Chapter 6

Agronomy and Cropping Systems

Dietrich Leihner

Research, Extension and Training Division, Sustainable Development Department,
FAO, Via delle Terme di Caracalla, 00100 Rome, Italy

Introduction

Cassava is often grown under low-input/low-output production systems, particularly when it is grown as a food crop. Planting material is easily obtained from the plant stems available from the farmers' own or neighbouring fields. Although the crop is affected by a number of arthropod pests, diseases and by weed competition, it generally requires little attention once established. Nevertheless, attention to a few simple aspects of agronomic management can result in a doubling or tripling of output at low cost. In this chapter principles of good agronomic management are described, dealing with the preparation and handling of planting material, soil preparation, planting techniques, weed control, intercropping techniques and soil conservation systems.

Planting Material Production and Handling

Rapid multiplication and selection

Propagation of cassava through true seed is feasible, but no commercially viable seed propagation system is yet available. Cassava continues to be propagated vegetatively through stem cuttings or stakes (as they should be called). The number of commercial stakes obtained from a single mother plant in a year ranges from three to 30, depending upon growth habit, climate and soil conditions. This is considerably less than the propagation rate that can be achieved with other commercial crops that are propagated through true seed. Thus the development of improved cassava production technology should include more effective propagation schemes. A system using small two-node cuttings from which a number of successively growing shoots are obtained, rooted in boiled water and planted in the field was devised by Cock *et al.* (1976). This system produces 12,000–24,000 commercial stakes after 1 year. A much more productive method was devised later (Cock, 1985) using cassava leaves excised with their axillary buds, transferred to a mist chamber for sprouting and root formation of the propagules, which are transferred to a peat pot and 2–3 weeks later, to the field. Although this system is more labour intensive, 100,000–300,000 commercial stakes can be produced in about 18 months.

Stems must be transported with care to prevent bruising and peeling. Stakes should be cut at a right angle without placing stems on a base to prevent breaking or splitting that provides entry points for pathogens and insect pests. A stake should be at least 20 cm long and have a minimum of 4–5 nodes with viable buds to ensure crop establishment. Stems should be sufficiently lignified to ensure that stakes do not

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dry out too fast after planting, but overlignified tissue should be avoided. Stakes have the right degree of maturity when their pith diameter measures approximately half the total stake diameter.

Visual inspection of mother plants prior to cutting the planting material is an effective practice for reducing phytosanitary problems. Although infection with a viral, fungal or bacterial pathogen, producing no visible symptoms, can never be ruled out completely, many of these phytosanitary problems produce clearly visible signs of infection on leaf or stem tissue. Externally adhering insects can also be detected easily. If plants with visible symptoms are excluded from stake production, then a first important step towards a healthy new crop has been made (Lozano *et al*., 1977).

Stake treatment

Even if utmost care is taken to select planting material from apparently healthy mother plants, the presence of adhering pathogens or insects can never be fully avoided, either from carryover, or, from new infestation with soilborne pathogens and insects. The best way to reduce these problems and to protect stakes is to reduce soil infestation by means of crop rotations and cultural practices such as drainage or planting on ridges. Treatment of stakes with chemical disinfectants and protectants has a number of advantages. Mixtures of contact and systemic fungicides, with an occasional insecticide when necessary, can protect planting material, which in turn may enhance sprouting, root formation and growth. If stakes have to be stored, this treatment also provides a certain degree of protection and the period of viability under storage may be extended. Pesticide combinations for stake treatment have been suggested by Lozano *et al.* (1981).

Storage

In cassava-growing areas with dry, cool or flooded periods, during which planting is not recommended or feasible, planting material may have to be stored for several months. During storage the stems gradually deteriorate, leading eventually to a total loss of viability. The type of planting material to be stored, storage time and conditions can, however, retard this deterioration process.

Selection of well-developed and well-nourished mature and healthy stems from mother plants, and adequate storage conditions are the first steps towards minimizing detrimental storage effects. Mother plants whose stems are to be stored should have a well-balanced nutritional status to ensure good stand establishment after storage (Leihner, 1984b). Stems for storage should be as long as possible and not cut into stakes as this greatly accelerates dehydration.

Physiological deterioration of the planting material is principally linked to two processes: respiration and dehydration. Freshly cut cassava stems consist of living tissue that continues to metabolize during storage, losing mostly soluble carbohydrates for up to 60 days or more after cutting (Leihner, 1984b; Oka *et al*., 1987). This means that valuable reserves are being lost, reducing resprouting vigour after planting. Moist, hot storage conditions will enhance this process more than cool or dry conditions. Dehydration of stored cassava stems reduces metabolic activity of the tissue and may reduce respiration, but it leads to a progressive loss of viability, rendering stems unsuitable for planting. A minimum level of 60% moisture in the stakes has been identified as the threshold for satisfactory preservation of viability (Wholey, 1977; Leihner, 1984b, 1986).

Storing cassava stakes under inadequate conditions may lead to a drastic loss in viability even after rather short periods. Leihner (1984b) reported a drop in percentage sprouting from 100 to 30% when short stakes were stored for just 15 days at 24°C average temperature under sun exposure and without the possibility of reabsorbing moisture from soil, rain or dew. In contrast, stakes stored as long stems under shady conditions with 72% average relative humidity (RH) and chemical protection reached over 95% sprouting even after 201 days of storage (Leihner, 1986). Improvement of sprouting was reached through rehydrating stakes for 4 h in water or a nutrient solution. If the stored material is of high quality and storage conditions are right, long-term storage of cassava planting material is possible without losing viability.

Extensive research has been carried out on storage conditions (e.g. Silva, 1970; Correa and Vieira, 1978; Sales Andrade and Leihner, 1980; Centro Internacional de Agricultura Tropical (CIAT), 1980, 1982), making it possible to identify practices that keep cassava planting material viable for several months. Long stems (50–100 cm) should be treated with fungicides and insecticides before storage and kept in a shady place with high RH (70–80%) and moderate ambient temperature (20–23°C). Excessive heat and direct sun accelerate metabolic activity and dehydration. If longer-term storage is envisaged, stored stems may be buried 5–10 cm in the ground with their basal end allowing root formation below and sprouting of the apical buds above. Stems stored under those conditions may need watering if conditions get overly dry. Although this system keeps stems viable over long periods, a large portion on either end of the stem has to be discarded to ensure stakes come from parts of the stem that have not previously rooted or sprouted. All stored stakes should be re-treated chemically before planting to provide extra protection and stimulate rooting and sprouting.

Land Preparation

Tillage versus no till

Cassava needs a sufficiently loose-textured soil, not only for initial fibrous root penetration, but also to allow for root thickening. This may not always require a thorough manual or mechanized soil preparation. When cassava was domesticated, it was probably cultivated principally by slash-and-burn practices that eliminated competing vegetation but did not alter soil structure. The friable, high organic matter soil conditions that can be found in non-degraded slash-and-burn systems give cassava roots good growing conditions. The only soil preparation probably used by early planters was loosening of the soil locally with a planting stick to bury the stake. These ideal conditions essentially allowed a no-till soil preparation for cassava planting. Under more degraded slash-and-burn conditions, or, with permanent agriculture, a thorough loosening of the soil is normally required to allow the introduction of the stake and provide well-drained, aerated conditions for the root system. Cassava is a hardy crop withstanding many types of stress, but it easily succumbs to excessive soil moisture and root rot, resulting in extensive yield losses. To prevent these losses, soil preparation is necessary to allow good drainage and aeration.

Ridges, raised beds or mounds

Ezumah and Okigbo (1980) pointed out that in the humid and subhumid climates of West Africa, drainage conditions often determine the type of land preparation required, as well as the size of ridges or mounds and the location of crops on them. In the Democratic Republic of Congo, for example, there was no yield advantage from ridges as compared with flat or untilled plots whenever the field was mulched. Lowest root yields occurred in unmulched, untilled fields. In Cuba, a revolution in cassava production was achieved when traditional planting techniques similar to those used in sugarcane were abandoned for slanted planting on top of 40-cm high ridges (Rodriguez Nodals, 1980). In an erosion study, Reining (1992) compared mechanized soil preparation (flat, contour ridges) with a minimum tillage system, where cassava was planted in an existing grass sod by just loosening the soil with a shovel where stakes were to be inserted. Flat and ridged preparations gave no significant root yield differences over three growing seasons, while the minimum tillage system yielded less than 30% of that obtained in the other two systems. The higher bulk density of the soil under the grass sod and its quick hardening under dry conditions, together with competition from the grass, were thought to be responsible for the negative result of minimum tillage which, however, minimized soil erosion. A number of other researchers (reviewed by Toro and Atlee, 1980) agree that in most cases manual or mechanized soil preparation is preferred and that in areas of high rainfall or heavy soils, good drainage must be provided by preparing ridges, beds or mounds, although the exact configuration is not so important. There is evidence, however, that soil preparation intensity can be reduced when collateral practices improving soil structure and drainage, such as mulching, are implemented.

Planting Techniques

Stake position

Cassava cultivar, soil characteristics and climate together determine whether there is an advantage to vertical, inclined or horizontal planting, or, whether any position may be used. Since the first reports from Indonesia (Koch, 1916), extensive experimentation on positioning of the stake has been carried out in Latin America, Africa and Asia, a thorough review of which was presented by Toro and Atlee (1980). In tests conducted at CIAT by Castro *et al.* (1978) and Castro (1979), stake sprouting and emergence under field conditions were always more rapid with vertical planting than with any other method (Fig. 6.1). Vertical placement results in fast crop establishment and soil cover development, together with good anchorage provided by a deep root system and less risk of lodging. Under extremely adverse climatic conditions, placing a stake vertically 10–15 cm in the ground reduces heat damage and exposure of roots to erosion effects. Fast crop emergence also reduces weed competition. Horizontal planting has the advantage that there is no need to worry about planting stakes upside down. The planting operation itself does not require stooping or bending over, and the shallower root system resulting from horizontal planting allows for greater ease of harvest.

Based on experiences in many cassava-growing areas around the world, the following criteria for planting position should be considered: in regions with medium-to-heavy soils and adequate rainfall (1000–2000 mm year^{-1}), stake position does not matter because the moisture will be adequate for sprouting. In areas with sandy soils or erratic rainfall, however, vertical planting is safest. In this case 20-cm stakes should be planted at a depth of 10–15 cm in the soil to ensure better contact with available moisture. If stakes are planted horizontally, the buds will rot because of high soil temperature, while in vertical planting, the stake might serve as a heat defuser.

Planting depth

A literature review by Tan and Bertrand (1972) suggests that decisions on depth of planting, similar to position of planting, should be based upon the characteristics of locally planted cultivars as well as climatic and soil conditions. A too-shallow planting depth may expose stakes to less-than-optimum conditions of moisture and temperature, resulting in poor crop stands and low root yields. Celis and Toro (1974) define the conditions for deciding which planting depth should be adopted. On dry sandy soils, stakes should be

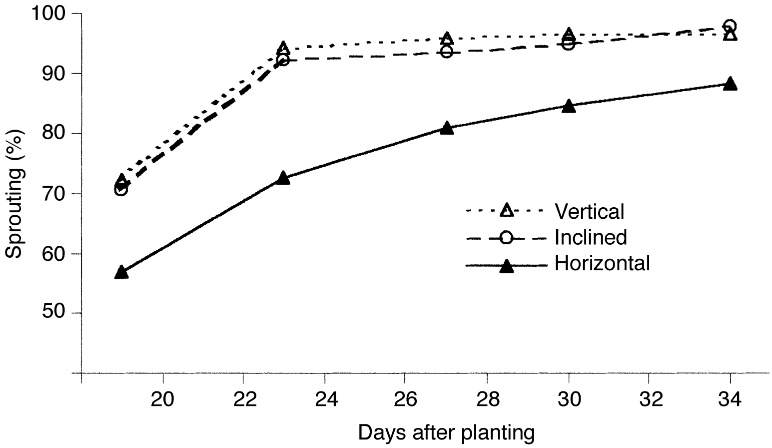

Fig. 6.1. Effect of planting position on rate of emergence and final percentage sprouting of cassava; mean of ten cultivars and four planting dates at CIAT, Cali, Colombia. (Source: CIAT, 1979.)

planted at greater depths than on wet and heavy soils where shallower planting is indicated. In the former case, however, deeper planting may make harvesting more difficult and raise costs, particularly when harvesting is done manually. These observations are supported by Normanha and Pereira (1950), who planted cassava at depths of 5, 10 and 15 cm in two seasons per year over a 3-year period. Under hot, dry conditions, stakes planted 15 cm deep sprouted more rapidly than those planted at shallower depths, probably due to more available moisture at the greater planting depth. Under better moisture and lower temperature conditions, however, the opposite occurred; moreover, harvesting was easier and yields greater when stakes had been planted at only 5 cm depth. For mechanized planting, which is common in Brazil, planting depths of 10–20 cm are common as this is the operating depth of the planters.

When moisture and temperature conditions at planting time are optimal and high-quality planting material is used, planting stakes vertically at a depth of 5–15 cm has little influence on emergence, crop growth and final root yield. Placing a 20-cm stake in vertical position to approximately half its length into the ground appears to be the most appropriate for both planting and harvesting operations.

Planting density

Information on optimum planting density for maximum root yield varies enormously from country to country and even from one ecological zone to another within the same country. Factors such as growth habit (early, late or non-branching), soil fertility, moisture regime and temperature all have an important influence on the size of the cassava canopy that has to be accommodated in the field as the crop matures.

Other aspects influencing plant density are cropping system and production objectives. In a survey dealing with cassava research by 37 institutions in 11 South and Central American countries, Leihner and Castro (1979) found that sole-cropped cassava is planted at an average density of 11,300 plants ha^{-1}; intercropped cassava at a lower density of 8900 plants ha^{-1}. When root production is the sole objective, densities around 10,000 plants ha^{-1} are normally adequate for producing a large number of commercial-size roots (Fig. 6.2), which are preferred for fresh consumption. In cases where root size is of no concern, higher planting densities can be used, resulting in a higher total production of small roots. For a combined objective of root and stake production, planting densities around 20,000 are adequate. If the sole objective is stake production, densities up to 40,000 plants ha^{-1} are optimal (Leihner, 1984a).

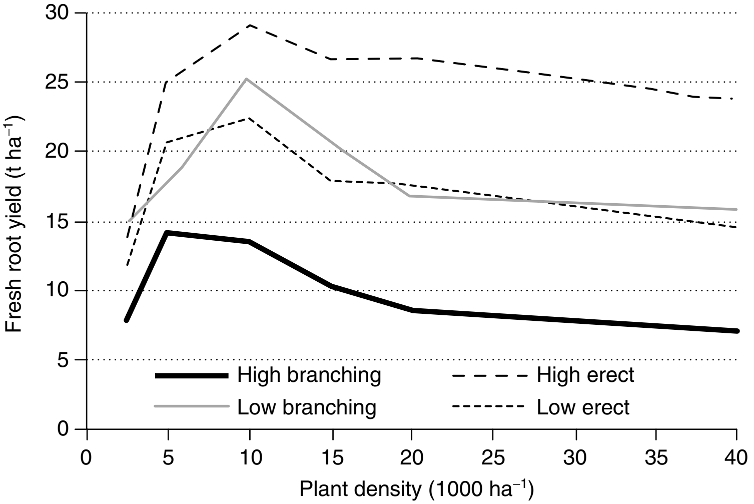

Fig. 6.2. Effect of planting density and growth habit on production of commercial cassava roots. (Source: CIAT, 1976.)

Many authors report that for most cassava genotypes no significant commercial root yield increases are to be obtained with planting densities much greater than 10,000 plants ha^{-1} (Tardieu and Fauche, 1961; CIAT, 1976, 1977; Castro *et al.*, 1978). The evaluation of new germplasm and other field experimentation as well as commercial production in many regions is thus carried out using a standard 10,000 plant ha^{-1} population. Significantly lower plant populations (5000 plants ha^{-1}) are justified when very tall vigorous and profusely branching genotypes are used (CIAT, 1976). Higher populations (up to 20,000 plants ha^{-1}) are recommended when less-vigorous genotypes are grown under low-fertility soil conditions (Santos *et al.*, 1972; Mattos *et al.*, 1973).

Planting pattern

In seeded, vegetatively planted or transplanted crops, the term 'spacing' includes both planting density and the spatial distribution of plants in the field. In order not to confound effects of either parameter, planting density and planting pattern are dealt with separately herein.

Whilst changes in planting density – in the range 2500–10,000 plants ha^{-1} – have usually produced a clear effect on cassava root yield, the crop appears to react much less to changes in planting pattern. A separate effect of spatial arrangement has seldom been reported but is relevant when cassava is intercropped, grown in agroforestry systems or when mechanization is introduced, requiring a spatial arrangement of plants other than the most frequently used square configuration.

There is little specific research on this topic, but available information suggests that cassava is a rather flexible crop, maintaining the same yield level, even when the strictly square arrangement is replaced by a variety of rectangular configurations. CIAT (1977) reports no significant yield differences either in total or commercial root production when three cultivars were grown at a standard 10,000 plants ha^{-1} density in spatial arrangements with 1–2 stakes per planting site ranging from the quadratic 1 × 1 m to a strongly square pattern of 2 × 0.5 m (Fig. 6.3).

Similarly, Leihner (1983) found no differences in root yield when comparing cultivars with different growth habit in three different ecological zones of Colombia using spatial arrangements from 1 × 1 to 2 × 0.5 m whilst maintaining planting density at around 10,000 plants ha^{-1}. Cock *et al.* (1978) tested mechanical harvesters and found that the standard spacing of 1 × 1 m was a problem for centrally mounted harvesters. At this spacing, two cassava rows had to be harvested simultaneously to prevent tractor wheels running over the unharvested crop. With one-row harvesters, however, this proved to be impossible. Changing to a 1 × 1.6 m row spacing, whilst maintaining the same plant

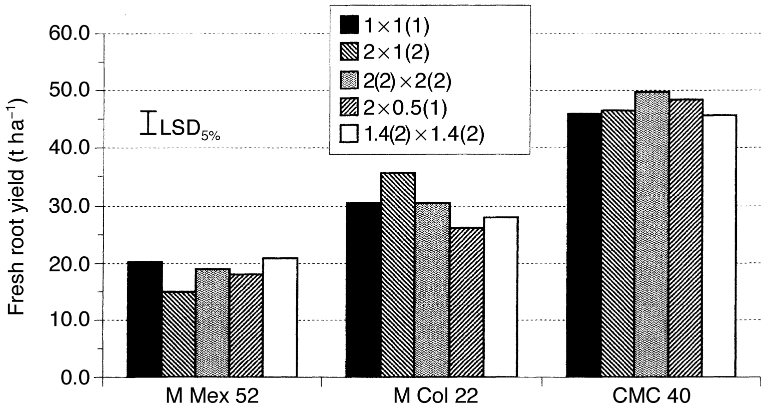

Fig. 6.3. Effect of planting patterns on commercial root production of three cassava cultivars grown at CIAT, Cali, Colombia, during 1976/77; standard planting density 10,000 plants ha^{-1}; no. of plants per site in parentheses. (Source: CIAT, 1977.)

population, allowed the operation of the one-row harvester with no sacrifice in yield.

Different spatial arrangements can thus be adopted to satisfy specific production system needs, without compromising yield potential. Considering the vast proportion of cassava grown in polycultural systems and its potential as an industrial crop requiring mechanization, this is an important point in the flexible management of planting systems.

Weed Control

Weed competition

Similarly to other crops, cassava suffers from competition with weeds for space, light, water and nutrients. In other annual crops there are critical periods during which weed competition causes significant yield decline. Until canopy closure, the earliest growth stages are normally the most susceptible, so that keeping crops weed-free during this period is a pre-condition for high productivity. Studies were carried out at CIAT by Doll *et al.* (1982) to determine the duration of this critical period for cassava on a fertile soil at a standard 10,000 plants ha^{-1} planting density, with high pressure from particularly aggressive weeds. From one to four hand weedings were carried out during the first 4 months, after which canopy closure was reached. Weed competition during the first 60 days after planting reduced yields to approximately 50% of the weed-free control. Weeding after 120 days did not increase root production. Thus, under conditions at CIAT, the critical period for weed competition in cassava lasts until 4 months after planting. Only if a good level of weed control is achieved during this period can acceptable root yields be obtained. In contrast, late weed infestations that occur when leaf area is gradually reduced before harvest appear to have little influence on root yield; but they may have a negative effect on the harvest operation itself and on stake quality.

Mechanical control

Worldwide, hand weeding is still the most frequent method of weed control. Hoes, machetes or sharpened shovels are used. Where these are lacking or where weeds are used for food or feed purposes, pulling them out by hand is the preferred method. In more technological production systems, mechanical weed control is also practised, using animal-drawn implements or tractors. In this case weeding should start as soon as competition begins and weeds are still easy to control. Montaldo (1966) and Delgado and Quevedo (1977) suggest that weeding should start 21 or at the latest 28–35 days after planting and should be repeated as necessary until canopy closure. On the other hand, too early mechanical weeding could damage young cassava plants and their superficially developing root system (CIAT, 1973). Whilst hand weeding is probably the most effective and least damaging weed-control method, it is also the most expensive, representing up to half the total production cost. Thus farmers decide on the number of hand weedings, not solely based on agronomic necessity, but also on the relationship between the number (and cost) of hand weedings and potential yield increase. Doll *et al.* (1982) found that with just two timely hand weedings carried out at 30 and 60 days after planting, 77% of maximum yield could be obtained at a relatively moderate cost. In this way, a small number of timely weedings, well spaced within the critical period, may give good yields at low cost and may thus be the most profitable option.

Chemical control

To date, no herbicide has been developed specifically for cassava. Most instructions for herbicide use do not even mention cassava and information on how to use them in cassava is not usually available. Comprehensive screening was therefore carried out with a large number of commercially available herbicides when chemical weed control in cassava was developed as a component of improved production technology. Doll and Piedrahita (1976) tested a number of herbicides in cassava for selectiveness and effectivity. They classified 18 products as highly selective and 12 as moderately so. As a group, the substituted ureas (diuron, linuron, fluometuron) were found suitable, being classified as moderately selective for cassava, particularly for controlling broadleaf weeds effectively. Mixtures with highly selective herbicides of the acetanilide group (alachlor, butachlor) are recommended for their extended effectiveness against grassy weeds. It is also possible to use wide-spectrum herbicides such as oxyfluorfen, which control both grassy and broadleaf weeds adequately.

Given the importance of early weed control in cassava, the use of pre-emergence herbicides is indicated. For cassava, as for other crops, this means that land preparation and planting should be done prior to herbicide application. Even if the vertical planting position is used, leaving cassava stakes partially exposed, this is not a problem if overhead herbicide application is done immediately after planting (up to 3 days later) because stakes suffer no damage from contact with herbicides if axillary buds have not started to sprout. If the application cannot be made at this early stage, then broadcast applications should be replaced by directed or banded applications, using protective shields to avoid herbicide contact with sprouting plants.

In the majority of cassava-growing areas, very little or no herbicides are used, either because of their unavailability or high cost. For this reason the further development of mechanical and cultural methods should have high priority. On the other hand, commercial plantations require simple-to-use, low-cost weed control methods. Chemical control has the greatest potential for fulfilling these requirements; thus further development of chemical methods should be continued for these conditions.

Cultural control

Cultural weed control makes use of non-mechanical and non-chemical practices that help suppress weeds by increasing the competing ability of the crop. Practices that contribute to good crop establishment and growth – such as selection of adapted cultivars, use of high-quality stakes, the correct planting density and plant protection – will in most cases significantly favour cultural control. With cassava, the exclusive use of cultural weed control methods is difficult during the first 3–4 months after planting because of its slow initial growth, even if agronomic practices are optimal. Supporting cultural measures such as the use of mulches, green covers or intercrops are, however, possible.

Both plant type and planting density determine the number of days needed by cassava to reach complete ground cover. The more vigorous, early-branching and leafy the plant type, the shorter will be the time to reach ground cover. Similarly, at higher planting densities, the cassava will reach ground cover earlier than at lower densities. To establish the cultural weed control potential of contrasting plant types and densities, Leihner (1980) carried out studies in the Colombian Atlantic Coast region, using both a vigorous and a non-vigorous cultivar planted at densities of 7500 and 15,000 plants ha^{-1} at three different manual weed-control levels (no control, intermediate or optimum control). Results (Fig. 6.4) showed that vigorous cultivars are less sensitive to deficiencies in weed control than non-vigorous cultivars. Unfortunately, however, the former are usually too leafy and therefore have a low root-yield potential. Although vigorous cultivars may achieve an acceptable yield with poor weed control, their yield will not reach that of less-vigorous cultivars under good weed-control conditions. By planting less-vigorous cultivars at high densities, rapid ground cover can be achieved, thereby improving the crop's ability to compete with weeds and attain high yield levels.

The possibility of preventing or reducing weed growth by using live or dead soil covers has been the subject of several studies in cassava-growing regions. In Bali, Nitis (1977) and Nitis and Suarna (1977) reported undersowing cassava with a *Stylosanthes guianensis* cover crop. The beneficial effect of *Stylosanthes* on root yields was, however, attributed more to its N-fixing ability than to cultural control of weeds. At CIAT, Leihner (1980) compared the use of a perennial legume (*Desmodium heterophyllum*) green cover, an annual legume (*Phaseolus vulgaris*) intercrop and sugarcane bagasse mulch as cultural weed control methods with manual weeding and chemical control. Manual weeding produced greatest cassava yields. Annual and perennial green covers, and also the mulch, produced somewhat lower cassava yields but at a much lower cost. The pre-emergent herbicide alone was the least effective method. More recent research on the effect of perennial legume cover crops on cassava sheds a more critical light on this practice as a whole (Leihner *et al.*, 1996a,b; Müller-Sämann and Leihner, 1999). Cassava undersown with *Pueraria phaseoloides*, *Centrosema macrocarpum*, *Centrosema acutifolium* or *Zornia glabra* suffered root yield reductions of up to 40% due to the competitive effect of these legumes. Moreover, the legumes were not able to control erosion effectively in their year of establishment because of slow initial ground cover, which made additional weeding operations necessary. Even with agronomic practices such as increased planting density of cassava, more vigorous cassava genotypes and less-competitive legumes such as *Chamaecrista rotundifolia*, a species with outstanding soil-cover capacity, the legume covers decreased cassava yields considerably. They were thus considered attractive only to farmers who can make efficient use of the 3–4 t ha^{-1} forage dry matter produced in these systems.

Leihner (1980) examined the weed-control effectiveness of intercropping cassava with common beans. Under good weed-control conditions, intercropped cassava yielded 15% less than the corresponding sole crop; but when no weed control was practised, a 44% greater root yield was observed in intercropped compared to sole cropped cassava (Fig. 6.5). These

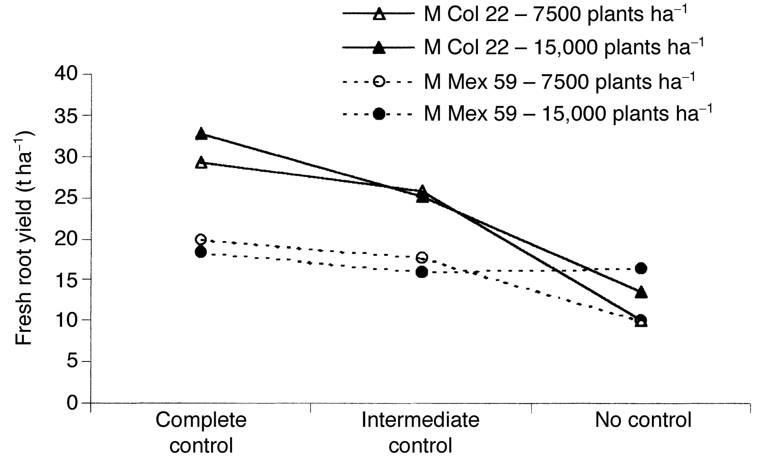

Fig. 6.4. Effect of plant type and planting density on cassava yield at different weed control levels; M Col 22 (non-vigorous) and M Mex 59 (vigorous), planted at ICA-Caribia, Atlantic Coast, Colombia, 1978/79. (Source: Leihner, 1980.)

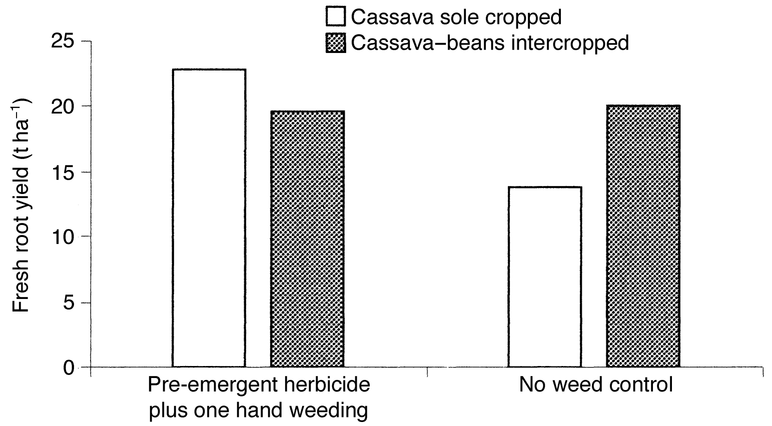

Fig. 6.5. Effect of two weed control levels on root yield in sole cropped cassava and a cassava–common bean intercrop. (Source: CIAT, 1979.)

data confirm the excellent cultural weed control potential of intercropping, particularly under marginal, low-input conditions.

Although these data show the effectiveness of specific cultural weed control methods in cassava, their exclusive use may entail a number of problems. The establishment of green covers or intercropping is usually more labour intensive than planting cassava alone. Cultural weed control alone may not be as effective as chemical or mechanical methods. The requirement of timeliness – a particularly critical aspect of weed control in cassava – may not always be fulfilled. On the other hand, cultural control is always ecologically sound and, depending on the method adopted and local availability of materials, it can also be low cost in terms of purchased inputs. The possibilities of combining cultural control with other weed-control methods are numerous and provide farmers with a variety of choices of either labour- or capital-intensive practices. This adds great flexibility to weed management, enabling cassava producers to adopt the system that best fits their means and thus obtain optimum results in terms of both crop productivity and economics.

Intercropping

Ecological, socioeconomic and nutritional aspects

Cassava adapts to a wide range of ecological conditions and is known for its tolerance of low soil fertility, drought and pests. This is why the crop holds an important position in traditional tropical cropping systems, particularly those of the small-farm and subsistence sectors. In these cropping systems, cassava is often found in mixed stands, together with a variety of other food or cash crops. For generations the traditional farmer has adopted intercropping as a production system in order to reduce the risk of crop failure, obtain production at different times during the year, make the best use of available land and labour resources, and provide the family with a balanced diet. Estimates indicate that at least one-third of the cassava grown worldwide is intercropped (Cock, 1985). Continents and regions reflect their own characteristic crop combinations and sequences, with cassava often being found at the end of the cycle. The greatest complexity of cassava intercropping systems is probably found in homestead gardens of rural farming families in Africa.

When farmers adopt cassava intercropping as a production system, a relatively small plot suffices to provide the family with the basic dietary elements. Sources of carbohydrates such as cassava, sweet potato (*Ipomea batatas*), yams (*Dioscorea* spp.), taro (*Colocasia* sp., *Xanthosomas* sp.) and plantains (*Musa* sp.) provide the primary caloric component. The intercrops such as common beans (*P. vulgaris*), cowpea (*Vigna unguiculata*), mung beans (*Vigna radiata*), groundnut (*Arachis hypogaea*) and pigeon pea (*Cajanus cajan*) contribute the necessary protein. Based on traditional farmers' yield levels, a very conservative estimate shows that 1 ha of cassava intercropped with black common bean can produce 10 t ha^{-1} of fresh cassava roots with 30% starch and 600 kg ha^{-1} of beans with 28% protein. At a caloric value of 4480 kcal kg^{-1} of starch, this would provide the following amounts of food energy and protein:

10,000 kg of cassava = 13.44 × 106 kcal
= 56,270 MJ
600 kg of beans = 168 kg of protein.

Assuming that the daily requirement of an adult person is 10.5 MJ (2500 kcal) and 100 g of protein, then 1 ha would supply 5376 caloric rations and 1680 protein rations, i.e. 1680 complete rations and a surplus of 3696 caloric rations or 38,686 MJ (9.24 × 106 kcal), without considering the protein content of cassava or the caloric value of beans. Thus 1 ha of a cassava–common bean intercrop supplies the annual food requirement for approximately five adults, leaving a surplus of about 6 t of cassava to be fed to animals or sold.

Although this is by no means a complete diet, it shows the enormous potential of cassava intercropping to provide a solid nutritional foundation on which to base a complete diet with minerals and vitamins added through vegetable and fruit consumption. Furthermore, there are still many poor around the world whose daily calorie and protein intake is far below the amounts quoted above.

Species and genotype selection

Cassava is intercropped with both long- and short-season crops. In plantation crops such as coconut palm, oil palm or rubber, the unproductive juvenile period of trees can last 5–7 years (Enjalric *et al.*, 1999). When intercropping newly established rubber with cassava and other food or cover crops in Gabon, early growth and ground cover development of rubber was so slow that four consecutive cycles of food crops were feasible before the trees started to compete seriously with the other crops for light (Leihner and Ziebell, 1998).

Cassava is also intercropped under mature coconut palms or rubber trees in regions of India or China, where arable land is extremely scarce (Cock, 1985). Under trees, the cassava tends to suffer from insufficient sunlight; hence productivity is very low. A selection of more shade-tolerant cultivars may, however, be feasible, yielding at least some extra carbohydrate without requiring additional land.

Intercropping cassava with perennial species is not widespread and the vast majority of systems involve cassava as a long-season crop, combined with short-season annual food or cash crops. Maize, cowpea, common bean and groundnut are the commonest intercropping partners. Associations with grain legumes are particularly promising, not only because of their aforementioned nutritional advantages but also for their soil-improving potential. Some agronomic implications of cassava–legume intercropping were discussed by Leihner (1979), and a comprehensive treatment of the issue was provided by CIAT as a cassava intercropping monograph (Leihner, 1983). Based on this information, it has been established that in cassava, genotypic traits such as vigour and branching habit (sometimes termed ‘leafiness’) are important determinants of suitability for intercropping. Cultivars with an erect growth habit (late branching) and medium vigour possibly produce less shade over an intercrop than those with early branching and high initial vigour. Furthermore, cultivars with medium vigour and late branching more closely resemble the ideal plant type for maximum yield in single culture described by Cock *et al.* (1979). It thus appears that medium-vigour genotypes with an erect growth habit are the most suitable for association with low-growing intercrops as they impose little competition on the intercrop initially and also have high yield potential. Only when cassava is intercropped with tall-growing maize, more vigorous plant types may be required to compete favourably with the maize.

When selecting grain legumes for intercropping at the beginning of the cassava growth cycle, an important characteristic of the legume is early flowering and maturity. With early maturity, the period of competition with cassava is reduced and excessive shading of the legume during pod filling is avoided. When both crops grow together in the field for a longer period of time, the interaction between them becomes more accentuated, and yields are mutually affected (Table 6.1). In associations of cassava with early-maturing legumes (common bean, cowpea), yield formation of both crops occurred largely independent from each other. An increasingly negative mutual influence was noticed, however, when the legume growth cycle exceeded 100 days.

Table 6.1. Correlations between yields of cassava and associated legumes with varying number of days to physiological maturity.

	Days to physiological maturity	Correlation of cassava/legume yields (*r*)
Bean	80	0.01
Cowpea	90	0.05
Groundnut	106	–0.14
Soybean	125	–0.35[a]

[a] Significant at $P = 0.05$.
Source: Leihner (1983).

Relative planting time

Relative planting time – i.e. planting the intercrop before, at the same time or after cassava – has both biological and practical implications. The biological implications include the fact that cassava does not impose much competition at the beginning of its growth cycle, but it does not tolerate much competition either. As a result, cassava yield can be drastically reduced if the intercrop is planted earlier than cassava, creating strong competition for light, water and nutrients at a time when cassava is still a weak competitor. On the other hand, if cassava is planted earlier than the intercrop, shading and competition for other growth factors may affect growth and yield of the latter. Thung and Cock (1979) established that simultaneous planting of cassava and common bean produced greatest total yields. This practice has been verified by growing cassava with various other grain legumes and maize. A practical implication of simultaneous planting is that it requires only one operation instead of two separate procedures to establish the association. To a certain degree, this facilitates the use of mechanization in intercropping systems if already existing machinery is adapted for that purpose.

While relative planting time can help regulate light competition when the associated crops initiate their growth cycle together, the situation is different for an intercrop sown into a fully developed cassava stand. Here, light may be the most limiting factor for the intercrop; nevertheless, observations made at CIAT showed that cassava intercepted less light towards the end of its growth cycle. This allowed the production of common bean intercrops during the last months prior to the cassava harvest. Comparing results of interplanting at 7, 8 and 9 months after cassava, bean yield was reduced the least when interplanting was done at 9 months, beans reaching up to 50% of their yield as a sole crop. It was concluded that the later an intercrop is sown into an already established cassava crop, the better is its yield. Nevertheless, the productivity of an intercrop grown under these conditions is much below that of an association where both crops begin their growth cycle together.

Planting density

In traditional cassava intercropping, farmers tend to use lower planting densities than in sole crops. The reduced number of plants per unit area, together with the competition imposed by one or several intercrops, may partially explain the low productivity of cassava in traditional intercropping systems. There is however, ample scope for improvement. The flexibility of cassava with regard to spatial arrangement (see Fig. 6.3) allows use of a wider-than-usual spacing between rows and still maintain optimum planting density by using smaller plant-to-plant distances within the row. Such a rectangular planting pattern has no adverse effect on cassava yield, but it facilitates the accommodation of intercrops and reduces competition. Different optimum planting densities for genotypes with different growth habits that have been found for sole crops appear to be valid for intercropped cassava as well. With leafy and early-branching cultivars, maximum sole crop yields are obtained at relatively low densities of 5000–8000 plants ha^{-1}. These densities produced the best yields when these cultivars were intercropped with common beans (Thung and Cock, 1979). Cultivars with less foliage and late branching do not show the same degree of coincidence. Nevertheless, this type of cassava when sole cropped still produces up to 92% of maximum yield at intermediate planting densities of 7000–9000 plants ha^{-1}, and also gives acceptable yields (75–90% of maximum) in association with common beans. This suggests that near-optimum planting densities for sole-cropped cassava may also be used in intercropping to obtain best results.

The yield of grain legumes does not vary greatly in response to planting densities within a relatively wide range. Trials with common bean, cowpea and groundnut grown as sole crops and intercropped with cassava showed either constant yields or not very accentuated responses when planting density of the legumes ranged from 50 to 200% of optimum sole-crop density (Leihner, 1983). Using the optimum density for sole-cropped legumes or only slightly increased densities, for cassava–grain legume intercrops frequently results in maximum grain legume yield when legumes are planted simultaneously with cassava. Similar observations have been reported for maize when optimum sole-crop densities were used in intercropping systems with cassava, with rectangular spacings that allowed an easy accommodation of both crops in the field and reduced competition (CIAT, 1981; Meneses, 1980).

Nutrient management

Nutrient requirements of cassava and the crops most frequently intercropped with it are well studied for sole culture conditions (Jacob and von Uexküll, 1973; Andrew and Kamprath, 1978; Asher *et al.*, 1980; Howeler, 1981).

There is, however, little information on nutrient requirements and response to fertilization of cassava and intercrops when grown in association. Intercropping represents an intensification of the demand for nutrients, particularly when each associated crop is planted at its normal single culture density. In this situation the removal of elements from the soil is greater in the intercropping system than in single culture. If these nutrients are not replaced by an adequate nutrient supply, soil fertility deteriorates. Results from research in Colombia (Leihner, 1983) point to a contrasting response of cassava to NPK under sole cropping as opposed to intercropping conditions. When a cassava–cowpea intercrop and its respective sole crops were amended with 0–300 kg ha^{-1} N, sole cropped cassava root yield only responded positively up to the first increment (50 kg ha^{-1}), then gradually declined below the control level. Sole cropped cassava normally requires only modest quantities of N to reach optimum leaf area index (LAI) for maximum root yield. Any amount of N in excess results in overly heavy top growth to the detriment of root filling. In contrast, intercropped cassava took advantage of an increase in N supply, producing the highest root yields only with the final increment of N (Fig. 6.6). Under competition from cowpeas, top growth and canopy development of cassava was below optimum at low N rates, reaching optimum LAI for maximum root yield only when large amounts of N were applied. Cowpeas, on the other hand, did not show a response to N fertilization under either sole- or intercropped conditions. The response pattern was the same for both cassava and cowpeas when the reaction to K fertilizer was tested in a similar sole crop–intercrop trial.

A totally different behaviour of cassava and cowpea was observed by the same author when the sole- and intercrop response to P was tested on a highly P-deficient soil. Cassava responded with root yield increases up to the last increment of P (132 kg ha^{-1} P) only when sole cropped.

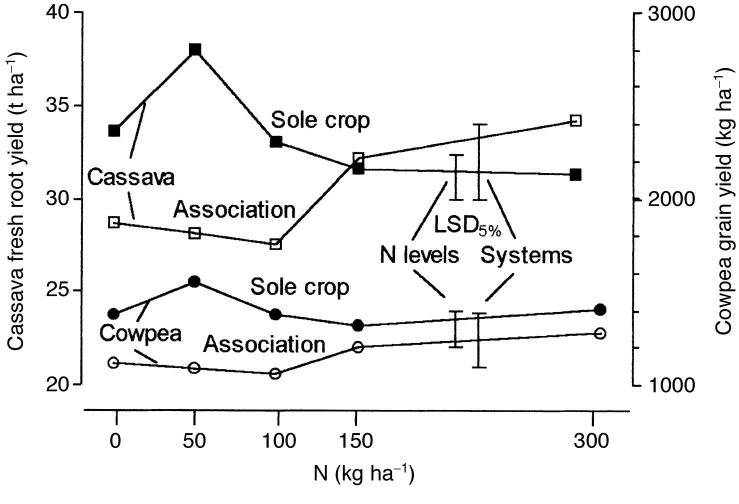

Fig. 6.6. Yield response from cassava and cowpea when sole cropped or intercropped and amended with different levels of nitrogen.

Under intercropped conditions, a negative response was noted, starting with the second increment (44 kg ha^{-1} P). On the other hand, cowpea responded positively from the first to last increment of P, irrespective of cultivation system (Fig. 6.7). At higher P rates, cowpea became so competitive that it reduced growth and yield of cassava whilst taking full advantage of the improved P nutrition for grain yield formation.

These examples demonstrate that the same nutrient management may lead to sharply contrasting responses in mixed crop systems and single cultures. In all cases changes in nutrient supply also changed the competitive ability of cropping-system components. Nutrient management in cassava intercropping systems must therefore be based on specific knowledge of intercropping-system responses to a given nutrient as the interaction between crops may lead to different growth and nutrient requirements compared to the sole crops.

Soil Conservation in Cassava-based Systems

Background of soil degradation and conservation in cassava

The problem of soil degradation currently is of worldwide importance, tropical regions being more seriously affected than temperate zones. The erosive nature of tropical rainstorms and the increasing cultivation of marginal and steep lands have reduced the depth of fertile topsoil in many regions of the tropics. In parts of the tropical lowlands, sandy soils have been exhausted and eroded through permanent cultivation. Under these conditions high-value cash crops such as vegetables or grain legumes, can no longer be grown and they are replaced by less demanding but low-value crops, such as cassava. With its slow early growth and poor initial soil cover, cassava creates conditions favourable to water erosion and soil degradation, particularly when cultivated without fertilizer. Thus agricultural lands degrade further, and environmental constraints build up to such a degree that it may be increasingly difficult for small-scale farmers to grow even cassava, their 'crop of last resort'. Hence there is a need to incorporate soil-conservation components into cassava-production systems.

There are differences among crops regarding their tendency to hinder or enhance soil erosion, related to root system development, growth habit and canopy dynamics. A number of studies appear to suggest that cassava is more erosion-enhancing than other crops due to its wide spacing and slow initial canopy development (Howeler, 1998; Putthacharoen *et al.*, 1998), but contradictory results have also

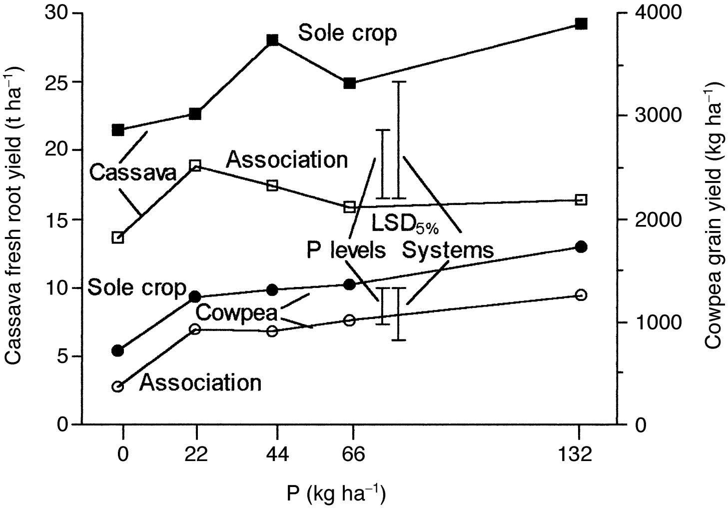

Fig. 6.7. Yield response from cassava and cowpea when sole cropped or intercropped and amended with different levels of phosphorus.

been reported (Howeler, 1991b). In most situations, however, appropriate crop management practices are more important to achieve soil conservation than crop selection. Soil conservation in cassava as in other crops should therefore follow a set of practices that have at least one of the two following objectives in common: (i) maintain soil infiltration rates at sufficiently high levels to reduce runoff to a negligible amount; and (ii) dispose of runoff water safely from the field should rainfall exceed the infiltration capacity of the soil (Lal, 1977). Cultural practices that help maintain a high infiltration capacity frequently involve conservation tillage practices, the use of mulch or live vegetation cover. The safe disposal of runoff is mostly achieved through physical manipulation of the surface by constructing contour bunds or terraces, surface drainage ways, and contour or tied ridges. Some of these practices have been tested successfully in cassava and will be discussed below.

Conservation tillage

Lal (1990) reviewed a wide range of conservation tillage options. He described the two key concepts to be included in conservation tillage for soil and water conservation as: (i) residue mulching; and (ii) an increase in random soil surface roughness. Whilst residue mulching can be implemented in no tillage, minimum tillage or mulch farming systems, an increase in random roughness can be achieved through various forms of soil tillage including chisel ploughing, strip tillage, ridge–furrow systems and tillage methods that cause soil inversion.

Lal (1977, 1990) has pointed out the many advantages of crop production involving a soil cover with mulch. This practice reduces water erosion by reducing raindrop impact, decreases crusting and surface sealing, increases surface storage of runoff water, decreases runoff velocity, improves soil structure and porosity, and improves the biological activity of the soil, favouring the formation of macropores, which maintain high infiltration rates and keep runoff low. Calculating the cropping factor (C-Factor) of the Universal Soil Loss Equation for different cropping systems in Indonesia, Abdurachman *et al.* (1984, cited in Lal, 1990) found a high C-Factor (little soil protection) of 0.588 for a rice + maize + cassava intercrop without additional soil protection. The same intercrop managed with residue mulch reached a C value of 0.357, whilst the use of rice straw mulch at a rate of 6 t ha^{-1} reduced the C-Factor to 0.079, demonstrating the good soil-protection potential of this management practice. On a sandy, low-fertility soil of the Colombian Atlantic Coast, Cadavid *et al.* (1998) grew cassava over an 8-year period with an annual application of 12 t ha^{-1} of dry *Panicum maximum* mulch. Mulch applications significantly increased root and top biomass, increased root dry matter (DM) content whilst reducing its yearly variation, and decreased root HCN, particularly in the absence of fertilizer. Mulch applications also significantly reduced soil temperatures within the top 20 cm and increased soil organic carbon, K, P, Ca and Mg. Without mulch, soil pH and root yield decreased over the years.

Although mulching is a useful concept and has its well-documented virtues in many crops including cassava, its practical use in farmers' fields is minimal. There are a variety of possible reasons: (i) the desired amount of mulch may not be available in all ecological regions and for all farming systems; (ii) labour for harvesting, transporting and applying the mulch may not be at hand or too costly; and (iii) on small farms there may be competing uses for mulching material, which might be needed as cattle feed, for roof thatching or other purposes. In these situations conservation tillage may include other tillage techniques such as contour ridges, tied ridges, raised bed systems and broad-bed furrow systems.

On either sloping or flat land, ridges increase surface roughness and help reduce runoff. On sloping land of two southwest Colombian test sites, Reining (1992) examined runoff control and soil-conservation effectiveness of contour ridges in cassava. Among six systems tested, ridges together with contour grass strips had the lowest average total runoff and the lowest average as well as maximum runoff rates at both test sites. Soil loss of 3 t ha^{-1} across test sites and years was amongst the lowest of all treatments, being similar to the minimum tillage treatment where cassava was planted in an existing grass or weed cover. With contour ridging, cassava fresh root yields of up to 31 t ha^{-1} were among the best of all soil-conservation treatments, whereas the minimum tillage system produced an average yield of just above 10 t ha^{-1}.

In South-East Asia intensive cassava cultivation on predominantly sandy, low-fertility oxisols poses a severe risk of soil degradation through water erosion. Howeler (1991b, 1998) presented an overview of the problem and discussed options on how to control it. Under tropical Asian conditions, conventional tillage including ploughing and harrowing – although leading to greater cassava yields – poses great risks of soil erosion unless followed by contour ridging. On Hainan Island in southern China, ploughing and harrowing followed by contour-ridge preparation produced fresh root yields of 26.3 t ha^{-1}, the greatest among seven methods of soil preparation examined, with the second smallest amount of erosion.

This information corroborates the general soil-conservation effectiveness of contour ridging. Special caution is warranted, however, when slopes are too steep, no proper sideward inclination of the furrows is used to facilitate surface drainage, or rainfall is overly heavy. Under these conditions too much water may accumulate behind the ridges, causing them to break and open the way to gully erosion, which leads to even greater soil losses than without ridges. In these cases an additional soil cover or more solid structures to reduce runoff and erosion, such as planted barriers, may be needed.

Cover crops

In the context of conservation tillage, Lal (1990) reviewed information on perennial cover crops providing ample documentation on their runoff and erosion-reducing potential. He also provided a list of suitable grasses and legumes for both tropical and temperate zones. Whilst most of the listed species are suitable only for rotations because of their strong competitive effect, a few (e.g. *Mucuna utilis*) can also be used as a simultaneous cover with food crops, being termed as 'live mulches'.

In cassava a fast-establishing simultaneous cover may be advantageous as soil protection by the crop itself usually sets in too late to be effective during the critical 2–4 months after planting. Grain legumes such as common bean, cowpea, mungbean or groundnut grown as intercrops simultaneously with cassava, can provide a rapid ground cover without being overly aggressive competitors. This might be one reason why farmers in Indonesia frequently intercrop legume food crops with cassava (Howeler, 1998). The positive effect on farm income is seen as an additional benefit of this form of soil protection. Reports from southwestern Colombia were less encouraging, where Reining (1992) recorded a cassava solecrop ground cover of only 10–35% 2 months after planting. To accelerate soil protection, he used intercropped cowpea and common bean, reaching average soil covers of 58% after 2 months at the warmer test site and 50% at the cooler one. However, the improved early ground cover reached through intercropping did not result in less erosion. Average soil loss in the cassava–legume intercrops was 26 versus 3 t ha^{-1} with sole cropped cassava planted on contour ridges. This was apparently the result of the more intense soil preparation to obtain a fine legume seed bed, together with more compaction during manual legume seeding.

As annual grain legume intercropping is not always an effective option for soil protection in cassava, the focus has frequently been on perennial legume covers. Although the maintenance of a continuous, simultaneous ground cover in cassava has definite beneficial effects in controlling runoff, erosion and nutrient leaching, root yields can be suppressed by vigorously growing or climbing legumes. Howeler (1991a) stressed the cassava–legume competition issue. When cassava was planted in an already established legume cover crop, soil protection was good, but cassava yields generally decreased because of severe competition from the legume. With less-aggressive legumes such as *Arachis pintoi*, the drop in cassava yields is slight, but with highly productive legumes such as *S. guianensis*, it is considerable. The deep-reaching legume taproots compete strongly with cassava for nutrients and for water during droughts. Leihner *et al.* (1996b) pointed to the difficulty of establishing cover legumes under cassava in the first year of cultivation and to their competitive effects at later stages. Averaged over the first 2 years after legume undersowing, cassava yield was reduced by 37% with *P. phaseoloides*, by 35% with *Z. glabra* and by 27% with *C. acutifolium*. Even when *C. rotundifolia*, a legume with a creeping, non-aggressive growth habit was used, yield reductions on the order of 10–20% were common, restricting the attractiveness of this combination to small farmers with cattle who could make use of additional forage production.

A realistic view of cover crops in cassava appears to be that despite their positive contribution to reducing soil degradation, their adoption is compromised by difficulties in obtaining seed or planting material, laborious establishment in the field, and their adverse impact on root yield. Their actual use may thus remain limited to a rather restricted set of ecologies and farming systems where their undoubted potential is not offset by existing disadvantages.

Live barriers

Engineered soil conservation options to shorten or interrupt slopes, such as contour bunds or bench terraces are prohibitively expensive for small producers in the tropics. As a result, there is interest in low-capital technologies for reaching these objectives. Live barriers formed by grass strips or barrier hedges are among these options. An overview provided by Gallacher (1990) stated that grass strips have almost become a tradition in several countries where cultivated fields would have been more severely eroded without the filtering and retarding effect of the strips on runoff. Furthermore, the author states that grass strips do not always need to be planted, they can be left to establish naturally from native grasses if unhoed or unploughed strips are left in the field. A list of suitable grasses, perennial legumes and other plants was presented by Stocking (1993), who described the typical situation in which the specific kind of material and conservation practice was used, the farming system, the current technical recommendations for implementation, possible support practices and variations in implementation.

Among the soil conservation practices tested in cassava fields in a number of Asian countries, Howeler (1991b) found that the most successful were fertilizer application, minimal tillage, contour ridging, subsoiling, closer plant spacing, intercropping, mulching and planting live barriers of grasses, legumes or hedgerow trees. On Hainan Island, for example, experiments conducted by the South China Academy of Tropical Crops showed the effect of live barriers planted with *S. guianensi* in reducing runoff and erosion. In reports from China, Vietnam and Thailand, Howeler *et al.* (1998) demonstrated the same positive results obtained with vetiver grass (*Vetiveria zizanioides*) barriers.

Working on Andean inceptisols in southwestern Colombia, Ruppenthal (1995) and Leihner *et al.* (1996b) described long-term testing of cassava soil conservation systems, including live barriers of dwarf elephant grass (*Pennisetum purpureum* cv. Mott) and vetiver grass. Average runoff rates (% of total rainfall) on slopes with a 7–20% gradient were lowest with contour ridges (3.6%), followed by vetiver grass (4.0%) and dwarf elephant grass (4.2%) barriers. After full establishment of the grasses, cassava yield with dwarf elephant grass barriers reached 81% and with vetiver grass barriers 90% of sole cropped cassava planted on flat land. Although yield reduction was partially due to a reduced cropping surface, it also reflects the greater competitiveness of elephant grass compared to vetiver grass. Grasses vary widely with regard to the aggressiveness with which their roots expand into neighbouring crop areas, vetiver grass being among the least spreading and competing species (Tscherning *et al.*, 1995).

Results of individual research projects and on-farm testing in the Andean region in respect of the use of live barriers in cassava were summarized by Müller-Sämann and Leihner (1999). Grasses with different uses were identified as suitable for live barrier planting in cassava. Vetiver grass, a non-forage species, exhibited outstanding technical properties as a soil-conservation component. It is recommended for very critical, erosion-prone situations on already degraded land. Citronella grass (*Cymbopogon nardus*) was less dense and effective, and its root system competed slightly more with cassava; however, it is also recommended for acid, low-fertility hillside soils because of its good adaptation and ease of propagation and handling. Adoption constraints for using this non-forage grass were overcome by constructing an essential oil extraction plant, adding value to this by-product of soil conservation. Among forage species, imperial grass (*Axonopus scoparius*) and dwarf elephant grass were the most promising, although the latter competed severely with the adjacent crop 3–4 years after establishment. Based on work with farmers, it was concluded that despite their usefulness for cut-and-carry systems, the use of forage grasses was difficult to implement on a larger scale due to high establishment and maintenance costs, amounting to 8 man-days 1000 m^{-1} or approximately US$74 for imperial grass barriers. Furthermore, transporting large quantities of forage on sloping land was difficult. It was concluded that barriers on fields distant from homesteads or stables should be functional, yet produce only a modest amount of biomass with high potential value to reduce soil-conservation costs.

Agroforestry systems with cassava

Forest areas generally show less nutrient leaching and runoff, resulting in smaller soil losses and less degradation as compared with agricultural fields planted to seasonal crops. Trees appear to have a stabilizing influence, most likely related to the permanent soil cover provided by the tree canopy, the leaf litter and the undergrowth, as well as to the fine, dense root distribution in the top layers of forest soils. Agroforestry systems try to make use of some of these advantages by combining crops with a tree component. In the end, however, management practices, more than tree or crop characteristics, determine whether the land use system has a conservation-enhancing character and is sustainable (Lal, 1990).

Agroforestry can be regarded as a special type of intercropping system. Thus observations on cassava intercropped with trees (e.g. plantation crops) may also be relevant to cassava grown in agroforestry systems. Although cassava is a frequent element in these systems, little specific information on tree–cassava interaction is available. In southern Benin, Akondé *et al.* (1996) conducted alley cropping research with cassava and maize (Fig. 6.8). Over a 6-year period, cassava root yields were increased by applying an average of 3 t ha^{-1} of *C. cajan* DM as a mulch obtained from 4-m spaced hedgerows, but increases were significant only when mulch and a mineral fertilizer were used. When *Leucaena leucocephala* hedgerows were grown with cassava, twice the amount of mulch was produced; but cassava yields did not increase with or without mineral fertilizer, presumably due to the much stronger competitive effect of *Leucaena* as compared to *Cajanus*. Studying light competition in the same cropping systems, Leihner *et al.* (1996a) concluded from light-transmission and row-position data that there were no important shading effects in tree–crop competition when trees were pruned two to three times a year. Competition effects were attributed mostly to the interference of lateral tree roots with those of cassava. Lateral root spread was

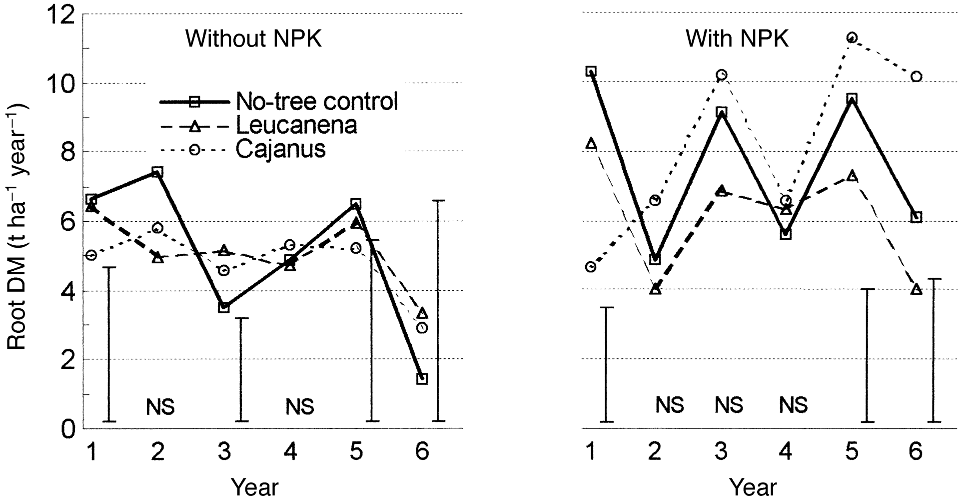

Fig. 6.8. Effect of NPK fertilization (90 N, 39 P, 75 K) and alley cropping on cassava root yield during 6 years of crop rotation with maize on an ultisol in Benin. (Source: Akondé *et al.*, 1996.)

much more aggressive with *Leucaena* than with *Cajanus*, which showed a characteristic tap-root pattern. Considering the specific nutrient demands of cassava, *Leucaena* appeared to contribute a high amount of N whilst competing strongly for K. Given the moderate N, but high K requirement of cassava, this may have caused excessive leaf and stem growth, leading to low harvest indices and root yields.

This observation points to possible crop–tree preferences that may be founded on plant–nutrient relationships, as well as on other, yet-unexplored complementarities or antagonisms based on physiological, agronomic or microbiological interactions. In agroforestry systems with cassava, leaf cuttings from the forage legume *Flemingia macrophylla* were found to have a more positive influence on root yield than other materials, whereas *Gliricidia sepium* was reported to benefit maize in particular (Böhringer and Leihner, 1997).

Rotations

General observations on the effects of rotation as opposed to continuous cultivation systems by Gallacher (1990) and Lal (1990) coincide in that rotations benefit both soil conservation and crop productivity. Different crops deplete or recycle soil nutrients to different degrees; others may add nitrogen. Rotations can restore organic materials and promote biological soil activity with beneficial consequences for structural stability. This in turn improves soil resistance to erosion and increases infiltration capacity. Furthermore, rotations are said to slow down the build-up of pathogenic soil-borne microorganisms and noxious weed populations.

Leihner and Lopez (1988) described a cassava rotation study on a fertile inceptisol (typic eutrandept) of the Colombian central Andean mountain chain. Over a 9-year period, sole cropped, unfertilized cassava showed a fresh root yield decline from 37 to 12 t ha^{-1}. After five farmer-managed cassava sole crop cycles, the field was subdivided, and a combination of fertilization and rotation treatments were established on large, commercial-size plots. Moderate fertilization with macro- and micronutrients had no positive influence on cassava productivity. In a rotational scheme with *Crotalaria juncea* as green manure, maize, cassava, maize, common bean, sorghum and cassava again, cassava yields returned to an average 30 t ha^{-1} level even without fertilization. It appeared that soil nutrients were not deficient, but cassava may not have been able to make use of them due to an overall biological degradation of the soil after so many years of unilateral use by a monoculture. Soil organic matter in the 'continuous cassava' system was stagnant with a tendency to decline. After 4 years of rotation cropping, however, organic matter increased by an average 1.5%. Legumes (*Crotalaria*, common bean) formed effective nodulation (suggesting efficient nitrogen fixation) and they improved P availability significantly, which was not observed under monoculture. With respect to mycorrhizal sporulation, spore counts were 36% higher at the end of the fourth year of rotation than for monoculture.

For healthy growth and good yield, cassava depends strongly on mycorrhizal symbiosis. Soil life as a whole may have been more active with rotation than under continuous cassava cultivation. Whilst there was no singular disease, insect, weed or nutritional problem responsible for the dramatic yield decline in monoculture cassava, it would appear that several minor interrelated factors added up to a substantial effect. The somewhat weaker monoculture cassava appeared to have suffered more from hornworm (*Erinnyis ello*) attack than the vigorous rotation crops. More defoliation allowed a more serious weed problem to develop in the cassava monoculture. In contrast, the greater diversity in the rotation system kept individually minor – but, in their combined action, important – phytosanitary problems below an economically relevant threshold level.

Another example of successfully controlling soil degradation and yield decline in cassava with rotations was reported by Müller-Sämann and Leihner (1999). Under cassava monoculture, the breakdown of structural stability (accompanied by an increase in erosion) occurred after just two crop cycles. Nevertheless, the factors governing erodibility such as degree of aggregation and structural stability could be restored effectively with agronomic practices including undersown cover crops, minimum tillage, weed fallow and grass–legume mixtures in rotation, the latter having the profoundest and longest lasting effect on soil strength. An analysis of hot water-extractable carbohydrates (secretions of soil microorganisms) showed that cassava–grass–legume rotations enhanced microbial soil activity, which resulted in significant levels of binding substances for soil particles, thereby increasing aggregation and decreasing erodibility (Häring, 1997). When using a modified 'productivity index' model (Flörchinger, 1999), it was possible to predict that traditional cassava monoculture would lead to complete yield loss after 25–84 years, depending upon whether a best or worst case scenario was adopted. When soil conservation practices such as contour ridges, grass barriers or rotations were used, cassava production could be expected to be feasible for another 90–100 years with only minor yield losses of 4–14%.

These examples demonstrate the importance of diversified cassava production systems. Rotations with green manure, live mulch or crops of the *Gramineae* family can potentially lead to balanced nutrient extraction and recycling whilst counteracting the build-up of cassava-specific pests. Enhancing soil life by rotating with grass–legume mixtures leads to the chemical, physical and biological restoration of degraded soils, thereby reducing vulnerability to degradation by erosion in cassava-based systems.

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