AS

IDRC-151e

CASSAVA CULTURAL PRACTICES

Proceedings of a workshop held in Salvador, Bahía, Brazil, 18-21 March 1980

Editors:
Edward J. Weber, Julio Cesar Toro M., and Michael Graham

Organized by:
Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)
Centro Internacional de Agricultura Tropical (CIAT)
International Development Research Centre (IDRC)

The International Development Research Centre is a public corporation created by the Parliament of Canada in 1970 to support research designed to adapt science and technology to the needs of developing countries. The Centre's activity is concentrated in five sectors: agriculture, food and nutrition sciences; health sciences; information sciences; social sciences; and communications. IDRC is financed solely by the Parliament of Canada; its policies, however, are set by an international Board of Governors. The Centre's headquarters are in Ottawa, Canada. Regional offices are located in Africa, Asia, Latin America, and the Middle East.

Postal Address: Box 8500, Ottawa, Canada K1G 3H9
Head Office: 60 Queen Street, Ottawa, Canada

Weber, E.J.
Toro M., J.C.
Graham, M.

Empresa Brasileira de Pesquisa Agropecuária, Brasilia BR
Centro Internacional de Agricultura Tropical, Cali CO
IDRC Ottawa CA

IDRC-151e

Cassava cultural practices : proceedings of a workshop held in Salvador, Bahía, Brazil, 18–21 March 1980. Ottawa, Ont., IDRC, 1980. 152 p. : ill.

/IDRC publication/, /cassava/, /cultivation practices/ — /planting/, /plant production/, /crop yield/, /storage/, /soil fertility/, /fertilization/, /soil management/, /weed control/, /agricultural mechanization/, /agricultural research/, /recommendation/, /agricultural statistics, list of participants.

UDC: 635.23:631.58 ISBN: 0-88936-245-9

Microfiche edition available

IDRC-151e

Cassava Cultural Practices

Proceedings of a workshop held in Salvador, Bahía, Brazil, 18–21 March 1980

Editors: Edward J. Weber, Julio Cesar Toro M., and
Michael Graham

Organized by:
Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)
Centro Internacional de Agricultura Tropical (CIAT)
International Development Research Centre (IDRC)

Contents

Foreword 5
Participants 7
Discussion Summary and Recommendations 9

Agronomic practices for cassava production: a literature review
Julio Cesar Toro M. and Charles B. Atlee 13

Cassava planting material: management practices for production
Abelardo Castro M. 29

Influence of period and conditions of storage on growth and yield of cassava
Antonio M. Sales Andrade and Dietrich E. Leihner 33

Cassava production and planting systems in Brazil
José Osmar Lorenzi, Edgard Sant'Anna Normanha, and Antonio José de Conceição 38

Cassava planting systems in Africa
H.C. Ezumah and B.N. Okigbo 44

Cassava planting systems in Asia
Sophon Sinthuprama 50

Double row planting systems for cassava in Brazil
Pedro Luis Pires de Mattos, Luciano da Silva Souza, and Ranulfo Correa Caldas 54

Soil-related cultural practices for cassava
Reinhardt H. Howeler 59

Soil and water conservation and management for cassava production in Africa
H.C. Ezumah, R. Lal, and B.N. Okigbo 70

Soil-related intercropping practices in cassava production
Carlos F. Burgos 75

Long-term fertility considerations in cassava production
S.K. Chan 82

Cassava production in low fertility soils
Jaime de Cerqueira Gomes and Reinhardt H. Howeler 93

Chemical weed control in cassava
José Eduardo Borges de Carvalho 103

Cultural control of weeds in cassava
Dietrich E. Leihner 107

Integrated control of diseases and pests of cassava
J.C. Lozano and A.C. Bellotti 112

Mechanical planting and other cassava cultural practices in Cuba
Adolfo Rodríguez Nodals 118

Cultural practices for large cassava plantations
Hélio Correa 120

The effect of mycorrhizal inoculation on the phosphorus nutrition of cassava
Reinhardt H. Howeler 131

Bibliography 138

Agronomic Practices for Cassava Production: a Literature Review

Julio Cesar Toro M. and Charles B. Atlee[1]

This paper reviews the main agronomic practices for cassava. Cassava production requires good soil preparation, and, specifically, soil drainage must be adequate. The stakes must be fresh and come from mature healthy plants from which the most lignified part of the basal stem is preferred. The stakes' quality and size are of fundamental importance if high yields are expected. Stakes with signs of cankers, galls, tumours, galleries, or insect infestations should be eliminated, and 30-cm stakes are highly recommended.

Planting on the flat can only be done in areas where root rot is not a serious risk. The vertical planting position is generally recommended, especially in regions with erratic rainfall because it ensures better contact with available moisture, thus provoking faster sprouting. It also gives better and more uniform distribution of roots, and, hence, better anchorage and protection against lodging. The most recommended planting time is the beginning of the rainy season, but in areas where plant diseases are prevalent, planting is usually done at the end of the rainy season.

In general, poor soils show good response to plant population increases, but in rich soils the response to increases in plant population depends on the growing habits of the varieties. For most cassava production, 10 000 plants/ha is recommended unless local research indicates otherwise. Proper selection and treatment of planting material will ensure a sprouting percentage so high that no replanting is needed.

Good weed control, either manually or chemically, is probably the most important factor in obtaining high cassava yields. There are about 19 selective herbicides recommended for cassava. Because of its exceptional ability to extract nutrients from the soil, cassava is usually the last crop to be planted in a rotation scheme. It is advisable to leave the land fallow or rotate following the second or third consecutive harvest, especially in medium-to-poor fertility soils.

It is concluded that the most important cultural practices for cassava production are the selection of healthy and mature 30-cm stakes and good weed control. These practices apply everywhere.

The aim of this literature review is to present a more thorough and up-to-date coverage of the main agronomic–cultural practices used to produce cassava in various parts of the world. No effort has been made to list all references, only selected ones mostly published during the past 20 years. Both fertilization and multiple cropping have been omitted.

Much of the literature is repetitive; however, some excellent work has been done during the past 10 years with the emphasis on cassava research at several national and international research centres. Until recently most agricultural researchers had overlooked cassava, even though it is the seventh most important crop in the world. One reason is that it is primarily a subsistence crop grown in tropical countries (Nestel and MacIntyre 1973). Although grown in more than 60 tropical countries, it has assumed major importance in only six countries that account for nearly two-thirds of the world production.

Although experimental yields greater than 70 t/ha have been obtained, the average yield of cassava worldwide is only 9.4 t/ha. Cock (1974) has suggested that yields in farmers' fields are low because of the lack of suitable varieties and poor agronomic practices.

Cassava is an extremely efficient producer of

[1]Cassava Program, CIAT, Cali, Colombia and Crop Science Department, California Polytechnic State University, San Luis Obispo, California, respectively.

carbohydrates. It is a native of tropical America, tolerant to drought, grows fairly well in poor soils with low pH, and is relatively resistant to disease and insect pests. It has no precise maturity and can be left in the ground and harvested nearly any time of the year, thus being a good security against famine. Its potential yield is greater than for other crops that have been researched extensively. Production of calories per hectare per day is higher than for any other staple food crop. Its foliage can produce up to 5 t of crude protein per hectare a year (Moore 1976). According to recent FAO projections for cassava, present world production is about 110 million tonnes, equal in dry matter to nearly 40 million tonnes of grain (FAO 1978). Of this production, approximately 60% is used for human food. It is an important staple in the diet of more than 500 million people. The rest is used as livestock feed or is converted to starch or alcohol for industrial purposes. Cassava is extremely perishable when harvested fresh, but if dried or processed it can be stored like most cereal grains. Although not much cassava is consumed in Thailand, it has become that country's major export crop after rice.

Brazil, the largest cassava-producing country, is presently growing a considerable amount of cassava for alcohol production to be used as a gasoline supplement.

Land Preparation

As for any other crop, cassava production requires good soil preparation. Land preparation practices vary considerably, depending mainly on climate, soil type, vegetation, topography, degree of mechanization, and other agronomic practices (Seixas 1976).

Where no mechanization is available and cassava is grown as the first crop in forest clearings, no preparation is required, other than removal of the forest growth by cutting down small trees, shrubs, and vines, and cutting off the branches of large trees to admit sunlight. Trees and bushes are piled and burned at the end of the dry season (Viegas 1976). When the first rains soften the ground, the soil is loosened with a hoe, planting stick, or sharp instrument, so that the cassava stakes can be easily planted. Grace (1977) reported that the layer of ashes left after burning increases the amount of potash available to the cassava crop.

Where mechanization is available, many cassava growers plow and disk the land to prepare a good seed bed, aerate the soil, and control weeds. In Brazil a common practice is to open furrows 10–20 cm deep so that stakes can be planted horizontally. Ribeiro Filho (1966) has suggested that on steep land these furrows be made on the contour to prevent erosion, a serious problem in sandy soils, especially during the first few months of the crop. Plowing and the first disking should be about 30 days before planting (EMBRAPA/EMBRATER 1976). The second disking should be done just before planting to improve the soil condition and eliminate weed seedlings.

Tineo (1976) has recommended plowing to a depth of 25 cm and then harrowing. In poorly drained soils, ridges should be 15 cm. According to Diaz (1978), in heavy textured soils where danger of root rot exists, cassava must be planted on ridges in accord with experimental results obtained at the CIAT Cassava Program.

Seixas (1976) found no significant difference in cassava yields from soil plowed to depths of 10 cm, 15 cm, or 20 cm, but results could be different in heavier soils.

Normanha (1976b) has suggested that plowing and disking should loosen soil to a depth of at least 20 cm, the depth at which most roots grow. This provides for easy root penetration.

In light, sandy soils, land preparation requires a minimum energy expenditure, and planting is on the flat. However CIAT (1976) has reported that planting on ridges makes harvesting easier, even though yields are sometimes slightly lower than on the flat. Tractor time is 8.40 h/ha for flat planting compared with 12.60–15.33 h/ha for ridges, depending on the height and shape of the ridge.

Santos (1967) found that the percentage of sprouting and yields of cassava were significantly influenced by the method of land preparation. The ordinary method, consisting of harrowing, plowing, harrowing, and making furrows before planting, gave the highest percentage of sprouting and the highest yields (17.6 t/ha). The harrowing-plowing-planting treatment followed (14.9 t/ha). Next were the plowing-planting and harrowing-punching-hole treatments, yielding 15.5 and 10.6 t/ha respectively.

Land preparation, according to Tan and Bertrand (1972), is usually started in the dry season, except in regions with a very humid climate. In the latter, land is prepared at the end of the "heavy rain" season, and stakes are then planted at the beginning of the dry season during which they can take advantage of the lighter rainfall for early root development. Also in lower rainfall areas, earlier plowing is sometimes necessary because the soil is too dry and hard for tillage during the dry period.

In large plantings, the land is usually prepared as for maize; the field is plowed to a depth of at least 20 cm and is then disk harrowed. Planting is done in rows on the flat surface, although heavy soils in humid areas demand "banking" or making beds on ridges at least 15 cm high so that drainage is improved and root rot minimized. In some cases a second plowing is needed before the harrowing. Many farmers in Southeast Asia plow to a depth of only 15 cm, but this practice frequently results in a decrease of root yield.

Storage of Stakes

For best results in any cassava production enterprise, fresh stakes from mature plants are ideal. However, when they are not available because of cold, prolonged drought, or even excess moisture, many producers have to depend on the reliability of methods to preserve them. Common storage practices usually cause poor sprouting and reduce plant vigour. Long storage causes loss of moisture and exposure to the attack of pests.

Bertoni (1945) indicated that, in Paraguay, stakes stored in a dry place maintained their viability after 5 months. He also stated that a sample of stakes that showed sign of a rotting disease were used as planting material after 6 months of storage in a wood house during the dry season.

Mendes (1949) recommended that stakes be piled in a well-ventilated, shaded area under trees or a straw roof where direct sunlight and dampness are avoided. With this method, stakes have been kept in southern Brazil for 3–5 months without deterioration.

Kiernowski (1950) in Argentina used three cassava varieties stored in straw piles, straw clamps, damp straw huts, dry straw huts, and dry, shaded areas and found that storing in damp straw huts and dry straw huts gave the best results. He also concluded that the response to storage varies according to variety and moisture and to the method of placing stakes under straw.

Stephens (1965) stated that, for any storage method, some factors must be kept in mind: stakes must be mature when stored; stakes must not be stored wet or allowed to get wet; and stakes must be covered lightly at first so that surplus moisture can escape and covered more heavily later as protection against the cold.

Sanchez and Rodriguez (1967) studied three methods to preserve cassava during winter in the province of Misiones, Argentina. Stakes were stored vertically and horizontally in a straw hut, in a forest, and in an open field. In all cases stakes were covered with soil, straw, or both. The stakes that were stored horizontally and completely covered with soil in a straw hut were preserved best.

Krochmal (1969) stated that uncut stems are usually stored in shady, well-ventilated areas. In southern Mexico the bundles of stakes are kept upside down under mango trees for as long as 8 weeks. In the south of Brazil, stakes are stored up to 8 weeks, many times horizontally in the open during the cool dormant season (July and August).

In India, stakes are tied in bundles and stored upright in shade or ventilated sheds for up to 6 weeks. If the crop is harvested during heavy rainfall, storage is limited to 10 days.

CIAT (1972) found that stakes kept at 4 °C for 29 days did not sprout, whereas stakes with both ends protected with a fungicide were viable for 65 days. When the tips of the stakes were immersed in liquid wax, the viability was increased to 85 days; in this case, wax was removed at the time of planting.

Castellar and Mogollón (1972) mentioned that in Caribia, Colombia, stakes of 30 and 50 cm covered with banana leaves were stored for 40 days with optimum results. The viability of stakes longer than 30 cm was improved when the tips were dipped in wax.

CIAT (1973) cited findings that stakes longer than a metre have been kept for up to 3 months with the central portion viable; however, stakes shorter than 25 cm deteriorated rapidly. Also cited were findings that stakes with paraffin-waxed ends, when compared with unwaxed stakes in an investigation of moisture loss, did not exhibit reduced fresh weight. Storage position did not affect overall storage behaviour, although stakes stored in the inverted position had delayed bud breaking and horizontally stored stakes produced a larger proportion of shoots from nodal buds than did stakes in either vertical or inverted positions. The moisture content of stakes fell from 67 to 46% after 50 days storage at room conditions. Waxing was not recommended for storage.

CIAT (1974) showed that long stakes wrapped in sacking and stored in a palm-thatched shelter maintained viability better than short or unprotected ones. After 2 weeks, shoots appeared from the apical end of the stakes. The shoots grow, thus exhausting the reserves of the stem and transpiring water.

CIAT (1978) treated 70- and 20-cm stakes of two varieties (one with good sprouting ability and the other with poor ability) by dipping them in Bavistin and Orthocide (2000 ppm a.i. each) or Daconil and Manzate (4000 ppm a.i. each) and found varietal differences in sprouting after storing them in shade. It was concluded that treatment with fungicide prevents losses due to storage.

Lozano et al. (1977) recommended that the storage area should be well-shaded with some light but not excessive relative humidity (about 80%) and with a moderate temperature (20–23 °C). An additional treatment before planting with fungicides favours sprouting even more. He also indicated that although it is not known whether there is varietal resistance to factors affecting stakes during storage highly significant varietal differences have been found.

CIAT (1979) to solve some of the stake-storage problems found that dehydration was prevented by storing stakes in polyethylene bags or by treating with sodium alginate (Agricol), a water-soluble gel. A dry film of this gel allows oxygen interchange and prevents water loss. To avoid damage by insects and diseases, CIAT treated stakes before storage with fungicide-insecticidal solutions. Ninety percent of the 20-cm stakes rooted, and buds sprouted after 12 weeks of storage when treated with Captan/BCM and kept in polyethylene bags at room temperature. About 95% of the 20-cm stakes from long stems (70 cm) rooted, and buds sprouted when stored for 10 weeks on a dry floor at room conditions (24 °C, 80% RH) after treatment with Captan/BCM (2000 ppm a.i. each). Similarly, 90% of the 20-cm stakes rooted, and buds sprouted after 90 days of storage when they were dip treated in a Captan/BCM (3000 ppm) plus sodium alginate (10 000 ppm) solution and kept at room conditions. Treating stakes immediately after harvest regardless of later storage time increased yield of fresh roots per hectare.

Correa (1977c) for the state of Minas Gerais, Brazil, recommended that, when storage is necessary, long stems be placed in a vertical position and the 10-cm base covered with soil and straw as protection against desiccation.

Stake Size

In any production system, size and quality of the stake are of fundamental importance if high yields are expected. According to Lozano et al. (1977), the quality of the stake per se is determined by the age of the stem used, the number of nodes per stake, the thickness of the stake, the size of stake, varietal differences in sprouting, duration of storage, and the extent of mechanical damage to the stake when it is being prepared, transported, stored, and planted.

A cassava plant may be obtained from a very small stake, with only one bud (Cock et al. 1976), but the possibilities of sprouting under field conditions are very low especially when soil moisture is deficient. Celis and Toro (1974a, b) indicated that early development is affected if planting is done in poor soils because the nutritional reserves are insufficient in a small stake for the initial growth stages. They also said that the smaller the unburied portion of the stake, the tougher the competiton with weeds. The advantages of using very long stakes, i.e. 60 cm long, are higher initial height of the plant and, hence, greater shading of the soil surface, which increases the ability of the cassava plant to compete with weeds.

The length of stake commonly used by farmers is 15–25 cm, which seems appropriate unless a field trial that includes production costs indicates a more convenient size. It has to be kept in mind that economic aspects as well as practical considerations about handling the stake may affect the size of the propagating material.

CIAT (1975), working with local varieties in three different locations using 20-, 40-, 60-, and 80-cm stakes planted vertically, obtained the best results with 40-cm stakes without irrigation.

Gonzales (1973) in Jusepin, Venezuela, using 10-, 20-, 30-, and 40-cm stakes planted horizontally, vertically, or in an inclined position in rain-fed conditions for 2 years found no difference that could be traced to planting positions but found that 40-cm stakes always gave the highest yields. In contrast, CIAT (1979) using 20-, 40-, and 60-cm stakes planted vertically at the CIAT-Palmira experiment station under irrigated conditions found that 20-cm stakes yielded significantly better than the other two. Rosas (1969) in La Molina, Peru, using three planting positions and stake lengths of 10, 20, and 30 cm found no yield differences due to planting positions but found that the 10-cm stakes gave the highest yield. Silva (1970) reported that experiments in the state of Santa Catarina, Brazil, with stake lengths of 10, 15, 20, 25, and 30 cm have indicated that 30-cm stakes are superior. Normanha and Pereira (1964) recommended stakes, 20–25 cm long, planted horizontally, 10 cm deep, for Brazil in general. Chan

(1970) in Malaysia found no differences in yields using stakes 8, 15, and 23 cm long.

Gurnah (1974) in two experiments carried out during 2 years in the forest zone of Ghana with adequate rainfall (1080 mm) using stakes of 2, 3, 4, 5, 6, 7, and 8 nodes found that yield increased with the number of nodes up to five. An increase in the number of nodes beyond five per stake did not affect yields. The longer stakes had more buried nodes than did the shorter ones and presumably produced more stems and leaves and in turn higher yields. Also, Donkor (1971) observed that when more nodes are buried, more roots and stems are initiated. However, it must be pointed out that the stakes used in his experiments were from freshly cut stems. If the stems had to be transported over long distances or stored for a long time before planting, hardiness and ability to survive storage would have been important, the more mature basal and middle stakes probably giving better sprouting and possibly better yields. During Donkor's experiments, there was adequate, well-distributed rainfall. It is likely that if there had been no rain for a long period after planting, the types of stakes also would have made a difference, as top stakes are most likely to suffer from lack of rain. In the forest zone, where rainfall is plentiful, any type of stake can be used reliably.

Jeyaseelan (1951) working in Ceylon (Sri Lanka) with basal and apical stakes, 15 and 30 cm long, and investigating horizontal and vertical planting positions found that best yields were obtained with 30-cm stakes from the basal part, planted vertically.

Rodriguez and Sanchez (1963) in Misiones, Argentina, in a 3-year study using 30-cm stakes and two planting positions (inclined and horizontal) and comparing the results with those from 10-cm stakes planted horizontally, found that the 30-cm stakes gave higher yields, as did the inclined position, although the latter made harvesting difficult.

Conceição and Sampaio (1973a) for 3 years in Bahia, Brazil, used 10-, 12-, 15-, 20-, 25-, and 30-cm-long stakes from 12-month-old plants in sandy, clay, loam latosol with 1196 mm of rain and 24 °C. Stakes were planted horizontally, 10 cm deep. They found that high yields were obtained with 20-, 25-, and 30-cm stakes.

Jennings (1970) suggested that long stakes gave higher yields than short ones. He recommended 30- and 45-cm-long stakes (moderately thick), taken from the basal part of the plant rather than from terminal parts.

Planting Methods

Whatever planting method is used, good sprouting of the stakes requires adequate soil moisture and good soil preparation. Land preparation and the corresponding planting methods depend primarily on soil type and climate. Toro et al. (1978) reported that studies carried out by CIAT, on the flat plains of Colombia, showed that flat planting is advantageous when done during the dry season. Ridge planting was desirable during the rainy season. A "bed" system, developed at CIAT, uses a flat-top ridge. The beds are made by a shaper attached to a rototiller; therefore only one operation is needed to prepare the land for planting. (Beds or ridges are not recommended for sandy soils because they will not hold their shape, and, in any case, such soils have good drainage.) Beds are somewhat more practical than ridges for intercropping cassava with beans or cowpeas, which can be planted mechanically at the same time as cassava on a heavier soil. When machinery is not available to make ridges or beds, cassava can be planted on the top of a cone-shaped hill or mound built manually with a hoe (Toro et al. 1978).

As Normanha (1976b) also indicated, heavier, more compact soils should be prepared in beds or ridges. Heavy soils that seal or waterlog have a detrimental effect on cassava during the rainy season because of poor aeration. Without adequate oxygen, the cassava cannot form storage roots, probably because starch accumulation needs large quantities of free oxygen.

In 1976 Conceição reported that horizontal planting, 10 cm deep in furrows, facilitates commercial harvesting and reduces weed problems. Ezeilo et al. (1975) found that in Nigeria cassava is grown on lighter soils and that 77% is planted on hills, 11% on ridges, and 11% on the flat. In Malaysia, Lulofs (1970) reported that planting on the flat is satisfactory but ridging may give a more even stand, easier harvesting, and better erosion control.

Lozano and Terry (1978) recommended that, in areas where rainfall is more than 1200 mm, clay soil should be prepared in ridges to promote better drainage, which improves crop stand and yield considerably. Yield losses of 80% caused by root rots have been reported. However, Koch (1916) found no significant difference in yield between planting on the flat or on ridges, and Grace (1977) wrote that some experiments have shown ridging to produce somewhat lower yields than flat planting. Harper (1973) also reported that planting on ridges in Thailand produced lower yields than did flat planting. In one experiment with commercial-sized plots conducted in the loamy soils of the Caicedonia area, CIAT (1976) reported similar results; however, ridging reduces weedings and facilitates harvesting.

Krochmal (1969) stated that planting on furrows or ridges is a rare practice and not one to be encouraged because machine planting is impossible with such systems and the costs of the additional operations do not pay off in any increased returns.

Planting Position

Like the literature on planting methods, that for planting position is equivocal, and the most appropriate planting position varies with cassava variety, soil characteristics, and climate.

Galang (1931) in the Philippines using 30-cm stakes of 21 different varieties found that 13 gave higher yields when planted vertically, whereas the remaining eight responded better to an inclined position. After two experiments he concluded that stakes may be planted in either an inclined or a vertical position with practically equal results. But, Fernando and Jayesundera (1942) indicated the significant superiority of vertical planting over horizontal. Later, Rao (1952) stated that vertical planting is superior where rainfall is moderate and that inclined position is adopted where rainfall is more than 1700 mm a year.

Brandao (1959) compared two systems of planting cassava in heavy soil. Basal stakes, 40 cm long, planted vertically, 10 cm deep, yielded 30% more than 20-cm stakes planted 10 cm deep horizontally. The root distribution was different, with roots being nearly 5 cm deeper from vertically planted stakes than from those planted horizontally. The latter were easier to harvest.

Crawford (1961) working in Jamaica came to the conclusion that horizontal planting of 25-cm stakes is best if soil moisture is limited at planting time. If the stakes are covered with 2–3 inches (5–7 cm) of soil, there is less "drying out" and therefore sprouting percentage is improved. Roots originate from a greater number of points along the length of the stake and therefore have more room to develop; they also tend to spread and develop closer to the soil surface, making better use of applied fertilizer and organic matter. Horizontal planting gave higher yields than did inclined plantings (an angle of 15 or 45 degrees).

Loria (1962) in Costa Rica studied three planting positions, horizontal, inclined, and vertical, and found no significant difference in yield although vertical planting produced the highest yield. Similarly, Chan (1970) found no differences in yield from horizontal, vertical, or inclined planting of 15-cm stakes. On the other hand, Krochmal (1969) in the Virgin Islands reported that it would be better to plant 20- or 25-cm stakes with three buds, horizontally at 5–10 cm under the soil surface than to have them inclined. Kunju (1972) indicated that, when stakes are planted on ridges, vertical planting is always found to be better.

Harper (1973) in Thailand found that the planting position depends on soil and climatic conditions. Generally horizontal planting is carried out in the dry season (October to May), producing more sprouting and greater yield due to the fact that roots are produced from more growing points. Also roots tend to grow nearer to the surface of the soil, which makes harvesting easier. Vertical or inclined planting is used in areas where rainfall is high during the wet season (May–October) or where horizontal stakes would rot, such as in areas with high soil moisture.

Gonzales (1973) in Venezuela made a study involving two tests on size and planting position. He used four sizes: 10, 20, 30, and 40 cm and three positions: vertical, inclined, and horizontal. In both tests, the 20-, 30-, and 40-cm stakes were significantly superior to 10-cm stakes, and he, therefore, recommended continued research using 20- to 40-cm stakes. With respect to planting position, the results of the first test gave 15.0, 13.7, and 12.0 t/ha respectively for horizontal, vertical, and inclined positions. Although the horizontal and vertical were superior there was no significant difference between the two. In the second test yields from the three positions were not significantly different, ranging from 22 to 23.8 t/ha. The lower yields of the first test may have been due to deficient rainfall.

In other work on planting position, some workers found no significant difference in yield but a decided difference in depth and root distribution (Gurnah 1974). Vertical planting produced roots that were deeper and closer together, whereas horizontal planting produced shallow roots distributed along the length of the stake.

Cock (1974) stated that studies on planting position do not show consistent trends.

Chew (1974), with cassava grown in Malaysian peat soils for 2 years, used horizontal, inclined, and vertical planting and found no significant difference in yield from the three positions. However, he recommended horizontal planting because it provides better protection against desiccation of stakes and also gives better sprouting.

Conceição and Sampaio (1975a, c) undertook an experiment involving four planting systems with four cultivars. The effect of the planting system was not statistically significant; consequently it was recommended to plant on the flat using 20-cm stakes planted horizontally at a depth of 10 or 20 cm because it would be less expensive for mechanical planting.

Wahab et al. (1977) found no significant difference in yields from manual and mechanized horizontal planting in Guyana.

In Colombia, Diaz et al. (1977) observed that cassava was widely planted in the vertical position in only one of the five cassava-growing areas they studied. This region was characterized by sandy soils with a prolonged dry season (up to 4 months) and a mean annual rainfall of 1200 mm.

According to Grace (1977), under low rainfall conditions, vertical planting may result in the desiccation of the stakes, whereas in areas of higher rainfall, horizontally planted stakes may rot. In general, horizontal planting, 5–10 cm below the soil surface, is recommended in dry climates and when mechanical planting is used. This system makes manual harvesting easier too. Vertical planting is used in rainy areas and inclined planting in semi-rainy regions.

Castro et al. (1978) determined that neither the cut angle nor the planting position of the stake had a significant effect on yield. With the right-angle cut, the roots were distributed uniformly around the perimeter. With horizontal planting, harvesting and separation of the roots was easier compared with vertical or inclined planting. A right-angle cut and vertical planting position were recommended because of a slight tendency toward higher yield. The horizontal position was recommended for mechanized planting when soil moisture is adequate.

Onwueme (1978a) by using 20- to 35-cm stakes planted vertically upright and inverted found that yield was significantly higher for the upright planting.

Celis and Toro (1974a, b) recommended that for vertical planting at least four buds should be underground for good sprouting. In this position, roots tend to form at the lower end of the stake and are distributed radially, more or less uniformly. Inclined planting means inserting the stakes in the soil at a 45-degree angle. In this case the roots tend to follow the same direction of the angle at which the stake is planted. Some farmers think that harvest labour is easier with this method because of the position of the roots. Horizontal planting involves placing the stake horizontally, usually in a furrow, and burying it completely. This planting position lends itself well to mechanical planting. In this position roots tend to form at the butt end of the stake. When stakes are long (30–40 cm), roots may form along the sides at the nodes.

In tests at CIAT, sprouting and emergence of stakes under field conditions were always more rapid with vertical planting than with any other method. Even though there are good reasons and clear advantages to planting cassava stakes vertically, there are also some advantages to horizontal planting: (1) horizontal planting is easier; (2) there is no need to worry about planting stakes upside down, which Bolhuis (1939) showed to be undesirable; (3) there is no need to stoop or bend over (Odigboh 1978); and (4) the roots are shallower and easier to harvest. However, some of the obvious disadvantages are: (1) under extremely adverse climatic conditions, the shallow (5 cm) planting allows more heat damage, more exposure of roots to erosion effects, and more lodging from wind (Koch 1916 and Castro 1979), due to poor anchoring in the ground; (2) deeper planting (10 cm) can cause slower sprouting and emergence, resulting in more weed competition (Castro 1979), and during weeding more damage to stakes that have not yet emerged (Ribeiro Filho 1966); and (3) sometimes lower commercial yields are produced than with vertical or inclined plantings.

In sum, experience in many cassava-growing areas of different countries has indicated that planting position should be decided according to the following criteria:

(1) In regions of medium to heavy soils with adequate rainfall (1000–2000 mm/year) it does not matter whether stakes are planted horizontally, inclined, or vertically because the moisture will be adequate for sprouting of the buds.

(2) In areas of sandy soils or erratic rainfall, vertical planting is safest. In this case, 20-cm stakes will have at least 10–15 cm in the soil, and thus have better contact with available moisture. When stakes are planted horizontally in such regions, the buds will rot because of the heat, which is always greater in the soil than in the surrounding air. In the case of vertical planting, the stakes serve as a heat diffuser (Lozano personal communication 1975).

Planting Dates — Time of Planting

The most common planting time for cassava is at the beginning of the rainy season when competition for labourers for planting is at its peak. In areas with adequate temperature and soil moisture during the dry season, planting can be done at almost any time when labour is available. Planting in the dry season also reduces disease problems and increases yields. It is advisable to plant after the first well-defined rains to avoid losing the plants. Research done by Normanha and Pereira (1947) in São Paulo, Brazil, indicated that planting cassava during the normal harvest (May–July) produced the highest yields and starch content. This timing would also solve the problem of storing planting material and would result in less soil erosion than planting during September and October after rains begin. Correa (1977c) stated that in other areas of Brazil it is advisable to plant at the beginning of the rainy season, which in Minas Gerais is October–mid-December, or during the rainy season in drier areas such as Bahía (April–June). Albuquerque et al. (1974) cautioned against planting during October–January in eastern Para in the Amazon Valley because that is the wettest period and rotting can be a problem. Viegas (1976) however, recommended October planting in northeastern Brazil because of the long season (12–24 months). In southern Brazil, all cultivars should be planted in August (or October in dry years).

Silva (1979) recommended planting at the beginning of the rainy season, but Ribeiro Filho (1966) indicated that earlier planting is recommended by Normanha and Pereira for São Paulo and Drumond for Belo Horizonte.

Many factors that could influence soil moisture such as the texture of the soil, rainfall, relative humidity, temperature, and wind; in heavy, poorly drained soils excess moisture encourages root rot (Oliveros et al. 1974). Lozano and Terry (1978) stated that appropriate planting time may reduce the incidence of disease. For instance, planting at the beginning of the rainy season ensures good establishment and ensures sufficient growth of the canopy to provide shade during the dry season, approximately 4 months after planting. Because of the dry environment (in spite of poor air circulation and high relative humidity between plants), the microclimate will not be favourable to pathogens. For this same reason, planting has been recommended at the end of the rainy season in the eastern *llanos* of Colombia.

In many cassava-growing areas, rainfall is evenly distributed throughout the year and offers the possibility of several different planting dates with only minor differences in yield especially where soils are well drained yet maintain moisture. Two planting dates have been recommended for the Philippines and Colombia because of two rainy seasons per year.

According to Correa (1971), the timing of planting is the most important production factor. Zijl (1930) also stated that planting dates markedly influence production and recommended November planting for Java (Indonesia). Celis and Toro (1974a, b) commented that probably the most important factor related to time of planting is lack of moisture, which during the first 20 days after planting may cause serious losses in sprouting.

Viegas (1976) stated that although planting should be done at the beginning of the rainy season it is important to plant only on a clear, dry day. One problem with waiting until after the rainy season is well under way is that good propagation material may be difficult to find. If stems have already started to sprout, the sprouts are easily broken off in handling, and if stakes have been stored for a long time, they become dehydrated and lose their sprouting vigour.

An experiment, reported by Rodriguez et al. (1966), was conducted in the Misiones province of Argentina, over a 3-year period. The findings were that one variety was best planted early (August–September) and harvested in May and that another was best planted late (October–November) and harvested in June. In other words, specific varieties may each have different optimum planting and harvesting dates. This is probably the reason that many subsistence farmers plant several different varieties throughout the year so that they can have cassava to harvest at any time.

In 1977, Grace indicated that time of planting is influenced by both weather conditions and the availability of planting material. Planting is sometimes divided between the two rainy seasons, but is usually carried out throughout the year in regions with year-round rainfall. It is desirable to plant and harvest during approximately the same season to avoid storing the stalks for a long time. Experience has shown that starch production in the cassava plant is best when planting takes place at the beginning of the rainy season.

Ninam et al. (1977) found that in Kerala, India, cassava can be grown all year and that for maximum root yields, planting should be done in April. The second best season for planting is September. Nair (1978) recommended April–May as the best time for planting in Kerala and Tamil Nadu where the climate is warm and rainfall is 1500 to 2000 mm/year distributed evenly.

Planting Depth

Normanha and Pereira (1950), using three depths (5, 10, and 15 cm) and two planting seasons during 3 years, concluded that under hot dry conditions stakes planted 15 cm deep sprouted faster than did those planted at shallower depths perhaps because of increased moisture at the 15 cm depth. The opposite was true when temperature and moisture were adequate. The harvest was much easier for stakes planted at 5 cm deep than for those planted at 15 cm because of the rooting depth of the latter. The yields were 18.2, 16.5, and 13.2 t/ha for stakes 5, 10, and 15 cm deep, respectively. The planting depth of 5 cm was quite advantageous but had drawbacks, such as the lack of protection against erosion and lodging, that made a 10-cm planting depth more suitable.

Campos and Sena (1974), to measure the rooting depth of cassava, planted 20-cm stakes in rows 10 cm deep in a horizontal position and spaced 1.00 × 0.60 metres apart. The results showed that the roots reached depths of 90 and 140 cm at 140 and 365 days, respectively. Within the 30-cm depth were found 95.3 and 96.4% of all roots, and of these 65.6 and 85.7% developed in the top 10 cm of soil.

Conceição and Sampaio (1975a, c) recommended the flat planting of 20-cm stakes, 10–20 cm deep in a horizontal position, because this lowers the cost per hectare for mechanical planting.

In Brazil it is recommended that cassava be planted in continuous rows horizontally 10–15 cm deep and that animal- or tractor-powered machines be utilized.

Holguín et al. (1978) found that, under optimum conditions, such as adequate soil moisture and good quality treated stakes, planting depth did not affect the growth or yield of cassava planted vertically. The 10-cm planting depth for the vertical position was easiest for both planting and harvesting. This study should be repeated in light sandy soils with little moisture because under adverse conditions these soils become extremely hot and dry at a depth of 5 cm and would create a most unfavourable environment for sprouting and rooting of cassava stakes (Normanha and Pereira 1950).

Ribeiro Filho (1966) suggested that deeper planting makes harvesting more difficult, and Celis and Toro (1974a, b) noted that stakes can be planted shallow or deep in any one of several positions. A good practical rule is that cassava stakes planted in dry sandy soil should be inserted relatively deep, whereas those in moist, heavy soil require shallow planting. In the latter case, it should be remembered that a deep planting will make harvest difficult and increase production costs.

In 1972, Tan and Bertrand commented that depth of planting must be regulated in terms of environmental conditions. Too much exposure of the stakes in areas where soil moisture is below optimum can result in poor stands and consequently low yields.

Mechanized Planting

According to Normanha (1970), the highest degree of cassava crop mechanization in Brazil has been reached through the use of a two-wheeled mechanized cassava planter, made in Brazil, which simultaneously accomplishes furrowing, fertilizing, horizontal planting, covering of stakes, and firming of the soil. It is tractor pulled and plants two rows at a time.

At present, the need for a more efficient machine for planting is becoming very important, especially where large areas have to be planted in a short time. The old Sans two-row planter is very heavy and requires stakes already cut. This latter "drawback" may be useful because the stakes can be treated prior to planting. Massey Ferguson also has a two-row planter, lighter than Sans. This planter opens up the furrow, cuts the stakes to the size desired, deposits them in the furrow, places fertilizer on either side of the stakes, covers them with soil, and compacts the soil if required. It has a planting capacity of 3–4 hectares per day. The Delfosse machinery manufacturers in Montes Claros, Minas Gerais, are engaged in developing cassava planters for 4–6 rows.

Monteiro (1963) reported that the Sans planter was tested at Piracicaba, Brazil, and it did an almost perfect job. It operates at normal tractor speed even on fairly steep land. Using it, eight persons can plant 10 ha/day, whereas 30 persons are needed to plant the same area by hand.

Leihner (1979) stated that implements of the vegetable or tobacco-transplanting types should be looked at for possible adaptation to vertical planting. Mechanization in grain–legume planting has existed for a long time and cannot be considered as a technical problem but an intercrop planter would have to combine the different elements of the single crop planters into one machine. Cock (personal communication 1978) indicated that the cassava program of Cuba has developed a planter prototype for vertical planting.

According to Odigboh (1978) the manual planting of cassava stakes, in a vertical or inclined position, is an arduous and back-breaking operation and constitutes one of the major factors limiting the development of large-scale cassava industries in Nigeria. So the development of a new two-row cassava planter in that country may be particularly important. The machine is fully automatic, tractor-drawn at speeds up to 10 km/h. It plants stakes of diameters between 2 and 5 cm and excludes smaller diameters, which have lower viability. Stakes 25 cm long are planted 17 cm deep at inclinations of up to 80° to the horizontal, depending on tractor speed. Spacing is 0.9 m on small ridges that are 0.9 m apart. The metering mechanism is driven by the drive wheels. The machine is quite sensitive to the quality of field preparation, especially at high speeds; 6 km/h is recommended. The within-row plant spacing is practically independent of planter speed. Makanjuola (1975) reported that several units of this automatic planter can be mounted side-by-side for planting more than one row at a time. The machine can be manufactured in Nigeria except for the ridge disks and bearings.

Schulte et al. (1973) reported good results with a New Holland vegetable transplanter, which planted an average of 0.28 ha/hr. He indicated that it should be possible to develop a transplanter that would make ridges and plant the cassava stakes in one operation.

Plant Population

Optimum plant density of cassava is highly dependent on edaphiclimatic factors, cassava varieties, soil fertility, cultural practices, and the final utilization of the roots. Calderón (1972) working with two varieties in a fertile soil at populations from 10 000 to 30 000 plants/ha found that yield increased with population in only one of the varieties. CIAT (1976) reported that optimum plant population per unit area depends on the size of the plant. Two short and two tall varieties with different branching characteristics were selected and planted at CIAT at densities between 2500 and 40 000 plants/ha harvested at 12 months. It was found that total root yield increased as plant population increased. This is a good characteristic for industrial cassava cultivation. However, for commercial fresh consumption optimum plant population was 10 000 plants/ha for short and tall varieties of erect type and 5000 plants/ha for tall branched varieties.

Experiments conducted by CIAT (1975) in different zones showed that optimum plant population changed according to ecologic conditions. In general, poor soils show good response to plant population increases, whereas in rich soils the response to plant population increases depends on the growing habit of the varieties. In 1970, Silva reported that in the southern state of Santa Catarina and the Sete Lagoas region at Minas Gerais it is convenient to plant from 16 666 to 20 000 plants/ha in soils of good fertility.

Normanha and Pereira (1963) also recommended from 16 666 to 20 000 plants/ha in low fertility soils of the state of São Paulo even if plants are fertilized and 13 888 plants/ha in fertile soils due to the more vigorous growth in this type of soil. Nunes et al. (1976) reported that using nine populations in three municipalities of the state of Rio de Janeiro with low fertility soils, he found that 20 000 plants/ha gave the best result for total roots. He also concluded that for every 20 cm of extra space yield was reduced by 765 kg/ha. Drumond (1954) found that in the experiment station of Patos in Minas Gerais in fertile soil the best population was 20 000 plants/ha; Mattos et al. (1973) recommended 16 666 plants/ha for the Cruz das Almas region in Bahía for soils of low fertility without fertilizer application. Santos et al. (1972) recommended 10 412 plants/ha for the state of Pernambuco. He also indicated that for the poor soils of the northeast 20 000 plants/ha is recommended in contrast with 13 888 for the good fertile soils of the same region. Albuquerque (1970) has recommended after many years of cassava research 10 000 plants/ha for the low fertile soil of the state of Pará in the Amazon basin, 17 777 for soils of fertility below average, and 4473 for the fertile soils. Mandal et al. (1973) at the Central Tuber Crops Research Institute found that the highest root yield was obtained at 12 345 plants/ha for a branched variety and 17 777 plants/ha for a nonbranched variety during a 2-year study. Consequently, the requirement of spacing for different types of varieties was ascertained. He also found that with increases in shoot numbers from one to two shoots per plant root, yield increased significantly in both branched and nonbranched strains.

Narasimhan and Arjunan (1976) found at Tamil Nadu in India that by adopting wider spacing in cassava at 12 345 plants/ha they could minimize incidence of mosaic. In general, it has been observed that as plant population increases, the total root yield also increases; however, the number of roots per plant, root size, and harvest index decrease, while weed control by competition improves. CIAT (1973) with a systematic fan design planted three varieties at populations ranging from 2000 to 80 000 plants/ha. At the 7th-month harvest, CMC-84 gave its highest yield (18 t/ha) at populations of between 5000 and 9000 plants/ha whereas CMC-49 produced its highest yield (18 t/ha) at between 2000 and 5000 plants/ha. The variety Llanera yielded 24 t/ha between 3000 and 7000 plants/ha so it seems that optimum plant density in cassava changes with varieties. The yield decreases at populations larger than optimum because of the weight reduction in roots.

Tardieu and Fauche (1961) recorded the highest yields of cassava with 10 000 plants/ha; however, Rodriguez et al. (1966) recommended much higher populations 13 300–20000 plants/ha. Gurnah (1973) obtained the best yield of roots at populations of 18 500 plants/ha planted at 60 × 60 cm and observed that spacing above or below 60 cm reduced root yields in the forest zone of Ghana. Gurnah's optimum spacing of 60 cm was closer than that (90 cm) generally recommended in Ghana (Doku 1969). Takyi (1972) observed that spacings of 90 × 90 cm and 90 × 60 cm on sandy loam in ochrosol at Kwadaso, Ghana, gave significantly higher yields than spacings of 90 × 120 cm, but there were few large roots with the closer spacings. Enyi (1970, 1972) used 90 × 120 cm in experiments on cassava in Sierra Leone, but Godfrey-Sam-Aggrey and Bundu (1972) spaced experiments at 120 × 120 cm in Sierra Leone. Godfrey-Sam-Aggrey (1978) using a multishooted variety in Njala upland soils of Sierra Leone found that increasing plant population to more than 7000 plants/ha decreased all parameters studied except top/root weight ratio, which increased. The observed effects were attributed to competition for environmental resources, because area of land/plant unit decreased as plant population increased.

The literature with respect to optimum plant populations and yields conflicts both among and within countries. Because the growth habits and morphology of the crop, as well as environmental conditions, influence cassava yields, recommendations on plant populations for one variety in a particular environment may not be appropriate elsewhere or with a different variety of cassava.

Replanting

Replanting consists of replacing stakes that for some reason do not sprout 1 month after being planted. If the planting material has been properly selected and treated (Lozano et al. 1977), replanting may not prove necessary. Economic considerations are important because a decision must be made about the percentage of sprouting failure at which replanting is economically feasible. By following a careful selection and treatment of stakes, Toro (1979) was able to get 94% sprouting mean in 28 trials with 38 promising and 10 local varieties in 10 Colombian locations during 3 years covering a wide range of ecologic conditions. According to Tan and Bertrand (1972), if a high yield is desired, stakes that fail to develop should be replaced as soon as possible. Grace (1977) suggested replanting no later than 1 month after planting, when at least 5% of plants fail to sprout.

In Caicedonia, Colombia, Ramon Duque (personal communication, 1979) used long-heeled stakes coming from the first branching of a mature plant for replanting. The stake was planted in such a way that the long part remained inclined (75°), whereas the heel (about 20 cm) was buried horizontally. The length of the stake was always 25 cm longer than the average height of the crop at replanting time. The replanted stakes sprouted rapidly and caught up with the rest producing yields comparable with those from stakes. The use of heeled stakes has been recommended by Hartman and Kester (1968).

Weed Control

Good weed control is one of the most important factors in obtaining high root yields in cassava. According to Ribeiro Filho (1966), it is especially important during the first months after planting and during the rainy season. In 1976, Doll and Piedrahita pointed out that with no weed control cassava yields can be reduced by 50% but with only minimal weed control cassava has the ability to survive, compete, and produce good yields. Nearly all researchers agree about the importance of early weed control when the crop is young and most susceptible to damage from weed competition for light, water, and nutrients.

Gonzales (1976), Delgado and Quevedo (1977), and Doll et al. (1977) reported that weeding represents more than 45% of the cost of production. This cost is almost entirely for labourers, who are at times not available because of other priorities. When weeds are small, they are much more easily controlled than they are later when they may have already produced an abundant seed crop.

The number of weedings necessary for cassava varies considerably in different reports, depending mainly on soil fertility, climatic factors, and varieties. In 1975, Onochie stated that experiments in Nigeria showed that, when limited labour is available for cassava production, it should be used for weed control during the 3rd month after planting. Weeding at this stage was as effective (in terms of yield) as weeding throughout the entire growing period. Santos et al. (1972) recommended 3–5 weedings during the first 6 months and 1–2 times the 2nd year, for the northeast of Brazil; Crawford (1961) suggested 4–5 weedings during the first 12 months in Jamaica.

Ezeilo et al. (1975) reported an average 2–3 weedings in Nigeria, and Diaz et al. (1977) observed 3 weedings within 6 months of planting in Colombia. Tan and Bertrand (1972) recommended weeding as often as needed until the foliage canopy closes; according to Doll and Piedrahita (1976) this process takes 2–4 months. Weeding should begin as soon as weeds start to compete with the cassava. Delgado and Quevedo (1977) suggested the first weeding be done 28–35 days after planting and Montaldo (1966) said 21 days after planting plus other times when weeds begin to be a problem. CIAT (1973) stated that early weedings about 2 weeks after planting may be harmful to young unrooted cassava plants.

The amount of weeds and therefore the frequency of weeding depends on a number of factors such as: planting time and prevailing weather — lower soil moisture encourages fewer weeds (Ribeiro Filho 1966); soil fertility — pH-poor soils or infertile soils may have few weeds (Castro 1979); vigour of planting stock — fresh stakes, carefully selected and chemically treated (Leihner 1979), produce the best results; proper soil preparation — harrowing, waiting 2 weeks, then listing or ridging would eliminate two flushes of weeds (Viegas 1976); planting method — horizontal planting results in slower sprouting of stems, which in turn results in more weed competition (Silva 1971b; Ribeiro Filho 1966); variety, especially growth charactistics (Doll and Piedrahita 1976); spacing — closer planting shades out weeds earlier (Conceição 1975); weed species — some species are particularly difficult to control (Ribeiro Filho 1966); weedseed in soil — good previous crop management prevents weeds from going to seed and therefore reduces weed populations (Ribeiro Filho 1966); and shading by cassava — 3–4 months after being planted, the cassava produces shade that inhibits weed germination and growth (Silva 1971b; Doll and Piedrahita 1976).

Weed control in cassava is traditionally done by hand with a hoe. EMBRAPA/EMBRATER (1976) for Ceara state in Brazil recommended making the first two weedings with an animal or tractor-drawn cultivator, returning with a hoe between plants in the rows. Silva (1979) suggested mechanizing weed control whenever possible, and Delgado and Quevedo (1977) indicated that furrowing and listing with a cultivator is advisable at about 2–3 months after planting because this operation not only controls weeds but improves drainage and facilitates harvesting. Earlier, Ribeiro Filho (1966) had recommended listing during the second and third cultivation but had said that thereafter weeds should be controlled only by hoeing because too much damage is done to the cassava plants by the cultivator.

The use of herbicides in cassava is quite new, but in recent years some excellent work has been done, especially in Latin America. Diaz and Arismendi (1973) in Venezuela obtained the highest root yields with Fluometuron (Cotoran) at 3 kg/ha and Ametrina (Gesapax) at 2–3 kg/ha in a sandy loam soil; however Coelho and Correa (1971) in a heavy oxisol in Sete Lagoas, Brazil, found some phytotoxicity with Fluometuron during early development of the plant. Cunha et al. (1975) in latosolic soils of Cruz das Almas, Bahia, Brazil, found Diuron (Karmex) to be selective. On the other hand, Moody (1972) observed 84 and 62% yield reduction by using Diuron and Linuron (Afalon, Lorox) at 3 kg/ha on sandy clay loam soils in Ibadan, Nigeria.

Jennings (1970) reported that weed control was only necessary during the early growth of cassava and the use of chemicals to control weeds in cassava is uncommon in Africa. In Sierra Leone, Godfrey-Sam-Aggrey and Bundu (1972) suggested 30-day intervals between weedings; Godfrey-Sam-Aggrey (1978) studied the effects of not weeding and of weeding by hand at 30-, 45-, 60-, and 90-day intervals and found that time and frequency of weeding were important in influencing root yield. Delayed weed control depressed root yield. The critical period of competition was in the 45-day weeding interval.

Valles (1977) in Tarapoto, Peru, found the critical period to be between 45 and 60 days and the best treatment to keep the crop weed free during the entire growing cycle. In most cassava-growing areas herbicides are not available and are a considerable expense, initially, to the farmer. According to Montaldo (1966) herbicides should be used if plantings are of a commercial size of 20 or more hectares. In sandy soils extreme caution should be used in applying herbicides. Work done at CIAT (1975) showed that even at low doses, the herbicides leach enough in sandy soils to damage or kill the cassava. Ridging appeared to exacerbate the problem. Some cassava cultivars have been shown to be more susceptible to herbicide toxicity (CIAT 1974). In other soils Doll and Piedrahita (1976) found that Diuron (Karmex) applied as a preemergence spray plus one hand weeding about 60–75 days after planting gave the most economic weed control under CIAT conditions of heavy clay vertisols.

There are a lot of selective herbicides; Doll and Piedrahita (1976) listed 18 herbicides highly selective and 12 moderately selective. Leihner (personal communication 1979) found Oxifluorfen to be moderately selective alone or in mixture with Alachlor. This new herbicide controls both broad leaf and grasses in preemergence. It can be used safely at dosages between 0.5 and 1.0 kg/ha a.i. CIAT (1976) recommended the mixture of Diuron and Alachlor (Lazo) at different dosages, according with soil texture (Table 1), Diuron to control broad leaves and Alachlor to control grasses.

Leihner (1979) recommended the mixture of Linuron and Fluorodifen (Preforan) at 0.5 + 2.5 kg a.i./ha applied in preemergence to cassava intercroppped with dry beans (*Phaseolus vulgaris*).

Irrigation

According to Cock and Howeler (1978), there are few data on the water requirements of cassava, critical periods when water is essential, or the response to irrigation. Their experience with cassava, unfortunately not yet supported by data, has suggested that cassava requires moist

Table 1. Different dosages of Diuron and Alachlor mixture according to soil texture.

Soil texture	Dosage Diuron (kg/ha)		Alachlor (l/ha)
Clay	2.0	+	3.0
Silt loam	1.5	+	2.5
Clay loam	1.5	+	2.0
Sandy	1.0	+	2.0

soil for sprouting and establishment of a stand. If a drought occurs after the first 2 months of growth, the cassava plant virtually stops growing.

Under these circumstances leaves fall off, and the plant essentially becomes dormant, whereas other crops like corn, beans, and rice would die. With the onset of rain, cassava utilizes carbohydrate reserves in stems and roots to produce new leaves (Cours 1949). These observations suggest that cassava is an extremely useful crop in tropical areas of uncertain rainfall.

In low rainfall areas, Campos and Sena (1974) found that irrigating cassava affects root distribution. Irrigated cassava had 91–98.5% of its roots in the upper 10 cm of soil, but the nonirrigated cassava had roots as deep as 140 cm with only 28.8% of the roots in the upper 10 cm of soil.

Muthukrishnan et al. (1973) and Smith (1968) both reported decreased yields for cassava when irrigation was applied more frequently than once a week. Cock and Howeler (1978) speculated that too frequent irrigation leads to excessive top growth and reduces yields of many varieties. Hence, cassava appears to be better adapted to low rainfall areas and soils with low water-holding capacity. Cassava, like most other crops, will not tolerate excess water; yields are seriously reduced by poor drainage. Menezes (1958) came to the conclusion that cassava actually has the highest moisture requirements at 4–6 months after planting.

Smith (1968) found that increased irrigation results in lower starch content of harvested cassava — a finding that may explain why many cassava growers try to harvest at the end of the dry season before the rainy season provides enough moisture to encourage a new flush of vegetative growth that uses starch reserves in the roots and stems. For Bahía, Brazil, Conceição (1975) recommended the application of about 35 mm of water every 18 days during periods of little or no rainfall. In addition it was suggested that irrigation just prior to harvest moistens heavy soil enough to facilitate harvesting. Shanmugavelu et al. (1973) reported from India that irrigated cassava nearly always outyields nonirrigated plantings. Best results were obtained when cassava was irrigated every 8 days.

When reporting about irrigation, many researchers do not include enough information about soil type (moisture holding capacity) and climatic conditions, which are extremely important for decisions on whether a crop needs irrigation. In addition, the spacing, age, and vigour of the crop influence its needs.

Celis and Toro (1974a, b) indicated that lack of moisture causes serious losses in sprouting if the deficiency occurs during the first 20 days after planting. A severe drought when plants are very small may also cause plant losses. Consequently, the soil should be irrigated to field capacity when moisture is lacking. If there has been no rain for at least 4 days during planting and irrigation is not feasible, planting should be suspended until the next rain.

Pruning

Some methods of planting such as horizontal often result in three to five main sprouts that compete for space during the development of the cassava plant. For this reason, EMBRAPA (1975) for Amazonas, Brazil, recommended thinning sprouts to two per plant after sprouting of the stakes. This is normally done during the first weeding. Santos et al. (1972) stated that later pruning should not be done until the plants are a year old and then only when propagation material is needed or when the crop is attacked by other pests. In the latter case the pruned portions should be removed from the field and burned.

EMBRAPA/EMBRATER (1976) also recommended that for the state of Ceara, Brazil, pruning be done only for problems with pests or for propagation material. In the latter case, branches should only be pruned when the crop is dormant, which in this area is January–March.

Some Colombian farmers commonly remove the suckers, vigorous shoots that arise from the bases of the main stem usually after the basic plant structure has been well established. CIAT (1976) reported that suckers are useful to a plant only at low populations or with low vigour types; otherwise, they are inefficient and reduce yields. For this reason removing the suckers is probably a beneficial practice for some cultivars.

Enyi (1972) reported from Africa that single-shoot plants outyielded multishoot plants, the difference increasing with a decrease in spacing distance. The single-shoot system and certain spacings were recommended for specific cultivars. The removal of the extra shoots should be carried out soon after the plant's emergence. Chan (1970), however, reported that pruning the plant to one stem led to a reduction in the root yield, and Shanmugham and Srinivasan (1973), studying the effect of single shoots and multishoots, found that two shoots outyielded the single-shoot and multishoot plants.

In 1977, Correa recommended against pruning until harvest because of the possibility of spreading bacterial blight and virus diseases. It was found that pruning at 6, 9, and 12 months limited yield by 43, 44, and 53% respectively. There was no effect after 15 months. Lozano et al. (1978) found that pruning plants about 25 cm above ground and leaving the roots in the ground for up to 20 days before harvesting actually decreased postharvest root deterioration from 100% to less than 20% depending on the variety. Tan and Bertrand (1972) stated that, as soon as stakes have sprouted new stems, many growers choose to maintain one stem per plant, whereas others prefer two stems per plant. Whether one chooses the single- or double-shoot system is of special importance in areas where cassava leaves are harvested periodically for human and livestock consumption; however, the choice at present is based more on tradition than on scientific research.

Crop Rotation

Usually cassava is the last crop to be planted in a rotation program because of its exceptional ability to extract nutrients from the soil. Cassava extracts more nutrients from the soil than most other tropical crops at least in respect to phosphorus, potassium, and magnesium, (Howeler 1978). For this reason it is often advisable to leave land fallow or to rotate crops following the second or third consecutive cassava harvest, especially in medium to poor soils. If another crop must be planted immediately after cassava, fertilization with chemicals or manure should be considered.

Okigbo (1978) reported that in fields left fallow in East Africa, several different crops are commonly planted such as maize and beans, sweet potatoes, bananas, yams, or sugarcane, which are in turn followed by cassava. Albuquerque (1969) indicated that in poor soils in Brazil the most recommended rotation for cassava is with legumes especially *Cannavalia ensiforme*, *Cajanus indicus*, and *Arachis hypogaea*. Sasidhar and Sadanandan (1976) found that growing cassava after cowpeas on a red loam acid soil (pH 5.8) was more profitable than any other sequences involving cassava. Normanha (1971) noted that crop rotation is very important, cassava being a good crop to follow such crops as cotton, maize, rice, sorghum, peanuts, soybeans, and beans. Rotation is especially advisable following years of cotton cultivation because of the expected phosphate residues in the soil. Control of cotton insects should also benefit cassava as would any crop residues

(O.M.) in the soil. Correa (1977c) recommended beginning a rotation program as soon as cassava yields begin to decline and using soybeans or any legume normally grown in the area. In São Paulo state, good results were obtained in cases where the legume *Stizolobium* sp. was planted, cut, and plowed under as a green manure following every two cycles of cassava. Castro (1979) recommended, as a soil management practice, rotation of crops as a means to maintain soil fertility and to avoid the incidence of pest problems. Lozano and Terry (1978) recommended rotating cassava with corn or sorghum or fallowing land for 6 months when root rot levels are higher than 3% due to *Phytophthora drechsleri*. This practice should reduce the inoculum population enough so that cassava can be grown again.

Although cassava is noted for its ability to yield well on acid, infertile soils, it extracts 100 kg of K_2O for each 25 t of roots. Grown continuously without adequate fertilization, the cassava may exhaust the potassium reserves in the soil (Howeler 1978).

Harvesting

Harvesting is extremely laborious when performed manually; it is also costly. Diaz et al. (1974) reported that harvesting in Colombia represents more than 30% of the production costs. The manual methods that are usually employed are rudimentary and inefficient, although Toro and Jaramillo (1974) have described several manual and semimechanical devices that facilitate harvesting, improve efficiency, and thus reduce costs and fatigue. In 1970, Beeny indicated that vibration would facilitate cassava harvesting, and according to Briceño and Larson (1972), vibration combined with pulling or lifting is an efficient means of harvesting. When pulling alone is used, the stem may break and the roots remain buried. Briceño and Larson developed a blade lifter that is attached to the tractor by a three-point hitch. The tool requires 80 h.p. at the power take-off and gives a field capacity of 0.29 ha/day. Bates (1957) suggested that a modified potato harvester could do the job in cassava.

Hossne (1971) indicated that a couple of resistant and modified bands inclined like those used for sugar beets could be used for harvesting. Leihner (1978) evaluated two cassava harvesting machines in a friable clay-loam ultisol at CIAT-Quilachao experiment station using three different varieties at 5000, 10 000, and 20 000 plants/ha planted vertically on the flat. Plots of varieties MMex-11, CMC-84, MCol-22, which are classified as difficult, intermediate, and easy for manual harvesting, were harvested mechanically and by hand. The machines used were a Richter harvester manufactured by Richter Engineering Ltd, Boonah, Australia, and a CIAT lifter. The results indicated that both mechanical methods left fewer roots in the soil than did manual harvesting of the difficult-to-harvest variety, and the difference in performance of the two machines was small. Both harvesters cut down time and effort involved. Kemp (1978) with the same machines in the same field with the same varieties found that both harvesters proved to be positive alternatives to the drudgery of manual harvesting. For mechanical harvesting, Cock et al. (1978) recommended a compact or clumped type of rooting that can be obtained by selection of the right variety and by use of stakes that have been cut straight across and planted vertically on ridges.

Wijewardene and Garman (personal communication) reported the performance of four mechanical cassava harvesters working in a wet clay soil with 10 000 plants/ha planted on the flat. Cassava tops were manually cut and removed before the trial. The results were: Ransomes, a European root-crops harvester with a fixed blade and chain elevator, performed well with good separation of dirt and roots with a rate of operation of 4.5 hours/ha; A.P.I. operating on the vibrating blade principle with oscillatory elevator was a failure in the clay soil, although it had worked satisfactorily in dry, light soils of Ghana; Alpha-Record, an oscillatory blade and lifter design, also demonstrated the unsuitability of oscillating mechanisms on wet clay soils; and CIAT, a simple blade with lifter, designed and developed at CIAT by agricultural engineer, Alfonso Diaz, and built at IITA, performed the best of all. The soil and cassava roots flowed well over the blade, the lifting mechanism leaving the roots well loosened and exposed (about 50% out of the soil). The rate of operation was 3.5 hours/ha.

This trial was valuable in that it pointed out the right way to go for fully mechanized harvesting: a simple lifting blade, like the CIAT tool, 2 m wide for two rows, followed by a two-stage, endless-belt elevator to separate soil and dirt and deposit the roots into a trailer traveling alongside.

With cassava production increasing, many machinery manufacturers are interested in developing new harvesters; for instance, G.M.D. of Reims, France, has released a cassava diggertype mounted for linkage on the hydraulic lift of the tractor.

No matter what harvesting method is used, some general considerations are applicable: if planting is done on ridges or beds, harvesting tends to be easier than on flat ground; in loose or sandy soils, harvesting is easier than in clay or heavy soils; and in any type of soil, harvesting is easier when the soil is wet than when it is dry.

Conclusions

One cannot generalize about cultural practices for growing cassava in any country, although there are some agronomic practices that have proved to be effective everywhere. Each production area has soil and climatic factors that are specific to the locality, and the responses of individual cassava varieties differ from one place to another. Whenever an appropriate technology is needed for a specific cassava-growing region, it must be developed by national research organizations. In many cases, little adjustments to recommended technological packages are enough for good cassava production.

IITA and CIAT have been engaged in cassava research for the last decade. Working in a multidisciplinary team approach, they have obtained good results from applied research.

Using improved cassava technology based on low inputs, CIAT, after 5 years of regional trials with consistent results, has indicated that it is possible for farmers to double cassava yields with their own local varieties by following the recommended technological package. The package comprises two parts: one for areas where cassava is traditionally grown and the other for areas of subutilized ultisols and oxisols, which represent about 1.76 billion hectares of the world.

Technology for traditional cassava-growing areas: (1) good soil preparation; (2) selection and treatment of planting material (Lozano et al. 1977); (3) planting at the beginning of the rainy season; (4) planting 20 cm stakes in vertical position with buds facing up; (5) planting on ridges where soils are heavy and rainfall is more than 1200 mm/year (Lozano and Terry 1978); and (6) planting 10 000 stakes per hectare unless local research indicates a different population.

Technology for ultisols and oxisols: (1) all steps described for traditional cassava-growing areas and (2) fertilization (Table 2). The plan in Table 2 was derived from 9 years research at ICA-CIAT, Carimagua station. The plan contemplates

Table 2. Fertilization plan for continuous cassava production in ultisols and oxisols (Howeler, personal communication 1979).

	Dosage (kg/ha)[a]			
Fertilizer	1st year	2nd year	3rd year	4th[b] year
10-20-20	1000	750	500	1000
Dolomitic limestone	1000	–	–	1000
Sulfur	10	10	10	10
Zinc	5	5	5	5

[a]When cassava is planted only 1 year, fertilizer should be split accordingly.

[b]After the 3rd year, the plant starts over again.

planting cassava in the same field year after year. Dolomitic limestone must be incorporated, and the other products can be applied in bands side by side at the time of planting. For the treatment of stakes, 20 g of zinc sulfate per litre of water should be added to the fungicide and the stakes immersed in the mixture for 15 minutes. For the Colombian oxisols, planting time should be between 15 September and 20 October so that the incidence of pests and diseases is minimized (Lozano and Terry 1978).

To take more advantage of future information on cassava production research, investigators need detailed descriptions of soil, climate, the objectives of research, materials and methods used, data collected, and statistical evaluation. With these factors, they can extrapolate results.

Because the cassava dry matter content is highly correlated with its starch content and because starch is the most important product of cassava anyway, it is of great importance to indicate this information. Also, researchers must know the number of days to harvest to make real comparisons on yield because the dry matter accumulation per hectare per day is one of the best indicators of the yield potential of any variety. Experiments must be repeated at least 3 years in the same location before conclusive results and recommendations can be arrived at.

More research is needed in the area of cassava forage production and utilization because the cassava tops represent 40–50% of the total plant. More is needed also in the area of storage and production of cassava stakes, especially in areas of extreme climatic conditions and severe pest and disease stress.

Finally, one may conclude with Normanha (1975) that the most important cultural practices for cassava root production are selection of healthy and mature stakes; planting time; and good weed control. These simple practices can be considered universal in cassava production because they apply everywhere.