CASSAVA AGRONOMY RESEARCH IN ASIA: HAS IT BENEFITTED CASSAVA FARMERS?

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ABSTRACT

During the past decade (1990-2000) the area planted to cassava in most countries in Asia has generally decreased, while production has remained stable or also decreased. Cassava yields have increased mainly in India, Indonesia and China but remained nearly the same in Malaysia, Thailand and the Philippines, and actually decreased in Vietnam. Yield stagnation or declines, inspite of widespread adoption of higher yielding varieties, is partly due to displacement of cassava to more marginal regions, and partly a result of the deterioration of the soil resources due to erosion and inadequate or unappropriate fertilizer use.

The paper describes research results obtained in the development of improved cultural practices, such as time and method of planting, weed control, fertilization, intercropping and erosion control. Experiments have shown that cassava yields are seriously reduced if either low rainfall or low temperatures are limiting growth during the period of 3-5 months after planting; that planting vertically or inclined produces higher yields than planting horizontally, especially during periods of drought; that planting on ridges is better in the rainy season but planting on the flat is better in the dry season; that high yields can be sustained over many years of continuous cassava planting if adequate amounts of N and K are applied annually; that intercropping with peanut generally increases total income and protects the soil from erosion; and that fertilization, intercropping, contour ridging and contour hedgerows of grasses are very effective ways to reduce erosion. Areas in which additional research is needed are suggested.

Improved cultural practices, such as the use of chemical fertilizers and herbicides have been adopted in some regions or countries, such as Tamil Nadu, Malaysia, Thailand (to some extent), Indonesia and south Vietnam (mainly fertilizers). Constraints to adoption are identified and policy changes are suggested that will enhance the adoption of better practices that will contribute to increasing the income of cassava farmers and maintaining or improving the productivity of the soil.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) was introduced to Asia about 200 years ago, first to the Philippines, India and Indonesia and later spreading to Malaysia, Thailand, Vietnam and China. Initially it was grown mainly as a food security crop, but was later used for small-scale starch processing and on-farm pig feeding. After the Second World War cassava production expanded rapidly, while in some countries its role changed from a source of human food to a raw material for production of animal feed and starch. Cassava production in Asia increased rapidly from the early 1960s to the late 1980s, mainly due to a rapid increase in planted area in Thailand, and to a lesser extent in the other countries. Cassava production reached its peak in Asia in 1989, after which production declined, mainly due to reduction in planted area, not only in Thailand but also in most other countries. **Table 1** shows the trend in harvested area, production and yield over the past eight years. During that period the harvested area declined at an annual rate of 2.02%, while production declined at 1.68%. The significant reduction in area was only partially

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offset by a slight increase in yield, from 13.28 t/ha in 1992 to 13.60 t/ha in 1999, corresponding to an annual growth rate of 0.34%.

Table 1. Trend in cassava harvested area, production and yield in Asia from 1992 to 1999.

	Area ('000 ha)	Production ('000 t)	Yield (t/ha)
1992	3,872	51,419	13.28
1993	3,892	50,429	12.96
1994	3,818	48,622	12.73
1995	3,646	46,083	12.74
1996	3,716	48,301	13.00
1994	8,507	47,549	13.56
1998	3,316	44,416	13.39
1999	3,366	45,768	13.60
% Annual growth	-2.02	-1.68	+ 0.34

Source: *FAOSTAT, 2001.*

In India the first improved varieties were released in 1971 and since then a total of 11 new varieties have been released, which contributed to a remarkable increase in yield from about 15 t/ha in 1971 to 24 t/ha in 1999. In Thailand the first new variety was introduced in 1983 followed by seven others up till 1999; these new varieties are now planted in about 87% of the total cassava area (Sarakarn *et al*., 2001). In contrast to India, this did not result in a substantial increase in the national average yield, which remained constant at about 14 t/ha, increasing only during the past five years from 13 to 16 t/ha. In most other countries, harvested area declined while yields increased only slightly, in spite of the release of about 18 new high yielding varieties during the past decade. Many of these varieties have the potential to increase yields 10-20%, and in some cases (Vietnam) up to 100%. Still, this expected yield increase has not materialized, except in India. In India yields in Kerala increased modestly, from 15.85 t/ha in 1976/77 to 18.23 t/ha in 1996/97 (Edison, 2001); this is partially due to a shift from the infertile uplands to more fertile lowland soils. While planted area declined rapidly in Kerala, the area increased in Tamil Nadu, where yields during the same period also increased markedly, from 23.5 to 46.3 t/ha. The very high yields in Tamil Nadu are attributed to production of cassava on high-fertility Alfisols and Vertisols, the use of high-yielding varieties for industrial purposes, high inputs of fertilizers, pesticide, and most importantly, irrigation during the long dry season (with high solar radiation). In most other countries, on the other hand, cassava has been displaced from more favorable areas to those with more marginal soils or climatic conditions. Thus, in Thailand, the cassava planted area has moved from the slightly better soils in the east to the highly infertile sandy loam soils in the northeast as well as to hilly areas in the lower north (Sriroth *et al*., 2001). In Indonesia, the cassava area is decreasing on the more fertile soils in Java and increasing in acid infertile soils in Sumatra (Nasir Saleh *et al*., 2001). In China cassava production on the better soils of

Guangdong province has shifted mainly to the poorer soils in Guangxi province (Tian Yinong *et al*., 2001). Similarly, within a particular area, cassava tends to be replaced by higher value crops from the better areas to the more marginal areas, from flat land to hilly land, and from areas with high rainfall to areas that are more drought prone. This may explain at least partially why cassava yields in Asia have not increased dramatically in spite of the fact that now about 1/3 of the cassava area (over 1 million ha) is planted with new high-yielding varieties.

Another reason for stagnating yields may be the decline in soil productivity as a result of continuous cassava production without adequate fertilization and measures to control erosion. In Asia there are no serious pests and diseases (except in India), so declining yields can be attributed mainly to declining soil productivity. There is good evidence for that in south Vietnam (Cong Doan Sat and Pol De Turck, 1998; Nguyen Huu Hy *et al*, 2001), where continuous production of cassava was found to result in a decline in physical, chemical and biological conditions of the soil, compared with those soils under forest, sugarcane, rubber or cashew. Long-term fertility trials conducted in India (Kabeerathumma *et* al, 1990), Malaysia (Chan, 1980), Thailand (Tongglum *et al*, 2001), Vietnam (Nguyen Huu Hy *et al*, 2001), Indonesia (Wargiono *et al*., 2001) and China (Li Jun *et al*., 2001) all indicate that cassava yields will decline when the crop is grown continuously on the same land without adequate fertilizer inputs, especially K and N. While little cassava in Asia is grown in the highlands, much cassava is grown on sloping land with slopes ranging from 0-10% in Thailand to 40-60% in Hainan and Yunnan provinces of China. Surprisingly, soil erosion is more serious on the gentle slopes in Thailand (due to the sandy nature of the soil) than on the steeper slopes in China (with heavier and well-aggregated soils). In any case, serious erosion will result in substantial losses of nutrients, both in runoff water and in eroded soil (Puthacharoen *et al*., 1998; Howeler, 2001; Howeler *et al*., 2000) resulting in a decline in soil productivity and yields (Howeler, 1986). While most cassava farmers do apply some farm-yard manure (FYM) and/or chemical fertilizers, the rates of application are usually insufficient to compensate for the removal of nutrients in the harvested products. For instance, calculations of nutrient balances in Vietnam, based on results of a country-wide survey conducted in 1990/91 (Pham Van Bien *et al*., 1996) indicate that the N and K balances were highly negative in three of the six regions, while the P balance was slightly negative in only one of six regions (Howeler, 2001b). Thus, in Vietnam cassava farmers were applying too much P and not enough N and K. A similar situation probably exist in India, Thailand and Indonesia where fertilizer applications tend to be high in N and P but too low in K. Thus, while recent research has indicated the importance of adequate K fertilizer inputs for maintaining high cassava yields, this has not yet translated in a significant change in fertilizer recommendations and applications in most countries. Similarly, many erosion control trials have shown that erosion can be controlled effectively by various simple soil and crop management practices, but these practices are not yet adopted extensively by farmers, leading to a continued degradation of the soil. Thus, to improve this situation and achieve real increases in productivity it is necessary to develop still better cultural practices (in addition to high-yielding varieties), and more importantly, to develop more effective ways of enhancing the adoption of these practices by cassava farmers.

RESULTS OF CASSAVA AGRONOMY RESEARCH IN ASIA DURING THE PAST 25 YEARS

Agronomic practices used by cassava farmers in Asia vary markedly between countries and even between regions within countries, depending mainly on farm size, availability of labor, soil and climatic conditions, as well as on socio-economic factors and cultural traditions. These practices are broadly summarized in **Table 2**. The results of cassava agronomy research in the major cassava growing countries in Asia have been summarized by Evangelio (2001), George *et al.* (2001), Nguyen Huu Hy *et al.* (2001), Li Jun *et al.* (2001), Tan (2001), Tongglum *et al.* (2001) and Wargiono *et al.* (2001). These results will be briefly described and compared among countries in order to identify areas where further research may be necessary.

1. Time of Planting

Time of planting studies have been conducted in Thailand (Tongglum *et al*, 2001), Indonesia (Wargiono, 2001; Fauzan and Puspitorini, 2001), China (Zhang Weite, 1998) and the Philippines (Villamayor and Daviner, 1987). In general, yields were found to be higher when cassava was planted in the early part of the rainy season (May-June in most countries, but Oct-Nov in Indonesia) or the early part of spring (Feb-March in north Vietnam and China). In many countries some cassava is also planted at the end of the rainy season, such as Aug-Sept in Kerala, or Sept-Nov in Thailand and south Vietnam (**Table 2**). In Hainan island of China it was found that cassava can be planted throughout the year when harvested at 12 months after planting (MAP), but only from Feb-May when harvested at 8 MAP; starch contents were always highest when the roots were harvested in the dry and cold months of Nov-March (Zhang Weite *et al.*, 1998). Several reports indicate that root yields were best correlated with rainfall during the 3^{rd}-5^{th} month (Zhang Weite *et al*, 1998), during the initial 7 months (Villamayor and Davines, 1987) or during the 4^{th}-11^{th} month (CIAT, 1998), while Fauzan and Puspitorini (2001) reported the lowest yields when a long drought occurred during the middle part of the growth cycle, i.e. the 3^{rd}-7^{th} or 4^{th}-8^{th} months. Obviously, cassava needs adequate soil moisture at planting for the stakes to germinate, but once established the crop seems to tolerate drought better in the early than in the middle part of the growth cycle, i.e. highest yields are obtained when cassava is planted 3-4 months before the start of the rainy season as long as soil moisture is adequate for land preparation and germination of stakes (**Table 3**). Thus, in sandy soils of Thailand cassava is now often planted during the dry season (Jan-April), usually immediately after an occasional rain storm.

Figure 1 and **Table 4** show that the root starch content was positively correlated with rainfall during the 6^{th}-9^{th} month, but was slightly negatively correlated with rainfall during the last one or two months before harvest (CIAT, 1998). Similar results were obtained in China (**Figure 2**), while Vichukit *et al.* (1994) and Fauzan and Puspitorini (2001) reported the highest starch content when the crop was subjected to drought during the last 2-3 months before harvest. There was no significant correlation between total rainfall received during the growth cycle and either root yield or starch content as long as rainfall was more or less well distributed (Fauzan and Puspitorini, 2001).

Table 2. Characteristics of cassava cropping systems and cultural practices used in major production zones in Asia in 1999/00.

	China	India		Indonesia		Malaysia	Philippines	Thailand	Vietnam	
		Kerala	Tamil Nadu	Java	Sumatra				North	South
-Cassava area (ha/farm)	0.2-0.4	<0.1	0.5-1.0	0.3-0.5	0.5-1.0	4-500	-	2-3	0.1-0.3	0.2-0.9
-Intercrops	none/peanut	none	none/ vegetables	maize+rice- soybean/peanut	maize	rubber	none/maize	none (95%) maize (5%)	none/peanut	none/maize
-Land preparation	manual/ animal	manual	tractor	manual/ animal	animal/ tractor	tractor	animal/ manual	tractor 3disc+7disc	animal/ manual	animal/ tractor
-Fertilizer use										
-organic (t/ha)	3-5	10-20	10-20	3-10	low	none	none	little	2-7	0-5
-inorg. (kg N+P_2O+K_2O/ha)	some NPK	some	high	N only	medium	>400	little	30-120	0-80	0-60
-Seasonality in planting	Feb-Apr (90%)	Apr-Jun (60%)	Jan-Mar (90%) Sept-Oct	Oct-Dec (90%)	Oct-Dec (90%)	year round	year round	March- May(70%) Sept-Nov	Jan-Mar (70%)	Feb-May (80%) Oct-Nov
-Harvest time	Nov-Jan	Jan-Mar	Oct-Jan	Jul-Sept	Jul-Sept	year round	year round	Dec-May Aug-Dec	Nov-Jan	Feb-Mar Sept-Oct
-Planting distance (m)	1.0x1.0 0.8x0.8	1.0x1.0	1.0x1.0	1.0x0.8 2.0x0.5	1.0x0.8 2.0x0.5	1.0-1.2x 0.8-1.0	1.0x0.8	0.8x1.2 0.8x0.8	1.0x1.0 0.8x0.8	1.2x0.8 0.8x0.8
-Planting method	horizontal	vertical	vertical	vertical	vertical	horizontal	horizontal	vertical	horizontal	horizontal
-Weed control	hoe 2-3x	hoe 2-3x	hoe 4-5x	hoe 1-2x	hoe 1-2x	herbicides/ hoe	animal/ hoe 2-3x	hoe 2-3x small tractor/ Paraquat	hoe 2-3x/ animal	hoe 2-3x
-Harvest method	hand	hand	hand	hand	hand	hand/tractor	hand	hand/tractor	hand	hand
-Main varieties	SC205 SC201 SC124	local var. M-4	H-226 local var. H-165	many local varieties	Adira 4	Black Twig	Golden Yellow Lakan	KU50 Rayong 90 Rayong 60 Rayong 5	Vinh Phu La Tre[2] KM60	KM94 KM60 H34 HL23
-Labor use (m-days/ha)	90-180	150-200	200-350	200-300	150-200	50-60	100-200	50-60	200-450	100-200
-Variable prod. costs ($/ha)[1]	300-450	500-600	400-700	300-600	250-300	390-520	350-700	300-400	300-600	350-400
-Fixed costs ($/ha)	5-100	200-500	50-250	NA[3]	50	NA	NA	50	20	20

[1]including family labor, harvest + transportation.
[2]La Tre = SC205; KM60 = Rayong 60; KM94 = KU50.
[3]NA = data not available

Source: *modified from Hershey et al., 2000.*

Table 3. Effect of different planting dates on the average rainfall received, soil losses due to erosion, cassava growth and yield, as well as the gross income obtained when cassava, cv Rayong 90, was grown for three consecutive cycles on 4.2% slope at Rayong Field Crops Research Center in Thailand from 1994 to 1998.

Month of planting[1)]	Total rainfall[2)] (mm)	Dry soil loss (t/ha)	Canopy cover[3)] (%)	Final plant stand (%)	Root yield (t/ha)	Starch content (%)	Gross income[4)] ('000B/ha)
June	1402	15.64	77.3	97	23.32	21.27	19.25
August	1409	18.21	55.0	97	18.92	22.33	16.02
October	1267	15.73	55.0	91	24.56	25.73	22.46
December	1665	12.88	82.0	90	32.18	25.07	29.01
February	1633	13.05	89.2	88	27.92	30.35	28.11
April	1616	14.30	87.8	87	25.67	26.13	23.68

1)roots were harvested after 11 months
2)rainfall received during the 11 month growth cycle
3)percent canopy cover averaged over all months of the growth cycle
4)assuming a price of B 1.0/kg fresh roots with 30% starch, and a reduction in price of B 0.02/kg for each per cent drop in starch content
Source: *CIAT, 1998b.*

Figure 1 and **Table 4** also show that soil loss due to erosion was significantly correlated with rainfall during the 1st-3rd months, which is to be expected as high rainfall when plants are still small will result in high runoff and erosion. Tongglum *et al* (2001) reported that while cassava yields tended to be slightly higher when the crop was planted in the early rainy season as compared to the early dry season, the cost of weeding was much lower when planted in the dry rather than the wet season. Thus, it appears that cassava might best be planted before or very early in the wet season (if soil moisture permits planting and germination), and harvested in the middle of the dry season. Other times of planting and harvest may be feasible or desirable (to spread the harvest period) but may result in lower starch yields, higher weeding costs and more erosion.

2. Land Preparation

Table 2 shows that land preparation for cassava is usually done by hand, using a hoe, or by an animal-drawn plow. In Thailand, Malaysia, Tamil Nadu of India and much of South Vietnam, land is now prepared by tractor, usually on contract.

Mandal and Mohankumar (1973) reported no significant differences between shallow and deep tillage – either by hand or animal drawn plow - while Villamayor (1983) also reported no benefits from tillage beyond 20 cm depth. In most countries research has shown that highest yields were obtained with two plowings followed by disking and ridging. One or two passes with a 7-disk harrow followed by ridging produced the highest yields in Thailand (Tongglum *et al*., 1992), but ridging may not be necessary or recommended when planting during the dry season.

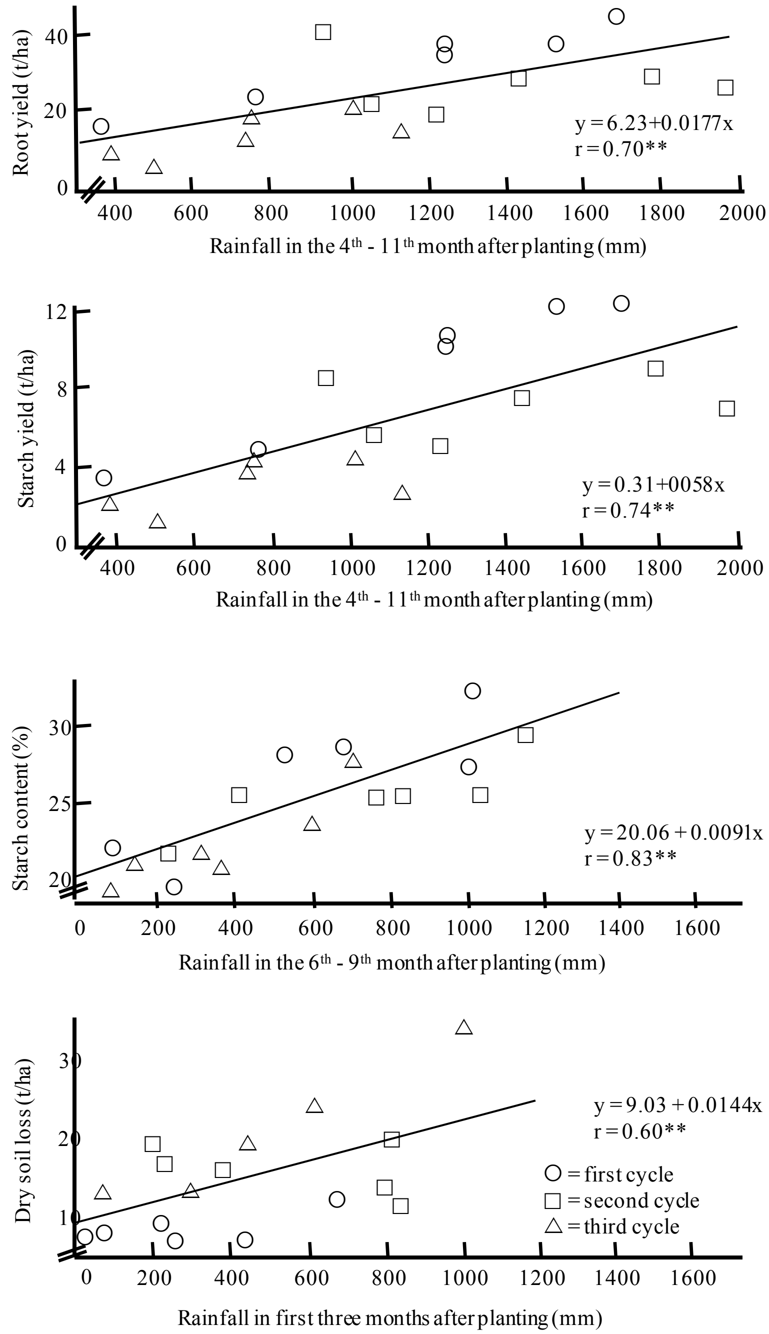

Figure 1. Linear regressions between cassava root yield, starch yield, starch content and dry soil loss due to erosion and the rainfall received during certain periods of the crop cycle when cassava, cv Rayong 90, was grown at bimonthly intervals for three complete cropping cycles on 4.2% slope at Rayong Research Center in Thailand from 1994 to 1998.

***Source**: CIAT, 1998 b.*

Table 4. Correlation coefficients between cassava root yield, starch content and starch yield, as well as dry soil losses due to erosion and rainfall during certain periods in the cropping cycle when cassava, cv Rayong 90, was planted at bimonthly intervals for three consecutive cropping cycles on 4.2% slope in Rayong Research Center in Thailand from 1994 to 1998.

Parameters	Correlation Coef. (r)	%P
Cassava root yield vs rainfall from the 4^{th}-11^{th} MAP[1)]	0.7025	0.001
Cassava root yield vs rainfall from the 3^{rd}-11^{th} MAP	0.6726	0.002
Cassava root yield vs rainfall from the 2^{nd}-11^{th} MAP	0.6005	0.008
Cassava root yield vs rainfall from the 1^{st}-11^{th} MAP	0.5115	0.030
Cassava root yield vs rainfall during the 1^{st} MAP	-0,4258	0.078
Cassava root yield vs rainfall from the 1^{st}-2^{nd} MAP	-0,4146	0.087
Root starch content vs rainfall from the 6^{th}-9^{th} MAP	0.8298	0.000
Root starch content vs rainfall from the 5^{th}-9^{th} MAP	0.7981	0.000
Root starch content vs rainfall from the 6^{th}-8^{th} MAP	0.7966	0.000
Root starch content vs rainfall from the 10^{th}-11^{th} MAP	-0.1290	NS
Root starch content vs rainfall during the 11^{th} MAP	-0.0772	NS
Starch yield vs rainfall from the 4^{th}-11^{th} MAP	0.7411	0.000
Starch yield vs rainfall from the 4^{th}-10^{th} MAP	0.7096	0.001
Starch yield vs rainfall from the 5^{th}-11^{th} MAP	0.7090	0.001
Starch yield vs rainfall from the 5^{th}-10^{th} MAP	0.6950	0.001
Dry soil loss (erosion) vs rainfall from 1^{st} -3^{rd} MAP	0.6016	0.008
Dry soil loss (erosion) vs rainfall from 1^{st} -4^{th} MAP	0.5515	0.018
Dry soil loss (erosion) vs rainfall from 1^{st} -5^{th} MAP	0.5290	0.024
Dry soil loss (erosion) vs rainfall from 1^{st}-2^{nd} MAP	0.5087	0.031

Note: cassava was harvested after 11 months

[1)] MAP = month after planting

***Source:** CIAT, 1998b.*

On steep slopes cassava can be planted by preparing only the planting holes with a hoe. This produced similar yields as twice plowing and disking in Hainan but resulted in much less erosion (Zhang Weite *et al*, 1998). Alternatively, zero tillage (with herbicides) sometimes produced good yields in Thailand (Tongglum *et al*, 1988; 1992; 2001) and may or may not reduce erosion (Jantawat *et al*., 1991). Zero tillage is most feasible when the land comes out of bush fallow or had previously a good crop of cassava which prevented excessive weed growth. In very weedy plots or in compacted soil, zero tillage will generally result in low yields and difficulty in planting, weeding and harvesting.

3. Preparation of Planting Material

Research in India, Indonesia, Philippines, Malaysia and Thailand on production of good-quality planting material, indicates that higher yields are obtained when stakes are cut from the mid- and lower-part of stems taken from mother plants that are about 8-12 months old.

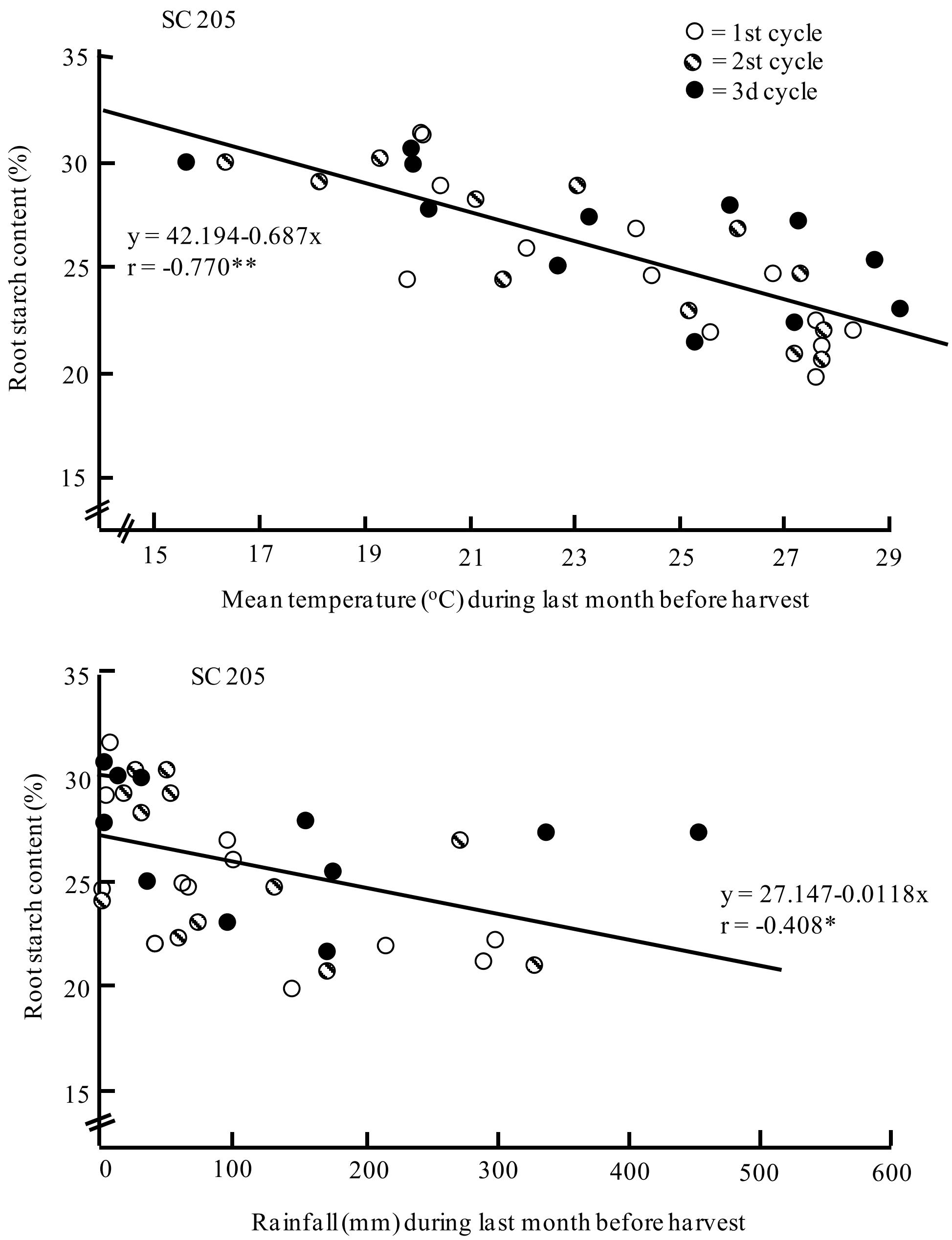

Figure 2. Linear regressions between root starch content and the mean temperature (top) or rainfall (bottom) during the last mouth before harvest of SC205 (harvested at 8 MAP) during three consecutive cropping cycles at CATAS, Danzhou, Hainan,China, from 1990 to 1993.

After cutting the stems, these can be stored for up to 1 month, preferribly in a vertical position under shade. Storing stems for more than 60 days resulted in a lower percentage of germination (George *et al*., 2001). On the other hand, Villamayor, Perez and Destriza (unpublished data) found that stems could be stored in a vertical position in the open and covered with coconut palm fonds for up to four months without affecting the yield of the subsequent crop (Evangelio, 2001). The length of time stakes can be stored depends a lot on the variety and climatic conditions during storage. In subtropical climates, such as in northern Guangxi and Guangdong provinces of China, stems need to be cut before the first frost and stored in trenches at least one meter deep and covered with straw and soil to prevent damage from frost. Again, some varieties are more tolerant to low temperatures during storage than others.

At time of planting the stems are cut into stakes or cuttings. The most suitable length of cuttings was found to be 15-20 cm in Thailand (Tongglum *et al*., 1988), 20-23 cm in Malaysia (Tan, 2001) and 25-30 cm in India (George *et al*. 2001). In the Philippines short stakes are recommended for horizontal planting and longer stakes for vertical planting (Villamayor *et al*., 1992). Most farmers will cut stakes at an angle with a machete, but in India it is recommended to make a smooth circular cut for uniform callus formation and root initiation (CTCRI, 1970, 1972). In some big plantations in Indonesia 50 stems are bundled together with rubber bands spaced at 20 cm distance. In between two rubber bands they are cut with a circular power saw and the top of each bundle of stakes is dipped in red ink to facilitate planting stakes vertically in the correct position with buds facing upward.

When planting material is scarce it is possible to use short stakes of 2-3 nodes placed for 7-10 days on wet paper towels to produce roots and sprouts before transplanting to the field (Wargiono *et al*., 1992). In India 1-3 node stakes are planted closely together in moist sand in a nursery for 20 days before transplanting to the field. This nursery method is particularly useful in areas with a very short rainy season (Mohankumar *et al*., 1998).

Chemical treatment of stakes was found to be unnecessary as few diseases and pests in Asia are transmitted via the planting material (except CMD in India). A stake dip in 2% $ZnSO_4$. $7H_2O$ solution for 15 minutes before planting is recommended in areas with high-pH soils resulting in Zn deficiency (Howeler, 2001a).

4. Planting

Planting position varies from country to country (**Table 2**) with vertical planting being practiced in India, Thailand and Indonesia, and horizontal planting in China, Malaysia, Philippines and Vietnam. Research on planting position usually shows no significant differences in yield due to planting position, although vertical or inclined planting produced slightly higher yields in China (Wen Jian, 1964; Zhang Weite, 1998) and significantly higher yields than horizontal planting in both the rainy and dry season plantings in Thailand (Tongglum *et al*., 1992). Horizontal planting may result in poor germination when the surface soil is very hot and dry. Horizontal planting tends to result in shallower roots which are easier to harvest. In the Philippines it is recommended to plant vertically on ridges in areas of heavy rainfall, and horizontally on flat land or in furrows in areas of low rainfall (Mendiola, 1958).

Depth of planting may vary from 5 to 15 cm, with the deeper planting producing better yields then shallow planting in the dry season (Tongglum *et al*., 1992). In India it is recommended to plant vertically to a depth of 5-10 cm (George *et al*. 2001).

The optimum plant population and spacing depends on the fertility of the soil, the branching habit of the variety and the cropping system. In general, cassava should be planted at a higher population (12,000-16,000 plants/ha) for non-branching varieties and for all varieties planted in infertile soil, and at a lower population (10,000-12,000 plants) in more fertile soils, especially for branching varieties (Nguyen Huu Hy *et al*., 1998). In India a planting distance of 90x90 cm is recommended for semi-branched and 75x75 cm for non-branched varieties (Mandal *et al*., 1973). In intercropping systems the cassava population can be maintained at 10,000 plants/ha, but the row spacing is often increased to 1.25 or ever 2.0 m, while in-row spacing is reduced to 0.8 or even 0.5 m. The wider row spacing allows for the planting of 1 or 2 rows of intercrops between cassava rows, resulting in reasonably good yields of both cassava and the intercrops. Planting cassava at 2 m between rows or in double rows of 2.73x0.6x0.6 m produced the highest net income in intercropping systems of cassava-upland rice-maize followed by peanut in Lampung, Indonesia (Wargiono *et al*. 1995; 1998); a double row system was also found superior to the single row system for intercropping cassava with sweet corn in Malaysia (Tan, 1990). In contract, a square planting pattern of 1.0x1.0 m produced the highest crop value during two years of planting in Yogyakarta, Indonesia (Wargiono *et al*., 1992) and also a higher net income than the double-row system for various intercrops in south Vietnam (Nguyen Huu Hy *et al*., 1995).

When stakes don't germinate, the surrounding plants will usually cover over the empty space and compensate for missing plants. Villamayor and Labayan (unpublished data) found that replanting of missing plants is justified only if more than 30% of plants are missing (Villamayor, 1988). They suggest replanting before plants are more than 13 days old. In India, research at CTCRI (1984) found that replanting with 40 cm long stakes produced 50% higher yields than replanting with normal 20 cm stakes; they suggest replanting at about 15 days.

5. Fertilization

a. Nutrient removal

Continuous cassava cultivation on the same land may lead to nutrient depletion due to nutrient absorption by the crop and nutrient removal in the harvested products. How much nutrients are actually removed from the field depends on whether only roots are harvested or the plant tops (sometimes including fallen leaves) are also removed from the field; it also depends on the root and top yield as well as the nutrient concentration in the various plant parts. In general, the nutrient removal in either the roots or the whole plant per tonne of fresh roots is higher at high than at low yield levels (**Figures 3** and **4**) because at higher levels of fertility, plants have higher nutrient concentrations, resulting in higher yields. From **Figures 3** and **4**, which are based on 19 data sets found in the literature, we can estimate that in an "average" crop producing 15 t/ha of fresh roots, the nutrient removal in those roots is only about 30 kg N, 3.5 kg P and 20 kg K/ha (**Figure 3**). If all plant parts are harvested, the nutrient removal will be about 80 kg N, 9 kg P and 50 kg K/ha (**Figure 4**); these values are considerably lower than previously reported (Howeler, 1981; 1991), as the latter were calculated from "average" nutrient removal per tonne of dry of fresh roots, based on data from experiments that tend to have much higher yields than those obtained by farmers. Thus, nutrient removal in an "average" yield of cassava (15 t/ha fresh roots) is much lower than that in the harvested product of most other crops (Howeler, 1991).

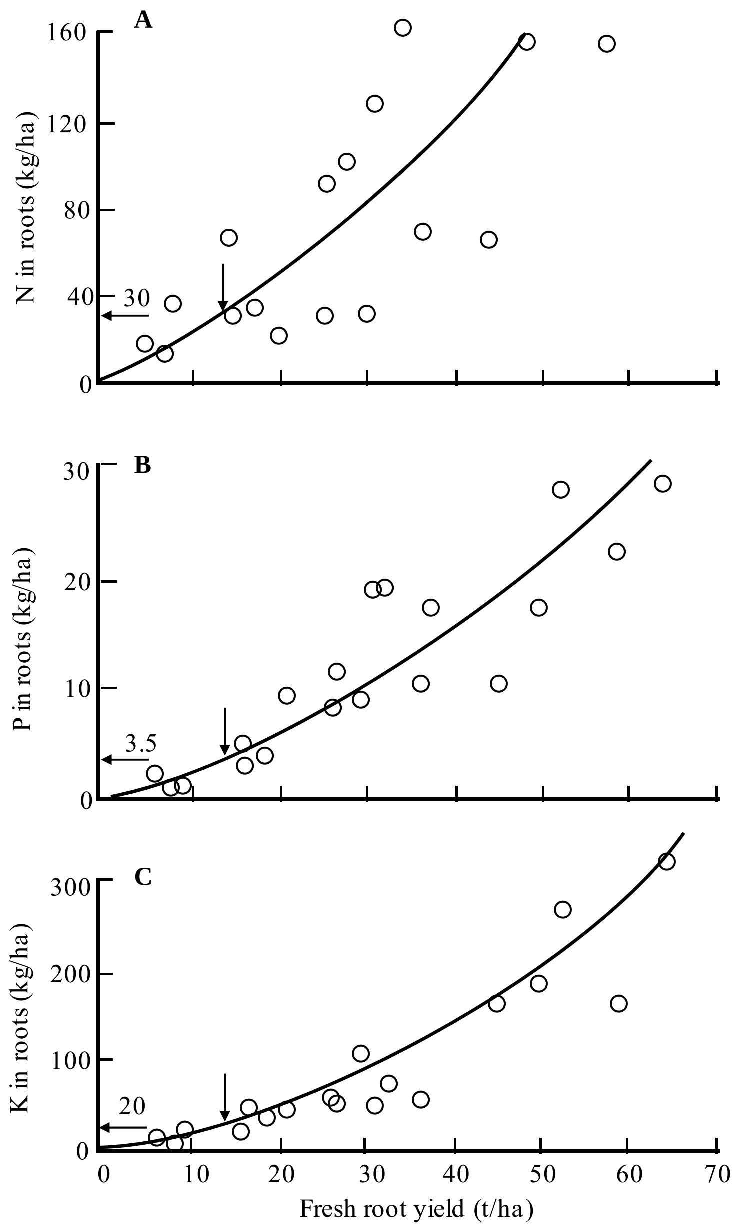

Figure 3. Relation between the amounts of N, P and K in cassava roots and the fresh root yields ,as reported by various sources in the literature. Arrows indicate the approximate nutrient contents corresponding to a fresh root yield of 15 t/ha. ***Source:*** *Howeler, et al., 2000.*

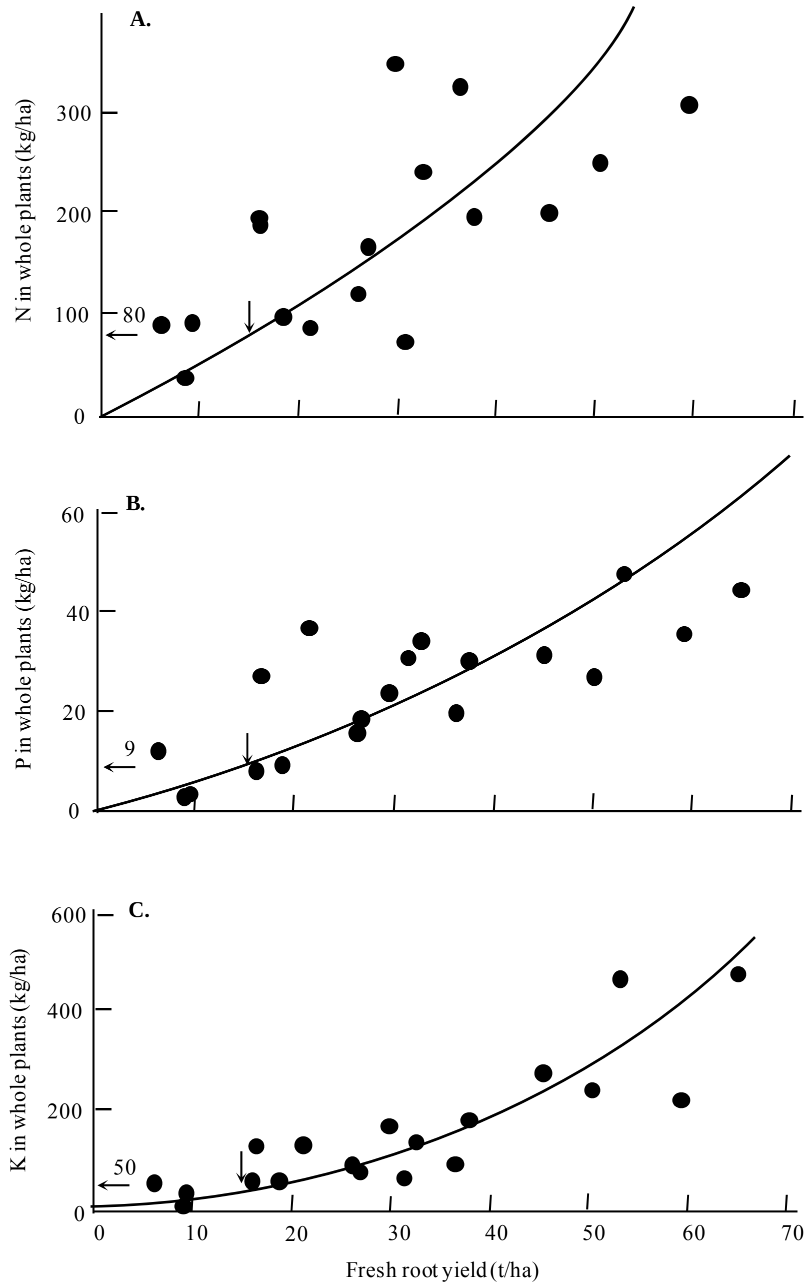

Figure 4. Relation between the amounts of N, P and K in the whole cassava plant at time of harvest and the fresh root yields, as reported by various sources in the literature. Arrows indicate the approximate nutrient contents corresponding to a fresh root yield of 15 t/ha.
Source: *Howeler et al., 2001.*

However, nutrients lost by crop removal, volatilization, leaching or erosion need to be replaced through the application of fertilizers, animal manures or through biological N-fixation.

b. Application of NPK fertilizers

Numerous short- and long-term fertilizer trials have been conducted to determine the optimum rates of application of N, P or K to produce maximum yields or maximum net income in a particular soil or region. Optimum rates of N, P_2O_5 and K_2O in kg/ha, as reported by researchers in various countries in Asia, are shown in **Table 5**.

Table 5. Optimum fertilizer applications for cassava production in various locations, soils and systems in Asia.

Location/Soil/System	N: P_2O_5: K_2O (kg/ha)	Reference
in Nanning, Guangxi, China	100:50:100	Zhang Weite *et al*., 1998
in CATAS, Danzhou, Hainan, China	200:100:200	Zhang Weite *et al*., 1998
in CTCRI, Thiruvananthapuram, Kerala, India	100:50:100	Susan John *et al*., 1998
for cassava monocrop in Tamanbogo, Lampung, Indonesia	90:25:45	Wargiono *et al*., 2001
in intercropped cassava in Tamanbogo, Lampung, Indonesia	90:50:90	Wargiono *et al*., 2001
in ViSCA, Baybay, Leyte, Philippines	60:90:60	Evangelio and Ladera, 1998
in Ubay, Bohol, Philippines	120:60:120	Evangelio *et al*., 1995
in La Granja, Negros Occidental, Philippines	100:50:100	Evangelio *et al*., 1995
in Hung Loc Center, Dong Nai, Vietnam	80:40:80	Nguyen Huu Hy *et al*., 1998
at Thai Nguyen Univ., Thai Nguyen, Vietnam	160:80:160	Nguyen Huu Hy *et al*., 1998
on mineral soils at MARDI in Serdang, Malaysia	60:30:160	Chan, 1980
on peat soils in Johor, Maysia	50:30:40	Tan, 2001
for most cassava soils in Thailand	100:50:50	Sittibusaya *et al*., 1995
in Khon Kaen with tops incorporated	50:50:50	Tongglum *et al*., 2001
for soils used continuous for cassava cultivation in Thailand	100-50-50	Sittibusaya *et al*., 1995
for Quartzipsamments (sandy loam Entisols) in Thailand	50-100:0:50-100	Ho and Sittibusaya (1984)
for Paleustults (sandy loam Ultisols) in Thailand	80-100:0-30:30-50	Ho and Sittibusaya (1984)

Most long-term fertilizer experiments have shown an increasing response to the application of N and K (**Table 6**), while many short-term on-farm fertilizer trials show an initial response mainly to N (Sittibusaya, 1993; Hagens and Sittibusaya, 1990; Sittibusaya and Karamarohita, 1978). In very general terms it is recommended to fertilize cassava with N-P_2O_5-K_2O ratios of 2:1:2 or 2:1:3. However, optimum fertilizer rates depend on soil fertility which can vary greatly from field to field. Thus, specific recommendations should be based on soil analyses results, supplemented with analyses of youngest-fully-expanded leaf (YFEL) blades taken at 3-4 months after planting. Critical levels for each nutrient in soil and YFEL-blades have been reported (Howeler, 2001a), and from those an approximate classification of the nutritional status of soils and YFEL-blades for cassava production has been developed, as shown in **Tables 7** and **8**. These tables can be used as a general guide in the interpretation of soil and plant tissue analyses results, and to diagnose nutritional deficiencies or toxicities.

Table 6. Response of cassava to annual application of N, P or K after several years of continuous cropping in long-term fertility trials conducted in various locations in Asia.

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

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

Source: *CIAT, 1998a.*

Table 7. Approximate classification of soil chemical characteristics according to the nutritional requirements of cassava.

Soil parameter	Very low	Low	Medium	High	Very high
pH[1]	<3.5	3.5-4.5	4.5-7.0	7.0-8.0	>8.0
Organic matter[2] (%)	<1.0	1.0-2.0	2.0-4.0	4.0-8.0	>8.0
Al saturation[3] (%)			<75	75-85	>85
Salinity (mS/cm)			<0.5	0.5-1.0	>1.0
Na saturation (%)			<2	2-10	>10
P[4] (µg/g)	<2	2-5	5-20	20-50	>50
K[4] (meq/100 g)	<0.10	0.10-0.15	0.15-0.25	>0.25	
Ca[4] (meq/100 g)	<0.25	0.25-1.0	1.0-5.0	>5.0	
Mg[4] (meq/100 g)	<0.2	0.2-0.4	0.4-1.0	>1.0	
S[4] (µg/g)	<20	20-40	40-70	>70	
B[5] (µg/g)	<0.2	0.2-0.3	0.3-1.0	1-2	>2
Cu[5] (µg/g)	<0.1	0.1-0.2	0.2-1.0	1-5	>5
Mn[5] (µg/g)	<5	5-10	10-100	100-250	>250
Fe[5] (µg/g)	<1	1-10	10-100	>100	
Zn[5] (µg/g)	<0.5	0.5-1.0	1.0-5.0	5-50	>50

[1]pH in H_2O.
[2]OM = Walkley and Black method.
[3]Al saturation = 100 x Al(Al+Ca+Mg+K) in meq 100 g^{-1}.
[4]P in Bray II; K, Ca, Mg and Na in 1N NH_4-acetate; S in Ca phosphate.
[5]B in hot water; and Cu, Mn, Fe and Zn in 0.05 N HCl+0.025 N H_2SO_4.

Source: *modified from Howeler, 1996a; 1996b.*

Table 8. Nutrient concentrations in YFEL blades of cassava at 3-4 MAP, corresponding to various nutritional states of the plants; data are averages of various greenhouse and field trials.

	Nutritional states[1]					
Nutrient	Very deficient	Deficient	Low	Sufficient	High	Toxic
N (%)	<4.0	4.1-4.8	4.8-5.1	5.1-5.8	>5.8	-[2]
P (%)	<0.25	0.25-0.36	0.36-0.38	0.38-0.50	>0.50	-
K (%)	<0.85	0.85-1.26	1.26-1.42	1.42-1.88	1.88-2.40	>2.40
Ca (%)	<0.25	0.25-0.41	0.41-0.50	0.50-0.72	0.72-0.88	>0.88
Mg (%)	<0.15	0.15-0.22	0.22-0.24	0.24-0.29	>0.29	-
S (%)	<0.20	0.20-0.27	0.27-0.30	0.30-0.36	>0.36	-
B (µg/g)	<7	7-15	15-18	18-28	28-64	>64
Cu (µg/g)	<1.5	1.5-4.8	4.8-6.0	6-10	10-15	>15
Fe (µg/g)	<100	100-110	110-120	120-140	140-200	>200
Mn (µg/g)	<30	30-40	40-50	50-150	150-250	>250
Zn (µg/g)	<25	25-32	32-35	35-57	57-120	>120

[1] Very deficient = <40% maximum yield
Deficient = 40-80% maximum yield
Low = 80-90% maximum yield
Sufficient = 90-100% maximum yield
High = 100-90% maximum yield
Toxic = <90% maximum yield

[2] - = no data available

Source: *Howeler, 1996a; 1996b.*

c. Time and method of fertilizer application

Most researchers in Asia recommend the full application of P at time of planting while N and K should be split at planting and at 30 DAP; or alternatively, all fertilizers should be applied at 30 DAP. Zheng Xueqin *et al* (1992) reported highest yields with the application of all fertilizers at 30 DAP, or split at 30 and 90 DAP. In India, however, Mandal *et al* (1971) reported best results with application of all N and K at or shortly after planting, while Mohankumar *et al*. (1971) reported best results with ½ of K applied at planting and ½ at 1 MAP. In the Philippines there were no significant differences between various split applications between 0 and 2 MAP; the highest yield was obtained with all P and K applied at planting, and N split at planting and 30 DAP (Abenoja, 1978). Few studies in Asia have included a treatment with all NPK applied at planting, but in Latin America no significant differences were found between applying all three nutrients at planting and applying all P at planting and N and K split at 0, 1 and 2 MAP (CIAT, 1977; 1978).

In general, slow release fertilizers, such as lime, manures, rock phosphates and fused Mg-phosphate should be broadcast and incorporated before planting, while highly soluble fertilizers should be band applied at planting or shortly after planting. Early application is especially essential for P since small cassava plants can not yet rely on a mycorrhizal association for P uptake. Early application of N and K will result in rapid canopy cover, which will reduce weed competition and erosion.

d. Application of organic manures

Cassava farmers in many countries apply farm-yard manure (FYM), either alone or in combination with chemical fertilizers, to maintain or improve soil fertility. Thus, CTCRI in India recommends the application of 12 ½ t/ha of manure in combination with N, P and K fertilizers (Susan John *et al*., 1998), while in the Philippines an application of 10 t/ha of chicken manure and in Vietnam 5-10 t/ha of pig manure are recommended. Lower rates, ranging from 1.3 t/ha of chicken manure to 4.4 t/ha of cow manure, could not maintain soil fertility, especially K, and cassava yields declined during six cropping cycles (Quirol and Amora, 1987). In north Vietnam farmers obtained highest yields and net income with the application of 10 t/ha of pig manure in combination with 80 kg N and 80 K_2O/ha (Nguyen The Dang *et al*., 1998).

While animal manures may contribute to improving the soil's physical conditions and are an important source of Ca, Mg, S and micronutrients, they contain only low and highly variable amounts of N, P and K (**Table 9**). As a rough comparison, one 50 kg bag of 15-15-15 chemical fertilizers contains about the same amounts of N, P and K as one tonne of wet pig manure. Large applications of manure are probably economical only in areas where the manure is locally available; otherwise, transport and application costs may be higher than the cost of chemical fertilizers. Where available, a combination of 5-10 t/ha of manure with 50-80 kg/ha of N and K_2O is probably adequate to maintain soil fertility and high yields. However, if leaves and stems are also removed from the field, then higher rates of N, P and K (especially N) are recommended.

Table 9. Average nutrient contents of various manures, composts and wood ash.

Source of manure	Moisture (%)	N	P	K (% of dry matter)	Ca	Mg	S
Cattle manure	68.2	1.85	0.81	1.69	1.54	0.62	0.29
Pig manure	60.0	2.04	1.38	1.38	-	-	-
Chicken manure	43.0	2.91	1.37	1.54	4.56	0.83	-
Sheep manure	-	3.00	0.62	2.68	1.72	0.86	0.43
Human manure	-	1.20	0.06	0.21	-	-	-
City/rural compost	-	1.16	0.37	0.90	-	-	-
Rice straw compost	73.7	1.07	0.19	0.69	-	-	-
Peanut stems + leaves compost	58.6	0.81	0.10	0.38	-	-	-
Water hyacinth	-	2.00	1.00	2.30	-	-	-
Wood ash	-	-	0.87	4.17	23.2	2.10	0.40

Source: *Howeler, 2001b.*

e. Green manures and alley cropping

Many experiments have been conducted on the use of green manures to maintain soil fertility (Tongglum *et al*., 1992; 1998; Nguyen Huu Hy *et al*., 1998; 2001; Thai Phien and Nguyen Tu Siem, 1998; Mohankumar and Nair, 1996) using mainly forage or grain legumes to be incorporated before planting cassava, or leguminous shrub legumes in alley cropping systems. **Table 10** shows the results of a recent experiment in Thailand in which green manures were either intercropped at planting and cut and mulched at 45-60 DAP; interplanted at 6-7 MAP cassava and incorporated before the next crop; or planted as a normal green manure crop and incorporated before planting cassava, the latter being harvested after 18 months for a 2-year crop cycle. The last method was more productive than the first two, but application of chemical fertilizer was still more productive. Since most farmers in Asia can not afford to use their limited land for an unproductive green manure crop, green manuring or alley cropping has not been adopted anywhere, except for the use of *Tephrosia candida* as an erosion control barrier *cum* alley crop in north Vietnam. Most farmers opt for the use of animal manures or chemical fertilizers.

Table 10. Effect of three ways of planting four green manure species on the yield of cassava, Rayong 90, planted during three cropping cycles at Rayong Field Crops Research Center, Rayong, Thailand from 1994 to 1999[1].

Treatments[1]	Cassava root yield (t/ha)				
	1st cycle	2d cycle	3d cycle	Av.	Σ5 years[2]
1. Cassava without GM, 156 kg/ha 13-13-26	17.56	30.06	14.39	20.67	103.3
2. Cassava without GM, 467 kg/ha 13-13-26	29.78	40.39	21.42	30.53	152.6
3. C+*Crot. juncea,* cut at 1½-2 months	23.75	29.19	14.02	22.32	111.6
4. C+*Canavalia,* cut at 1½-2 months	26.94	27.75	15.50	23.40	117.0
5. C+pigeon pea, cut at 1½-2 months	21.39	26.97	14.47	20.94	104.7
6. C+*Mucuna,* cut at 1½-2 months	20.28	18.75	11.31	16.78	83.9
7. C+*Crot. juncea,* planted at 6-7 months	8.75	31.44	14.97	18.39	91.9
8. C+*Canavalia*, planted at 6-7 months	22.83	24.17	12.94	19.98	99.9
9. C+pigeon pea, planted at 6-7 months	15.86	28.81	14.27	19.65	98.2
10. C+*Mucuna,* planted at 6-7 months	17.25	27.02	14.77	19.68	98.4
11. *Crot. juncea* GM, cut at 2-3m, C 18 months	46.17	49.04	36.94	44.05	132.1
12. *Canavalia* GM, cut at 2-3m, C 18 months	42.98	43.81	34.14	40.31	120.9
13. pigeon pea GM, cut at 2-3m, C 18 months	38.81	45.97	37.00	40.59	121.8
14. *Mucuna* GM, cut at 2-3m, C 18 months	38.86	46.32	30.22	38.47	115.4

[1]C = cassava; GM = green manure
T_1-T_{10} were planted annually from 1994/95 to 1996/97, while T_{11}-T_{14} were planted in three 21-month cycles from 1994/96 to 1997/99.
[2]for T_1-T_{10} estimated from the average yields in the first three years; for T_{11}-T_{14} actual yields during the three crop cycles completed in slightly over five years.
Source: *CIAT, 2000.*

f. Mycorrhizal inoculation

Cassava grows well on low-P soils and usually does not respond much to P applications because of a very efficient symbiosis with VA-mycorrhizal fungi occurring in nearly all natural soils. Soon after germination and root formation, the fibrous roots become infected with vesicles, arbuscules and hyphea of mycorrhiza. These hyphae grow into the soil and play an important function in the transport and uptake of P (and Zn) into the roots. Since practically all natural soils have a native mycorrhizal population, there is seldom a need to inoculate with more effective VAM species. In Asia a significant response to VAM inoculation has only been reported by Potty (1988), who found that VAM inoculation increased yields when stakes were germinated in moist sand in the nursery before transplanting in the main field.

g. Application of lime, Mg, S and micronutrients

Cassava is extremely tolerant of soil acidity (Howeler, 1991b). Thus, in most cassava growing areas the crop does not respond to the application of lime (Pardales *et al*., 1984, Ramos and Mosica, 1982). Nevertheless, Mohankumar and Nair (1985) reported a significant response to liming up to a level of 3.5 t $CaCO_3$/ha in an experiment conducted at CTCRT. Similarly, Tan and Chan (1995) reported a significant response to application of 3 t/ha of lime on very acid peat soils in Johor, Malaysia. In many cases this is a response to Ca rather than the neutralizing effect of lime. High applications of lime can also have a detrimental effect by inducing Zn deficiency in soils with a low available Zn content (Howeler, 2001a).

In many low organic matter (OM) sandy soils cassava has shown symptoms of Mg deficiency, especially when only chemical fertilizers are applied. In that case an application of 20-40 kg Mg/ha as band applied $MgSO_4$ or fused Mg-phosphate can eliminate the symptoms and increase yields.

In Asia responses to S and micronutrient applications have been observed only in India, where Nair and Mohankumar (1980) reported a significant response to 12.5 kg Zn/ha, 1.0 kg Mo/ha and 10 kg B/ha, applied as zinc sulfate, ammonium molybdate and borax, respectively, while Mohankumar and Nair (1985) also reported a significant response to application of 50 kg S/ha in an acid lateritic soil of CTCRI. In addition, Chew *et al*. (1978) reported a significant response to application of 10-15 kg $CuSO_4.7H_2O$/ha in peat soils of Malaysia.

Symptoms of Fe or Zn deficiency are commonly observed in caleareous soils, such as in Tamil Nadu, southern Java, and the central part of Thailand. Zinc deficiency can be controlled with a stake dip for 15 min in a 2.0% solution of $ZnSO_4.7H_2O$ before planting, with a foliar spray of 1% $ZnSO_4.7H_2O$, or by band application of 10 kg Zn/ha as $ZnSO_4.7H_2O$. There are no reports of a significant responses to the application of Fe, but foliar sprays or a stake dip in 4% $FeSO_4.7H_2O$ may solve the problem. Large varietal differences in tolerance to Fe and Zn deficiency have been observed, and a change of variety may be a more practical solution than micronutrient applications.

6. Erosion Control

During the past decade numerous erosion control experiments have been conducted on experiment stations as well as in FPR trials on farmers fields. Most experiments showed that soil losses due to erosion can be marked reduced by zero tillage, contour ridging (Jantawat *et al*., 1994) or staggered mounds (Kabeerathumma *et al*., 1996), closer plant spacing, intercropping, mulch application (Evangelio and Ladera, 1998), fertilization and planting contour hedgerows of grasses, such as vetiver grass, lemon grass, elephant grass, *Paspalum atratum, Brachiaria brizantha (*Garrity *et al*., 2000), or legumes, such as *Arachis pintoi, Chamaecrista rotundifolia, Gliricidia sepium, Leucaena leucocephala* or *Calliandra* *calothyrsus* (Utomo *et al*., 1998). Some of these practices have long been adopted by farmers, such as intercropping in Indonesia, staggered mounds and bunds in Kerala, and closer plant spacing and fertilizer or manure application in many areas. Contour ridging is sometimes applied on gentle slopes, but up-and-down ridging is more common, especially in areas where land is prepared by tractor. Mulching has been shown to be highly effective (Evangelio, 2001) but is seldom practiced as mulching material is often not available and/or its transport is too labor intensive. Planting of contour hedgerows to control erosion is seldom practiced as it requires additional labor for planting and maintenance, it takes part of the land out of production and the hedgerows may compete with nearby crop plants. Moreover, in areas where land is prepared by tractor, contour hedgerows interfere with the commonly used practice of up-and-down tillage in straight lines. In the Claveria area of northern Mindanao, Philippines, farmers have accepted the use of contour strips of natural grasses (weeds) to control erosion (Fujisaka, 1998) as that requires less inputs in planting and maintenance, provides some cut-and-carry fodder for cattle, and does not interfere with carabao plowing.

In order to make farmers aware of the problem of soil erosion and the need for better soil conservation practices, it is important to conduct simple demonstrations and on-farm erosion control trials followed by farmer participatory research (FPR). These trials show farmers first of all the extent of soil loss due to erosion on their own land, and secondly, various alternative practices that can markedly reduce erosion. When farmers do their own FPR trials (in collaboration with researchers and/or extensionists), they realize that erosion may be a serious problem but that the practices they themselves tested and selected can be easily adopted to reduce erosion on their fields. This will enhance the adaption of soil conserving practices.

7. Weed Control

All farmers know that good weed control is essential for obtaining high crop yields. Most research conducted in Asia indicate that for cassava it is important to maintain the field weed free for at least the first three months after planting. In most countries weeds are controlled by hand weeding with a hoe, 2-3 times during the first 3 MAP. In parts of the Philippines this is done with a *bolo* and in Indonesia and Tamil Nadu of India with a short-handled hoe. Hand weeding may require between 25 (Thailand) and 100 mandays (Tamil Nadu) (Howeler, 1988). With the use of oxen or carabao labor use for weeding may be reduced to about 10 mandays/ha. In the Philippines it is recommended (Villamayor and Reoma, 1987) to use a carabao for off-barring at 2 weeks after planting (WAP) followed by hand weeding within the row at 3 WAP and hilling up at 5 and 7 WAP.

Research on chemical weed control has been limited to Malaysia, Thailand, South Vietnam and Lampung of Indonesia. In Malaysia the recommended practice is to use a pre-emergence mixture of 2 liters alachlor + 2 kg fluometuron/ha, followed by post-emergence control by hand weeding or directed spray of 2 liters/ha of paraquat and a pre-harvest spray of 2 liters/ha of paraquat (Tan, 1988).

In Lampung, Indonesia, best results were obtained with the application of a mixture of paraquat and diuron (3.75 l/ha) at 30 DAP (Bangun, 1990). Research in Thailand indicated best results with the pre-emergence application of 1.56 kg a.i./ha of metolachlor with or without post-emergence spraying with paraquat (0.5 kg a.i./ha) or with fluazifob-butyl (0.38 kg a.i./ha). This produced similar yields and resulted in similar weeding costs as twice cultivation with bullocks followed by spot treatment with paraquat (0.5 kg a.i./ha) (Tirawatsakul *et al*., 1988). Similarly, in south Vietnam best results were obtained with application of pre-emergence metolachlor (2.4 l/ha) (Nguyen Huu Hy *et al*., 2001). An alternative to paraquat is the application of glyphosate (1.5 kg a.i./ha) for post-emergence control of weeds. In all cases, it is recommended to use a shield on the sprayer to prevent damage of cassava plants.

8. Pruning

Research in some countries has indicated the benefit of removing excess stems, leaving only the two strongest stems per plant (Mandal *et al*., 1973; Wargiono and Sumaryono, 1981). Others report that the pruning of older leaves (Sugito, 1990) or young leaves (topping) at 2 MAP (Arana, 1979) improved yields. Others reported significant yield reductions due to pruning (Villamayor and Labayan, 1982; Evangelio and Ladera, 1998). The prunings can be used (after drying or ensiling) for animal feed.

9. Irrigation

Irrigation of commercial cassava fields is practiced only in Tamil Nadu, India. Experiments at CTCRI in Kerala, India indicate that highest yields were obtained when cassava was irrigated at a rate equivalent to cumulative pan evaporation (Nayar *et al*., 1985). The crop should be irrigated whenever the available soil moisture content drops below 75% (CTCRI, 1984). Similarly, Pardales and Esquivel (1996) found that plant development was reduced if the available moisture content dropped below 80% of field capacity, especially during the first 3 MAP.

10. Intercropping

Intercropping cassava with upland rice, maize and grain legumes is a common practice in Indonesia, while intercropping with maize is common in the Philippines and in some provinces of south Vietnam (**Table 2**). Intercropping with peanut is more common in north Vietnam and China, while vegetables are a profitable intercrop in Tamil Nadu of India. Intercropping is not practiced much in Kerala, Malaysia or Thailand, except for intercropping cassava in young rubber or old coconut plantations. Similarly, cassava is often grown among recently planted cashew nut trees in South Vietnam and among young fruit trees in north Vietnam. On good soils in Guangxi province of China cassava is sometimes intercropped with watermelon, which is planted in plastic mulch during the winter, while cassava is planted two months later. Numerous intercropping experiments have been conducted in Thailand, Indonesia, Vietnam and the Philippines. In Thailand, intercropping widely-spaced (1.25 x 0.8 m) cassava with two rows of either peanut or mungbean, spaced at 20 x 10 cm, was found to be most productive (Tongglum *et al*., 1988). The highest Land Equivalent Ratio (LER) was obtained with a cassava spacing of 1.80 x 0.55 m intercropped with three rows of mungbean, but the highest gross income was obtained with peanut planted at the same plant spacing (Tongglum *et al*., 1992). Intercropping with muskmelon, cucumber and pumpkin, can also be highly profitable (Tongglum *et al*., 1998) but also quite risky as either too much or too little rain can lead to crop failure. Long-term intercropping trials in Thailand have shown that intercropping with sweetcorn was by far the most profitable (Tongglum *et al*., 2001); a similar result was obtained in Malaysia (Tan, 1988).

In north Vietnam, Le Sy Loi (2000) reported highest gross and net income by intercropping cassava with peanut, planted at the same time as cassava, in two rows between cassava rows spaced at 1x0.8 m. This also markedly reduced erosion. Similarly, in Indonesia, Wargiono *et al*. (1998) reported that intercropping cassava with upland rice and maize followed by grain legumes resulted in the highest total crop value and low levels of erosion (Wargiono, 2001). In India, intercropping with French bean or vegetable cowpea was found to be most profitable (Gosh *et al*., 1987; Mohankumar and Ravindran, 1991), because their early harvest caused little reduction in cassava yields.

Since cassava is usually widely spaced and has slow initial development, intercropping at the early stage of crop development is highly feasible and usually results in higher total income and less erosion. However, cassava is a poor competitor and can easily be shaded out by tall intercrops like maize, or suffer from nutrient and/or water competition from intercrops that are planted too closely to the cassava row; cassava yields can also be seriously affected if the intercrop competition extends beyond 2 ½-3months, as is often the case with field maize. Thus, intercropping cassava with many other crops is feasible, but the most suitable crop combinations depends on the soil and climatic conditions, the varieties used, the availability of labor, and on market conditions.

AREAS REQUIRING FURTHER RESEARCH AND POLICY INITIATIVES

In the past, most agronomists have aimed at developing new crop and soil management practices that would maximize yields or net income for the farmer. However, in an era of globalization and removal of international trade barriers one also has to consider the crop's competiveness, not only *vis a vis* cassava grown in other countries but also with other crops which have similar end uses, such as maize and coarse grains for animal feed, maize and potato for starch and its derivatives, wheat for bakery products and sugarcane or molasses for sweeteners, MSG and alcohol production. To remain competitive farmers not only need to produce high yields but also at a low cost, so that the cost of production per tonne is low, resulting in a low-cost raw material for the various processing industries. **Table 11** compares the cost of production of cassava in various countries in Asia, using the latest and most complete data available. From this table it is clear that Thai cassava remains the most competitive on the world market due to the lowest cost of production per tonne and low profit margins for cassava farmers. This has been achieved through the widespread use of high-yielding varieties (Sarakarn *et al*., 2001) and low-cost production practices that limits labor and purchased inputs. In contrast, in spite of exceptionally high yields obtained in Tamil Nadu and the lowlands of Kerala, India, the cost of production per tonne is 2-3 times higher than in Thailand due to the use of extremely labor-intensive practices, the high cost of fertilizers and a very high cost of land.

Thus, for cassava to remain a remunerative crop for farmers as well as competitive in world markets (Hershey and Howeler, 2001), agronomist must develop cultural practices that increase yields *and* reduce costs, both labor costs and purchased input costs such as fertilizers, chemicals, fuel etc. Since much research on cassava cultural practices was conducted in the 1970s, using the then prevalent varieties, under quite different economic circumstances, it is recommended to review or repeat some of this research using the new high-yielding varieties and including economic as well as statistical analyses of the results. Some areas that warrant particular attention are:

Table 11. Cassava production costs (US $ /ha) and profitability in various countries in Asia in 1998-2000.

	China[1)]	India[2)]	Indonesia[3)]	Philippines[4)]	Thailand[5)]	Vietnam[6)]
Labor Costs ($/ha)	***167.40***	***421.70***	***185.37***	***218.80***	***167.18***	***213.60***
Labor costs ($/manday)	1.86	1.29	1.11	2.00	3.24	1.78
-land preparation (mandays/ha)	*7.5*	*1.5*	*45*	*8.1*	*2.4*	*5*
-preparation planting material	-	*1.9*	*5*	-	-	*5*
-planting	*15.0*	*14.8*	*15*	*9.4*	*9.1*	*10*
-application fert. and manures	*5.0*	*10.7*	*12*	*2.5*	*6.4*	*5*
-application other chemicals	-	*0.3*	-	-	-	-
-irrigation	-	*51.9*	-	-	-	-
-weeding and hilling up	*40.0*	*208.6*	*40*	*26.9*	*8.0*	*40*
-harvesting (includes loading)	*22.5*	*37.2*	*50*	*37.5*	*25.7*	*55*
-transport and handling	-	-	-	*25.0*	-	-
Total (mandays/ha)	*90.0*	*326.9*	*167*	*109.4*	*51.6*	*120*
Other Costs ($/ha)	***260.22***	***242.15***	***80.55***	***163.25***	***198.73***	***171.07***
-Fertilizers and manures	130.11	159.39	79.44	53.75	61.97	80.36
-Planting material	-	26.83	1.11	25.00	-	-
-Other materials (herbicides, sacks)	37.17	2.23	-	20.00	25.84	-
-Transport of roots	-	-	-	-	70.38	-
-Land preparation by tractor	92.94	53.70	-	64.50	40.54	90.71
Total Variable Costs ($/ha)	**427.62**	**663.85**	**265.92**	**382.05**	**365.91**	**384.67**
-Land rent and/or taxes	94.94	236.50	46.67	-	48.89	60.00
Total Production Costs ($/ha)	**520.56**	**900.35**	**312.59**	**382.05**	**414.80**	**444.67**
Yield (t/ha)	20	40	20	25	23.40	25
Root price ($/t fresh roots)	29.74	38.00	17.78	25.00	21.62	21.42
Gross income ($/ha)	294.80	1,520.00	355.60	625.00	505.91	535.50
Net income ($/ha)	74.24	619.65	43.01	242.95	91.11	90.83
Production costs ($/t fresh roots)	26.03	22.51	15.63	15.28	17.73	17.79

Sources: [1)]Tian Yinong for Guangxi, China
[2)]Srinivas, 2001; for irrigated cassava in Tamil Nadu, India
[3)]J. Wargiono for monoculture cassava in Lampung, Indonesia
[4)]Bacusmo, 1999; for monoculture cassava in the Philippines
[5)]Adapted from TTDI, 2000; average of 527 advanced farmers in Thailand
[6)]Farmers estimate for monoculture cassava in Dongnai province of Vietnam

Note: for more detailed information, see Appendix 1, Tables 1-6.

1. Weed control: weeding requires between 20 and 200 mandays/ha, making it one of the most costly cultural practices. Use of bullocks or hand tractors for intercrultivation, use of herbicides – especially pre-emergence herbicides which are presently hardly used at all – and intercropping, mulching or planting in the dry season, may all reduce weeding costs. Moreover, weeding after 3 MAP may not be necessary. The future deployment of herbicide resistant varieties may make the use of herbicides more cost-effective.

2. Fertilization: most cassava farmers apply between 5 and 10 tonnes of manure per ha, because it is available on the farm and thus considered free. Still, there is an opportunity cost to manure, as this input could also be applied to other crops, vegetables or fruit trees. Moreover, transport and application of manures require 10-20 times more labor than that of chemical fertilizers. While more and more farmers are now applying chemical fertilizers, they often apply too much (India, Malaysia) or the incorrect balance of N, P and K (Thailand, Vietnam, Indonesia). Both short- and long-term fertilizer trials have established without doubt the need for annual application of N and K, while P applications can be drastically reduced or applied less frequently. The challenge is to convince farmers, who traditionally have applied mainly N and P. This can best be done through on-farm and farmer participatory research (FPR), emphasizing not only yield but also economic returns to various fertilization practices. Similarly, farmers should be shown that fertilizers are most effective when applied at the early stage of the crop cycle.

Presently, few countries have a well-functioning soil testing service for farmers. Since soil fertility can vary markedly from field to field, accurate and economically optimum fertilizer recommendations can only be made based on soil test results. Fertilizer use efficiency could be improved and costs reduced if farmers had access to an efficient soil testing service, which would also have to be able to make cost-effective fertilizer recommendations. Moreover, governments have to make sure that a variety of compound fertilizers are available on the market, so farmers can purchase those that are most suitable for the crop and their particular soil.

3. Land preparation: presently, most cassava farmers prepare their land by 2-3 passes of a tractor- or bullock-drawn plow; in Kerala state of India and Java island of Indonesia it is mostly done by hand, requiring much input of labor. Plowing the soil with a tractor-mounted 3- and 7-disc plow leaves the soil surface smooth and clean, but also results in hardpan formation at the plow sole, which inhibits drainage, causing poor growth, root rots and excessive runoff and erosion. Moreover, the turning over of soil exposes soil organic matter to high temperatures and rainfall, resulting in rapid decomposition of soil OM. To counter these soil degrading effects of conventional land preparation practices, effective and efficient methods of "conservation tillage" must be developed; this probably requires a combination of minimum tillage with a chisel plow and the use of herbicides, both pre-emergence and post-emergence.

4. Harvesting: harvesting requires between 20 and 40 mandays per ha, and with transport of the roots constitutes a major part of production costs. The efficiency of harvesting depends a lot on the soil texture and moisture conditions, on weeds and the depth and the shape of roots. Selection of varieties with a compact root mass will facilitate the harvest. A well-developed crop that has outshaded weeds is also easier to harvest than a poorly established and/or maintained crop. Harvest costs may be further reduced with the use of a tractor-mounted implement that digs under the roots, loosening the soil and pushing the roots to the soil surface, where they can be easily collected.

5. Planting: while cassava planting can be mechanized, as done in parts of Brazil and Colombia, manual planting is still practiced throughout Asia (even in large plantations) as it does not require excessive hand labor. Experienced planting crews in Thailand can cut the stakes and plant in perfectly straight lines using only 8 mandays per ha. In large plantations, the cutting of stakes with a motorized saw may be justified.

6. Cassava for leaf production: it has long been known that cassava leaves are high in protein with a favorable balance of amino-acids. In spite of having a high content of cyanogens, they can be used for animal feeding after proper drying or ensiling. Numerous feeding trials with pigs, poultry, dairy and beef cattle have shown good results. Since cassava roots are high in carbohydrates and their leaves are high in protein, the combined use of dry cassava root and leaf powder (together with some minerals and vitamins) in commercial animal feed rations should be further investigated. Since in the past, cassava breeders have concentrated on the development of high harvest index varieties to maximize root production, these varieties may not necessarily be the best for high leaf protein production. Thus, new varieties may need to be developed for this purpose. Similarly, plant spacing, fertilization and pruning times and methods need to be optimized in order to obtain high leaf and protein yields at a low cost. If this can be achieved, cassava leaves in combination with roots may be able to enter the low-cost animal feed rations in many Asian countries, which presently spend foreign exchange for the importation of maize and soybeans. To realize this possibility will require a concerted effort among cassava agronomists and breeders, animal nutrition specialists and the private animal feed sector. It may also require government intervention and changes in importation policies so that cassava farmers may at least enjoy the same privileges presently extended to many maize, sugarcane and soybean farmers. Through this combined effort, the crop could become truly competitive on the world or domestic market as a highly efficient producer of both carbohydrates and proteins.

CONCLUSIONS

Much research on cassava cultural practices have been conducted over the past 20-30 years in many Asian countries. Optimum practices to increase yields have been identified and recommended to farmers. A constraints analysis conducted in 1996, indicate that Asian researchers estimate that improved soil and crop management combined could increase current cassava yields by 56%; this is much greates than the potential yield increase expected from better varieties or pest and disease control (Henry and Gottret, 1996; Van Norel, 1997). To what extent cassava agronomy research has led to adoption by farmers is difficult to gauge. No doubt much information has reached farmers and many recommended practices on methods of land preparation, planting, weeding and fertilization have been adopted by farmers. Still, the transfer of technology remains the weak link in the chain between technology development and adoption. More research conducted on-farm and with full farmer participation and decision making will enhance not only the relevance and quality of the research, but also the adaptation and adoption by farmers. Since both the biophysical and socio-economic conditions of cassava farmers are extremely diverse, the practices that have been developed by researchers on experiment stations need to be verified on-farms and with farmers, in order to make the necessary adaptations to the unique environment of each site. Only when farmers are empowered to participate in this research and make their own decisions will the research results be truly relevant to their conditions and adapted to their needs. Once farmers feel confident that they themselves contributed to the development of the technology, the adoption of the technology will follow naturally. To facilitate this process, the research and extension organizations at various levels should work in partnership with each other and with the farmers. There are hopeful signs that this is already happening in many countries in Asia, particularly in Thailand and Vietnam, but more needs to be done to institutionalize the participatory approach in order to achieve greater adoption of improved practices to the benefit of cassava farmers.

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Appendix 1.

Table 1. Cassava production costs (US $/ha) in China in 2000/01.

	Guangxi[1)]	Hainan[2)]	Kongba village, Hainan[3)]
Labor Costs ($/ha)	***167.40***	***339.45***	***232.50***
-Labor costs ($ /manday)	1.86	1.86	1.86
-land preparation (mandays/ha)	*7.5*	*45.0*	*26.0*
-preparation planting material	-	*2.5*	-
-planting	*15.0*	*15.0*	*6.0*
-application manures	-	-	-
-application fertilizers	*5.0*	*15.0*	*5.0*
-application other chemicals	-	-	-
-irrigation	-	-	-
-weeding	*40.0*	*60.0*	*41.0*
-harvesting (includes loading)	*22.5*	*45.0*	*32.0*
-transport	-	-	*15*
Total (mandays/ha)	*90.0*	*182.5*	*125.0*
-Other Costs ($/ha)	***260.22***	***130.81***	***77.43***
-Fertilizers	130.11	55.76	38.78
-Planting materials	-	13.94	7.00
-Other chemicals (herbicide)	37.17	5.35	11.65
-Transport of roots	-	55.76	20.00
-Land preparation by tractor	92.94	-	-
Total Variable Costs ($/ha)	**427.62**	**470.26**	**309.93**
Land rent or tax ($/ha)	94.94	34.70	3.72
Total Production Costs ($/ha)	**520.56**	**504.96**	**313.65**
Yield (t/ha)	20	20	20
Root price ($/tonne)	29.74	29.74	29.74
Gross income ($/ha)	594.80	594.80	594.80
Net income ($/ha)	74.24	89.84	281.15
Production costs ($/tonne cassava roots)	26.03	25.25	15.68

[1)]Estimate by Tian Yinong
[2)]Estimate by Li Kaimian
[3)]Based on RRA in 1998.
1 US $ = 8.07 yuan in 2000/01

Appendix 1.

Table 2. Cassava production costs (US $/ha) in India in 2000/01.

	Tamil Nadu		Kerala	
	Irrigated	Rainfed	Upland	Lowland
Labor Costs ($/ha)	***421.70***	***226.69***	***336.70***	***387.42***
-Labor costs ($ /manday)	1.29	1.12	2.09	2.20
-land preparation (mandays/ha)	*1.5*	*1.9*	*64.8*	*74.2*
-preparation planting material	*1.9*	-	-	-
-planting	*14.8*	*18.0*	*10.7*	*9.9*
-application manures	*4.8*	*4.1*	*15.2*	*16.6*
-application fertilizers	*5.9*	*5.4*	*0.6*	*2.6*
-application other chemicals	*0.3*	*0.2*	*3.7*	*1.2*
-irrigation	*51.9*	-	-	*9.2*
-weeding	*208.6*	*132.8*	*37.4*	*38.8*
-harvesting	*37.2*	*40.0*	*28.7*	*23.6*
Total (mandays/ha)	*326.9*	*202.4*	*161.1*	*176.1*
Other Costs ($/ha)	***242.15***	***201.40***	***198.33***	***174.36***
-Manures	78.84	55.96	122.45	105.37
-Fertilizers	80.55	50.97	63.83	61.67
-Planting materials	26.83	21.50	10.36	4.59
-Other chemicals (plant protection)	2.23	0.24	1.69	2.73
-Land preparation by tractor	53.70	72.73	-	-
Total Variable Costs ($/ha)	**663.85**	**428.09**	**535.03**	**561.78**
Land rent ($/ha)	236.50	68.54	190.22	527.27
Total Production Costs ($/ha)	**900.35**	**496.63**	**725.25**	**1,089.05**
Yield (t/ha)	40	25	15	25
Root price ($/tonne)	38	33	76	87
Gross income ($/ha)	1,520.00	825.00	1,140.00	2,175.00
Net income ($/ha)	619.65	328.37	414.75	1,085.95
Production costs ($/tonne cassava roots)	22.51	19.87	48.35	43.56

1 US $ = 46 Rp in 2000/01.

Source: *Adapted from Srinivas, 2001.*

Appendix 1.

Table 3. Cassava production costs (US $/ha) in Indonesia in 2000/01.

	Monoculture (Lampung)[1]	Intercropped (E. Java)[1]	Intercropped (Ringinrejo village)[2]
Labor Costs ($/ha)	***185.37***	***414.75***	***218.67***
-labor costs ($ /manday)	1.11	1.11	1.11
-land preparation, hoeing (mandays/ha)	*40*	*55*	*44*
-land preparation, plowing	*5*	*6*	-
-preparation planting material	*5*	*5*	*5*
-planting	*15*	*28*	*23*
-application manures	*6*	*7*	*7*
-application fertilizers	*6*	*33*	*11*
-application herbicides/insecticides	-	*28*	*2*
-weeding + hilling up	*40*	*70*	*35*
-harvesting (includes loading)	*50*	*85*	*70*
-transport to house or market	-	-	-
Total (mandays/ha)	*167*	*317*	*197*
Other Costs ($/ha)	***80.55***	***152.36***	***93.05***
-Manure	35.00	50.00	50.00
-Fertilizers	44.44	55.00	24.72
-Planting materials	1.11	44.33	16.94
-Insecticides	-	1.56	1.39
-Herbicides	-	1.47	-
Total Variable Costs ($/ha)	**265.92**	**567.11**	**311.72**
Land rent ($/ha)	46.67	-	-
Total Production Costs ($/ha)	**312.59**	**567.11**	**311.72**
Yield -cassava (t/ha)	20	12	15
-maize (t/ha)	-	1.5	2.0
-rice (t/ha)	-	2.0	-
-soybean (t/ha)	-	0.5	-
Gross income ($/ha)[3]	355.60	690.68	377.80
Net income ($/ha)	43.01	123.57	66.08
Production costs ($/tonne cassava roots)	15.63	-	-

[1]Estimate by J. Wargiono
[2]Based on RRA in Ringinrejo village, Blitar, E. Java in 1998
[3]Prices: cassava $ 17.78/t fresh roots; maize $ 55.55/t dry grain; rice $100/t dry grain; soybean $388/t dry grain; labor costs for plowing =$2.77/day, herbicide application $ 3.00/day.
1US $ = Rp 9000 in 2000/01.

Appendix 1.

Table 4. Cassava production costs (US $/ha) in the Philippines in 1998/99.

	Monoculture	Intercropped with maize
1. Labor Costs ($/ha)	***218.80***	***425.60***
-Labor costs ($ /manday)	2.00	2.00
-land preparation	*8.1*	*8.1*
-planting	*9.4*	*11.2*
-application fertilizers/manures	*2.5*	*8.8*
-weeding	*18.8*	*37.5*
-cultivation	*8.1*	*10.0*
-harvesting	*37.5*	*56.2*
-shelling and drying of maize	-	*45.0*
-transport and handling	*25.0*	*36.0*
Total (mandays/ha)	*109.4*	*212.8*
Other Costs ($/ha)	***163.25***	***277.00***
-Fertilizers and chemicals	53.75	127.50
-Land preparation by tractor	64.50	64.50
-Planting materials	25.00	65.00
-Sacks	20.00	20.00
Total Variable Costs ($/ha)	**382.05**	**702.60**
Land rent ($/ha)	-	-
Total Production Costs ($/ha)	**382.05**	**702.60**
Yield - cassava (t/ha)	25	20
-maize (t/ha)	-	4.0
Gross income ($/ha)[1)]	625.00	1,100.00
Net income ($/ha)	242.95	397.40
Production costs ($/tonne cassava roots)	15.28	-

[1)]Prices: cassava $ 25.00/tonne fresh roots; maize $ 150/tonne dry grain
1 US $ = 40 Philpesos in 1998/99
Source: **Adapted from Bacusmo, 1999.**

Appendix 1.

Table 5. Cassava production costs (US $/ha) in Thailand in 1999/2000.

	Average all farmers[1)]	Average advanced farmers[2)]
1. Labor costs ($/ha)	***168.48***	***167.18***
-Labor costs ($ /manday)	3.24	3.24
-land preparation (mandays/ha)	*1.6*	*2.4*
-planting	*9.1*	*9.1*
-fertilizer application	*6.1*	*6.4*
-weeding	*14.0*	*8.0*
-harvesting	*19.4*	*25.7*
-loading	*1.8*	-
Total (mandays/ha)	*52.0*	*51.6*
Other costs ($/ha)	***125.68***	***198.73***
-Fertilizer and manures	20.23	61.97
-Planting meterials	26.66	-
-Herbicides and perticide	8.57	25.84
-Fuel and lulicants	2.15	-
-Inplements and others	3.64	-
-Land preparation by tractor	40.50	40.54
-Transport of harvest	-	70.38
-Interest and apportunity costs	23.93	-
Total Variable Costs ($/ha)	**294.16**	**365.91**
Land rent and taxes	44.15	48.89
Depreciation machinery	3.39	-
Total Production Costs ($/ha)	**341.70**	**414.80**
Yield (t/ha)	16.52	23.40
Root price ($/tonne)	21.62	21.62
Gross income ($/ha)	357.16	505.91
Net income ($/ha)	15.46	91.11
Production costs ($/tonne fresh roots)	20.68	17.73

1US $ = 37 baht in 1999/2000.; cost of labor 120 baht/day

Sources: [1)] *Office of Agric. Economics (OAE), 2001.*

[2)]*Adapted from TTDI, 2000.*

Appendix 1.

Table 6. Cassava production costs (US $/ha) in Vietnam in 2000/01.

	North Vietnam[1)]		Central Vietnam		South Vietnam	
	mono-culture	peanut intercrop	mono-culture[2)]	peanut intercrop[3)]	mono-culture[4)]	maize intercrop[5)]
Labor Costs ($/ha)	***198.80***	***337.96***	***175.45***	***482.80***	***213.60***	***281.24***
-Labor costs ($/manday)	0.71	0.71	1.21	1.42	1.78	1.78
-land preparation (mandays/ha)	*56*[6)]	*56*[6)]	*40*	*40*	*5*	*5*
-preparation planting material	-	-	-	-	*5*	*5*
-planting –cassava	*56*	*56*	*10*	*40*	*10*	*10*
-intercrop	-	*84*	-	*40*	-	*10*
-fertilizer application	-	-	*15*	*20*	*5*	*10*
-weeding –cassava	*56*	*56*	*35*	*80*	*40*	*30*
-intercrop	-	*56*	-	-	-	*20*
-harvesting – cassava	*56*	*56*	*45*	*60*	*55*	*50*
-intercrop	-	*56*	-	*60*	-	*18*
Total (mandays/ha)	*224*	*420*	*145*	*340*	*120*	*158*
Other Costs ($/ha)	***119.54***	***248.89***	***39.50***	***228.57***	***171.07***	***107.01***
-Fertilizers	48.11	52.55	34.86	100.00	80.36	44.64
-Manures	71.43	100.00	-	-	-	-
-Herbicides/pesticides	-	-	4.64	42.86	-	-
-Intercrop seed	-	96.43	-	85.71	-	26.66
-Land preparation by tractor	-	-	-	-	90.71	35.71
Total Variable Costs ($/ha)	**318.34**	**586.94**	**214.95**	**711.37**	**384.67**	**388.25**
Land rent and taxes	-	-	5.43	28.57	60	60
Total Production Costs ($/ha)	**318.34**	**586.94**	**220.38**	**739.94**	**444.67**	**448.25**
Yield (t/ha) -cassava	17	16	21	20	25	20
-intercrop	-	1.0	-	2.0	-	4.0
Price ($/t) -cassava	35.71	35.71	19.28	14.28	21.42	21.42
-intercrop	-	357.14	-	357.14	-	72.85
Gross income ($/ha)	607.07	928.50	404.88	999.88	535.50	719.80
Net income ($/ha)	288.73	341.56	184.50	259.94	90.83	271.80
Production cost ($/tonne fresh roots	18.72	-	10.49	-	17.79	-

1 US $ =14.000 dong in 2000/01

1)Based on RRAs in north Vietnam in 1999/00

2)Based on farmer estimates (average 5 locations) during FPR training course, Hue, Aug 2001

3)Based on RRA in Huong Van commune, Huang Tra district, Thua Thien-Hue province

4)Based on farmer estimates in Dongnai province during FPR training course, HCM city, Jan 2000

5)Based on RRAs in Chau Duc district of Baria-Vungtau province

6)labor costs for land preparation = $ 1.42/day