Food and Agriculture Organization of the United Nations

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PROCEEDINGS OF THE VALIDATION FORUM ON THE GLOBAL CASSAVA DEVELOPMENT STRATEGY

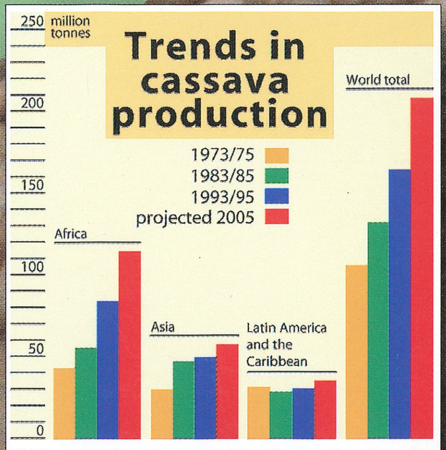
Rome, 26-28 April 2000

IFAD INTERNATIONAL FUND FOR AGRICULTURAL DEVELOPMENT

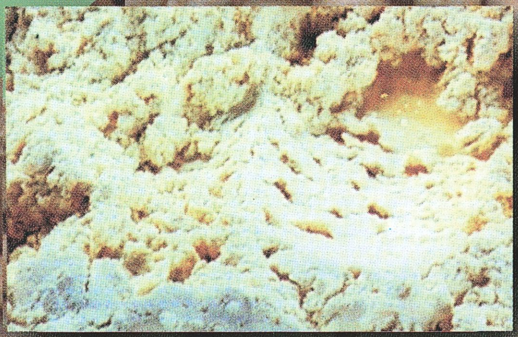
Strategic environmental assessment

An assessment of the impact of cassava production and processing on the environment and biodiversity

Volume 5



Global cassava production is expected to show continued growth over the next five years, with Africa leading the way. Five countries, Brazil, the Democratic Republic of the Congo, Indonesia, Nigeria and Thailand account for almost 70 percent of the world's cassava production. *Source:* FAO



CIAT INTERNATIONAL CENTER FOR TROPICAL AGRICULTURE

CIRAD INTERNATIONAL COOPERATION CENTRE ON AGRARIAN RESEARCH FOR DEVELOPMENT

INTERNATIONAL INSTITUTE OF TROPICAL AGRICULTURE

UNIVERSITY of GREENWICH NATURAL RESOURCES INSTITUTE

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
INTERNATIONAL FUND FOR AGRICULTURAL DEVELOPMENT
Rome, 2001

FOREWORD

The continuous increase in the supply and demand of cassava in developing countries has accentuated the negative impact cassava production and processing has had on the environment and biodiversity. Cassava is mostly produced by small-scale farmers on marginal soils and fragile environments in Africa, Asia and, Latin America and the Caribbean, where animal manure and chemical fertilizers are not commonly applied to the cassava crop. Expanded cassava production has resulted in deforestation, annual burning of indigenous vegetation, replaced fallow land or shortened fallow period. These factors have, in turn, contributed to soil erosion, depletion of soil nutrient supply, and loss of biodiversity.

The large-scale expansion of cassava processing has created improperly stored waste in the form of peels or fibrous by-products, which cause a very unpleasant odour, and depleted the water resources. In view of the above, new strategies are needed to balance the current need for food and fodder while maintaining a healthy environment for future generations.

As part of the effort to develop the Global Cassava Strategy, IFAD's generous financial contribution was fundamental in the preparation of an assessment, which analyzed the effects of smallholder cassava production and processing on the environment and biodiversity. The outcome of this study was presented at the International Validation Forum on the Global Cassava Development Strategy, jointly organized by FAO and IFAD, at FAO Headquarters in Rome, from 26 to 28 April 2000. The Forum officially endorsed the Strategy and adopted a plan outlining a sequence of follow-up actions for its implementation.

The Crop and Grassland Service has compiled these findings in the Proceedings of the Validation Forum for distribution to stakeholders, cassava producers and their organizations, governments and policy makers, donors, technical and research institutions and their networks, NGOs and their networks, the private sector - as well as to scholars, experts and other interested individuals.

We trust this information will not only increase awareness on the environmental problems related to cassava production and processing, but also effectively contribute to the development of new technologies and well-defined policies to sustain the natural resource base.

We express our gratitude to Dr. Clair Hershey for editing this document, and I personally thank Mr. NeBambi Lutaladio for his dedication to the Global Cassava Strategy, from which this publication has come forth.

Eric A. Kueneman
Chief
Crop and Grassland Service
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CONTENTS

ACRONYMS AND ABBREVIATIONS

ASEAN	Association of Southeast Asian Nations
CBN	Cassava Biotechnology Network
CIAT	International Center for Tropical Agriculture
CIP	International Potato Center
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développment
CNPMF	National Research Center for Cassava and Fruits
COSCA	Collaborative Study of Cassava in Africa
CTA	Technical Centre for Agriculture and Rural Cooperation
CVC	Cauca Valley Corporation for Conservation
EMBRAPA	Brazilian Agricultural Research Corporation
IBSRAM	International Board for Soil Research and Management
IDRC	International Development Research Center
IFAD	International Fund for Agriculture Develpment
IITA	International Institute of Tropical Agriculture
IRRI	International Rice Research Institute
MARDI	Malaysian Agricultural Research and Development Institute
NRI	Natural Resources Institute
PADEMER	Project to Support Development of Rural Small Enterprise
SCATC	South China Academy of Tropical Crops
UNDP	United Nations Development Programme

STRATEGIC ENVIRONMENTAL ASSESSMENT

An Assessment of the Impact of Cassava Production and Processing on the Environment and Biodiversity

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EXECUTIVE SUMMARY

Development projects of the International Fund for Agricultural Development (IFAD) often target areas where populations are extremely poor and suffer from seasonal food shortages. In these areas soils are generally infertile and long droughts are a common occurrence, causing crop failure and famine. Under those conditions, cassava (*Manihot esculenta* Crantz) is often a food of last resort, as the crop is very tolerant of poor soils and drought. Cassava is often grown in fragile environments, such as on slopes and in the forest margins. It has the reputation of depleting soil nutrient reserves and causing severe erosion when planted on slopes.

A large proportion of harvested cassava roots is processed into food, animal feed and various industrial products. The processing of some of these products requires large amounts of water and produces equally large amounts of waste water. This water may be high in organic constituents and cyanide, which can pollute the ground water or the lakes, streams or rivers into which it is released. Other waste products resulting from cassava processing are often inadequately disposed of, causing a foul smell and unattractive sight, and giving the cassava processing industry a reputation of polluting the environment.

As part of an intensive effort to develop a Global Cassava Research and Development Strategy, IFAD commissioned CIAT, in collaboration with other institutions, to review the existing information and make a comprehensive assessment of the effect of smallholder cassava production and processing on the environment and biodiversity.

Cassava production and the environment

Most cassava is produced by smallholder farmers living in marginal and fragile environments in Africa, Asia and Latin America. The crop is usually grown on very acid and infertile soils (often prone to erosion), where other crops would not grow well. But few farmers apply animal manures or fertilizers to their cassava crop, and those who do usually use only low rates. This study reviews available data in the literature on nutrient absorption, distribution and removal by cassava when either the roots alone or whole plants are harvested and removed from the field.

Nutrient removal is a function of dry matter production and yield, but as yields increase, so does the nutrient concentration of the plant tissues, resulting in a non-linear relationship between nutrient removal and root yields. Thus, at high yields, nutrient removal is indeed quite high, but removal of nitrogen (N) and phosphorus (P) is still lower than, and potassium (K) removal is similar to that of other crops. At low root yields (below 15 t/ha) cassava removes much less N, P and K than most other crops. This is because most nutrients (except K) are mainly present in leaves (intact and fallen) and stems, and if these are returned to the soil, nutrient removal is minimal. However, in areas where leaves and stems are also utilized and removed from the field, nutrient removal can double or triple, depending on each particular nutrient. In this case nutrient depletion can become of serious concern. Thus, returning leaves and stems to the soil is an essential first step in preventing nutrient depletion and maintaining soil fertility.

As for any other crop, to maintain soil productivity and sustain high yields, nutrients removed in the harvested products of cassava should be replaced in the form of chemical fertilizers, animal manures, ash or compost. In most soils cassava does not respond to high rates of P application because: 1) P removal in the root harvest is very low (much lower than that of N and K); and 2) the fibrous roots of cassava become naturally infected with mycorrhizal fungi present in all natural soils. The symbiosis between cassava and mycorrhiza enables the crop to absorb P even from soils with very low levels of available P. This, and cassava's tolerance to high levels of aluminum (Al), allow the crop to grow well in acid and low-P soils. Moreover, in soils that are low in nutrients, cassava reduces its growth rate and nutrient absorption, producing low but stable yields without seriously depleting the soil's nutrient supply.

For production of a moderate fresh root yield of 15 t/ha it is recommended to apply about 80 kg of N, 10-20 kg P_2O_5 and 50 kg K_2O/ha. To maintain a high yield of 30 t/ha, annual application of 150 kg N, 20-30 kg P_2O_5 and 150 kg K_2O/ha may be required. Compound fertilizers that are high in N and K but low in P are the most suitable for cassava. However, in some soils that are extremely deficient in available P (<2mg P/kg dry soil), mostly found in Brazil and Colombia, the crop responds mainly to the application of P. Initial applications of 100-200 kg P_2O_5/ha may be necessary to obtain maximum yields, but with continuous cropping on the same land these annual applications can be reduced in a few years to less than 50 kg P_2O_5/ha.

Where animal manures are available it is recommended to apply about 5 t/ha of manure together with chemical fertilizers high in K. Where chemical fertilizers are not available or too costly, it is recommended to apply 7-10 t/ha of manure in combination with wood ash. If neither manures or fertilizers are readily available, soil fertility can be maintained by planting a green manure crop and mulching or incorporating the green manure before planting cassava; alternatively, cassava can be rotated annually with green manures or grain legumes. Intercropping cassava with grain legumes may also improve soil fertility, especially if the legumes are well fertilized and the crop residues are returned to the soil. However, high yields cannot be achieved or maintained for very long if no outside nutrient sources (fertilizers or manures) are applied to compensate for nutrient removal in the harvested products, as well as losses by leaching, volatilization or erosion.

Cassava has the reputation of causing serious erosion when grown on slopes. Some people argue that this reputation is undeserved, since cassava is often grown on already-eroded soils where few other crops can survive and be productive. Nonetheless, a review of the literature indicates that production of cassava on slopes generally causes more erosion on an annual basis than other crops grown under the same circumstances. Cassava, together with castor bean, common bean (*Phaseolus vulgaris*), upland rice and cotton, seems to cause considerably more erosion than maize, peanut, sugarcane, pineapple or sweetpotato. This is mainly due to the fact that cassava needs to be planted at a relatively wide spacing. Initial growth and canopy formation are slow, leaving soil exposed to the direct impact of rainfall during 3-4 months after planting. On the other hand, once the crop canopy is closed, erosion is usually minimal during the remainder of the crop cycle.

Once the topsoil is eroded away, it is very difficult to restore the soil's productivity. For that reason erosion should be minimized. Many experiments have been conducted to develop effective ways to reduce erosion in cassava fields. Good agronomic practices that increase yields, such as adequate fertilization, closer plant spacing and planting on contour ridges, are very effective in reducing erosion. Intercropping, reduced tillage and planting contour hedgerows of grasses, such as vetiver or lemon grass, are very effective in reducing erosion and may also increase cassava yield or total income. These practices, used alone or in combination, can reduce erosion by 50-90%. Thus, when properly managed, cassava production on slopes does not necessarily cause serious erosion.

Most erosion-control practices will require some additional inputs of capital (e.g. fertilizers or seed of intercrops), labor (e.g. establishing and maintaining contour hedgerows) or may reduce cassava yields by competition (e.g. intercrops and hedgerows) or by reducing the area available for cropping (e.g. hedgerows). Moreover, some of these practices may not be feasible or do not fit well in the current production practices (e.g. fertilizer use in much of Africa or minimum tillage in Thailand). The choice of most suitable practices is very site-specific and often involves trade-offs between advantages and disadvantages. The most appropriate practices depend on the biophysical and socio-economic conditions of the region, and can best be determined by the farmers themselves. For farmers to adopt better soil-conserving practices it is essential that they are aware that soil erosion is a problem, and that they themselves are involved in the development and testing of better production practices that reduce erosion. The adoption of more sustainable cassava production practices is limited less by a lack of basic knowledge than by a lack of understanding of farmers' needs and limitations. The development and dissemination of sustainable practices require a holistic and farmer participatory approach. Governments can mandate certain regulations about land use and management of sloping land, but these can seldom be enforced, as poor farmers living in these areas have few other alternatives.

Cassava production and biodiversity

There is no documented evidence that cassava production has had a significant effect on the biodiversity of other species. But it has sometimes led to serious deforestation, such as in the northeast of Thailand, which has probably contributed to a loss of biodiversity. There is also no clear evidence that cassava production in Brazil or Mexico, the two centers of origin of *Manihot* sp., has contributed to the loss of biodiversity in that genus. However, continuous monocropping of cassava, accompanied by annual burning of the sparse native vegetation in northeastern Brazil is threatening the survival of seven native wild *Manihot* species. It is recommended to collect and conserve these species *ex-sitio*. It is also recommended to collect and conserve six other species which are closely related to *Manihot esculenta*, and which may be used in the future for interspecific breeding to incorporate favorable characteristics not presently found in *M. esculenta*.

Cassava processing and the environment

Most forms of cassava processing produce large amounts of waste, the type and composition of which are governed by the processing method and sophistication of the technology used. Cassava processing is generally considered to contribute significantly to environmental pollution and to depletion of water resources, due to the strong and unpleasant odor and the visual display of waste products. Some forms, especially starch extraction, also require large volumes of water.

A review of the literature suggests that in most areas water depletion is minimized by the adoption of processing technologies suitable for the water resources available. This balance is maintained as long as traditional processing methods are used, or volume of processed product is not increased substantially. However, technology changes can increase water demand. The recent adoption of more automated processing technologies in parts of Africa is especially noteworthy. This will allow the rapid processing of larger volumes of roots, which could create a serious strain on limited water resources. In other areas, even those with a large concentration of cassava processors (such as Tamil Nadu, India), the impact on water supply is minimal compared to that of other users, such as agriculture or domestic. At a site-specific level, starch processing may exacerbate an already existing water shortage problem, but is unlikely to be the prime cause.

Many scales of cassava processing exist in the world; each will affect the environment differently. Large-scale processing, if left unchecked, will have the largest impact on the environment. However, such processors usually are closely regulated by governments – given their size and relatively few number, this is easily achieved. The larger enterprises also have resources, financial and technological, that are not available to small-scale processors to deal with their waste. Small-scale processors, who generate only small amounts of waste individually, are usually clustered together, hence magnifying their impact.

This study was not able to find conclusive evidence that cassava processing contaminated groundwater supply. It is possible that groundwater supply near cassava processors is contaminated, but it is often difficult to disaggregate cassava processing from other forms of waste-generating activities. The proportion of contaminated sites in cassava processing areas is likely to be small, with most wells and bore holes remaining unaffected. However, studies are few and other processing sites may have ground geology that is not capable of protecting the groundwater supply from being polluted.

Surface water presents a different picture. Given sufficient volume of discharge, either from a large processor or from a high concentration of small processors, eutrophication of slow moving water systems (ditches, lakes, etc.) can occur. This is especially problematic during the dry season.

Cassava processing may also produce solid waste, either in the form of peels or fibrous by-product (pulp). The solid waste does not seem to be a problem; usually it is sold soon after its generation or it is stored before sale. Potential problems occur when the waste is improperly stored and left exposed to the rain. In this situation, leachates can be generated that filter through to the groundwater supply. However, reports of this are few.

Cyanide is liberated during cassava processing; this can be a problem, especially in processes that create large amounts of "squeezed juice". Care should be exercised that cyanide-containing waste is either diluted or stored in such a manner that the cyanide concentration is reduced. This is usually the case, even if the waste is stored for a short time.

Conclusions and recommendations

Cassava production can have some negative effect on soil fertility through crop removal of nutrients, but it is likely to have a more serious and long-lasting effect on the environment as a result of erosion. At current yield levels, soil nutrient depletion by cassava is generally far less than by that of other crops. But due to the low value of cassava products, application of manures and chemical fertilizers may not be economically justified, or farmers may not be able to afford the purchase of fertilizer. Once the nutrient supply in the soil is depleted this can easily be corrected by application of fertilizers. Cassava production, however, does *seem to cause serious erosion when the crop is grown on slopes. Soil degradation due to erosion is not easily corrected. Farmers should be encouraged and materially supported to plant cassava on less steep land, and to use appropriate measures to reduce erosion. With these practices, erosion can be reduced by 50 to 90%.*

Cassava production does not seem to have had broad effects on biodiversity, either of other Manihot *species or of those of other genera. There are, however, localized situations that merit attention, as well as the need for plans to minimize* future *genetic erosion.*

Cassava processing can have negative, mainly site-specific, effects on the environment, by producing unpleasant odors and an unsightly display of waste. However, the long-term and broad-based impact on the environment is generally minimal and can be corrected by proper waste treatment, with technologies which are either presently available or under development.

Recommendations are made for planners and policymakers, both of a technical and general nature, that will, (1) help producers reduce erosion and maintain soil productivity, (2) counter deforestation leading to a loss of biodiversity, and (3) establish guidelines and regulations for cassava processors to make more efficient use of water resources, to reduce the negative impact of processing waste on the environment, and support research and development on value-adding of by-products.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a major food and industrial crop in tropical and subtropical Africa, Asia and Latin America. In Africa and most of Latin America cassava is mainly used for human consumption, while in Asia and parts of Latin America it is used for on-farm animal feeding, for production of commercial animal feed, or processing into starch and starch-based products.

When used as human food, cassava can help feed the family; when fed to pigs or sold in nearby markets it can produce income and thus provide for necessities such as clothing, education and health care. Thus, for some, cassava is a staple food, while for others it may serve as a vehicle to increase income and escape poverty.

Because of its tolerance of soil acidity, low soil fertility and drought, the crop is often grown by poor, smallholder farmers in marginal areas with adverse climatic, edaphic and topographic conditions, such as steep slopes and forest margins. Good examples are the dry and infertile areas of northeast Brazil, the seasonally dry areas of southwest Nigeria and east and south of Lake Victoria in Tanzania, as well as the northeast of Thailand or the eastern part of Java. Because of its ease of planting and adaptation to minimum land preparation, the crop is often grown on slopes, both on gently rolling terrain and on steep hillsides. It can be grown with relatively few purchased inputs and often requires only family labor. These favorable attributes make cassava an appropriate crop for resource-poor farmers.

Production in these sensitive areas can lead to environmental degradation. Like any other crop, cassava extracts nutrients from the soil, and its continuous production in already poor soil, without addition of nutrients, will inevitably lead to nutrient depletion and a further decline in soil productivity. In addition, the wide planting distance used, and the relatively slow initial growth of the plants, result in slow closure of the crop canopy which in turn leads to poor protection of the soil surface; this can cause soil erosion when the crop is grown on slopes. Erosion leads to a decrease in rooting depth; a preferential loss of organic matter, clay and nutrients; and a loss of applied fertilizers. Erosion also has off-site effects of sedimentation of waterways and reservoirs, and potential eutrophication of lakes.

Cassava production can lead to new land clearing and loss of biodiversity. This may be especially notable in forested areas. Losses can include wild *Manihot* species, which may be of future importance for the incorporation of favorable characteristics, such as disease tolerance, in cultivated cassava. Moreover, the tendency to grow high-yielding and high-starch varieties has reduced the number of farmers' landraces, resulting in a narrowed germplasm base; this has increased the danger that new pests or diseases will destroy a large part of a single-variety crop. This problem cannot be solved by individual farmers, but should be considered by planners and policymakers. Research institutions must ensure the collection and safe conservation of cassava germplasm and that of its wild relatives, before they are lost.

Cassava is processed into a wide variety of products. The boiling of peeled roots, the simplest form of processing, is used in much of the Andean zone of Latin America, southern India and in parts of Vietnam. In West Africa, roots are peeled, grated, fermented, dehydrated, and then toasted to produce *gari*, a product particularly popular in Nigeria. In other countries, like Sierra Leone, the soaked, pounded and fermented mash is boiled with water to a thick paste called "foofoo". Many other processing techniques are used in Africa to produce a variety of either wet or dried products for human consumption. In the Andean zone of Colombia, in southern Brazil, in Java and northern Vietnam, cassava roots are processed into starch in small family-size processing units. Roots are grated, mixed with water and filtered. The starch is allowed to settle in tanks, and is then sun dried.

Extraction of starch from cassava roots requires large amounts of water. After separation of the starch and fiber, the residual water contains small amounts of starch, proteins and hydrocyanic acid. When this water is released directly into streams or rivers, the residual starch can cause rapid growth of bacteria, resulting in a depletion of oxygen and detrimental effects on aquatic life. There are also reports indicating that dissolved hydrocyanic acid has caused the death of fish. Problems arise when there is a high density of small-scale starch factories, which tend to use inefficient starch extraction methods and do not utilize pollution control devices. In larger factories, starch extraction is more complete and water use is more efficient, resulting in lower water use and less pollution. These larger factories are often forced to invest in pollution control devices. Nonetheless, the more efficient technology can also have a potential for negative environmental impact: with new high-speed grating machines, large quantities of cassava roots are mashed up in a minimum of time, resulting in high concentrations of hydrogen cyanide (HCN) in dust and water sprays. Such factory pollution may affect the health of workers.

The objectives of this assessment are to review the current knowledge on the effect of smallholder cassava production on the environment, to assess the degree to which cultivation of this crop is causing land degradation, to determine appropriate management practices to reduce such effects, and to find ways to disseminate this knowledge and enhance adoption of more sustainable production practices.

Similarly, this assessment reviews our present knowledge about the effects of small-scale cassava processing on the environment, suggests ways to mitigate against these problems, to identify constraints to their adoption and suggest possible policy changes that will encourage the use of more environmentally friendly processing techniques.

The study also identifies gaps in our knowledge, suggests areas where additional research is needed, and makes recommendations for planners and policymakers.

IFAD INTERFACE WITH CASSAVA

The International Fund for Agricultural Development (IFAD) has as its key objectives the alleviation of poverty and improvement of household food security, with emphasis on smallholders and rural women, while preventing environmental degradation. As such, its development projects target areas where the population is extremely poor and may suffer from seasonal food shortages. These areas are often characterized by poor soils and low or unpredictable rainfall. Root and tuber crops are often an integral part of the cropping system, and cassava is frequently an important component of the diet. Being very drought tolerant and well-adapted to grow on poor soils, cassava is often the crop of last resort. During the severe drought of 1982/83 in Ghana, when most other food staples perished, the rural population survived mainly on cassava. After this, and similar experiences elsewhere, cassava gained in importance.

A global cassava strategy

By working in marginal areas, IFAD found that cassava can help alleviate food insecurity, especially in times of war or social unrest, as the crop is easy to grow and can be stored for long periods of time in the ground. Surplus production can be fed to farm animals or sold as fresh roots or dry chips for human consumption or animal feed. Cassava can also be a source of income for small-scale rural processors, who transform cassava into a wide range of food products. In view of the crop's importance for marginalized producers and consumers, IFAD has taken the initiative to bring cassava to the attention of governments and donor agencies. It has spearheaded a worldwide consultation among cassava stakeholders from the government and private sectors, to try to reach a consensus about a global strategy for cassava research and development. It is hoped that a global strategy will enable a more effective and coordinated research and development effort.

IFAD operations

IFAD is presently involved in three cassava related projects. In Ghana IFAD has financed a Smallholder Rehabilitation Program, including a program for the development of new cassava technologies and the release of new varieties (IFAD, 1997). Because of the success of this program, and the fact that cassava is now grown by about 80% of all households, and has become a food of choice rather than a food of last resort, a new Root and Tuber Improvement Program was recently initiated. This program will concentrate on the multiplication and distribution of improved varieties, development of new technologies, integrated pest management and community support.

In Nigeria IFAD has financed a Cassava Multiplication Program in the southern part of the country (IFAD, 1995), emphasizing the multiplication and distribution of new varieties released by IITA. A new project is being developed to supplement cassava varietal distribution with low cost technologies and smallholder processing, and the construction of roads and other rural infrastructure to facilitate marketing.

In Colombia IFAD recently initiated a program to help set up and develop small-scale rural agro-enterprises, initially focusing on the Departments of Cauca, Bolivar and Sucre (IFAD, 1996). Although this program does not target cassava as a major raw material for these enterprises, the crop is important in all three Departments, and cassava processing could become a major component of the project.

IFAD is aware that cassava is already grown in many ecologically sensitive areas, usually with poor soils and located on sloping land or in the forest margins. Increases in cassava production could lead to degradation of soil and water resources. In addition, small-scale cassava processing is often blamed for causing environmental pollution. Therefore, any project that intends to enhance these enterprises must take into account these potential problems and seek effective solutions. For this reason, IFAD commissioned a study to assess the impact of smallholder cassava production and processing on the environment. The study would review best-bet solutions, identify the need for further research, and provide suggestions and policy options to mitigate against negative effects on the environment.

Cassava in Africa, Asia, Latin America and the Caribbean

Table 1 shows the area and dry matter (DM) production of the major food crops worldwide. In terms of dry matter production, cassava is the fourth most important crop in SE Asia, seventh in Asia, fifth in Latin America and the Caribbean (LAC), second in Africa, and the most important crop in Sub-Saharan Africa. Area planted to cassava (FAOSTAT, 1999) is highest in Africa at 10.10 million ha (62% of world total), followed by Asia at 3.48 million ha (21%) and LAC at 2.70 million ha (17%), for a total area of 16.28 million ha worldwide (Figure 1).

Africa accounts for 51%, Asia 29% and LAC 20% of world production. Fresh root yields are highest in Asia at 13.7 t/ha, followed by LAC with 11.9 and Africa with 8.4 t/ha. The higher yields in Asia are partially due to a near absence of diseases and pests (except in India), and relatively intensive crop management, which in a few isolated areas (Tamil Nadu of India) includes irrigation and high rates of fertilizers.

Production environments

Cassava is produced between 30° north and south latitudes, and near the equator up to an altitude of about 1800 masl. Because of the crop's tolerance to drought and low soil fertility, it is generally produced in marginal areas with poor soils, and/or high risk of drought.

Cassava grows best in areas with a mean temperature of 25-29°C, and a soil temperature of about 30°C; below 10°C the plant stops growing. While the crop grows best in areas with an annual well-distributed rainfall of 1000-1500 mm, it can tolerate semi-arid conditions with rainfall as low as 500 mm, and may have a competitive advantage over other crops under those conditions. Cassava can grow on a wide range of soils, but is best adapted to well-drained, light-textured, deep soils of intermediate fertility. Under high fertility conditions top growth may be stimulated at the expense of root growth. Optimum soil pH is between 4.5 and 6.5. The crop does not grow well in poorly drained soils, gravelly or saline soils, or in soils with a hardpan (Onwueme and Sinha, 1991).

Soils

Table 2 shows the distribution of cassava growing areas with respect to the various soil orders of the US soil classification system. In Asia about 55% of cassava is cultivated on Ultisols, which are characterized by low pH (but not low enough to limit cassava growth) and low nutrient content. Of the major plant nutrients K is usually the most limiting, especially if cassava is grown for many years on the same soil. Another 18% of cassava in Asia is grown on Inceptisols, mainly on Java island of Indonesia. These soils are also low in N, P and K, but which of these is the most limiting depends on the local soil characteristics. Another 11% of cassava in Asia is cultivated on Alfisols, mainly on Java. These soils tend to have a high cation exchange capacity, a relatively high pH and high fertility. Because of high pH and high levels of Ca and Mg, cassava may suffer from micronutrient deficiencies, especially Zn and Fe. Finally, about 9% of cassava is grown on Entisols, again mainly on Java. On these soils cassava production may be limited by an inadequate supply of N and K, or, in very sandy soils, Zn.

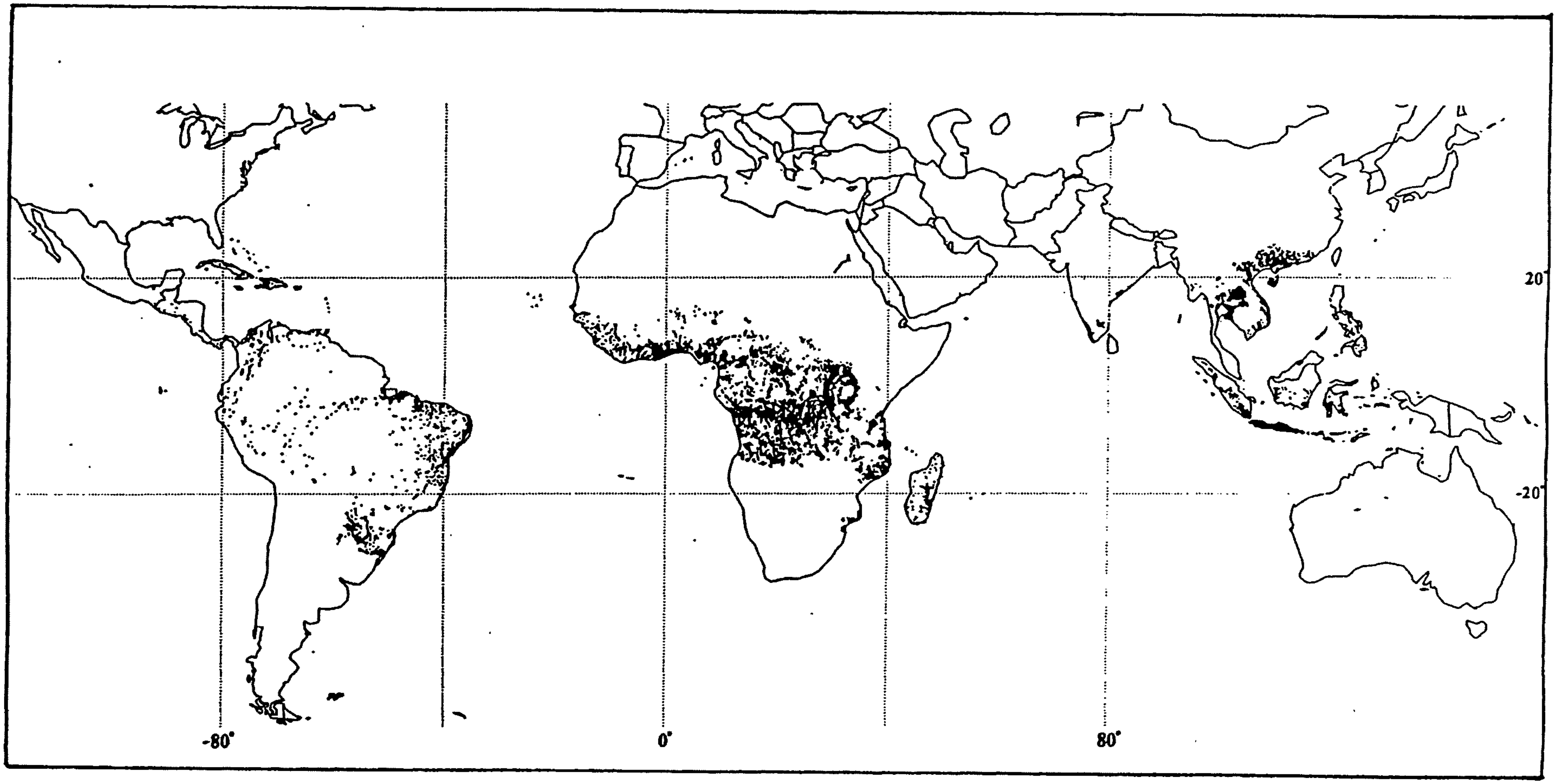


Figure 1. Distribution of cassava in the world. Each dot represents 1000 ha.
***Source:** CIAT, 1995.*

Table 1. Area and production (on dry weight basis) of major food crops in various regions of the world in 1997.

	Area harvested (million ha)					Production (million tonnes)[1]				
	SE Asia[2]	Asia total	Latin America &Caribbean	SSA[3]	Africa Total	SE Asia	Asia total	Latin America & Caribbean	SSA[3]	Africa total
Cassava	2.97	3.48	2.70	10.08	10.10	14.33	18.07	12.23	32.07	32.07
Rice	40.86	133.99	6.17	6.96	7.63	116.37	455.86	17.31	9.74	14.57
Maize	8.41	42.06	29.26	20.81	25.93	16.87	122.77	66.46	21.31	34.77
Sorghum			3.63	21.89	22.36			8.83	14.91	16.00
Wheat										
Sweet potatoes	0.65	7.23				0.88	23.98			
Sugarcane	2.21	8.75	8.87	0.90	1.46	30.68	138.79	143.88	11.53	21.06
Soybeans			20.15					35.61		
Potatoes	0.12	6.18	1.11			3.04	18.20	3.01		
Millet				19.63	19.71				10.69	10.72

1) On dry matter basis, assuming the grains to contain 86% DM, cassava 38%, sweet potato and potato 20%, and sugarcane 26%.
2) Includes Brunei, Cambodia, Indonesia, Laos, Malaysia, Philippines, Singapore, Thailand and Vietnam.
3) Sub-Saharan Africa includes Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Comoros, Dem Rep of Congo, Rep of Congo, Cote d'Ivoire, Dibouti, Equatorial Guinea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Nigeria, Niger, Rwanda, Reunion, Sao Tome and Principe, Senegal, Sierra Leone, Somalia, Sudan, Swaziland, United Rep. of Tanzania, Togo, Uganda, Zambia and Zimbabwe.

Source: FAOSTAT, 1999.

Table 2. Soils on which cassava is produced in Latin America and Asia and their principal constraints for the crop.

Soil Order	(% of cassava area) Latin America[1]	Asia[2]	Constraints Acidity	N	P	K	Micronutrients
Ultisols	27.0	55.1	-	+	+	++	
Alfisols	23.2	11.4	-	-	-	-	Zn, Fe
Oxisols	19.0	0.7	+	+	++	++	Zn
Entisols	13.4	8.9	-	++	+	++	Zn, Mn
Inceptisols	6.9	18.0	-	+	+	+	
Mollisols	5.5	1.7	-	-	-	-	
Vertisols	4.2	3.6	-	-	-	-	
Aridisols	0.4	-	-	-	-	-	
Histosols	-	0.6	++	+	+	+	Cu

[1] Based on a total cassava area of 2,512,000 ha in Latin America
[2] Based on a total cassava area of 3,582,000 ha in Asia
Source: [1] CIAT, 1983
[2] Howeler, 1992.

In sharp contrast to Asia, in Latin America and the Caribbean cassava is grown on almost equal proportions of Ultisols, Alfisols and Oxisols, with lower proportions of Entisols, Inceptisols and Mollisols. Brazil accounts for 70% of the cassava growing area in LAC and most of these soils are found in that country. Unlike in Asia, in LAC cassava is grown extensively on Oxisols, which are generally characterized by low pH (4.2-6.0), high levels of exchangeable Al and very low nutrient contents. In only a few areas, mainly the Eastern Plains of Colombia, will cassava benefit from small applications of lime, principallly as a source of Ca and Mg. The Oxisols also tend to be very low in P and K, the former generally being the most limiting nutrient during the first year of cassava cultivation, while K becomes more important in subsequent plantings on the same soil.

For Africa similar data are not yet available. However, according to the Collaborative Study of Cassava in Africa (COSCA) (Carter *et al.*, 1992), about 54% of the cassava growing areas are constrained by high acidity and low soil fertility. Since "high acidity" is defined as a soil with pH<5.5, it is unlikely that acidity is the real limiting factor, as cassava is known to tolerate pH values as low as 4.0-4.2 and high levels of exchangeable Al (up to 85% saturation) (Howeler, 1991b; Asher *et al.*, 1980). Most likely, cassava production in Africa is constrained by low soil fertility, as most cassava is grown on Oxisols, Ultisols and Entisols. The same COSCA study (Carter *et al.*, 1992) reports that 10% of the cassava area in Africa is constrained by shallow soil depth or texture, and another 4% by poor drainage.

Climate

Tables 3 and 4 show the distribution of cassava-growing areas in the three continents according to climatic zones[12]. In Latin America almost 30% of cassava is grown under subtropical conditions, sometimes with frost during the winter, which may kill the above-ground growth; in Asia this is about 15% and in Africa only 10%. In both Latin America and Africa about 20% of cassava is grown in the highlands with year-round cool temperatures of <22°C; in Asia almost no cassava is grown at high elevations.

Latin America and Africa are similar in terms of dry-season length, with 40-45% of cassava grown in both the humid and seasonally dry zones, and with 10-15% in the semi-arid zone. According to Table 4 Asia has 26% of the cassava area in the semi-arid zone, but that is partially due to a wider definition of semi-arid climates used in Table 4 than in Table 3. According to the latest agro-ecological zone classification (Peter Jones, personal communication) practically no cassava in Asia is grown under semi-arid conditions, while this same classification used in LAC and Africa shows rather large areas (about 20-30%) in this zone, mainly in NE Brazil and in Mozambique (Appendix 1).

Table 3. Cassava distribution in Latin America and Africa by climatic conditions.

Climatic classification		Percent of total cassava area	
		Latin America[1)]	Africa[1)]
Altitude[2)]:	Lowland	77.3	80.1
	Highland	22.6	19.9
Rainfall[3)]:	Humid	45.4	43.3
	Seasonally dry	38.6	44.9
	Semi-arid	14.6	11.8
	Arid	1.3	0
Seasonality[4)]:	Tropical	70.9	89.8
	Subtropical	29.1	10.2

[1)] Based on total cassava area of 1,816,000 ha in LA and 7,992,000 ha in Africa
[2)] Mean growing season temperature: Lowland >22°C; Highland <22°C
[3)] Length of dry season (<60mm rain): Humid 0-3; Seasonally dry 4-6; Semi-arid 7-9; Arid 10-12 months
[4)] Seasonality (difference between hottest and coldest month): Tropical <10°C; Subtropical >10°C
Source: CIAT, 1989.

[12] Tables 3 and 4 do not correspond, because they include different areas (*only* Latin America in Table 3 and Latin America *and* the Caribbean in Table 4) and use somewhat different classification systems. The authors consider that consensus about the best criteria for a useful cassava agro-ecological zone classification is urgently needed.

Table 4. Cassava distribution in Latin America and the Caribbean (LAC) and in Asia by climatic zones.

Climatic zone[1]	Percent of total cassava area[2] Latin America & Caribbean	Asia
Lowland humid tropics	15	18
Lowland subhumid tropics	33	41
Lowland-semi-arid tropics	8	26
Highland tropics	15	0
Subtropics	29	15

[1] Altitude (masl): Lowland < 1000; Highland > 1000
Length of dry season (<60mm rain): Humid: 0-3; Subhumid 4-5; Semi-arid >5 months
Latitude: Tropics: between 20°N and S
[2] Based on 2,781,000 ha in LAC and 3,921,000 ha in Asia
Source: Norel, 1997.

Elevation and topography

About 80% of cassava in Africa is grown in the lowlands and the remaining 20% in the highlands, mainly in tropical highlands in Angola and the Great Lakes Region of Uganda, Rwanda, Burundi and northern Tanzania. In Africa some cassava is also found in subtropical highlands, mainly in Zambia and Madagascar. In these areas cassava may be found on steep slopes of 10-50% (Carter et al., 1992).

In Asia very little cassava is found at elevations above 1000 masl (Table 4). Most is grown on gentle slopes of 0-10%, but in southern China, north Vietnam and on Java the crop can be found on steep slopes of 15-50%. Especially in Indonesia these areas are usually terraced and cassava is often intercropped with other food crops on narrow strips of terraced land. In China the crop is sometimes planted on steep slopes as an intercrop between young trees in areas recently reforested (Henry and Howeler, 1996).

In Latin America about 417,000 ha of cassava are found in the highlands. Cassava grown in the tropical highlands is found mainly in the Andean zone of Colombia, Ecuador and Peru, as well as in Central America; that grown in the subtropical highlands is found mainly in southeast Brazil, eastern Paraguay and northern Argentina. In the highlands, cassava is often cultivated on slopes up to 40%, and occasionally on steeper slopes. In the southern states of Brazil, such as Sao Paulo, Parana and Santa Catarina, cassava is often grown on gentle slopes of <10%, but because of intensive mechanical land preparation serious erosion can occur under those conditions. Where land is prepared by hoe or oxen-drawn plow, land preparation tends to be less intensive and fields are smaller, resulting in less serious erosion.

Cropping systems

In much of the African lowlands cassava is grown in slash-and-burn systems, usually as the last crop in a rotation, after maize, cowpea and upland rice, and before the plot is returned to bush fallow. Cassava is generally the last crop in the rotation because it will still produce a reasonable yield on nutrient-depleted soils. This is most likely a significant part of the reason for very low cassava yields in Africa. In the African highlands cassava is generally grown after short-term fallows.

Cassava is mainly grown intercropped with maize, yam, peanut or cowpea in West Africa, or with banana, maize, cowpea and beans in East Africa (Ezumah and Okigbo 1980); C. Wortman, personal communication). In western Nigeria cassava is grown together with yam, maize and egusi melon on the same mound, while in other areas crops are grown in separate rows (Okeke, 1984). In Sierra Leone cassava is often intercropped with upland rice, planted 4-6 weeks after cassava (Dahniya *et al.*, 1994).

Cassava farmers in Africa seldom apply any chemical fertilizers to cassava (or most other crops) even though trials have shown that cassava is highly responsive to fertilizer applications (Richards, 1979; FAO, 1980). Instead, most farmers rely on natural fallows to restore soil fertility; they may apply small amounts of animal manure or ash, but usually to the intercrop. Soil preparation is mainly done by men, using a short-handled hoe in southern Nigeria, while in the northern part of the country farmers use oxen for plowing. In Tanzania cassava is planted on ridges and in Uganda without ridges. Planting, weeding and harvesting is done mostly by women.

In Central America and the Andean zone of South America cassava is often planted after short (2-4 year) fallows. After slashing and burning of the fallow vegetation, cassava is planted for 2-3 years without fertilizer or manure input, until the soil's fertility has been exhausted and low yields do not permit further cultivation. However, the fallow period is often too short and the native soil fertility too low to allow for adequate regrowth of vegetation to restore soil fertility. If cassava cultivation is also associated with serious erosion, then soil fertility in these areas cannot be restored, and farmers are caught in a downward spiral of productivity decline, leading to ever increasing poverty.

In the mountainous areas of Central America and the Andean zone, cassava is usually grown intercropped with maize, cowpea or beans. The intercrops may receive some fertilizers or manure, but these are seldom applied to cassava, as the low value of the crop does not justify expensive inputs of fertilizers. In Cauca Department of Colombia farmers are now applying rather high amounts of chicken manure, with good results.

Along the eastern coast of Brazil and in extensive areas of the Northeast, cassava is mostly grown by smallholders under very marginal conditions of drought and low and declining fertility. In the southern states of Sao Paulo, Parana and Santa Catarina, climate and soil conditions are more favorable and management is more intensive, leading to higher yields. In Brazil the crop is grown mainly in monoculture or intercropped with maize, beans or cowpea. In many areas in the South, fields are plowed by tractor followed by furrowing. Fertilizers (P and K) are often applied at the bottom of the planting furrow, after which they are covered with a little soil before placing the stakes horizontally in the furrow and filling over with soil.

Table 5 shows the details of the prevailing cassava cropping systems used in the various countries of Asia. Even within countries there may be marked differences among regions.

Crop management is mainly determined by the size of farms and the availability of labor. In countries with comparatively larger farms, such as Thailand and Malaysia, and on large plantations in Indonesia and the Philippines, cassava is generally grown in monoculture, and land preparation is by tractor. In areas of small farms, such as Kerala state of India, Java island of Indonesia, northern Vietnam and southern China (Henry and Howeler, 1996), land preparation is usually by hand using a hoe, or by an animal-drawn plow. In many cases cassava is intercropped with peanut or maize, and occasionally with sweetpotato or watermelons (China). In India and Indonesia farmers tend to apply 5-20 tonnes of cattle or chicken manure, while in north Vietnam and China farmers apply 3-7 tonnes of pig manure, often mixed with rice straw. Fertilizers are commonly applied at high rates in Malaysia and Tamil Nadu state of India, but at low rates in Thailand, Indonesia (mainly N), China and Vietnam (Pham Van Bien *et al.*, 1996). Little or no fertilizer is used in Kerala state of India, in the Philippines and in central Vietnam. In Kerala state short-duration (6-7 months) varieties are now often planted after rice in lowland fields, producing very high yields due to adequate soil moisture and better fertility. This, and the very intensive high input systems used in Tamil Nadu, result in very high yields (average of 22 t/ha) of cassava in India (Nayar *et al.*, 1995).

On-site effects of cassava cultivation on soil fertility

Many people are convinced that cassava production leads to soil degradation, and some governments do not encourage cassava cultivation in the belief that it causes serious erosion and nutrient depletion. In Vietnam, Thai Phien and Nguyen Tu Siem (1996) stated that, "as a direct consequence of planting upland rice and cassava for food self-sufficiency, more than one million ha have become eroded skeleton soils with no value for agriculture or for forestry". Figure 2 shows that after four years of continuous cassava cultivation without fertilizer inputs in Vietnam, yields declined from 19 to about 7 t/ha. However, in the same experiment, yields of upland rice declined from 2.5 t/ha to zero in the same time span. No soil data are available to indicate which crop caused greater nutrient depletion and/or soil degradation, but after four years cassava still produced a reasonable yield while rice produced none. There is little information in the literature on the relative rates of soil degradation and yield decline over time for different crops.

In south Vietnam, Cong Doan Sat and Deturck (1998) determined the physical and chemical characteristics of similar soils (Haplic Acrisols) that had been under continuous forest, rubber, cashew, sugarcane or cassava for many years. Table 6 and Figure 3 summarize their results. The data indicate that long-term cassava cultivation resulted in the lowest levels of organic C and total N (mainly due to frequent and intensive land preparation and weeding); the lowest CEC (associated with a decline in soil organic matter and preferential loss of clay due to erosion), and the lowest levels of K and Mg. P-levels, however, were higher than in cashew or forest, due to cassava's low off-take of P, and some application of P fertilizers to cassava, rubber and sugarcane. Figure 3 shows that continuous cassava cultivation resulted in a high bulk density, low water infiltration rate, low aggregate stability, low clay content and low water holding capacity (not shown). The conclusion is clear: continuous cassava cultivation under these conditions has a definite detrimental effect on both the physical and chemical properties of the soil[13], and is thus unsustainable. Unfortunately, there are no comparisons with other annual food crops, which, like cassava, require intensive and frequent

[13] More recent research also indicates lower microbial activity (Cong Doan Sat and Huang Van Tam, 1999).

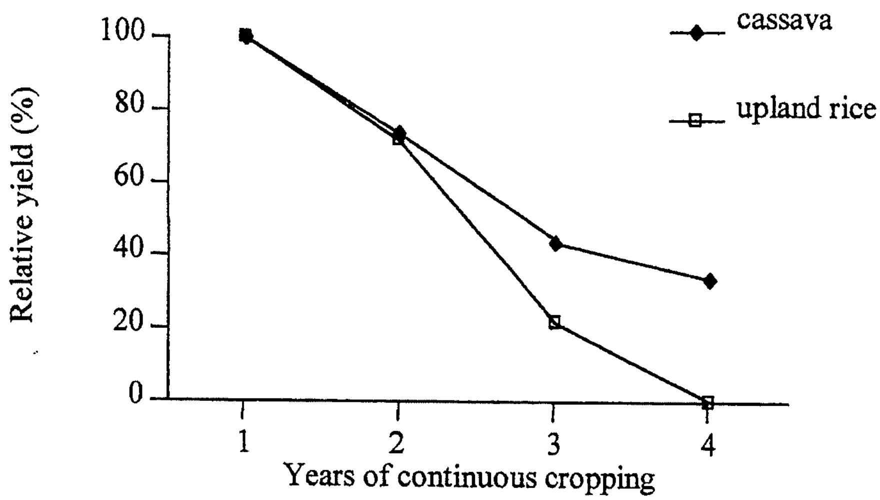


Figure 2. Yield reduction of upland rice and cassava due to fertility decline as a result of continuous cropping without fertilizer application. 100% corresponds to 18.9 t/ha of fresh cassava roots and 2.55 t/ha of rice.
***Source:** adapted from Nguyen Tu Siem, 1992.*

land preparation and weeding, and which leave the soil exposed to the impact of rainfal, leading to erosion during part of the year.

There is no doubt that land clearing and conversion of forest to annual crops often lead to a rapid decline in OM content, in aggregate stability and nutrient supply, as well as a sharp increase in soil losses due to erosion. This decline is mainly due to exposure of the soil surface to high temperatures, leading to more rapid OM decomposition, as well as to the direct impact of rainfall, leading to the breakdown of soil aggregates, surface crusting, and erosion, with preferential losses of OM, clay and soil nutrients in the sediments and runoff. In addition, soil preparation by heavy machinery will increase bulk density and create hard pans, which further aggravates soil degradation. The question, however, remains whether cassava is worse in that respect than other annual crops, like cotton, soybean, maize, upland rice, peanut and mungbean.

Figure 4 is another example of the long-term effect of cassava cultivation on soil productivity in Thailand. In fertilizer trials conducted in different farmers' fields on three soil series since 1955, the yields of cassava decreased from initial levels of 26-28 t/ha to levels of 10-13 t/ha after 20-30 years of cropping without fertilizer inputs. This gradual yield decline was attributed both to nutrient depletion due to removal of nutrients in the harvested roots, as well as erosion. After the conversion of forest to cropland, the cultivation of cassava (or other crops) without nutrient inputs will inevitably result in a decline in soil productivity, even if crops are rotated or fields are fallowed occasionally. Again, the basic question is whether this yield decline observed in cassava is more or less rapid than that observed in other crops grown under similar conditions.

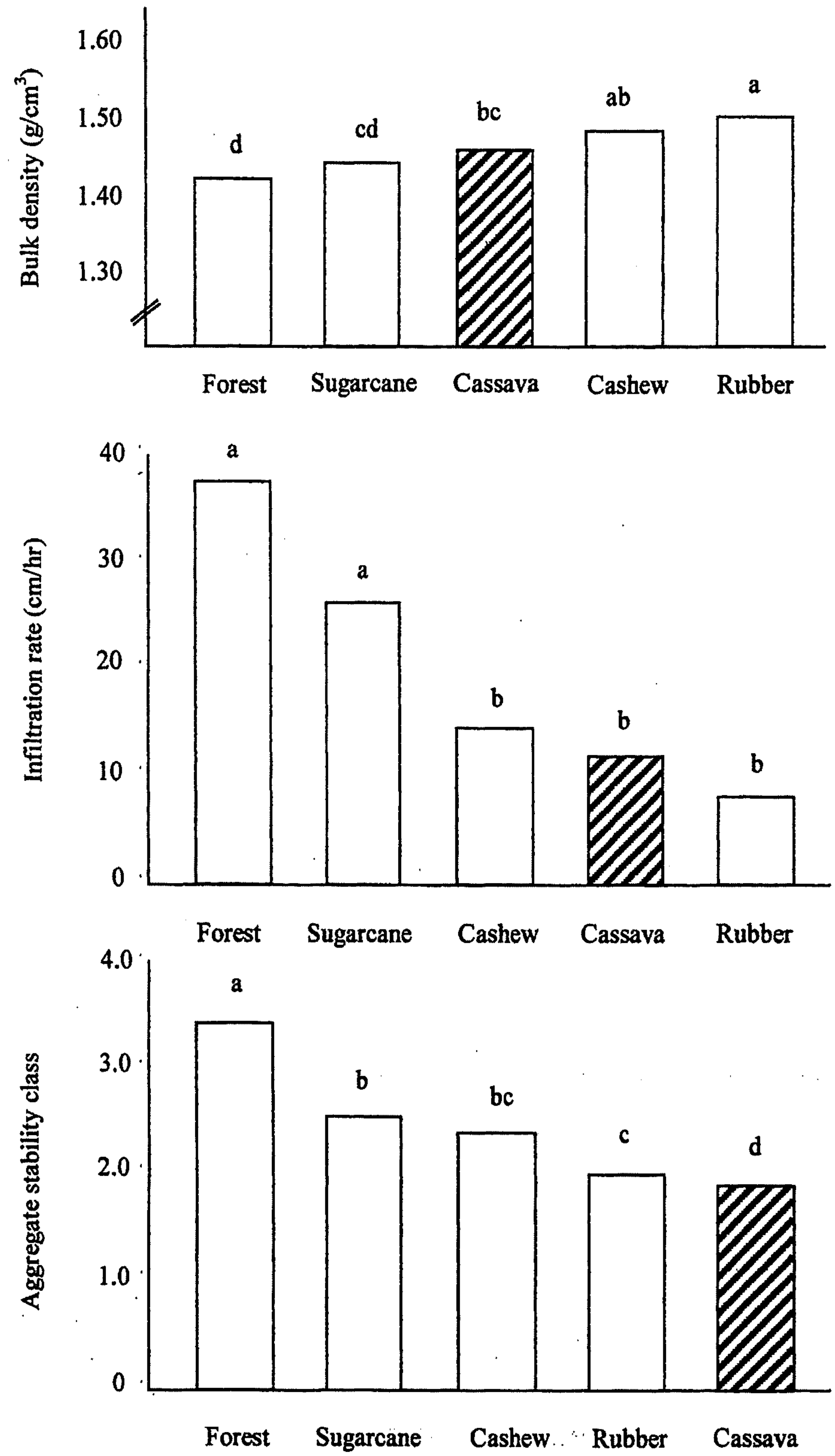


Figure 3. Bulk density (top), infiltration rate (middle) and aggregate stability (bottom) of Haplic Acrisols under different cropping systems in south Vietnam. Values are the average of at least 7 profiles per cropping system and three horizons per profile.
Note: Aggregate class stability: 1 = highly unstable, 2 = unstable,
3 = relatively stable, 4 = stable
***Source:** Cong Doan Sat and Pol Deturck (1998).*

Table 5. Characteristics of cassava cropping systems and cultural practices used in major production zones in Asia.

	China	India		Indonesia		Malaysia	Philippines	Thailand	Vietnam	
		Kerala	Tamil Nadu	Java	Sumatra				North	South
-Cassava area (ha/farm)	0.2-0.4	<0.1	0.5-1.0	0.3-0.5	0.5-1.0	4-500	-	2-3	0.1-0.3	0.2-0.9
-Intercrops	none/peanut	none	none/ vegetables	maize+rice- soybean/peanut	maize	rubber	none/maize	none (95%) maize (5%)	none/peanut	none/maize
-Land preparation	manual/ animal	manual	animal	manual/ animal	animal/ tractor	tractor	animal/ manual	tractor 3disc+7disc	animal/ manual	animal/ manual
-Fertilizer use										
-organic (t/ha)	3-5	10-20	10-20	3-10	low	none	none	little	2-7	0-5
-inorg. (kg $N+P_2O+K_2O$/ha)	some NPK	some	high	N only	medium	>400	little	30-80	0-80	0-60
-Seasonality in planting	Feb-Apr (90%)	Apr-Jun (60%)	Jan-Mar (90%) Sept-Oct	Oct-Dec (90%)	Oct-Dec (90%)	year round	year round	March- May(80%) Sept-Nov	Jan-Mar (70%)	Feb-May (80%) Oct-Nov
-Harvest time	Nov-Jan	Jan-Mar	Oct-Jan	Jul-Sept	Jul-Sept	year round	year round	Oct-Mar	Nov-Jan	Feb-Mar Sept-Oct
-Planting distance (m)	1.0x1.0 0.8x0.8	1.0x1.0	1.0x1.0	1.0x0.8 2.0x0.5	1.0x0.8 2.0x0.5	1.0-1.2x 0.8-1.0	1.0x0.8	0.8x1.2 0.8x0.8	1.0x1.0 0.8x0.8	1.2x0.8 0.8x0.8
-Planting method	Horizontal	vertical	vertical	vertical	vertical	horizontal	horizontal	vertical	horizontal	horizontal
-Weed control	hoe 2-3x	hoe 2-3x	hoe 4-5x	hoe 1-2x	hoe 1-2x	herbicides/ hoe	animal/ hoe 2-3x	hoe 2-3x small tractor/ Paraquat	hoe 2-3x/ animal	hoe 2-3x
-Harvest method	Hand	hand	hand	hand	hand	hand/tractor	hand	hand/ small tractor	hand	hand
-Main varieties	SC205 SC201 SC124	local var. M-4	H-226 local var. H-165	many local varieties	Adira 4	Black Twig	Lakan Golden Yellow	Rayong 1 Rayong 90 Rayong 60 Rayong 5 KU50	Vinh Phu KM60	H34 HL23 KM94
-Labor use (m-days/ha)	120-200	100-120	100-150	75-90	75-80	50-60	60-100	60-70	300-400	130-300
-Variable prod. costs ($/ha)[1)]	240-300	200-300	300-400	70-120	70-120	390-520	300-350	250-350	150-250	115-150
-Fixed costs ($/ha)	-	-	-	30	30	-	-	40	10	10

1) Including family labor, harvest + transport
Source: Hershey et al., 1999.

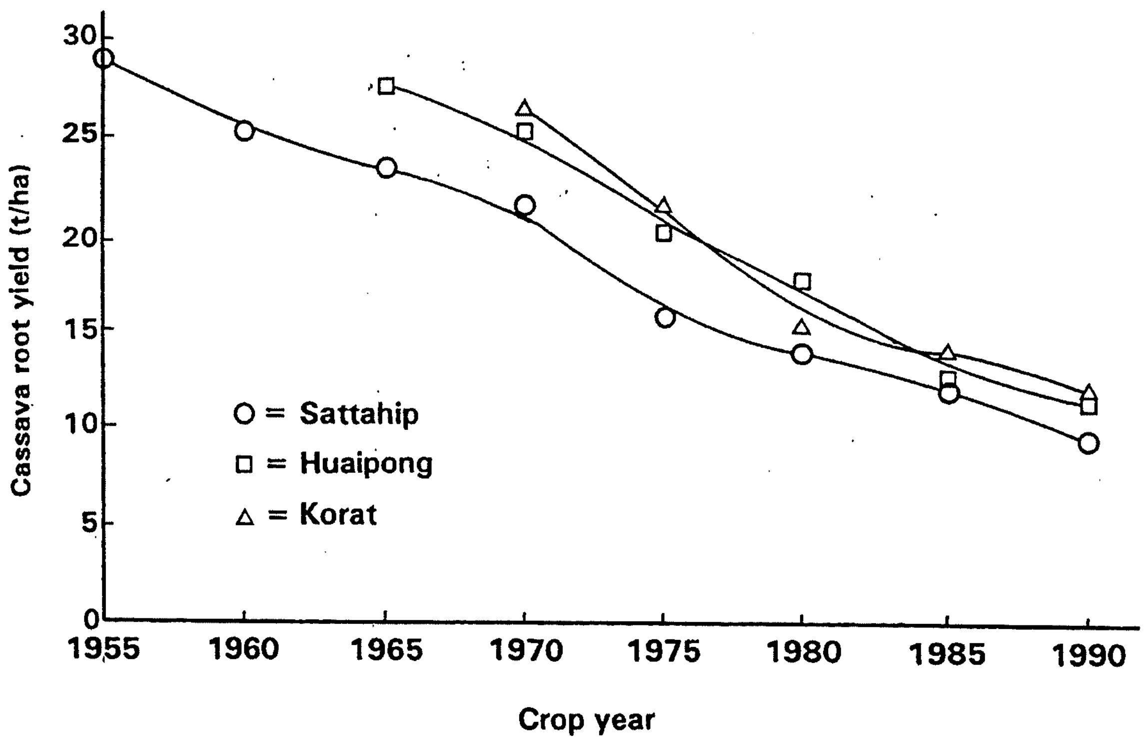


Figure 4. Decline in fresh root yields due to continuous cultivation without fertilizers in three soil Series in Thailand.
Source: *Sittibusaya, 1993.*

Table 6. Chemical properties of various horizons of Haplic Acrisols that have been under different land use in southeastern Vietnam.[1)]

	Forest	Rubber	Sugarcane	Cashew	Cassava	CV (%)
Organic C (%)	1.032 a	0.839 ab	0.796 ab	0.579 ab	0.496 b	44.7
Total N (%)	0.058 a	0.054 ab	0.040 abc	0.032 bc	0.022 c	36.7
Available P (Bray II)(ppm)						
-1st horizon	5.21 b	20.90 a	20.68 a	4.85 b	15.33 ab	37.5
-2nd horizon	2.48 b	7.03 a	7.92 a	3.19 b	5.31 ab	32.6
-3rd horizon	1.57 b	2.83 ab	3.82 a	1.08 ab	3.82 a	44.6
CEC (me/100g)	3.43 a	2.94 a	3.24 a	2.39 ab	1.53 b	27.1
Exch. K (me/100g)						
-1st horizon	0.132 a	0.127 a	0.051 b	0.070 ab	0.060 b	66.3
-2nd horizon	0.073 a	0.046 ab	0.022 b	0.031 ab	0.021 b	75.1
Exch. Mg (me/100g)	0.145 a	0.157 a	0.055 ab	0.046 ab	0.036 b	89.1

[1)] Values are average of 6-10 profiles per cropping system. Within rows data followed by the same letter are not significantly different at 5% level by Tukey's Studentized Range Test.
Source: Cong Doan Sat and Deturck, 1998.

Nutrient removal in the crop harvest

Cassava grows relatively well on poor soils, which may result in a further reduction in soil fertility (Table 6). For that reason the crop has a reputation of removing large amounts of nutrients from the soil, leaving the soil depleted of nutrients and too infertile for further crop production. This may or may not be the case.

Table 7 shows the dry matter (DM) distribution and nutrient content in roots, stems and leaves for cassava harvested in Curvelo, Minas Gerais, Brazil, both in fertilized and non-fertilized plants (Paulo *et al.*, 1983). In both cases, DM in the roots was about 50-55% of that in the total plant, but fertilized plants produced more than twice the root yield of unfertilized plants. Since fertilization not only increased the DM production but also increases the nutrient concentration in the tissue (Table 8), the nutrient content of the total plant and that of the roots were 2-3 times higher in the fertilized compared to the non-fertilized plants. If only roots were harvested and stems and leaves returned to the soil, the removal of nutrients from the field in this experiment was only 51 kg/ha of N, 2.1 kg of P, 20 kg of K, 6 kg of Ca and 3 kg of Mg. In fertilized plants it was 130 kg/ha of N, 9.3 kg of P, 80 kg of K, 15 kg of Ca and 12 kg of Mg. The removal of micronutrients was insignificant. Thus, in poor soils, the total amount of nutrients absorbed and that removed with the root harvest are relatively low when plants are not fertilized, but increase markedly with fertilization. The same has been reported by Howeler and Cadavid (1983) and by Howeler (1991a; 2001).

Table 7. Average dry matter and nutrient content in roots, stems and leaves of two cassava varieties (Riqueza and Branca de Santa Catarina) planted with or without fertilizers in Curvelo, Minas Gerais, Brazil in 1982.

	Dry matter and nutrient content (kg/ha)										
	Dry matter	N	P	K	Ca	Mg	B	Cu	Mn	Zn	Fe
Without fertilizers											
Roots	4,409	51	2.1	20	6	3	0.021	0.012	0.08	0.12	1.84
Stems	3,034	48	1.8	16	39	8	0.043	0.031	0.26	0.05	0.21
Leaves	1,139	45	2.1	14	19	3	0.027	0.009	0.39	0.06	1.55
Total	8,582	144	6.0	50	64	14	0.091	0.052	0.73	0.23	3.60
With fertilizers											
Roots	11,440	130	9.3	80	15	12	0.210	0.020	0.24	0.21	6.75
Stems	7,164	119	6.7	43	81	15	0.036	0.072	1.55	0.08	1.02
Leaves	1,537	91	6.5	13	13	6	0.051	0.011	0.48	0.17	0.15
Total	20,241	340	22.5	136	109	33	0.297	0.103	2.27	0.46	7.92

Source: Paulo M.B. de et al.,1983.

In some countries, notably in northern Vietnam, southern China, Indonesia and India, farmers not only harvest the roots, but also the green leaves to feed cattle or fish, and the stems as fuel wood. In that case, nutrient removal would be 2-3 times higher, as about 60-65% of N, 50-60% of P, 40-50% of K, 85-90% of Ca and 70-80% of Mg are found in stems and leaves (Tables 7 and 9). Sometimes fallen leaves are collected as kindling. Nutrient removal, especially of N and Ca, would be even higher (Howeler, 1985). Thus, it is clear that nutrient removal by cassava depends on the fertility of the soil, the yield levels obtained, and whether only roots or other plant parts are removed from the field. Using data from many sources in the literature, Howeler (2001) calculated an "average" removal per tonne of fresh roots of 2.53 kg/ha of N, 0.37 kg of P, 2.75 kg of K, 0.44 kg of Ca and 0.26 kg of Mg if only roots are removed, but 6.68 kg/ha of N, 0.76 kg of P, 4.87 kg of K, 2.78 kg of Ca and 0.87 kg of Mg if the whole plants are removed (Table 9). If nutrient removal were proportional to yield, an average yield of 15 t/ha of fresh roots would remove "on average" 37 kg N, 6 kg P, 41 kg K,

Table 8. Nutrient concentrations in plant parts of fertilized and unfertilized cassava, cv. MVen 77, at 3-4 months after planting in Carimagua, Colombia.

	Unfertilized			Fertilized		
Plant part	N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
Leaf blades						
Upper	4.57	0.34	1.29	5.19	0.38	1.61
Middle	3.66	0.25	1.18	4.00	0.28	1.36
Lower	3.31	0.21	1.09	3.55	0.24	1.30
Fallen	2.31	0.13	0.50	1.11	0.14	0.54
Petioles						
Upper	1.50	0.17	1.60	1.49	0.17	2.18
Middle	0.70	0.10	1.32	0.84	0.09	1.84
Lower	0.63	0.09	1.35	0.78	0.09	1.69
Fallen	0.54	0.05	0.54	0.69	0.06	0.82
Stems						
Upper	1.64	0.20	1.22	2.31	0.23	2.09
Middle	1.03	0.18	0.87	1.57	0.21	1.26
Lower	0.78	0.21	0.81	1.37	0.28	1.14
Rootlets	1.52	0.15	1.02	1.71	0.19	1.03
Thickened roots	0.42	0.10	0.71	0.88	0.14	1.05

Source: Howeler, 1985.

Table 9. Average nutrient removal (kg) per ton of harvested fresh cassava roots when only the roots or the whole plants are removed at harvest. Calculations are based on data from 14 experiments with root yields ranging from 6 to 65 t/ha. Numbers in parentheses indicate the proportion of each nutrient present in the roots.

Nutrient	Only roots removed		Whole plants removed[1)]
N	2.53	(38%)	6.68
P	0.37	(49%)	0.76
K	2.75	(56%)	4.87
Ca	0.44	(16%)	2.78
Mg	0.26	(30%)	0.87

[1)] Does not include fallen leaves
Source: Howeler, 2001.

6.6 kg Ca and 3.0 kg of Mg. Comparing nutrient removal data reported in the literature by various authors, Howeler (2001) reported that N removal was quite variable but more or less proportional to dry root yield, but that P and K removal increases more than proportionally with an increase in yield. According to the data in Figure 5, a fresh root yield of 15 t/ha would result in the removal of about 40 kg N, 3.5 kg P and 20 kg K/ha, considerably lower for P and K than previously estimated (Howeler, 1981). These relatively low levels of nutrient removal may explain why cassava yields of less than 10 t/ha do not seem to deplete the nutrients in the soil and that those low yields can be sustained for many years without application of fertilizers or manures as long as plant tops are re-incorporated into the soil (see Figure 8B).

It may be concluded that in a cassava root harvest considerable amounts of N and K are removed from the field, while the removal of P, Ca, and Mg is relatively low. The harvest of leaves and stems increases markedly the removal of mainly N and Ca.

Table 10 shows the nutrient removal in the harvested product of cassava and various other crops, calculated both in terms of nutrient removal per ha and per tonne of DM produced (Howeler, 1991a). In spite of a very high average cassava yield of 35.7 t/ha used in these calculations, the removal of N and P by cassava was similar to that of many other crops, while the removal of K was higher than in most other crops. Similar results have been reported by Prevot and Ollagnier (1958) and Amarasiri and Perera (1975). When calculated per tonne of DM produced, cassava removed much less N and P, and less or similar amounts of K compared with most other crops.

Cassava may be highly efficient in absorbing nutrients from poor soils, but the amounts of nutrients removed in the root harvest are rather low compared to other crops, with the possible exception of K. However, if stems and leaves are also removed from the field, then nutrient removal can be quite high and nutrient depletion of the soil can become a serious problem.

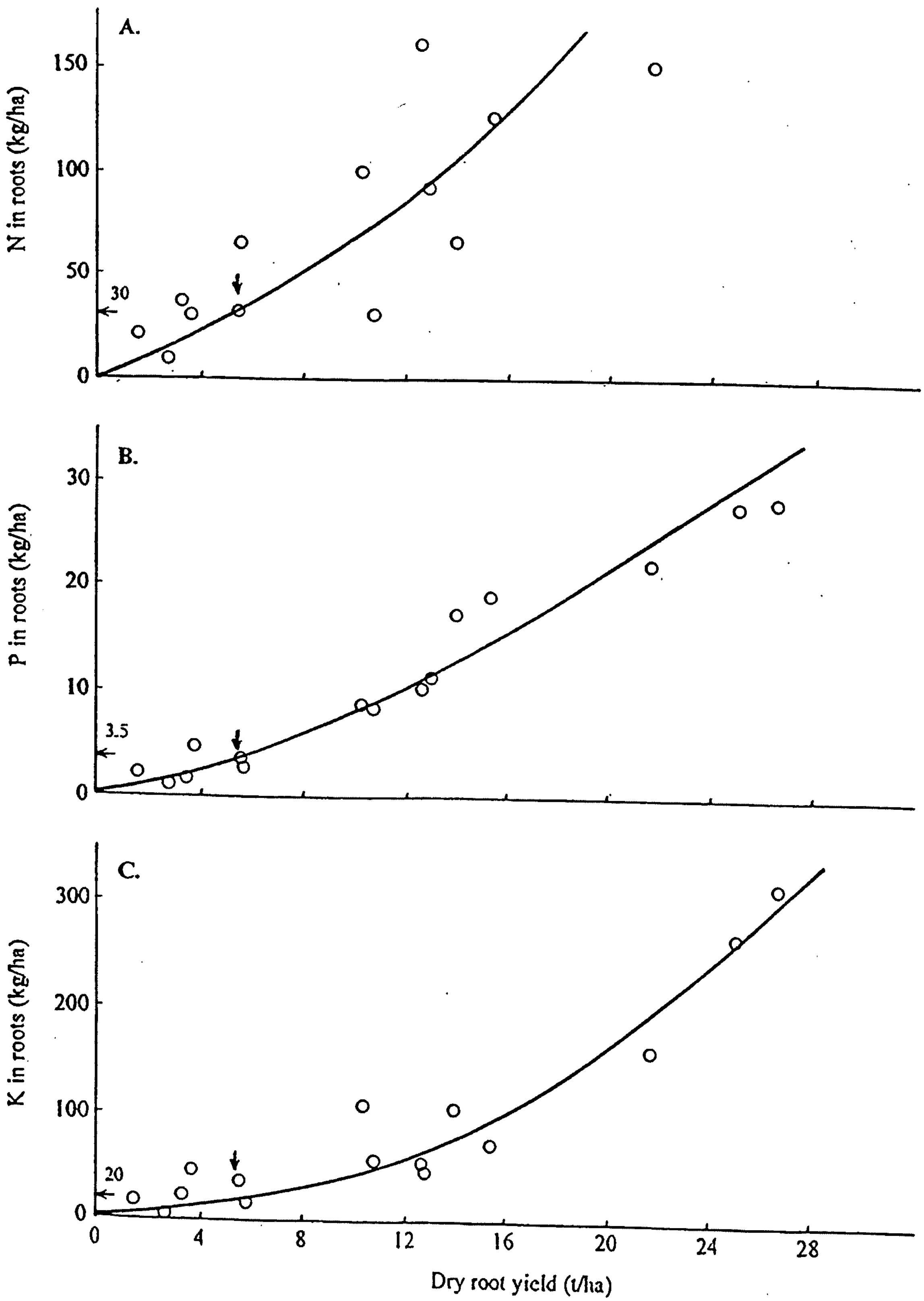


Figure 5. Relation between the N, P and K contents of cassava roots and dry root yield, as reported in the literature. Arrows indicate the approximate nutrient contents corresponding to a fresh root yield of 15 t/ha.
Source: *Howeler, unpublished. (see Appendix 2)*

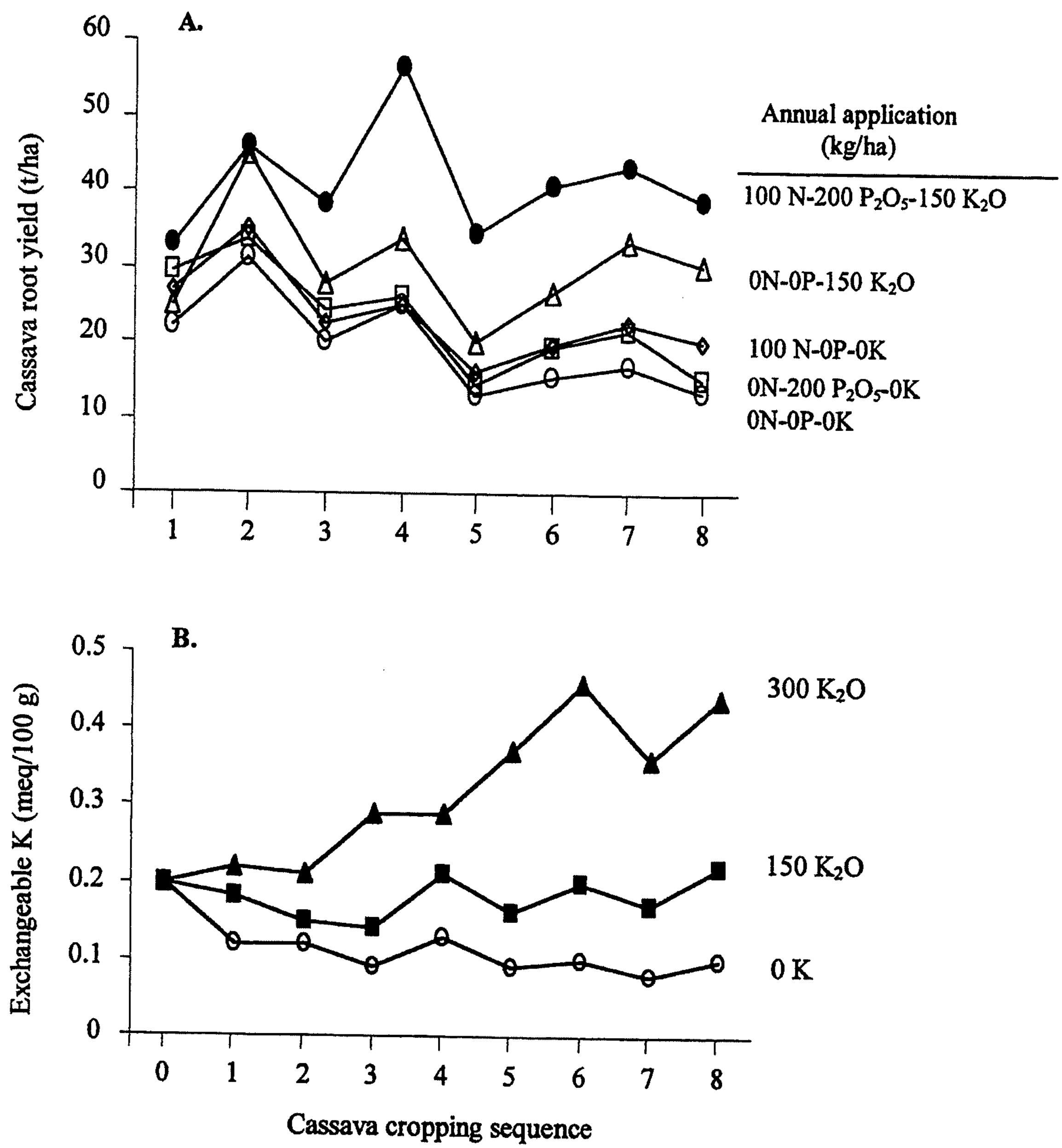


Figure 6. Effect of various levels of annual applications of N, P and K on cassava fresh root yield (A), and on the exchangeable K content of the soil (B) during eight consecutive cropping cycles in a long-term NPK trial conducted in CIAT-Quilicao, Colombia.
Source: *Howeler and Cadavid, 1990.*

Table 10. Average nutrient removal by cassava and various other crops, expressed in both kg/ha and kg/t harvested product, as reported in the literature.

Crop/plant part	Crop yield (t/ha) fresh	Crop yield (t/ha) dry[1)]	Nutrient removal (kg/ha) N	P	K	Nutrient removal (kg/t DM produced) N	P	K
Cassava/fresh roots	35.7	13.53	55	13.2	112	4.5	0.83	6.6
Sweet potato/fresh roots	25.2	5.05	61	13.3	97	12.0	2.63	19.2
Maize/dry grain	6.5	5.56	96	17.4	26	17.3	3.13	4.7
Rice/dry grain	4.6	3.97	60	7.5	13	17.1	2.40	4.1
Wheat/dry grain	2.7	2.32	56	12.0	13	24.1	5.17	5.6
Sorghum/dry grain	3.6	3.10	134	29.0	29	43.3	9.40	9.4
Beans[2)]/dry grain	1.1	0.94	37	3.6	22	39.6	3.83	23.4
Soya/dry grain	1.0	0.86	60	15.3	67	69.8	17.79	77.9
Groundnut/dry pod	1.5	1.29	105	6.5	35	81.4	5.04	27.1
Sugarcane/fresh cane	75.2	19.55	43	20.2	96	2.3	0.91	4.4
Tobacco/dry leaves	2.5	2.10	52	6.1	105	24.8	2.90	50.0

[1)] Assuming cassava to have 38% DM, grain 86%, sweet potato 20%, sugarcane 26%, dry tobacco leaves 84%.
[2)] *Phaseolus vulgaris*
Source: Howeler, 1991a.

Yield trends with and without fertilizer application

Figures 2 and 4 show the effect of continuous cassava production on yield in the absence of fertilizers. Figure 6A shows the long-term effect when various levels of nutrients were applied annually during eight years of cropping on an Andept of volcanic origin in CIAT-Quilichao, Colombia. Without fertilizer application, yields declined gradually from about 25 to 14 t/ha. With applications of only N or P a similar yield decline was observed. But when K or NPK were applied at sufficiently high rates (100 kg N, 200 P_2O_5 and 150 K_2O/ha) very high yields of 30-40 t/ha could be sustained, while the original level of exchangeable K could be maintained (Figure 6B). Higher rates of fertilization had no beneficial effect on cassava yields, but increased the P and K levels in the soil (Howeler and Cadavid, 1990).

Figure 7 shows similar results in a long-term fertility trial conducted on a sandy loam Ultisol in Khon Kaen, Thailand. In the first year of cropping yields were high (around 30 t/ha), and there was no response to fertilization. In the second year yields dropped precipitously to 10-15 t/ha in those treatments without K. With K, yields dropped to about 20 t/ha. In subsequent years, when no K was applied, the yields further declined to levels of 5-6 t/ha. With K application, even without any P, yields could be maintained between 20 and 25 t/ha for 19 years. Like in the case of Quilichao-Colombia (Figure 6), K became the most crucial nutrient for maintaining long-term productivity of cassava soils. The importance of K application to cassava for the maintenance of long-term soil productivity has also been observed in both northern and southern Vietnam (Nguyen Huu Hy *et al.*, 1998), in three locations of China (Zhang Weite *et al.*, 1998), as well as in southern Sumatra of Indonesia (Wargiono *et al.*, 1998). The importance of K application for cassava and several other crops, like sweet-

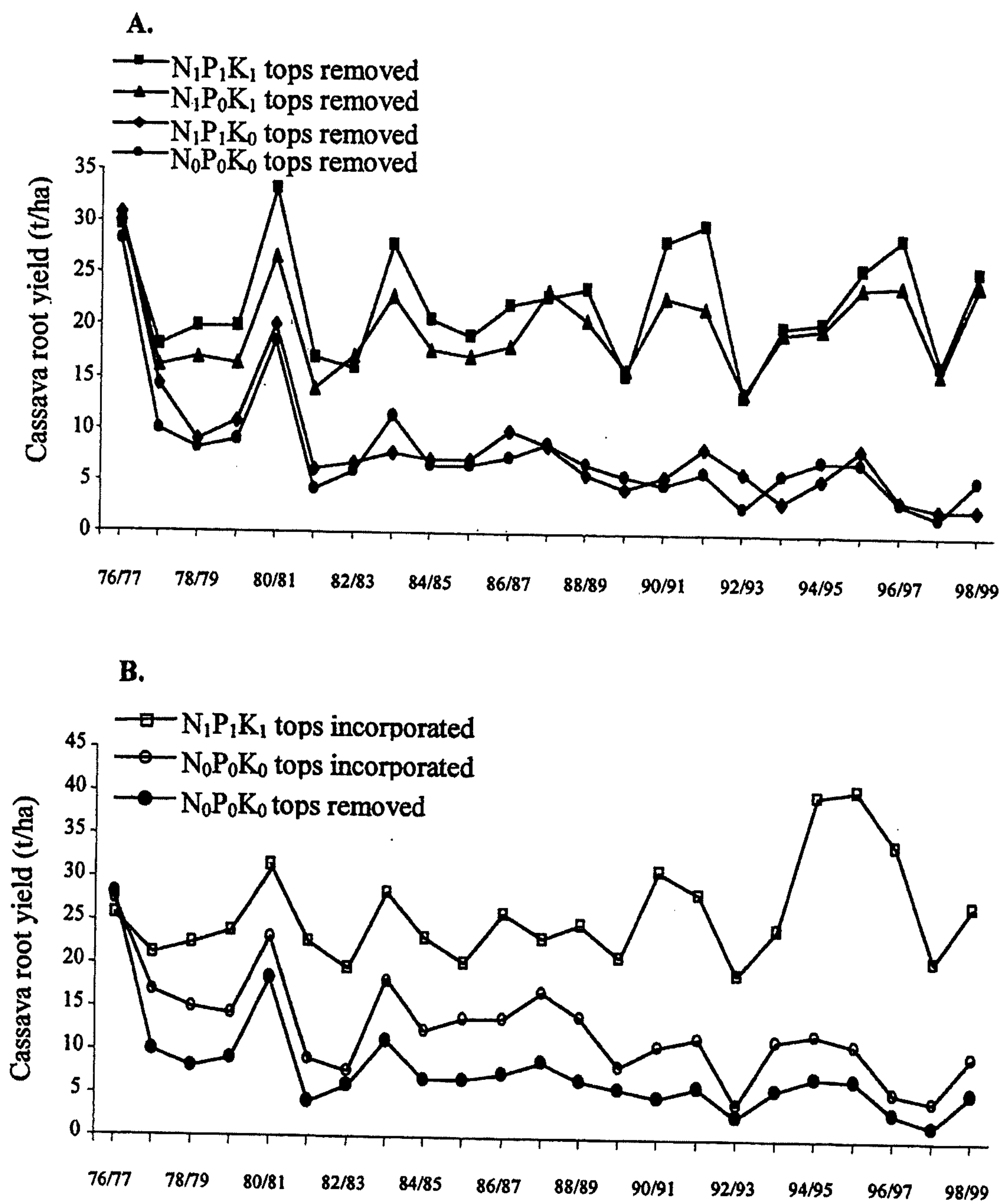


Figure 7. Effects of annual application of various combinations of NPK (top) and crop residue management (bottom) on cassava yield during 23 consecutive crops grown in Khon Kaen, Thailand, from 1977 to 1999.
***Source:** C. Nakviroj and K. Paisancharoen, DOA, Bangkok. (personal communication)*

potato, banana, sugarcane, pineapple and oil palm, is due to the relatively high off-take of K in the harvested products of these crops.

Figure 7B, for the same long-term fertilizer trial in Khon Kaen, also shows that if plant tops (leaves and stems) were reincorporated into the soil after each harvest, nutrient depletion was much less severe, and reasonable yields of 10-15 t/ha could be maintained over 19 years of continuous cropping without any outside nutrient input. This clearly indicates the importance of incorporating stems and leaves into the soil to prevent serious nutrient depletion.

Cassava is drought tolerant because it has the ability to regulate its water consumption by closing its stomata during periods of drought, so as to prevent excessive water use (El-Sharkawy, 1993); this allows slow but continuous growth without death of the plant until growth accelerates again when soil moisture conditions improve. Similarly, *cassava adjusts its rate of growth to the nutrient supply of the soil, maintaining a level of productivity that can be sustained by the nutrient-supplying power of the soil. When fertility conditions improve, cassava responds quickly with increased growth and yield.*

Nutrient balances

When we know the amount of nutrients that enter and leave the system, we can calculate the balance for each nutrient and determine whether this balance is positive (leading to accumulation), or negative (leading to depletion).

Table 11 shows a nutrient balance for cassava production in various regions of Vietnam, using officially published yield data for each region for 1991/92. The removal of N, P and K, when both roots and plant tops are removed from the field (as commonly practiced in Vietnam), was calculated from these yield data and "average" nutrient removal data shown in Table 9. Nutrients applied were calculated from the average fertilizer and manure input data obtained from over 1000 questionnaires in a cassava production survey conducted in 20 provinces in 1990/91 (Pham Van Bien *et al.*, 1996). Finally, the nutrient balances were calculated by subtracting the outputs from the inputs. The results show that there was a positive P balance in four of the six regions, a positive N balance in three regions, and a positive K balance in only two regions. In four regions, the outflows of K were greater than the input, even when other losses of K, such as by leaching, erosion and runoff, were not considered. Thus, in most cassava growing areas of Vietnam, farmers are applying too much P but not enough K for the needs of the crop, resulting in a downward trend in soil fertility (see Table 6) and a decline in soil productivity. This is at least a partial explanation for the low cassava yields in Vietnam and the general perception that cassava is a soil degrading crop.

On-site effects of cassava cultivation and soil erosion on the environment

Because cassava is easy to grow and does not require intensive land preparation and a smooth seed bed, the crop is often grown on steep hillsides. These hillsides are often already depleted and eroded by production of other crops, and cassava may be the only crop that will still grow on the highly infertile and acid soils. When cassava is grown on steep slopes, or even on gentle but long slopes (like in Thailand), runoff and erosion can be a problem. The question often asked is whether cassava is the cause of severe erosion, or merely the result of erosion, as it is still capable of producing some yield on poor eroded soils where other crops would fail. In other words, does the cultivation of cassava result in more erosion than the cultivation of other crops?

Table 11. Nutrient removal and application in the production of cassava in various regions of Vietnam in 1991/92.

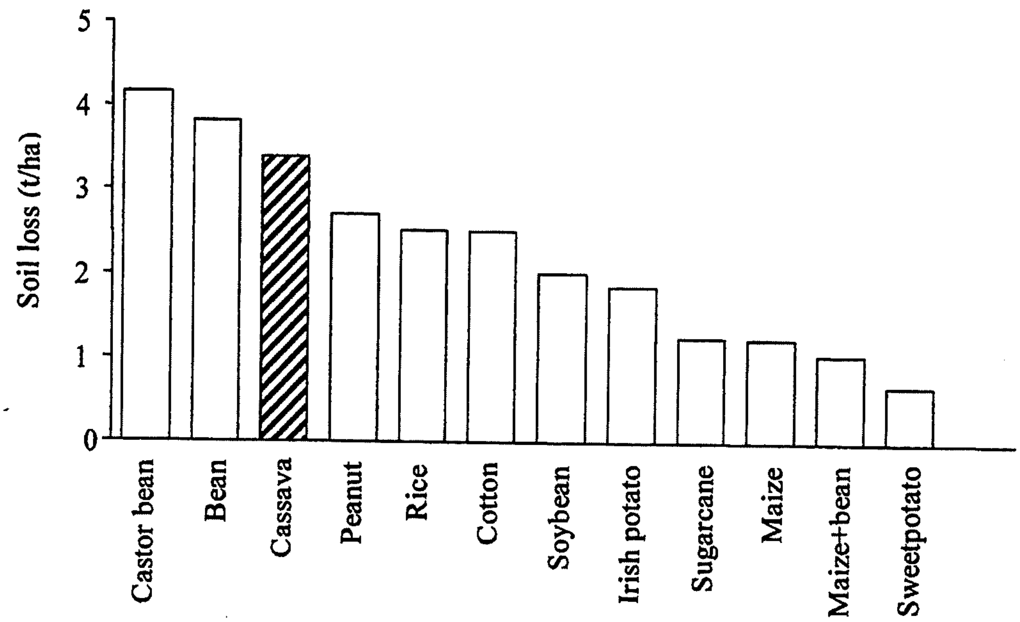
	Cassava root yield (t/ha)	Nutrient removal (kg/ha)[1]			Nutrients applied (kg/ha)[2]			Nutrient balance (kg/ha)[3]		
		N	P[4]	K[4]	N	P	K	N	P	K
Total Vietnam	9.04	60.4	6.9	44.0	47.7	31.3	35.2	-12.7	24.4	-8.8
North Vietnam	8.61	57.5	6.5	41.9	50.1	42.1	47.2	-7.4	35.6	5.3
-North Mountainous Region	9.19	61.4	7.0	44.8	28.7	23.0	23.5	-32.7	16.0	-21.3
-Red River Delta	8.66	57.8	6.6	42.2	86.6	69.1	96.4	28.8	62.5	54.2
-North Central Coast	7.30	48.8	5.5	35.6	76.9	70.2	66.8	28.1	64.7	31.2
South Vietnam	9.60	64.1	7.3	56.0	45.4	22.2	25.1	-18.7	14.9	-21.7
-South Central Coast	8.66	57.8	6.6	50.5	69.3	40.0	41.5	11.5	33.4	-0.7
-Central Highlands	7.69	51.4	5.8	44.8	5.2	1.4	1.2	-46.2	-4.4	-36.3
-Southeastern Region	13.29	88.8	10.1	77.5	33.4	8.8	15.5	-55.4	-1.3	-49.2

[1] Assuming all plant parts are removed from the field and nutrient removal per ton of fresh roots harvested is: 6.68 kg N, 0.76 kg P and 4.87 kg K (Table 9)
[2] Nutrients applied as organic manures and chemical fertilizers
[3] Nutrient balance = nutrients applied – nutrients removed in harvested products
[4] P and K in elemental form

Source: Howeler et al., 2001

Comparison of cassava to other crops

Figure 8 shows a summary by Quintiliano *et al.* (1961) of the results of 48 erosion trials conducted in four experiment stations in Sao Paulo state of Brazil from 1943 to 1959, comparing the effect of different crops and management practices on soil loss by erosion and on runoff (see Appendix 2 for more details). Figure 8 shows that highest soil losses and runoff were observed in castor bean, common bean (*Phaseolus vulgaris*) and cassava (33.5 t/ha of soil loss and 11.4% of rainfall lost as runoff), followed by peanut, rice, cotton, soybean, potato, sugarcane, maize and sweetpotato. Using the relative soil loss as the criterion, with castor bean considered 100, then cassava would have an index of 83, below that of beans (92), but higher than peanut (64), rice (60), cotton (60), soybean (48), sugarcane (30), maize (29) and sweetpotato (16).



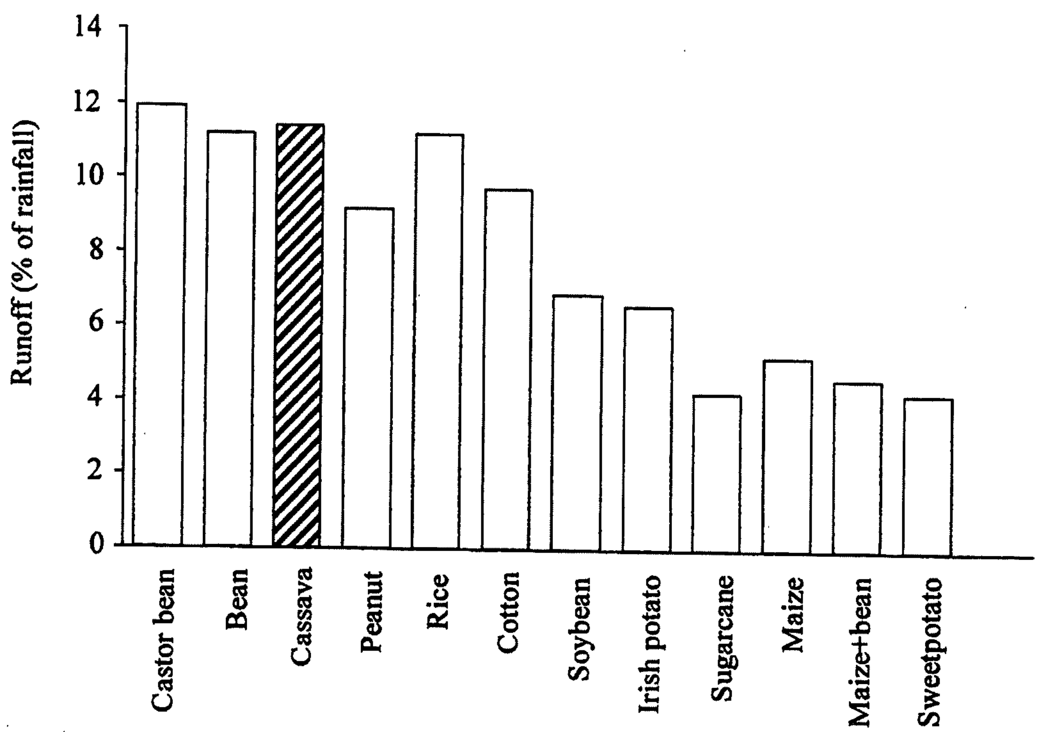


Figure 8. Effect of crops on annual soil loss by erosion (top) and on runoff (bottom). Data are average values (corrected for a standard annual rainfall of 1,300 mm) from about 48 experiments conducted from 1943 to 1959 on sandy, clayey and Terra roxa soils with slopes of 8.5-12.8%.
***Source:** Quintiliano et al., 1961.*

In other trials conducted for ten years on 12% slope on a red-yellow Podzolic soil in Pernambuco, Brazil, Margolis and Campos Filho (1981) reported that cassava on average produced an annual soil loss of 11.0 t/ha, compared with 8.3 t/ha for cotton, 3.0 for maize, 2.8 for velvet bean (*Mucuna* sp.) and 0.4 t/ha for guinea grass (*Panicum maximum*), while soil loss on a bare plot was 59.9 t/ha. Although annual soil losses were much lower than those reported by Quintiliano *et al.* (1961), crops are listed in a similar order.

Table 12 shows similar data for soil losses in eight crops planted during four years on 7% slope in Sri Racha, Thailand (Putthacharoen *et al.*, 1998). By far, highest levels of erosion were observed in cassava for root production (planted at 1.0 x 1.0 m), followed by cassava for forage production (planted at 0.5 x 0.5 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 tonnes of soil were lost for every tonne of roots produced. These are extremely high rates of erosion on a slope of only 7%.

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

	No. of crop cycles	First Period (22 months)	Second period (28 months)	Total (50 months)
Cassava for root production	4	142.8 a	168.5 a	311.3
Cassava for forage production	2	68.8 b	138.5 ab	207.3
Maize	5	28.5 d	35.5 cd	64.0
Sorghum	5	42.9 c	46.1 cd	89.0
Peanut	5	37.6 cd	36.2 cd	73.8
Mungbean	6	70.9 b	55.3 cd	126.2
Pineapple[1)]	2	31.4 cd	21.3 d	52.7
Sugarcane[1)]	2	-	94.0 bc	-
F-test		**	**	
cv (%)		11.4	42.7	

[1)] Second cycle is ratoon crop; sugarcane only during second 28-month period
Source: Putthacharoen et al., 1998.

Erosion losses for cassava in the Thai study were much higher than those of other crops mainly because cassava was planted at a rather wide spacing while initial plant growth was slow, leaving much soil exposed to the direct impact of rainfall during 3-4 months after planting and before the canopy closed. In contrast, the other annual food crops were planted at much higher population densities (50,000-100,000 plants/ha) and had a faster initial growth. Moreover, these row crops were planted along contour lines, which helps considerably in reducing runoff and erosion. Except for mungbean, which was planted six times in four years, all other food crops could be planted only once a year due to the

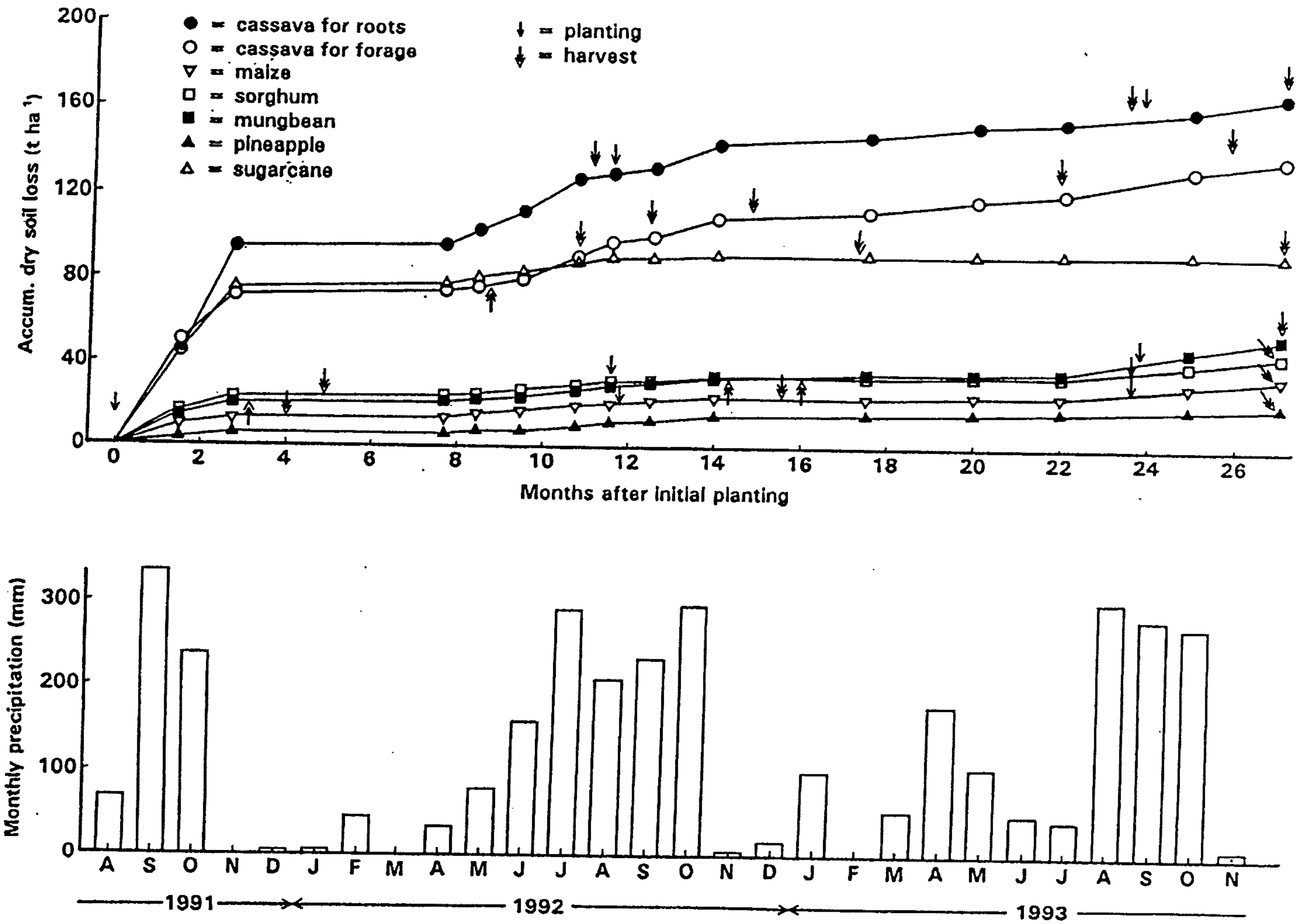


Figure 9. Accumulative dry soil loss due to erosion in various crops grown during a 27 month period on 7% slope in Sri Racha Thailand, from 1991 to 1993. Arrows indicate time of planting and harvest. Rainfall distribution is shown below. ***Source:*** *Putthacharoen et al., 1998.*

relatively short (6 month) rainy season in Thailand. Once harvested, the fields remained in weeds with crop residues protecting the soil from further erosion (Figure 9) (Putthacharoen *et al.*, 1998).

In regions with a longer wet season it is often possible to plant short-cycle food crops, such as maize, rice, soybean, mungbean and peanut, twice a year. In that case, because of more frequent land preparation and weeding soil losses tend to increase. Comparing one crop of cassava with two successive crops of maize, soybean, peanut and a rice-soybean rotation, Wargiono *et al.* (1998) reported that annual soil losses for cassava were similar to those obtained with two successive crops of soybean, slightly higher than the rice-soybean rotation or two crops of maize, and about twice as high as that of two crops of peanut.

Sheng (1982) reported that in Taiwan, with 2500 mm annual rainfall and on slopes of 20-52%, erosion in cassava was 128 t/ha, compared with 62 for pineapple, 92 for banana, 172 for sweetpotato and 208 t/ha for sorghum, peanut, sweetpotato, soybean and maize grown in rotation. In that case, cassava cultivation resulted in less erosion than the growing of several short-cycle crops in rotation during the same year.

Finally, when four successive crops of beans (*Phaseolus vulgasis*) were grown on 15% and 30% slope in Popayan, Cauca, Colombia, during the same 17-month period as one crop of cassava[14], soil losses for beans in both trials were about four times higher than for cassava, due to the frequent land preparation and weeding required for the beans (Howeler, 1987; 1991a). Once the cassava canopy was well established, runoff and erosion losses were greatly diminished; this was also reported by Tongglum *et al.* (1992), Howeler (1995), Tian *et al.* (1995) and Wargiono *et al.* (1995, 1998).

While slow initial growth and the need for wide plant spacing are intrinsic characteristics of the crop, they can be mitigated against somewhat by planting at a closer spacing, by selecting more vigorous varieties, and by enhancing early growth through fertilizer application. All these have been shown to markedly reduce erosion (see below).

Cultivation of cassava, in general, causes more erosion than that of other annual crops grown under similar conditions, especially if those other crops are planted only once a year. The high levels of erosion observed in cassava fields are due to the wide plant spacings used and the slow initial growth of the crop.

<u>Crop (C) factor in the Universal Soil Loss Equation</u>

Another way to compare crops or land use systems in terms of their effect on soil erosion is to calculate the C-factor used in the Universal Soil Loss Equation (USLE), as suggested by Wishmeier (1960). In this methodology erosion in a particular crop is measured on (or corrected to) a standard runoff plot of 22 m length and a slope of 9%, and compared with soil losses on a similar but bare plot. The latter is given a value of 1.0, while the C-factor of the crop is a fraction thereof in proportion to the soil losses measured in the crop *versus* that on bare (tilled and weed-free) soil.

[14] Due to the year-round low temperature at about 1800 masl, cassava grew slowly and required 17 months to produce a reasonable yield.

In order to put the effect of cassava cultivation on erosion in perspective, Table 13 summarizes C-value data from four sources in the literature. As the data indicate, there is no doubt that natural or planted forests and natural or well-managed grasslands protect the soil better and cause less erosion than annual crops. The perennial plantation crops and fruit trees, like oil palm, cacao, coffee, cashew, mango, jackfruit and bananas have C-values of 0.1-0.3, which is not too different from some annual crops like upland rice or moderately grazed pastures. Other annual crops, like maize, sorghum, peanut, soybean, cotton and tobacco seem to cause slightly more erosion than pineapple, but less erosion than cassava. Cassava has a very wide range of C-values, which indicates that erosion depends mainly on the way the crop is managed, such as plant spacing, fertilizer application or ridging. Leihner *et al.* (1996) actually reported very low C-values, comparable to those of well-managed range land, when forage legumes were grown as a ground cover under cassava. While highly sustainable, this practice is seldom economically viable as the cover crops compete strongly with cassava, resulting in very low cassava yields (see below).

According to the C-values reported in the literature, cassava is indeed a crop that can cause severe erosion, but the level of soil loss is highly variable, depending on the management of the crop.

<u>Other factors determining soil loss by water erosion</u>

According to the USLE, soil loss by erosion is a function of the erosivity of the rainfall, the erodability of the soil, the length and gradient of the slope, the crop (C-factor) and management (P-factor). Farmers make the choice of crop and decide about its management; they may also determine to some extent the slope length and gradient by selecting the site of planting within the boundaries of their farm, or they can change the length and slope by contour barriers or terracing.

Table 14 shows average dry soil losses measured in cassava erosion control experiments in seven countries. Even though slope gradients were greatest in Colombia, soil losses were relatively low due to well-aggregated high-OM soils. Erosion losses were highest in Hainan island of China due to high intensity rains in the early part of the growing season when cassava plants grow slowly because of low temperatures in spring. Thus, the extent of erosion is determined by many factors that are beyond the control of farmers.

<u>Nutrient losses in eroded sediments and runoff</u>

Little information exists about the amounts of nutrients lost in eroded sediments and runoff. In most cases where sediments have been analyzed, results are reported as total N (organic + inorganic N), available P and exchangeable K, Ca and Mg. The total loss of P, K, Ca and Mg in the sediment could be an order of magnitude higher than the "available" or "exchangeable" fractions reported. Table 15 shows results from cassava experiments conducted in Thailand and Colombia. Nutrient losses were a direct function of the amount of soil eroded: practices that reduced erosion automatically reduced nutrient losses. N losses ranged from 4 to 37 kg/ha, while exchangeable K and Mg losses ranged from 0.13 to 5.1 and from 0.1 to 5.4 kg/ha, respectively. Available P losses were considerably lower, ranging from 0.02 to 2.2 kg/ha. As mentioned above, total nutrient losses are considerably higher but no data are available from cassava fields.

Table 13. C-values for various land uses and crops calculated by the Universal Soil Loss Equation, as reported by four sources in the literature.

Vegetative Cover/ Crop	C-value 1)	2)	3)	4)
Forest				
Primary forest (with dense undergrowth)	0.001	0.001		
Second-growth forest with good undergrowth and high mulch cover	0.003			
Second-growth forest with patches of shrubs and plantation crops of five years or more	0.006			
Industrial Tree Plantations				
Benguet pine with high mulch cover	0.007			
Mahogany, Narra, eight years or more with good undergrowth	0.01-0.05			
Mixed stand of industrial tree plantation species, eight years or more	0.07			
Agroforesty Tree Species				
Mixed stand of agroforestry species, five years or more with good cover	0.15			
Coconuts, with annual crops as intercrop	0.1-0.3			
Leucaena leucocephala, newly cut for leaf meal or charcoal	0.3			
Cashew, mango and jackfruit, less than three years, without intercrop and with ring weeding	0.25			
Oil palm, coffee, cacao with cover crops		0.1-0.3		
Grasslands				
Imperata or thermeda grassland, well established and undisturbed, with shrub	0.007			
Shrubs with patches or open, disturbed grasslands	0.15			
Well-managed rangeland, cover of fast development, ungrazed two years or more	0.01-0.05			
Savanah or pasture without grazing		0.01		
Grassland, moderately grazed, burned occasionally	0.2-0.4			
Overgrazed grasslands, burned regularly	0.4-0.9			
Guinea grass (*Panicum maximum*)			0.01	
Covercrops/green manures				
Rapidly growing cover crop		0.1		
Velvet bean (*Mucuna sp*)			0.05	
Annual Cash Crops				
Maize, sorghum	0.3-0.6	0.3-0.9	0.05	
Rice	0.1-0.2	0.1-0.2		
Peanut, mungbean, soybean	0.3-0.5	0.4-0.8		
Cotton, tobacco	0.4-0.6	0.5	0.14	
Pineapple	0.2-0.5			
Bananas	0.1-0.3			
Diversified crops	0.2-0.4			
New kaingin areas, diversified crops	0.3			
Old kaingin areas, diversified crops	0.8			
Cassava monoculture		*0.2-0.8*	*0.18*	
Cassava with well-established leguminous ground cover				*0.01-0.02*
Crops with thick layer of mulch		0.001		
Other				
Built-up rural areas, with home gardens	0.2			
Bare soil	1.0	1.0	1.0	1.0

Sources: 1)Data from David, 1987, for watersheds in the Philippines.
2)Data from Roose, 1977.
3)Data from Margolis and Campos Filho, 1981, for Pernambuco, Brazil.
4)Data from Leihner et al., 1996, for Cauca, Colombia.

Table 14. Average dry soil loss due to erosion measured in cassava trials in various countries of Asia and in Colombia, S. America.

Country	Site	Annual rainfall (mm)	Slope (%)	Soil texture	Organic matter (%)	Dry soil loss (t/ha)
China	Shifeng, Hainan	2000	8	sandy clay loam	2.4	154
	SCATC, Hainan	1800	15	clay	1.8	128
	SCATC, Hainan	1800	25	clay	2.0	144
	Nanning, Guangxi	1405	12	clay	1.7	16
Indonesia	Malang, E. Java	2052	8	clay	1.5	42
	Tamanbogo, Lampung	2180	5	clay	1.8	47
	Umas Jaya, Lampung	2180	3	clay	2.7	19
Malaysia	MARDI, Serdang	2300	6	clay	-	10
Philippines	Baybay, Leyte	2000	25	clay loam	1.9	54
Thailand	Sri Racha, Chonburi	1300	8	sandy loam	0.6	15
	Sri Racha, farmer's field	1300	8	sandy loam	0.5	18
	Pluak Daeng, Rayong	1400	5	sandy loam	0.7	21
Vietnam	Agric. Col.#3, Thai Nguyen	2100	5	sandy clay loam	1.6	23
	Agric. Col.#3, Thai Nguyen	2100	10	sandy clay loam	1.6	39
	Agric. Col.#3, Thai Nguyen	2100	15	sandy clay loam	1.6	105
Colombia	Mondomito, Cauca	2130	27	clay	4.7	45
	Mondomito, Cauca	2130	30	clay	-	2
	Las Pilas, Cauca	2130	40	clay loam	11.0	3
	Agua Blanca, Cauca	2130	42	clay loam	5.1	18
	Popayan, Cauca	2500	15	loam	24.8	15
	Popayan, Cauca	2500	25	loam	24.8	7

Source: Adapted from Howeler, 1994.

Table 15. Nutrients in sediments eroded from cassava plots with various treatments in Thailand and Colombia.

Location and treatments	Dry soil loss (t/ha/year)	Nutrients in sediements (kg/ha/year) N[1)	P[2)]	K[2)]	Mg[2)]
Cassava on 7% slope in Sriracha, Thailand[3)]	71.4	37.1	2.18	5.15	5.35
Cassava planted on 7-13% slope in Quilichao, Colombia[4)]	5.1	11.5	0.16	0.45	0.45
Cassava with leguminous cover crops in Quilichao, Colombia[4)]	10.6	24.0	0.24	0.97	0.81
Cassava with grass hedgerows in Quilichao, Colombia[4)]	2.7	5.8	0.06	0.22	0.24
Cassava planted on 12-20% slope in Mondomo, Colombia[4)]	5.2	13.3	1.09	0.45	0.36
Cassava with leguminous cover crops in Mondomo, Colombia[4)]	2.7	6.5	0.04	0.24	0.20
Cassava with grass hedgerows in Mondomo, Colombia[4)]	1.5	3.5	0.02	0.13	0.10

[1)] Total N
[2)] Available P, and exchangeable K and Mg
[3)] *Source: Putthacharoen et al., 1998.*
[4)] *Source: Ruppenthal et al., 1997.*

Phommasack *et al.* (1995, 1996) reported total nutrient losses in sediments and runoff from maize fields on 25-35% slope in Luang Prabang, Laos. In the second year of cropping, N, P and K losses in the eroded sediments (9.2 t/ha) were 53.9, 9.3 and 24.0 kg/ha, respectively, while those in the runoff (2,120 m^3/ha) were 2.3, 0.9 and 26.1 kg/ha, respectively. Although in this case soil loss and runoff were not particularly high, nutrient losses in the sediments and runoff were substantial, especially that of N and K in the sediments and K in the runoff.

On-site effect of erosion on productivity

The loss of surface soil due to erosion can have serious on-site effects on the productivity of the land. This is seldom uniform across the landscape as soil is lost mainly on the steeper parts of the hillside but may be deposited at the bottom of the hill (Figure 10). The effect of topsoil loss on crop productivity depends on the crop, the depths of soil above bedrock, and the chemical and physical characteristics of the top- and subsoil. Loss by erosion of OM and nutrients, normally concentrated in the topsoil, will affect the productivity of almost all crops; but in soils with a very acid subsoil, loss of topsoil by erosion can limit root penetration and markedly reduce the productivity of those crops susceptible to soil acidity and high levels of Al. Lal (1976) reported that the loss of 10 cm of topsoil reduced the yields of maize and cowpea by about half. Figure 11 shows that in Mondomo, Colombia, the yield of cassava was also reduced to less than half when planted in eroded *versus* non-eroded soil. For the same region in Colombia, Howeler and Cadavid (1984) reported that without P application

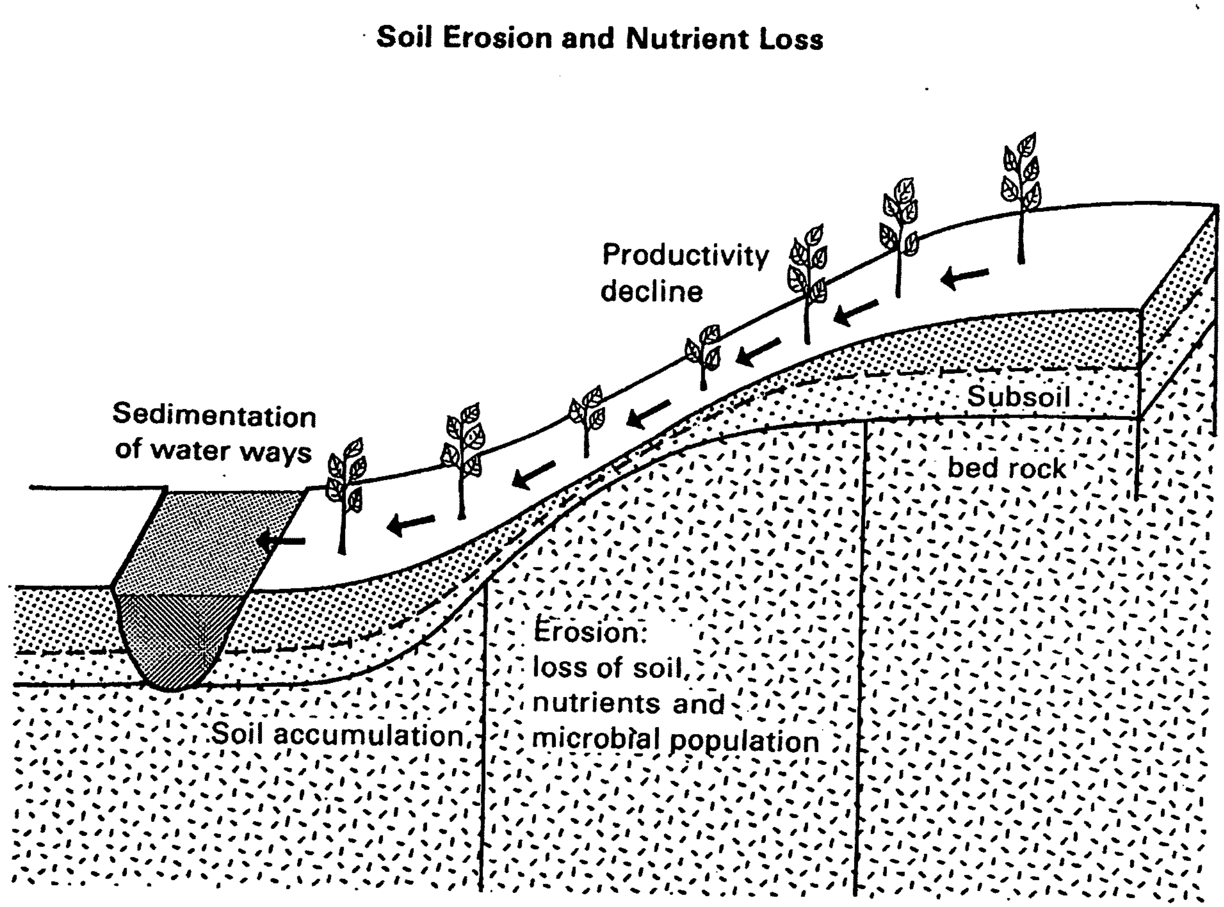


Figure 10. Conceptual representation of the differential effect of erosion in various parts of the landscape on soil depth, nutrient distribution and growth of crops.

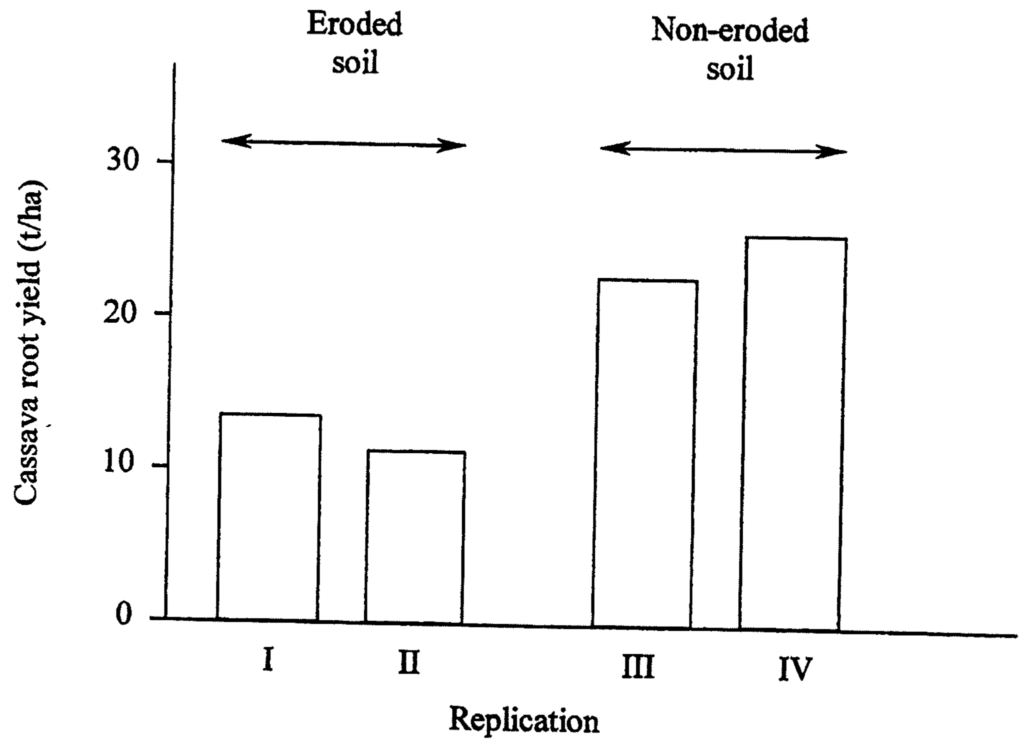


Figure 11. The average yield of 18 cassava varieties planted in two replications on an eroded slope and two replications on an adjacent non-eroded flat area in 1983/84 in Mondomo, Cauca, Colombia.
***Source:** Howeler, 1986.*

cassava yields were 7.7 t/ha in eroded and 22.6 t/ha in nearby non-eroded soil; with application of 115 kg P_2O_5/ha cassava yields were 18.3 and 30.0 t/ha in eroded and non-eroded soil, respectively. *Thus, topsoil loss due to erosion can seriously reduce the productivity of the land. Even with the application of high rates of fertilizers, the productivity cannot easily be restored.*

Off-site effects of cassava cultivation and soil erosion on the environment

Off-site effects of agricultural activities -- of which cassava production may be one, but seldom the only, component -- are defined as the indirect effects of the activities on areas outside the immediate production area. Off-site effects may be in the neighbor's field, but usually refer to impact on the rest of the watershed, especially the effect of eroded soil on water quality and sedimentation. The latter may result in additional maintenance and dredging costs of irrigation systems, reservoirs and harbors.

Effect of cassava cultivation on quality of water resources

Reduced water quality as a result of agricultural activities is usually associated with the runoff of agricultural chemicals into nearby streams, causing either pollution of the water with toxic chemicals or with excessive amounts of nutrients from fertilizer, which may in turn lead to eutrophication of lakes and reservoirs. Cassava is grown mainly by poor farmers, who usually apply no or very low rates of fertilizers, no pesticides to control insects or diseases, and very few farmers are presently using herbicides. *It is, therefore, very unlikely that cassava production will lead to water pollution; however, pollution from herbicides being washed into nearby streams could in the future, become an issue of concern.*

Effect of eroded sediments on soil and water resources

Soil eroded from cassava fields may travel down-slope across other fields until either deposited in low spots elsewhere or washed into nearby streams, after which it may be deposited along river banks, in river deltas (after flooding), in reservoirs, irrigation systems, harbors or be carried out to sea. Only a fraction of eroded sediments will end up in streams and even a smaller fraction will end up at sea, as most sediments are deposited somewhere on land or along the water's course. Figure 12 shows the annual discharge of suspended sediments from various drainage basins of the world (Milliman and Meade, 1983).

It is clear that soil erosion and the associated discharge of sediments by the major river systems is most serious in Asia, followed by Latin America, and then Africa. Higher rates of soil erosion are observed in Asia due to high and poorly distributed annual rainfall, as well as extremely high population densities, which has resulted in intensive crop cultivation on steep slopes. The annual sediment yields of 100-1000 t/km^2, measured in much of southeast Asia, would correspond to "average" erosion rates of 1-10 t/ha for the whole drainage basin. These would be considered low rates of erosion in cassava fields, indicating that erosion levels for the whole watershed are usually only a fraction of that measured in individual plots or fields, as erosion tends to be much lower in undisturbed areas under native vegetation. In addition, much of the eroded sediments are deposited elsewhere in the landscape without ever reaching the streams and rivers below.

While erosion causes degradation of soils in the area of origin in the uplands, it may add fertility to lower spots on the slope, as well as to the lowlands and river deltas. These lower areas have greatly benefitted from erosion upstream and are the main areas for food production in many countries, such as along the river Nile in Egypt, the Chao Phraya river delta of Thailand, and the Red River and Mekong deltas of Vietnam.

Apart from these beneficial effects downstream, however, there are also negative effects, such as the deposition of eroded sediments in irrigation systems, reservoirs and harbors. This may require additional maintenance and dredging, while the siltation of reservoirs will also shorten the life of hydro-electric projects, and thus add to their cost. Deposits of soil sediments in rivers and reservoirs reduces their depths and water storage capacity, which may also increase the incidence and severity of flooding (El-Swaify and Dangler, 1982).

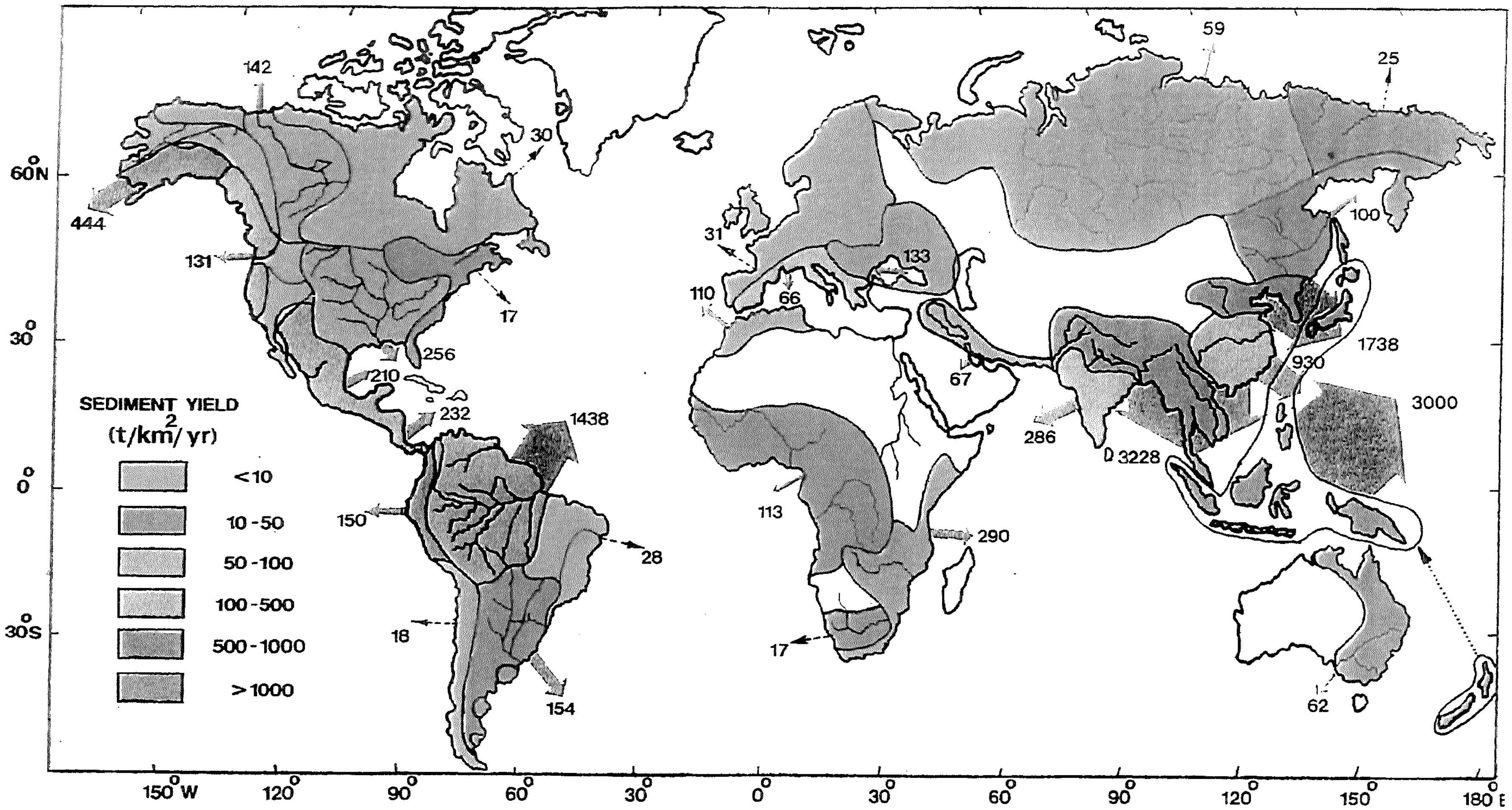


Figure 12. Annual discharge (millions of tons) of suspended sediments from various drainage basins of the world. Width of arrows correspond to relative discharge. Direction of arrows does not indicate direction of sediment movement.
Source: Milliman and Meade, 1983.

Cassava can definitely contribute to both the positive and negative off-site effects of soil erosion. It is impossible, however, to trace the sediments back to their place of origin, and establish a direct link with cassava production. Cassava is usually only one of many crops grown in the watershed, in addition to grasslands and forests, which all contribute in varying degrees to erosion and associated problems of sedimentation. Magrath and Arens (1989) tried to quantify the cost of erosion on Java island of Indonesia, both the on-site effects of present or future loss of income due to soil degradation as a result of erosion, and the off-site effects on the cost of maintenance and dredging of waterways, reservoirs and irrigation systems. Cassava is an important component of the upland cropping systems used in Java, where the crop is usually intercropped with maize, upland rice, peanuts, soybean and mungbean. Annual rates of dry soil loss of 25-100 t/ha have often been measured in erosion control experiments using these intensive intercropping systems (Wargiono *et al.*, 1992; 1995; 1998). Magrath and Arens (1989) used values of 76 to 144 t/ha of annual soil loss for agricultural land in Java in their calculations, and estimated the resulting annual decline in yield of 3.8 to 4.7%. Table 16 summarizes their results and indicates that for the whole of Java the value of annual production losses due to erosion was about 315 million US dollars, while the annual off-site costs were valued at 26-91 million dollars.

Thus, it is clear that, while off-site effects are highly visible, and can cause serious damage and even loss of life during flooding, the "invisible" effect of loss of soil productivity seems to account for most of the actual costs associated with soil erosion (Magrath, 1990; World Bank, 1990).

Table 16. Annual on-site and off-site costs of erosion in Java, Indonesia.

Province	Total area (km^2)	Average annual soil loss on agricultural land (t/ha)	Weighted average annual productivity loss (%)	Capitalized value of productivity loss (million US$)	Of-site cost[1)] (million US$)
West Java	47,370	144.3	4.4	142	
Central Java	33,013	133.3	4.1	29	
Yogyakarta	3,346	118.2	3.7	6	
East Java	45,308	76.0	3.8	139	
Total On-site	129,037	123.2		315	
Total Off-site					26-91
Total				341-406	

[1)] Includes cost due to siltation of irrigation canals, reservoirs and harbors
Source: Magrath and Arens, 1989.

EXISTING CASSAVA PRODUCTION/ENVIRONMENT KNOWLEDGE BASE

Technologies and crop/soil management systems

Crop/soil management to prevent nutrient depletion

Slash-and-burn

Over the ages farmers have developed ways to produce food while maintaining soil productivity. Some of these "sustainable" production systems were based on slash-and-burn agriculture, in which plots in the forest were cut and burned, crops were produced for 2-3 years until fertility had declined, after which new forest plots were burned and the cycle was repeated. Old plots gradually returned to forest and could be cut again after 20-30 years when the original fertility had been restored. This system worked well when the population density was low and land was amply available, and is still used in the less densely populated areas of Africa, Latin America and Asia.

Crop rotation and fallowing

In areas with a higher population density farmers try to maintain fertility by crop rotations and short-term fallows, sometimes in combination with organic or chemical fertilizers. When population pressure increases fallow periods may decrease to 1-2 years, which is not sufficient for regeneration of the native fertility, leading to a downward spiral of ever decreasing fertility and productivity.

On very acid and poor hillsides in Cauca Department of Colombia, cassava is one of the main crops, usually produced without fertilizer inputs but using bush fallow to maintain fertility. But even after 10-15 years of fallow the native vegetation consists mainly of small trees and underbrush. To study the effectivenes of fallowing on soil fertility maintenance and productivity, simple fertilizer trials were established on seven farms with different periods of fallow before cassava planting. Figure 13 shows that without fertilizer application cassava yields varied from 2 to 10 t/ha, independent of the length of fallow period which ranged from 1-2 to more than 15 years (CIAT, 1988). Yields were maintained at those low levels for the second and third cassava crops. However, with application of P alone, and especially with a combination of N, P and K fertilizers, yields could be doubled or tripled, irrespective of fallowing period. Simple economic analyses indicate that fertilizer application produced larger economic benefits than relying on bush fallow for fertility maintenance. Moreover, with fertilizer application, farmers could continuously cultivate the flatter areas and those closer to their homes, using the steeper slopes for planting fruit trees or coffee, or leaving these under permanent forest. This would also save a considerable amount of labor normally used for fallow clearing and land preparation.

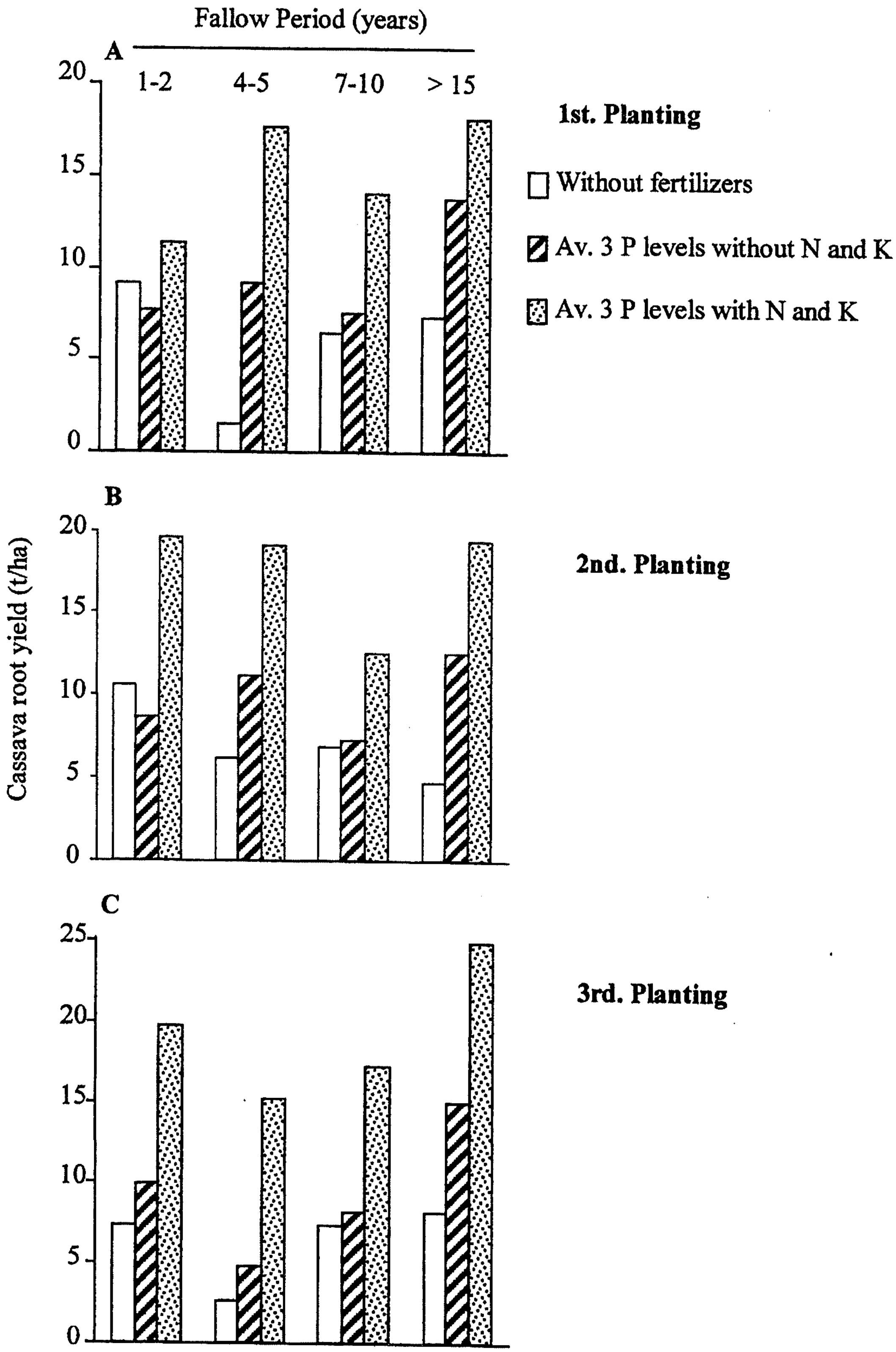


Figure 13. Effect of length of fallow period on the yields of three consecutive cassava crops grown with various fertilizer treatments in the area of Mondomo, Cauca, Colombia.
***Source:** CIAT, 1988.*

In areas where soil and climatic conditions permit the rotation of cassava with other crops, this may be another alternative to prevent excessive depletion of nutrients (especially K) resulting from continuous cassava cultivation. In a long-term rotation experiment, conducted in Khon Kaen, Thailand, cassava was rotated in alternate years with peanut followed immediately by pigeon pea, crop residues of which were incorporated into the soil. In the 15th year of cropping this resulted in a 78% yield increase over continuous cassava monocropping without fertilizers, and a 37% yield increase when fertilizers and soil amendmends (lime, rock phosphate and municipal compost) were applied. However, neither the fertilizers nor the crop rotation could completely restore the level of productivity of the original soil (Tongglum *et al.*, 1998).

Green manures, alley cropping and intercropping

Numerous experiments have been conducted to study the effects of green manuring, alley cropping and intercropping on cassava yields and on soil fertility. Green manures are usually planted in the early wet season and are either mulched or incorporated into the soil before planting cassava. Experiments conducted in CIAT-Quilichao, Colombia, indicate that green manuring cassava with kudzu (*Puerarea phaseoloides*), zornia (*Zornia latifolium*), or peanut (*Arachis hypogea*) had a significant beneficial effect on the subsequent yield of cassava in the absence of fertilizers. On sandy soils in Media Luna on the north coast of Colombia, *Canavalia ensiformis* or natural weeds were most effective (Howeler *et al.*, 1999a). Similar experiments conducted in Thailand (Tongglum *et al.*, 1992; 1998; Sittibusaya *et al.*, 1995; Howeler, 1995; Howeler *et al.* 2001) indicate that green manuring with *Crotalaria juncea* was most effective, followed by *Canavalia ensiformis, Mucuna fospeada* and pigeon pea. However, in Thailand this use of green manures is not practical, as cassava planted late in the rainy season, following the incorporation of green manures, produced very low yields. The system might be acceptable if farmers would leave cassava in the ground for another wet season, harvesting only after 18 months. This combination of green manuring followed by an 18-month crop of cassava in a 2-year cycle produced high cassava yields, but is unlikely to be popular with farmers as it produces an income only every other year (Tongglum *et al.*, 1998).

At Ibadan, Nigeria, Hahn *et al.* (1993) showed that rotating cassava in alternate years with either a green manure (*Mucuna pruriens*) or weed fallow could sustain the yield of an improved cassava line at about 20 t/ha, and that of a local variety at 11 t/ha, for 18 years without any fertilizer inputs.

Few alley cropping experiments have been conducted with cassava. On a very N-deficient soil in Malang, Indonesia, alley cropping with *Leucaena leucocephala, Gliricidia sepium* and *Flemingia macrophylla* markedly increased cassava yields and reduced erosion in the fourth year of cropping. Intercropping with peanut had a similar beneficial effect (Wargiono *et al.*, 1995; 1998). A similar trial conducted on a rather fertile Oxisol near Ho Chi Minh city, Vietnam, also showed that alley cropping with *Gliricidia* significantly increased cassava yields, but only in the seventh year of cropping. Except for Indonesia, where farmers plant hedgerows of *Leucaena* or *Gliricidia* for animal feed along plot borders, and in some parts of north Vietnam where farmers have planted *Tephrosia candida* for erosion control, alley cropping is seldom adopted by farmers. This is because the hedgerows occupy considerable space in the field, they require labor for regular pruning, and the beneficial effect is generally long-term rather than immediate.

Intercropping experiments conducted in Colombia (Leihner, 1983), Nigeria (Okeke, 1984), Thailand (Tongglum *et al.*, 1992; 1998), and Indonesia (Wargiono *et al*, 1992; 1995; 1998) usually show that intercropping cassava with maize, cowpea or peanut, slightly decreases cassava yields, but increases the gross and net income, as well as the land equivalent ratio (LER), indicating that intercropping makes more efficient use of the land than growing each crop separately. Many trials have been conducted to optimize the system in terms of intercrop selection, varieties, interrow and interplant spacing, relative time of planting, fertilization and weed control (Leihner, 1983; 1999). Intercropping can also provide crop residues, which, when incorporated, add nutrients and organic matter to the soil. The long-term effect of this on soil fertility and productivity has been much speculated about, but has not been well quantified. Tongglum *et al.* (1993) showed that intercropping with peanut could maintain the OM and P contents of the soil, but that the K content decreased from 0.19 in the first to 0.12 me K/100g in the 18^{th} year of continuous cropping in Rayong, Thailand. Planting cassava in monoculture, or intercropping with sweet corn, mungbean or soybean were less effective than peanut in maintaining soil fertility, even with annual applications of 46 kg each of N, P_2O_5 and K_2O/ha. Intercropping with sweet corn generally produced the highest gross income (Tongglum *et al.*, 1993).

Mulch

Application of mulch of local weeds, of cut-and-carry grass or of crop residues, such as maize stalks, rice straw, or stems of grain legumes, can also improve soil fertility, reduce the soil surface temperature, conserve soil moisture and control weeds and erosion. In Africa, application of mulch, especially that of leguminous species, increased cassava yields on acid sandy soils (Ofori, 1973; Hulugalle *et al.*, 1991), but had no significant effect on a gravelly Alfisol. In sandy soils on the north coast of Colombia, Cadavid *et al.* (1998) found that annual mulch applications of 12 t/ha of dry grass of *Panicum maximum* significantly increased cassava yields during eight years of continuous cropping, especially in the absence of chemical fertilizers. Mulch application also increased the root dry matter and decreased the HCN content. Available soil P and exchangeable soil K gradually increased, while mulch application prevented the decline in soil Ca and Mg. In addition, mulching reduced significantly the surface soil temperature, which enhanced the maintenance of soil C. Thus, where available, application of mulch can help maintain or improve both the physical and chemical conditions of the soil to increase yields.

Fertilization

i. Responses to fertilizer applications

While cassava grows better than most crops on very acid and infertile soils, this does not mean that the crop does not need, or does not respond to, fertilizer application. Like most other crops cassava grows and yields better on more fertile soils and responds well to fertilizer applications when grown in poor soils. Table 17 shows the average yield response of cassava in comparison with that of other crops, as determined from thousands of fertilizer trials and demonstrations conducted by FAO throughout the world. Cassava trials were conducted in Ghana and Nigeria in West Africa, and in Brazil and Indonesia in Latin America and Asia, respectively. It is clear that in all three continents cassava responded as much as, or even more than, other crops to fertilizer application.

Table 17. Average response to fertilizer application of cassava and other major crops in fertilizer trials conducted by FAO from 1961 to 1977. Numbers in parentheses indicate the number of countries in which trials were conducted.

Region/crop	No of trials/demonstr.	Average yield (t/ha) Control	Average yield (t/ha) Highest	Yield increase (%)
West Africa				
cassava (2)	477	12.30	18.30	49
groundnuts (8)	3,929	1.01	1.52	50
maize (7)	11,905	1.36	2.29	68
millet (4)	1,437	0.57	0.95	67
rice (6)	6,267	1.41	2.02	43
sorghum (4)	1,213	0.77	1.47	91
yam (5)	1,577	8.82	12.64	43
Latin America				
cassava (1)	66	11.87	24.88	110
maize (10)	3,995	2.25	3.45	53
rice (6)	865	1.94	3.91	102
Asia				
cassava (1)	158	4.46	8.00	79
groundnut (1)	144	1.01	1.54	52
maize (2)	430	2.22	3.92	76
rice (6)	6,912	2.87	4.61	61

Source: Richards, 1979.

In Africa relatively few fertilizers trials have been conducted with cassava, mainly because fertilizers are not readily available or are too costly for most poor cassava farmers. Okogun *et al.* (1999) reported that in West Africa cassava responded most frequently to N. Responses to P were reported in Ghana (Stephens, 1960; Takyi, 1972) and in Madagascar (Cours *et al.*, 1961), while responses to K were reported mainly for acid sandy soils of southwest Nigeria (Kang and Okeke, 1984; Odurukwe and Oji, 1984) and for strongly acid soils in eastern Nigeria (Okeke, unpublished).

In Latin America, principally Brazil and Colombia, short-term fertilizer trials showed mainly a response to P in acid Oxisols, Ultisols and Inceptisols, which are extremely low in P and have a high P fixing capacity. Available P (Bray II) levels were often below 1-2 ppm. In that case, P was the main limiting nutrient and yields could be doubled or tripled by P application. Responses to K were found at intermediate frequencies, with significant responses to K observed in 9 out of 48 trials in Brazil and 6 out of 22 trials in Colombia. In Latin America, responses to N were the least frequent, with significant responses to N reported in only 5 out of 41 trials conducted in Brazil (Gomes, 1998) and in 5 out of 22 trials conducted in Colombia (Howeler and Cadavid, 1990). However, in sandy soils of the eastern coast of Santa Catarina, Brazil, and the north coast of Colombia, the crop responded markedly to application of N (Moraes *et al.*, 1981; Howeler and Cadavid, 1990).

In nearly 100 short-term NPK trials conducted by FAO on farmers' fields in Thailand, there was mainly a response to N, followed by K and P (Hagens and Sittibussaya, 1990). Similar results were obtained in 69 trials conducted in Indonesia (FAO, 1980). Trials conducted more recently in four other countries in Asia (Table 18) show an initial response mainly to N and some response to K; in most locations the crop did not respond significantly to application of P, as the P content of the soil was usually above 5-6 ppm. After several years of continuous cropping, however, the responses to K increased markedly, those to N to a lesser extent, while those to P increased only slightly over time (Howeler, 1992; 1995; 1998). Similar results were obtained in long-term experiments conducted in Colombia (Howeler and Cadavid, 1990; Howeler, 1991a; CIAT, 1995), in Thailand (Figure 7), in India (Kabeerathumma *et al.*, 1990) and in Malaysia (Chan, 1980), always showing that K became the most limiting nutrient after several years of continuous cassava cultivation.

In most low-fertility soils cassava responds to applications of fertilizers in the ratio of N-P_2O_5-K_2O of 2-1-2, 3-1-2 or 2-1-3, but in some soils very low in P (<2µgP/g) an initial application of 100-200 kg/ha P_2O_5 may be required to overcome acute P-deficiency. When grown continuously for many years on the same land, cassava responds mainly to applications of K.

Table 18. Response of cassava to annual application of N, P and K during the first year and after several years of continuous cropping in long-term fertility trials conducted in various locations in Asia.

Country-location		Years of cropping	First year N	First year P	First year K	Last year N	Last year P	Last year K
China	- Guangzhou	4	**[1)]	NS	NS	**	**	**
	- Nanning	8	*	NS	NS	**	**	NS
	- Danzhou	7	*	NS	NS	**	*	**
Indonesia	- Umas Jaya	10	**	NS	NS	NS	NS	NS
	- Malang	8	**	**	**	**	NS	**
	- Lampung	7	NS	NS	*	NS	NS	**
	- Yogyakarta	4	NS	NS	NS	NS	NS	NS
Philippines	- Leyte	6	NS	NS	NS	NS	NS	NS
	- Bohol	4	NS	NS	NS	**	NS	**
Vietnam	- Thai Nguyen	9	**	**	**	**	**	**
	- Hung Loc	9	NS	NS	NS	**	NS	**

[1)] NS = no significant response
* = significant response (p< 0.05)
** = highly significant response (p<0.01)

ii. Organic vs inorganic nutrient sources

If chemical fertilizers are not available or too expensive, farmers often apply organic manures, or to a lesser extent, composts to maintain soil fertility, especially if these sources are available on their own farm. Thus, north Vietnamese cassava farmers usually apply 2-7 t/ha of pig manure, while Indian farmers apply up to 20 t/ha of cattle manure (Table 5); in the mountainous areas of southwest Colombia, cassava farmers like to apply chicken manure, which, they claim, gives better results than chemical fertilizers. These manures are excellent sources of both macro- and micro-nutrients and may also improve the physical condition of the soil. However, organic manures and composts have very low nutrient contents as compared to chemical fertilizers, so large amounts are required to have the desired effect; this may result in high costs of transport and application. Most manures are relatively low in K and high in P to be suitable for cassava production. Thus, a combination of organic manures and NK or NPK fertilizers often gives the best results (Kabeerathumma *et al.*, 1990; Nguyen The Dang *et al.*, 1998).

<u>Measures to reduce erosion</u>

Soil erosion control measures can be separated into two broad categories, i.e. engineering structures and vegetative techniques. In many cases both are used at the same time.

Engineering structures

These include land leveling, the construction of contour earth banks or bunds, hillside ditches and various types of terraces. Although these structural solutions were emphasized in the past, their cost effectiveness was found to be rather poor. This is because of their high cost of installation ($400-1000/ha for terraces), as well as high cost of maintenance (Magrath and Doolette, 1990). If terraces or contour banks are not well designed or maintained they can easily collapse, causing severe loss of land. Moreover, drainage ways need to be constructed and maintained, to safely conduct the water down slope. Besides the loss of productive land by terrace risers, there is an additional loss of land of 3-5% for drainage ways. Also, depending on slope and depth of top soil, there may be considerable exposure of infertile subsoil, resulting in low yields or increased fertilizer requirements during the first few years after terrace construction. If terraces are built with heavy machinery, this may lead to soil compaction and extremely high rates of erosion during and shortly after construction.

Vegetative techniques

These include various crop and soil management practices that will provide a vegetative cover of the soil to reduce the impact of raindrops and increase infiltration, or to provide barriers to reduce the speed of runoff. Some examples of these techniques are:

- *Fertilization* is one of the most effective ways to enhance early canopy closure, which protects the soil against rainfall impact and reduces erosion (Howeler and Cadavid, 1984; Jantawat *et al.*, 1994)
- *Closer plant spacing* (0.8 x 0.8 m) will also speed up cassava canopy closure and is often very effective in reducing erosion (Jantawat *et al.*, 1994).
- *Vertical* or *inclined* planting will result in more rapid germination and canopy closure than horizontal planting (Zhang Weite et al., 1998).

- *Varieties with high early vigor* may provide a more rapid cover of the soil surface (Howeler et al., 1993).
- *Intercropping* cassava with maize, grain legumes, melons or pumpkin will help to cover the soil between cassava plants during the first 1-2 months after cropping (Aina *et al.*, 1979) and thus reduce erosion (Tongglum *et al.*, 1992; Jantawat *et al.*, 1994).
- *Contour cultivation* is one of the most effective ways to reduce runoff and erosion, capture soil moisture and increase yields. On moderate slopes (up to 15%) this can be done by tractor, although it may take more time than up-and-down tillage. On steeper slopes (up to 50%) land can be prepared with animal-drawn equipment. A reversible plow, utilized in the Andean zone of Colombia was found to be very effective in contour plowing of steep slopes (Howeler *et al.*, 1993).
- *Minimum tillage* and/or stubble mulching can be very effective in reducing runoff and erosion. In loose and friable soil, seeds can be planted directly using a pointed stick to make holes while cassava can be planted by pushing the stakes directly into the soil. In compacted soil or in weedy plots it may be necessary to prepare individual planting spots with a hoe. Another form of minimum tillage is to either reduce the intensity of tillage (one plowing instead of various passes with plow or harrow) or in the area to be tilled, alternating contour strips of tilled and untilled soil. While minimum tillage can decrease erosion significantly, it often leads to a reduction in yield due to soil compaction, weed competition and reduced efficiency of fertilizers when these are left on the soil surface (Ruppenthal, 1995). When soils are compacted or the surface is sealed by heavy rains, runoff and erosion may actually increase and water infiltration decrease (Jantawat *et al.*, 1994).
- *Contour ridging* was found to be very effective in reducing runoff and erosion on gentle slopes and in stable soils; it often also increases yields by concentrating topsoil in the ridge, increasing rooting depth and conserving soil moisture. However, on steep slopes or with unstable soils, too much water accumulating behind the ridges may cause them to break, resulting in concentrated water flow and gulley erosion. In poorly drained soil, contour ridges may keep the soil too wet, resulting in poor growth and/or root rot.
- *Mulching* with crop residues or grass on the soil surface greatly improves water infiltration, protects the soil from direct raindrop impact and reduces runoff and erosion. Annual application of grass mulch has been shown to more than double the yields of cassava in the absence of fertilizers (Cadavid *et al.*, 1998) by supplying nutrients and reducing surface soil temperatures. However, sufficient mulching materials are often not available or their collection and transport is costly. For that reason, *in-situ* production of mulch by rotating or intercropping cassava with leguminous cover crops may be another solution (Tongglum *et al.*, 1998).
- *Cover crops or "live mulches"* of *Calopagonium, Pueraria phaseoloides* or *Macroptillium atropurpureum* have been used successfully for erosion control under perennial trees like rubber or oilpalm. Attempts to use perennial legumes as cover crops in cassava have been less successful due to severe competition of the cover crops with cassava (Muhr *et al.*, 1995), especially once the cover crops are well established (Howeler *et al.*, 1999a, 1999b). Cassava yields were reduced on average 20-50% by nine cover crop species in Thailand (Howeler, 1992) and by 40% or more in Colombia (Leihner *et al.*, 1996).
- *Vegetative barriers* may include:
  a. Contour strips of cut-and-carry grasses such as elephant or napier grass (*Pennisetum purpureum*), king grass (*Saccarum sinense*), Bermuda or Bahama grass (*Cynadon dactylon*), Imperial grass (*Axonopus scoparius*), *Paspalum atratum* and *Setaria sphacelata*. These have been used successfully to reduce runoff and erosion and to supply cut-and-carry feed for cattle or water buffaloes (CIAT, 1995; Howeler *et al.*,

1999b). Contour grass strips of about 50-100 cm width are usually planted at 1-2 m vertical intervals. The drawback of this system is that 15-25% of the land must be taken out of crop production, the grass trimming is labor-intensive, feed production is often more than the family can use, and the grass stolons or feeder roots can seriously reduce yields of adjacent rows of food crops (Leihner *et al.*, 1996; Tscherning *et al.*, 1995).

b. Contour hedges of vetiver grass (*Vetiveria zizaniodes*) are very effective in reducing runoff and erosion and may increase crop yields by improved water conservation and reduced nutrient loss (Howeler *et al.*, 1998). Single-row hedges of about 30-50 cm width are generally sufficient, taking less than 10% of land out of production on gentle slopes. Moreover, the deep vertical root system of this grass does not compete much with adjacent crops (Tscherning *et al.*, 1995). However, the low forage quality of the grass is a serious drawback for those farmers that need to produce animal feed. Lemon grass (*Cymbopogon citratus*) is intermediately effective in controlling erosion, but may be favored by farmers if it has commercial value.

c. Contour strips of native grasses or weeds. In this system contour-plowed strips of 4-10 m width are alternated with 50-100 cm wide unplowed strips. These unplowed strips often have native grasses such as cogon grass (*Imperata cylindrica*) and *Paspalum conjugatum*, which can be cut regularly for animal feed (Fujisaka 1993). Depending on the dominant grass species and its management, the competition with the adjacent crop can be light or quite substantial. Competition from native grass strips of *Paspalum notatum* caused a reduction in cassava yield of about 13% in Quilichao, but strips of less aggressive native grasses had no significant effect on cassava yields in Mondomo, Colombia (Reining, 1992). In this system about 15-25% of land area is taken out of crop production, which may be a serious drawback in areas where land is scarce. By making the unplowed strips a little wider, these "macro-contour lines" can be used to plant fruit trees or coffee and provide enough fodder for ruminants, which in turn produce manure to improve soil fertility in the cropped areas (Basri *et al.*, 1990; Garrity *et al.*, 1998).

d. Hedgerows of leguminous trees. This system is also called "alley cropping" and consists of planting fast-growing leguminous tree species such as *Leucaenae leucocephlala, Gliricidia sepium* or *Tephrosia candida* in single or double contour rows about 5-10 m apart. Crops are grown in the space between the hedgerows. To prevent light competition the trees need to be pruned regularly to about 30-50 cm height and the prunings can be used as either animal feed (*Leucaena* and *Gliricidia*) or placed between the hedgerows as a mulch and source of nutrients (*Tephrosia*). While rather labor intensive and slow to establish, this system can eventually be effective in forming terraces, reducing erosion and increasing yields (Wargiono *et al.*, 1995). Initially, however, yields may be reduced due to substantial competition for water and nutrients from the hedgerows.

The advantages of these various vegetative techniques are:

- low cost of installation: barriers of vetiver grass cost only $16 per ha compared with $21-80/ha for construction of earthen bunds in India (Margrath, 1990);
- adaptability: allows for flexible management and does not require much expertise;
- greater farmer control;
- less area out of production: about 15-25% for hedgerows in alley cropping systems, but less than 10% for vetiver hedgerows;
- no need for water disposal systems; better water retention;

- natural terrace formation by such practices as alley cropping and contour grass barriers;
- may provide animal fodder by hedgerow trees or grass barriers, or additional income from perennials grown in contour strips; and
- usable for a wide range of land tenure situations.

Many of these vegetative techniques can be applied solely or in combination and in many cases they act synergistically to increase productivity as well as reduce erosion. However, each technique has its own benefits and its own limitations, which may require certain trade-offs.

To be effective and acceptible to farmers these techniques must:

- produce direct and tangible benefits to farmers in the form of increased productivity or income;
- require few outside inputs and have low labor requirements for installation and maintenance;
- be simple and not require expensive machinery nor expert advice;
- be adapted to the local conditions of soil and climate as well as the availability of necessary inputs or markets for outputs; and
- be effective in soil and water conservation.

Enhancing the adoption of soil-conserving practices by farmers

Upland ecosystems in which cassava is grown are highly diversified and each region has a unique set of physical and socio-economic conditions as well as a unique complex of interrelated problems, such as poverty, lack of secure tenure, land degradation, sedimentation, irregular stream flow etc. Therefore, solutions to these problems are obviously site-specific and must take into account both the physical conditions of the site and the resources and needs of the local population. Solutions may have to be highly diversified and include agriculture, forestry, animal husbandry and vegetable or fruit production. Attempts in the past at implementing soil conservation measures have often failed because the proposed solutions were inappropriate for the site, they were too narrowly focused on a particular crop or soil conservation practice and/or they did not take into account the indigenous knowledge nor the needs of the population.

Because of the diversity of upland ecosystems, the technology development must start with adequate problem identification through Rapid Rural Appraisal (RRA) techniques, farmer participatory planning, the description of land classes and uses, the determination of causes of land degradation and a definition of local needs, objectives and possible solutions. The principle objective is to improve upland agricultural productivity and income, while a secondary objective is environmental improvement. These two objectives can best be achieved through simple low-cost innovations in crop/soil management so as to conserve moisture and maintain soil fertility. A reduction in soil erosion will enhance moisture conservation and increase moisture- and fertilizer-use efficiency, thus increasing yields and farm income. To be acceptable the proposed solutions must address immediate and short-term needs and must be based on existing practices rather than on the introduction of a "package" of new practices.

Because problems and solutions are site-specific, the technology development can best be done by multidisciplinary teams through networking and improvement of research capabilities in local and national institutes. The right choice of options could involve some trade-offs and thus requires a thorough knowledge of local conditions and needs; this is best left to local researchers. Once promising technology components have been identified, linkages must be established with development-oriented and extension institutes for the technology adaptation and dissemination. This may best be done through farmer surveys, on-farm trials and demonstrations and Farmer Participatory Research (FPR) so as to obtain feedback about the farmers' priorities and the effectiveness and acceptability of various options. From a menu of many options farmers will be able to select the most appropriate ones and then experiment with these on their own farm, with the help of researchers and extensionists trained in farmer participatory research approaches. After determining which practices are most beneficial, these can be further adapted and then adopted by the farmers. Finally, they are disseminated to others through regular extension methodologies and farmer participatory extension. Spontaneous adoption of soil conservation practices can only be expected if farmers themselves and the whole community are involved in their development, the practices are of low risk and satisfy immediate needs for food and income. In other cases, some incentives may be necessary, including public investments in soil erosion control measures, especially if these have to be implemented at the community or watershed level.

Table 19 summarizes the effect of various soil/crop management practices in cassava-based cropping systems on erosion control, terrace formation and cassava yield, and indicates their relative costs and labor requirements as well as their long-term benefits and limitations. Obviously, the benefits and limitations depend to a certain extent on local conditions of climate, slope, soil, prices of inputs and products, farm size and resources availability. For that reason it is unlikely that any one practice would be universally effective and attractive to farmers. In order to develop effective soil and crop management practices for a particular region and to achieve their adoption, a strategy is required that links the research and extension institutions with farmers' organizations, and considers both socio-economic as well as technical factors. Figure 14 shows the activities and possible outputs of such a strategy.

Besides basic and applied research for the development of a menu of effective technology components, it is necessary to test these components in a particular region by conducting simple soil management and erosion control trials (Howeler, 1987; 1996a), using treatments selected in consultation with farmers. These trials can serve as demonstration plots so farmers can clearly observe the effect of certain practices on erosion and yield. Once the effectiveness of various practices has been determined, then farmers can be asked to select those practices that best satisfy their needs. These practices can be further tested on farms with direct farmer and community participation (Howeler, 1999). By actually collecting and measuring the soil loss due to erosion, the problem becomes visible and farmers will become more aware of the seriousness of soil erosion, and more willing to adopt better management practices that not only increase yields but also reduce soil losses. At the same time, researchers and extension officers should be trained, not only in conducting better soil conservation trials, but also in farming systems research and farmer participatory research methodologies, so as to increase their knowledge of, and sensitivity to, farmer's priorities and needs. Only when those needs are taken into account in the development and selection of improved soil and water conservation practices, might we reasonably expect some adoption of these practices, which in turn, will have a positive impact on the environment. In addition, cassava is not necessarily the only or the best option available to farmers to increase income and preserve their soil resources. Ecosystem research teams, comprising both agricultural and social scientists, should study a wide range of possible technical as well as policy options to determine the best land use that will improve the income and well-being of farmers, while at the same time prevent any further degradation of soil and water resources. To be successful, this will require increased collaboration between various national and international research and development-oriented institutes, so as to tap the expertise available in each institute and make maximum use of scarce financial resources.

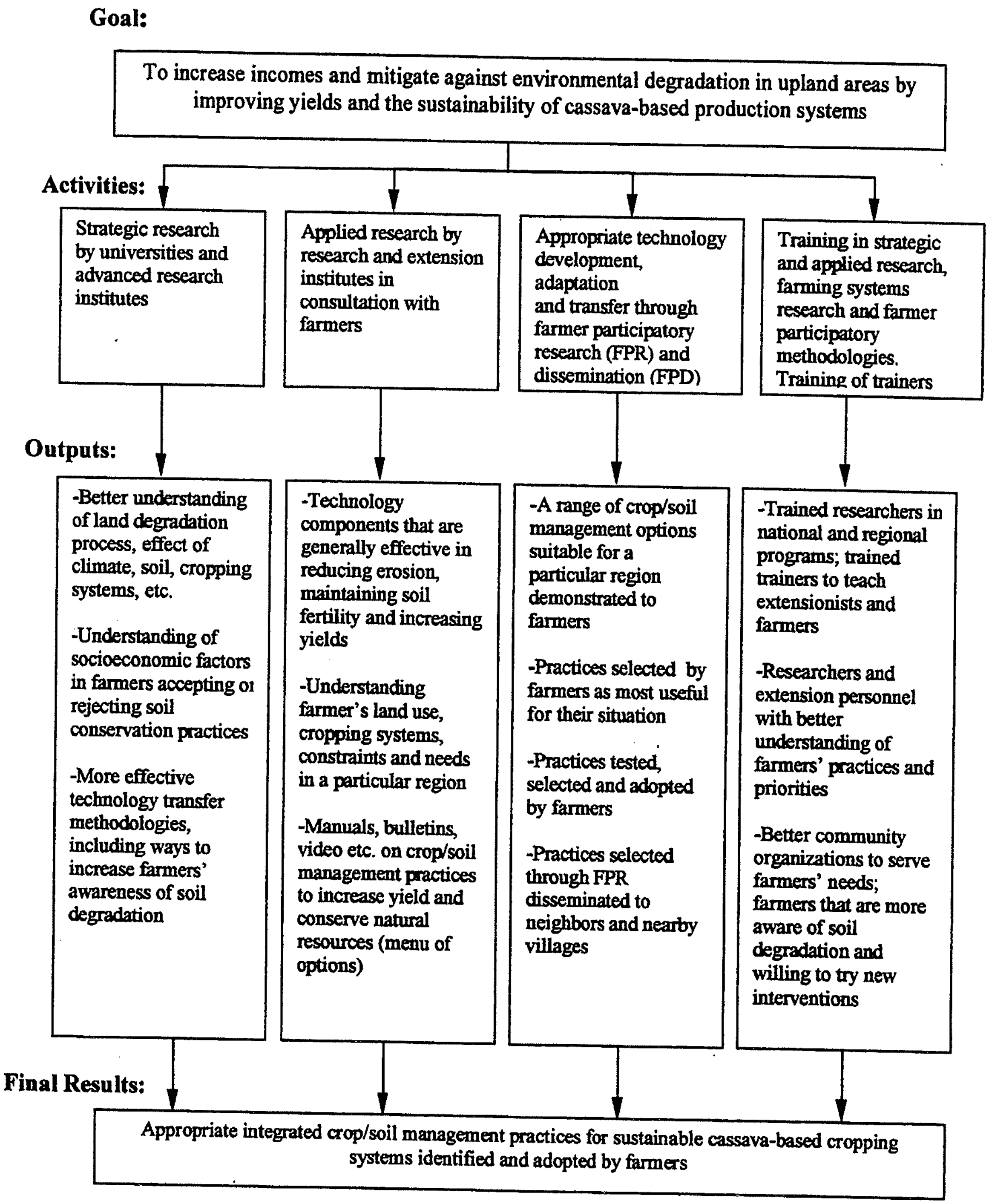


Figure 14. Strategy to improve the sustainability of cassava-based cropping systems.
***Source:** Howeler, unpublished.*

Table 19. 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	Terrace Formation	Effect on cassava	Labor requirement	Monetary cost	Long-term benefits	Main limitations
Minimum or no-tillage	++	-	-	+	--	+	compaction, weeds
Mulching (carry-on)	++++	-	++	+++	+	++	Mulch availability, transport cost
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, high maintenance
Vetiver grass hedgerows	+++	+++	+	+	+	+++	
Natural grass strips	++	++	-	+	-	++	high maintenance cost
Cover cropping (live mulch)	++	-	---	+++	++	+	severe competition, high maint.
Manure or fertilizer application	+++	-	+++	+	+++	+++	high cost
Intercropping	++	-	-	++	++	+++	labor intensive
Closer plant spacing	++	-	+	+	+	++	

+=effective, positive or high
- =not effective, negative or low
1)=value added in terms of animal feed, staking material or fuel wood
Source: Howeler, 1994.

Gaps in knowledge

Intensive research on cassava nutrition and fertilization, on crop/soil management practices to maintain soil fertility and reduce erosion, has been conducted over the past 25 years in both Latin America and Asia, and to a lesser extent in Africa. Much is known both about the principal causes of soil erosion and fertility decline and about specific measures to be taken to mitigate against these problems. Gaps in our knowledge may still exist on:

1. Effect of continuous production of cassava in comparison with that of other annual food crops on crop yields, and on the chemical, physical and biological conditions of the soil.
2. Long-term effect of crop rotations and intercropping on crop yields and the chemical, physical and biological conditions of the soil.
3. Nutrient balances at several levels of scale
4. Nutrient losses in runoff and eroded sediments.
5. Effect of various tillage practices on cassava yield, production costs and erosion.
6. Diagnostic criteria and effective methods to control micro-nutrient deficiencies, especially in calcareous or organic soils.

This knowledge is important for improving our understanding of erosion processes and may help to predict the effect of changing land-use practices on soil and water resources; it may also help to develop more efficient management practices to increase farm income and protect the soil from degradation. However, the greatest gap in our knowledge is not in the technical aspects but in the social and economic aspects.

By far the greatest challenge is to develop soil conservation practices that are not only technically effective but also economically efficient and acceptable to farmers, and to develop methodologies, strategies and institutional arrangements that will effectively disseminate these practices and facilitate their adoption.

Conclusions and recommendations

1. Nutrient removal by cassava depends mainly on the yield level obtained and on the plant parts removed from the field. When only roots are removed and yield levels are relatively low, cassava removes less N, P and K than most other crops; when yield levels are relatively high, cassava removes less N and P and similar amounts of K as other crops. However, when leaves and stems are also removed from the field, nutrient removal (especially of N and Ca) increases substantially, and in that case cassava may remove more N and K than most other crops.

2. When cassava is grown continuously on the same soil, without nutrient replenishment, the crop tends to deplete soil-K first, followed by N, Mg and Ca (the latter two nutrients mainly if plant tops are removed from the field).

3. Cassava is highly dependent on mycorrhiza for P uptake, but in practically all soils cassava roots become infected with native soil mycorrhiza resulting in a highly effective symbiosis. This enables the crop to take up P from soils with low levels of available P. Thus, the critical soil-P level for cassava is much lower than for most other crops.

4. Cassava is extremely tolerant of low pH and high levels of Al. For those reasons the crop is well-adapted to acid soils and seldom requires lime applications.

5. When grown on infertile soils, cassava responds as well as other crops to fertilizer application. In some soils with extremely low levels of available P (<2 μg P/g), the crop responds initially mainly to P applications. In most other soils, however, it responds mainly to applications of K and N. Compound fertilizers with N, P_2O_5 and K_2O ratios of 2-1-2, 3-1-2 or 2-1-3 will generally give the best results. Of the micronutrients Zn is the most important.

6. Cassava is extremely tolerant of drought and can be grown in areas with less than 500 mm annual rainfall. Once established, the crop will survive long (6-8 months) periods of drought.

7. Cassava adjusts its rate of growth to the moisture and nutrient conditions of the soil. When these conditions are unfavorable the growth rate slows, and yields are low. But plants generally survive, and when conditions improve the growth rate increases, resulting in higher yields. In the case of drought, the crop consumes little water; in the case of poor soils, the crop absorbs few nutrients and is able to sustain low but stable yields without serious soil nutrient depletion.

8. When grown on slopes, cassava causes more erosion than most other crops, due to slow initial growth and wide plant spacing. Erosion is particularly serious on sandy, low-OM soils on which cassava is often grown. These soils have poor aggregate stability and become particularly susceptible to erosion if water infiltration is limited by a hardpan in the subsoil.

9. When cassava is grown on slopes, farmers must take measures to reduce erosion. These can include common cultural practices, such as fertilization, reduced tillage, contour ridging, closer plant spacing, intercropping and chemical weed control; or it may include special measures, like planting contour barriers or making trash lines, stone walls or terraces. On gentle but long slopes, the speed of runoff should be reduced by contour grass strips or hedgerows, or by contour land preparation and ridging.

EFFECT OF CASSAVA PRODUCTION ON BIODIVERSITY

Impact on the biodiversity of other native species

Cassava has been cultivated for centuries in the Americas, initially only for human consumption and more recently for production of dry chips used as animal feed and for starch. Since cassava was mostly a poorly commercialized crop in the past, area under cultivation has increased slowly, in pace with increases in the rural population. However, due to rapid urbanization in Latin America during the past 30 years, the cassava growing area has remained constant. Massive clearing of land for cassava cultivation has not occurred, or may have occurred only in isolated areas, mainly in the semi-arid region in northeast Brazil and in the eastern frontier regions of Paraguay. The effect of this expansion on the native biodiversity, if any, is poorly documented.

In Sub-Saharan Africa the cassava growing area has expanded in pace with a rapidly increasing population. Recent changes in government policies concerning the importation of other foods, like wheat, rice and maize, as well as improvements in cassava processing techniques, have markedly increased demand for cassava. This in turn has led to a very rapid expansion in cassava production areas, especially in Nigeria, partially at the expense of other crops, but also by deforestation in slash-and-burn agriculture. According to McNeely (1992), by 1986 Africa had already lost 65% of its wildlife habitats by conversion into farming land; this process must have accelerated even further during the past decade. This inevitably resulted in a serious loss of the biodiversity of the natural flora. Cassava production for human consumption clearly contributed to this process, but the large-scale cultivation of export crops, like groundnut, oil palm, coffee, cotton and cacao probably had a much greater impact on biodiversity than the small-scale production of cassava.

In Asia the situation is different. While cassava is still mostly a small farmer crop, it is also grown in some large plantations, mainly for starch extraction, in Sumatra island of Indonesia, and in Mindanao island of the Philippines. Owners of these starch factories acquired large tracts of land and quickly converted these to cassava plantations using heavy machinery for deforestation and subsequent land preparation. Locally this may have had a dramatic effect on the flora and fauna, but the areas involved were still too small to have major and long-lasting effects on the biodiversity of native species.

In Thailand, on the other hand, cassava has remained a small farmers' crop, but it is grown almost exclusively for export in the form of dry pellets for animal feed and of starch. From the mid 1970s to the late 1980s cassava production increased dramatically, from 10 million tonnes to 24 million tonnes annually, in response to a growing and very profitable animal feed market in western Europe. This increase in production was achieved mainly through area expansion, from about 460,000 ha in 1974/75 to 1.6 million ha in 1988/89. The area expansion through deforestation of frontier areas, mainly in the northeast, was not only permitted but actively promoted by the government as a way of combatting communist insurgents hiding in those forested areas at the time. The area has mainly poor soils and rather unpredictable rainfall, so cassava was the upland crop of choice for opening the area. The massive deforestation continued until the late 1980s, when most land within Thailand's borders, up to the borders with Laos and Cambodia, had already been cleared; at that time the government proclaimed a national logging ban to arrest the alarming rate of destruction of the native forest. The rapid area expansion for cassava production in northeastern Thailand from

1975 to 1989 must have resulted in a loss of biodiversity of many native forest species, including many plants used for traditional Thai herbal medicines, but the exact nature of this is not known.

Impact on *Manihot* biodiversity

Species inventory and ecogeography

The genus *Manihot,* estimated at 70 species, is exclusive to the New World. South America is home to 55 species, and Central and North America to the other 15. The two largest areas of diversity are Brazil, with close to 80% of the species, and Mexico with 15%. In Mexico, the genus is mostly restricted to xerophytic areas or dry thorny forest vegetation. In Brazil, many species occur in the Brazilian savanna known as the *Cerrado*, but important secondary centers of diversity exist in northeastern and southeastern regions, besides parts of the Amazon (Allem, 1994).

Effect of cassava production

Although cassava is more important in the food and industrial economies of Africa and Asia than in the Americas, there is potential for competition between the crop and wild *Manihot* species for arable land only in the latter. In general, the largest producing countries (e.g., Brazil, Colombia and Paraguay) have the most potential for cassava cultivation to displace wild species.

Cassava is of very minor economic importance in Mexico, and therefore expansion of production currently presents little risk to the rich diversity of species. In Central America and the Caribbean, cassava is locally quite important (e.g., Haiti, Dominican Republic, Cuba), but impact of its cultivation on wild species is minimal. In most of South America, the impact on the original vegetation of clearing land for cassava cultivation is likewise minimal. In Colombia and Paraguay, cassava cultivation may expand on virgin land, particularly in traditional rural communities, but there is negligible risk from a conservationist frame of reference. The picture changes in Brazil, where there is reason for concern about wild *Manihot.*

Brazil's southern (sub-tropical) and southeastern (*cerrado*, or savanna) regions have been grossly deforested over the last five decades for the cultivation of cash export crops, like soybeans, wheat, oranges, coffee and cocoa, besides pastures. The Cerrado remained virtually untouched until 1946, but 43% of this eco-region is now farmland. As a result, 10-12 wild *Manihot* species native of these areas were eliminated from their local habitats. Brazil's huge Cerrado savanna, home to tens of species of *Manihot,* covers 22% of the country's territory. Cassava is highly important in the south of Brazil, but less so in the Cerrado. Its participation in the displacement of local wild relatives has been minimal relative to the impact of the export crops mentioned above.

The Brazilian Amazon, home to an estimated 7 forest species of *Manihot*, has lost 15% of its original vegetation (Walker and Holmes, 1996). The importance of cassava in slash-and-burn agriculture in traditonal Amazonian communites is well-established (Salick *et al.*, 1997; Emperaire *et al.*, 1998). Thus, the threat of cassava cultivation *per se* to *Manihot* populations is not negligible.

Brazil's large semi-arid northeastern region is characterized by vegetation known as *caatinga*, spanning over 930,000 km^2 or 11% of the Brazilian land surface, and encompasses eight states. The region has lost much of its native vegetative cover to agriculture. The native *caatinga* vegetation decreased from a 64% cover to 47% in the period between 1984 and 1990 (Allem, 1997), and declined further to an alarming 41% cover by the year 1997.

The consumption of cassava in Brazil's semi-arid Northeast is among the world's highest, with a per capita consumption at just under 100 kg/year. Because cassava is an important staple, local species are more likely to experience the thinning out or eventual extinction of their populations.

The clearing of land to cultivate cassava in the Brazilian semi-arid region has been most prevalent in areas inhabited by seven wild *Manihot* species known as *maniçobas*. These species live in the thorny bushy vegetation called *carrascos* and in the harsh conditions of the innermost area called *sertão*. They are: *M. caerulescens, M. diamantinensis, M. dichotoma, M. glaziovii, M. jacobinensis, M. janiphoides,* and *M. maracasensis.* The clearing and burning of the vegetation in drought-plagued areas of the *caatinga* has the potential to hit hard local populations of *Manihot,* because they are usual components of the vegetation. About 100 municipalities of the area have annual rainfall rates below 500 mm, and not seldom between 0-250 mm. Few other crop species are adapted to the harsh conditions of the *caatinga,* and therefore intercropping of cassava is rather uncommon, especially in the harshest sites. As a result, staples like cassava may assume the form of monocrop plantations. These ecological and climatic conditions, along with a high human population density of the *sertão*, further compound the plight of *Manihot* populations in the area.

Effect of cassava breeding

Demand for wild *Manihot* species on the part of cassava breeders had a positive effect on their conservation and study. The plants became better known and this in turn raised interest in further collection and conservation efforts. In addition, the wild *Manihot* germplasm assembled in research institutions in Africa and Asia from the early 1930s through the late 1950s was multiplied for generations and made available to the community for other characterization studies.

During the 1970s the International Institute of Tropical Agriculture (IITA) in Nigeria remained the sole institution that continued to cross selected wild species, particularly *M. glaziovii*, with cassava with the aim of producing improved genotypes, especially resistance to African mosaic virus (Hahn *et al.*, 1980a).

Most of the crossings involving cassava and wild species were carried out in Africa and Asia. In South America, breeders had access to a much broader range of genetic variability within the species *Manihot esculenta*, and did not resort to use of wild species for obtaining rare traits. African institutes crossed cassava and the Brazilian species *M. dichotoma, M. catingae,* and *M.glaziovii,* besides the Surinamese species *M. saxicola* and *M. melanobasis* (Nichols, 1947; Jennings, 1957).

Rationale for the conservation of wild *Manihot*

Historically a number of wild *Manihot* species were agronomically evaluated and had genes transferred to cassava, but these hybrids rarely reached commercialization. An exception is the species *M. glaziovii,* which was successfully crossed with cassava in Africa and provided high-yielding local commercial varieties with genes for resistance to the destructive African cassava mosaic virus (Hahn *et al.*, 1980b).

Conservation policies and breeding goals can and should be complementary. For example, there are recommendations to conserve wild species for their potential contribution to elucidating the processes that led to the domestication and further evolution of the crop (Hershey, 1994), or because they are the very gene pools of the crop (Valle, 1991).

Blueprint for the long-term conservation of wild *Manihot*

Wild genetic resources of *Manihot* fall into the following five utilitarian categories (Allem *et al.,* 1998): (1) agricultural value (agrobiodiversity – direct or indirect economic application either as food suppliers or as income generators); (2) scientific value (enlargement of knowledge); (3) social value (recreation); (4) cultural value (broader spectrum of interest to the community); and, (5) ecological value (*keystone* species or as participants in nature's food chains).

A first conservation target should be the group of species known as 'the cassava species complex' which is composed of the wild progenitor of the crop and four other closely related species from the Brazilian tropics. Study of this complex, from the perspectives of taxonomy, biosystematics and cladistics, will shed new light on the origin, phylogeny and evolutionary patterns of cassava. It was only through recent systematic studies of the biodiversity that the long-searched origin of cassava seems close to completion, a quest that lasted over a century (Allem, 1994, 1999; Olsen and Schaal, 1998).

A second conservation effort should elect as target species the so-called *maniçobas* from northeast Brazil's semi-arid *caatinga* region. Three of them in particular merit attention: *M. caerulescens* ("maniçoba do piauí", a source of cheap latex), *M. dichotoma* ("maniçoba de jequié", a minor supplier of latex and domestic utensils such as wooden spoons), and *M. glaziovii* ("maniçoba do ceará"). The latter is a most versatile species. It provides commercially useful latex and wood, and has been studied for potential use as feed for goats and cattle in Brazil's semi-arid Northeast (Barros *et al.*, 1990). Most importantly, *M. glaziovii* supplied African cassava breeders with genes for resistance to the African cassava mosaic virus (Hahn *et al.*, 1980a) and the cassava bacterial blight (Hahn *et al.*, 1980b).

Collection and conservation of select stocks is timely, *inter alia,* because landraces of the crop growing in the Americas may be genetically very close to cassava's wild progenitor. A more far-reaching implication is the possibility that commercial cassava stocks worldwide share much of their genome with that of the wild progenitor. Wild materials related to the ancestry of the crop, and making up the wild primary genepool, should be in storage to enable comparative tests. Such materials enjoy scientific-cultural value for fields as diverse as agronomy, sociology, anthropology, archaeology and economic botany. A condensed summary of the species discussed in the text and assessments are given in Table 20.

Effect of breeding on the biodiversity of cassava

Breeding efforts to increase the yield potential and disease/pest resistance of cassava have in some cases reduced the number of commercially grown varieties and thus eliminated the use of certain farmers' landraces. However, extensive collections of *Manihot esculenta* varieties in the centers of origin in Latin America, and their conservation in field-grown germplasm banks, *in vitro* culture, of under cryopreservation, have helped to prevent the loss of biodiversity in *Manihot esculenta.* Presently, CIAT, in Cali, Colombia, maintains over 5500 cassava accessions. Moreover, the widespread distribution of sexual seed of Latin American origin, from CIAT to Africa and especially Asia, has greatly contributed to the increased biodiversity of cassava in those two continents.

Conclusions and recommendations

1. Cassava production has had a minimal effect on the biodiversity of other species, with a possible exception of Thailand, where a dramatic extension of cassava cultivated area during the late 1970s and early 1980s resulted in extensive deforestation in the northeastern part of the country. The actual loss of biodiversity in this process has not been well-documented.

2. Cassava production has had a minimal effect on the biodiversity of *Manihot* in the center of origin of the species, i.e. in Mexico and Brazil, with a possible exeption of the semi-arid northeast of Brazil where intensive monocropping of cassava may threaten the survival of seven *Manihot* species native to that area.

3. It is recommended to protect the wild *Manihot* species from extinction by conserving their natural habitat, mainly in the *caatinga* region of northeast Brazil and the *cerrado* of central west Brazil. Furthermore, wild *Manihot* species should be collected and conserved *ex situ*, especially the six species most closely related to *Manihot esculenta*, for possible future interspecific breeding to transfer favorable characteristics to the cassava plant.

4. Narrowing of the genetic base of commercial cassava varieties by the use of a small number of widely-adapted high-yielding varieties should be avoided, by the continued release of new varieties with a broad genetic background. This will reduce the risk of widespread crop failure, for example in case of adverse climatic conditions or the appearance of new diseases or pests.

Table 20. Species of* Manihot *of particular concern for humankind.

1[1]	2[2]	3	4	5
M. aesculifolia	*M. anomala*	*M. caerulescens*	*M. flabellifolia*	*M. brachyloba*
M. angustiloba	*M. baccata*	*M. diamantinensis*	*M. peruviana*	*M. pilosa*
M. auriculata	*M. brachyloba*	*M. dichotoma*	*M. pruinosa*	*M. triphylla*
M. caudata	*M. compositifolia*	*M. glaziovii*		
M. chlorosticta	*M. flabellifolia*	*M. jacobinensis*		
M. crassisepala	*M. flemingiana*	*M. janiphoides*		
M. davisiae	*M. hassleriana*	*M. maracasensis*		
M. foetida	*M. mossamedensis*			
M. michaelis	*M. peruviana*			
M. oaxacana	*M. pilosa*			
M. pringlei	*M. pruinosa*			
M. rhomboidea	*M. quinquepartita*			
M. rubricaulis	*M. sagittato-partita*			
M. subspicata	*M. tripartita*			
M. tomatophylla	*M. triphylla*			
M. walkerae	*M. violacea*			
M. websterae				

[1] 1= Mexican species threatened because of development;

2= Brazilian species threatened because of development and cassava cultivation;

3= Species of *maniçobas* conomically valuable to dwellers of Brazil's NE semi-arid region;

4= Species involved in the ancestry of cassava and constituting the wild primary genepool of the crop;

5= The putative closest wild relatives of cassava and assumed to participate in the secondary genepool of the crop

[2] Includes species of column 3

IMPACT OF CASSAVA PROCESSING ON THE ENVIRONMENT

Introduction

Cassava processing, especially in areas where the industry is highly concentrated, is regarded as polluting and a burden on natural resources. Some forms of processing, particularly for starch, have developed beyond traditional methods and are now water intensive yet often sited in areas of water scarcity. By its nature, cassava processing for starch extraction produces large amounts of effluent high in organic content. If untreated this may be displayed in the form of stagnant effluent ponds from which strong odors emanate. Other forms of processing, despite not requiring water, generate very visible dust waste. As a consequence of the visual display of pollution, cassava is often perceived by local populations as contributing significantly to environmental damage and water deficit. Yet, despite this notion, supported mainly by the visual display of pollution, few systematic impact studies have been conducted.

Most studies have tended to focus on the quantity and composition of waste produced by this industry, but do not consider the environmental impact.

Areas and products

Asia

Annual cassava production in Asia is about 48 million tonnes, mainly in Thailand (18), Indonesia (15), India (6), China (4) and Vietnam (2). Diversity is the characteristic of cassava products in Asia, both within and across countries. Between 33 and 60% of the cassava produced in the region is processed for industrial purposes, mainly as pellets for animal feed and as starch. Large amounts of dry chips and pellets are produced in Thailand, Indonesia and China. Cassava flour is produced in some countries in the region, most notably in Indonesia (Figure 15). Thailand, Indonesia, India, China, Vietnam, Malaysia and the Philippines all produce cassava starch. Processing is done at a wide variety of scales, ranging from small family-size units to modern large-scale factories (Table 21). The industry in Thailand, Philippines and Indonesia is large-scale and modernized. China and Vietnam have made considerable advances in modernizing their starch industry, especially in Guangxi province of China and in the southeastern region of Vietnam. Throughout the region, the industry is moving toward larger, more technologically advanced plants, and small less-efficient factories are closing.

In Vietnam, cassava processing has increased in overall scale since the 1970s. Starch processing is of major importance, the development of which is driven by an expanding range of applications for starch. Despite an increase in overall output, processing in north Vietnam is still by small-scale artisan methods (Ha *et al.*, 1996). The process (Figure 16) is typical for many tropical countries and consists of wet-milling washed roots, washing the starch from the milled pulp in mixing tanks, sedimenting the starch in canals or tanks, followed by sun drying. Processing regions such as Cong Hoa village, Quoc Oan district, Ha Tay province, which is close to Hanoi, are characterized by a large number (about 1000) of such enterprises (Viet, 1998). In the six-month processing season, an average family in Cong Hoa village will process 250-300 kg roots each day (producing 50-60 kg starch) and in the peak of the season,

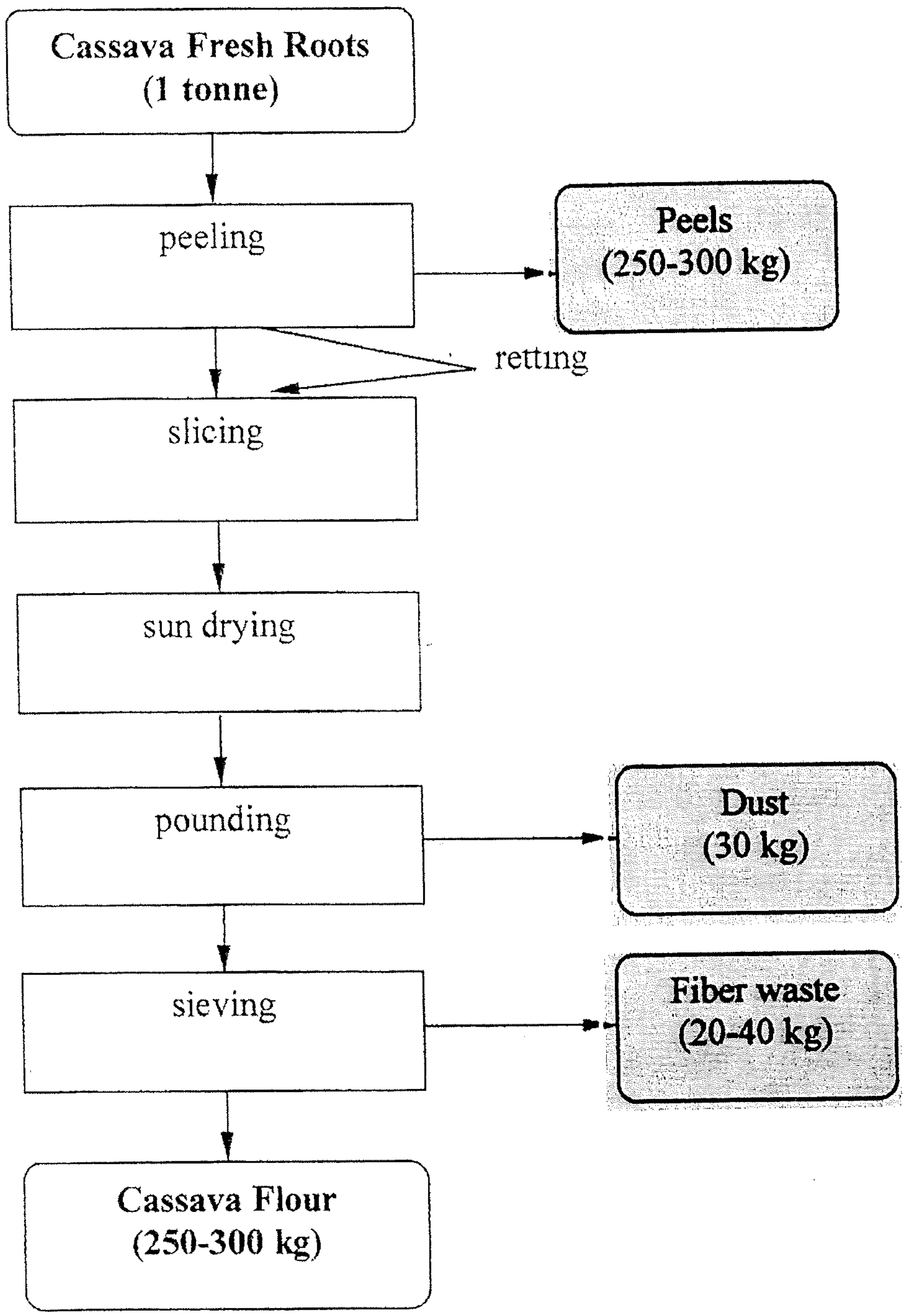
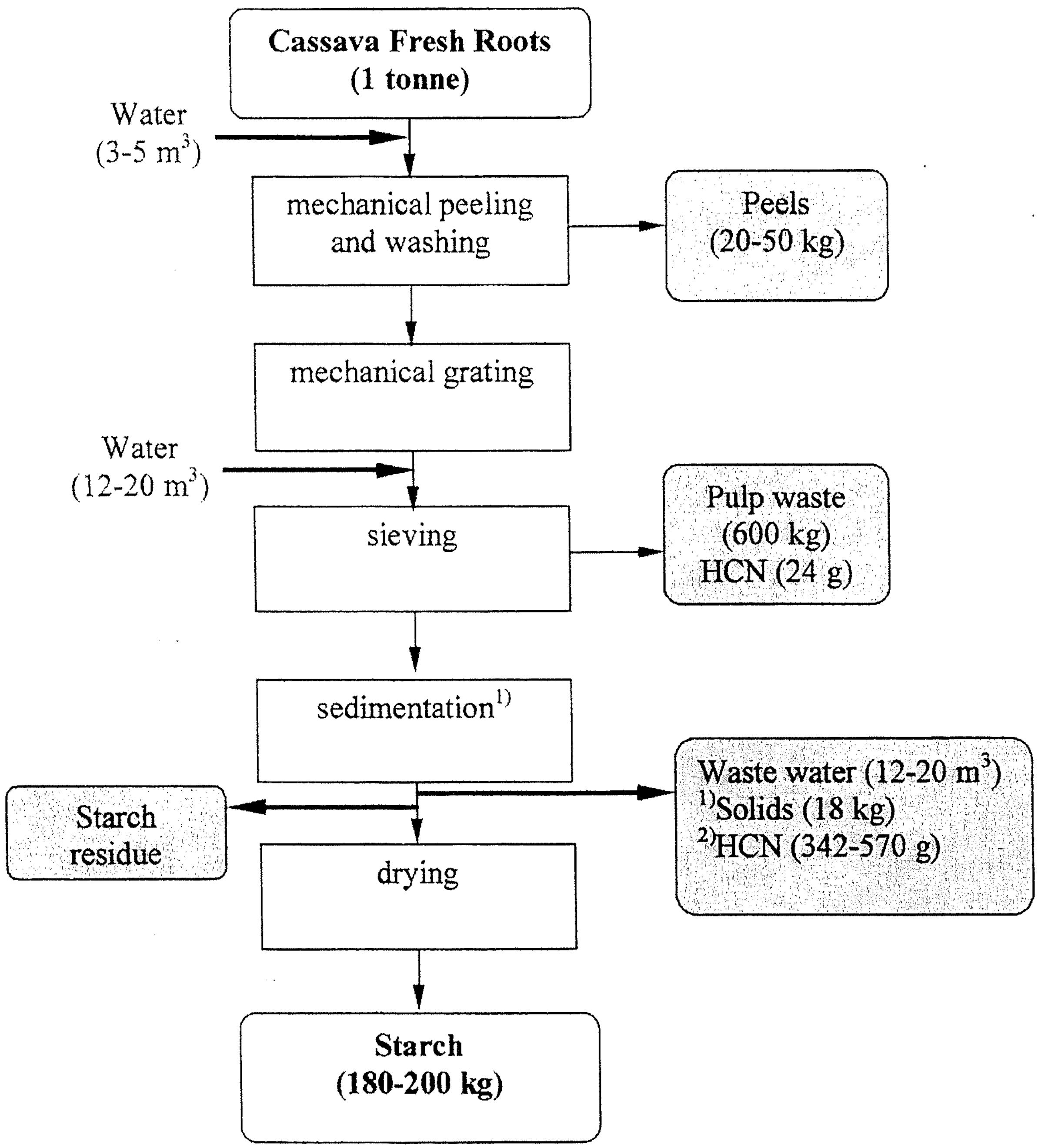


Figure 15. Flow chart for small-scale production of cassava flour.
Source: G. Chuzel. (personal communication)

Table 21. Examples of three scales of starch processing in Asia.

Scale	Location	Number of processors	Daily average capacity per processor (tonnes)		Annual average capacity per processor (tonnes)		Annual capacity for the region/country('000 tonnes)	
			Fresh roots	Starch	Fresh roots	Starch	Fresh roots	Starch
Small	North Vietnam (Cong Hoa village, Ha Tay province[1])	1,000	0.25-0.50	0.05-0.60	45-91	9-11	55	11
Medium	India (Salem district, Tamil Nadu[2])	850-1,000	10-50	2-10	1,520-7,600	300-1,520	1,875-2,000	375-400
Large	Thailand[3]	51	400-1,200	100-300	40,000-272,000	10,000-68,000	6,400-7,200	1,600-1,800
	South Vietnam[4]	11	100-800	25-200	25,000-200,000	6,000-50,000	945	236

Source [1] *Tran Quoc Viet, 1998.*
[2] *ERM, 1996.*
[3] *Sriroth et al. (submitted)*
[4] *R. Howeler (personal communication)*



[1]This step may be repeated several times.

Figure 16. Flow chart for small-scale production of cassava starch.
Source: *G. Chuzel. (personal communication)*

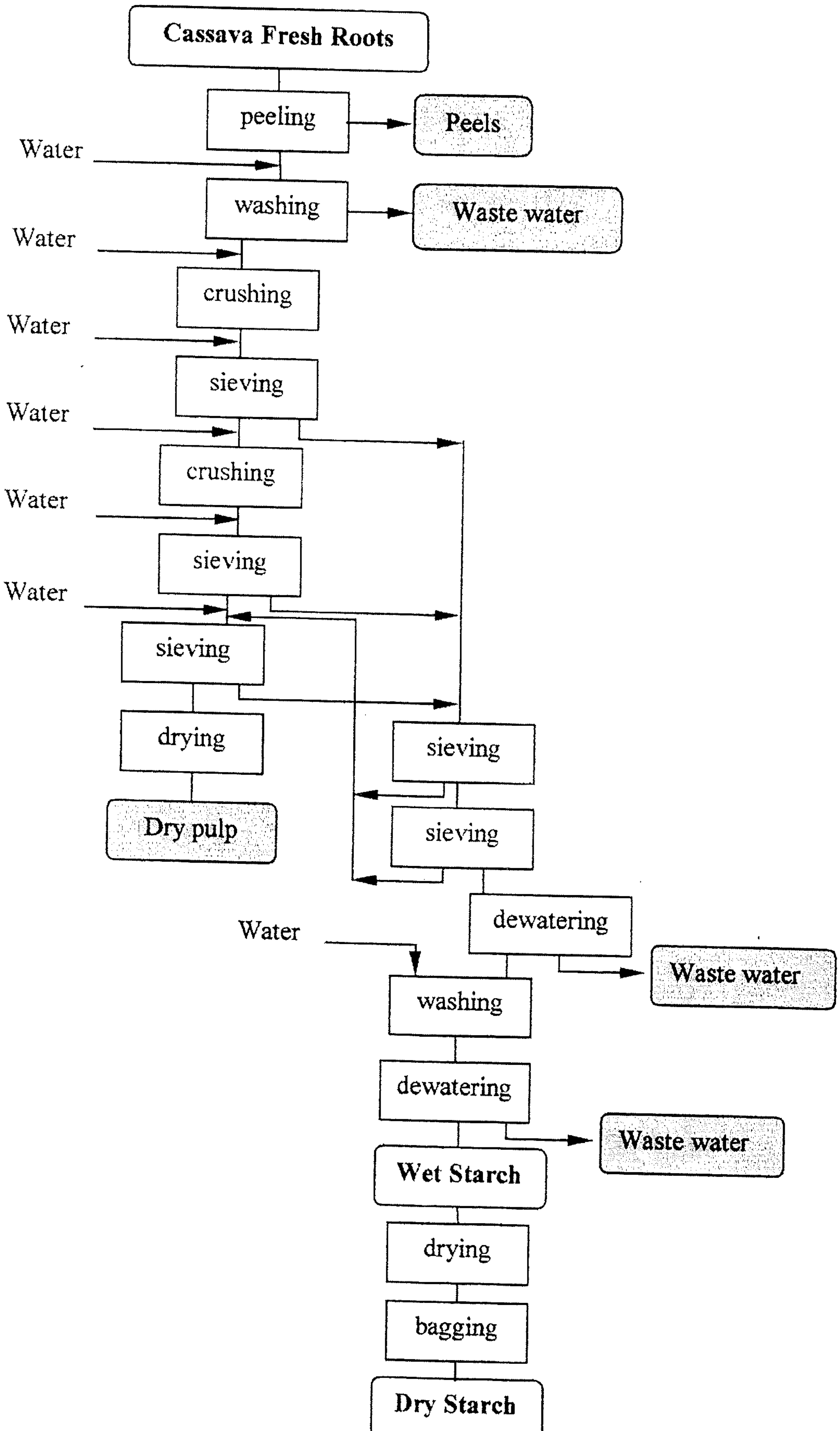


Figure 17. Flow chart for medium-scale production of cassava starch (Tamil Nadu).
***Source:** ERM, 1996.*

this increases to 400-500 kg of roots per day. This equates to a total daily processing load for the village of about 300 tonnes of roots.

India's starch industry centers on Salem district in Tamil Nadu. In this area, 850-1000 processing enterprises operate, each with a daily capacity of about 10-50 tonnes of cassava roots (equivalent to 2-10 tonnes of starch). This area probably represents the greatest concentration of such type of cassava starch processing in the world. The level of technology is small-to-medium scale, with large tanks used for starch sedimentation (Figure 17). The starch extraction process involves hand peeling, washing, mechanicalcrushing over a rotating drum fed continuously with water, followed by sieving/screening of the fibrous pulp. Starch is separated in sedimentation tanks and finally dried in the sun. The total production of starch in the area is estimated to be in the range of 375,000-400,000 tonnes per year (ERM, 1996). The two main products are native starch and sago (starch being a raw material for sago production). The industry is seasonal, usually operating at peak production for a period of 4-5 months per year, starting Oct/Nov.

The cassava industry in Thailand is the most developed in the world. Processing enterprises are large-scale, but are supplied by small-scale farmers. The total annual cassava production (about 18 million tonnes) is converted to 4 million tonnes of chips/pellets, and about 1.6-1.8 million tonnes of starch (Sriroth *et al.*, in preparation). The starch industry in its present form has undergone a series of structural changes, developing from a relatively large number (approximately 170) of medium-scale factories, utilizing simple technology of sedimentation, to a smaller number (approximately 51) of modern automated processing factories (Figure 18). On average, an individual starch processor can process between 400 and 1,200 tonnes of roots each day.

Africa

Annual cassava production in Africa is about 84 million tonnes, mainly in Nigeria (30), the Democratic Republic of Congo (16.8), Ghana (7.1), Tanzania (5.7), Mozambique (5.3) and Madagascar (2.4). Cassava is primarily produced by small-scale farmers and processed at the family- or village-level. Despite the small scale of operation, cassava production in Africa is highly commercialized, with as much as 45% of the total output marketed (Nweke, 1992). A great diversity of products are derived from cassava. The most representative are *gari* in West Africa (Figure 19), *chickwangue* in Central Africa (Figure 20) and *atap* and *ugali* in East Africa. The range of products in Africa is described in the COSCA study (reported in Nweke, 1992), and summarized in Figure 21.

Traditional processing techniques are flexible in their use of the different processing resources. Retting (soaking) is employed in humid regions (central Africa), while in the dryer regions (Western Africa) a fermentation step is usually included. Cassava granules are commonly produced in areas of high population density, while chips and flour are more widely used in those with low population density (Nweke, 1992). In some regions, techniques for making chips and flour are water-intensive, but in other areas only sunshine is required. A major feature of cassava processing in Africa is that villages in each climatic zone concentrate on making products for which the zone is endowed with the necessary resources (Nweke, 1992). Cassava processing has many technological pathways adapted to the use of locally available processing resources. Where water for fermentation is scarce, heaping or stacking fermentation techniques are used.

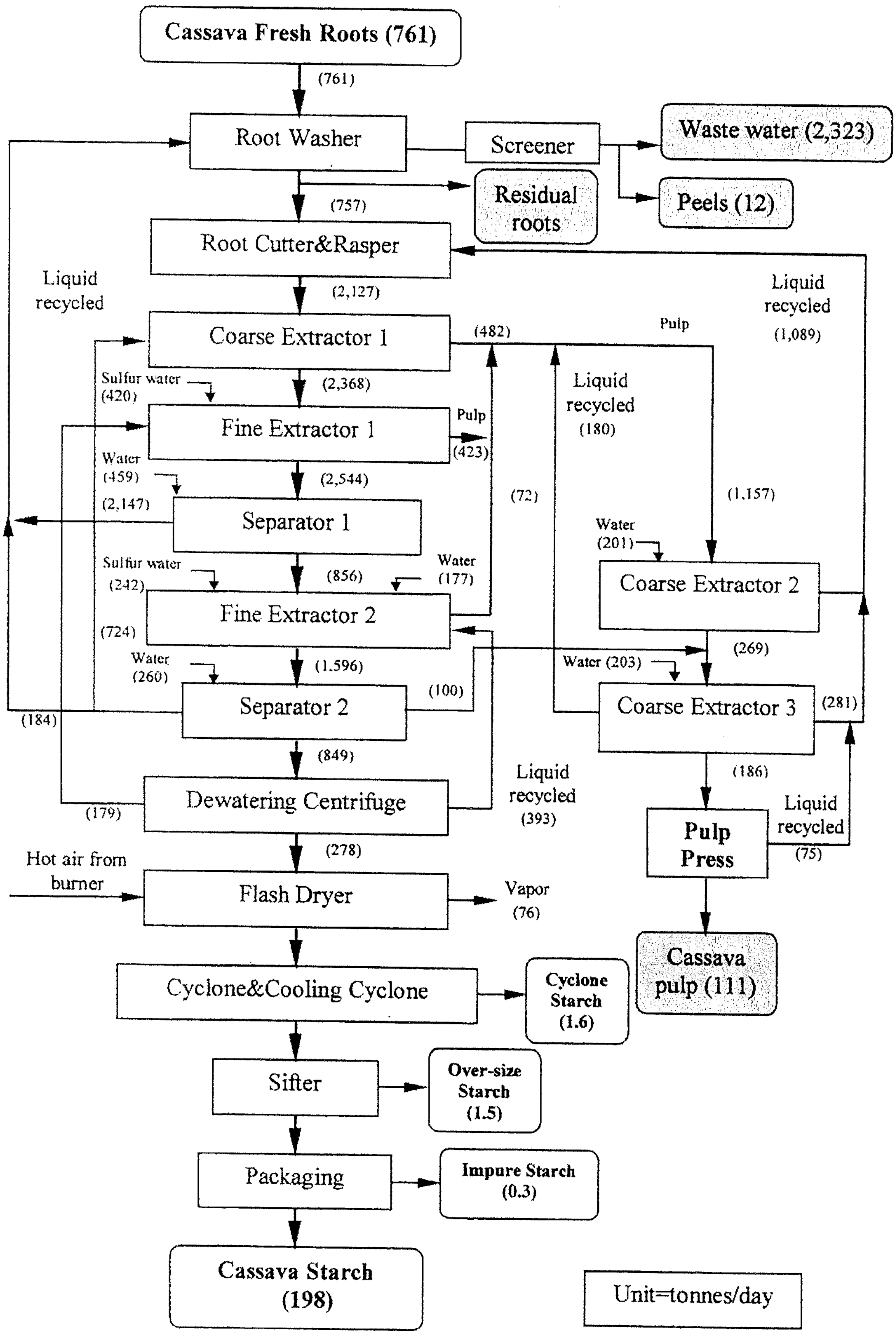


Figure 18. Flow chart for large-scale production of cassava starch.
***Source:** Adopted from Sriroth et al., 2000a.*

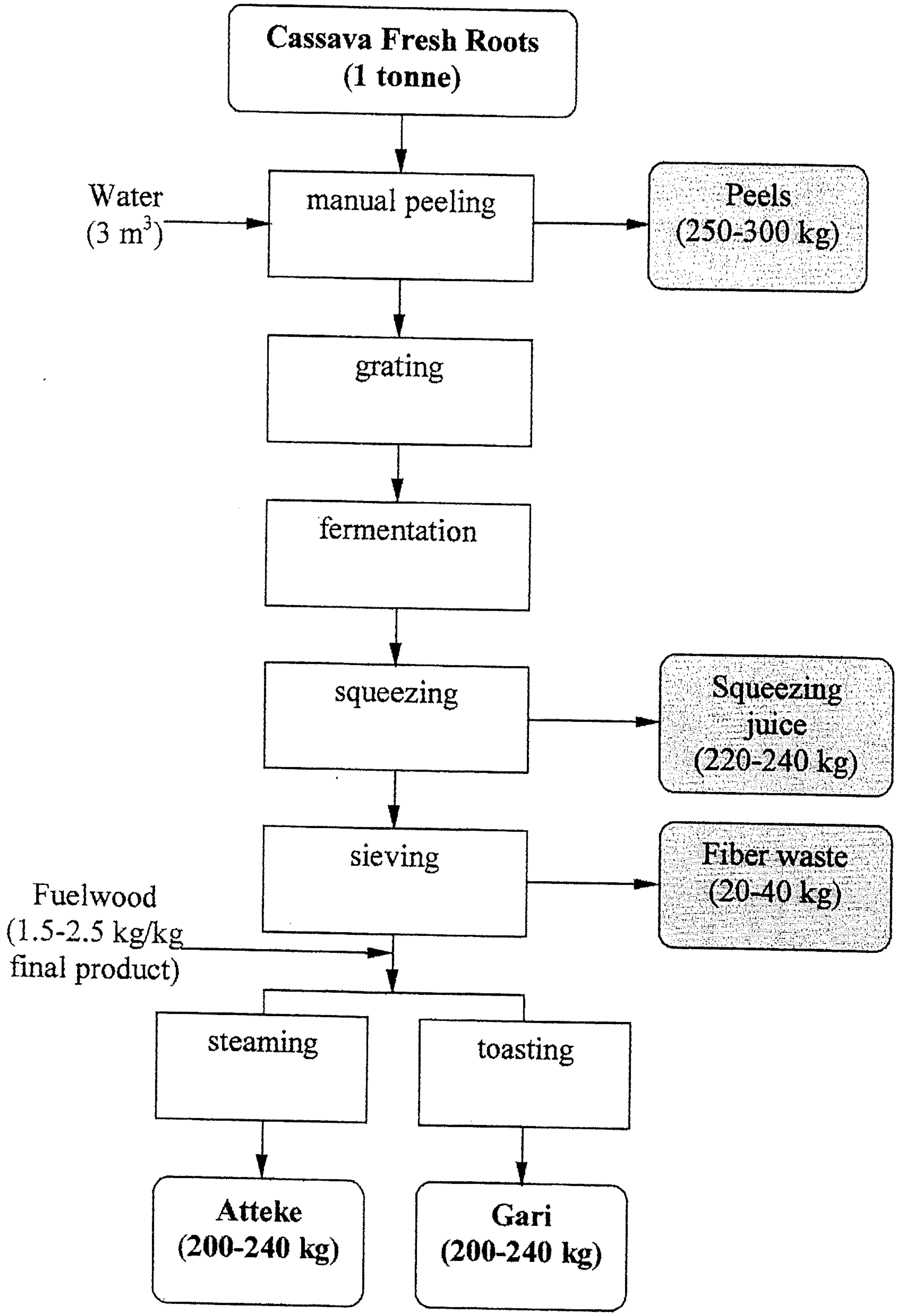
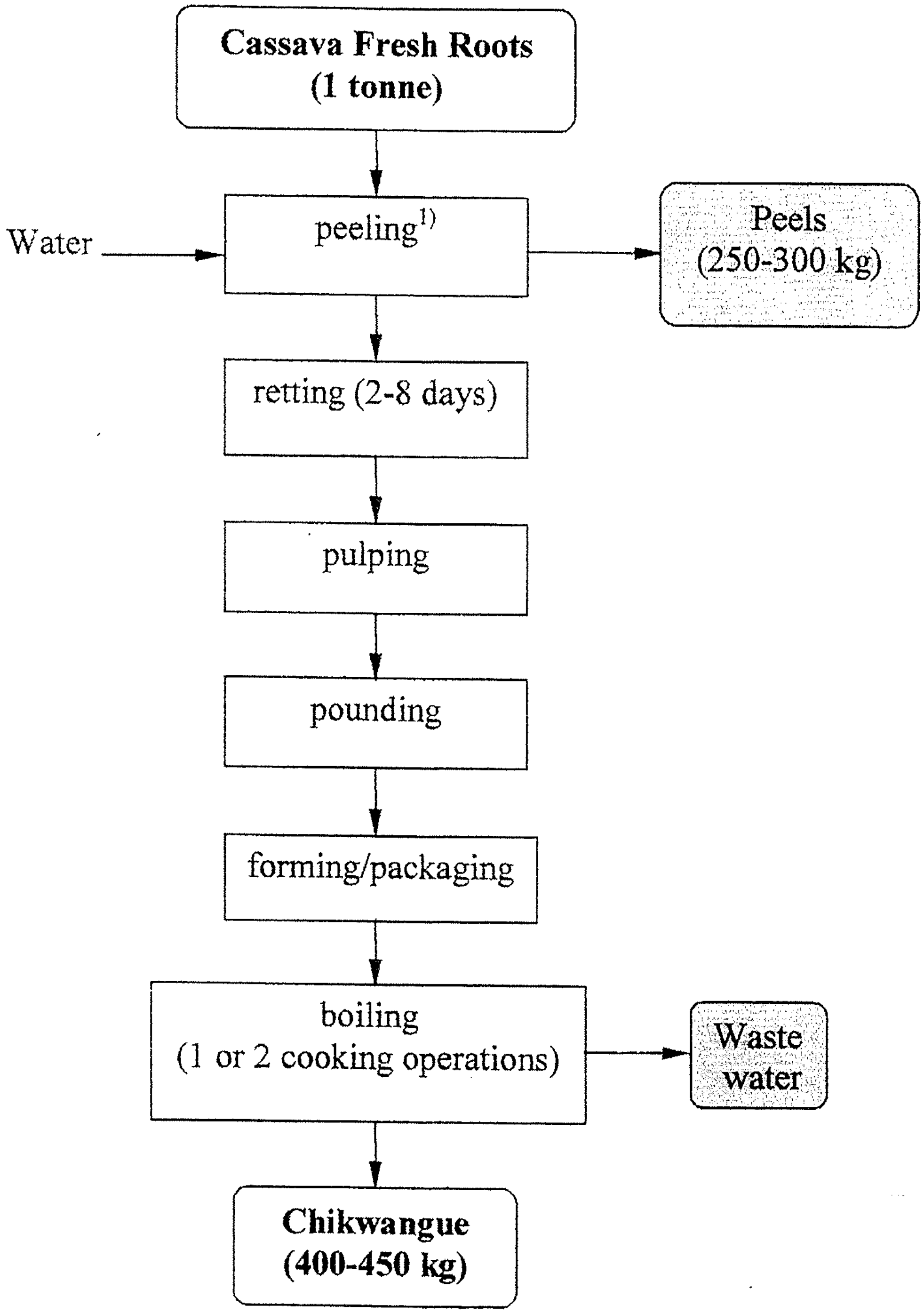


Figure 19. Flow chart for production of gari or atteke.
Source: *S. Chuzel. (personal communication)*



[1)]Time of peeling
-before retting (64 %)
-during retting (8 %)
-after retting (28 %)

Figure 20. Flow chart for production of chikwangue.
Source: *G. Chuzel. (personal communication)*

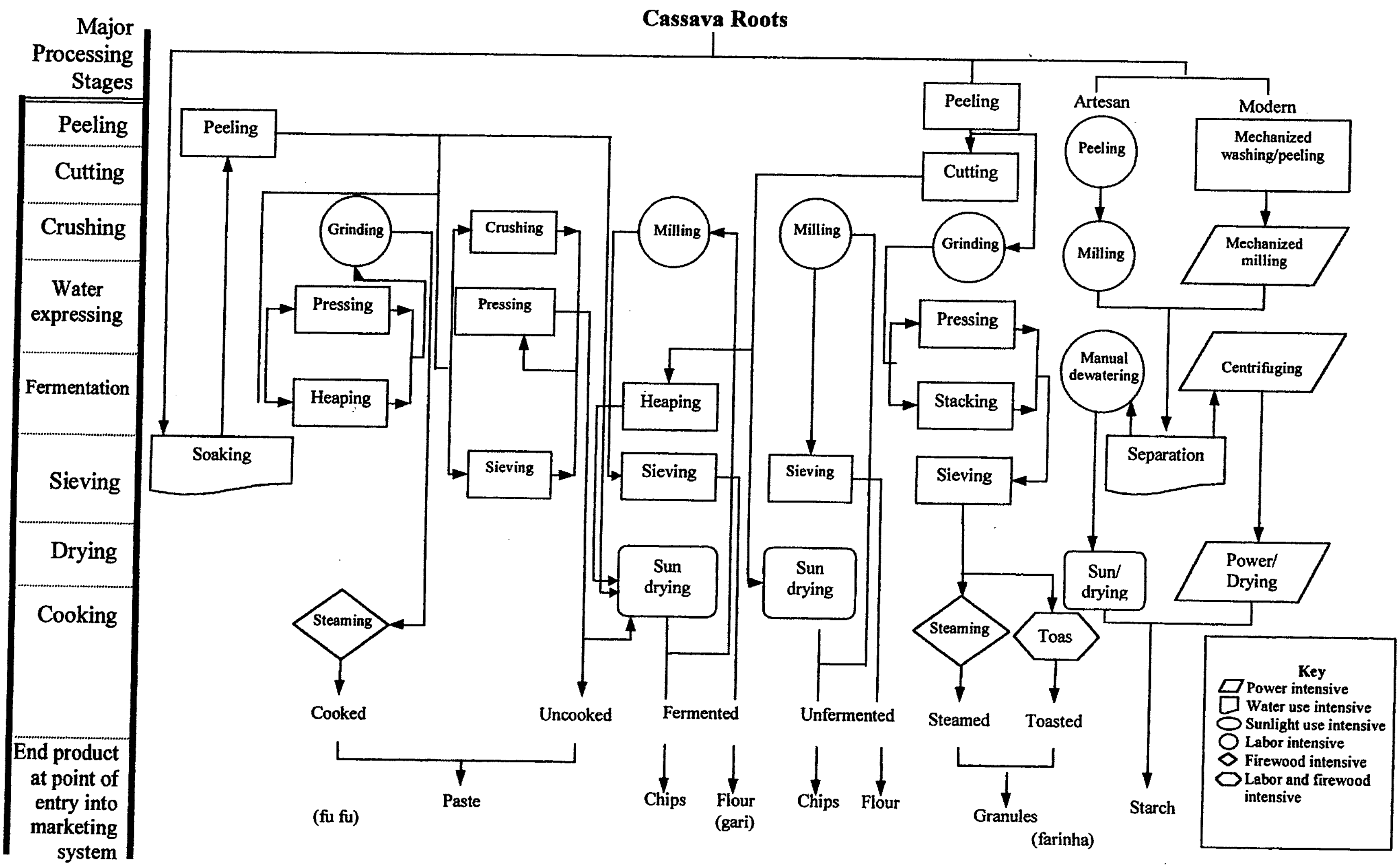


Figure 21. Unit operations in the processing of various cassava products.
***Source:** Adapted from Nweke, 1992*

This adaptation strategy has implications for the environmental impact of a processing method, minimizing a drain on natural resources. However, the balance between processing and environmental sustainability is threatened with technology changes from traditional to more automated processes.

Latin America and the Caribbean

Annual cassava production in Latin America and the Caribbean is about 32 million tonnes, mainly in Brazil (24), Paraguay (3.1) and Colombia (1.8). Cassava is used principally as fresh or processed roots for human consumption, but also to a lesser extent for animal feed and starch. In Brazil *Farinha* is a traditional mechanically dried product derived from cassava (Figure 22); it may also be prepared from sweet or sour (fermented) starch. In the northeastern region of Brazil *farinha* is processed by farmer-producers on a small scale, processing as little as 100 kg of roots per day. In southern Brazil, cassava is a large-scale industrial crop, and factories process about 10-50 tonnes of roots per day for *farinha* (Marder *et al.*, 1996). About 3 million tonnes of *farinha* are produced each year in Brazil, and depending on the maturity of roots, the yield of *farinha* varies between 30-40%.

In southern Brazil, cassava is also an industrial crop for starch extraction. The enterprises are large-scale, processing 200-500 tonnes of fresh roots per day. Brazilian legislation is strict on waste water management. All the factories have installed water treatment plants (aerobic digestion or lagoons). Two types of starch are produced:

a. **Native (sweet) starch**. Total production of 200,000 tonnes is processed from 18-24 month old roots by large factories handling 100-900 tonnes of roots per day. The final product is sun dried. Starch yield is 20% when roots are harvested at the correct time, and 18-19% when less mature roots are used. Several starch derivatives are produced from native starch, including glucose syrups and maltose (Henry and Westby, 2000).

b. **Sour (fermented) starch.** Total production is about 100,000 tonnes. Factories producing sour starch are smaller than those for sweet starch and are less sophisticated. Each processes about 20-25 tonnes of roots per day. Starch is produced in a manner similar to that described previously for sweet starch (Figure 16), except that after final settling, the wet starch is dug out and stored in fermentation tanks for 4-6 weeks. After fermentation, the starch is sun-dried. Starch yields are similar to those for sweet starch manufacture.

In Colombia, production of sour starch is concentrated in the Andean zone. Production ranges from 6,000-10,000 tonnes each year. In Colombia starch accounts for 3% of fresh root production. About 200 factories are capable of processing 1-4 tonnes of fresh cassava roots per day.

A similar small-scale industry exists. Traditional starch is also produced in the western region of Paraguay (about 60 small-scale processors producing a total of 9,000-10,000 tonnes of starch per year). In the northeast of Argentina there are 15 small-scale plants, with a total capacity of 2,000 to 3,000 tonnes of starch per year. The starch is mainly for use in the preparation of traditional cheese bread called *chipa*, similar to *pan de bono* or *pan de yuca* in Colombia and *pao de queijo* or *biscoito* in Brazil. The process used is at a low technological level (manual processing, equipment fabricated from wood) and is of low efficiency.

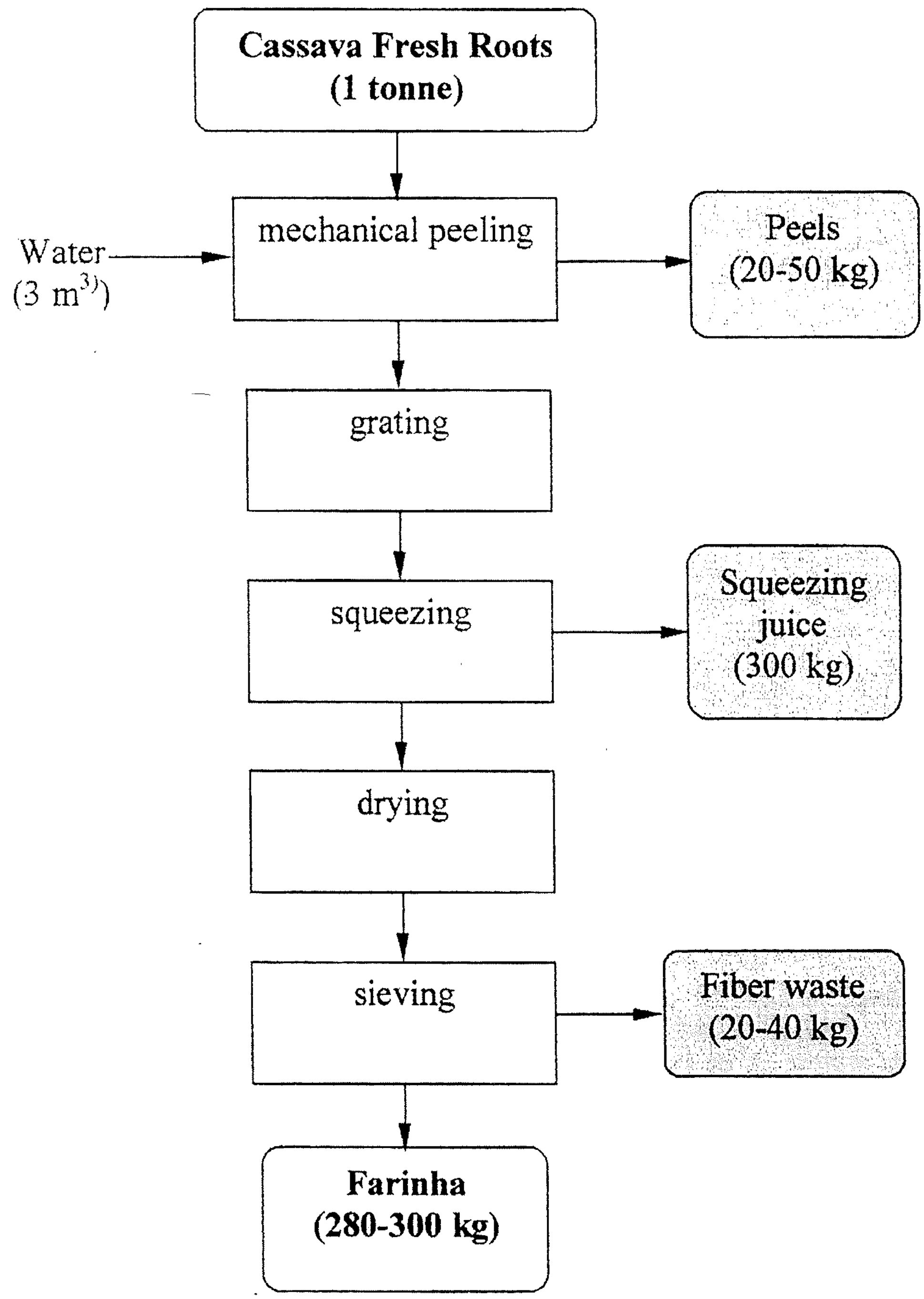


Figure 22. Flow chart for production of farinha.
Source: *G. Chuzel. (personal communication)*

Table 22. Types of waste and their environmental impact of various unit operations used in cassava processing.

Unit operation	Type of waste generated	Expected environmental impact
1. Washing	Organic matter, soil.	Little impact.
2. Retting	Cyanide diffused into rivers, ponds or back-water. Organic matter.	High HCN concentration in the waste water can be a problem if used directly on land. Dissipation is rapid if passed to waterways. Organic matter is a problem, causing high BOD and COD, and eutrophication of waterways and foul odors.
3. Peeling	Peels with high fibre and high cyanide content.	Can contaminate ground water supply during rain. Foul odor. Cyanide is a problem if used as a feed.
4. Squeezing	Effluent with high content of cyanide and organic matter (mainly starch).	High HCN may kill plants if effluent is allowed to run out on land. Dissipation should be rapid if released into waterways. Organic content may contaminate ground water supply and cause eutrophication of surface water and foul odor.
5.Drying and cooking	Cyanide vapors, ash (from firewood).	Cyanide vapor is not likely to be a problem unless processing is done in an enclosed space.
6. Sieving	Fibrous waste.	If exposed to rain, the seepage of organic material from stored waste could contaminate the ground water
7. Sedimenting	Starch residue. Waste water.	Foul odor Organic matter is a problem, causing high BOD and COD, and eutrophication of water ways.

Source: Adapted from Nweke, 1992.

In Venezuela, several medium- to large-scale cassava processing units are operating, mainly for production of native starch and glucose syrups (Henry and Westby, 2000).

Environmental impact

General background

Cassava processing methods are a combination of various operations, each having a different potential impact on the environment. In essence, all cassava products will involve some or all of the unit operations highlighted in Table 22 and Figure 21. The impact of cassava processing should be considered at two levels – broad scale and site-specific. Generally, the maximum impact will be at the site-specific level.

Two categories of methods typify cassava processing: methods that require a lot of water and those that do not require much water. Most traditional products, such as *farinha*, have modest water input requirements. Water consumption in the production of *farinha* is a relatively low 5 m^3/tonne product. For starch production, however, water is required at all stages irrespective of processing scale. Therefore, large volumes of water are needed -- on average 2-6 times more than for *farinha* production (Table 23). Large factories possess the technological ability to efficiently use water, often incorporating recycling systems (Figure 18). The theoretical maximum water conservation rate is never achieved, as a minimum quantity of water is required for complete washing of starch. If this need cannot be satisfied, starch quality is adversely affected.

Table 23. Water consumption in the processing of various cassava products.

		Water consumption	
Country/region	Product	(m^3/tonne fresh roots)	(m^3/tonne dry starch)
Brazil[1)]	farinha	5	
Brazil[2)]	sour starch	6-7	21-32
Brazil[1)]	sweet starch	10	
India/Tamil Nadu[3)]	starch	6	31
Ecuador[1)]	sweet starch	9-12	36-76
Colombia/Cauca[4)]	sour starch	12-15	60-75
Thailand[5)]	starch	10-18	25-45
Indonesia[5)]	starch	5-11	
Vietnam/north[6)]	starch	8	
China/Guangxi[7)]	starch	10	40

Source: [1)] *G. Henry (personal communication)*
[2)] *A. Westby (personal communication)*
[3)] *ERM, 1996.*
[4)] *Rojas et al., 1996.*
[5)] *K. Sriroth (personal communication)*
[6)] *Tran Quoc Viet, 1998.*
[7)] *Howeler, 1996b.*

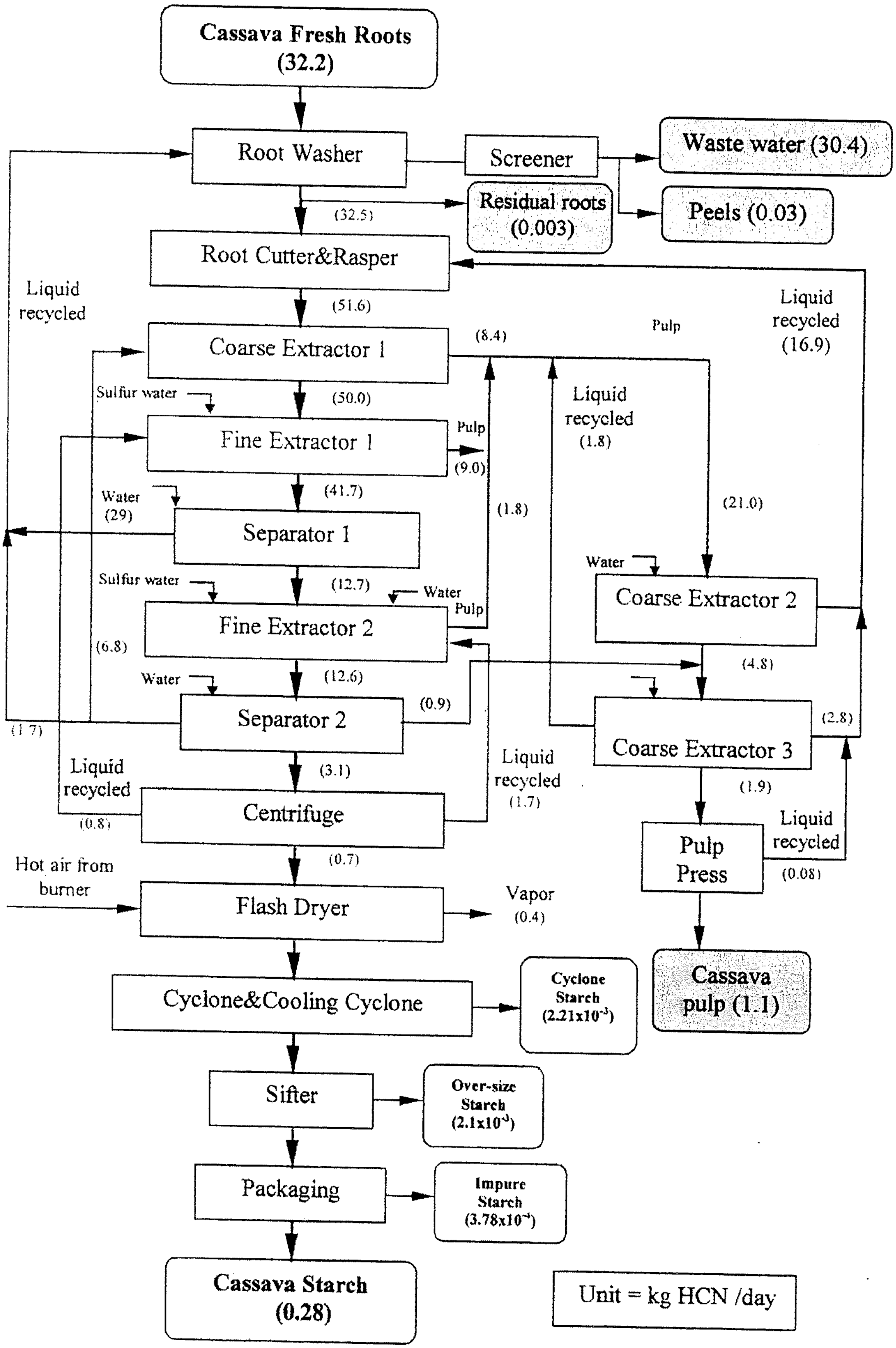


Figure 23. Flow chart of hydrogen cyanide during production of 200 tonnes of cassava starch per day.
Source: *Wanlaphathit, 1998.*

Water use and quality

As a rule, the amount of water used for starch processing varies, depending on the processing scale and the level of technological sophistication; requirements range from 21-76 m^3 per tonne of dry starch (Table 23). In some areas, micro- and small-scale processors are highly concentrated, and hence the seemingly modest individual water requirements should be viewed from the perspective of the high concentration of processors in a limited geographic region. For example, in Cong Hoa village, Vietnam, despite a modest requirement of only 2.4 m^3/day by individual processors, the total daily water demand for the area is 2,400 m^3, required to process 300 tonnes of roots (Viet, 1998). By comparison, to process a similar quantity of roots in Tamil Nadu 1,920 m^3 of water are required (ERM, 1996). In Thailand a typical factory processing a similar amount of roots requires 4,500 m^3 of water (Sriroth, personal communication), of which only 600 m^3 need be fresh water if an efficient recycling system is used (K. Sriroth and A. Annachhatre, personal communications) (Figure 16). The apparent increasing demand for water with scale of operation reflects a need for higher quality of the final product. The only study reviewing the impact of starch processing on groundwater supply suggests that such problems are usually site-specific and are not directly the result of starch processing (ERM, 1996). Despite perceptions to the contrary, starch processing in most areas probably does not consume a significant proportion of the groundwater. In Tamil Nadu, is an area of limited water supply and has a high concentration of starch processors, all of which obtain water from either open ponds or bore holes, Nonetheless, only 1.1-1.2% of the total groundwater recharge is consumed by the starch industry. Tamil Nadu possibly represents the extreme case for direct demand on groundwater supply. In many other cassava processing areas, water is also obtained from a surface water supply, especially streams and rivers.

The proportion of water used by the starch processing industry is small compared to overall use (i.e. industrial, agricultural and domestic), and broad impacts are not usually expected. Site-specific problems, however, can occur, especially if processors are clustered and are close to other major water users. Within a cluster of processors, the combined demand for water can have a significant impact on the water level in open wells in the immediate vicinity. This situation is exacerbated if the processors are situated close to domestic users. As a useful strategic planning tool, a model based on local recharge rates and demand by other users should be available to assist the determination of a critical number of processors within a cluster.

Water utilization in the production of other starch products is small and can safely be assumed not to have significant impact. There are no reports of water supply for starch processing being a problem in Brazil.

In Africa, the demand for water tends to be self-regulating when processing methods are traditionally selected and adapted to the amount of available water in a specific geographic location.

Wash water and effluents

Waste water from cassava processing, if released directly into the environment before proper treatment, is a source of pollution. In many areas where traditional processing is practiced, waste water is normally discharged beyond the "factory" wall into roadside ditches or fields and allowed to flow freely, settling in shallow depressions. Eventually this will percolate into the subsoil or flow into streams. In Colombia, starch processors usually return the effluent directly to streams and other surface water sources.

Besides large quantities of soil, discharged waste water contains a number of contaminating substances. Normally, waste water discharged from a cassava starch processing factory is acidic with a high organic matter content (soluble carbohydrates and proteins) and suspended solids (lipids and non-soluble carbohydrates -- starch or cellulose fibers). Waste water also contains cyanide as well as sulfur dioxide if this is used during the extraction process.

Cassava roots contain cyanogenic glucosides (the precursors of HCN) in various concentrations depending on the variety and growing conditions. Cyanide is released during peeling, slicing and crushing, such that these operations can reduce the level of cyanide to safe limits (Figure 23). The bound cyanide is converted to free cyanide during the milling operation. Forty to 70% of the total cyanide appears in the water used to wash the starch from the disintegrated tissue, and about 5 to 10% in fibrous residue used in animal feed (Arguedes and Cooke, 1982). Released cyanide, either in expressed juice, wash water or water spray, quickly evaporates. Evaporation of cyanide will occur either during processing or after discharge (Cooke and Maduagwu, 1978).

Source and description of waste water

(1)Squeezing

Water released from cassava during squeezing can have potentially harmful effects on the environment, especially if generated in large amounts. The main products of squeezing cassava are *gari* and *farinha* (Figures 19 and 22). Waste water is generated from two operations: pressing and washing. The press water, although produced in relatively low volumes (250-300 liters per tonne of roots), is the main problem because of its high biological oxygen demand (BOD) of 25,000-50,000 mg/l and a typical cyanide concentration of more than 400 mg/l (Table 24). In contrast, the BOD of wash water can be on the order of 500-2,500 mg/l.

Table 24. Comparison of the volume and composition of squeezed water from two types of cassava processing.

	Squeeze water production (liters)		Composition of squeeze water	
	Per tonne roots	Per tonne product	BOD (mg/l)	HCN (mg/l)
Farinha[1)]	289	1,142	25,000-50,000	400
Gari[2)]	220-240	1,050	na	na

Source: [1)] Arguedas and Cooke, 1982.
[2)] G. Chuzel. (personal communication)

(2)Aqueous extraction methods
Starch is the main product of aqueous extraction. Waste water is generated at three stages (Figure 18):

1. Root washing
2. Primary settling of starch milk
3. Secondary settling of starch milk

In the processing of starch, about 85% of the average 30 m^3 of water required to produce one tonne of starch is discharged as liquid waste; the remainder is lost through evaporation. The average amount of waste water discharged from all sources during starch extraction is between 20-40 m^3/tonne starch for a modern factory, and about 20-100 m^3 water/tonne starch for a medium-scale factory. High daily and within-season variation for waste water generated is normal.

A rigorous review of the literature is difficult because of differences in reporting formats, choice of analytical methods and sampling strategies. However, within these limitations general observations can be made.

The composition of waste water varies among different scales of processors (Table 25) and extraction methods. Total solids in the waste water from small-scale processors in north Vietnam are about 1,500 mg/l and the total nitrogen content about 15 mg/l. These values reflect a tendency to maximize starch yield at the expense of quality. By comparison, waste water released by medium-scale processors (India) contains about 4,100 mg/l total solids, 70 mg/l total nitrogen and has a BOD of 4,900 mg/l. Changing the extraction technology can markedly affect starch quality, as shown by the comparison of waste water measurements from Thai cassava processors, taken 25 years apart – the earlier when sedimentation was the main method for starch extraction and the later one from a fully automated modern factory. Waste water from the more technologically sophisticated processors is purer. For a modern factory, typically found in Thailand or Indonesia, the composition of combined waste waters will be similar to that shown in Table 25.

Each stage of starch extraction creates waste water with different amounts of contaminating materials. For example, waste water from decanters is high in organic substances and contains starch, fat and protein. The chemical oxygen demand (COD) of waste water from the decanters is 30,000 mg/l, and the combined waste water 15,000 mg/l. The composition of waste water produced at various processing stages for a medium-scale processing operation is given in Table 26. As a comparison, international waste water standards are given in Appendix 3.

Impact

Problems created from waste water occur when this is removed from the factory, especially if handled incorrectly. Waste water generated by starch and *farinha* processors is sometimes directed into pits (starch processors in Brazil) for conversion, but depending on the soil characteristics, partial leaching may contaminate the groundwater, while overflow may affect surface water. Waste water is also released directly to neighboring land (Vietnam, India), or is returned directly to streams and other surface water sources (sour starch producers in Brazil and Colombia).

Table 25. Quantity and composition of waste water from cassava starch processing factories of various scales.

	Brazil [1]	Brazil [1]	Vietnam [2]	India [3]	Colombia [4]	Thailand	
						Late 1970s [5]	1995 [6]
Scale	Small	Large	Small	Medium	Small	Medium (intermediate technology)	Large (continuous process)
Wastewater (m^3/t starch)	71	40	40	31	60-75	20	25-45
PH	NA	3.8-5.2	NA	4.5-5.6	3.9-4.7	3.4-6.5	4.5-6.5
Total solids (mg/l)	5,000	5,800-56,460	1,500	4,000-6,600	2,680-10,020	234-2592	7,604
Suspended solids (mg/l)	NA	950-16,000	NA	1,868-2,960	NA	NA	2,642
Total dissolved solids (mg/l)	NA	4,900-20,460	NA	3,425-3,680	NA	1.3-30.1	6,483
BOD (mg O_2/l)	5,000	1,400-34,300	NA	4,600-5,200	1,500-8,600	2,508-16,880	3,608
COD (mg O_2/l)	NA	6,280-51,200	NA	5,631-6,409	4,000-12,800	4,950-36,840	8,842
Total nitrogen (mg N/l)	NA	140-1,150	15	66-72	29-233	84-375	172
HCN (mg CN^-/l)	60	22.0-27.1	NA	NA	1.2-4.0	NA	9.0

Source: [1] *Cereda and Takahashi, 1996.*
[2] *Tran Quoc Viet, 1998.*
[3] *ERM, 1996.*
[4] *Rojas et al., 1996.*
[5] *Tanticharoen et al., 1986.*
[6] *K. Sriroth. (personal communication)*

Note: NA = data not available

Table 26. Typical waste water composition at each stage of a small- to medium-sized processing factory in Salem district, Tamil Nadu, India.

	Root washing	Primary settling	Secondary settling
pH	6.5-7.5	4.3-5.4	4.5-4.7
Total solids (mg/l)	550-700	4,200-4,400	4,000-6,600
Suspended solids (mg/l)	400-500	680-730	1,868-2,960
Total dissolved solids (mg/l)	150-200	3,520-3,670	2,132-3,620
BOD (mg/l)	40-60	4,800-5,700	3,400-6,018
COD (mg/l)	100-150	5,760-6,840	3,870-6,670
Total nitrogen (mg/l)	30-38	70-75	65-74

Source: ERM, 1996.

(1) On groundwater

(a) Magnitude

Contamination of groundwater is often the outcome of seepage of untreated effluent into shallow and deep aquifers. This is a problem in a few areas, such as India (documented) and Vietnam (cited). From the limited information it is clear that open wells and bore holes in close proximity to starch processors can be contaminated by high levels of suspended solids and high BOD (in Tamil Nadu BODs of up to 23 mg/l were recorded (ERM, 1996); US Public Health Department drinking water standard is 5 mg/l). Nevertheless, even in areas of intensive starch processing (e.g. Tamil Nadu), the proportion of contaminated sites is minimal, with the majority not affected. Geology and soil characteristics are important in determining if the groundwater supply will become contaminated; porosity and degree of saturation are the principal factors.

Cyanide contamination, even site-specific, of groundwater seems not to be a problem. In areas close to intensive cassava processing in India the cyanide concentration in the groundwater was found to be below detectable levels. Despite this apparent low incidence of contamination, it is still important to know the frequency of site-specific impacts and be able to predict problem sites. It should be noted that studies are limited and the same conclusions may not be true of a site with geology/soil characteristics that promotes seepage of waste water.

(b) Significance

Depending on the geology, groundwater supplies can remain protected from contamination. However, where physical conditions permit, untreated effluent can reach groundwater in sufficient quantities to pollute open wells and bore holes. If such conditions prevail, groundwater quality may be affected, leading to health problems of nearby communities. This may be the case in Cong Hoa village, Vietnam. However, further surveys are needed to verify the claims of local health officials.

Complaints from the public of stomach ailments are few, but consistent. The possibility of drinking groundwater contaminated with starch effluent, in the areas neighboring starch-processing sites, should not be ruled out. In Cong Hoa village pollution caused by draining cassava waste water to surrounding land is claimed to be the cause of detrimental health effects. Reports by various health authorities claim that the incidence of lung and digestive tract diseases in the village is 22-27% higher than in other villages.

(2) On surface water

Surface water includes all rivers, streams, canals, ditches, lakes, reservoirs, lagoons, estuaries and coastal waters. Environmental impact on surface water may be due to the addition of substances, heat or microorganisms to the water. This leads temperature changes and/or increases in microbial populations. The main problem originating from cassava processing is through the addition of organic substances. This results in eutrophication, which in-turn is responsible for an increase in the number of microorganisms and the growth of algae. This can alter water quality and/or change the aquatic ecology, affecting plants and animals, human health and visual aspects.

(a) Magnitude

The impact to surface water will depend on environmental conditions during the processing season; in the dry months the effects are most apparent. The magnitude depends on the concentration of processors and their distance from water bodies capable of facilitating rapid dispersal. Streams, slow flowing rivers, ponds and lakes are therefore most at risk. Surface water can remain contaminated (high BOD levels) even after dispersal downstream from a factory (Table 27). In extreme cases, surface water can become anaerobic due to the formation of a thick crust forming on the water surface. However, usually the main effect is that water becomes eutrophic from excessive organic matter loading. Contamination of surface water has been reported to be severe in several areas of Vietnam (Viet, 1998). No measurements are available, but reports suggest a high degree of eutrophication.

Table 27. Impact of release of starch factory waste water on the quality of surface water.

	COD (mg/l)	BOD (mg/l)	Suspended solids (mg/l)	pH	HCN (mg/l)
Supernatant liquor	14,778	3,370	4,979	5.38	62
Wash water	3,475	618	1,797	6.21	0
River water (down-stream from factory)	79	3,052	232	6.43	0

Source: A. Westby (personal communication)

The water used in aqueous extraction methods will help to dilute the cyanide. Hence, there is little risk of water contamination from cyanide on a broad scale. However, site-specific effects can be significant. For example, high cyanide content in waste water discharged by sour starch processors in Brazil (representing 50-60% of the total cyanide content of the roots) was not present in river water downstream of the factory; in fact, no cyanogens could be detected. In comparison, when microtox and tropical duckweed were exposed to untreated effluent from a cassava starch factory in Thailand, the waste was found to be toxic to the plants. The toxicity was thought to be associated with the high cyanide content and to a lesser extent other components (Bengtsson and Triet, 1994). Cyanide content in by-products and wastes also depends on the cassava variety. The high yield varieties used throughout Asia generally contain high amounts of HCN. For production of 200 tonnes of starch/day, about 800 tonnes of roots are required, which will contain about 32 kg of HCN. Generally, the HCN concentration of fresh peeled roots varies from 6-250 mg/kg fresh weight. The factory with a process discharge of 2,323 tonnes of waste water will also discharge about 30 kg HCN, equivalent to 13 mg HCN per liter of waste water (Figure 23). In Vietnam, small-scale processors released 28 mg HCN per liter of waste water.

(b) Significance

The significance of surface water contamination should be interpreted from the perspective of seasonal variation. It is most acute in an extended dry season. Care should be exercised to identify all possible sources of contamination, as starch processing may only be a minor contributor. This is especially difficult when examining the impact of processing on river water quality. It is also not easy to determine the number of lakes and ponds affected by starch processing because of problems in distinguishing between starch effluents, agricultural run-off and domestic sewage. Reports suggest that in some cassava processing areas, where increasing agricultural intensification has taken place, many water bodies have become progressively more eutrophic. The contribution to this problem from cassava processing is difficult to assess, except for a few areas where cassava processing is the only source of effluent to the body of water.

Environmental problems from cyanide in wash water or expressed liquid can occur if the water is used, without dilution, for irrigation (e.g. young stages of rice, vegetables) (Bengtsson and Triet, 1994). Negative effects on local agriculture and sensitive stages of fish and crustacean populations in receiving water bodies can also be expected if the concentration of cyanide increases above 0.3 mg/l. However, this has never been documented.

Starch effluents may have significant environmental effects on lakes and ponds, ultimately affecting local communities. Effluent from the Brazilian sour starch processors is claimed to kill fish and other animals. Reports concerning contaminated water courses in processing areas increase towards the middle and end of the dry season. Further research is required to substantiate such claims, as there has not been any systematic monitoring.

Waste water generated by small-scale processors, unless they are highly concentrated, has minimal impact on the environment. In contrast, the much higher volumes generated by larger factories can have a significant and serious impact on the environment.

Solid wastes

Solid waste is created by all forms of cassava processing. For example, in the artisan production of starch about 60-66% of the fresh root is liberated as waste material (including water). Solid waste from cassava starch processing is divided into three categories:

1. Peelings from initial processing
2. Fibrous by-products from crushing and sieving (pulp waste)
3. Starch residues after starch settling

(1)Magnitude

An indication of the proportion of solid waste produced during cassava processing is shown in Figures 15-21. In starch processing, pulp waste is the main problem, especially for the bigger factories, which produce massive quantities (each year the 51 starch processors in Thailand will generate about 1 million tonnes of pulp waste). Dealing with this waste is difficult, as it is not easily dried, due to its high moisture and starch contents (Sriroth *et al.*, 1999a). Smaller scale processors have less of a problem as the smaller volumes are more easily disposed of. For example, starch processors in Cong Hoa village, Vietnam, produce from each 100 kg of roots: 14.5 kg peel, 23.5 kg pulp and 3.6 kg residue. During the processing season, 130-160 tonnes of residue are produced daily (equivalent to 200 tonnes of residue per family each year). Yet despite such quantities it is not locally regarded as a source of pollution (Viet, 1998). Another report for a similar scale of processing suggests that, on a dry weight basis, pulp constitutes about 20% and residue 0.8-1% of the original roots (Preston and Maurgucito, 1992).

Peel waste is also generated in the production of *farinha*, *gari*, and *chikwangue*. *Farinha* factories in Brazil generate 2,000-5,000 tonnes of peel each day. Only in the case of *chikwangue* are there reports of a possible problem. Inappropriate storage of solid waste for long periods is the main issue, especially with heavy rainfall. This culminates in the production of leachate that can contaminate groundwater. In the dry season there is little problem, but if stored through the monsoon season the problem can be quite significant.

(2)Significance

Usually even the small-scale processors manage their solid waste well. There is therefore little or no problem. In many areas, such as Vietnam, despite the large amounts of residue produced, it is usually disposed of quickly – sold as animal feed or dried and used as fuel. In India solid residue is dried and sold as cattle feed or soil conditioner.

Under most conditions, solid waste will not create an environmental problem. However, if conditions for storage are inappropriate, problems can occur during periods of heavy rainfall. In the dry season, there is little problem except for a foul odor.

Visual impacts

(1)Magnitude

Most factories discharge untreated effluent to the land, often in quantities that exceed the field capacity of the soil. This results in stagnant ponds and ditches that increase in number and area as the processing season progresses. These ponds are unsightly and have a negative visual impact on the environment.

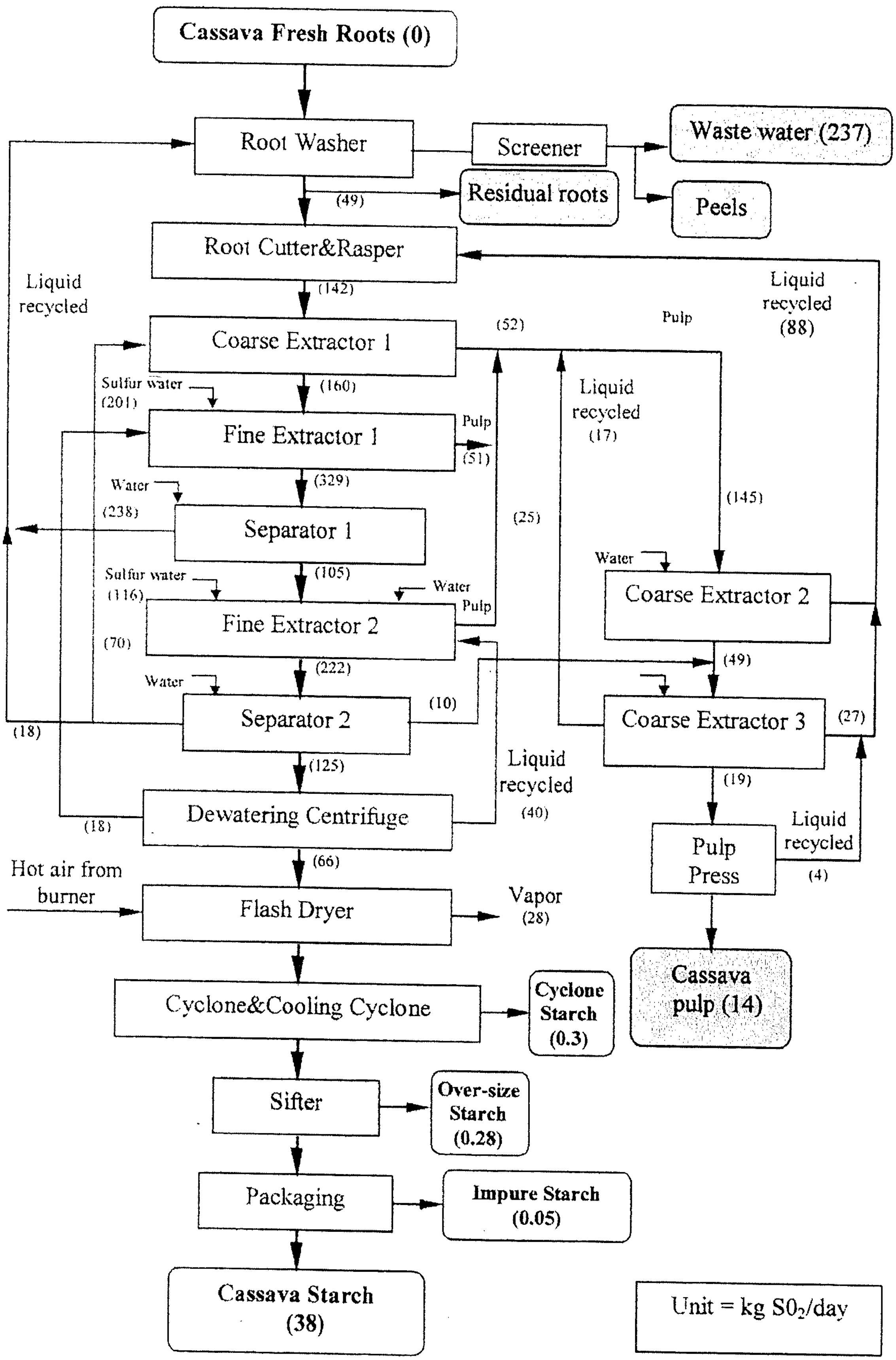


Figure 24. Flow diagram of sulfur dioxide used for production of 200 tonnes of cassava starch per day.
Source: *Wanlaphathit. 1998.*

(2)Significance

The major significance is the nuisance of this impact to a large number of people. This type of pollution reinforces the negative image of starch processing.

Chemical use

Almost all large-scale factories use sulfur dioxide as a bleaching and anti-microbial agent – in Thailand only one of the 59 factories does not use sulfur dioxide (Sriroth *et al.*, 1999b). Sulfur dioxide is discharged mainly to the atmosphere (Figure 24). If used, 1.6 kg of sulfur is burned to sulfur dioxide for each tonne of starch. For production of 200 tonnes of starch, resulting in 2,323 tonnes of waste water, about 38 and 237 kg of sulfur dioxide were found in the starch and waste water, respectively. The rest is released to the atmosphere. Release of sulfur dioxide to the atmosphere by a cassava processor is assumed to be safe, but no systematic study has been undertaken to substantiate this assumption.

Atmospheric pollution

Hydrogen cyanide

As already mentioned, most of the cyanide released during cassava processing ends up in the waste water and will eventually evaporate into the atmosphere without detrimental effects. However, the effect of volatile HCN on the health of cassava processors may be a problem that requires further study, especially in the design of toasters and boiling equipment. Processors (mainly women and children) producing *gari* in ill-ventilated sheds are often exposed to high levels of HCN liberated during frying. Design of the processing facility with adequate ventilation is critical. In Thailand, there are reports (K. Sriroth, personal communication) that high-speed grating machines produce levels of HCN in dust and water sprays that effect the health of workers if located in a not well-ventilated space. This needs further study.

Dust

Dust can also be a problem in areas of intensive production of cassava; as high as 10% of the dry weight of cassava can be lost as dust. Reference This is mainly a problem in large-scale chipping and drying operations (Thailand).

Odor

Odor is generated from an uncontrolled fermentation of the organic matter in cassava processing waste. This is a cited problem in Vietnam, India, and Thailand, especially during the processing season. Odor is the most noticeable and widespread impact. It affects the greatest number of people and increases in impact as the processing season progresses. Despite being unpleasant and widespread, the significance of this impact is small. The biggest problem is its contribution to the image of cassava processors.

Effect of cassava processing on forest resources

Wood is the principal energy source where heat is required in small-scale cassava processing, e.g. boiling, drying or toasting. The use of wood is common in Africa (*gari*, *attieke*, *chikwangue*), in the Caribbean (starch) and Brazil (*farinha*). Wood supply is an increasing problem in many cassava-growing areas.

Conclusions

The main problems of cassava processing are its unattractive visual display and odor. The impact of other forms of pollution is generally not as large as one might imagine given the magnitude of the visual display. Different types of products of cassava processing will each impact the environment differently; these are summarized in Tables 28 and 29.

Table 28. Summary of the magnitude and significance of the broad-scale and site-specific impacts of cassava starch factory wastes on the environment.

Environmental Component	'Broad-scale' impacts		'Site-specific' impacts	
	Magnitude	Significance	Magnitude	Significance
Impacts on ground water supply	—	—	+	+
Impacts on groundwater quality	—	—	++	++
Impacts on surface water quality	—	—	+	++
Storage of waste residue impacts	—	—	+	++
Health effects	—	—	+	+
Odor	+++	++	+++	++
Visual Impacts	+++	++	+++	++

Source: ERM, 1996.

Table 29. Processed cassava products and their impact on the environment.

	Ground water		Waste water	Solid residue	Atmospheric emissions	Odor	Visual display
	Supply	Quality					
Starch							
-Small-scale	+	++	++	++	-	+++	+++
-Large-scale[1)]	++	+++	+++	+++	+	+++	+++
Flour	-	-	-	-	++	-	-
Chips	-	-	-	-	+++	-	-
Gari	-	++	+	++	-	++	++
Chikwangue	-	++	+	+	-	++	+
Farinha	-	++	+	++	-	++	++

[1)] Assuming no re-cycle system
Source: C. Oates, unpublished

EXISTING CASSAVA PROCESSING/ENVIRONMENT KNOWLEDGE BASE

Currently available technologies to control pollution

Dealing with a waste situation

Small-scale processors, when well-dispersed, will have minimal impact on the environment due to the low discharge rates. Large-scale processors are more easily monitored, as they are few in number, and will have the financial and technical resources to deal adequately with waste management. Environmental pollution from medium-scale cassava processors is the more difficult to deal with. At this level of development, plant concentration and individual plant discharges can easily combine to create significant environmental impact. Yet, each processor has limited resources (financial and technical) to deal with environmental waste. Compounding the problem is our limited ability to develop a targeted, low-cost treatment processes for small- and medium-scale cassava processors given our present knowledge. Basic knowledge on environmental impact is still lacking, and without this information it is difficult to develop appropriate technologies that do not negatively impact the environment.

Given that suitable technologies are available or can be developed, the problems of pollution from cassava processing are more social and economic in nature than technological. Interventions, usually from the government, are required. Most governments recognize the need to control waste produced by cassava factories, but they are equally aware of the economic risk involved in such a strategy. Accessible technologies for most scales of processing are available; however, the cost of implementing the technology is, in many cases, prohibitive. According to starch processors, the installation of pollution control devices can be 20-50% of the total investment cost of a large-scale factory. Full implementation of strict environmental controls too quickly can have negative consequences, forcing the industry to forfeit its competitiveness. In many countries two policies operate -- those applied to established processors and stricter requirements imposed on new entrants. The scale of a processing enterprise is important; the smaller number of large-scale processors is, logistically, easier to regulate than a large number of small processors.

In Brazil, the government has intervened through legislation and recommendations for waste treatment technology. The legislation passed in 1992 requires all processors to reduce waste water BOD by 80%, or render it such that the BOD of the water course, after receiving the treated waste, is less than 5 mg/l. Unfortunately, the government seems to be slow in enforcing the regulations (G. Chuzel, personal communication). In contrast, the government of Thailand enforces 'clean-up standards' that must be followed by all factories. The government of Colombia, through a regional agency (CVC) is now conscious of the need to develop a cleaner technology for sour starch extraction. Joint projects are currently being carried out to develop appropriate technologies for waste water treatment, such as bamboo filters and lagoons. However, since the implementation of this stricter legal framework for waste management in 1999, the livelihood of small-scale processors is being threatened as non-complying units have to close.

Dealing with environmental problems resulting from processing is generally regarded as a necessary expense with no direct return. This does not have to be the case. New opportunities can be realized through tackling of environmental problems, especially when the industry is still developing. At that time, strategies do not have to be dovetailed into the restraints of an existing structure, but can be built into the development process.

A number of approaches are used to 'clean' environmental problems created by cassava processing. For a processor to use such 'end of the pipe' technology, developmental work is required. The investment in new, or modification of existing, technologies would be more efficiently directed to investing in improving, or at least preventing the problem. If the only choice is to deal with an environmental problem, it is recommended that efficiency be compromised and the most suitable available and fully developed technology chosen.

In cassava-processing areas dominated by small to medium-sized enterprises, none of the producers has an effluent treatment system capable of treating waste to permissible levels. Most waste is discharged without any treatment. Some factories store the effluent in settling tanks for a number of days before discharge; in this case, BOD and COD levels are reduced and most cyanide evaporates. Others dig effluent pits and channels, which, depending on the conditions of the underlying soil, can provide an adequate means of disposing of waste.

Treatment technologies for wastes from processing

Technologies available for treating cassava processing waste (from small and large factories) include:

- *Land filling*. This is sometimes used to dispose of solid residue.
- *Use as animal feed.* Use of solid waste for further processing into animal feed is practiced in many regions, including South America (Pereira, 1987), Africa (Montilla, 1977; Adebowale, 1981, 1985; Tewe, 1987; Adeyanju and Pido, 1978; Obioha *et al.*, 1985) and Asia (Hutagalung, 1983; Manilal *et al*, 1991). This is widely practiced, but does have limitations depending on the availability of other resources. For example, in Cong Hoa village, Vietnam, use of waste as animal feed is restricted by the amount of available protein to supplement the carbohydrate, and by a lack of knowledge. One novel approach has been to develop an integrated cassava starch processing/bioreactor/aquatic plants/animal production/system. In this system, the cassava is indirectly used as a source of animal feed (Viet, 1998).
- *Ensiling of solid residue*. Ensiling lowers the cyanide level to one that is non-toxic, leads to a reduction in pH to 4.0 and allows lactic acid to build-up. The product is subsequently used as animal feed. (Nguyen Thi Loc *et al.*, 1997).
- *Fermentation of cassava peel.* Cassava peel is a major residue in some countries. Utilization of the peel is limited by its low digestibility and toxicity from extremely high levels of hydrocyanic acid. Fermentation not only reduces toxicity, but the enzyme-resistant ligno-cellulose material is converted into a more digestible substrate. Following fermentation, cassava peel can be formulated into pig and poultry feed (Ofuya and Obilor, 1993).
- *Use of waste water for irrigation.* A traditional method of dispersing of processing wastes is to return it to the land as irrigation water. This requires careful monitoring to ensure that long-term soil degradation does not occur. Use of waste water for irrigation or as a source of fertilizer may be restricted as the high HCN content can have a negative effect on plant growth (Taesopapong and Bhanuprabha, 1987; Bengtsson and Triet, 1994). In one study cassava waste water was used as a direct fertilizer for duckweed at a dilution rate greater than 60% (waste in water). All duckweed died; a dilution of 10-20% was required for plant survival.

- *Infiltration of waste water into the soil.* In many sites, especially those where small- and medium-scale processors predominate, waste water is minimally treated by channeling into shallow seepage areas, ideally situated away from natural water courses and groundwater abstraction points.
- *Storage in aerobic or anaerobic lagoons.* Some of the starch factories in Brazil, India (in Kerala), Vietnam and Thailand have built anaerobic and aerobic lagoons to treat waste water before disposal. These units are of varying efficiency, require a large area of land and are capital intensive. In anaerobic digestion of cassava waste, cyanide is released in the fermentation liquor and then liberated by enzymatic and non-enzymatic reactions. The removal of cyanide has been shown to be sufficiently fast to maintain a cyanide concentration in the reactor, which is non-inhibitory for methanagenic bacteria (Cuzin and Labat, 1992).
- *Anaerobic digesters.* Traditionally anaerobic digestors have been used for the treatment of agricultural wastes. These processes require large tanks or bioreactors and long retention times of 20-25 days. Recent advances in treatment technology and knowledge of microbial process control have led to the development of high-rate anaerobic treatment processes, some of which are being contemplated or used by the cassava starch industry. High-rate anaerobic treatments make use of microbial films to achieve high cell residence time. These processes operate in low hydraulic retention time and can process large amounts of organic material. Biofilm processes used by the industry comprise different engineered configurations, such as fixed bed, moving bed, fluidized bed, recycled bed and upflow anaerobic sludge blanket (UASB). All these reactors can handle loads up to 20-30 kg COD/m^3/day). All of these processes require a relatively small reactor size, and a vastly reduced requirement for land and capital. The following systems are frequently used:
  - **a.** Fixed bed: (anaerobic filter, packed bed filter, packed bed, submerged filter, stationary fixed film reactors). The principle of operation is that the support material is also the surface for attachment of the microorganisms and can act as an entrapment mechanism for unattached flocs. Many support types are used, including quartz, plastic, clay, oyster shells, stones, polymer foam, activated carbon and sand.
  - **b.** Fluidized bed reactor: In this type of reactor most of the biomass is attached as films to small-sized inert media. The biomass-covered particles are lifted (fluidized) by the high vertical velocity of the incoming waste. Various support materials are used, such as sand, PVC, and granular activated carbon.
  - **c.** Upflow anaerobic sludge blanket (UASB): This type of reactor consists of a dense bed of granular sludge (microorganisms) placed in a reactor that is designed to allow upward movement of liquid waste. Waste water entering at the reactor bottom is distributed across the cross-section and flows upward through the bed of sludge granules retained in the system. Sufficient upflow velocities are maintained in the reactor to facilitate sludge blanket formation and to provide a greater surface area for contact between sludge granules and waste water.

Alazard (1996) describes a laboratory-scale evaluation of different anaerobic treatments for waste-water from starch extraction in Colombia. These studies include comparison of UASB, UASB with phase separation, a "transfilter" process (Farinet, 1993) and a rustic biofilter "bamboo horizontal flow". All these processes seem to be efficient in lowering the organic load of the waste. In all cases, efficient biodegradation (up to 90%) at an organic loading of 5g COD/l/day is attainable, while maintaining a hydraulic retention time of nine hours. The production of biogas with 70% methane is about 350 l/kg of COD removed. Given the low investment costs of the bamboo horizontal flow method, and its comparable efficiency with other more expensive procedures, this technique has potential for small-scale processors.

In Brazil, two units of anaerobic treatment with phase separation have been installed in farinha factories, each with a capacity of 10 to 20 m^3 per day (Cereda, 1996). Despite encouraging results in terms of removal of organic material (reduction of 80%), the high cost of maintaining these units has resulted in their decommissioning.

Biological treatment of waste water

The biological treatment of waste water is based on a simple process, in which mixed populations of microrganisms utilize the nutrients in the waste. Their efficiency is extended by use of chemical engineering techniques that allow the basic process to be intensified and accelerated. This gives the range of biological treatment systems currently in use for treating agricultural waste water (Degremont, 1991).

Waste water containing both organic material and a source of nitrogen is brought into contact with a dense population of microorganisms. Sufficiently long contact times are engineered into the process so that the microorganisms can break down and remove the pollutants (organic material) to a desirable level. This process can occur in the presence of oxygen (aerobic) or absence of oxygen (anaerobic). In addition to clean water, the nature of the other products will depend on the process. Anaerobic systems produce biogas (methane, carbon dioxide, and small amounts of hydrogen sulfide and ammonia) and biomass (microorganisms); aerobic systems create carbon dioxide and a large amount of biomass (microorganisms).

Lagoons are the simplest form of biological treatment, and the type of lagoon used (anaerobic, facultative, aerobic) is dependent on the available area and amount of waste to be treated. Because of the high organic content of cassava processing waste, the first lagoon is usually anaerobic.

Cost estimates of lagoon systems need to take into account the land area required and the soil type. A lagoon or ponding system is cheap to construct but requires a large land area. If the lagoons are constructed in permeable soil, the need for lining, consisting of either clay or synthetic material, will add significantly to construction costs.

Lagoon systems are normally operated at low rates with organic loading ranging from 0.2-0.35 kg BOD/m^3/day. Because of the size and configuration of the lagoons, they are quite difficult to control and monitor. Energy required to operate a lagoon system is minimal. Electricity is only required to run the pumps; gravity flow is exploited where possible. Different types of lagoons include:

Aerated lagoons

Aerated lagoons have an aerobic surface layer, generally maintained by floating surface aerators, with an anaerobic zone below. A large amount of organic material can be applied; thus, maximum organic reduction with minimal odor and associated nuisances can be achieved.

Activated sludge

Activated sludge is an anaerobic process, named because the treatment takes place in an activated (containing microorganisms) and intimately mixed liquor. This increases the mass of organisms available for waste reduction.

Anaerobic digestion

Anaerobic digestion is a complex two-stage biological process in which the organic matter is reduced in an anaerobic environment. Anaerobic digestion facilities may range from a simple, unmixed, unheated open tank (low rate digestion) to a mixed and heated covered tank (reactor), incorporating collection and utilization of the gas produced, followed by a secondary digester for liquid/solids separation (high rate digestion). An anaerobic lagoon is essentially a crude uncontrolled anaerobic digester.

The lagoon system is the most popular treatment system used by cassava starch processors for treatment of waste water. Popular in Thailand are "no-discharge" systems that consist of up to 20 ponds. The combined waste water is often collected in a storage pond from where it is pumped through a screen into a pretreatment pond. After this, the waste water is pumped through a series of treatment ponds, the first 2-3 being anaerobic, where organic substances are successively degraded by natural breakdown processes. The amount of organic material that can be added is about 800-1,000 kg COD/ha/day. Thus, in order to treat 6,000 m^3 of waste water per day (a typical discharge from a Thai cassava factory) with a COD concentration of 14,000 mg/l, requires a land area of about 100 ha. This will involve 20 lagoons, each with an area of 5 ha. Typically, residence times of 350-400 days are necessary. An alternative system will discharge the water after a period of 100-200 days. This system differs in that during later stages the ponds are aerobic, to accelerate the breakdown of organic matter. The treated waste water will have a BOD as low as 15 mg/l and can be used for irrigation (see Appendix 3). This system requires fewer ponds (10) and less land area (8 ha).

These technologies for treating the waste of cassava processing, whilst removing the environmental problem, incur investment costs from which there will be no direct return. Much research has been conducted to address this problem.

<u>Value-adding of waste products</u>

Transforming the waste offers the possibility of creating marketable value-added products. This is successfully exploited by the maize wet milling industry, which generates about 40% of the total revenue from the by-products of maize starch processing. It is a powerful incentive for cleaning waste streams. This strategy can relieve some of the financial burden incurred by waste treatment. The composition of the raw material is important, and for cassava limited opportunities exist. There should also be sufficient market opportunity for the product. In most processing zones, cassava waste is treated as a low value product, but is sold.

In Thailand cassava peel is utilized as a medium for mushroom cultivation or is used to produce compost. In Guangxi, China, pulp, which is generally used as an animal feed, is used as a raw material for the production of ethanol (Henry and Howeler, 1996). In Vietnam, solid waste (mainly pulp) is sun dried and used as fuel for production of maltose in the same village. In Thailand, most fibre waste is sun dried, mixed with ground chips and pressed into pellets for export to Europe. As starch production increases and pellets exports decrease this may not take care of the problem in the future.

The literature is replete with 'novel' technologies for treating agricultural waste, including that produced by cassava processing, many involving fermentation by bacteria or yeast for production of a biofuel, such as ethanol (Tanticharoen *et al.*, 1986; Abraham and Muraleedhara, 1996) or biogas (Tanticharoen *et al.*, 1986). Other technologies involve the production of single cell protein from cassava waste (Manilal *et al.*, 1991) or *spirulina* (Tanticharoen *et al.*, 1991). Adoption of such technologies should be with caution. Markets are often poorly identified for the ultimate product and development work (scaling up technology from laboratory to field) must be financed.

A phased approach to the introduction of an effluent treatment system is recommended. Rapid progression from no treatment to full treatment may be unrealistic, both for technical and financial reasons. The staged approach allows time for the operator to adjust to new equipment and solve new problems, increasing the overall project success.

Prevention

Preventing the waste problem from occurring in the first place, is the ultimate solution, and one that is available for some cassava processors.

The most appropriate form of prevention for the starch processing industry is to reduce the water requirements and hence the amount discharged. This can be achieved simply through more efficient use of water through re-cycling. Some factories use water from the sedimentation tanks for root washing (Figure 18). The lower pH of this water also has the advantage that it better removes the soil and debris from the roots.

ERM (1996) has conducted field studies of small- to medium-scale starch and sago processors in Salem district of India to investigate the potential application of hydrocyclone technology for water conservation. The use of this technology led to a reduction in the water requirement by 50-60%, and a reduction in waste water volume by 40-50% (Marder, 1994). The pollution load of the waste water was also reduced by 50% (Trim and Marder, 1995). This still needs to be used together with an 'end-of-pipe' waste water treatment solution. However, the amount of water to be treated is markedly reduced, and thus the demand on the treatment technology is lower.

Water can also be suitably treated with compounds such as alum (concentration of 80 mg/l water) to precipitate the suspended solids and reduce BOD; afterwards, the water can be reused in a recycling system (Ong and Loh, 1986).

Important gaps in knowledge

While cassava processing is generally perceived as polluting the environment, very little research has been conducted to quantify the levels of pollution, and determine the magnitude and significance of this pollution on people and the environment. Also, little research has been conducted to develop efficient and cost-effective ways to reduce pollution, especially by small- and medium-size processors. Specific gaps in our knowledge exist on:

1. Criteria to identify pollution "hot spots", and a model to determine the maximum number of processors able to operate in a particular geographical area before water availability and/or pollution becomes a major problem.
2. Relationship between soil characteristics and the effect of processing on groundwater supply and quality.
3. Effect of key cassava processing unit operations, such as retting, squeezing or grating, on the environment.
4. Relationships between processing parameters and the resulting COD, BOD, HCN and SO_2 concentrations of various waste products.
5. Cost-effective ways of reducing COD and HCN in the waste water of small-scale processors.
6. Value-adding of waste products, such as fermentation and protein enrichment of cassava pulp to be used as animal feed, especially for small-scale processors.

Conclusions and recommendations

From the above discussion the following conclusions and recommendations can be made:

1. With the exception of starch extraction, most other cassava processing does not require large quantities of water. Cassava starch processing should be located in areas of adequate water supply. But even in areas with a limited water supply, cassava starch processing normally does not seriously deplete natural water resources.
2. There are few studies investigating the effect of cassava processing contaminating the ground-water supply. From those undertaken, evidence is not conclusive. Contamination is most likely to occur in regions where a large number of processors are concentrated in a small geographical area. These potential pollution "hotspots" should be identified, and groundwater quality, along with complaints about public health problems, should be closely monitored.
3. Water consumption should be minimized by the use of hydrocyclones or other water recycling systems. These systems also increase extraction efficiency and reduce the amount of waste water produced.
4. Waste water should be either contained within the premises of the factory or treated before release to water sources outside. Depending on the size of each processing operation and their spatial distribution, the following waste water treatments are recommended:
   a. For small-scale and isolated processing units:
      Seepage pits are the cheapest solution, guaranteeing a limited degree of effluent reduction. Such pits can provide a viable and easily replicable means of containing wastes. Soil conditions should be considered carefully before choosing a site for the pits.
   b. For small-scale but densely clustered processing units:
      Common effluent treatment, which may include storage in aerobic or anaerobic lagoons before release to outside water sources.
   c. For medium- to large-scale starch factories:
      Individual effluent treatment, such as storage in aerobic or anaerobic lagoons, either alone or in combination with various types of anaerobic digesters. After treatment the water can be used for irrigating crops or safely released to rivers or streams.

5. Solid waste such as cassava peels, fibrous residue and starch residue can be disposed of as follows:
    a. Land filling.
    b. Value-adding by drying or ensiling of peel and fibrous residue to produce animal feed (to be mixed with a protein source).
    c. Production of alcohol or compost.
6. HCN released from cassava roots during processing will be present in:
    a. Cassava peel. These should be ensiled or fermented to reduce toxic levels of HCN before use as animal feed.
    b. Press water (*gari* and *farinha* production). High concentrations of HCN in press water can be toxic for humans, plants and animals. The press water must be stored or fermented to reduce the HCN content by evaporation before release or further utilization.
    c. Waste water. By storing waste water in seepage pits or lagoons, most HCN will evaporate and be rendered innocuous.
    d. Vapor and water sprays during processing. Work areas where cassava roots are grated in high-speed graters, or where cassava products are toasted or boiled, must be well-ventilated to prevent high concentrations of HCN in the air, affecting the health of workers.

RECOMMENDATIONS FOR PLANNERS AND POLICYMAKERS

Soil/crop management

1. Although cassava is often perceived to be a nutrient-depleting crop, this is normally not the case. Unless yields are very high and/or plant tops are also removed from the field, nutrient removal is considerably lower than that of most other crops, with a possible exception of K. For continuous cassava production on the same land it is recommended to apply chemical fertilizers in the ratio of 2-1-2, 3-1-2 or 2-1-3 of N, P_2O_5 and K_2O, depending on the fertility conditions of the soil. For maximum efficiency, compound fertilizers with the above balance of nutrients should be available to farmers.

2. In very P-deficient soils, cassava responds well to relatively high applications of P in the form of triple- or simple superphosphate, DAP, MAP, fused Mg-phosphate or rock phosphate. With continuous cropping the rates of P application can be reduced over time.

3. In many regions where cassava has been grown for many years, farmers who apply animal manures and/or fertilizers tend to apply too much P and not enough K to obtain high and sustainable yields. This is partly due to the unavailability or high cost of K-fertilizers.

4. In areas of high-pH or calcareous soils, cassava yields are often limited by low availability of soil Zn and Fe. These problems are often incorrectly diagnosed. Simple and cost-effective solutions are either already available or can be developed.

5. In areas where animal manures are available, it is recommended to apply about 5 t/ha of manure together with high-K fertilizers.

6. In areas where chemical fertilizers are not available or are too costly, it is recommended to apply 7-10 t/ha of animal manure, to plant green manures about 3-4 months before cassava, or to rotate cassava on an annual basis with green manures or grain legume crops. In that case, application of ash to the soil is highly recommended. Maintaining soil fertility through long-term fallowing is an option only in sparsely populated areas.

7. Cassava has a reputation to cause erosion when cultivated on slopes. This was found to be a serious problem even on gentle but long slopes where large amounts of runoff can accumulate in natural drainage ways. Cassava should normally not be planted on slopes of more than 15-20%. If planted on steeper slopes, special measures should be taken to control erosion, such as minimum tillage, closer spacing, fertilizer application, intercropping and the planting of contour barriers of grasses (at 1 to 3 meter vertical distance between barriers).

8. While it may be impossible to prevent farmers from planting cassava on steep slopes, as this may be the only or most profitable crop that can be grown, it is recommended to prohibit the use of land preparation by tractor up-and-down the slope. On slopes of

more than 15%, contour land preparation by animal traction or hand preparation of individual planting holes is recommended.

9. Mechanical terracing of land for cassava cultivation is seldom economically justified, but the planting of contour hedgerows or leaving 1 m wide contour strips unplowed and unweeded for the formation of natural grass strips, will result in the formation of natural terraces after several years. The prunings of grass hedgerows or grass strips can be mulched on the soil surface between plants. The barriers, the mulch and the naturally formed terraces all contribute to highly effective erosion control.

10. When cassava is grown rather extensively in mountainous areas, by rotating crop cultivation with several years of fallow vegetation, it might be better to recommend the continuous cropping of a small area of the flattest land (using chemical fertilizers and manures to maintain fertility) and leave the rest of the farm in pastures or fallow, or to plant fruit or timber trees. This will eliminate the arduous task of annual slashing and burning, facilitate land preparation, increase yields (by fertilizer application), and reduce erosion and CO_2 emisions from burning. It may also reduce the need for P applications as the VA-mycorrhizal population builds up under cassava cultivation. Where possible, cassava should be rotated with other crops or green manures.

Biodiversity

1. Farmers should be encouraged to plant a range of cassava cultivars in a particular region or country, so as to mitigate against the devastating effect of a sudden outbreak of diseases or pests. Cassava breeders should maintain a wide genetic variability in germplasm collections, and use materials of varied genetic background in their crossing programs.

2. The introduction of genetic material from Latin America (the center of origin of cassava) to Asia and Africa should be encouraged (with due quarantine precautions), in order to broader the limited genetic base of cassava cultivars in those two continents.

3. Large-scale deforestation to increase cassava growing areas should be prevented to safeguard the native biodiversity in those ecosystems.

4. Collection and conservation of wild *Manihot* species will allow a more detailed study of their characteristics, with a potential of incorporating certain favorable characters into commercial cassava varieties; it will also safeguard against their possible extinction.

Processing

1. Cassava processing is often perceived as consuming large amounts of water and causing serious pollution. But, water consumption is high only in large-scale or highly clustered small- or medium-scale cassava starch factories. In spite of this, water consumption seldom leads to significant depletion of groundwater resources.

2. Pollution, due to the disposal of inadequately treated solid and liquid wastes from cassava processing is a problem mainly when a large number of small- or medium-size processors are clustered together in a relatively small geographical area. These pollution "hotspots" should be identified and groundwater quality and public complaints in the area closely monitored. This is a potential problem area as the number of processors is large, hence difficult to control, and they generally do not have the financial resources and technical know-how to comply with existing pollution control laws.

3. The cassava starch industry should be encouraged to reduce their water consumption and waste water production by the installation of efficient water recycling systems.

4. Waste water should be either retained within the factory's premises or adequately treated before release to outside water sources. TNPCB tolerance limits for discharge of effluents into surface waters are 30 mg/l for BOD, 250 mg/l for COD and 0.2 mg/l for cyanide (Appendix 3). An alternative is to set standards as a proportion of total organic loading before treatment, e.g. in Brazil the BOD in waste water must be reduced by 80% before release to the environment.

5. Factory owners should keep records of water use and waste output, so as to facilitate environmental monitoring. The impact on biological systems should be closely observed.

6. Incentives need to be available for the processor to use additional technology. If there are no economic advantages for the use of a technology, it will never be adopted.

7. Regulations should be imposed to ensure that processors have sufficient land for disposal of waste, e.g. in India a starch factory must have access to 2 ha of land for disposal of waste water at an average rate of 86 m^3/ha/day.

8. Processing facilities should be sited at some distance from key waterways, e.g. in India processors are banned from establishing a factory within one kilometer of important streams, rivers or municipal drinking water sources.

9. Full cost recovery for water could be imposed on the larger processors, charging water at the going rate even if abstracted from rivers or wells.

10. The formulation and enforcement of sensible legislation is the key to success. Implementation should be phased in slowly against agreed time scales. This will give the processor time to adjust to the change and new equipment.

11. Enforcing and monitoring of regulatory standards is critical for success and suitable systems for this purpose should be in place.

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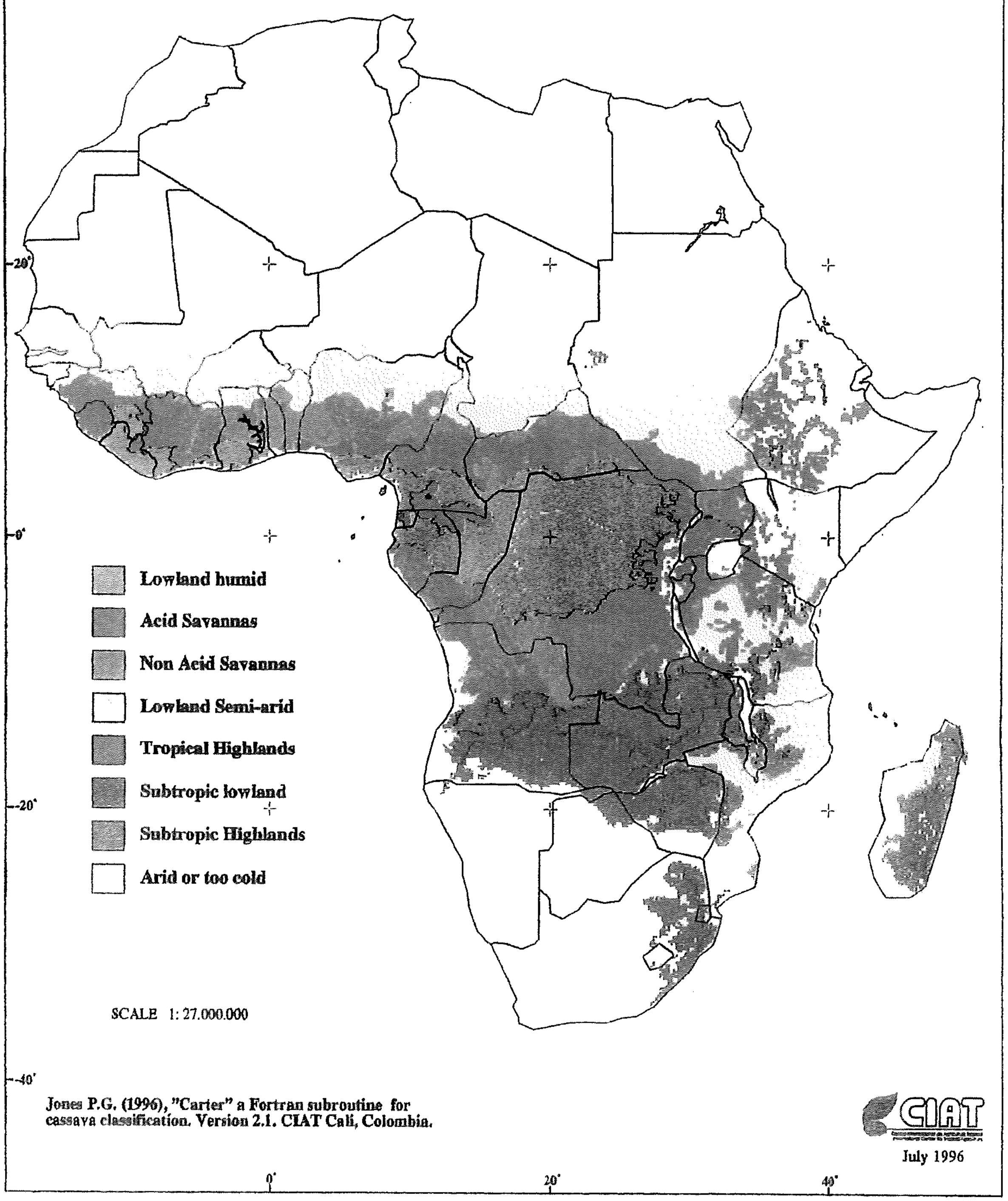
APPENDICES

Appendix 1. Edapho-climatic classification of cassava production for Africa, Asia and Latin-America and Caribbean.

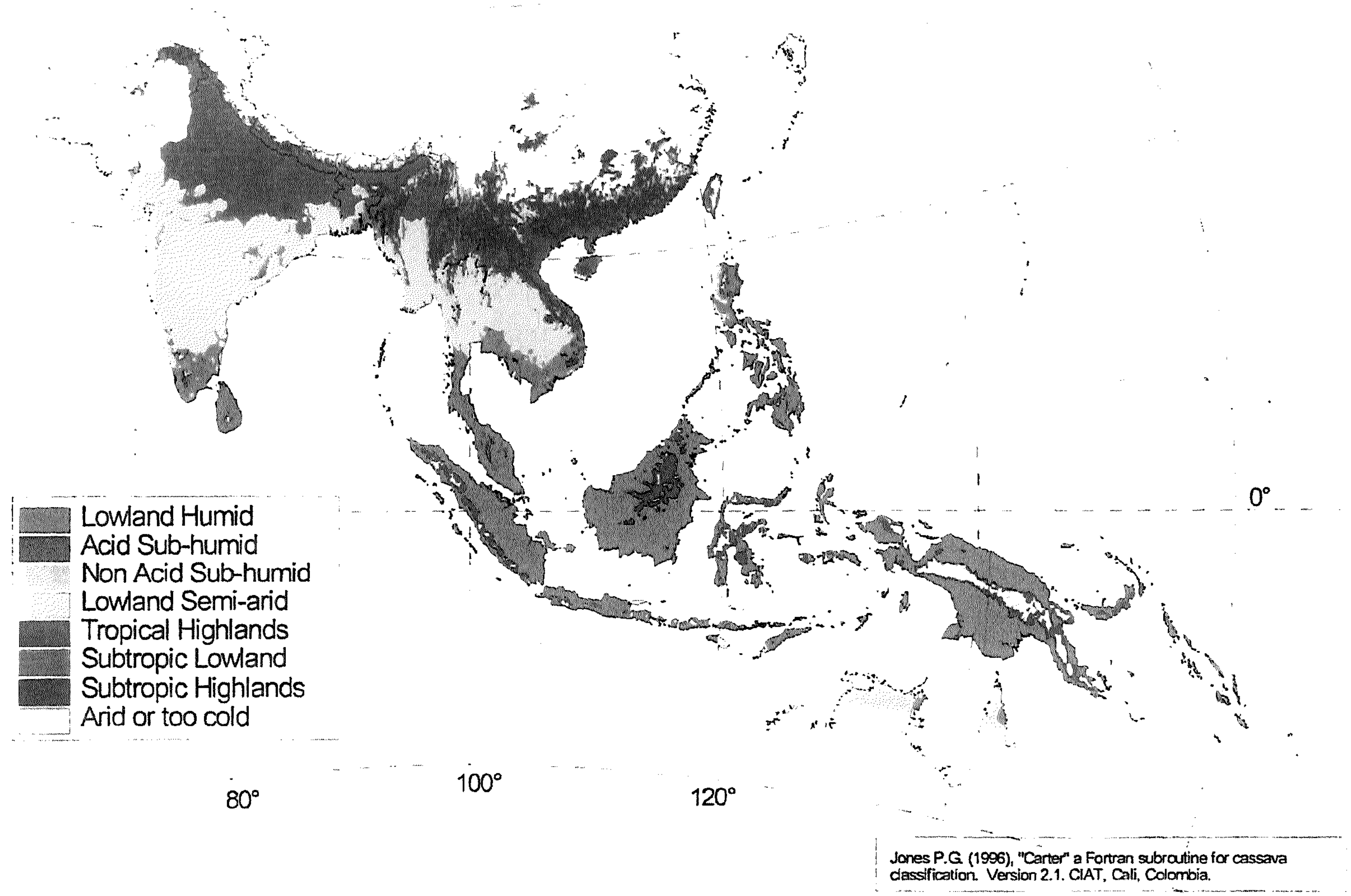
Edafo-climatic Zone	Mean temperature (^{0}C)	No. of months dry season[1]	Daily temp. range (^{0}C)	Soil pH
1. Lowland humid	>22	0-3	<10	
2. Acid sub-humid	>22	4-6	<10	<5.3
3. Non-acid sub-humid	>22	4-6	<10	>5.3
4. Lowland semi-arid	>22	7-9	<10	
5. Tropical highlands	$18<t<22$		<10	
6. Subtropical lowlands	>22		>10	
7. Subtropical highlands	$18<t<22$		>10	
8. Arid or too cold	<18	10-12		

[1] Dry month: Rainfall <50% Evapotranspiration
Source: P.G. Jones (personal communication).

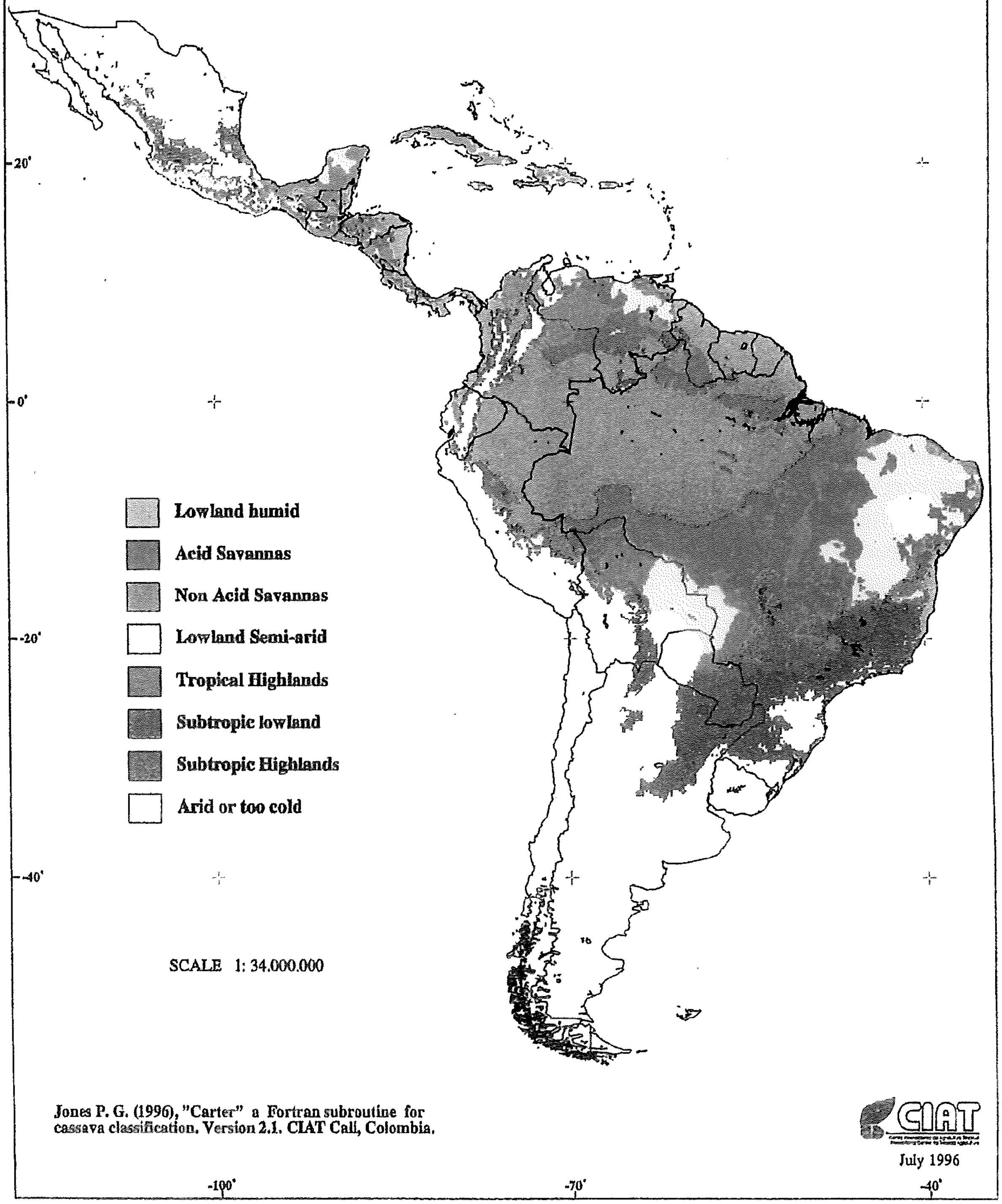
EDAPHO-CLIMATIC CLASSIFICATION OF CASSAVA PRODUCTION FOR AFRICA



Edapho-Climatic classification of Cassava production for Asia



EDAPHO-CLIMATIC CLASSIFICATION OF CASSAVA PRODUCTION FOR LATIN-AMERICA AND CARIBBEAN



Appendix 2. Results of erosion experiments conducted with various crops and cropping systems in four Experiment Stations in Sao Paulo, Brazil from 1993 to 1999.

Table 1. Average annual soil loss by erosion and runoff during 16 years of growing various crops on sandy soil with 12% slope in the Experiment Station of Pindorama, Sao Paulo, Brazil from 1943 to 1959

	Soil loss (t/ha)	Runoff[1)] (mm)
Common beans	42.8	139
Cassava	31.7	102
Cotton in rotation	30.1	96
Upland rice	28.2	126
Maize with residues burned	25.5	89
Soybean in rotation	25.5	82
Maize in rotation	24.1	91
Cotton continuous	21.8	88
Maize continuous	21.8	77
Maize + beans	18.4	70
Maize + *Canavalia* mulched	10.6	39
Sweetpotato	9.0	50
Maize + *Canavalia* incorporated	8.5	37
Maize + cow manure	4.5	23
Gordura grass	1.2	17

[1)]Average rainfall during 16 years was 1,104 mm (range 489-1,452 mm)

Source: Quintiliano et al., 1961

Table 2. Average annual soil loss by erosion and runoff during five years of growing various crops on mixed red soil with 12.8% slope in the Experiment Station of Campinas, Sao Paulo, Brazil from 1954 to 1959.

	Soil loss (t/ha)	Runoff (mm)
Bare fallow	51.6	66
Common beans	33.3	66
Irish potato	10.9	38
Cassava	10.7	22
Castor beans	8.2	23
Maize + beans	1.0	5
Upland rice	0.5	16
Sugarcane (2 crops/5 years)	0.1	2

[1)]Average rainfall during five years was 1,237 mm (range 984-1,607 mm)

Source: Quintiliano et al., 1961

Table 3. Average annual soil loss by erosion and runoff during 14 years of growing various crops on massape soil with 9.4% slope at the Experiment Station of Mococa, Sao Paulo, Brazil from 1945 to 1959.

	Soil loss (t/ha)	Runoff[1)] (mm)
Cassava	53.1	254
Cotton in rotation	38.1	250
Soybeans continuous	34.7	208
Cotton continuous	32.7	228
Soybeans in rotation	26.1	146
Sugarcane	23.3	108
Maize in rotation	18.9	151
Maize + common beans	13.6	128
Maize continuous	12.2	67
Maize + *Mucuna* incorporated	10.3	100
Maize + manure	6.6	97
Maize + *Mucuna* mulched	3.0	42
Gordura grass	2.6	46

[1)]Average rainfall over 14 years was 1,347 mm (range 943-1,791 mm)

Source: Quintiliano et al., 1961

Table 4. Average annual soil loss by erosion and runoff during 12 years of growing various crops on red soil with 8.5% slope at the Experiment Station of Ribeirao Preto, Sao Paulo, Brazil from 1947 to 1959.

	Soil loss (t/ha)	Runoff[1)] (mm)
Castor beans	56.1	199
Common beans	54.3	180
Rami	54.2	196
Cotton	51.4	183
Cassava	42.6	170
Upland rice	36.6	143
Maize with residues incorporated	30.9	144
Peanut	30.6	134
Maize with residues burned	29.0	131
Maize+*Mucuna* incorporated	28.2	133
Sugarcane	21.0	88
Maize+lime	19.1	96
Maize+manure	8.9	62
Tephrosia candida	8.4	37
Jaragua grass	5.5	45

[1)]Average annual rainfall over 12 years was 1,286 mm (range 1,110-1,663 mm)

Source: Quintiliano et al., 1961

Appendix 3: Water quality standards.

		Drinking water quality standards									Effluent standards				
				WHO standard[1]		Indian standard[2]					TNPCB tolerance limits for discharge of trade effluents				WHO[1]
Paramaters	Unit	ISI	ICMR	Permissible	Excessive	Acceptable	Tolerable	USPH	WHO standard	European standard	Inland surface water	Public sewers	Marine coastal areas	On land for irrigation	raw water standards
pH		6.5-8.5	6.5-9.2	7.0-8.5	<6.5 >9.2	7.0-8.5	6.5-9.2	6.0-8.5	6.5-9.2	6.5-8.5	5.5-9.0	5.5-9.0	5.5-9.0	5.5-9.0	
BOD	mg/l							5	6		30	350	100	100	6
COD	mg/l							4	10	5	250	-	250	-	10
TSS	mg/l							5			100	600	100	200	
TDS	mg/l	500	1500	500	1500	500	1500	500	500		2100	2100	-	2100	1500
Sulfates	mg/l	150	400	200	400	200	400	250			1000	1000	1000	1000	
Chlorides	mg/l	250	1000	200	600	200	1000	250	500	25	1000	1000	-	600	
Oil & Grease	mg/l										10	20	20	10	1
Electral Conductivity	µmhos/cm							300		400					
Cyanides	mg/l	0.05	0.05		0.2	0.05	0.05	0.05	0.05		0.2	2	0.2	0.2	0.2
Ammonical Nitrogen	mg/l							0.5	0.5		50	50	50		
Phosphates	mg/l							0.1			5				
Nitrate Nitrogen	mg/l			45	45	45	45	<10	<45	<45					45
Iron as Fe	mg/l	0.3	1	0.3	1	0.1	1	0.3		1					50
Pesticides	mg/l							0.005		0.005	Absent	Absent	Absent	Absent	
Free Ammonia (as NH_3)	mg/l							0.5	0.5		5		5		0.5

ISI = Bureau of Indian Standards
ICMR = Indian Council of Applied Research
WHO = World Health Organisation
USPH = United States Public Health Drinking Water Standards
1 WHO Standard 1963
2 Burea of Indian Standards

TECHNICAL ADVISORY NOTES

I. INCREASING THE PRODUCTIVITY AND SUSTAINABILITY OF CASSAVA BY BETTER SOIL/CROP MANAGEMENT

Expected benefits: Increased yields and income, reduced soil erosion, increased soil fertility.

Crops and enterprises: Cassava and intercrops.

Agro-ecological zones: Humid, Subhumid and Semi-arid Tropics and Subtropics.

Source of technology: Research carried out by the International Center for Tropical Agriculture (CIAT) and the International Institute for Tropical Agriculture (IITA) in collaboration with national programs.

Cassava is grown on over 16 million hectares worldwide and is a staple food for over 500 million people. The crop is very tolerant of drought and can produce reasonable yields on very poor soils. For this reason it is a favored crop in areas of infertile soil and with low or erratic rainfall. When other crops fail under these conditions, cassava can stave off famine or provide the farmer with at least some income. However, when grown continuously on infertile soils without inputs of fertilizers or manures, soil nutrients may become depleted leading to a decrease in soil productivity. In addition, when grown on slopes, cassava provides little protection from the direct impact of rainfall during the first 3-4 months after planting, which can result in serious erosion. Better soil/crop management can help to reduce these problems while at the same time increasing yields and income.

Improved nutrient management will increase yields – now and in the future

Although cassava grows better than most other crops in poor soils, it will yield better in more fertile soils and responds well to fertilizer and manure applications. Moreover, with the use of higher yielding varieties, nutrient absorption and removal in the harvested products increases. Unless these nutrients are replaced the soil becomes poorer.

Major nutrient requirements: As a starch-producing root crop, cassava requires mainly potassium (K) for translocation of carbohydrates from leaves to roots. The crop also requires nitrogen (N) to stimulate leaf formation and photosynthesis, but requires smaller amounts of phosphorus (P). In most sandy or sandy loam soils that are low in organic matter the crop responds well to applications of 50-100 kg N/ha (100-200 kg urea), 10-20 kg P_2O_5/ha (50-100 kg simple superphosphate) and 50-100 kg K_2O/ha (80-160 kg potassium chloride). Only in some soils that are extremely low in P (mainly in Brazil and Colombia) does the crop respond to higher rates of P application. In that case high rates of 100-200 kg P_2O_5/ha need to be applied, but only for a few years to build up the available P content of the soil. Simple or triple-superphosphate and rock phosphates are good sources of P.

Lime requirements: Cassava is highly tolerant of soil acidity and seldom responds to applications of lime. In fact, high lime applications can reduce yields by causing more severe deficiencies of micronutrients, particularly zinc (Zn).

Micro-nutrient requirements: In most soils there is no need to apply micro-nutrients. However, in calcareous soils the crop may suffer from zinc and/or iron deficiency. In that case, dipping the stakes in a 2% solution of zinc or iron sulfate for 15 minutes before planting is recommended.

Fertilizer application: Fertilizers should be applied close to but never in direct contact with the planting stakes. Applications of NPK fertilizers in small bands at 5-10 cm from the stake or base of the plant is recommended. Bands are made with a hoe and are covered over after fertilizer application. Fertilizers, especially P, should be applied early in the growing cycle, normally at or one month after planting; N and K applications are sometimes split, half applied at planting and half at two months after planting.

Manure application: Application of animal manure will not only supply nutrients but also organic matter, and may improve the soil's physical condition. Applications of 5 t/ha of chicken or cattle manure in combination with N and K fertilizers is recommended. If no fertilizers are available, wood ash can substitute for K-fertilizers. Manures are generally broadcast and incorporated into the soil before planting.

Integrated crop/soil management will increase yields and reduce erosion

Soil erosion occurs when rainfall strikes the soil surface and dislodges soil particles, which are subsequently carried down-slope with runoff water. The result is a loss of top soil, loss of organic matter, clay, soil nutrients and fertilizers, all leading to a reduction in soil depth and soil productivity. Because of slow initial growth and wide spacing, cassava production on slopes can cause serious erosion. However, research has shown that better crop/soil management practices can markedly reduce erosion, either by providing more rapid soil cover or by reducing the flow of runoff.

Providing soil cover: Cassava canopy formation can be enhanced by the use of vigorous and high-yielding varieties, good quality planting material, closer plant spacing (0.8x0.8m), and especially, by fertilizer or manure application. Intercropping with maize, peanut, bean, cowpea, melon and pumpkin can also provide a rapid soil cover to protect the soil from rainfall impact. Application of mulch of grass or crop residues can also provide soil cover without causing competition.

Reducing or slowing runoff: Soils with high levels of organic matter, with worm and root channels and with stable soil aggregates provide pathways for rapid water infiltration, thus reducing runoff. Fallowing and the incorporation of green manures, animal manures and crop residues will enhance these favorable physical conditions. Runoff flow can be markedly reduced by maintaining a rough seed bed through minimum tillage, or by contour tillage, contour ridging or the planting of contour hedgerows of grasses (e.g. vetiver grass, lemon grass, *Paspalum atratum*) or legumes (e.g. *Leucaena, Gliricidia, Stylosanthes*). Alternatively, farmers can stake out contour lines with an A frame or a simple line level and leave a 50-100 cm strip of unplowed and unweeded land to form natural grass-covered contour strips. Contour hedgerows or grass strips help reduce the speed of runoff and trap eroded soil sediments and fertilizers. With time, natural terraces are formed, thus reducing the slope of the cultivated plots and enhancing water infiltration.

Farmers have many options to improve soil fertility and reduce erosion, but some require additional capital or labor. Yields may increase, but can also decrease due to crop competition from intercrops or by reducing the land available for cropping (e.g. by planting grass barriers). Thus, farmers should carefully weigh the pros and cons of each option and choose the best combination of practices for their own conditions.

Supporting References:

1) Developing sustainable cassava production systems with farmers in Asia. R.H. Howeler. *In*: Systems and Farmer Participatory Research, Developments in Research on Natural Resource Management. CIAT, Cali, Colombia. 1999.
2) Soil fertility maintenance and strategies for cassava production in West and Central Africa. J.A. Okogun, N. Sanginga and E.O. Adeola. IFAD Stakeholder Consultation Meeting. Accra, Ghana. 1999.

II. MINIMIZING ENVIRONMENTAL IMPACT THROUGH SUSTAINABLE CASSAVA PROCESSING METHODS: SMALL-, MEDIUM- AND LARGE-SCALE STARCH PROCESSING

Expected benefits:	Lower water requirements, lower environmental impact of wastes, reduced costs, improved aesthetics in processing areas, improved health and well-being of local communities.
Crops and enterprises:	Cassava production, starch processors, cassava product processors.
Targeted region and country:	Asia, Africa, and Latin America – Benin, Brazil, Cameroon, China, Colombia, Democratic Republic of Congo, Ghana, Ecuador, India, Indonesia, Ivory Coast, Nigeria, Paraguay, Philippines, Thailand, Vietnam.

Every year millions of tonnes of cassava are converted to intermediate and higher-value products. For all, in addition to the desired product, by-products are co-generated, which, if incorrectly managed or controlled, will have significant negative impacts on the environment. The cost of treating these products if they are allowed to accumulate can be *on a par* with that of primary processing.

Choosing a site location

Adequate local land and water resources should be available to supply the required quality and quantity of raw materials and processing inputs (such as water) without causing unacceptable environmental impact. The processor should have access to additional land area to accommodate waste disposal from planned and expanded processing capacity. Minimal land requirements should be assessed on a case-by-case basis, as size of the processing operation, type or sophistication of processing technology used, and local geology will all contribute to the estimate.

The processing site should be in close proximity of receiving land or water capable of handling the effluent discharge without significant impact on the biological environment. These discharge sites are not to include important rivers, streams, or sources of drinking water. Similarly, land should not be densely populated, close to water abstraction points or near to drinking water sources. The processing unit should not be located in an area where it compounds the problems of an already contaminated water source. Facilities should not be sited in areas heavily affected by industrial discharges, because of the risk of product contamination. Nor should the facility be sited in environmentally sensitive areas or at locations where wastes cannot be assimilated without environmental degradation.

Starch processing requires large volumes of water; thus, to prevent conflict with other users or overburdening the supply system, the processing operation should not be within a pollution hotspot zone. These zones are identified as having a large number of factories within close proximity of each other, close to large rural communities and having potential water supply problems (high demand, poor recharge rates).

Water supply must be consistent and not placed under pressure by the entrance of new processing activities; groundwater recharge rates should be sufficient to sustain demand from the processing operation. If surface water is the supply source, seasonal fluctuation should be minimal and water quality constant. Industrial and agricultural activities upstream need to be evaluated and any impact of their discharge on starch quality considered.

Evidence suggests that most of the environmental impact of cassava starch processing is site-specific. Rationalizing the concentration of processors within an area will minimize site-specific problems. Distribution strategies will be balanced with a need to contain resources; they also depend on whether or not a communal waste disposal system can be considered.

Choosing a technology

Small- to medium-scale

Upgrading traditional processing technology should be balanced with sustainability. Specific technology that disturbs the balance between processor and environment should not be used. The technology should not place additional strain on the system, either by increased demand for processing inputs or the generation of larger amounts of waste that are not easily disposed of. Technology adoption should be appropriate and tested. Specific technology requirements are:

1. **Root grating**. Roots must be grated or milled finely, in order to wash out starch granules; fibers still contain starch. Pulp waste with a lower content of starch is easier to handle. Although a hammer mill may be used, there could be a substantial damage to the starch granules.

2. **Sieving out fiber**. Before sedimentation, the starch slurry should be passed through a screen no coarser than 120 mesh (125 μm). This removes the remaining fiber particles that may be instrumental in the microbial deterioration of the starch. This will also lead to some loss of large starch granules, but this amounts to less than 1%.

3. **Settling**. Settling tanks should be extensive and shallow, rather than compact and deep. This will ensure a more efficient settling of the starch granules and hence purer discharge water.

4. **Storage of wet starch**. Starch should not be kept wet for more than 24 hours. If kept wet too long, the starch granules may erode due to residual enzyme activity; this will create waste water high in soluble solids and odor problems at the processing site.
5. **Cleaning of factory equipment at stops**. Equipment should be cleaned thoroughly after each prolonged factory stop; if this is not done, the new start will be accompanied by increased microbial activity.

Large-scale

The technology for large-scale factories should be new, and of original design. Locally fabricated equipment is difficult to calibrate, this often leading to inefficiencies, either in water use or starch separation (high waste water BOD). The factory design should include a water re-circulation system with appropriate control. A water purification system should also be included. The choice of separator should be considered carefully. Centrifuges using cloth screens result in faster build up of organic material in the re-cycle water, which can be better controlled if hydrocyclones are used. Adequate processing space and ventilation are essential to minimize the risk of cyanide poisoning.

Conserving Water

Starch processing requires 15-76 m^3 of water/t starch. Processors should target to be at the lower end of this range. Processors must develop an increased awareness of the importance of minimizing water utilization. Efficient use of water can be promoted by adopting a suitable recycle system.

Small- to medium-scale

The strategy for recycling water will be determined by the size of the processing facility. For the small units simply re-using the water removed from secondary sedimentation for root washing will be of benefit. Through water conservation measures and recycling systems both the volume and loading of waste water are reduced. This has benefits in lowering the cost of effluent treatment as this is related to the quantity of waste water.

For medium-scale processors, incorporation of hydrocyclone units in the cassava starch factory should be promoted. Use of this technology can lead to reduction in the volume of fresh water required for root crushing and starch separation by 50-60%, and reduction in waste water volume by 40-50%. Achieving a reduction in the volume of waste water will allow for a smaller effluent treatment plant.

Large-scale

Large-scale processing units must use water re-circulation systems to minimize their daily demand for water. The water should be purified and its pH adjusted at regular intervals to ensure efficient re-circulation.

Dealing with waste water

Waste water released directly to the environment is a source of pollution and subsequent environmental problems. Simply disposing of the waste water directly to the environment (fields, ditches and surface water) should be discouraged. Proper waste water management is not usually a problem. However, the water originating from settling tanks or decanters is potentially polluting because it can have a high concentration of organic matter, cyanide and processing chemicals.

Small- to medium-scale

In a situation where the only alternative is to discharge to surface water, this should not be to slow moving water bodies, as problems will be compounded; local lakes and ponds are therefore not suitable for receiving waste. This outlet for effluent disposal should be used sparingly and only small-scale processors should avail themselves of this course of action.

From larger processing units water should not be released directly into surface water systems. Prior reduction in the organic material and cyanide must be achieved before release. For small- and medium-scale starch processors effluent seepage pits can be constructed and operated. These pits serve the dual purpose of containing wastes and providing a rapid pathway for groundwater recharge. These seepage pits should be sited over permeable soils away from natural water courses and ground water abstraction points. The pits should be suitably designed and carefully managed and maintained.

In certain areas, particularly where factories are clustered or located close to populated areas, more sophisticated waste treatment systems should be considered. These may be individually owned or be a common effluent treatment facility. The simplest technology available is to store the effluent in settling tanks for several days; this will lower BOD and COD and ensure that most cyanide has evaporated. Effluent pits or channels can be used, but the geology of the site should be reviewed and if necessary, the pits or channels lined. Ponding systems and anaerobic reactors are suggested, the choice dictated by available resources (land, technical and financial) and a need to minimize the nuisance factor of open ponds. The ponds should be constructed after due consideration of the site's geology, and all necessary precautions taken that water will not seep into the groundwater supply.

Waste water generated by smaller units may be used directly for irrigation, ideally after treatment, but if this is not possible, after dilution. Cyanide levels should be reduced to less than 0.3mg/l before discharge. Irrespective of whether the waste water is treated or used directly, it must be carefully monitored to ensure that the cyanide level is not too high.

Large-scale

Large-scale processors must treat the waste water before its release to the environment. The simplest technology suitable for this scale of operation is a ponding (lagoon) system requiring as many as 20 ponds. The first ponds should be anaerobic, to reduce odor problems. A more efficient high-rate anaerobic reactor, such as UASB, is recommended.

Dealing with solid waste

The main problem from solid waste is that of foul odor, especially from the final slurry waste. Careful storage, ideally in sealed tanks, will help reduce this problem. Dry waste stored on-site should be stored on concrete paving and under-cover.

Solid waste must be stored in a well-managed manner; it should be covered and protected from the rains. Apart from odor and visual aspect, the main problem from solid waste is that of leachates formed by rain. The solid waste should be stored for a minimum period. Adequate market outlets should be established early in any development process for solid waste products; this may require development of suitable enterprise linkages.

Small- to medium-scale

Solid waste generated by cassava processing should be sold or used quickly. Excess may be land-filled if the necessary precautions have been taken, and if sufficient land area is available. Ideally the waste should be sold or used for composting or animal feed. As a feed, it can be used directly or after partial breakdown through fermentation to improve bioavailability and reduce the cyanide content. The simplest approach would be to ensile the waste, but other possibilities are available. Care should be exercised in the formulation of feed rations, as the waste from cassava processing is deficient in protein, and this should be supplemented from other sources.

Large-scale

Large-scale factories generate huge amounts of pulp waste that must be removed from the factory soon after production. Adequate markets for this waste must be found before processing starts. In line with the quantities of pulp waste generated, it is usually the responsibility of a third party to utilize or re-process this material.

Management measures

Environmental monitoring systems should be in place, adopted and carried out by the processing unit owner. At a minimum, these should include keeping records of water in and out and notes on the environmental impact. This may be gauged by changes in the biological habitat in and around the processing unit.

Monitoring by both the factories and officials of waste piles during the off-season should be incorporated into the management system.

Supporting References:

1) Cassava wastes: Their characterization and uses and treatment in Brazil. M.P. Cereda and M. Takahashi. *In*: Cassava Flour and Starch: Progress in Research and Development. CIAT publication no. 271, Cali, Colombia. pp. 221-232. 1996.

2) Processing pf cassava waste for improved biomass utilization. Kanarong Sriroth, R. Chollakup, S. Chotineeranat, K. Piyachomkwan and C.G. Oates. Bioresource Technology 71(1):63-69. 1999.

III. MINIMIZING ENVIRONMENTAL IMPACT THROUGH SUSTAINABLE CASSAVA PROCESSING METHODS: PASTES, CHIPS AND FLOUR

Expected benefits:	Lower water requirements, lower environmental impact of wastes, reduced costs, improved aesthetics in processing areas, improved health and well-being of local communities.
Crops and enterprises:	Cassava production, cassava product processors.
Targeted region and country:	Asia, Africa, and Latin America – Benin, Brazil, Cameroon, China, Colombia, Democratic Republic of Congo, Ghana, Ecuador, India, Indonesia, Ivory Coast, Nigeria, Paraguay, Philippines, Thailand, Vietnam.

Every year millions of tonnes of cassava are converted to intermediate and higher-value products. For all, in addition to the desired product, by-products are co-generated, which, if incorrectly managed or controlled will have significant negative impact on the environment. The cost of treating these products if they are allowed to accumulate can be *on a par* with that of primary processing.

Choosing a site location

Adequate local land and water resources should be available to supply the required quality and quantity of raw materials and processing inputs (such as water or fuel wood) without causing unacceptable environmental impact. The processor should have access to additional land area to accommodate waste disposal from planned and expanded processing capacity. Minimal land requirements should be assessed on a case-by-case basis as size of the processing operation, type or sophistication of processing technology used and local geology all contribute to the final estimate.

The site, if it generates waste water, should be in close proximity to either receiving waters or land capable of handling the effluent discharge without significant impact on the biological environment. Water bodies should not be important rivers, streams, or sources of drinking water; similarly, land should not be densely populated, close to water abstraction points or near to drinking water sources. Waste discharge from the processing unit should not compound any existing problems of an already contaminated water source or site. Processing units should not be sited in areas heavily affected by industrial discharges because of the risk of product contamination. The facility should not be sited in environmentally sensitive areas or at locations where wastes cannot be assimilated without environmental degradation.

Some forms of cassava processing require moderate quantities of water. If sited in a region of water scarcity care should be taken to minimize the impact. Ideally, the technology/process should be adapted to suit the natural resources available. Processing units should be located away from environmental hotspot zones, regions characterized by a large number of factories within close proximity of each other, close to large rural communities and having potential water supply problems (high demand, poor recharge rates).

Choosing a technology

Upgrading traditional processing technology should be balanced with a continued need for sustainability. Specific technologies that disturb the balance between processor and environment should be avoided. Particular care is required if automation of a traditional process is planned. The added impact to the environment must be carefully determined. Adopted technology should not place additional strain on the system by an increased demand for processing inputs or generation of larger amounts of waste. The added waste volume will be more difficult to disperse through traditional outlets. Technology adoption should be appropriate and tested.

Cyanide is released during peeling, processing and cooking. This can be a problem if the processing facility is not of sufficient volume, or if the airflow is too low. Precautions should be made to protect the operators. Adequate ventilation should be provided. Better roasting equipment should also be adopted.

Conserving water

Process: (a) retting
(b) root washing

Products: (a) chikwangue, flours
(b) farinha

Problem definition: Despite a processing requirement for only low volumes of water, many processors face a water shortage.

The production of many types of cassava products does not require water, and those that do, require only a modest amount of water. Water is used for either washing, retting or soaking cassava. The problem often lies with the water-scarce location of many cassava-processing regions.

Processors must develop an increased awareness of the importance of minimizing water utilization. For small-scale processing, this can contribute significantly in lowering overall water demand. Close adherence to local practices is recommended. In many areas, especially Africa, these have become highly adapted to local conditions. Water should be conserved, either by re-using soaking water or adopting procedures that require less water, such as retting in dry conditions, i.e. in bags, or solid state fermentation.

Dealing with wash water

Process: (a) retting,
(b) squeezing

Products: (a) chikwangue, some flours
(b) farinha, gari, attieke

Problem definition: Low volumes of water, but that are high in cyanide and organic matter.

At the family-scale, waste water volumes are small. However, because of high cyanide content, this water can be poisonous to small animals. The scale of the problem increases with the scale of production. In regions where many processing units are sited in close proximity of each other the problems are magnified.

Waste water released directly to the environment is a source of pollution and subsequent environmental degradation. Simply disposing of the waste water directly to the environment (fields, ditches and surface water) should be discouraged. Wash water is not a problem, but that from retting or squeezing can be. Water from both sources will contain a high amount of cyanide and organic matter.

In a situation where the only alternative is to discharge to a surface water body, slow moving water should not be used for receiving the waste; local lakes and ponds are therefore not suitable for receiving effluent. This approach to effluent treatment should only be used sparingly and only small-scale processors are to avail themselves of this course of action.

Waste water generated by larger processing units should not be released directly into surface water. Prior reduction of the organic material and cyanide must be achieved before release. For small- and medium-scale processors, effluent seepage pits can be constructed and operated. These pits serve the dual purpose of containing wastes and providing a rapid pathway for groundwater recharge. The seepage pits should be sited over permeable soils away from natural water courses and ground water abstraction points. The pits should be suitably designed and carefully managed and maintained.

In certain areas, particularly where factories are clustered or located close to populated areas more sophisticated waste treatment systems should be considered; these may be individually owned or be a common effluent treatment facility. The simplest technology available is to store the effluent in settling tanks for several days; this will lower BOD and COD and ensure that most cyanide has evaporated. Effluent pits or channels can be used, but the geology of the site should be reviewed and if necessary, the pits or channels lined. Ponding systems and anaerobic reactors are suggested, the choice dictated by available resources (land, technical and financial) and a need to minimize the nuisance factor of open ponds. The ponds should be constructed after due consideration of the site's geology and all necessary precautions taken that water will not seep into the groundwater supply.

Waste water generated by smaller units may be used directly for irrigation, ideally after treatment, but if this is not possible, it must be diluted. Dilution should be to the extent that the cyanide level is reduced to less than 0.3 mg/l before discharge. These precautions are particularly important when treating "squeeze water" waste, because of its high cyanide content. Also, if high cyanide varieties of cassava are processed, waste water treatment is necessary. Irrespective of whether the water is treated or used directly, it must be carefully monitored to ensure that the cyanide level is not too high.

Dealing with solid waste

Waste type: (a) cassava peel
(b) dry fiber

Products: (a) farinha, gari, attieke, chikwangue, flour
(b) flour, attieke, gari

Problem definition: Large amounts of solid waste can degrade the aesthetics of a processing environment, and can lead to deterioration in groundwater quality, if exposed to rain during storage.

Solid waste must be stored in a well-managed manner; it should be covered and protected from the rains. The only problem from solid waste is that of leachates formed during heavy rain. The solid waste should be stored for a minimum period. Adequate market outlets need to be established early in the development process for solid waste products; this may require development of suitable enterprise linkages.

The main problem from solid waste is that of foul odor, especially from the final slurry waste. Careful storage, ideally in sealed tanks will help reduce this problem. Dry waste stored on-site should be stored on concrete paving and under-cover.

Solid waste should be sold or used shortly after its production. Excess may be land-filled, following the necessary precautions and if sufficient land is available. Waste could be used as an animal feed, either directly or after partial breakdown through fermentation; this improves bioavailablity and reduces the cyanide content. The simplest approach would be to ensile the waste, but other possibilities are available. Care should be exercised in the formulation of feed rations, as the waste from cassava processing is deficient in protein, and this should be supplemented from other sources.

Dealing with cyanide

Procedure: (a) toasting
(b) steaming
(c) drying and cooking

Product: (a) gari
(b) attieke

Problem definition: Cyanide, released during processing of cassava, can be harmful to plant operators. If discharged directly to the environment, it can harm aquatic life.

Further details of methods for dealing with cyanide waste are discussed in the main text.

Dealing with dust

Process: (a) turning and distribution
(b) pounding
(c) sieving

Product: (a) chips
(b) flour
(c) dry products

The production and use of cassava chips is associated with a significant dust problem. For small-scale industries the problem is minimal, but as process capacities increase and the operation becomes semi-automated significant dust discharge is expected. Precautions are limited to care in processing, and locating chipping factories away from populous areas. Workers should be appropriately protected from skin contact with the dust that can cause dermatological problems and from inhalation that can trigger a variety of respiratory diseases. Dust can be minimized by spraying a fine coat of vegetable oil (0.3 – 0.5%) to bind dust. This should be done after a screening stage. Screening will remove the major proportion of dust particles and broken fragments. Equipment for screening should be covered and able to contain the dust.

Management measures

Environmental monitoring systems should be adopted and carried out by the processing unit owner. At a minimum, these should include keeping records of water in and out, and notes on the environmental impact of the processing unit. This may be gauged by biological changes in the environment and around the processing unit.

Monitoring by both the factories and officials of waste piles during the off-season should be incorporated into the management system.

<u>Supporting References:</u>

1) Cassava wastes: Their characterization and uses and treatment in Brazil. M.P. Cereda and M. Takahashi. *In*: Cassava Flour and Starch: Progress in Research and Development. CIAT publication no. 271, Cali, Colombia. pp. 221-232. 1996.

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This publication presents an assessment of the impact of cassava production and processing on the environment and biodiversity.The information was presented at the Validation Forum on the Global Cassava Development Strategy, held at FAO headquarters, Rome from 26 to 28 April 2000. This document will interest a wide range of readers including cassava producers, policy-makers, donors, scientists and technicians.

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