and with P (in back) in Lao PDR (on bottom) and in Guangdong and Guangxi provinces of China (in middle and on top).

In a low-P soil with a highly effective VAM population in Colombia, cassava grows very well even without P application.

In other soils with equally low levels of available P but with a less effective mycorrhizal population, cassava responded very markedly to P applications. In extremely P-deficient soils in the Eastern Plains of Colombia, highest cassava yields were obtained with the application of 200–400 kg P_2O_5/ha. Of the seven P sources tested, banding of triple superphosphate (TSP) or broadcast applications of basic slag were most effective. Partially acidulated rock phosphate or rock phosphate mixed with elemental sulphur (S) were also quite effective in these very acid soils.

Soluble P sources, such as single- or triple-superphosphate, and mono- or di-ammonium phosphate, should be band applied near the stakes, while less soluble sources, such as basic slag and rock phosphates should be broadcast and incorporated. All P fertilizers should be applied at or shortly after planting as the split application of P does not increase the yield. Alternative methods of P application, such as stake treatments or foliar sprays, are not as effective as soil application in increasing yields.

The following practices can be recommended about the application of phosphorus:

- Cassava grows well on many low-P soils without the need for P fertilizers, where many other crops would require high levels of application for normal growth.

- In extremely P-deficient soils, those with less than 4 ppm of available P, cassava may respond initially to rather high rates of application of about 100–200 kg P_2O_5/ha, but after the first 1–2 years, these levels should be reduced to 40–50 kg P_2O_5/ha, since much of the applied P remains in the soil.

- The most effective P fertilizers are the highly soluble sources, such as single- or triple-superphosphate and mono- or di-ammonium phosphate (which also contain

N), which should be band applied near the stakes or plants and covered with soil.

- Also effective is the less soluble P source called “basic slag,” which should be broadcast over the entire soil and incorporated before planting. This source is also high in calcium and thus helps to decrease soil acidity (increase pH).

- In very acid soils, the application of finely ground rock phosphates may also be effective, but rock phosphates from different sources may differ in their solubility. These less soluble P sources should be broadcast and incorporated before planting.

- All P fertilizers should be applied at the time of planting or at 30 days after planting, as split applications are generally not effective.

Potassium (K)

Research in many parts of the world has shown that K application not only increased root yields but also the starch content of the roots. In general, root starch content increases up to application rates of about 80 kg K_2O/ha, and then levels off or decreases at higher rates. The application of K also decreases the cyanogenic potential of the roots and increases plant resistance to pests and diseases. Adequate levels of available K also increase stem yields and improve the quality of stakes cut from those stems.

Potassium deficiency is usually most severe in light-textured sandy or sandy loam soils, which tend to have low levels of available potassium, calcium, and magnesium. After land clearing, these soils may have reasonably good levels of K, but often show a significant K response in the second year of planting because of low K reserves in the soil’s parent material.

Long-term experiments in Asia and Colombia have shown that potassium almost always becomes the main limiting nutrient when cassava is grown continuously on the same soil without adequate K fertilization. **Figure 8-2** shows the results of a long-term NPK trial conducted on a light-textured soil at Thai Nguyen University in Thai Nguyen, North Vietnam. Two cassava varieties were grown in the same plots with the same annual applications of N, P, and K for 17 years. During the last year, the average yield increased from 3.4 to 21.8 t/ha with the application of 80 kg K_2O/ha, but did not increase further with the higher rate of application of 160 kg K_2O/ha. Thus, relatively high yields of about 20–25 t/ha could be maintained during 17 years of continuous cropping with the annual application of 80 kg of N, 40 P_2O_5, and 80 K_2O/ha. However, the available K content of the soil did not increase with these rates of K application and remained at a very low level.

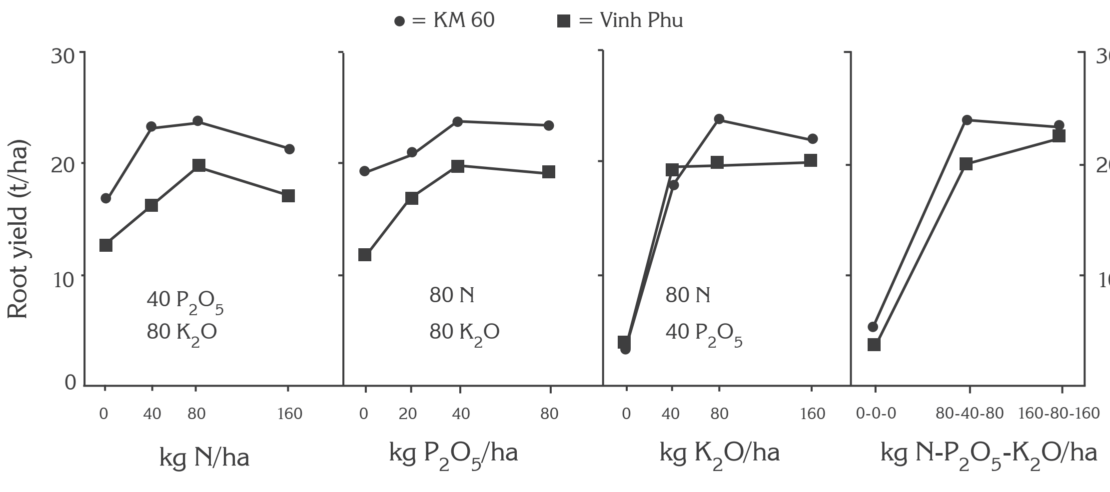


Figure 8-2. Effect of annual applications of various levels of N, P, and K on the root yield of two cassava varieties during the 17th consecutive crop cycle at Thai Nguyen University in Thai Nguyen, Vietnam, in 2006.

During the ninth crop cycle in Thai Nguyen, Vietnam, cassava plants without K application (in front) and with annual application (in back).

In some very poor sandy soils in Cambodia, there was a strong response to the application of K fertilizers (in back) already during the first year of cropping.

Among different K sources, potassium chloride is the cheapest and most commonly used source. In most soils, potassium chloride and potassium sulphate are equally effective K fertilizers, except in those few soils with low sulphur contents. In those soils, it is recommended to use potassium sulphate, or mix elemental sulphur with potassium chloride to prevent the induction of sulphur deficiency by high applications of chlorides.

The following recommendations about potassium fertilization can be made:

- K deficiency is most common in light-textured soils or on very acid soils with low levels of available K, Ca, and Mg.
- When cassava is grown year after year on the same land, potassium is likely to become the first limiting nutrient, and application of K fertilizers will have the biggest beneficial impact on yield.
- To prevent K depletion of the soil, about 80–120 kg K_2O per ha should be applied to compensate for the K removed with the root harvest.
- K fertilizers are best applied at time of planting or at about 30 days after planting; they should be band applied near the stake or plant and covered with soil.
- Most farmers use potassium chloride as this is the cheapest potassium fertilizer, but potassium sulphate should be used if soils are also sulphur deficient.

CHAPTER 9

CONTROL OF SECONDARY- AND MICRO-NUTRIENT DEFICIENCIES AND THE NEED FOR LIME APPLICATION

Among the various nutrients that plants need for normal growth are three secondary nutrients: calcium (Ca), magnesium (Mg), and sulphur (S); and at least five micro-nutrients, such as boron (B), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn). Secondary nutrients are taken up by the plant in relatively large amounts, like the macro-nutrients N, P, and K, but most soils can supply enough of these nutrients and there is normally no need to apply them. By contrast, although micro-nutrients are needed in very small quantities, they are essential for normal growth and sometimes need to be applied if the soil is low in any of them, or if they have become unavailable for plant uptake due to changes in soil pH as a result of the application of lime or other nutrients.

Secondary nutrients

Calcium (Ca)

In very acid low-Ca soils of the Eastern Plains of Colombia, highly significant responses to application of Ca were obtained in a sandy loam soil with a pH of 5.1 and very low levels of Ca and Mg (**Figure 9-1)**. Highest yields were obtained with application of 200–400 kg Ca/ha as broadcast and incorporated gypsum. Broadcast calcitic or dolomitic lime were less effective, while band-applied gypsum was completely ineffective in increasing cassava yields. Calcitic lime is basically finely ground limestone consisting only of calcium carbonate, while dolomitic lime also contains magnesium carbonate and is thus a source of both Ca and Mg. As these Ca sources are relatively insoluble, they should all be broadcast and incorporated before planting.

Clear symptoms of Ca deficiency are seldom observed in the field but are rather common on triploid varieties planted mainly in India.

Due to its low Ca content of only 8–11% and high cost, gypsum is an expensive source of Ca compared with lime, which has about 30% Ca. However, **Figure 9-1** shows that application of 100 kg Ca/ha as gypsum was even more effective in increasing yield than 400 kg Ca/ha applied as calcitic lime.

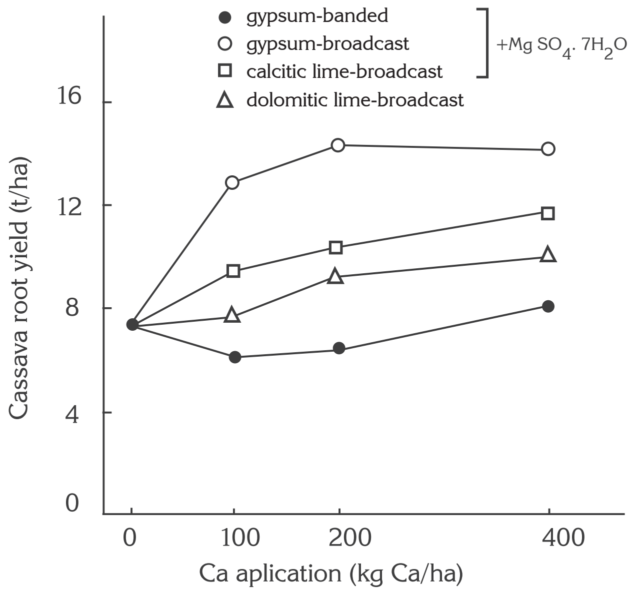


Figure 9-1. Effect of different levels, sources, and methods of application of calcium on the fresh root yield of cassava in Carimagua, Colombia.

Mg deficiency. Green veins on a yellow background (fish-bone pattern) on older leaves.

Magnesium (Mg)

Cassava is quite susceptible to Mg deficiency, requiring higher Mg concentrations in nutrient solution than cowpea or cotton. High applications of K can also enhance Mg deficiency.

Two Mg experiments conducted in the very poor and acid soils of the Eastern Plains of Colombia showed a significant response to Mg applications up to the highest level of 60 kg Mg/ha, but there were no overall significant differences among Mg sources. The more soluble Sulphomag was more effective at intermediate rates of Mg, while banded magnesium sulphate or broadcast magnesium oxide were better at higher rates of application. Incorporation of dolomitic lime was less effective in increasing yields. Although magnesium sulphate is relatively soluble, it was found that broadcasting and incorporating was more effective than applying it in short bands near the stakes, together with the NPK fertilizers.

Sulphur (S)

Symptoms of S deficiency are not often seen in cassava fields because much of the plants' sulphur requirements are met from S emissions by industry into the environment; this sulphur in the atmosphere will eventually come down in rainfall. Only in very isolated places, far from industry, cassava is likely to suffer from sulphur deficiency and respond to applications of sulphur. Sulphur deficiency can also be induced by high applications of potassium chloride, and can be eliminated by applying potassium sulphate or other sulphate sources, as well as by incorporation of elemental sulphur.

S deficiency. Small plants (in foreground below) and uniform yellowing (chlorosis) of upper leaves.

Band application of potassium or magnesium sulphates produced slightly higher yields than application of ammonium sulphate, which in turn was slightly better than broadcasting and incorporating elemental sulphur.

Without S application (in front).

Here are some recommendations on applying calcium, magnesium, and sulphur:

- Symptoms of Ca and S deficiencies are rarely seen in the field, while Mg deficiency symptoms are more common and easily recognizable.
- Ca and Mg deficiencies are only common in very acid soils, which in general have low levels of available Ca, Mg, and K.
- In soils with low levels of available Ca, apply 100 kg Ca/ha in the form of gypsum (about 1 t/ha), or about 400 kg of Ca in the form of calcitic lime (about 1.3 t/ha).

- Both gypsum and lime should be broadcast and incorporated before planting
- In soils with low levels of Mg or when plants show Mg deficiency symptoms, apply about 50 kg Mg/ha in the form of banded Sulphomag (which contains K, Mg, and S) or broadcast and incorporate magnesium sulphate (500 kg/ha)
- In the unlikely case that cassava suffers from S deficiency, apply 20–40 kg S/ha in the form of potassium or magnesium sulphate, or Sulphomag.

Cu deficiency. Chlorosis and curling down of tips of upper leaves.

Without (on left) and with application of copper sulphate on peat soils.

Micro-nutrients

Deficiencies of micro-nutrients are most often observed in high-pH or limestone-derived soils, but zinc deficiencies have been observed in both acid and alkaline soils. High rates of lime application to acid soils with low levels of available zinc may induce Zn deficiency, resulting in low yields and even death of young plants. Zn deficiency can also be induced by frequent high applications of phosphorus.

Boron (B)

Some symptoms of B deficiency have been observed in both acid and in alkaline soils in Colombia. Applications of 1–2 kg B/ha, band applied as Borax at the time of planting, eliminated these symptoms, increased plant height, and increased the B concentration in the leaves, but had no significant effect on yield. Cassava seems to be much more tolerant of low B concentrations in the soil than maize or common beans.

Copper (Cu)

Copper deficiency in cassava results in some reduction of plant height, chlorosis, and curling down of the tips of upper leaves and necrosis of leaf tips. Lower petioles tend to be long and droopy. Severe Cu deficiency has been reported only in peat soils of Malaysia. A basal application of 2.5 kg Cu/ha applied as copper sulphate increased yields from 4 to 12 t/ha.

Fe deficiency. Uniform yellowing of upper leaves.

Iron (Fe)

Iron deficiency has been observed mainly in limestone-derived soils, but is also commonly seen in soils where old termite hills have been removed, since the soil in these hills tend to have a higher pH value. A practical solution is to soak stakes for 15 minutes in a solution of 2–4% iron sulphate (20–40 grams per liter) before planting, or foliar applications of iron sulphate at 1, 2, and 3 months after planting.

Spots of Fe deficiency in old termite hills.

Manganese (Mn)

Manganese deficiency is characterized by yellowing along the edges and between the veins of cassava leaves in the middle part of the plant in "fish-bone" patterns, similar to Mg deficiency. When severe, the whole leaf turns uniformly yellow, very similar to Fe deficiency or salinity. Manganese deficiency symptoms in cassava have only been observed occasionally, in alkaline soils in the Cauca Valley of Colombia, along the coast in north-eastern Brazil, and in northern Vietnam, but only near houses built with lime. Stake treatments before planting with manganese sulphate, or foliar sprays with manganese sulphates, are the most practical solutions.

Mn deficiency. Green veins on a yellow background (fish-bone pattern) in the lower and middle part of the plant.

Zn deficiency. White spots on young leaves; upper leaves often chlorotic and leaf lobes narrow and pointing outward.

Zn deficiency (on right) and after stake treatment with Zn (on left) in Colombia.

Zinc (Zn)

On acid soils, Zn deficiency can be controlled by incorporating zinc oxide or band application of zinc sulphate at the rate of 5–10 kg Zn/ha. Also effective are foliar applications at 1, 2, and 3 months after planting with solutions of 1–2% zinc sulphate, or soaking the stakes in a solution of 2–4% zinc sulphate during 15 minutes before planting.

After application of 2 t/ha of lime to a very acid soil in the Eastern Plains of Colombia, an experiment was conducted with two cassava varieties and band application of different levels of Zn as zinc sulphate. Both varieties were seriously affected by Zn deficiency, with one variety producing zero yield in the check plot without zinc application. The yield of the other variety increased from 5 to 15 t/ha with the application of 10 kg Zn/ha (about 50 kg/ha of zinc sulphate), band applied together with NPK fertilizer at the time of planting.

In alkaline or limestone-derived soils, application of zinc sulphate to the soil is not so effective because the applied Zn will be precipitated at high pH and become unavailable for plant uptake. Foliar applications or stake treatments are more effective.

When 20 cassava varieties were planted in a very alkaline, low-Zn soil in Colombia, soaking the stakes for 15 minutes in a solution of 4% zinc sulphate before planting, yields increased from an average of 11.5 t/ha without the Zn treatment to 25.0 t/ha when the stakes had been soaked in the Zn sulphate solution. Large varietal differences in low-Zn tolerance were observed, with some varieties dying without the Zn treatment, while others produced high yields with or without Zn. If Zn deficiency is a serious problem, it may be worthwhile to try planting a different variety that may be more tolerant of low levels of Zn.

What about the need for lime?
Cassava is usually grown on acid soils because the crop is unusually tolerant of soil acidity (low pH), while it is rather susceptible to alkalinity (high pH). For that reason, there is usually no need to apply lime to cassava, while other crops, such as maize, rice, common beans, or soybeans, may need high doses of lime application. Only in extremely acid soils, such as those found in the Eastern Plains of Colombia, the Plain of Jars in Lao PDR or on peat soils in Malaysia and Indonesia, there will be a need for lime application. Under those conditions in Colombia, cassava required applications of 1–2 t/ha of lime to reach maximum yields, while on peat soils in Malaysia, a good response was observed to the application of 3 t/ha of lime. Higher rates of application of lime may reduce yields by inducing a deficiency of zinc. If available, dolomitic lime should be applied if the soil is deficient in both Ca and Mg.

Based on the results of these experiments, we can make the following recommendations about the application of micro-nutrients and the need to apply lime:

- Symptoms of micro-nutrient deficiencies are seldom observed, except in alkaline or limestone-derived soils, with the exception of zinc deficiency, which is rather common in both acid and alkaline soils.

- In alkaline or limestone-derived soils, cassava may turn completely yellow or even white due to iron deficiency, or occasionally show interveinal yellowing of leaves in the middle section of the plant due to Mn deficiency.

- These problems can best be solved by foliar application of solutions containing 1–2% iron- or manganese-sulphates, or by soaking the stakes for 15 minutes in a solution of 2–4% iron- or manganese-sulphates before planting.

- Symptoms of Zn deficiency can be observed in both alkaline and acid soils, especially if the latter have received high applications of lime or P. In acid soils, Zn can be applied to the soil at a rate of about 10 kg/ha of Zn as zinc sulphate (50 kg/ha), while in both acid and alkaline soils, cassava stakes should be soaked in a solution of 2–4% zinc-sulphate for 15 minutes before planting.

- In most soils where cassava is grown in Asia, there is no need to apply micro-nutrients as most soils supply enough of these nutrients for normal plant growth. Also, in most soils there is no need to apply lime.

- In very acid soils, there may be a need to apply 1–2 t/ha of lime to increase pH or to provide additional Ca to the plants. Higher applications of lime may actually decrease yields by inducing Zn deficiency.

- Farmers should be aware that in many countries unscrupulous vendors try to sell useless products claiming to contain micro-nutrients or hormones that will markedly increase yields. Farmers should buy fertilizers only from well-known companies.

CHAPTER 10

COMMERCIAL FERTILIZER OR ANIMAL MANURE TO IMPROVE SOIL FERTILITY AND INCREASE YIELD?

In the past, when cassava was mainly a subsistence food crop, farmers tried to maintain soil productivity by practicing slash-and-burn agriculture, or by application of animal manures. Slash-and-burn agriculture is still practiced in many parts of Southeast Asia, especially in mountainous or isolated areas. In densely settled areas where slash and burn is no longer possible, farmers generally apply between 5–10 tons of manure per hectare.

As cassava has become more of an industrial crop in Asia, farmers have sought to benefit from greater demand for cassava roots and higher prices by planting new, high-yielding varieties, and by applying chemical fertilizers. But many cassava farmers are not applying the right amounts nor the right balance of nitrogen (N), phosphorus (P), and potassium (K). Farmers can further increase yields and income by tailoring fertilizer inputs to the needs of the crop and the specific characteristics of the soil.

When cassava yields go up, the removal of nutrients in the harvested roots will also increase dramatically, leading to the depletion of some nutrients and a marked decline in yield when cassava is grown continuously on the same land. Cassava does not necessarily remove more nutrients than other crops, but the roots are relatively high in K; this is usually the nutrient that is most rapidly depleted if only roots are harvested. Relatively large amounts of both N and K are removed if not only the roots but also the stems and leaves are harvested. The removal of P is much less than that of N and K.

Manure produced on farm may be cheap, but transporting, applying, and incorporating 5–10 t/ha is hard work.

Manure application

Cassava farmers who also raise cattle, goats, pigs, or chickens may use the manure that these animals produce to apply on their cassava fields. The manure may be cheap, but transporting, applying, and incorporating 5–10 t/ha of manure is hard work. Manures are a good source of secondary, macro-, and micro-nutrients, as well as organic material that will improve the structure and the nutrient- and water-holding capacity of the soil. However, manures contain only small amounts of the macro-nutrients N, P, and K, which crops need in larger quantities. Also, manures tend to be wet, which further reduces their nutrient contents, and the relative amount of the different nutrients in the manure cannot be tailored to specific requirements of each crop and soil. Moreover, the nutrient content of different manures will vary according to the animal producing it and the type of feed they consume, and will also vary with the time and method of storage of the manure. In most cases, farmers do not know the nutrient content of the manure and how much they should apply to meet the requirements of their crops.

Commercial fertilizers

By contrast, each commercial fertilizer has a fixed ratio of nutrients, usually expressed in the traditional form as the percent of N, P_2O_5, and K_2O (in some countries this is now expressed as the percent of each element: N, P, and K). Thus, a fertilizer like urea will be labeled as 46-0-0, because it has 46% N but no P or K, while a fertilizer like triple superphosphate will be labeled as 0-46-0 because it contains 46% P_2O_5, but no N or K; and potassium chloride (muriate of potassium) will be labeled 0-0-60 because it contains 60% K_2O but no N or P. These are called **single-element fertilizers**, because they contain only one of the three macro-nutrients. Then there are **compound fertilizers**, which contain two or all three macro-nutrients. Thus, a fertilizer labeled 15-15-15 contains 15% N, 15% P_2O_5, and 15% K_2O (this is equivalent to 15% N, 6.5% P, and 12.5% K).

When farmers buy single-element fertilizers, they will need to mix two or three of these together to produce a mixture that will supply the nutrients that the crop needs for their particular soil. By mixing single-element fertilizers, one can apply any ratio of N, P, and K desired. However, in countries where many different types of compound fertilizers are available in the store, farmers often prefer to buy these instead of single-element fertilizers, so they do not have to mix large amounts of different fertilizers. Farmers can usually buy the exact type of compound fertilizers which will supply the right balance of N, P_2O_5, and K_2O recommended for their soil and crop. Another advantage of commercial fertilizers is that they are sold in dry form, so they contain a minimum amount of water and a maximum amount of the required nutrients. This will reduce the cost of transport and the amount of work involved in applying commercial fertilizers as compared to animal manures or compost. In very general terms, one 50-kg bag of a compound fertilizer like 15-15-15 contains about the same amount of N, P, and K as 1000 kg (one ton) of animal manure, as shown in **Table 10-1.**

Table 10-1. Average nutrient content of one ton of various types of wet manure and compost as compared to 50 kg of 15-15-15 compound fertilizers.

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

It is clear that many commercial fertilizers contain 10–20 times more macro-nutrients (N, P, and K) than most of the organic fertilizers, but the latter contain also small amounts of secondary and micro-nutrients, which are also essential for normal plant growth, but in much smaller quantities.

Many experiments have been conducted on different soils to determine which nutrients most limit the cassava yield, and what rates and balance of nutrients are necessary to increase the yield, or maintain high yields. This information will help researchers and extension workers make the best fertilizer recommendations, which in turn will help farmers apply those fertilizers that will result in the highest yield at the lowest cost.

How do we increase cassava yields without degrading soil fertility?

Several experiments, in which cassava was grown continuously for many years on the same land without application of adequate amounts of manure or the right kind of commercial fertilizers, have shown that yields decreased over time due to nutrient depletion, mainly as a result of nutrient removal in the harvested products (**Figure 10-1**).

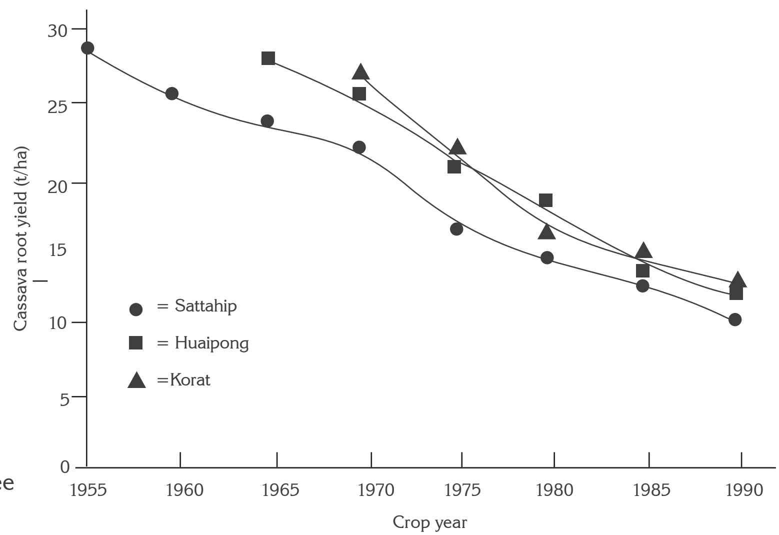


Figure 10-1. Decline in fresh root yield of cassava due to continuous cultivation without fertilizers in three soil series in Thailand.

Nutrients can also be lost by volatilization, leaching or in eroded soil or rainfall runoff.

In many soils, the most serious decline was in the level of soil K, and over time the greatest response was therefore to the application of potassium. This has clearly been shown in many long-term NPK-fertilizer experiments with cassava conducted in both Latin America and Asia. A good example is shown in **Table 10-2.**

The data in **Table 10-2** clearly show that, after 21 years of continuous cropping, the cassava yield was very low when no fertilizer had been applied; and even lower when N and P had been applied but K had been omitted.

Although in this location the original soil was rather fertile and there were no significant responses to fertilizer application during the first 3 years of cropping, in the following years the response to K application increased almost year after year, followed by the response to N, and then P. The root starch content also increased with the application of each nutrient, but most markedly with the application of K.

The results in **Table 10-2** also clearly show that the application of the right amount and the right balance of N, P, and K was highly economic. The cost of the fertilizers naturally increased as the amount of each applied nutrient increased, but this was usually more than offset by the increase in yield and gross income obtained. While the net income was only 11 million Vietnamese Dong (VND) without application of NPK, and even lower with the application of N and P but without K, it was about 34 million VND/ha (US$1,700/ha) with the application of 80 kg N, 40 P_2O_5, and 80 K_2O/ha. Higher rates of application did not further increase the net income. Similar results were obtained in many long-term NPK trials conducted in Asia and Latin America.

After 17 years of continuous cassava cultivation, plant growth and yields are markedly reduced by the lack of K application (in front).

During the 19th cropping cycle, cassava yield without K application was only about 26% of that obtained with annual NPK fertilization.

Table 10-2. Effect of annual application of various levels of N, P, and K fertilizers on the average root yields of two cassava varieties as well as the gross and net income per hectare obtained during the 23rd consecutive year of cassava cropping at Hung Loc Agricultural Research Center in Dong Nai, South Vietnam, in 2010/11.

Treatments[1)]	Average root yield (t/ha)	Average starch content (%)	Gross income	Fertilizer costs	Total production costs	Net income
			('000 VND/ha)[2)]			
1 $N_0P_0K_0$	11.2	22	17,167	0	5,700	11,467
2 $N_0P_{40}K_{80}$	21.0	26	32,099	1,671	7,671	24,428
3 $N_{40}P_{40}K_{80}$	24.7	26	37,852	2,219	8,219	29,633
4 $N_{80}P_{40}K_{80}$	28.1	25	42,962	2,767	8,767	34,195
5 $N_{160}P_{40}K_{80}$	26.9	25	41,157	3,863	9,863	31,294
6 $N_{80}P_0K_{80}$	21.4	26	32,711	2,202	8,202	24,509
7 $N_{80}P_{20}K_{80}$	23.4	26	35,771	2,485	8,485	27,286
8 $N_{80}P_{80}K_{80}$	26.8	25	41,065	3,332	9,332	31,733
9 $N_{80}P_{40}K_0$	8.8	22	13,464	1,660	7,660	5,804
10 $N_{80}P_{40}K_{40}$	23.9	24	36,628	2,214	8,214	28,414
11 $N_{80}P_{40}K_{160}$	26.6	27	40,622	3,874	9,874	30,748
12 $N_{160}P_{80}K_{160}$	29.2	28	44,645	5,534	11,534	33,111

1) Fertilizer rates are in kg/ha of N, P_2O_5, and K_2O, applied as urea, single superphosphate and potassium chloride.

2) 1 US$ = 20,000 VND in 2010/11.

Can we get the same results applying only animal manures or compost?

The answer is "not likely." Research in North Vietnam has shown that application of 15 t/ha of pig manure increased cassava yields from 3 to 13 t/ha, while application of only 80 kg/ha of both N and K increased yields to 16 t/ha. However, the application of both chemical fertilizers and rather small amounts (5 t/ha) of manure further increased yields to 18 t/ha, indicating that the combination of chemical fertilizers plus manure was the most effective in increasing yields and produced the highest net income (**Table 10-3**). In this case, the chemical fertilizer supplied most of the macro-nutrients – N, P, and K – while the manure contributed small amounts of secondary and micro-nutrients and supplied organic matter, which further increased yields and will improve the soil's structure.

During the 11th crop cycle, plant growth without NPK application (in front) was markedly reduced as compared with well-fertilized plants (in back) at CATAS in Hainan, China.

Table 10-3. Effect of the application of FYM[1)] and chemical fertilizers on cassava yield and economic benefits at Thai Nguyen University in Thai Nguyen province of north Vietnam in 2001.

Treatments	Cassava root yield (t/ha)	Gross income	Fertilizer costs	Production costs	Net income
		('000 VND[2)] per hectare)			
No fertilizers, no FYM	3.3	1,625	0	2,800	-1,175
5 t FYM/ha	7.8	3,895	500	3,300	595
10 t FYM/ha	10.0	5,010	1,000	3,800	1,210
15 t FYM/ha	13.1	6,555	1,500	4,300	2,255
80 N+80 K_2O/ha, no FYM	15.5	7,735	680	3,580	4,155
80 N+80 K_2O/ha + 5 t FYM/ha	18.0	8,990	1,180	4,080	4,910
80 N+80 K_2O/ha + 10 t FYM/ha	18.7	9,350	1,680	4,580	4,770
80 N+80 K_2O/ha + 15 t FYM/ha	18.5	9,250	2,180	5,080	4,170

1) FYM = farm-yard manure (pig manure); manure plus application: 100,000 VND (US$6) per ton.

2) 1 US$ = 16,000 Vietnamese Dong (VND) in 2001.

Similar results were obtained in Malang, Indonesia, in a cassava–maize intercropping system. In this case, the combined application of 135 kg N/ha with 5 t/ha of compost increased cassava yields from 11 t/ha without fertilizers or manures to 39 t/ha, and produced the highest net income. The application of 10 t/ha of compost without fertilizers increased yields to only 23 t/ha.

Ideally, farmers should apply organic manures combined with adequate and well-balanced chemical fertilizers to maintain their soil's fertility. If animal manures are not available, farmers can also improve their yields by incorporating the crop residues of cassava or those of weeds and intercrops into the soil to supply additional organic matter as well as secondary and micro-nutrients. If farmers apply fertilizer to intercrops or cash crops preceding cassava in a crop rotation system, cassava can also exploit the residual fertilizers left in the soil from these crops.

To increase both yields and income while maintaining or improving the fertility of the soil, it is recommended to:

- Determine which nutrients are most limiting yield by carefully observing possible deficiency symptoms, by having the soil or plant tissue analyzed, or by conducting simple experiments in the field, as indicated in **Chapter 7.**

- If this information is not available, a general recommendation would be to apply about 80–100 kg/ha of N, 40–50 kg P_2O_5, and 100–120 kg/ha of K_2O as single-element fertilizers like urea, single or triple superphosphate, and potassium chloride.

- If compound fertilizers are available, apply about 600 kg/ha of fertilizer, for example, 15-15-15, 16-16-16; or better still, about 600 kg/ha of 15-7-18.

- If cassava is intercropped with cereals, such as maize or rice, apply the above fertilizers to cassava, and fertilizers high in N and P to the cereals; if the intercrops are grain legumes, such as soybean, peanut, or cowpea, apply mainly P to those crops.

- If cassava has been grown for many years in the same field, reduce the amount of applied P and increase the application of K, such as 20 kg/ha of P_2O_5 and 120 kg/ha of K_2O; or 500 kg/ha of a compound fertilizer like 14-4-24.

- If available, combine the chemical fertilizers with 4–5 t/ha of manure or compost.

- Manure and compost need to be broadcast and incorporated before planting, while the chemical fertilizer should be applied in a hole or short furrow next to the stake or young plant and covered with soil, either right after planting or at about one month after planting.

- If pests and diseases are not major problems, the previous crop's residues or weeds can be either incorporated into the soil before planting or left on the soil surface as mulch to improve soil fertility and reduce erosion. This has a similar effect as the application of manures.

CHAPTER 11

BIOLOGICAL WAYS TO INCREASE YIELD AND IMPROVE THE SOIL

In many parts of the world, crops are still grown without application of chemical fertilizers, either because they are not available or they are considered too costly. In that case, farmers often try to maintain soil fertility through various biological means, including shifting cultivation, agro-forestry, crop rotation, green manuring, mulching, cover cropping, alley cropping, and intercropping, as well as the application of animal manures or compost. In general, these methods are most suitable in areas where labor is available and cheap, and where purchased inputs like fertilizers are unavailable or expensive, particularly in extensive agriculture systems. They can also be used to supplement the application of chemical fertilizers, mainly to increase the organic matter content of the soil, which will improve soil structure, bulk density, soil aggregate stability, water- and nutrient-holding capacity, and drainage.

Shifting cultivation

In many areas in the tropics, farmers try to maintain soil fertility through shifting cultivation, also known as "slash-and-burn" systems. After several years of cropping, the land is left to return to bush fallow or forest for 10–20 years, to let the soil rest and replenish nutrients lost during the cropping cycle. However, because of rapid population growth and the consequent increase in land pressure, the fallow period has steadily been shortened while the cropping cycle and intensity have increased.

Research conducted on very poor and degraded soils in southern Colombia indicates that even long periods of bush fallow were not able to fully restore soil fertility, and cassava yields remained below 8–10 t/ha. By contrast, with the

Shifting cultivation in Lao PDR.

application of N, P, and K in chemical fertilizers, cassava yields doubled or tripled, reaching over 24 t/ha in the third consecutive planting. In this and many similar situations, farmers could greatly increase their income if they would grow cassava on a more permanent basis on the best and flattest land using commercial fertilizers, while leaving the steeper and more degraded fields in permanent pasture or planting coffee, fruit trees, or forest.

In addition, when slash-and-burn systems are practiced on steep slopes, such as in Lao PDR, and parts of western Vietnam, after burning of the forest during the dry season, much of the resulting ash is washed down slope with the first rains of the wet season before crops can be planted, making the system ineffective in replenishing soil fertility. The result is a steady decline in soil fertility, an increase in soil erosion, and decreasing crop yields.

Growing cassava in the alleys between rows of leguminous trees has been shown to increase cassava yields and improve soil fertility.

Alley cropping

This is a type of agro-forestry in which crops and trees are combined in the same field with the objective of improving the nutrition of the crops, and in some cases to reduce erosion. Crops are planted in the alleys between rows of fast-growing leguminous trees. The space between hedgerows can be varied, but is usually around 4–5 meters, so that less than 20% of the total land area is occupied by the hedgerows. The trees are cut back at least once a year to about 50 cm above the ground and the prunings are either incorporated into the soil of the alleys before the crop is planted, or mulched on the soil surface to supply nutrients and to control weeds and soil erosion. The benefit of leguminous trees is that they can fix considerable amounts of N, which is added to the soil in the alleys through the decomposing prunings. In addition, the trees are deep rooted and are able to take up nutrients from deeper soil layers and recycle them to the top soil, where they become available to the crops. Also, because the trees are deep rooted they compete less for water and nutrients than fast growing intercrops. The trees will need to be pruned regularly, but do not require replanting for many years, and therefore do not require the annual purchase of seed.

The results of several alley-cropping experiments can be summarized as follows:

- Best results have been obtained with the leguminous shrub or tree species of *Leucaena leucocephala*, *Gliricidia sepium* and *Flemingia macrophylla.*

- The trees are planted in rows about 4–6 meters apart and several rows of cassava are planted in the space (alleys) between the rows of trees.

- The trees need to be cut back to about 50 cm above the ground at least once a year, before planting cassava, and the prunings are incorporated into the soil of the alleys before planting cassava, or are spread as a mulch on top of the soil.

- Cassava yields may or may not increase for the first few years of cropping as the trees take time to establish. But after a few years, cassava yields will increase, soil loss by erosion will decrease, and soil fertility will markedly improve.

- Mulching or incorporating the tree prunings will increase the organic matter content of the soil and improve the soil's chemical and physical characteristics.

- The three tree species mentioned above will not need to be replanted for many years, but the leguminous shrub, *Tephrosia candida,* will need to be replanted every 3–4 years.

Growing cassava with a cover crop of perennial legumes will usually result in excessive competition and low cassava yields.

Cover cropping

Cover crops are usually perennial forage legumes planted to fix N and recycle soil nutrients to improve soil fertility, and to prevent serious soil erosion on sloping land. Annual crops may be planted in individual planting holes or in strips where the cover crop has been incorporated into the soil or killed with herbicides. Several cover-cropping experiments, conducted in Colombia and Thailand, show that cassava is a weak competitor and that yields are reduced markedly if plants have to compete with deep-rooted and well-established forage legumes used as cover crops. This competition is particularly strong during cassava plant establishment, especially when this coincides with a period of drought. Thus, cover cropping with most forage legumes is not practical since it tends to reduce cassava yields and requires considerable additional labor.

Green manuring

This usually refers to the practice of growing a grain or forage legume on the land for several months prior to planting the main crop. The green manures are generally cut after 2–3 months of growth and are either incorporated into the soil or mulched on top of the soil before planting the main crop. This will improve the soil's fertility, especially that of N, due to N fixation by the legumes. However, green manures can also be planted as an intercrop within the main crop and slashed back and mulched after 2–3 months of growth; or they can be planted as narrow strips alternating with strips of the main crop.

Many green manure species have been tested to see their effect on the following cassava crop. In a highly acid soil in Colombia, green manures were incorporated into the soil before planting cassava. From this experiment, it can be concluded that cassava yields increased most by the application of fertilizers, but incorporation of green manures also helped to increase yields, especially when no fertilizers were applied to cassava. Peanut was among the most effective species, but *Zornia latifolia, Pueraria phaseoloides* and *Centrosema pubescens* were also very effective, especially in the presence of fertilizers.

Other experiments, conducted on sandy and highly infertile soil on the north coast of Colombia, suggest that among green manures tested, the mulching of *Canavalia ensiformis* and native weeds were most effective, while *Crotalaria juncea* was least productive and least effective in increasing cassava yields.

In India, the standard recommendation for cassava is to apply 100 kg N, 50 kg P_2O_5 and 100 kg K_2O/ha as chemical fertilizer, together with 12.5 t/ha of farmyard manure (FYM). Since FYM is expensive and cumbersome to transport and apply, a long-term experiment was conducted from 1990 to 2004 to determine whether green manuring with vegetable cowpea could reduce the need for FYM and/or reduce the high levels of chemical fertilizer input. Vegetable cowpea was planted during pre-monsoon rains in February and after the harvest of green pods, the total crop biomass was incorporated into the soil before planting cassava in May. The effect of incorporating the crop residues of cassava back into the soil after harvest was also investigated. The results indicate that by practicing green manuring with cowpea biomass, the application of FYM as well as that of N and P could be reduced to only 50% of the previously recommended rates. Also, the annual incorporation of cassava crop residues could completely replace the application of 12.5 t/ha of FYM as long as the recommended rates of N, P, and K were applied.

Many green manure experiments have been conducted in Thailand to determine the most effective green manure species and their management for the local climatic and soil conditions. In the cassava-growing areas of Thailand, total annual rainfall is about 1,200 mm, with the rainy season starting in about May and terminating in October.

In one experiment, conducted for five years, three green manures were planted in the very early part of the rainy season and their biomass incorporated into the soil after 60 days of growth, after which cassava was planted and then harvested after 10 months. It was found that cowpea was more effective than *Crotalaria juncea* in increasing cassava yields, while pigeon pea had little beneficial effect. Cowpea produced more biomass, and thus had a higher nutrient content. In addition, it improved the physical conditions of the soil, such as bulk density and water infiltration rates.

Green manures are normally grown before planting cassava, but can also be grown as an intercrop between cassava rows. In both cases, the green manures are cut after 2–3 months and either incorporated in the soil or left as a mulch.

Other experiments conducted in Pluak Daeng, Thailand, concluded that, among the green manures tested, *Crotalaria juncea* was the most productive and the most effective in increasing cassava yield; that incorporation of the green manures resulted in slightly higher cassava yields than mulching; and that some green manures were as effective as – or even more effective than – chemical fertilizer in increasing cassava yield. However, under the climatic conditions of Thailand, which has a 6-month dry season, the traditional use of green manures is impractical, since the better part of the relatively short rainy season is used for the production of green manures, while the following cassava crop produces low yield due to drought stress in the dry season. For that reason, green manuring is seldom adopted by Thai cassava farmers.

Another alternative is to plant the green manures in the early part of the rainy season, cut them back and mulch the biomass after 3–4 months; then plant cassava without further land preparation and leave the crop for 18 to 21 months. This can double cassava yields and reduce production costs as the land needs to be prepared only once every 2 years, and weeding and harvesting costs are also reduced.

From these various green manure experiments the following may be concluded:

- Planting green manures can increase cassava yields in areas with a relatively long wet season or with two short rainy seasons per year, especially when no fertilizers are applied.

- In areas with a single and relatively short wet season, planting green manures may seriously reduce cassava yields. This is because planting green manures in the early part of the rainy season markedly reduces the time that the following cassava crop can benefit from adequate rains – unless cassava is left in the ground during the entire following wet season and is harvested only after 18 months.

- Intercropping with green manures at the time of cassava planting and cutting back the green manure at 2–3 months after planting (MAP) can result in low cassava yield due to excessive competition of the green manure with cassava.

- Interplanting the green manures within a mature cassava stand at 7–8 MAP and incorporating the green manure just before the next cassava planting may increase the yield of the following cassava crop.

Although green manuring may have short-term benefits for crop productivity, the long-term effects on soil fertility are not very clear. Whenever labor is scarce, farmers will probably prefer to maximize their yields through the use of commercial fertilizers.

Excellent growth of cassava during the dry season when the soil is covered with rice straw mulch.

Mulching

Mulching, that is, leaving the crop residues or other biomass on top of the soil, or bringing in such biomass from other locations, has the advantage that the mulch will reduce weed growth, preserve soil moisture, and reduce temperature fluctuations, while it also protects the soil from the direct impact of raindrops, resulting in less erosion. Mulching biomass also eliminates the need for additional work incorporating the biomass into the soil. If the soil is loose the cassava stakes can be planted directly through the mulch into the soil. This method of minimum or zero tillage improves the organic matter and structure of the soil.

Results from a mulching experiment in Colombia indicate that application of large amounts (12 t/ha) of dry mulch of guinea grass *(Panicum maximum)* supplied the cassava plants with K, Ca, Mg, and N nutrients; helped maintain soil moisture; and reduced the temperature of the surface soil. This resulted in increased cassava root and top biomass, increased root dry matter content while reducing its yearly variation, and decreased the cyanogenic potential of the roots, particularly in the absence of fertilizers. Over the years, both the application of mulch and that of fertilizers increased the soil P and K levels, while without mulch, the soil's acidity increased. However, the application of such large amounts of mulch may be very labor intensive, depending on the distance between the cassava field and the source of mulch.

Crop rotation

In most countries in Asia, cassava is grown on the same fields year after year. Especially in areas with heavy soils and poor internal drainage, where root rots are frequently observed, farmers are advised to rotate cassava with other crops, especially cereals and grasses, in order to reduce the soil inoculum of the main causal agent, *Phytophthora* spp. With the recent appearance of witches'-broom disease, mainly in Vietnam, Thailand, and Cambodia, it is advisable to rotate cassava with other crops to prevent the spread of the disease through infected crop residues left from the previous cassava crop.

Crop rotations also can increase farmers' income. Short-duration varieties can produce a reasonably high yield when harvested after 7–8 months, leaving enough time for another short-duration crop to be grown during the same year.

In Kerala, India, cassava is now often grown in the lowlands after a rice crop.

In Kerala state of India, cassava is now often grown in lowland areas where short-duration cassava varieties are planted after the harvest of a short-duration rice crop. Under those conditions, yields of cassava are substantially higher than in the traditional upland areas. Even higher incomes can be obtained when cassava follows a crop of vegetable cowpea, or when a peanut crop follows cassava under lowland rice field conditions. However, growing cassava after a rice crop in lowland areas requires a lot of labor to build raised beds to grow the cassava without waterlogging. High cassava yields are obtained because of the higher fertility of the lowland soils as well as the higher water retention capacity of these soils during the dry season.

Cassava rotated annually with peanut followed by pigeon pea (on left) as compared with continuously grown cassava (on right) after 22 years of cultivation in Khon Kaen, Thailand.

Researchers in Thailand have shown that rotating cassava with well-adapted grain legumes, such as peanut and pigeon pea, has long-term advantages over continuous cassava production; however, the latter is still the common practice among farmers in northeast Thailand.

Intercropping

Crops grown in association tend to cause less loss of nutrients through erosion and leaching but more loss of nutrients removed in the harvested products. Intercropping represents an intensification of the demand for nutrients, particularly when each associated crop is planted at its normal density. In this case, the removal of nutrients from the soil is higher than when cassava is grown in monoculture (see **Table 5-1** in **Chapter 5**).

A long-term intercropping experiment conducted in Thailand, showed that after 24 years of intercropping cassava with peanut or soybeans the soil organic matter content had increased from the original 1.0% to 1.2 or 1.3%, while in plots with continuous cassava monoculture it had slightly decreased to 0.9%. In another long-term experiment conducted in South Vietnam, intercropping cassava with peanut and without fertilizer application, the soil organic matter and available P contents had increased, but the soil Ca and K contents had decreased, probably due to the greater nutrient removal by the harvest of both cassava and the intercropped peanut.

From these various intercropping experiments, we can conclude that, when well-managed, intercropping with short-duration food crops will generally result in reduced soil loss by erosion due to more rapid canopy development. Incorporation of the intercrop residues will tend to increase soil organic matter and, if the intercrop is a legume, may contribute more N fixed from the air. But to maintain high yield of both cassava and the intercrops, both crops should be adequately fertilized.

Conclusions

It can be concluded that cassava is a very weak competitor and suffers serious setbacks if it has to compete with weeds, intercrops, or cover crops, especially at the early stage of establishment, due to its slow initial rate of growth.

Specific observations and recommendations on how to increase cassava yields and improve soil fertility through biological means can be summarized as follows:

- Most perennial cover crops will strongly compete with cassava at the early stages of growth, resulting in low cassava yields. Most intercropped green manures or long-duration intercrops will also tend to reduce cassava yields.

- Most beneficial are some of the green manures when they are grown and incorporated before planting cassava, but only in areas with a long wet season that provides sufficient soil moisture during most of the cassava growth cycle.

- Among biological solutions mentioned above, alley cropping between leguminous hedgerow species seems to have the greatest long-term beneficial effect on cassava yields and soil fertility. Once established, the hedgerows require little maintenance besides regular pruning and they can survive for at least 15–20 years without the need for replanting. Besides improving soil fertility, the prunings, when mulched on the soil surface, will help to control weeds and erosion, reduce soil surface temperatures, and increase soil moisture.

- Similar beneficial effects of mulching have also been obtained when native weeds were cut and mulched before planting cassava with minimum tillage.

- In the past, shifting cultivation was practiced when land was plentiful and no other alternatives existed for restoring fertility after several cropping cycles. However, in most countries, land is now scarce and not enough land is available for the long fallow periods necessary to maintain soil fertility.

- For that reason, it is recommended to apply commercial fertilizers in combination with animal manures or compost; and, if diseases and pests are not a major problem, to incorporate back into the soil all the cassava crop residues in order to return organic matter and plant nutrients.

- If no chemical fertilizers are available or are too costly, soil fertility can at least be partially restored by some of the biological solutions discussed in this chapter.

CHAPTER 12

HOW TO PREVENT SOIL EROSION

Soil erosion is a serious problem in Southeast Asia. This is partly because rainfall is high. In addition, due to population pressure, steep slopes are intensively cultivated and forests are disappearing at alarming rates. Many of the light-textured soils used for cassava production in Asia are also very susceptible to erosion.

As cassava is often grown on light-textured sandy soils, this can cause serious sheet and gully erosion.

Erosion processes

When raindrops fall at high speed on unprotected soil, they break the soil aggregates into smaller units and disperse the individual clay or sand particles. Soils of intermediate texture, with a large proportion of silt and fine sand particles, have little aggregate stability, and are most susceptible to erosion. Similarly, soils with little organic matter and/or low biological activity, or those with a low content of iron and aluminum oxides, are most susceptible to erosion. Once the aggregates are broken down, the smaller particles may be carried away by runoff water, causing erosion.

When the runoff water collects and concentrates into small rivulets in natural drainage ways, the force of the running water can detach particles, and this may result in rill erosion, which may progress into the formation of gullies. The objectives of most soil conservation techniques are:

- To protect the soil from direct rainfall impact by stimulating rapid early crop growth and canopy closure, or by establishing crop residue or mulch vegetative cover, which can absorb the energy of the impact of raindrops.

- To reduce the quantity and slow the speed of water runoff by improving water infiltration into the soil.

- Reduce the length or steepness of the slope by contour cultivation, contour ridging, contour grass barriers or hedgerows, and by terracing.

The erosion process selectively removes mainly the organic matter and certain clay fractions, which provide the soil with its water and nutrient holding capacity. Thus, water runoff results in a direct loss of potentially soil-stored water as well as that of nutrients, especially from fertilizers. Soil loss due to erosion removes mainly the top soil, which is the most productive part of the soil containing most of the organic matter and a considerable amount of nutrients – especially organic N, P, and S – as well as very important micro-organisms, such as N-fixing bacteria and mycorrhiza. Finally, the physical removal of part of the topsoil reduces the depth of the soil to underlying bedrock or subsoil layers. This reduces the potential rooting depth of crops and the water storage capacity of the soil, and further increases the detrimental effect of rainfall runoff and erosion (**Figure 12-1**).

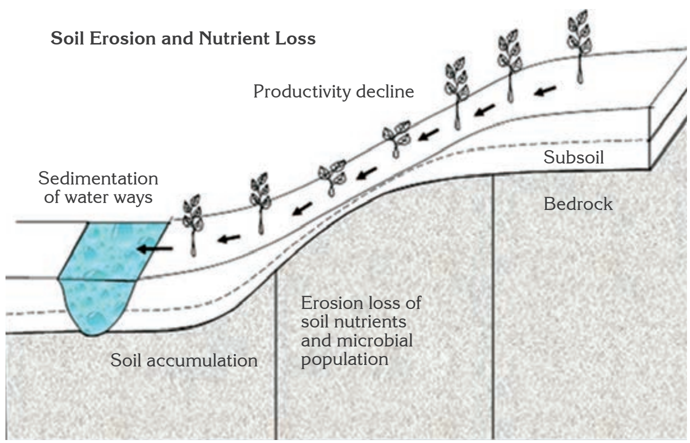


Figure 12-1. Conceptual representation of the effect of erosion in various parts of the landscape on soil depth, nutrient distribution, and growth of crops.

Nutrient losses in eroded sediments and runoff, and their effects on yield

Although little information exists about the quantity of nutrients lost in eroded sediments and runoff, experiments show that nutrient loss is a direct function of the amount of soil eroded: practices that reduced erosion automatically reduced nutrient losses. Erosion results in deteriorating soil physical and chemical characteristics, which in turn affect the soil's productive capacity. Cassava yields in severely eroded soils in Mondomo, Cauca, Colombia, were about 50% of those in adjacent non-eroded soil (**Figure 12-2**), but this depended also on the fertilizers used and the susceptibility of the variety.

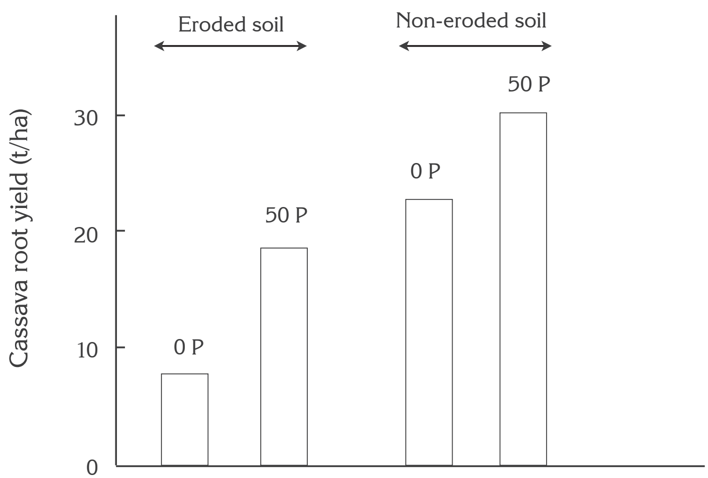


Figure 12-2. Effect of P application on the root yield of cassava grown in eroded and in adjacent non-eroded soil in Mondomo, Cauca, Colombia.

Effect of different crops on erosion

Cassava is often considered a crop that causes severe erosion when grown on hillsides. While it is true that the opening of hillsides for cultivation of annual crops will usually increase erosion by several orders of magnitude compared with undisturbed forest or grassland, whether or not cassava causes more erosion than other food crops depends on the circumstances.

Many erosion control trials conducted in Sao Paulo State of Brazil show that highest soil losses and runoff were observed in castor bean, common bean (*Phaseolus vulgaris*), and cassava, followed by peanut, rice, cotton, soybean, potato, sugarcane, maize, and sweet potato. In other trials conducted for ten years in Pernambuco State of Brazil, it was found that cassava cultivation on average resulted in more annual soil loss than cotton, maize, velvet bean (*Mucuna* sp.), and guinea grass (*Panicum maximum*), while the soil loss on bare soil was by far the highest. Although annual soil losses in Pernambuco were much lower than those reported for the experiments in Sao Paulo, the crops are listed in a similar order.

Table 12-1 shows data for soil losses in eight crops planted during 4 years on 7% slope in Sri Racha, Thailand. By far, highest levels of erosion were observed in cassava for root production (planted at 1.0x1.0 m), followed by cassava for forage production (planted at 0.5x0.5 m), mungbean, sorghum, peanut, maize, and pineapple. Annual erosion losses for cassava averaged about 75 t/ha, while the average yield was 16 t/ha of fresh roots. Thus, nearly 5 tons of dry soil were lost for every ton of roots produced. These are extremely high rates of erosion on a slope of only 7%.

Table 12-1. Total dry soil loss by erosion (t/ha) due to the cultivation of eight crops during 4 years on 7% slope with sandy loam soil in Sri Racha, Thailand, from 1989 to 1993.

Crops	No. of crop cycles	First period (22 months)	Second period (28 months)	Total (50 months)	Average (t/ha/year)
Cassava for root production	4	143	169	312	75
Cassava for forage production	2	69	139	208	50
Maize	5	29	36	65	16
Sorghum	5	43	46	89	21
Peanut	5	38	36	74	18
Mungbean	6	71	55	126	30
Pineapple[1)]	2	31	21	52	12
Sugarcane[1)]	2	-	94	-	-

1) Second cycle is ratoon crop; sugarcane only during second 28-month period.

Under the soil and climatic conditions of Sri Racha, cassava for root production did cause more severe erosion than most other crops. This is because cassava plants have to be widely spaced, while the initial growth is very slow, resulting in large areas of soil between plants being exposed to the direct impact of rainfall during the first 2–3 months after planting. On the other hand, the closer spacing and more rapid growth of most other crops resulted in more rapid canopy closure, which protected the soil from rainfall splash. Moreover, the rather short rainy season permitted only one crop per year of short-cycle crops, such as maize, sorghum, and peanut, while after their harvest, the soil remained well protected by crop residues and weeds.

Among eight crops tested, cassava for root production caused the largest amount of soil loss by erosion.

Effect of agronomic practices on cassava yield and erosion

a. Land preparation

The method of land preparation – ranging from zero-tillage, or preparation of only planting holes (minimum tillage), to full preparation using plows, harrows, and ridgers – has a profound effect on cassava yields and the intensity of erosion.

Results of two experiments conducted in Thailand are shown in **Table 12-2**. In Sri Racha, in Chonburi Province, zero tillage produced the highest level of erosion due to sealing of the surface soil by heavy rain in the early wet season. In contrast, in Pluak Daeng in Rayong Province, zero tillage produced the lowest level of erosion. In both locations, there was serious erosion when cassava was planted after conventional preparation of once plowing and disking, but without ridging or fertilizer application. This also resulted in the lowest cassava yields. Fertilizer application reduced soil losses by 42% in Sri Racha and by 32% in Pluak Daeng. The combination of contour ridging and fertilizer application was the most effective in reducing erosion when the land was prepared by conventional tillage.

Table 12-2. Effect of various tillage practices and fertilizer application on the average annual soil loss due to erosion and yield of cassava planted on 5–8% slope in Sri Racha, Chonburi Province, and in Pluak Daeng, Rayong Province of Thailand.

Tillage treatment	Dry soil loss (t/ha)		Cassava yield (t/ha)	
	Sri Racha (1987/88)	Pluak Daeng (1989/90)	Sri Racha (1987/88)	Pluak Daeng (1989/90)
No tillage, with fertilizers	50	11	29	17
Conventional tillage[1)], no ridging, with fertilizer	21	18	29	14
Conventional with contour ridges, with fertilizer	8	13	33	16
Conventional with up-down ridging, with fertilizer	24	20	29	16
Conventional tillage, no ridging, no fertilizer	36	26	22	12

[1)] Conventional tillage is plowing with 3-disk plow followed by harrowing with 7-disk harrow.

b. Contour hedgerows

Among the various soil conservation practices used to reduce erosion, the planting of contour hedgerows to slow the flow of runoff water is one of the most effective and practical ways to reduce soil loss by erosion.

Two experiments were conducted at the Jatikerto station near Malang, East Java, Indonesia on 5% slope, one over the period of 4 years from 1987 to 1990, and one over 5 years from 1991 to 1995. The results of the first trial, shown in **Table 12-3**, indicate that grass or legume tree hedgerows, planted on every 6th contour ridge, did not increase cassava yields during the first 2–3 years of establishment, but the legume trees *Leucaena leucocephala* and *Gliricidia sepium* increased yields during the third, and especially during the fourth year of cropping. During the fourth year, cassava in all plots looked very N deficient, except in those plots with the two legume tree hedgerows, in which cassava had dark green leaves and grew more vigorously. It is clear that the prunings of these trees had contributed considerable amounts of nutrients, especially N.

Table 12-3. Effect of various crop/soil management practices on dry soil loss due to erosion and on cassava root yields during four consecutive cropping cycles on 5% slope at Jatikerto Experiment Station near Malang, Indonesia, from 1987/88 to 1990/91.

	Dry soil loss (t/ha)				Cassava root yields (t/ha)			
Treatments	**87/88**	**88/89**	**89/90**	**90/91**	**87/88**	**88/89**	**89/90**	**90/91**
C+M, CR, no HR	98	45	21	19	21	28	22	18
C+M, CR, elephant grass HR	69	20	14	13	25	26	20	19
C+M, CR, *Setaria* grass HR	80	34	15	13	21	20	22	17
C+M, CR, *Gliricidia* HR	91	39	18	8	20	18	25	25
C+M, CR, *Leucaena* HR	86	41	16	11	24	25	27	28
C+M, CR, peanut strips	94	37	17	16	20	18	22	16
C+M, no CR, *Setaria* grass HR	115	50	29	26	24	26	18	14
C+M, no CR, peanut strips	127	54	23	24	23	25	19	13
Control of bare soil	224	119	62	-	-	-	-	-

C+M = cassava intercropped with maize; CR = contour ridges; HR = hedgerows.

Planting cassava between hedgerows of Leucaena leucocephala *(in back) did not only increase yields but also reduced erosion substantially. Note the N deficiency of plants grown without the hedgerows (in front).*

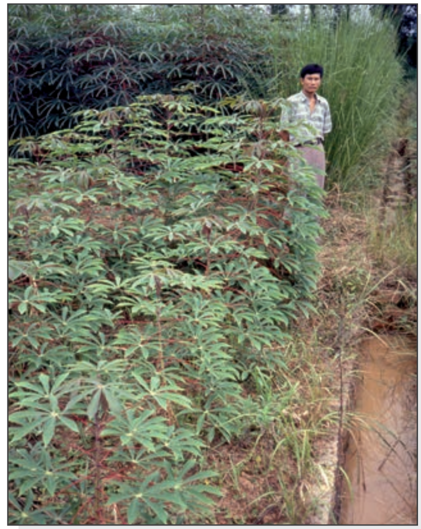
The results also show that all hedgerows reduced soil losses due to erosion starting in the second year, and became increasingly more effective in the following two years; the hedgerows of *Leucaena leucocephala* and *Gliricidia sepium* were the most effective, followed by the two grass hedgerows, while the peanut strips were slightly less effective. Planting cassava on contour ridges also helped to reduce erosion, while leaving the soil bare without vegetation resulted in the highest levels of soil loss due to serious erosion.

Very similar results were obtained in the second experiment. In this case, some plots had hedgerows of elephant grass, *Gliricidia sepium* and *Flemingia macrophylla* or no hedgerows, while other plots had a cover crop of *Mimosa envisa* or a peanut intercrop, with cassava planted on contour ridges, with or without fertilizer application. The hedgerows were again planted on every 6^{th} contour ridge. During the first 3 years, the hedgerows decreased cassava yields by occupying space in the field, but in the fourth and fifth year, they increased yields substantially by contributing nutrients through the decomposition of the leaf prunings. Moreover, starting in the second year, these hedgerows reduced soil loss by erosion by covering the soil with mulch and slowing the flow of runoff water; this resulted in about 40% reduction in soil loss in the 4^{th} and 5^{th} year. Thus, while planting contour hedgerows of leguminous shrubs or trees may not have much beneficial effect during the first years of establishment, by pruning the trees and using the prunings as mulch, they will have a long-term beneficial effect by increasing cassava yields and substantially reducing erosion.

c. Various cultural practices

Many experiments have been conducted using a wide array of cultural practices to determine which practices are most effective in reducing erosion. These experiments usually included treatments of no-ridging, contour ridging and up-and-down ridging, with and without fertilizers, different methods of land preparation, intercropping systems, closer plant spacing, and different vegetative barriers or hedgerows.

Table 12-4 shows that in an experiment conducted at the Guangxi Subtropical Crop Research Institute (GSCRI) in Nanning, Guangxi, China, contour hedgerows of vetiver grass *(Vetiveria zizanioides)* combined with fertilizer application was the most effective in reducing erosion, from 20 to 3 t/ha, and increasing yields, from 15 to 23 t/ha. Similarly effective was planting cassava on contour ridges or intercropping with peanut. Fertilizer application and the application of mulch of intercropped *Crotalaria juncea* were also effective in reducing erosion and increasing yields.



Planting cassava without fertilizer (in front) produced the lowest yields and the highest soil loss by erosion, while planting with fertilizer and contour hedgerows of vetiver grass (in back) produced the highest yield and the least amount of erosion.

Table 12-4. Effect of various cultural practices on the average dry soil loss due to erosion and the root yield of cassava grown on 12% slope at the Guangxi Subtropical Crop Research Institute (GSCRI), from 1993 to 1995 (3 years).

Treatments	Cassava yield (t/ha)	Dry soil loss (t/ha)
Plowing+disking, no ridges, no fertilizer	15	20
Plowing+disking, no ridges, with fertilizer	21	10
Plowing+disking, contour ridges, with fertilizer	22	4
Plowing+disking, no ridges, with fertilizer, peanut intercrop	23	6
Plowing+disking, no ridges, with fertilizer, *Crotalaria* intercrop for mulching	22	10
Plowing only, no ridges, with fertilizer	19	11
Plowing only, no ridges, with fertilizer; vetiver grass hedgerows	23	3

Figure 12-3 shows that, in an experiment conducted in Thailand, no fertilizer application caused the most serious soil loss by erosion due to the slow establishment and lack of vigor of cassava, which resulted in slow canopy cover. Zero tillage, subsoiling and contour ridging were most effective in reducing erosion as soil losses were only about half of those observed with conventional tillage of two passes with 3-disk plow and 7-disk harrow and without ridging.

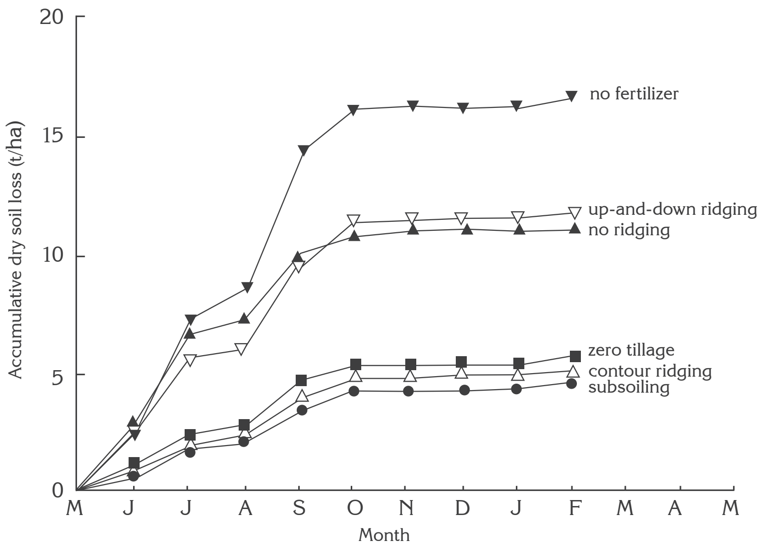


Figure 12-3. Effect of various soil/crop management practices on the accumulative dry soil loss by erosion in Sri Racha Experiment Station, Thailand, during a 9-month growth cycle of cassava in 1988/89.

Planting cassava without fertilizer application (on top in front) resulted in the highest soil loss by erosion, while planting on contour ridges (on bottom, in front) caused much less erosion than planting on up-and-down ridges (in back).

Most erosion control experiments were continued for 2–3 years in the same location with the same treatments, after which some treatments were discontinued while others were added. However, in Hung Loc Agricultural Research Center in Dong Nai province of South Vietnam, the same treatments were continued for 16 consecutive cropping cycles, from 1997 to 2012.

Table 12-5 shows the results of the 16th year of cropping. All intercropping and hedgerow treatments increased cassava yields, mainly by supplying organic matter and nutrients in the crop residues or prunings. Intercropping with peanut and hedgerows of *Leucaena leucocephala* were most effective in increasing yields, while vetiver grass was most effective in reducing erosion, followed by hedgerows of *Leucaena* or *Gliricidia sepium*.

Table 12-5. Effect of various soil and crop management practices on cassava yield and soil loss by erosion, as well as gross and net income obtained when cassava, SM 937-26, was grown during the 16th consecutive cropping cycle on 11% slope at Hung Loc Agricultural Research Center in Dong Nai province of South Vietnam in 2012/13.

Treatments[1)]	Dry soil loss (t/ha)	Root yield (t/ha)	Starch content (%)	Intercrop residue FW yield (t/ha)	Gross income[3)]	Production costs[3)]	Net income
					('000 VND/ha)		
Cassava monoculture	38	24	25	-	23,580	14,114	9,466
C+mungbean GM	31	27	26	1.7	27,270	17,914	9,346
C+peanut[2)] IC	25	29	27	3.1	33,288	18,914	14,374
C+vetiver HR	12	28	27	10.2	28,000	15,314	12,686
C+*Leucaena* HR	17	29	27	9.6	28,850	15,314	13,536
C+*Gliricidia* HR	18	28	27	7.1	27,500	15,314	12,186

[1)] GM = green manure; IC = intercrop; HR = hedgerows; FW = fresh weight

[2)] Peanut yield = 255 kg dry pods/ha

[3)] VND = Vietnamese dong

None of the three hedgerow species were effective in controlling erosion during the first year of establishment, but their effectiveness increased over time and, in the fifth and subsequent years, they reduced soil losses to only 20–50% as compared to the plots without hedgerows. Vetiver grass was consistently the most effective in reducing erosion, followed by hedgerows of *Leucaena* and *Gliricidia*. Since the seed of vetiver grass is sterile this species needs to be planted vegetatively using tillers. The advantage is that vetiver grass does not seed itself and become a weed problem. All three hedgerow species increased cassava yields about 10–20%, with *Leucaena* generally being the most effective species. This is similar to results reported under alley cropping systems in **Chapter 11**, in which alley cropping with *Leucaena leucocephala* and *Gliricidia sepium* in another experiment at Hung Loc Agricultural Research Center resulted in highest yields and net income.

Other experiments have shown that the grass *Paspalum atratum*, which can be planted either from seed or from tillers and can serve as a good feed for animals, is almost equally effective as vetiver grass in reducing erosion. Furthermore, the leguminous shrub, *Tephrosia candida*, often planted as a contour hedgerow in North Vietnam to improve the soil, is also very effective as an erosion control measure. This species grows best in temperate climates like in northern Vietnam and southern China.

Enhancing the adoption of soil conservation practices

There are many agronomic and soil conservation practices that can reduce soil losses by water erosion and even increase yields. They include:

- Planting cassava at a closer plant spacing (at populations of more than 10,000 plants per hectare).
- Applying fertilizer or manure, planting contour hedgerows of certain grasses or leguminous tree species.

- Contour plowing and ridging, applying mulch, and intercropping with peanut, melons, or squash.

However, most of these practices have certain advantages and disadvantages; some are very effective in reducing erosion, but also may reduce yields, and may be costly or laborious to install or maintain. **Table 12-6** shows the relative importance of the positive and negative attributes of various soil conservation practices.

Since most soil conservation practices have advantages and disadvantages, trade-offs will need to be made. Those are best made by farmers themselves as they will greatly depend on the specific conditions at each site. Thus, farmers are encouraged to conduct simple erosion control and various other types of trials on their own fields with guidance from researchers and extension workers, in order to determine the most effective practices for their particular situation. These are called Farmer Participatory Research (FPR) trials.

Before conducting their own FPR trials, farmers from a village evaluate various potential treatments to reduce erosion.

After discussion and selection of the most suitable treatments, extension workers help the farmers set out the trials on their own fields.

When farmers conduct FPR erosion control trials on their own fields and see that certain practices markedly reduce erosion, they will soon adopt these practices, like vetiver grass hedgerows, in their production fields.

Table 12-6. Effect of various soil/crop management practices on erosion and yield, as well as on labor and monetary requirements, and long-term benefits in cassava-based cropping systems.

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

+ = effective, positive or high
- = not effective, negative or low
1) = has additional value in terms of animal feed, staking material or fuel wood.

While contour hedgerows of vetiver grass are usually the most effective in reducing soil losses by erosion in experiments and FPR trials conducted in small plots on a uniform slope, when this practice is scaled up to a larger production field, the results are often disappointing. In areas of rolling terrain, large amounts of runoff water may accumulate and run down slope in natural drainage ways. The force of the water is likely to wash out vetiver grass recently planted along the contour across the drainage way, and this may result in serious gully erosion. Attempts to repair these gullies by placing sand bags or other obstacles across them have usually failed as these obstacles are washed away too.

Over the past few years, farmers and extension workers have experimented with ways to reduce the speed of water in these gullies. They found that it is most effective to place a row of soil-filled plastic fertilizer bags across the gully in line but slightly below the washed out vetiver grass contour hedgerow. The bags need to be secured in place by pounding bamboo stakes into the soil behind them (**Figure 12-4**). Once some eroded soil is deposited in the gully above the soil bags, vetiver grass can be planted in this moist and fertile sediment. When the vetiver grass is well established across the gully and in line with the rest of the hedgerow, this will further slow the speed of runoff water resulting in further deposition of sediments in the gully above the vetiver hedgerow.

Anchoring soil-filled bags across erosion gullies will soon produce enough sediments above the row of bags to plant a vetiver grass hedgerow, which in turn will trap more sediments leading to rapid terrace formation that will further slow the speed of runoff water and fill up the gully.

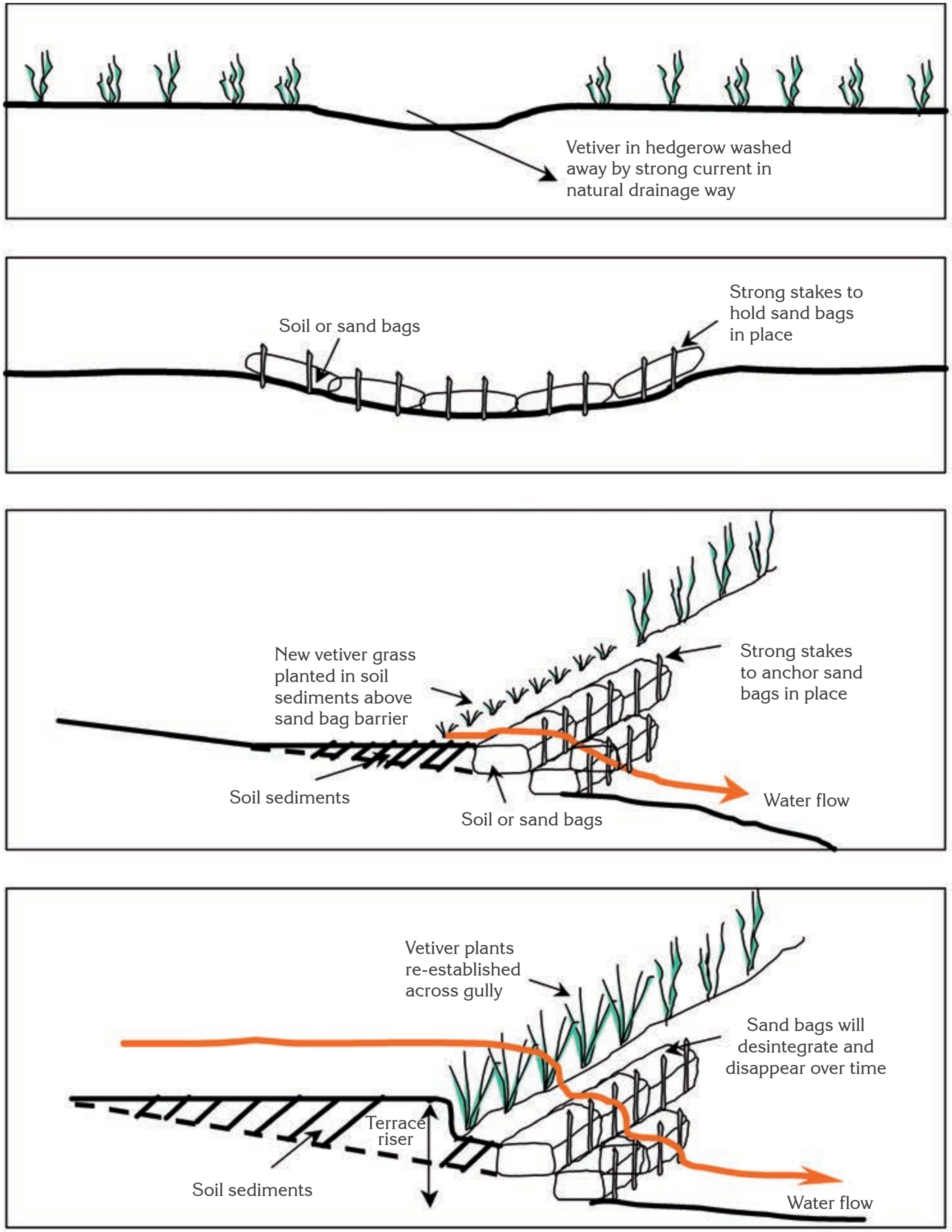


Figure 12-4. Simple and effective way to repair gullies by placing soil bags across the gully and planting vetiver grass in the soil sediments accumulating above the barrier.

This allows weeds to reestablish in the gully bottom protecting the gully from further erosion. With the next plowing along the contours, parallel to the hedgerows, the gully will generally be filled up again with soil, while the hedgerows prevent further gully formation (**Figure 12-4**). In some sites in Thailand, terraces of up to a meter in height were formed within two years by the placing of soil bags and planting of vetiver hedgerows across the gully. This local adaptation of the traditional contour hedgerow system markedly increased its effectiveness under real field conditions.

In conclusion, we can make the following observations and recommendations:

- Cassava can cause serious erosion when planted on slopes, even gentle slopes, as the crop needs to be planted at a wide spacing and initially grows rather slowly, leaving large areas of soil between plants exposed to the direct impact of raindrops.

- Cassava is often planted on very light-textured sandy soil with low levels of organic matter (OM); these soils have low aggregate stability and are thus very susceptible to erosion.

- To prevent soil erosion and degradation, cassava should be planted on the flattest land available, using a variety with vigorous early growth.

- Application of chemical fertilizers, having the right N-P-K balance, at the right rate, right time, and in the right way, is one of the best practices to reduce erosion by stimulating early growth. This will also reduce the need to weed and increase yield and income.

- Land preparation should be reduced to the minimum necessary for planting the stakes, preferably through a mulch of cut grass, weeds or crop residues left on the soil surface; the use of a subsoiler instead of a plow is recommended.

- Planting cassava at a closer plant spacing (80x80 cm) will speed up canopy closure and reduce erosion.

- Planting cassava on contour ridges rather than up-and-down ridges will greatly reduce erosion as long as the slope is not too steep and the rainfall not too high; on steep slopes or with heavy rainfall, too much water may accumulate behind the ridges, which may break, resulting in serious gully erosion.

- Planting contour hedgerows of vetiver grass is usually the most effective in reducing erosion by trapping eroded sediments, slowing down the runoff. Cutting the vetiver grass before planting cassava also provides mulch to cover the soil surface. Over time enough sediments accumulate above each vetiver barrier to produce natural terraces that will reduce the slope and thus the speed of runoff water.

- If vetiver plantlets are not available or are too cumbersome to plant in large fields, farmers can also plant hedgerows of *Paspalum atratum*, which does not compete much with neighboring cassava plants and can be cut for animal feeding. In more temperate climates, hedgerows of *Tephrosia candida* are also very effective in reducing erosion. Both species can be planted from seed.

- Hedgerows of other grasses, such as *Panicum maximum, Brachiaria ruziziensis, Brachiaria brizantha* or elephant grass are too competitive and will seriously reduce the yield of cassava growing nearby.

- Planting contour hedgerows of leguminous shrub or tree species, such as *Leucaena leucocephala, Gliricidia sepium*, and *Flemingia macrophylla,* will help to reduce erosion by providing prunings to place as mulch between cassava plants. These prunings will also provide nutrients and organic matter to improve the soil structure, internal drainage, and crop growth and yield.

- Planting fast-growing but short-duration intercrops between cassava rows, such as peanut, cowpea, mungbean, soybean, pumpkin, squash, water melon, upland rice, or maize, will provide early canopy cover in the inter-row space and reduce erosion.

- Existing gullies can be repaired by placing fertilizer bags filled with soil across the gully and anchoring these down with bamboo stakes. After some eroded soil has accumulated behind the bags, vetiver grass can be planted along the contour in these sediments. With time, enough soil sediments accumulate behind the vetiver to form terraces, thus slowing down the runoff water and filling in the gully.

CHAPTER 13

CASSAVA MANAGEMENT PRACTICES FOR HIGH YIELD, PROFITABILITY, AND ENVIRONMENTAL PROTECTION

– A Summary –

Land preparation

In steep sloping areas, it is recommended to:

- Cut or uproot all competing vegetation; leave dead vegetation on the soil surface.
- Loosen the soil with a hoe only in small planting holes of about 30x30 cm.
- Plant one stake in each planting hole, either vertically, slanted, or horizontally.
- Apply a spoonful of chemical fertilizer, like 15-15-15, near each stake to enhance early growth and increase yields. A fertilizer labeled 15-15-15 contains 15% N, 15% P_2O_5, and 15% K_2O.

In areas of intermediate farm size, on flat or slightly sloping land, it is recommended to prepare the land as follows:

- Plow the field with bullocks or water buffalos one or two times to loosen the soil and incorporate crop residues and weeds.
- On sloping land, plow along the contour to reduce erosion.
- Make contour ridges by hand using a hoe if labor is available; or use a moldboard plow pulled by cattle.

- Plant cassava stakes on top of the ridges.

- Apply a spoonful of chemical NPK-fertilizer, like 15-15-15, near each stake to enhance early growth and increase yields.

In areas where cassava fields are prepared by tractor-mounted equipment, it is recommended to prepare the land as follows:

- Apply systemic herbicides, such as Glyphosate, to kill the weeds and volunteer cassava plants.

- Loosen the soil with a subsoiler to 40–50 cm depth to break up the plow sole; if a subsoiler is not available, use a chisel plow to loosen the soil to 20–30 cm depth.

- Loosen and smooth out the soil surface with a disk harrow (or rototiller on flat land).

- Make ridges along the contour or when cassava suffers from root rot or waterlogging during periods of heavy rain.

- Plant on top of ridges or on the flat.

- Prepare the land when the soil is moist, but do not enter the field with heavy machinery when the soil is very wet.

- Apply a spoonful of NPK-fertilizer, like 15-15-15, near each stake to enhance early growth and increase yield.

Preparation of Planting Material

- Cut stems used for planting material from mother plants that are 8–18 months old and that do not have any disease or pest symptoms.

- Use as planting material only the lower and middle part of the total stem, eliminating the immature (green) top parts.

- Cut stems from mother plants that are grown in fertile soil, or in soil that has been well fertilized, especially with potassium.

- Cut stems from mother plants that have produced above-average root yields.

- If it is necessary to store the stems until the next planting season, store the bundled stems in an upright position in the shade of trees or buildings. Loosen the soil slightly with a hoe before placing the bundles and keep the soil moist by occasional watering.

- Before cutting the stems into stakes, discard the upper parts of the stems if these have sprouted, as well as any part that has obviously dried out.

- Cut stems into stakes only on the field where they are to be planted and never before they are transported to the planting site.

- Cut stems into stakes with a sharp knife, cleaver, lopper or saw to make a clean cut, preferably at a 90° angle.

- In areas with serious disease or pest problems, treat the stakes by soaking for 10–15 minutes in a solution containing insecticides, fungicides, and possibly micro-nutrients.

Planting Time

- In areas with a tropical climate and only one long wet season, plant cassava at the start of the wet season and harvest during the middle of the dry season.

- In this case, cassava can also be planted towards the end of the wet season as long as there is enough soil moisture during the first two months of the crop cycle, and cassava is harvested after at least 10–11 months of growth.

- In areas with a tropical climate and two short wet seasons, cassava can be planted at the start of either wet season.

- In areas with a temperate climate and cold winters, cassava is best planted in the early part of spring and harvested during the winter when starch contents are highest.

Plant Spacing

- The best plant spacing of cassava will vary according to the branching habit of the variety, the fertility of the soil, and climatic conditions, and whether the crop is grown in monoculture or in association with intercrops.

- Under favorable climatic conditions and in fertile soil, cassava under monoculture can be planted at a population of about 10,000–12,000 plants per hectare, or a spacing of about 100x100 cm to 90x90 cm.

- Under less favorable climatic conditions or in less fertile soil, the cassava plant population under monoculture should be increased to between 12,000 to 18,000 plants per hectare, corresponding to a spacing of about 90x90 cm to 75x75 cm.

- When cassava is intercropped but grown under favorable conditions, the inter-row spacing is widened and the inter-plant spacing reduced to obtain a cassava plant population of about 8,000 to 10,000 plants per hectare.

- When cassava is intercropped and grown under less favorable conditions, the cassava plant population should be increased to about 10,000 to 12,000 plants per hectare, with the inter-row and inter-plant spacing adjusted according to the relative importance of cassava in comparison with the associated crop(s).
- Highly branching varieties will require a wider spacing than semi-branched varieties, which in turn require a wider spacing than non-branching varieties.

Planting Position and Ridging

- In light textured sandy or sandy loam soil, cassava stakes can best be planted in a vertical or inclined position, especially when planting coincides with a dry period.
- In heavy clay soil, it is advised to plant horizontally, as the roots tend to grow closer to the soil surface, making harvesting easier.
- During the wet season, there is little difference in yield between vertical, inclined, or horizontal planting.
- When planting vertical or inclined, it is important to plant stakes with the buds facing upward.
- Planting on ridges is recommended during periods of heavy rainfall, but planting without ridges is better during dry periods as the ridged soil tends to dry out faster.

Weed Control

- Control weeds 2–4 times during the first three months of growth, starting at 2–4 weeks after planting.

- Weeds can be controlled by hand, using a hoe, by hand-pulled or tractor-mounted cultivator or by herbicides; or by any combination of these.

- If labor is scarce or expensive, apply recommended pre-emergence herbicides right after planting, even right over the top of stakes planted vertically or inclined. Do not walk in the field for about 30 days after application in order not to damage the herbicide film on the soil surface.

- The pre-emergence herbicide application can be followed by once or twice hand weeding, followed by the application of a post-emergence herbicide at 4–5 months after planting. The post-emergence herbicide should be applied with a shield over the nozzle to prevent hitting the lower stems and leaves of cassava.

- Do not apply post-emergence herbicides on windy days as the spray may drift onto the cassava plants.

Managing the Harvest

- Cassava used for human consumption is usually harvested at 6–10 months, while that used for processing is best harvested at 10–18 months after planting (MAP).

- Delaying the harvest to 18 MAP will greatly increase the root yield at minimal extra cost, while generally having little effect on the starch content.

- In areas with a long dry season, cassava is best harvested in the middle of the dry season, while in areas with a temperate climate, cassava is best harvested during the winter when the starch content is highest.

- In light-textured or loose soils, the root clumps can often be lifted out of the ground by pulling on the lower stems, but in heavier or compacted soil the harvest is much facilitated by using some simple harvesting tools or by the use of a tractor-mounted cassava harvester.

Intercropping

- To reduce the competition between cassava and the associated crops, cassava is best intercropped with short-duration crops, such as maize, upland rice, peanut, cowpea, soybean, and mungbean; or with creeping crops, such as watermelon, squash, etc.

- Cassava can also be planted between young rubber, cashew, or banana trees, or under mature coconut trees as long as there is adequate light penetration.

- Highest total yields and income are usually obtained when cassava and the first intercrop(s) are planted at the same time, or within one or two weeks of each other.

- Plant spacing will depend on the branching habit of the cassava variety, with highly branching varieties needing a larger inter-row space than moderately branching or erect varieties.

- In areas with a long wet season, cassava can be intercropped sequentially with 2 or up to 3 other crops within a one-year period as long as the inter-row space is wide enough (usually 1.8–2.0 m) to allow enough light penetration between the cassava rows for the 2nd or 3rd intercrop to grow.

- In areas with a relatively short wet season, cassava can usually be intercropped with only one other crop, because a second intercrop would normally not produce well due to lack of soil moisture.

- In that case, cassava can be grown at a normal square planting arrangement, such as 1.0x1.0 m, with 1–2 rows of intercrops between cassava rows; or, to favor the intercrop, the inter-row space can be widened to allow for more rows of intercrops.

- Most grain legumes should be planted at least 50–70 cm from the nearest cassava row and with 30–50 cm between intercrop rows.

- To maximize total yield, both cassava and the intercrops should be adequately fertilized, with cassava receiving mostly N and K, intercropped cereals mostly N and P, and the grain legumes mostly P and K.

- While the fast growth of most intercrops will reduce weed competition, it is usually necessary to do at least one hand weeding after which the canopy of both cassava and the intercrops will generally prevent further weed growth.

- Weeds can also be controlled by application of pre-emergence herbicides as long as the herbicides are selective for both cassava and the associated crop(s).

Managing Pests and Diseases

- Plant cassava varieties with tolerance or resistance to the most important diseases and pests.

- Use high-quality planting material cut from mother plants that are free of pest and disease symptoms.

- As an extra precaution, treat the stakes with a mixture of fungicides and insecticides before planting.

- Apply adequate amounts of fertilizers or manures to stimulate vigorous growth, which enhances resistance or tolerance.

- Do not apply insecticides to the crop as these may kill the natural biological control agents that will keep some major pests and diseases under control. Pesticides should only be used as 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. Pesticides can be used to control soil-borne pests, such as termites, as this will not affect the natural enemies of foliar pests.

- To reduce soil-borne diseases, mainly root rots, rotate cassava with other crops, especially cereals or grasses.

- Monitor the crop regularly and pull out plants with symptoms of disease or pest problems. Burn infected plant residues after harvest.

- Prevent the movement of diseased or pest-infested planting material from infested to non-infested fields.

- Do not purchase planting material from unknown sources, as pests and diseases may be a risk.

Application of N Fertilizers

- In most soils, cassava root yields can be increased with the application of 80–120 kg N/ha, all applied at planting or at 30 days after planting.

- If leaves are regularly harvested during the growth cycle, or stems and leaves are removed at the time of root harvest, the rate of N application should increase to 120–200 kg N/ha.

- In sandy well-drained soils, apply N in two or more fractions, such as half at planting and half at 1–2 months after planting; or apply 1/3 of the total at planting, 1/3 at 30 days, and another 1/3 at 60 days after planting.

- There are usually no major differences between various sources of nitrogen, such as urea, ammonium sulphate, ammonium nitrate, or mono-, or di-ammonium phosphate. The latter two sources also contain phosphorus.

- Most nitrogen fertilizers are highly soluble in the soil solution and should therefore be band applied in a hole or in a short furrow made with a hoe at the side of each stake or plant, and then covered with soil.

- Do not leave N fertilizers on the soil surface, as part of the nitrogen will be lost by volatilization or be washed away by runoff water.

Application of P Fertilizers

- Cassava grows well on many low-P soils without the need for P fertilizers, where many other crops would require high levels of application for normal growth.

- In extremely P-deficient soils, those with less than 4 ppm of available P, cassava may respond initially to rather high rates of application of about 100–200 kg P_2O_5/ha, but after the first 1–2 years, these levels should be reduced to 40–50 kg P_2O_5/ha, since much of the applied P remains in the soil.

- The most effective P fertilizers are the highly soluble sources, such as single- or triple-superphosphate and mono-or di-ammonium phosphate (which also contain N), which should be band applied near the stakes or plants and covered with soil.

- Also effective is the less soluble P source called “basic slag,” which should be broadcast over the entire soil and incorporated before planting. This source is also high in calcium and thus helps to decrease soil acidity (increase pH).

- In very acid soils, the application of finely ground rock phosphates may also be effective, but rock phosphates from different sources may differ in their solubility. These less soluble P sources should be broadcast and incorporated before planting.

- All P fertilizers should be applied at the time of planting or at 30 days after planting, as split applications are generally not effective.

Application of K Fertilizers

- K deficiency is most common in light-textured soils or on very acid soils with low levels of available K, Ca, and Mg.

- When cassava is grown year after year on the same land, potassium is likely to become the first limiting nutrient, and application of K fertilizers will have the biggest beneficial impact on yield.

- To prevent K depletion of the soil, about 80–120 kg K_2O/ha should be applied to compensate for the K removed with the root harvest.

- K fertilizers are best applied at time of planting or at about 30 days after planting; they should be band applied near the stake or plant and covered with soil.

- Most farmers use potassium chloride as this is the cheapest potassium fertilizer, but potassium sulphate should be used if soils are also sulphur deficient.

Calcium, Magnesium, and Sulphur

- Symptoms of Ca and S deficiencies are rarely seen in the field, while Mg deficiency symptoms are more common and easily recognizable.

- Ca and Mg deficiencies are only common in very acid soils, which in general have low levels of available Ca, Mg, and K.

- In soils with low levels of available Ca, apply 100 kg Ca/ha in the form of gypsum (about 1 t/ha), or about 400 kg of Ca in the form of calcitic lime (about 1.3 t/ha).

- Both gypsum and lime should be broadcast and incorporated before planting.

- In soils with low levels of Mg or when plants show Mg deficiency symptoms, apply about 50 kg Mg/ha in the form of banded Sulphomag (which contains K, Mg, and S) or broadcast and incorporate magnesium sulphate (500 kg/ha).

- In the unlikely case that cassava suffers from S deficiency, apply 20–40 kg S/ha in the form of potassium or magnesium sulphate, or Sulphomag.

Micro-nutrients and Lime

- Symptoms of micro-nutrient deficiencies are seldom observed, except in alkaline or limestone-derived soils, with the exception of zinc deficiency which is rather common in both acid and alkaline soils.

- In alkaline or limestone-derived soils, cassava may turn completely yellow or even white due to iron deficiency, or occasionally show interveinal yellowing of leaves in the middle section of the plant due to Mn deficiency.

- These problems can best be solved by foliar application of solutions containing 1–2% iron- or manganese-sulphates, or by soaking the stakes for 15 minutes in a solution of 2–4% iron- or manganese-sulphates before planting.

- Symptoms of Zn deficiency can be observed in both alkaline and acid soils, especially if the latter have received high applications of lime or P. In acid soils, Zn can be applied to the soil at a rate of about 10 kg/ha of Zn as zinc sulphate (50 kg/ha), while in both acid and alkaline soils, cassava stakes should be soaked in a solution of 2–4% zinc-sulphate for 15 minutes before planting.

- In most soils where cassava is grown in Asia, there is no need to apply micro-nutrients as most soils supply enough of these nutrients for normal plant growth. Also, in most soils there is no need to apply lime.

- In very acid soils, there may be a need to apply 1–2 t/ha of lime to increase pH or to provide additional Ca to the plants. Higher applications of lime may actually decrease yields by inducing Zn deficiency.

- Farmers should be aware that in many countries unscrupulous vendors try to sell useless products claiming to contain micro-nutrients or hormones that will markedly increase yields. Farmers should buy fertilizers only from well-known companies.

Balanced Soil Fertility Management with Chemical Fertilizer and Manure

- Determine which nutrients are most limiting yield by carefully observing possible deficiency symptoms, by having the soil or plant tissue analyzed, or by conducting simple experiments in the field, as indicated in **Chapter 7**.

- If this information is not available, a general recommendation would be to apply about 80–100 kg/ha of N, 40–50 kg of P_2O_5, and 100–120 kg/ha of K_2O as single-element fertilizers like urea, single or triple superphosphate, and potassium chloride.

- If compound fertilizers are available, apply about 600 kg/ha of fertilizer like 15-15-15, 16-16-16; or better still, about 600 kg/ha of 15-7-18.

- If cassava is intercropped with cereals, such as maize or rice, apply the above fertilizers to cassava, and fertilizers high in N and P to the cereals; if the intercrops are grain legumes, such as soybean, peanut, or cowpea, apply mainly P to those crops.

- If cassava has been grown for many years in the same field, reduce the amount of applied P and increase the application of K, such as 20 kg/ha of P_2O_5 and 120 kg/ha of K_2O; or 500 kg/ha of a compound fertilizer like 14-4-24.

- If available, combine the chemical fertilizers with 4–5 t/ha of manure or compost.

- Manure and compost need to be broadcast and incorporated before planting, while the chemical fertilizer should be applied in a hole or short furrow next to the stake or young plant and covered with soil, either right after planting or at about one month after planting.

- If pests and diseases are not major problems, the previous crop's residues or weeds can be either incorporated into the soil before planting or left on the soil surface as mulch to improve soil fertility and reduce erosion. This has a similar effect as the application of manures.

Improving Soil Fertility through Biological Means

- In the past, shifting cultivation was practiced when land was plentiful and no other alternatives existed for restoring fertility after several cropping cycles. However, in most countries land is now scarce and not enough land is available for the long fallow periods necessary to maintain soil fertility.

- For that reason, it is recommended to apply commercial fertilizers in combination with animal manures or compost; and, if diseases and pests are not a major problem, to incorporate back into the soil all the cassava crop residues in order to return organic matter and plant nutrients.

- Most perennial cover crops will strongly compete with cassava at the early stages of growth, resulting in low cassava yields. Most intercropped green manures or long-duration intercrops will also tend to reduce cassava yields.

- Most beneficial are some of the green manures when they are grown and incorporated before planting cassava, but only in areas with a long wet season that provides sufficient soil moisture during most of the cassava growth cycle.

- Among biological solutions mentioned above, alley cropping between leguminous hedgerow species seems to have the greatest long-term beneficial effect on cassava yields and soil fertility. Once established, the hedgerows require little maintenance besides regular pruning, and they can survive for at least 15–20 years without the need for replanting. Besides improving soil fertility, the prunings, when mulched on the soil surface, will help to control weeds and erosion, reduce soil surface temperatures, and increase soil moisture.

- Similar beneficial effects of mulching have also been obtained when native weeds were cut and mulched before planting cassava with minimum tillage

- If no chemical fertilizers are available or are too costly, soil fertility can at least be partially restored by some of the biological solutions discussed in **Chapter 11**.

Erosion Control

- Cassava can cause serious erosion when planted on slopes, even gentle slopes, as the crop needs to be planted at a wide spacing and initially grows rather slowly, leaving large areas of soil between plants exposed to the direct impact of raindrops.

- Cassava is often planted on very light-textured sandy soil with low levels of organic matter (OM); these soils have low aggregate stability and are thus very susceptible to erosion.

- To prevent soil erosion and degradation, cassava should be planted on the flattest land available, using a variety with vigorous early growth.

- Application of chemical fertilizers, having the right N-P-K balance, at the right rate, right time, and in the right way, is one of the best practices to reduce erosion by stimulating early growth. This will also reduce the need to weed, and increase yield and income.

- Land preparation should be reduced to the minimum necessary for planting the stakes, preferably through a mulch of cut grass, weeds, or crop residues left on the soil surface. The use of a subsoiler instead of a plow is recommended.

- Planting cassava at a closer plant spacing (80x80 cm) will speed up canopy closure and reduce erosion.

- Planting cassava on contour ridges rather than up-and-down ridges will greatly reduce erosion as long as the slope is not too steep and the rainfall not too high;

on steep slopes or with heavy rainfall, too much water may accumulate behind the ridges, which may break, resulting in serious gully erosion.

- Planting contour hedgerows of vetiver grass is usually the most effective in reducing erosion by trapping eroded sediments, slowing down the runoff. Cutting the vetiver grass before planting cassava also provides mulch to cover the soil surface. Over time, enough sediments accumulate above each vetiver barrier to produce natural terraces that will reduce the slope and thus the speed of runoff water.

- If vetiver plantlets are not available or are too cumbersome to plant in large fields, farmers can also plant hedgerows of *Paspalum atratum*, which does not compete much with neighboring cassava plants and can be cut for animal feeding. In more temperate climates, hedgerows of *Tephrosia candida* are also very effective in reducing erosion. Both species can be planted from seed.

- Hedgerows of other grasses, such as *Panicum maximum, Brachiaria ruziziensis, Brachiaria brizantha* or elephant grass, are too competitive and will seriously reduce the yield of cassava growing nearby; they can also become a serious weed problem.

- Planting contour hedgerows of leguminous shrub or tree species, such as *Leucaena leucocephala, Gliricidia sepium*, and *Flemingia macrophylla*, will help to reduce erosion by providing prunings to place as mulch between cassava plants. These prunings will also provide nutrients and organic matter to improve the soil structure, internal drainage, and crop growth and yield. The trees need to be pruned at about 50 cm above the ground at least once a year to prevent seed formation and weed problems.

- Planting fast-growing but short-duration intercrops between cassava rows, such as peanut, cowpea, mungbean, soybean, pumpkin, squash, water melon, upland rice, or maize, will provide early canopy cover in the inter-row space and reduce erosion.

- Existing gullies can be repaired by placing fertilizer bags filled with soil across the gully and anchoring these down with bamboo stakes. After some eroded soil has accumulated behind the bags, vetiver grass can be planted along the contour in these sediments. With time, enough soil sediments accumulate behind the vetiver to form terraces, thus slowing down the runoff water and filling in the gully.

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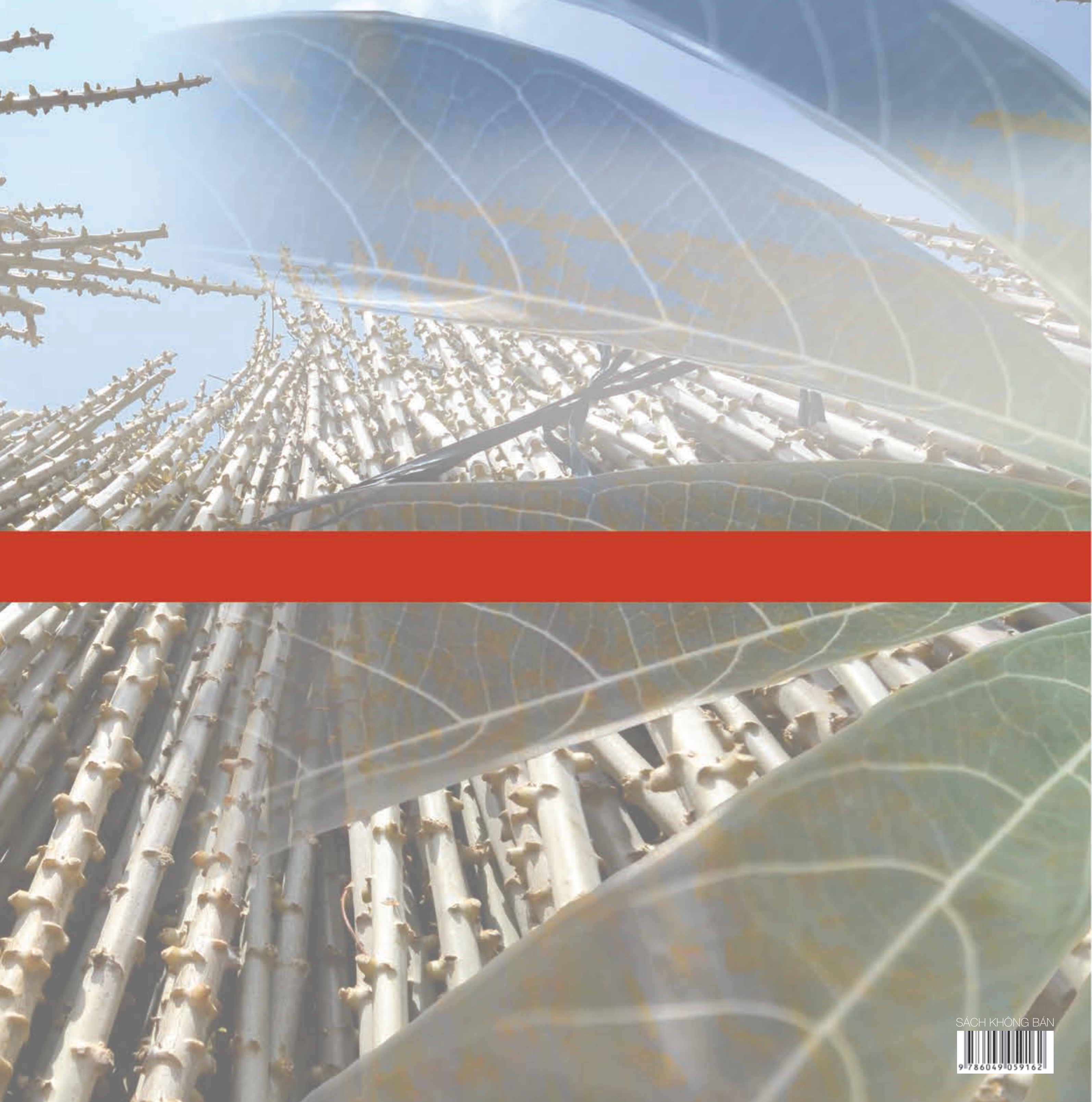

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