CHAPTER 20

Mechanized Systems for Planting and Harvesting Cassava (*Manihot esculenta* Crantz)

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Background

The progress made recently in developing cassava varieties with high yield potential has helped improve the crop's productivity and competitiveness. It has facilitated its entry in various markets, especially those of balanced feeds for animals, and of industrial applications such as starch, glues, and bioethanol.

To compete in these markets, the costs of producing cassava must be kept as low as possible. The crop requires intensive labor, especially for planting and harvesting. In countries such as Brazil, much progress has been made in developing mechanized planting and semi-mechanized harvesting systems for the cassava crop. In Colombia, the Latin America and Caribbean Consortium to Support Cassava Research and Development (CLAYUCA)[4] has recently been evaluating and adapting models of planters and harvesters for the cassava crop. These models were based on those developed in southern Brazil.

This chapter describes some of the technologies currently available to mechanize cassava planting and harvesting.

Importance of Agricultural Mechanization

The principal aim of agricultural mechanization is to ensure optimal conditions for crop development at all stages of its life cycle. It therefore implies the direct reduction of necessary labor, production costs, time spent at each task per unit area, and the final cost of the agricultural product. Hence, the planted area can be increased, thereby justifying the initial investment in machinery.

With the current trend towards economic globalization, agricultural sectors of developing countries face severe competition with agricultural products imported from developed countries where they were produced mostly under complex subsidy schemes for supporting agricultural activities. Consumers tend to choose the cheaper imported products, thus creating problems in marketing agricultural products produced domestically and endangering the developing countries' more fragile and vulnerable rural economies. Under these conditions, farmers urgently need access to technologies that will help them reduce their production costs and improve the productivity and competitiveness of their farming systems.

Mechanization of the cassava crop is priority for Colombian agriculture, if projections for that crop in national and international markets are to be taken into account. However, the current technological offer of machinery in local and international markets is narrow. The adaptability of such machinery to the country's conditions must first be assessed. We use the cassava crop's recent situation in Colombia and other cassava-producing countries of Latin America and the Caribbean (LAC) to illustrate this aspect.

The continuous growth of the poultry and balanced-feed sectors has meant an increased demand of raw materials, mainly cereals such as maize. National production is insufficient for supplying this growing demand, forcing countries to import, annually, massive volumes of maize that total several millions of tons. Balanced-feed markets see cassava as an alternative raw material that can be used as an energy source.

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4. For an explanation of this and other acronyms and abbreviations, see *Appendix 1: Acronyms, Abbreviations, and Technical Terminology*, this volume.

If cassava is to be incorporated in these markets, the crop needs to be traded at prices that compete favorably with imported maize prices. Considerable progress has recently been made in developing new high-yielding cassava varieties, but this was not enough to significantly reduce production costs or increase competitiveness.

Importance of soil preparation

As for any other crop, cassava requires good soil preparation as according to climate, soil type, vegetation cover, topography, the degree of mechanization the crop receives, and other agronomic practices.

An adequately prepared soil guarantees a propitious bed for the "seed" and, thus, high levels of germination and production. The seedbed should generally be about 20 cm deep, with a loose soil that is free of lumps to facilitate both horizontal and vertical root growth.

Soil preparation usually begins in the dry season, except in regions with very humid climates, where the land is prepared at the end of the heavy rains and stakes are planted at the beginning of the dry season. Advantage is therefore taken of the remaining small but copious rains to initiate root development. In areas with less rain, plowing before the dry season is sometimes necessary to take advantage of the rains as, later, the land dries up and hardens too much for tilling. In many regions, the disk plow is being replaced by other tools such as the chisel plow, which helps conserve soil structures.

Whenever this task can be mechanized, many cassava farmers prepare the soil with a simple plowing, followed by disk plowing. Thus, they obtain good conditions for planting, ventilate the soil, and control weeds. These days, soil structure and other physical properties must be evaluated to select the most suitable mechanization system. The concepts of sustainability and minimal tilling must also be applied where possible.

A common practice in Brazil, wherever planting is mechanized, is to prepare furrows, 10 to 20 cm deep, to plant stakes in a horizontal position. The first pass with a disk plow is made 30 days before planting; the second just before the stakes are planted. The goal is to improve soil conditions and eliminate weeds that may compete with the crop during its establishment.

Planting cassava on land that slopes at more than 15% is not recommended. If the crop is planted on such slopes, contour furrowing should be carried out, especially during the crop's first months of growth, to prevent erosion, which can become a serious problem, particularly if the soil is also sandy (Ribeiro 1996).

Planting

The introduction of new technologies has modified cassava cropping practices, particularly planting method and stake position. These two practices are fundamental for increasing yield and ensuring marketing of the product (Cuadra and Rodríguez 1983).

Cock et al. (1978) proposed several planting methods that take into account climate, soils, available equipment, topography, and farmers' customs. These methods are manual, semi-mechanized, and mechanized.

In Colombia, cassava is usually planted on ridges or on the flat. The selection of one site over another for planting depends on the area's humidity and soil texture (Figures 20-1 and 20-2).

Figure 20-1. Plot in which cassava was planted on ridges.

Figure 20-2. Plot in which cassava was planted on the flat.

Importance of soil type

Any method for planting cassava stakes should ensure shoot growth (i.e., "germination") and stake rooting. For these to happen, the soil must have adequate moisture and be well prepared. The planting method used will depend mainly on soil type and climate:

- In soils with a *clayey texture* and receiving more than 1200 mm of rainfall, ridges should be constructed to facilitate drainage, thereby effectively improving crop establishment and yield. It also facilitates manual harvesting (Lozano 1978).

- Conceição (1976) reports that planting stakes horizontally, at 10 cm deep and in furrows, facilitates commercial harvesting (Figure 20-3). Planting on ridges gives good results if weeds do not constitute a serious problem.

- In *heavier* and compacted soils, cassava should be planted in beds or on ridges. Such soils become saturated with water in the rainy season and are thus poorly aerated. They favor the spread of root rots, which cause crop losses.

- However, Lulofs (1970) reported that planting on the flat in this type of soil is satisfactory, although planting on ridges may increase yield, better control erosion, and facilitate harvesting. Significant differences in cassava production between the two methods were not found. Planting on ridges produced fewer roots than did planting on the flat, but it also reduced the amount of weeding needed and the physical effort required for harvesting.

- In soils with a *sandy texture*, as predominate in tropical dry climates, cassava is planted on the flat. In such soils, stakes should be planted vertically or on a slant (Figure 20-4), burying them by about 5 cm (the stake itself is about 20 cm long). One problem is potential damage caused by excessive soil heat to buried buds. These buds usually receive more heat than the buds remaining above ground. Any damage caused affects crop yield (Cadavid L. et al. 1998).

Importance of planting method

Four *important variables* must be taken into account when determining the method for planting cassava, whether manual or mechanized:

- planting depth
- stake length
- stake position
- spacing between plants and between furrows

Each has a different value according to the soil type and climatic conditions of the region in which planting is to be carried out (Figures 20-3 and 20-4).

Planting depth. To encourage tuberous root production, the stake should not be planted deeper than 10 to 15 cm. The fine roots responsible for taking up essential elements and water will extend to greater depths should the crop suffer hydric stress or drought.

Manual planting is traditional in all cassava-growing regions. Stakes, 20 cm long, are planted vertically or on a slant in a furrow, whether on a ridge or on the flat, to a depth of 5 to 10 cm. Planting is in the direction of bud growth, ensuring that a large number of buds is buried under the soil, with the number depending on the variety.

Figure 20-3. Stake planted horizontally.

Figure 20-4. Stake planted on a slant.

Several experiments have shown that the buried part of the stake should not be planted more deeply than 10 cm as, at greater depths, harvesting can be difficult. Shallow planting (<5 cm) may mean plants being carried away by water, or developing surface roots and thus becoming prone to lodging. Shallow planting will also hinder certain agronomic practices. In sandy soils, planting depth should not be less than 5 cm, as water may settle the earth and expose the planted stake.

Stake length. In any cassava production system, stake size and quality play a significant role in obtaining high yields.

Stake quality depends on several factors: stem age and thickness when selected for cutting, stake size, cassava variety, storage time, and mechanical damage suffered by the stake during preparation, transport, storage, and planting. Farmers commonly use a stake length that is between 15 and 25 cm.

Gurnah (1974) demonstrated that, where moisture is adequate (1000 mm annual rainfall) and stakes are planted between 2 and 8 internodes deep, yield is higher when the number of internodes increases from 2 to 5. Beyond this number, yield did not subsequently increase. Vertical stake length therefore depends on the number of desired internodes (i.e., between 3 and 5). That number, in its turn, depends on the phenotypic characteristics of the variety being planted (Figure 20-5). A high value for shoot growth ("germination") is guaranteed if the stake is fresh and newly cut.

Stake position. In Colombia, stakes are usually planted on a slant or vertically (Figure 20-4). When the stake is cut at right angles to its length (Figure 20-6), roots are distributed consistently around the periphery of the cut. If the stake is planted horizontally, the roots are more separated and harvesting is easier than when stakes are planted vertically or on a slant (Figure 20-7). Cock et al. (1978) found that neither the angle of the cut nor the position in which the stake is planted significantly affects yield.

Trials carried out at the Centro Internacional de Agricultura Tropical (CIAT) indicate that, under field conditions, stakes planted vertically are always quicker to root and germinate. Planting them horizontally is recommended when the operation is mechanized and soil moisture is appropriate.

No significant differences were found in root production between stakes planted on a slant, vertically, or horizontally. However, continuous observation suggests that vertical planting favors initial growth and reduces plant lodging (Solórzano 1978). Recent data obtained by CIAT scientists in Honduras also suggest that vertical or slanted planting helps plants maintain straight stems and

Figure 20-5. Number of internodes in a stake, compared with its length, cassava variety CM 533-4 (ICA Negrita)

Figure 20-6. Cassava stake cut at right angles to its length.

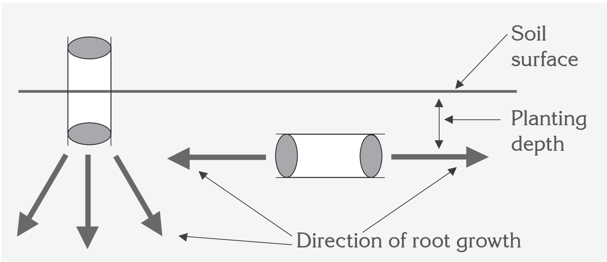

Figure 20-7. Diagram shows cassava root growth according to the position in which stakes are planted.

reduce heavy adventitious rooting. Although Conceição (1976) recommends planting horizontally in furrows for mechanized planting, CIAT data indicate that stakes planted vertically or on a slant can facilitate mechanical harvesting.

In regions with average to heavy soils and rainfall between 1000 and 2000 mm/year, planting stakes either horizontally or vertically makes no difference, as moisture is sufficient for germination.

In regions with sandy soils and irregular rains, planting stakes vertically is safest. Furthermore, stake length can be reduced from 20 cm to 10–15 cm. Thus, they take better advantage of available moisture. Vertically planted stakes also serve to disseminate heat.

Planting density. Planting density has an indisputable effect on crop production. It depends on factors such as soil fertility, cassava variety, topography, stake planting method, crop's purpose, planting time, harvesting time, and climate. Adopting a single spacing system that responds to all these variables is therefore impossible.

Cassava plants growing in a given area compete among themselves for water, light, and nutrients. Hence, the ideal spacing for planting each variety depends on soil fertility or planting time. Once determined, individuals can be better distributed in the field and more efficient advantage can be taken of production factors (Normanha and Pereira 1974).

In the cassava-producing areas of Rio de Janeiro, Brazil, a spacing of 1.20 m between furrows was found to present the best results, given the region's soils. No significant differences were found between spacing distances of 0.5, 0.7, and 0.9 m between plants in terms of root production for either industrial or commercial purposes. The spacing most used in Colombia is 1 m between plants and 1 m between furrows.

Planting systems and available machinery

The technological offer currently available for the cassava crop includes several machines that incorporate human activity for their correct operation. Three systems exist for planting cassava: one is totally manual, where only farmers' labor intervenes, as still happens in many cassava-producing countries of the developing world.

The second system is *semi-mechanized*, that is, it includes an initial step of chisel plowing that breaks the soil and leaves lines marked with small furrows. Stakes are then placed manually at the desired density and in a horizontal position within each furrow in the line. They are then covered with soil.

The third system is *mechanized*. It involves a planting machine to which a worker manually feeds stakes that were previously cut to the desired size. A tractor is needed to move the planter. Some models integrate the application of fertilizers into the planting operation of cassava stakes.

For Colombia and other South American countries, the progress made in this field in southern Brazil has been of great importance. Brazilian machines have been evaluated under local conditions with good results, including the definition of the basic requisites for their adaptation.

Evaluating two Brazilian prototypes for mechanized cassava planting

Performance. CLAYUCA imported two cassava planters from Brazil, one model that plants two furrows, and the other three. They were evaluated under the soil and climatic conditions of the Department of Valle del Cauca, Colombia. The 3-furrow model planted 9.2 ha/day, using four workers (3 planters and 1 tractor driver) over an 8-hour working day. The 2-furrow model could plant 6.2 ha/day, using three workers (2 planters and 1 tractor driver). These results compared most favorably with results obtained for the manual planting system, which usually requires a minimum of 7 working days to plant 1 ha. The results translated into savings of almost 50% of costs of manual planting when the 2-furrow planter was used, and 57% for the 3-furrow planter.

Mechanized planting is a viable alternative for cassava growers. However, the minimum area needed for recovering investment costs is 30 ha. The 2-furrow prototype was considered a better option, as it allows for variations in distances between furrows and between plants, stake length, and planting depth.

Two-furrow cassava planter, model PC-20. Figure 20-8 shows the principal technical characteristics of this prototype:

- Hydraulic lift system
- Stakes are cut by circular saws operated by power takeoff (PTO)

Figure 20-8. Two-furrow cassava planter, model PC-20.

- Distance between plants varies between 40 and 90 cm
- Distance between furrows varies between 0.8 and 1.2 m
- Stem ends are discarded
- 100-kg capacity hopper for granulated fertilizer
- Double concave disks for hilling
- Depth control in furrow aperture
- Approximate output: 7 ha/day
- Required minimum power: 70 hp
- Capacity seed deposit: 1.5 m^3

Three-furrow cassava planter, model PMT-3. Figure 20-9 shows the principal technical characteristics of this prototype:

- Hydraulic lift system
- Stakes cut by jaws operating from the steering wheel's traction

Figure 20-9. Three-furrow cassava planter, model PMT-3.

- Distance between plants is set at 90 cm
- Distance between furrows is set at 1 m
- Stem ends are not discarded
- Two hoppers, each with a 50-kg capacity, for granulated fertilizer
- Double concave disks for hilling
- No depth control in furrow aperture
- Approximate output: 12 ha/day

Parameters evaluated for prototype performance. Prototype performance was evaluated on two principal parameters:

Soil conditions.

- Chemical and physical characterization of soils in three regions where the work was developed
- Water content and apparent density (degree of soil compaction)

Prototype operation. The variables measured to determine the operation of the two prototypes were:

- Uniformity in planting depth
- Uniformity in length of the planted stake
- Uniformity in spacing between plants
- Mechanical damage to stakes
- Output in the field
- Production costs

Results Obtained

Table 20-1 presents results of experimental work. Data obtained at each site are the average of three replications. In each case, the parameter is expressed as a percentage, which indicates results according to the given conditions of the machines' operation. For example, if the desired stake length is 20 cm, the prototype is adjusted to the stake's dimensions. The parameter's results—uniformity of size—indicates the machine's efficiency in planting stakes of this size. The data obtained is based on an 8-hour working day and only the workers feeding the machine are included. For manual planting, comparisons are estimated by assuming that the same number of workers who feed the planting machine is used.

Discussion

Uniformity of spacing between plants

This parameter depends on the feeding mechanism of each prototype (Figure 20-10). It also depends on the degree of soil preparation. Overall, the functionality of the 2-furrow prototype was 92%. The advantage of this

Table 20-1. Comparing the performance of mechanical cassava planters with manual planting.

Parameter	Site 1	Site 2	Site 3	Average	Manual planting
(A) The 2-furrow cassava planter					
Uniformity of spacing between plants (%)	91.3	92.6	94.3	92.7	97.7
Uniformity of stake length (%)	98.0	97.3	98.0	97.7	98.3
Uniformity of planting depth (%)	94.5	96.6	96.6	95.9	100.0
Mechanical damage to stakes (%)	10.0	10.0	9.6	9.98	0
Output (ha/hour)	0.42	0.39	0.38	0.39	0.02[a]
Output (ha/day)[b]	6.72	6.24	6.08	6.34	1.00
				i.e., a 6-fold difference	
(B) The 3-furrow cassava planter					
Uniformity of spacing between plants (%)	74.0	77.0	87.3	79.4	98.1
Uniformity of stake length (%)	96.1	96.1	95.6	95.9	98.6
Uniformity of planting depth (%)	95.6	96.6	97.6	96.6	100.0
Mechanical damage to stakes (%)	36.6	25.0	22.3	27.9	0
Output (ha/hour)	0.37	0.42	0.36	0.38	0.02[a]
Output (ha/day)[b]	5.92	6.72	5.76	6.13	1.00
				i.e., a 6-fold difference	

a. The value for this output was calculated as the number of hectares planted per hour per worker, assuming a working day of 8 hours and 6 workers.

b. Assuming a working day of 16 hours.

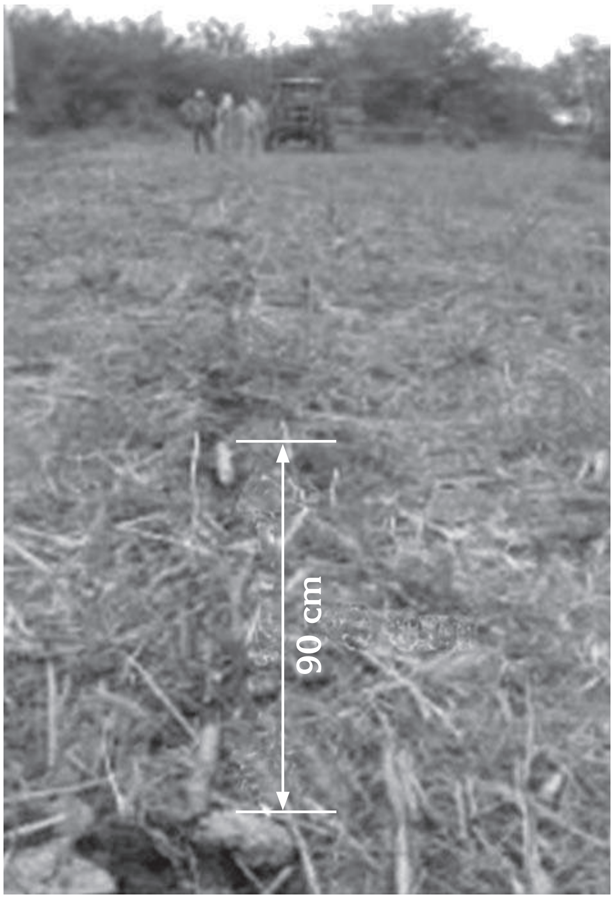

Figure 20-10. Planting distance in mechanized planting.

prototype is its device for discarding ends. Another advantage is that it permits different planting distances. The 3-furrow prototype does not include a device for discarding ends, and all stakes are cut to the same size. The functionality of this prototype was less than the 2-furrow type, having values of about 80%.

Uniformity of stake size

Although this parameter is independent of soil preparation, it plays a significant role in ensuring a high germination rate. Stake length and internode number are well known to affect sprouting. The 2-furrow prototype presented good functionality (97.7%) when 15-cm stakes were used (Figure 20-11). The 3-furrow prototype had lower results of about 95.9%. The stake length obtained was only 11 cm, which may be too short if the variety planted has few internodes.

Uniformity of planting depth

The two prototypes did not present major differences, as both machines obtained about 96% for this parameter, which is important for germination. Planting depth depends on soil preparation. If the planting area is not well prepared, the machine will vary in its regulation of planting depth. This effect is minimized with the 2-furrow planter, which has a device to control depth (Figure 20-12).

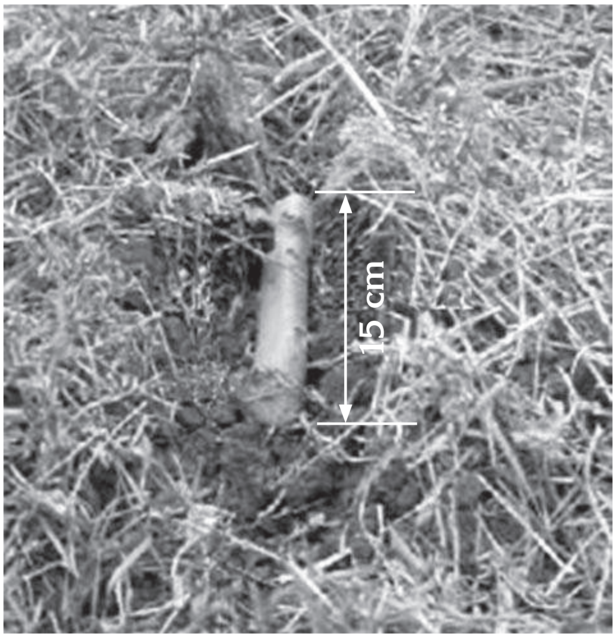

Figure 20-11. Cassava stake length in mechanized planting.

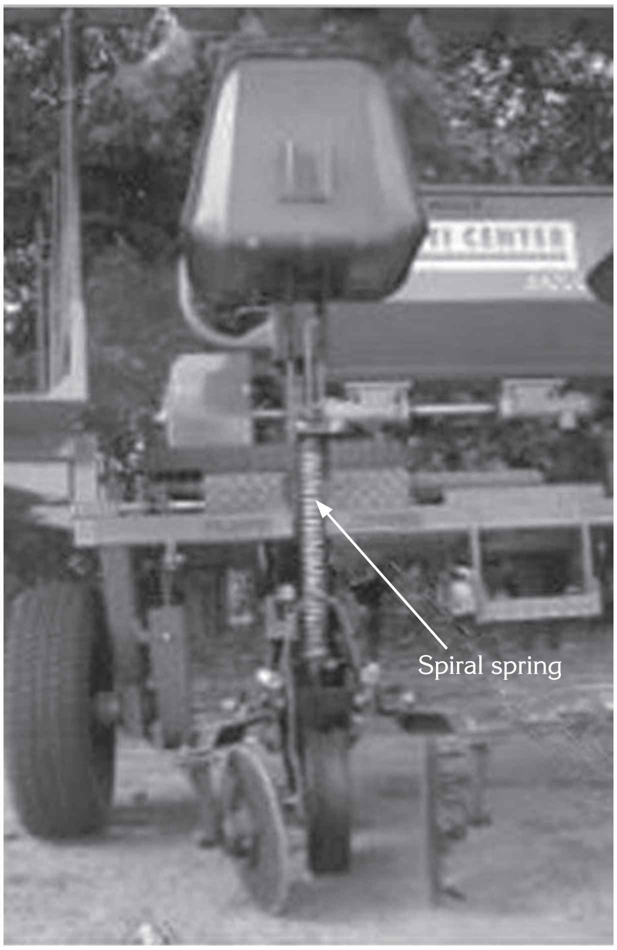

Figure 20-12. Planting-depth device used in the 2-furrow planter. Note the spiral spring.

Mechanical damage to stakes

For the two prototypes, the degree of damage to planting materials was evaluated. Differences were a consequence of the cutting device in each machine. In the 2-furrow prototype, the cutting system comprises circular saws that operate from the tractor's power takeoff. Damage to stakes from this device is minimal, being less than 10%. The 3-furrow planter had a lower functionality of about 28% because the cutting device uses a system of jaws that operate from the steering wheel's traction.

Prototype outputs

This parameter indicates the capacity of the two prototypes to plant according to given distances between rows and between plants. The machine's effectiveness is affected by parameters such as soil conditions (preparation and water content), the tractor's power, and the efficiency of the workers feeding the machine (Table 20-1). The 2-furrow planter had an average output of 6.3 ha/day or 0.8 ha/hour, using two people for an 8-hour working day. The 3-furrow prototype had an average output of 9.2 ha/day, employing three workers for an 8-hour working day, which corresponds to an average of 1.15 ha/hour. In neither case is the tractor driver included. The traditional planting system required six workers to plant 1 ha for an 8-hour working day.

Economic impact

The two prototypes evaluated did not differ significantly in operation, as the use of either one represented an important reduction in production costs. Table 20-2 illustrates the values obtained for the total operational costs of the two planters, compared with the traditional system, and the production costs of 1 ha of cassava.

The use of the 2-furrow planter reduced planting costs by 51% against the traditional system. With the 3-furrow prototype, planting costs were reduced by 55.6%. Compared with the 2-furrow prototype, the 3-furrow planter further reduced costs by US$2.30/ha.

The 2-furrow prototype was then modified by its manufacturers to improve efficiency and output. CLAYUCA validated the new 2-furrow prototype, *model Bazuca 1* (Figure 20-13), which had the following characteristics:

- Hydraulic lift system
- Distance between furrows varies from 0.85 to 0.96 m

Table 20-2. Production costs of planting 1 hectare of cassava, Valle del Cauca, Colombia, 2000.

Activity	Unit	Quantity (US$)[a]	Unit value	Total cost (US$)
(A) Traditional manual planting				
Cutting stakes	Workers/day	2	4.60	9.20
Chemical treatment for stakes				6.10
Labor for stake treatment	Workers/day	0.5	4.60	2.30
Manual planting	Workers/day	6	4.60	27.60
Replanting	Workers/day	1	4.60	4.60
Total costs of planting 1 ha				49.80
Total production costs of planting 1 ha				566.00
Estimated output was 1 ha/day				
Planting costs as proportion of total costs 8.8%				
(B) Mechanized planting, using a 2-furrow prototype				
Cutting and stacking stems	Workers/day	3	4.60	13.80
Adjusting fixed costs for planter	US$/ha	1.28	9173.00	5.30
Workers for mechanized planting	Workers/day	0.33	4.60	1.46
Wage for tractor driver	Workers/day	0.16	9.60	1.54
Replanting	Workers/day	0.5	4.60	2.30
Total costs of planting 1 ha				24.40
Total production costs of planting 1 ha				477.00
Estimated output was 6.2 ha/day				
Planting costs as proportion of total costs 5.1%				
(C) Mechanized planting, using a 3-furrow prototype				
Cutting and stacking stems	Workers/day	3.0	4.60	13.80
Mechanized planting costs, fixed and variable	US$/ha	0.87	3.94	3.42
Workers for mechanized planting	Workers/day	0.33	4.60	1.50
Wage for tractor driver	Workers/day	0.108	9.60	1.04
Replanting	Workers/day	0.5	4.60	2.30
Total costs of planting 1 ha				22.10
Total production costs of planting 1 ha				471.00
Estimated output was 9.2 ha/day				
Planting costs as proportion of total costs 4.7%				

a. Exchange rate (year 2000) was 1 U.S. dollar = $2,100 Colombian pesos; value of wage (worker/day) was therefore 10,000 Colombian pesos or US$4.60.

Figure 20-13. The modified 2-furrow cassava planter, Planti Center model Bazuca 1.

- Distance between plants varies from 0.30 to 0.96 m
- Tractor power: 60 to 75 hp
- Operational speed: 4 to 6 km/h
- Stake length: 13.5 cm
- Does not discard ends
- Cuts stems with saws
- 150-kg capacity hopper for fertilizers
- Output: 5–7 ha/day

The basic difference between this new model and the previous one is the device that feeds the stems to the machine. It was changed to a central hopper, contrasting with that of the previous model, which included a circle of multiple feeding points. Both the *Planti Center PC-20* and the *Bazuca 1* have devices for direct planting, which contributes to soil sustainability, as no heavy machinery is needed for soil preparation (Figure 20-14).

The Brazilian metalworking sector that makes the cassava planters and harvesters is dynamic. It includes several companies that continually innovate and present new prototypes to the market. Already, new prototypes with greater efficiencies exist. For example, 4- and 6-furrow planters are already being used for cassava planted to large extensions in agroindustrial projects (Figure 20-15).

Recently, a 1-furrow prototype (Figure 20-16) was launched on the market. It creates ridges, while simultaneously planting and applying fertilizers. This machine may represent a great advance for production systems where farmers operate small production areas and are limited by the lack of machinery for soil preparation. The characteristics of this new prototype are:

- Hydraulic lift system
- Distance between furrows vary from 0.85 to 0.96 m
- Distance between plants vary from 0.31 to 0.96 m (13.5-cm stake) and 0.42–1.30 m (18.5-cm stake)
- Tractor power: 45 hp
- Operational speed: 4 to 6 km/h
- Stake length: 13.5 cm; 18 cm (optional)
- Does not discard ends
- Cuts stems with saws
- 150-kg capacity hopper for fertilizers
- Output: 2–3 ha/day

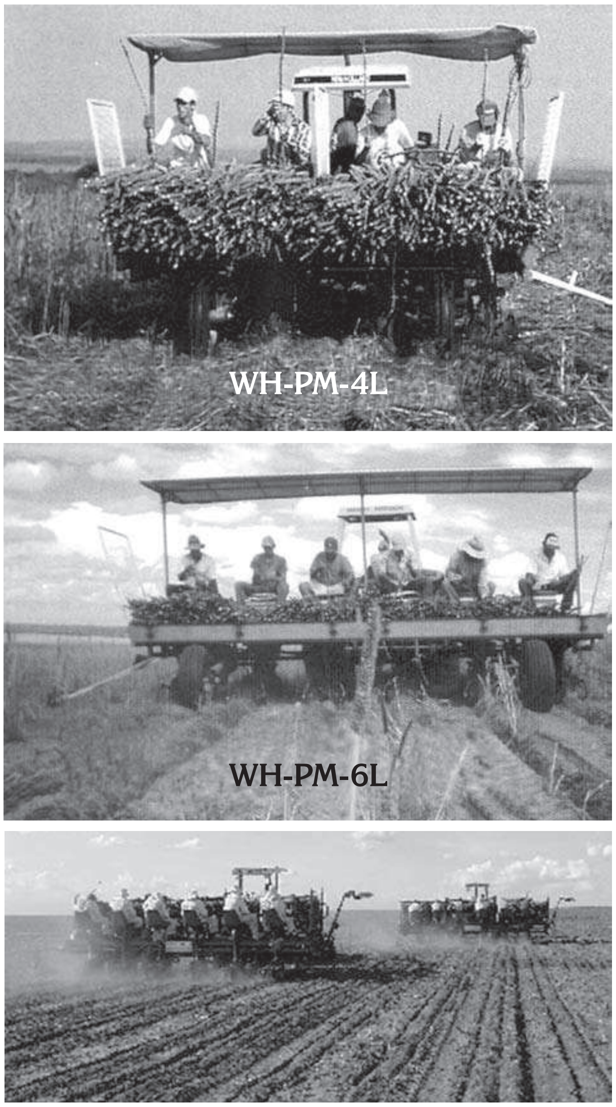

Figure 20-15. Four- (top) and six-furrow (middle and bottom) cassava planters.


Figure 20-14. Two angles of the direct-planting device in the 2-furrow cassava planter, Planti Center model PC–20.

Figure 20-16. One-furrow cassava planter–ridger.

To decide which mechanized system is the best for a given case, the following factors should be taken into account:

- The type of tractor and its available power
- The planting method for stakes (planting on the flat or on ridges)
- Conventional or direct planting

Mechanized planting, by itself, does not guarantee a higher output or higher germination rate for stakes. Essential conditions are fresh, recently cut, stakes, and good soil preparation. Other tasks should be carried out without exception.

The introduction of these technologies positively modifies the production cost structure for cassava. Planted area can be increased and final costs reduced, thus leading to higher profits. Furthermore, when high yields are obtained, costs are further reduced, but this is achieved only if minimal conditions are guaranteed to enable the planter to operate well.

Table 20-3 presents CLAYUCA's recent results after adapting the mechanized cassava planting technology, using prototypes developed in Brazil. Farmers should, however, include in their cost structure those costs incurred by the machine's depreciation and maintenance, so that calculations may approach closer to reality.

Cassava Harvesting

One task in cassava cultivation that is very difficult to mechanize is harvesting. Reasons include limitations that result from the shape and distribution of roots in the soil, the depth at which they are found, the collection of foliage residues and planting materials (stakes), and the adherence of soil to roots. The best time for harvesting—the crop's final stage—is defined by the farmer in terms of the crop's productivity, and the roots' starch content and culinary properties. Harvesting perhaps most influences the crop's cost structure, as it requires many working days.

In Colombia, the harvest represents more than 30% of the cassava crop's production costs, mainly because manual, rudimentary, and, sometimes, inefficient methods are used. Hence, some mechanization of the work is needed to increase operational efficiency, given that any mechanical method or device helps, even noticeably so, to reduce not only production costs, but also energy expenditure and fatigue on the part of the workers doing the harvesting (Toro M et al. 1976).

In northern Colombia, to obtain an average yield of 12.5 t/ha, 25 workers are needed for an 8-hour working day. Consequently, the daily output per worker is 500 kg/day. This value, however, does not include collection of planting materials or selection of roots and their packaging (B Ospina Patiño 2001, pers. comm.).

Manual harvesting

Certain tasks are common to any cassava harvesting, whether manual and mechanical. These are carried out in two stages:

- The cutting and selecting of (1) forage (cassava leaves and other aerial parts) and (2) planting materials. Only 20 to 40-cm lengths of the stems are left still attached to the roots underground, so that these may be more easily extracted or pulled out of the soil.

- The second stage is to extract, collect, clean, and package the roots.

Manual harvesting comprises four modalities:

Using hands. In light or sandy soils, roots can be easily pulled out by hand, without need of tools.

Table 20-3. General cost structure for planting cassava, according to three methods applied to flat areas in the Department of Valle del Cauca, Colombia, 2000.

Activities[a]	Unit[b]	Quantity	Unit value (Col$)[b]	Total value (Col$)[b]	RCD[c] (%)
(A) Manual planting					
Cutting stakes	Working day	5	10,000	50,000	
Inputs for stake treatment	Global			13,410	
Labor for stake treatment	Working day	0.5	10,000	5,000	
Manual planting	Working day	6	10,000	60,000	
Replanting	Working day	1	10,000	10,000	
Total for labor				138,410	10.38
Total cost per hectare				**1,333,610**	
(B) Planting with a 2-furrow machine					
Cutting and stacking stems	Working day	3	10,000	30,000	
Costs of machine, F and V	Col$/hour	1.28	9,174	11,761	
Costs of tractor, F and V	Col$/hour	1.28	12,743	16,337	
Workers for mechanized planting	Working day	0.32	10,000	3,200	
Tractor driver	Working day	0.16	21,000	3,360	
Replanting	Working day	0.50	10,000	5,000	
Total for labor				69,658	6.41
Total cost per hectare				**1,086,350**	
(C) Planting with a 3-furrow machine					
Cutting and stacking stems	Working day	3	10,000	30,000	
Costs of machine, F and V	Col$/hour	0.87	8,600	7,482	
Tractor costs, F and V	Col$/hour	0.87	12,743	11,086	
Workers for mechanized planting	Working day	0,326	10,000	3,260	
Tractor driver	Working day	0,108	21,000	2,268	
Replanting	Working day	0.50	10,000	5,000	
Total for labor				59,096	5.74
Total cost per hectare				**1,029,878**	

a. F and V = fixed and variable costs.
b. The exchange rate (year 2000) was 1 U.S. dollar = $2,100 Colombian pesos.
c. RCD = ratio between the costs of planting stakes and the total direct costs of cropping, expressed in percentage.

Using a lever. In soils with textures ranging from loamy to clayey and presenting problems of compaction, extraction is facilitated by tying the stem with a chain or rope to a pole that is 2.5 to 3 m long. The pole must be sufficiently straight and firm to serve as a lever against the soil.

Using a puller. This technique is a modification of the previous one. The stem is subjected to a puller, comprising a claw attached to a pole 2.5 m long or more, depending on the worker's height. The claw is fixed at 30 cm from that end of the pole supported by the soil. The claw is hooked onto the stem close to its base and leverage is applied downwards on the pole so that the claw pulls the roots upwards out of the soil, as in the previous method (Figures 20-17 and 20-18).

Figure 20-17. Puller used by Thai farmers to harvest cassava.

Figure 20-18. Thai farmer using a puller.

This tool is commonly used in cassava-producing regions of Thailand.

Using a band. In the Colombian Coffee Belt, where soils usually have a medium texture, a type of belt or band is widely used. The farmer ties the band onto himself, then passes it over his back and shoulder, and ties it to the stem. That end of the band tied to the stem may be a strong rope or chain, which the farmer grasps and shakes to loosen the plant while his body acts as a lever.

Semi-mechanized harvesting

CLAYUCA has adapted and evaluated semi-mechanized systems of harvesting cassava. The importance of this activity lies in the excessive costs of manual harvesting, which requires 25 to 35 working days to harvest an average production of 30 t/ha. CLAYUCA imported two prototype harvesters developed in Brazil and evaluated their operation under the specific soil and climatic conditions of regions in Colombia where cassava is planted. Both the harvesters had the following components:

- A disk to cut the soil crust or plant cover
- An element to remove earth such as another blade or subsoiler
- A device to separate roots from soil adhering to the machine

Operation. Before a harvester is used, the following factors should be taken into account:

- Soil moisture. Dry soil makes harvesting cassava more difficult. However, soil moisture should be such that machinery can enter the plot without too much soil adhering to it.
- Planting density. These machines can loosen the soil of two furrows at once, as the blade's "wing span" is 1.2 m. If furrows are less than 90 cm apart, losses may occur because roots may be buried or broken. If the blade is more than 1.2 m wide, then the roots will not loosen satisfactorily.
- Tractor's operational speed. This speed should be constant throughout harvesting because any sudden change, when the implement is digging, will modify the implement's working depth, thus increasing losses through broken or buried roots.

To quantify yield for comparing with manual harvesting, the daily output per worker should be separated from the machine's output, which depends on tractor speed. A speed of 4 km/h is mostly used. It can be increased, however, depending on soil moisture and texture. Hence, a machine's average daily output is 6.4 ha.

Prototype descriptions. Model P 900 Flexible (Figure 20-19) has the following characteristics:

- Weight: 200 kg
- Daily output: 5 to 8 ha/8-h day
- Operation: harvests two furrows at the same time
- Planting distances are 80 to 100 cm
- Includes front cutting disk, which facilitates work
- Minimum soil removal, functioning as a subsoiler and leaving the soil prepared
- Works in soils difficult for manual harvesting
- Before operation, stems must be cut at 20 to 40 cm above soil surface
- Works at depths of 40 to 60 cm, depending on tractor type being used
- The tractor needs more than 90 hp of power

The rigid-blade model (Figure 20-20) is similar to the previously described model. However, instead of having points or weeding hoes, it has a solid blade system in the form of a "V". This system may generate compaction, damaging the soil.

Parameters evaluated. The principal parameters for evaluating the two prototypes were:

- Operation with each harvest method (ha/day)
- Root losses: entire roots (%), broken roots (%), and buried roots (%)
- Output of manual harvesting (kilograms of roots per day)

Figure 20-19. Prototype of a cassava harvester, model P 900 Flexible.

Results obtained. For harvester output, the results obtained during the prototype's evaluation were as follows (values are the average of several replications and trials):

- Operational speed: 7 km/h
- Depth of work: 30–40 cm
- Tractor power: 90 hp
- Maximum width of work: 2.4 m
- Output: 1.1 ha/h

The greatest benefits obtained from using this machine are reduced number of working days and less labor, with workers being limited to removing rubble and packing cassava. Under the traditional system, a worker pulls up between 500 and 800 kg/8-h working day. With semi-mechanized harvesting, CLAYUCA obtained yields of more than 1300 kg/worker per working day. In Brazil, harvesting systems have been developed with these machines to obtain outputs as high as 4000 kg/worker per working day. CLAYUCA also found that when semi-mechanized harvesting is

Figure 20-20. Prototype of a cassava harvester with a rigid "V"-shaped blade.

incorporated into a cassava production system, harvesting costs drop by 42.8%. That is, harvesting costs are reduced by 6% in the relative cost of labor to total production costs per hectare (Table 20-4).

Economic impact of semi-mechanized harvesting on cassava production. The importance of using harvesters for the cassava crop lies in reducing the number of workers needed for this activity. Table 20-5 presents the results obtained when prototype P 900 Flexible was evaluated in Colombia, and compares them with those of the manual system. Introducing the harvester reduced total production costs by 12%. Also, total harvesting costs were reduced by 42%. Such reductions stemmed from a 52% cut in labor costs. Economic impact is also created through the larger number of roots harvested per unit area, as the semi-mechanical harvester removes many more roots than do traditional harvesting systems.

Mechanized harvesting

In the continual search to improve the cassava crop's productivity and competitiveness, great progress was recently made in southern Brazil to develop a prototype that completely mechanizes cassava harvesting. A group of cassava growers and processors in Brazil financed the development and adaptation of a prototype that was based on a potato harvester. The prototype eliminates all labor from the initial harvesting phase, using workers only for selecting and packaging roots. This prototype is now being evaluated. Preliminary results are so far highly satisfactory. Two prototype models are being evaluated:

Model WH-15.2L. Figure 20-21 illustrates its characteristics:

- Weight: 700 kg
- Daily output: 5 ha/8-h day
- Cutting width: 80 cm
- Required power: 100 hp
- Works with a mat system, where soil is removed from the roots, using blades
- Before operation, stems must be cut at 20 to 40 cm above the soil surface

Model WH-CM 4000. Figure 20-22 shows that this model is similar to the previous model. It also does the following:

- Roots are mechanically taken up to a large sack ("big bag" type)
- It possesses a work platform where workers remove roots from stems

Table 20-4. General cost structure (cost/ha) for harvesting cassava, applying manual and semi-mechanized methods, in flat areas of the Department of Valle del Cauca, Colombia, 2000.

Activities[a]	Unit	Quantity	Unit value (Col$)[b]	Total value (Col$)[b]	RCD[c] (%)
(A) Manual harvesting					
Pulling up roots	Working day	25	10,000	250,000	
Packaging	Sack	180	90	16,200	
Fique string	Roll	1	5,500	5,500	
Total for labor				271,700	20.4
Total cost per hectare				**1,333,610**	
(B) Semi-mechanized harvesting					
Costs of machine, F and V	Col$/hour	1.14	4,014	4,576	
Costs of tractor, F and V	Col$/hour	1.14	18,203	20,751	
Workers for pulling up roots	Working day	10.5	10,000	105,000	
Tractor driver	Working day	0.15	21,000	3,150	
Packaging	Sack	180	90	16,200	
Fique string	Roll	1	5,500	5,500	
Total for labor				155,177	14.4
Total cost per hectare				**1,086,350**	

a. F and V = fixed and variable costs.
b. The exchange rate (year 2000) was 1 U.S. dollar = $2,100 Colombian pesos.
c. RCD = ratio between the costs of harvesting cassava and the total direct costs of cropping, expressed in percentage.

Table 20-5. Costs per hectare of harvesting a cassava crop, Valle del Cauca, Colombia, 2000.

Activity	Unit	Quantity	Unit value (US$)	Total value (US$)
(A) Manual harvesting[a]				
Harvest workers	Workers/day	30	4.60	138.00
Packaging	Sack	180	0.04	7.20
Fique string	Roll	1	2.50	2.50
Total harvest costs				147.70
Total costs per hectare				566.00
	Harvest costs as proportion of total costs	**26.1%**		
(B) Semi-mechanized harvesting[a]				
Harvest workers	Workers/day	14	4.60	64.40
Packaging	Sack	180	0.04	7.20
Harvest costs per hectare, fixed and variable				9.50
Tractor driver				1.20
Fique string	Roll	1	2.50	2.50
Total harvest costs				84.80
Total costs per hectare				498.00
	Harvest costs as proportion of total costs	**17.1%**		

a. With a production of 15 to 25 t/ha.

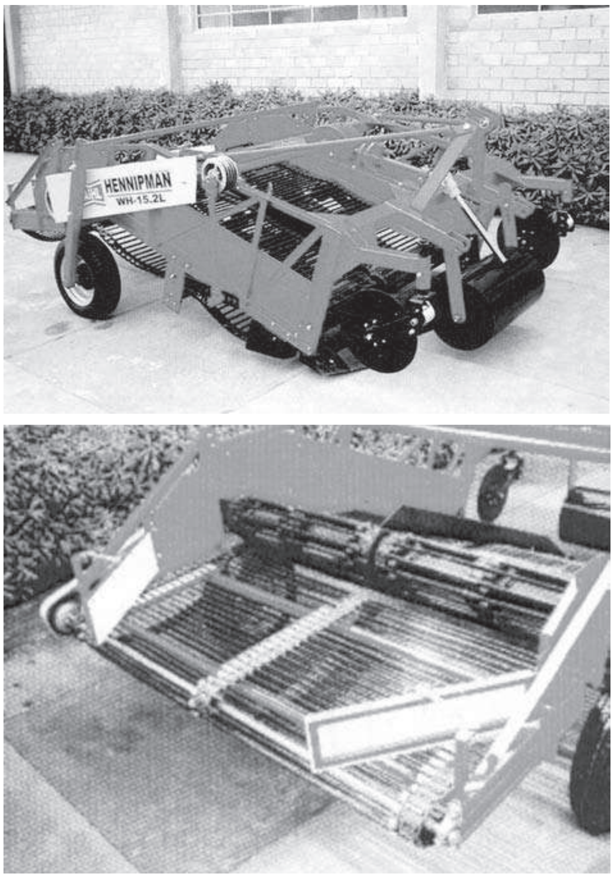

Figure 20-21. Prototype of a mechanical harvester, model WH-15.2L.

- The *big-bag* sack is released by a hydraulic system, enabling the machine to operate continuously
- Average capacity is 7 to 10 t/h
- Required power is 120 hp
- Cutting width is 240 cm
- The machine weighs 3500 kg

For the two machines to operate adequately, the crop must first be pruned to remove all aerial parts. The machine has blades 1.80 m wide, which are located at the front. They penetrate the soil to a depth of 30 cm, pull up the roots, and send them to a mechanical mat, where plant residues and some soil are removed. The roots immediately fall into a second higher mat, where the remaining adhering soil is removed. These first two phases are totally mechanized.

The roots then reach a third mat where workers remove the roots from their stems and place them in a central mat that takes them up to a *big-bag* sack (500-kg capacity) at the back of the machine. A worker controls the filling of this sack. When full, a device operates to deposit the sack on the ground and insert another sack, while allowing the machine to operate continuously (Figure 20-22, central right). The harvester is followed by a machine that winches the sacks off the ground and into a truck. The sack's

Figure 20-22. Prototype of mechanical harvester, model WH-CM 4000. Also shown are the use of the *big-bag* sack (central right) and the winch in operation (bottom right).

bottom opens up, discharging the roots in their entirety into the truck (Figure 20-22, bottom right).

This process completely eliminates the need for labor to carry roots to the truck. In some trials, this machine was able to lift as much as 70 tons of cassava during an 8 h working day, using 14 workers. These figures translate to an output of almost 5 t/worker per day. In a traditional harvest, for the same volume of roots, a minimum of 40 people would be needed.

Impact of mechanizing cassava planting and harvesting. The economic impact of mechanized harvesting can also be determined by the various technological options available to farmers to help them increase productivity and competitiveness. In the cassava production systems of Colombia, for example, part of the cassava production is traded as raw material for the balanced-feed market, competing in price against imported grains, mainly maize. Cassava production systems aim to keep production costs per ton of cassava as low as possible so to attract the interest of processing plants that transform cassava chips into flour destined for balanced-feed industries.

Table 20-6 summarizes cassava production costs for the traditional production system, where traditional varieties are used and neither planting nor harvesting is mechanized. Table 20-7 shows costs for a modern technology system where planting is mechanized and harvesting is semi-mechanized. The traditional system produces 1 ton of cassava at a 12% higher cost than the system with mechanized planting and harvesting. This significantly higher profit, complemented by increased yields from high-yielding improved varieties (instead of traditional varieties), can represent economic success for the farmer.

Figure 20-23 presents an analysis carried out by CLAYUCA that compares different technological options available to improve the efficiency of cassava production. If the farmer maintains the traditional varieties, cost reductions are slightly less than for improved varieties. In any case, with traditional varieties, the introduction of mechanized planting and harvesting enables farmers to reduce costs per ton of cassava to US$21.20 (versus US$29.40 for the traditional system), a significant reduction of 27.9%. At this level, cassava harvesting begins to be highly competitive with imported grains.

The ideal situation is where farmers have easy access to improved varieties, and are also introduced to mechanized planting and harvesting. Such a technology package helps farmers reduce production costs per ton of cassava to US$17.50 (versus US$29.40 for the traditional system). This price represents a reduction of 40.5% in production costs, against the traditional production system. Such a highly competitive price enables the crop to become incorporated into different markets.

Social impact. The social impact of mechanizing cassava planting and harvesting is highly significant. Field labor, especially for harvesting, becomes more humane, as workers can more easily carry out their work, thereby increasing their efficiency. With the possibility of developing more competitive systems, business is encouraged to invest in agroindustrial projects involving cassava. This, in its turn, helps stimulate rural economies and generate jobs and income for farmers.

On increasing the competitiveness of one segment of the cassava production chain, that is, supply, with cassava produced at lower prices, a simultaneous effect is generated in the segment of demand, which stimulates markets. Cassava becomes more attractive as a raw material in many industrial fields. Benefits are thus generated for all participants in the production chain.

Environmental impact. The environmental impact of introducing mechanized cassava planting and harvesting has two aspects: first, mechanized or semi-mechanized harvesting leaves the soil practically ready for planting, thus avoiding the use of heavy machinery to prepare the soil before planting. Indeed, in some regions of Brazil, after cassava is pulled up, direct planting is immediately carried out. The second aspect is that, by removing most of the roots from the earth, fewer roots remain to rot and thus become foci of bacterial or fungal diseases. Hence, a mechanized cassava crop contributes to the general ecosystem by using fewer agricultural defenses.

Conclusions

1. The introduction of mechanized prototypes for planting and harvesting is a practice that has high potential for reducing labor costs, thus contributing to the crop's competitiveness.

2. The costs of the prototypes—between US$6500 and $15,000 for the planter and about US$4000 for the harvester (FOB Brazil)—is attainable. Farmer organizations (associations or cooperatives) can easily acquire and administer these prototypes to set up cassava production systems at lower cost and improve the crop's competitiveness.

3. The operation of both planter and harvester is simple and easily adapted for farmers and their families.

4. For field workers, for whom manually pulling up cassava roots is arduous work, the possibility of using a harvester means a more comfortable and healthier harvest, with an improved output for labor.

Table 20-6. Cassava production costs, using the traditional system.

Activity	Unit	Quantity	Unit cost (Col$)	Cost/ha (Col$)
Direct expenses				
Land preparation				**150,000**
Plowing	Pass	1	50,000	50,000
Raking	Pass	2	35,000	70,000
Furrowing	Pass	1	30,000	30,000
Stakes and planting				**353,000**
Cost of stakes	20-cm stake	10,000	20	200,000
Transport	Sack	12	2,000	24,000
Inputs for stake treatment		1	25,000	25,000
Labor for stake treatment	Wage	1	13,000	13,000
Manual planting	Wage	7	13,000	91,000
Weed control				**295,000**
Preemergent herbicides		1	70,000	70,000
Labor for applying preemergent herbicides	Wage	1	13,000	13,000
Manual weeding	Wage	13	13,000	169,000
Postemergent herbicides	Liter	1	30,000	30,000
Labor for applying postemergent herbicides	Wage	1	13,000	13,000
Liming				**88,000**
Dolomite lime	Sack	10	7,500	75,000
Labor for applying lime	Wage	1	13,000	13,000
Fertilizer applications				**296,000**
10–20–20	50-kg sack	7	33,000	231,000
Labor for applying fertilizers	Wage	5	13,000	65,000
Pest and disease control				**63,500**
Insecticides and fungicides		1	37,500	37,500
Labor for applying pesticides	Wage	2	13,000	26,000
Manual harvesting				**339,200**
Cutting and collection	Wage	23	13,000	299,000
Packaging	Sack	360	95	34,200
Fique string	Roll	1	6,000	6,000
		Subtotal direct costs		**1,584,700**
		Direct production costs per ton (25 t/ha)		**63,388**
Indirect costs				
Financial costs (24%)				380,328
Lease of 1 ha land per year				300,000
		Subtotal indirect costs		**680,328**
		Total production costs per hectare		**2,265,028**
Total production costs per ton (25 t/ha)				**90,601**

5. The argument against the use of prototypes—that they reduce labor as a source of employment—needs to be analyzed according to the specific context. In many cases, where the crop's commercial planting is promoted, investors will not become involved with cassava as a business unless they are certain that production costs are competitive. In this case, mechanized planting and harvesting become indispensable conditions. If the unit is in a context of small-scale cassava cultivation, farmer adoption of mechanized planting and harvesting would be insignificant.

Table 20-7. Cassava production costs, using a mechanized system.

Activity	Unit	Quantity	Unit cost (Col$)	Cost/ha (Col$)
Direct expenses				
Land preparation				**150,000**
Plowing	Pass	1	50,000	50,000
Raking	Pass	2	35,000	70,000
Furrowing	Pass	1	30,000	30,000
Stakes and mechanized planting				**289,005**
Cost of stakes	20-cm stake	2000	100	200,000
Transport	Sack	12	2,000	24,000
Inputs for stake treatment		1	25,000	25,000
Labor for stake treatment	Wage	1	13,000	13,000
Mechanized planting	Wage	0.32	13,000	4,167
Cost of machine	Col$/ha	0.78	2,100	1,638
Tractor: rent + driver + fuel	Day	1	8,200	8,200
Replanting	Wage	1	13,000	13,000
Weed control				**293,000**
Preemergent herbicides		1	70,000	70,000
Labor for applying preemergent herbicides	Wage	1	12,000	12,000
Manual weeding	Wage	13	13,000	169,000
Post-emergent herbicide	Liter	1	30,000	30,000
Labor for applying postemergent herbicides	Wage	1	12,000	12,000
Liming				**88,000**
Dolomite lime	Sack	10	7,500	75,000
Labor for applying lime	Wage	1	13,000	13,000
Fertilizer applications				**296,000**
10–20–20	50-kg sack	7	33,000	231,000
Labor for applying fertilizers	Wage	5	13,000	65,000
Pest and disease control				**63,500**
Insecticides and fungicides		1	37,500	37,500
Labor for applying pesticides	Wage	2	13,000	26,000
Semi-mechanized harvesting				**183,036**
Cutting and collecting stems	Wage	9	13,000	117,000
Cutting and collecting stakes	Wage	1	13,000	13,000
Packaging	Sack	360	95	34,200
Fique string	Roll	1	6,000	6,000
Cost of machine	Col$/hour	1.80	842	1,516
Tractor + driver	ha	1	11,320	11,320
	Subtotal direct costs			**1,362,540**
	Direct production costs per ton (25 t/ha)			**54,502**
Indirect costs				
Financial costs (24%)				327,010
Lease of 1 ha of land per year				300,000
	Subtotal indirect costs			**627,010**
	Total production costs per hectare			**1,989,550**
Total production costs per ton (25 t/ha)				**79,582**

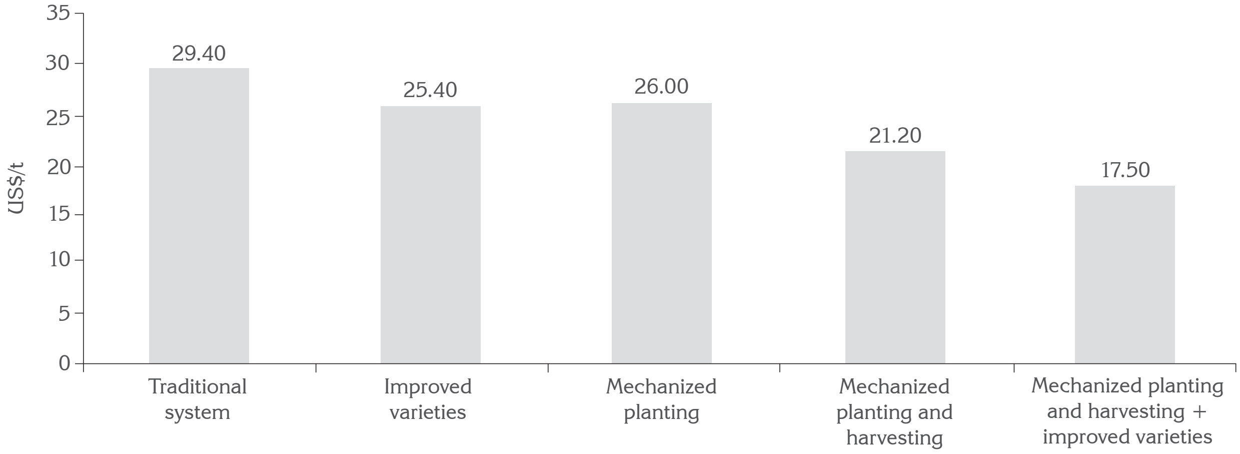

Figure 20-23. Differences in cassava production costs (in US$) according to technological option.

References

Cadavid L, LF; El-Sharkawy MA; Acosta A; Sánchez T. 1998. Long-term effects of mulch, fertilization and tillage on cassava grown in sandy soils in northern Colombia. Field Crops Res 57:45–56.

Cock JH; Castro M, A; Toro M, JC. 1978. Agronomic implications of mechanical harvesting. In: Weber EJ; Cock JH; Chouinard A, eds. Proc Workshop on Cassava Harvesting and Processing held in Cali, Colombia. International Development Research Centre (IDRC), Ottawa, Canada. p 60–65.

Conceição AJ da. 1976. A mandioca. In: Curso Intensivo Nacional de Mandioca, Cruz das Almas, Brasil. Empresa de Pesquisa Agropecuária de Minas Gerias (EPAMIG); Centro Nacional de Pesquisa de Mandioca e Fruticultura (CNPMF), Cruz das Almas, Bahia, Brazil. p 435–440.

Cuadra MA; Rodríguez MS. 1983. Estudio de diferentes métodos de plantación de la yuca (*Manihot esculenta* Crantz) y su relación con el rendimiento en el ecosistema de la provincia de Guantánamo. Cienc Téc Agric Viandas Trop 6(1–2):51–60.

Gurnah AM. 1974. Effects of method of planting, the length and types of cuttings on yield and some yield components of cassava (*Manihot esculenta* Crantz) grown in the forest zone of Ghana. Ghana J Agric Sci 7(2):103–108.

Lozano JC. 1978. Posibles efectos del ecosistema en algunas especies de cultivos tropicales. Fitopatol Colomb 7(2):94–107.

Lulofs RB. 1970. A study of method and costs for commercial planting of tapioca in Kedah. In: Blencowe EK; Blencowe JW, eds. Crop diversification in Malaysia. Incorporated Society of Planters, Kuala Lumpur, Malaysia. p 149–166.

Normanha ES; Pereira AS. 1974. Resultados e experiencias sobre épocas de plantío da mandioca. Rev Agric (Piracicaba) 22 (4/6):135–142.

Ribeiro FJ. 1996. Cultura da mandioca. Escola Superior de Agricultura [of the] Universidade Rural do Estado de Minas Gerais, Viçosa, Brazil. 80 p.

Solórzano H, A. 1978. Resultados de investigación para la yuca. In: Transferencia de resultados de investigación agropecuaria a los agentes de producción de la Región XII–Loreto, Tarapoto, Perú, vol 2. Centro Regional de Investigación Agropecuaria del Oriente y Cooperación [of] IICA–Peru, Lima. p 19–31.

Toro M, JC; Celis E; Jaramillo E. 1976. Métodos de cosecha de yuca. In: Curso sobre producción de yuca. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. p 225–232.