AGRONOMIC PRACTICES FOR SUSTAINABLE CASSAVA PRODUCTION IN ASIA

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ABSTRACT

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 and sustainable yields can be maintained either with the application of 5-10 t/ha of animal manure supplemented with 50-100 kg/ha of N and/or K_2O as chemical fertilizers (depending on soil fertility characteristics), or by the application of chemical fertilizers alone with a ratio of N:P_2O_5:K_2O of 2:1:2 or 2:1:3, but not by organic or green manures alone; 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 simple but effective ways to reduce erosion.

INTRODUCTION

Cassava is a hardy crop that grows reasonably well on poor soils and in areas with low or unpredictable rainfall. It is a popular crop among poor farmers because it requires few inputs besides labor to produce a reasonable yield. Still, to get higher yields and greater economic benefits, the crop should be well managed and some external inputs may be required. Moreover, to sustain high yields in the future, it is important to prevent soil nutrient depletion and soil losses by erosion. This can be achieved through simple agronomic or soil conservation practices.

1. Cassava-based Cropping Systems

Cassava can be planted either as a sole crop in monoculture system or intercropped with other crops. Farmers that have only small plots of land will generally prefer to intercrop cassava with other crops. In Indonesia cassava is often planted in widely-spaced rows with upland rice between rows and maize within the cassava row. After the harvest of rice and maize, a legume crop like peanut, cowpea or mungbean is planted in the space between rows in order to obtain four crops per year. In China cassava is often interplanted among recently established watermelon, while in Vietnam and China cassava is often intercropped with maize or peanut. In some parts of the Philippines cassava is interplanted among young maize plants, while in east Java of Indonesia cassava and maize are planted simultaneously. However, for commercial production of cassava for the starch or animal feed industry, such as in Thailand, China, south Vietnam and southern Sumatra of Indonesia, cassava is generally planted in monoculture. In other areas with plantation crops like rubber, coconut or cashew, cassava is often intercropped for a few years between the rows of young trees, or in case of coconut, among the old trees.

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Thus, there are many alternative ways of planting cassava in various intercropping systems. In most cases the cassava row spacing is widened to allow more space for the intercrop between the rows, while interplant spacing within the row is shortened to maintain a high cassava population.

Numerous experiments have been conducted to determine the best intercrops for cassava, as well as the best planting arrangements and relative time of planting (Leihner, 1983). **Tables 1** and **2** show that in north Vietnam the intercropping of cassava with one or two rows of peanut generally resulted in the highest net income. Intercropping with mungbean or soybean can be successful sometimes, but other times may result in complete crop losses due to drought or severe insect or disease problems. Peanut is a popular intercrop as it can be grown on similar acid infertile soils as cassava, it does not suffer severe pest and disease problems, and it protects the soil from rainfall splash, thus reducing erosion (**Table 1**). **Table 3** shows that when cassava was intercropped every year with four types of intercrops from 1981 to 1993 in Rayong, Thailand, the intercropping with peanut may have had a long-term beneficial effect on soil fertility as evidenced by the increases in cassava monocrop yields in 1987 and 1993 (Tongglum *et al.*, 2001).

Table 1. Effect of intercropping cassava with various grain legumes on the yield of crops, on gross and net income, as well as on dry soil loss due to erosion when grown on 10% slope at Agro-forestry College of Thai Nguyen Univ., Thai Nguyen, Vietnam in 1997.

Intercropping treatments	Yield (t/ha) cassava	Yield (t/ha) intercrop	Gross income[1)]	Costs fert. +seed[1)]	Net income	Dry soil loss (t/ha)
			(mil. d/ha)			
1. Cassava monoculture	18.67	-	7.47	6.22	1.25	31.24
2. C+peanut	16.50	1.08	12.00	8.77	3.23	24.03
3. C+soybean	18.42	0.15	8.27	7.98	0.29	28.50
4. C+mungbean	20.83	0.27	10.49	7.84	2.65	28.61
5. C+black bean	17.92	0.35	9.62	7.94	1.68	28.64
6. C+cuoc bean	17.67	0.17	7.92	7.87	0.05	28.14

[1)]Prices:

cassava:	d 400/kg fresh roots		
peanut:	5000/kg dry pods	peanut seeds:	d 7000/kg dry pod
soybean:	6000/kg dry grain	soybean seeds:	7000/kg dry grain
mungbean:	8000/kg dry grain	mungbean seeds:	8000/kg dry grain
black bean:	7000/kg dry grain	black bean seeds:	7000/kg dry grain
cuoc bean:	5000/kg dry grain	cuoc bean seeds:	5000/kg dry grain

Source: *Le Sy Loi, 2000.*

2. Time of Planting and Harvest

The best time to plant cassava not only depends on the climatic conditions at time of planting but also on climatic as well as marketing conditions at time of expected harvest. In those areas where the root price depends on the starch content, farmers want to try to maximize both yield and starch content at time of harvest. However, prices also depend on market conditions and are usually highest in the off-season, i.e. when most farmers do not harvest. Thus, some farmers may want to sacrifice some yield in order to benefit from higher prices in the off-season.

Table 2. Average results of four FPR intercropping trials conducted by farmers in Tran Phu commune, Chuong My district, Ha Tay, Vietnam in 2003.

Treatments	Cassava yield (t/ha)	Intercrop yield (t/ha)	Gross income[1)]	Seed costs[2)]	Product. costs[2)]	Net income
			('000 d/ha)			
1. Cassava monoculture	24.54	-	9,816	0	5,460	4,356
2. C+1 row peanut	21.93	1.187	14,707	480	8,115	6,592
3. C+2 rows peanut	22.52	2.000	19,008	960	8,595	10,413
4. C+2 rows mungbean	21.42	0	8,568	2000	9,635	-1,067
5. C+2 rows soybean	21.28	0.162	9,322	800	8,435	887

[1)] Prices:	cassava: dong	400/kg fresh roots	
	peanut:	5,000/kg dry pods	
	soybean	5,000/kg dry seed	
[2)] Costs:	labor: dong	15,000/manday	
	NPK fertilizers:		= 0.86 mil. dong/ha
	peanut seed (80 kg/ha):	12,000 /kg	= 0.96 mil dong/ha for 2 rows
	mungbean seed (80 kg/ha):	25,000 /kg	= 2.00 mil dong/ha for 2 rows
	soybean seed (80 kg/ha)	10,000 /kg	= 0.80 mil dong/ha for 2 rows
	labor for cassava monoculture without fertilizers		= 4.5 mil. dong/ha (300 md/ha)
	labor for cassava intercropping without fertilizers		= 6.675 mil.dong/ha (445 md/ha)
	labor for cassava fertilizer application		= 0.10 mil. dong/ha

Source: *Trinh Phuong Loan, personal communication, 2004.*

Table 3. Yield (t/ha) of cassava (C) and intercrop (INT) species in a long-term cassava intercropping trial conducted continuously at Rayong Field Crops Research Center, Thailand, from 1981 to 1993.

Intercropping patterns	Year									
	1981		1986		1987	1988		1992		1993
	C	INT	C	INT	C	C	INT	C	INT	C
Cassava monoculture	29.2	-	19.9	-	22.5 bc[2)]	9.9	-	27.9	-	22.8
Cassava+sweet corn[1)]	31.3	27.2	21.9	13.9	25.7 ab	10.2	9.8	30.7	20.1	26.2
Cassava+mungbean	24.4	0.88	17.9	0.09	21.6 c	9.1	0.33	32.9	0.23	26.4
Cassava+peanut	23.5	1.35	21.4	0.31	24.6 abc	7.3	0.22	24.9	1.94	28.3
Cassava+soybean	29.1	0.63	17.4	0.63	26.8 a	5.9	0.33	27.2	0	27.2
F-test										NS

[1)] Sweet corn yield in '000 cobs/ha.
[2)] Means in a column separated by DMRT at 0.05%
NS = not significantly different.
Source: *Tongglum et al., 2001.*

a. Tropical regions

In tropical regions with distinct dry and wet seasons and a mono-modal rainfall distribution, the best time to plant is early in the wet season, i.e. as soon as enough soil moisture allows for adequate germination of planted stakes. **Figure 1** shows that in Rayong, Thailand, highest yields were obtained with planting in May, at the start of the rainy season. In those areas with a bimodal rainfall distribution, such as in Kerala, India, planting at the start of the second rainy season, i.e. in Aug or Sept, will also result in high yields (George *et al*., 2001). In the southern hemisphere the wet and dry seasons are reversed in comparison with the northern hemisphere, and the wet season generally starts in Nov-Dec and ends in April-May. In that case, highest cassava yields are obtained when planted in Dec (Wargiono *et al*., 2001).

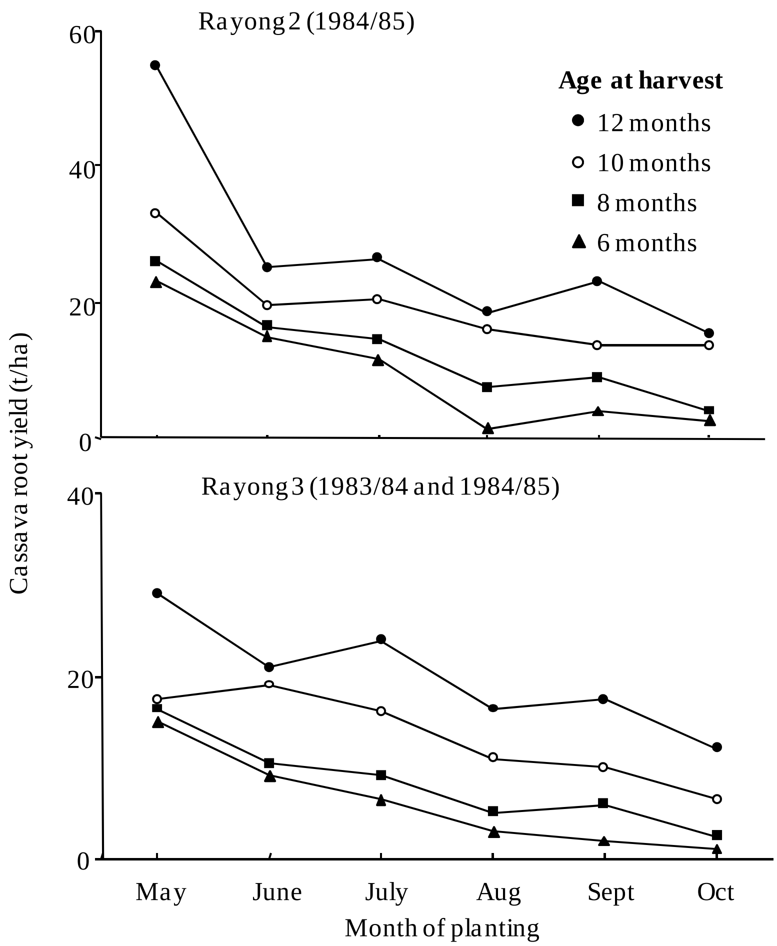

Figure 1. Effect of month of planting and age at harvest on root yields of cassava cultivars Rayong 2 and Rayong 3 planted at Rayong Field Crops Research Center, Thailand, in 1983-1985.
Source: *Tongglum et al., 2001.*

However, high yields may also be obtained when cassava is planted towards the end of the wet season. **Table 4** shows that highest yields in Rayong, Thailand were obtained when cassava was planted in Aug-Nov. In this case, plants get well established during the last months of the rainy season, grow slower during the dry season and have an additional period of fast growth during the following wet season. In this case, weed competition tends to be less severe as plant canopies are already well-established during the early part of the second wet season. **Table 5** and **Figure 2** indicate that total rainfall during the 4th to 11th month of the crop cycle was best correlated with root and starch yield when the crop was harvested at 11 months after planting (MAP), but starch content was best correlated with total rainfall during the 6th to 9th month, and was negatively correlated with rainfall during the 10th and 11th months.

Table 4. Fresh root yield (t/ha) of recommended cassava cultivars when planted in different periods at Rayong Field Crops Research Center, Thailand, 1987-1988.

	Cultivars				Average
Planting periods	Rayong 1	Rayong 3	Rayong 60	Rayong 90	
April-May	18.56	19.94	23.31	24.00	21.44 c[1)]
June-July	20.81	24.25	27.63	29.31	25.50 ab
August-Sept	22.31	24.44	32.31	27.81	26.75 a
Oct-Nov	21.81	26.62	30.19	26.06	26.19 a
Dec-Jan	19.38	20.38	29.44	23.87	23.25 bc
Feb-March	20.75	20.50	26.25	25.44	23.25 bc
Average	**20.62 d**	**22.69 c**	**28.19 a**	**26.06 b**	

[1)]Mean separation: DMRT, 0.01
Source: *Tongglum et al., 2001.*

b. Subtropical regions

Cassava is also grown in subtropical regions, such as southern China and north Vietnam. These regions are characterized by cold and dry winters (with occasional frost at higher latitudes) and hot and wet summers with relatively long daylight. **Figure 3** shows that cassava yields were little affected by date of planting when cassava was harvested at 12 months, but that yields markedly declined when planted in late summer (Aug-Nov) and harvested after 8 months in April to July. When harvested at 8 MAP, both root yields and starch content were lowest when roots were harvested during the hot months of June-July. In that case, root yields were positively and highly significantly correlated with both temperature and rainfall during the 3rd to 5th month after planting, i.e. at time of maximum growth rate of cassava (**Figure 4**), while starch content was negatively correlated with temperature and rainfall during the last month before harvest (**Figure 5**).

Figure 1 and **Table 6** indicate that root yields generally increase with increasing plant age at harvest, at least up to 18 months. Root starch content also tends to increase with plant age up to 9-10 month but may decrease sharply at the early part of the wet season as plants relocate starch from the roots to plant tops during resprouting.

It may be concluded that highest yields are generally obtained when cassava is planted as early as possible in the wet season or in early spring, while starch contents are highest when plants are harvested in the middle of the dry season. At planting time there should be enough soil moisture to get at least 80-90% germination, while soils should not be so wet as to prevent adequate aeration and root formation.

Table 5. 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 4th-11th MAP[1)]	0.7025	0.001
Cassava root yield vs rainfall from the 3rd-11th MAP	0.6726	0.002
Cassava root yield vs rainfall from the 2nd-11th MAP	0.6005	0.008
Cassava root yield vs rainfall from the 1st-11th MAP	0.5115	0.030
Cassava root yield vs rainfall during the 1st MAP	-0.4258	0.078
Cassava root yield vs rainfall from the 1st-2nd MAP	-0.4146	0.087
Root starch content vs rainfall from the 6th-9th MAP	0.8298	0.000
Root starch content vs rainfall from the 5th-9th MAP	0.7981	0.000
Root starch content vs rainfall from the 6th-8th MAP	0.7966	0.000
Root starch content vs rainfall from the 10th-11th MAP	-0.1290	NS
Root starch content vs rainfall during the 11th MAP	-0.0772	NS
Starch yield vs rainfall from the 4th-11th MAP	0.7411	0.000
Starch yield vs rainfall from the 4th-10th MAP	0.7096	0.001
Starch yield vs rainfall from the 5th-11th MAP	0.7090	0.001
Starch yield vs rainfall from the 5th-10th MAP	0.6950	0.001
Dry soil loss (erosion) vs rainfall from 1st -3rd MAP	0.6016	0.008
Dry soil loss (erosion) vs rainfall from 1st -4th MAP	0.5515	0.018
Dry soil loss (erosion) vs rainfall from 1st -5th MAP	0.5290	0.024
Dry soil loss (erosion) vs rainfall from 1st-2nd MAP	0.5087	0.031

Note: cassava was harvested after 11 months
[1)] MAP = month after planting
Source: *Howeler, 2001.*

3. Land preparation

Most farmers prefer to plant cassava in well-prepared loose soil without any weeds. This facilitates vertical or inclined planting and reduces early weed competition. In Thailand the soil is usually prepared by hired tractor using a 3-disk plow followed by 7-disk harrow, and sometimes ridging. The contractor prefers to plow the field in straight lines parallel to roads or plot borders, irrespective of slope direction. This method results in a loose and clean soil surface and high yields, but may cause severe erosion as well as formation of a “plow sole”, or compacted layer at 15-20 cm depth. This compacted subsoil impedes free drainage resulting in poor growth or root rot during the months of heavy rainfall. Moreover, the topsoil is rapidly saturated with water, which is followed by overland runoff and sometimes severe gully erosion. The regular use of a subsoiler will help to break the plow sole and improve internal drainage, which tends to improve plant growth during the height of the rainy season and increase yields (Watananonta *et al.*, 2006). The subsoiler should be followed by either a 3-disk or 7-disk plow to reduce weed competition and loosen the soil.

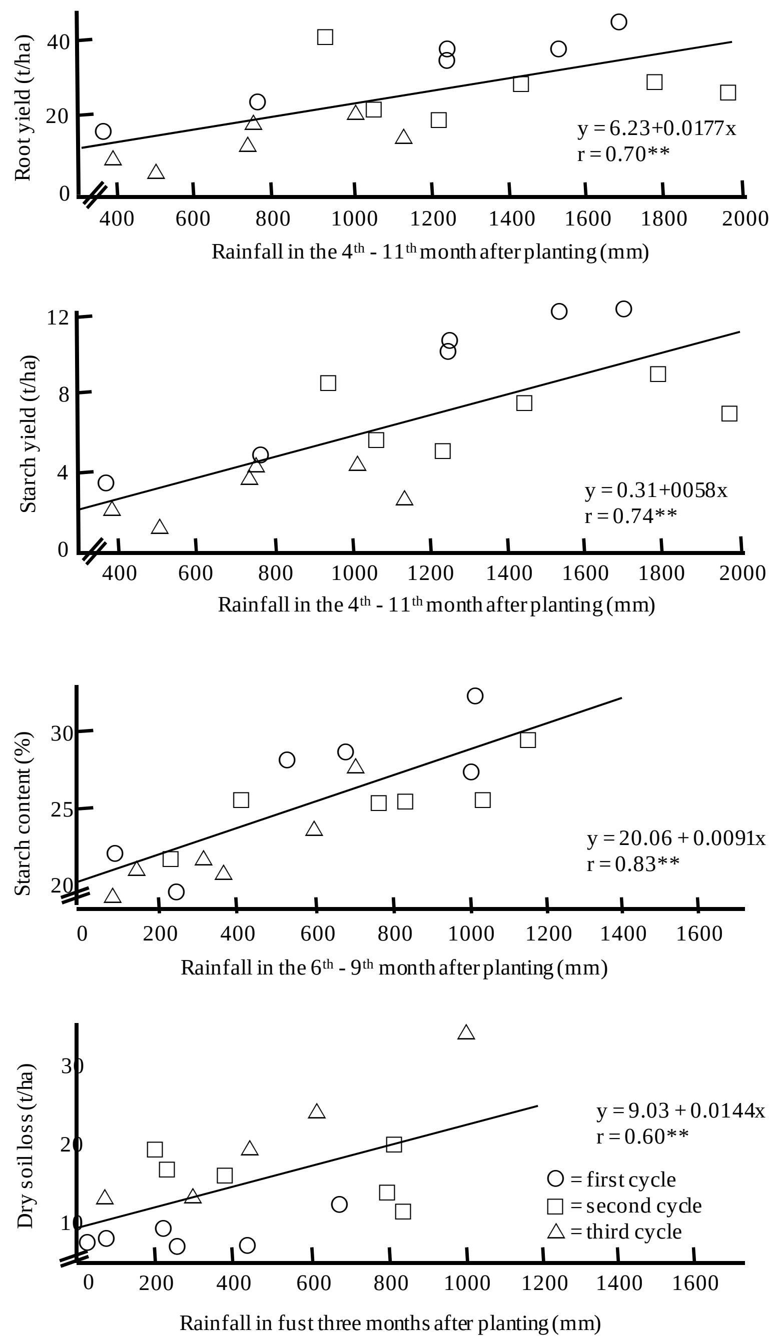

Figure 2. Linear regressions between cassava root yield, starch yield, starch content and dry soil loss due to erosion and the rainfall received during certain periods of the crop cycle when cassava, cv Rayong 90, was grown at bimonthly intervals for three complete cropping cycles on 4.2% slope at Rayong Research Center in Thailand from 1994 to 1998.
***Source:** CIAT, 1998 b.*

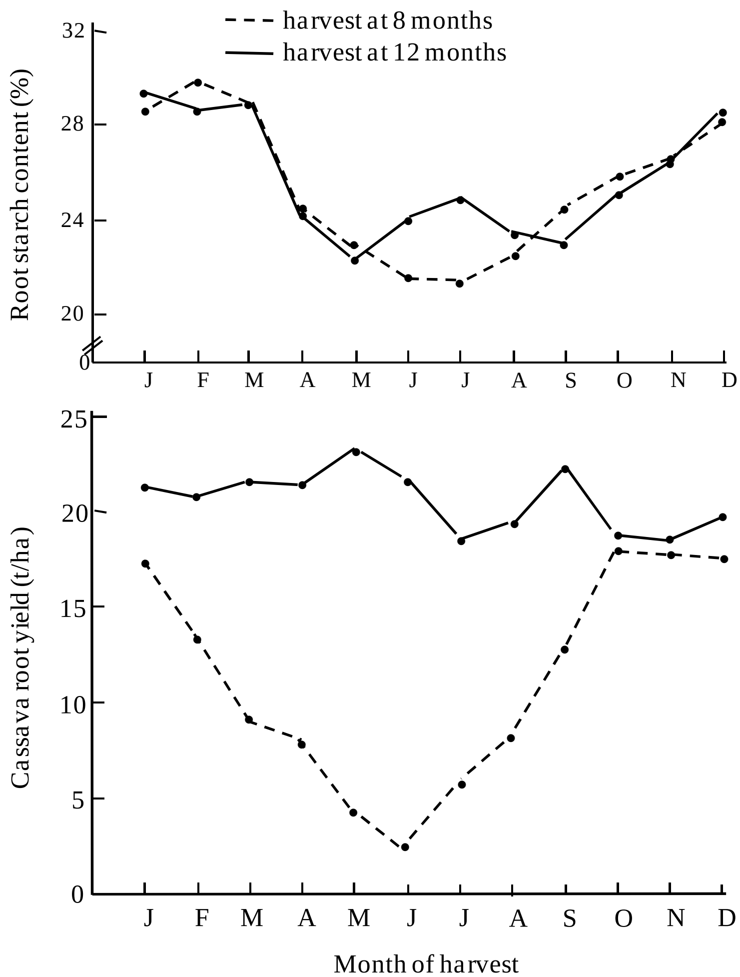

Figure 3. Cassava root starch content (top) and root yield (bottom) averaged over three varieties and three cropping cycles, when planted during different months of the year at CATAS, Danzhou, Hainan, China, and harvested after either 8 or 12 months.
Source: *Zhang Weite et al., 1998.*

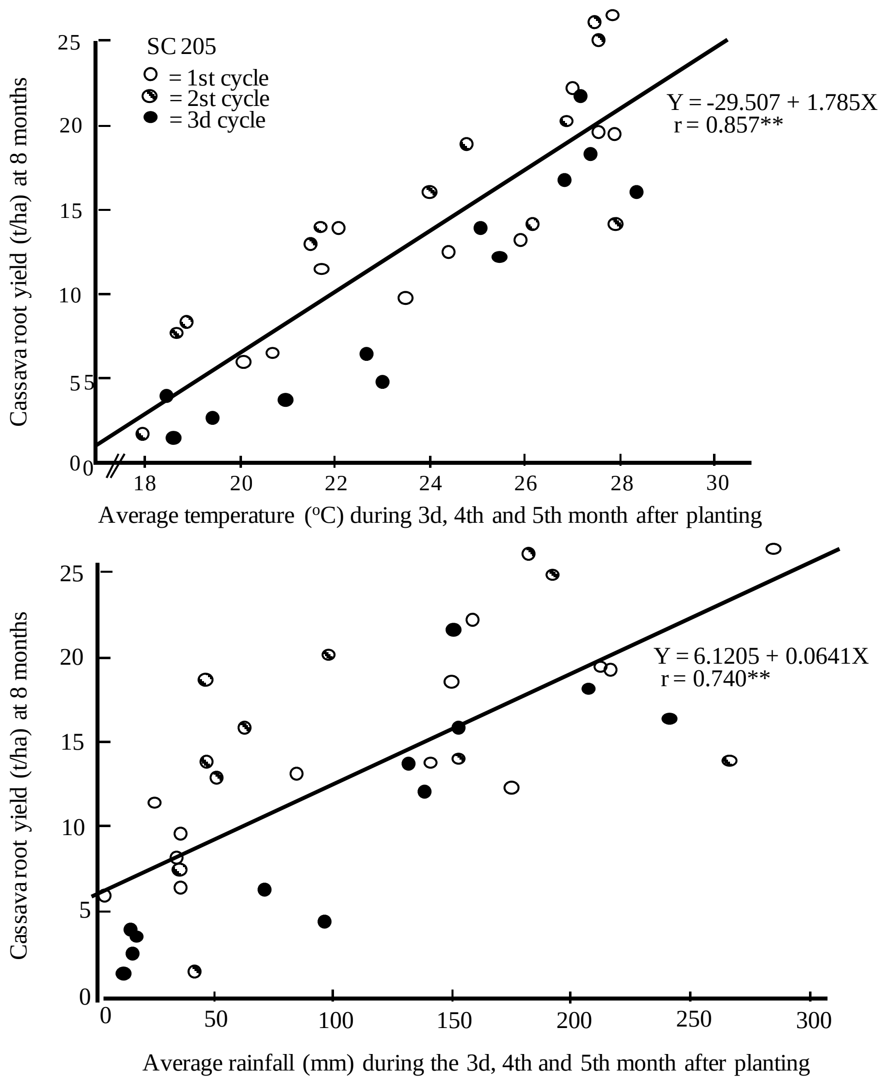

Figure 4. Linear regression between root yield of cassava, cultivar SC 205, harvested at 8 months, and the average mean temperature (top) or rainfall (bottom) during the 3d, 4th and 5th month after planting in CATAS, Danzhou, Hainan, China. Data are for 36 monthly plantings from 1990 to 1993.
Source: *Zhang Weite et al., 1998.*

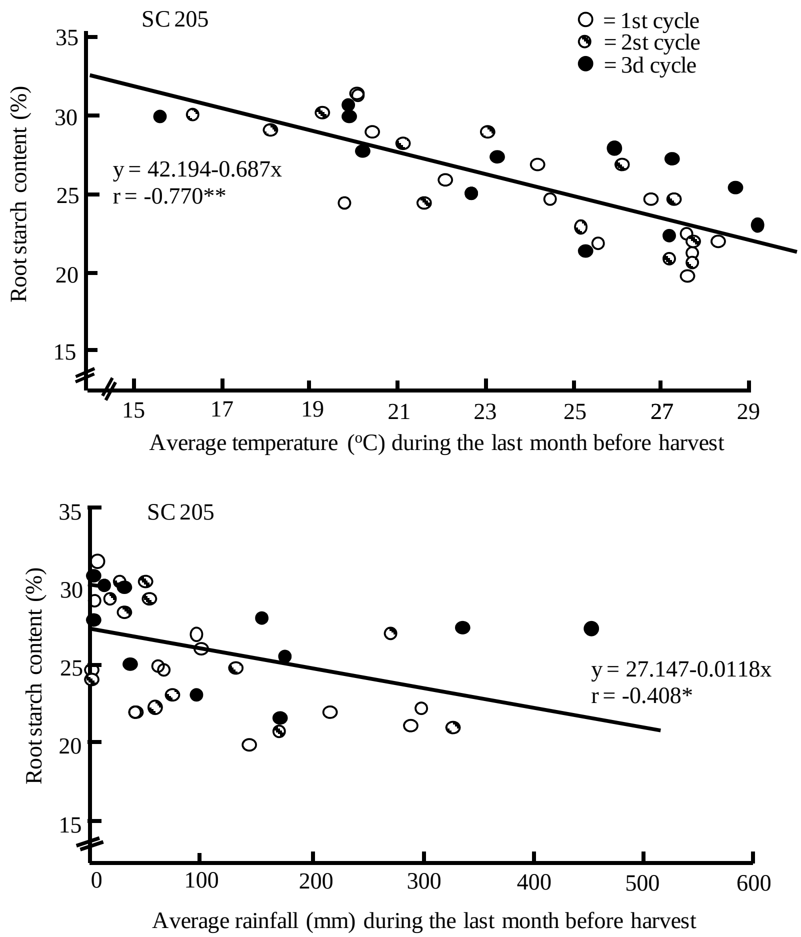

Figure 5. Linear regression between root starch content of cassava, cultivar SC 205, harvested at 8 months, and the average temperature (top) or rainfall (bottom) during the last month before harvest in CATAS, Danzhou, Hainan, China. Data are for 36 monthly plantings from 1990 to 1993.
Source: *Howeler, 2001.*

Table 7 shows that planting on top of ridges had no significant effect in root yield or starch content when planting occurred during either the rainy or dry season. However, in the dry season planting, germination was significantly better without ridges as ridging caused more rapid drying of the soil. On gentle slopes, contour ridging is an effective way to reduce run-off and erosion. However, when too much water accumulates above the ridge, this may cause water logging and lower yields, or the ridges may break causing serious gully erosion.

Table 6. Average fresh root yield of Rayong 1 as effected by age at harvest when planted at Rayong Field Crops Research Center, Thailand in 1975-1979.

Age at harvest (months)	Fresh root yield (t/ha)	Dry root yield (t/ha)	Starch yield (t/ha)	Starch content (%)
8	16.19 f[1)]	6.44 f	2.31 f	14.3
10	23.06 e	8.31 e	4.81 e	20.9
12	31.31 d	10.69 d	5.94 d	19.0
14	37.56 c	13.06 c	7.38 c	19.6
16	41.50 b	15.00 b	8.69 b	20.9
18	45.25 a	16.44 a	9.19 a	20.3

[1)]Mean separation within each column: DMRT, 0.01
Source: *Tongglum et al., 2001.*

Table 7. Effect of stake position, stake length, and planting depth on cassava yield, planted in both the rainy and dry season at Rayong Field Crops Research Center, Thailand (Average of 3 years, 1987-1989).

	Rainy season (May-August)			Early dry season (November)		
Treatments	Plants survived (‘000/ha)	Root yield (t/ha)	Starch content (%)	Plants survived (‘000/ha)	Root yield (t/ha)	Starch content (%)
Method of planting						
-Ridge	14.57 a	14.98 a	16.64 a	10.69 b	14.69 a	18.63 a
-No ridge	14.43 a	13.47 a	16.66 a	12.09 a	14.96 a	18.65 a
F-test	NS[3)]	NS	NS	**	NS	NS
Stake position						
-Vertical	14.87 a	16.04 a	17.03 a	13.04 a	17.74 a	19.04 a
-Inclined	14.89 a	15.46 a	17.14 a	11.99 b	16.40 b	18.68 a
-Horizontal	13.74 b	11.08 b	15.85 b	9.31 c	10.32 c	18.17 b
F-test	**[1)]	**	**	**	**	**
Stake length (cm)						
-20	14.55 a	14.52 a	16.67 a	10.58 b	14.53 a	18.51 a
-25	14.41 a	13.54 b	16.69 a	13.02 a	15.41 a	18.87 a
F-test	NS	*[2)]	NS	**	NS	NS
Planting depth (cm)						
-5-10	14.43 a	13.90 a	16.61 a	9.74 b	13.14 b	18.21 b
-15	14.56 a	14.43 a	16.73 a	12.71 a	16.17 a	18.97 a
F-test	NS	NS	NS	**	**	**

No interaction between methods and treatments in all characters
[1)]and [2)]: Mean within a column separated by DMRT at 0.01 and 0.05 %, respectively
[3)]NS = not significantly different.
Source: *Tongglum et al., 1992.*

On smaller farms, land is generally prepared by plowing with cattle or water buffalo or by hoeing. In Indonesia, land is often prepared by plowing with cattle followed by hand-ridging with hoe. In Kerala, India, small plots are generally prepared by hoe, making individual mounds for each plant. On steep slopes in Laos and southern China, land is cleared of vegetation by machete, followed by burning; land preparation is limited to making individual holes for planting each stake horizontally. In Hainan island of China this resulted in similar yields as twice plowing and disking, but markedly reduced soil erosion (Zhang Weite *et al.*, 1998). Similarly, zero tillage and using herbicides to control weeds sometimes results in high yields in Thailand if weed growth is not aggressive (Watananonta *et al.,* 2006). However, in very weedy plots or in compacted soil, zero tillage generally resulted in lower yields and difficulty in planting, weeding and harvesting.

4. Selection and preparation of planting material

Cassava is normally planted using stem cuttings, also called "stakes" or "setts". The stems are normally cut when the mother plant is 8-12 months old. Older plants usually have longer stems and have more buds per stem, thus producing more stakes per plant. Stakes derived from the lower and middle part of the stem had significantly higher germination rates than those derived from the upper part of the stem (George *et al.,* 2001), and 15-20 cm stakes had higher germination than shorter stakes of 5-10 cm length (Chankam, 1994). Stake germination is also affected by the method and length of stem storage after cutting. **Table 8** shows that germination and plant survival decreased with increasing length of storage, but decreased faster if stems were stored in the sun in the open field, or were only covered with leaves. Varieties differ markedly in the storability of their stems, but for most varieties stems should be stored upright in the shade, and for no longer than 1½-2 months to obtain at least 80% germination; other varieties lose their germination capacity already after 3-4 weeks of storage.

Table 8. Plant survival rate (%) from stakes stored under different conditions and for various periods at Rayong Field Crops Research Center, Thailand, in 1976-1978.

Storage time	Storage method		
(days)	Under shade	In sun	Covered with leaves
0	95.6	95.3	96.5
15	93.5	93.4	91.6
30	83.4	84.3	87.9
45	80.0	55.9	58.4
60	57.5	48.9	50.0
75	49.2	31.9	43.1
90	44.9	28.9	35.9
105	43.2	21.0	22.1

Source: *Sinthuprama and Tiraporn, 1986.*

5. Planting method

If the soil is loose and friable, stakes can be planted vertically or slanted by pushing the lower part of the stake about 5-10 cm into the soil. Stakes can also be planted horizontally at 5-7 cm depth by digging individual holes, or by making a long furrow, laying the stakes down and covering with soil. The latter method is common in heavy clay soils or with zero- or minimum-tillage methods of land preparation. When the soil is well prepared and friable, planting vertically or inclined is faster than planting horizontally, but care should be taken that the eyes or buds on the stakes face upward; with horizontal planting this is of no concern.

In sandy clay loam soils in Rayong, Thailand, planting vertically or inclined produced significantly higher root yields than planting horizontally (**Table 7**); this was especially the case when stakes were planted in the early dry season (Nov), when horizontal planting resulted in slower and a significantly lower rate of germination (Tongglum *et al.*, 2001). Research conducted in two locations in China indicate that vertical planting resulted in the highest germination percentage but that inclined planting produced the highest yields (**Table 9**). Similar results were recently obtained in Cambodia (Ung Sopheap, personal communication, 2006) where inclined planting produced the highest yield; planting one stake per hill significantly increased yields as compared to the traditional practice of planting two stakes per hill, slanted in opposite directions.

Table 9. Effect of stake planting position and ridging on cassava yield and germination at 1 month in GSCRI, Nanning, Guangxi, and in CATAS, Danzhou, Hainan, China. Data are the average for SC201 and SC205 in CSCRI, and for SC205 and SC124 at CATAS.

Planting Position		GSCRI (1990-1992)		CATAS (1994)
		Germination[1)] (%)	Root yield[2)] (t/ha)	Root yield (t/ha)
Horizontal				
	-ridging	61.5	11.7	20.0
	-no ridging	67.4	10.9	18.6
Inclined				
	-ridging	66.4	13.0	25.3
	-no ridging	78.1	11.5	16.9
Vertical				
	-ridging	82.8	11.1	19.4
	-no ridging	85.8	11.2	18.5

[1)]Average of 1991 and 1992 (no data taken in 1990)
[2)]Average of 1990 and 1992 (no harvest in 1991 due to drought)
Source: *Zhang Weite et al., 1998.*

6. Application of lime and fertilizers or manures

Cassava is extremely tolerant of acid soils, growing well even at a pH as low as 4.2-4.5 and at 75-80% Al saturation (= me Al/ me Al + me Ca + me Mg + me K/100 g x 100%). In Asia there are very few soils where cassava responds to the application of lime (Susan John and Venugopal, 2006). Responses have been obtained only on the peat soils in Malaysia and on the very acid soils of the Plain of Jars in Xieng Khouang province of Laos. In most cases this is mainly a response to the application of Ca and/or Mg if dolomitic lime is applied.

While cassava can grow better than most other crops in very infertile soils, the crop does respond well to the application of chemical fertilizers or animal manures. Like any other crop, cassava extracts nutrients from the soil during plant growth and some of these are removed in the root harvest, while others may be returned to the soil in the crop residues, such as leaves and stems. **Figure 6** shows the relation between fresh root yield and the removal of N, P and K in the harvested roots, as reported in the literature. It is clear that nutrient removal increases as yields increase, but this is not a linear relationship, as the nutrient contents of the roots also tend to increase with increasing yields. Thus, nutrient removal is quite large only when yields are very high. At an average root yield of 15 t/ha, only about 30 kg N, 3.5 kg P (= 8 kg P_2O_5) and 20 kg K/ha (= 24 kg K_2O) are removed from the soil. This is much less than that removed in the harvested products of most other crops (Howeler, 1991; 2001). Nevertheless, when cassava is grown on the same land for many years, the nutrient content in the soil may be depleted, resulting in decreasing yields unless the removed nutrients are returned in the form of chemical fertilizers or manures. **Figure 7** shows how cassava in Kerala, India, responded to the application of chemical fertilizers and farm-yard (= cow) manure (FYM). Without NPK or without K, yields decreased year after year as the exchangeable K in the soil decreased below the critical level of 0.15 me/100 g. But with adequate NPK fertilizers yields could be maintained at 20-30 t/ha, while the addition of 12.5 t/ha of FYM further increased yields slightly to 25-35 t/ha. Similar results have been obtained in long-term fertility trials conducted in three locations in Thailand (Nakviroj *et al*., 2007), in Hainan, China (Li Jun *et al.*, 2001), in Lampung, Indonesia (Wargiono *et al*., 2001), in Serdang, Malaysia (S.K. Chan, personal communication; Howeler, 1992), and in Thai Nguyen University and in Hung Loc Agric. Research Center, Vietnam (Nguyen Huu Hy *et al*., 2001). **Figure 8** shows the response of two cassava varieties to the annual application of various combinations of N, P and K during the 14^{th} year of continuous monocropping in Hung Loc Center in south Vietnam. It is clear that after continuous cropping soils had become depleted mainly of K and there was a highly significant response to application of K up to 80 kg K_2O/ha. This not only increased root yields but also the root starch content. With a high rate of application of 160 kg N + 80 P_2O_5 + 160 K_2O/ha high yields of 29-32 t/ha could be maintained after 14 years of continuous cropping, as compared to 11-12 t/ha without fertilizer application. **Figure 9** shows the root yields, relative root yields and the exchangeable K and available P contents of the soil during the 14 years of cropping. With a medium level of fertilization of 80 kg N + 40 P_2O_5 + 80 K_2O/ha yields increased over the years from about 15 t/ha to about 27 t/ha, while without fertilizers or with only N and P application yields declined from about 12 to 10 t/ha. While there was no significant response to fertilizer application during the first five years of cropping, after that the response to K application became more pronounced year after year. This is due to a gradual decrease in the exchangeable soil K content, which dropped below the critical level of 0.15 me/100 g during the 7^{th} year of cropping. Even after 14 years of continuous cropping there was only a minor response to the application of P as the available P content remained above the critical level of 5 ppm P over all these years.

Thus, in most soils in Asia, cassava responds mainly to the application of K>N>P, but in various locations in southern China and in Malang, Indonesia the initial response was mainly to N>K>P. The rates of NPK recommended in various locations, soils and cropping systems are shown in **Table 10**.

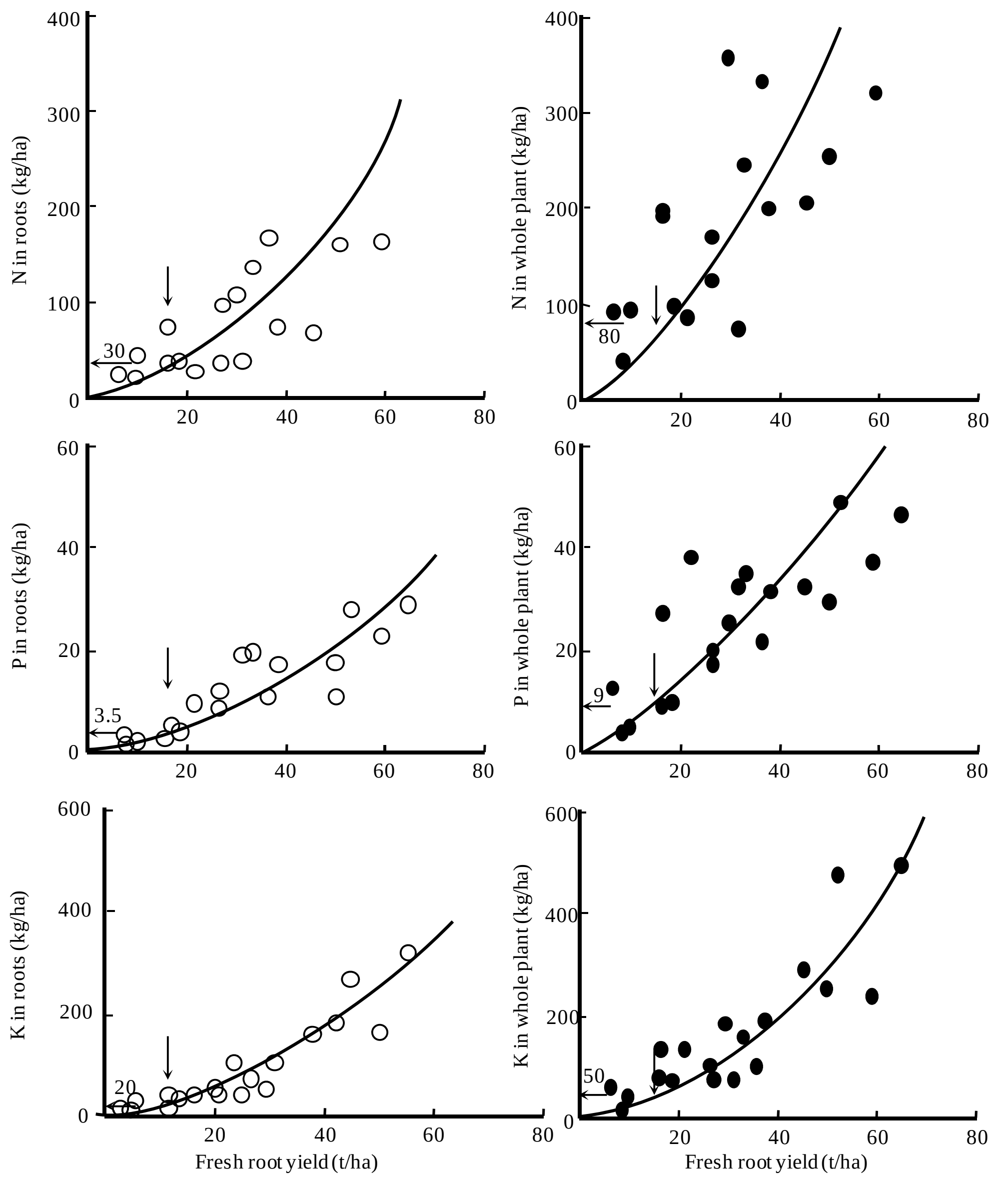

Figure 6. Relation between the amounts of N, P and K in cassava roots (left)or in the whole plant (right) and the fresh root yield, as reported by various sources in the literature. Arrows indicate the approximate nutrient removal corresponding to a fresh root yield of 15 t/ha. ***Source:*** *Howeler, 2001; 2002.*

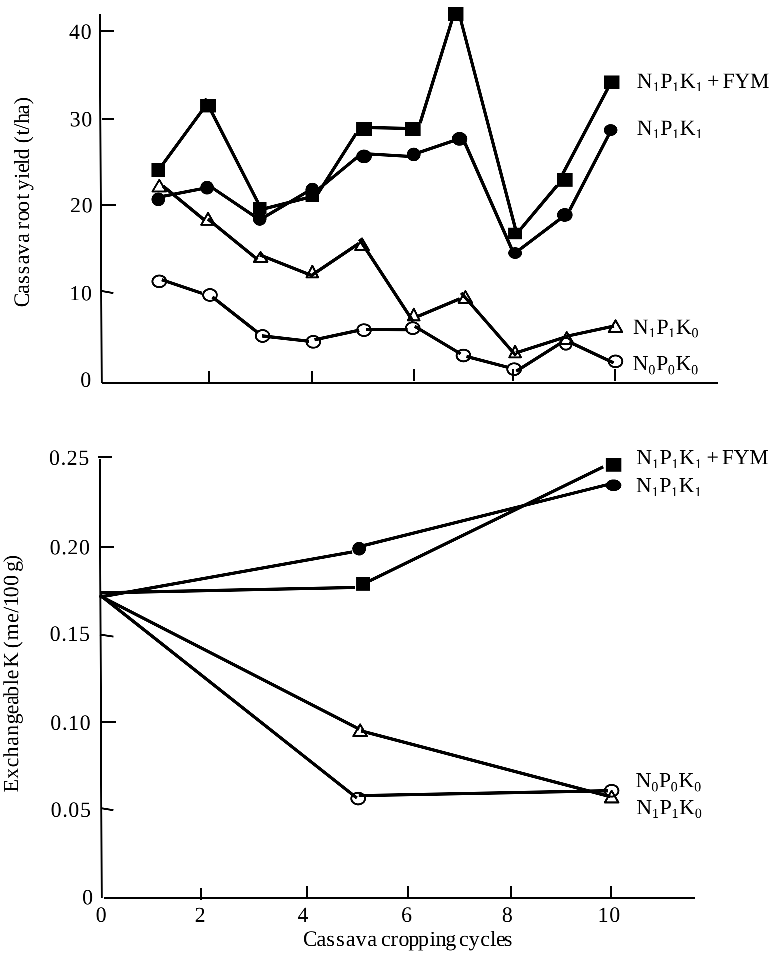

Figure 7. Cassava yield (top) and the exchangeable K content of the soil (bottom) during 10 years of continuous cropping with various NPK treatments in Trivandrum, Kerala, India.
Source: *Kabeerathumma et al., 1990.*

Animal manures are a good source of N, P and K as well as secondary- (Ca, Mg, S) and micro-nutrients (B, Cu, Fe, Mn, Zn). They are often times the only source of nutrients available for poor farmers. However, animal manures have very low levels of N, P and K as compared to chemical fertilizers (**Table 11**) and they tend to be too low in N and K as compared to P to be suitable for most cassava soils. **Tables 12** and **13** indicate that cassava yields are generally highest with either a well-balanced application of NPK fertilizers or a combination of a medium level (5/ha) of FYM or compost supplemented with N, or N and K depending on the fertility status of the soil. This combination of manure and chemical fertilizers, or chemical fertilizers alone, generally results in a higher net income than applying only organic manures. Similar results were also reported by Susan John *et al.* (2005) for two long-term experiments conducted at CTCRI in Kerala, India.

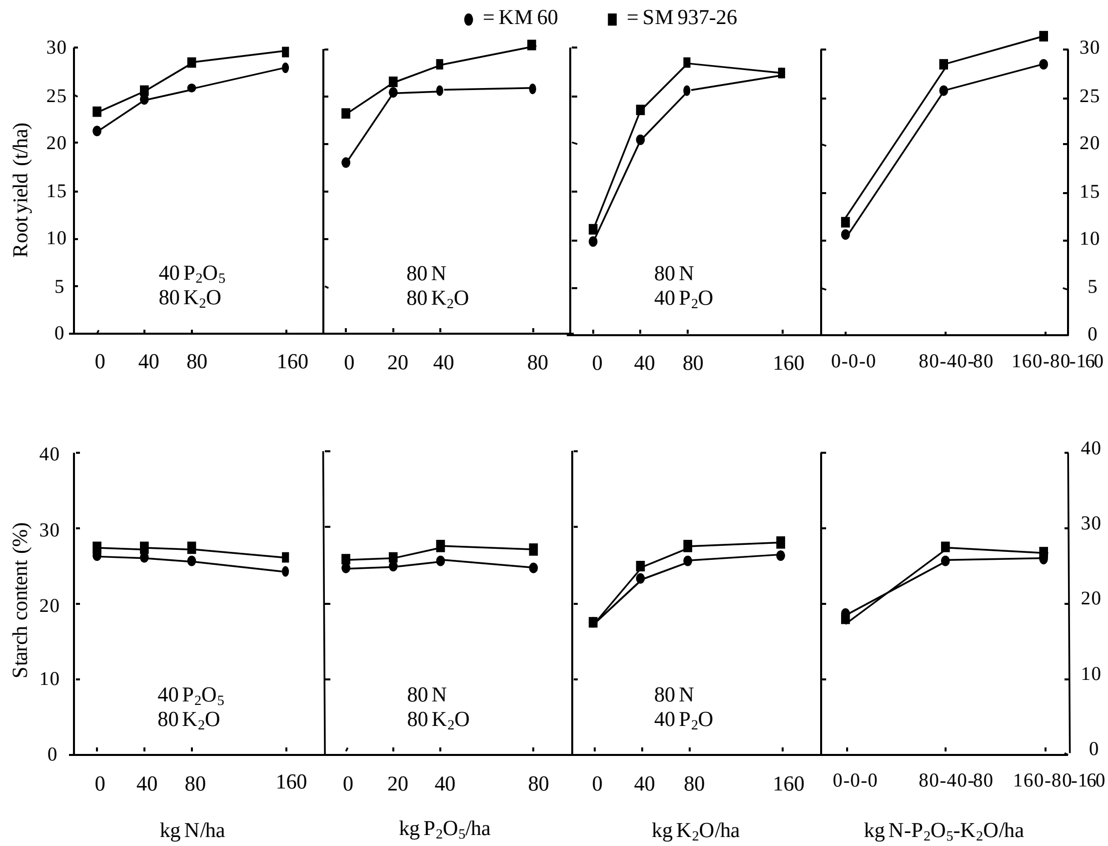

Figure 8. Effect of annual applications of various levels of N, P and K on the root yield and starch content of two cassava varieties grown at Hung Loc Agric. Research Center in Thong Nhat, Dong Nai, Vietnam in 2003/04 (14th year).

Source: *Nguyen Huu Hy, personal communication, 2004.*

Research on the best time and method of fertilizer application usually indicates that best responses are obtained when all fertilizers are either applied at time of planting or at one month after planting. Alternatively, all of the P and half of the N and K are applied at planting and the remaining N and K applied at 2-3 months after planting. Highly soluble fertilizers like urea, TSP, SSP, SP-36 and KCl, or any of the compound fertilizers, should be band or spot applied at 5-10 cm from the stake, while less soluble fertilizers like basic slag, rock phosphates, lime, gypsum and animal manures should be broadcast and incorporated into the soil before planting.

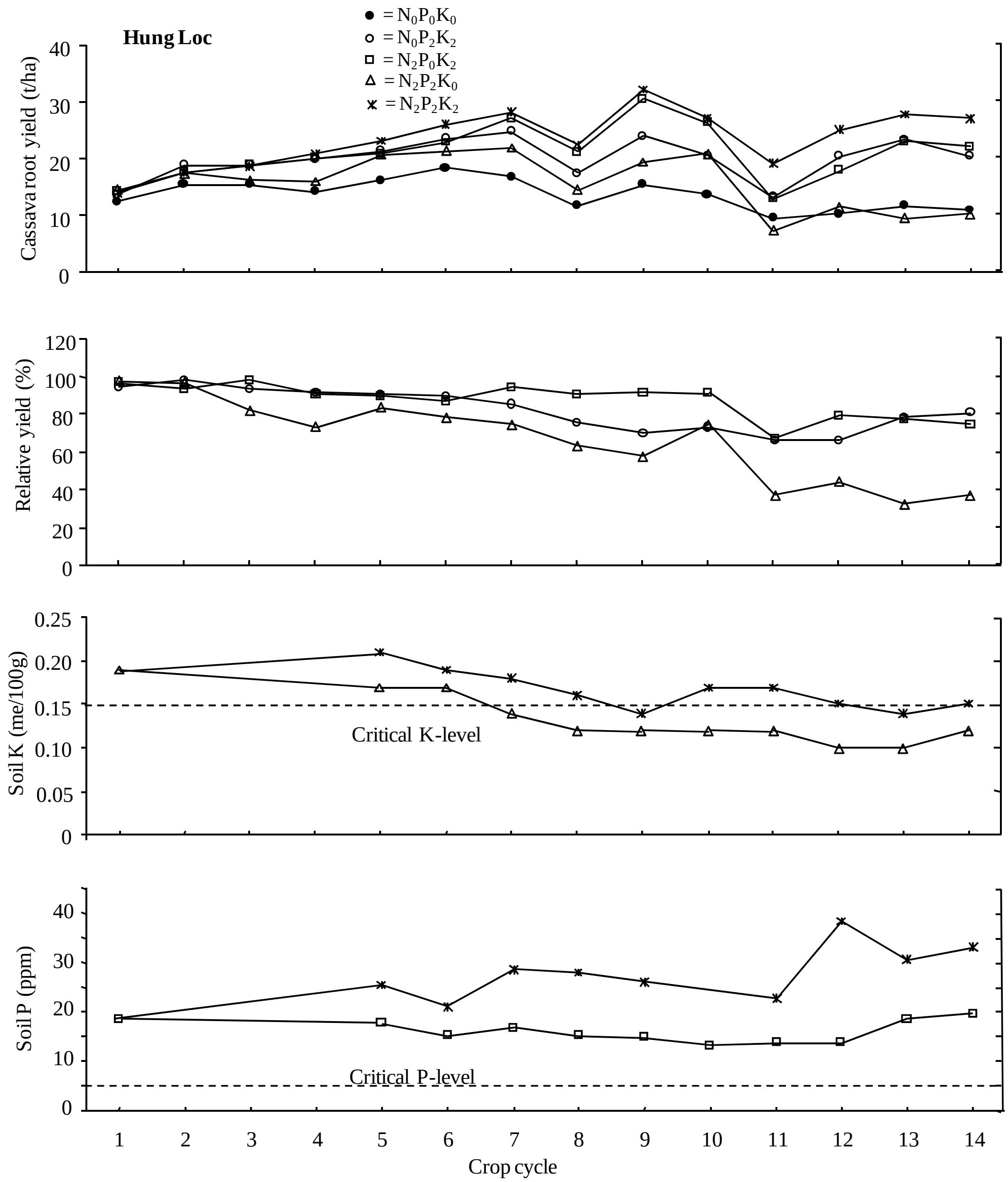

Figure 9. Effect of annual applications of N, P and K on cassava root yield, relative yield (yield without the nutrient over the highest yield with the nutrient) and the exchangeable K and available P (Bray 2) content of the soil during fourteen years of continuous cropping in Hung Loc Agric. Research Center, Dong Nai, Vietnam.

Source: *Nguyen Huu Hy, personal communication, 2004.*

Table 10. 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)

Source: *Howeler, 2001.*

Table 11. Average nutrient contents of various manures, composts, wood ash, and chemical fertilizers.

Source of manure	Moisture (%)	N	P	K	Ca	Mg	S
		(% of dry matter)					
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
15-15-15	0	15	6.55	12.50	0	0	0
Urea	0	45	0	0	0	0	0
Triple superphosphate	0	0	20	0	14	0	0
Potassium chloride	0	0	0	50	0	0	0

Source: *Howeler, 2001b.*

Table 12. Effect of the application of FYM[1)] and chemical fertilizers on cassava yield and economic benefit at Thai Nguyen University of Agric. and Forestry in Thai Nguyen province of Vietnam, in 2001 (2nd year).

Treatments[1)]	Cassava root yield (t/ha)	Height at 8 months (cm)	Leaf life at 3 months (days)	HI	Gross income[2)]	Fert. costs[2)]	Product. costs[3)]	Net income
					-----------('000 dong/ha)----------			
1. no fertilizers, no FYM	3.25	87.1	46.5	0.39	1,625	0	2,800	-1.175
2. 5 t FYM/ha	7.79	116.6	55.2	0.49	3,895	500	3,300	0.595
3. 10 t FYM/ha	10.02	133.9	65.0	0.52	5,010	1,000	3,800	1.210
4. 15 t FYM/ha	13.11	151.8	66.1	0.52	6,555	1,500	4,300	2.255
5. 80 N+80 K_2O/ha, no FYM	15.47	154.5	66.8	0.50	7,735	680	3,580	4.155
6. 80 N+80 K_2O/ha + 5 t FYM/ha	17.98	180.0	68.5	0.48	8,990	1,180	4,080	4.910
7. 80 N+80 K_2O/ha + 10 t FYM/ha	18.70	188.3	70.8	0.49	9,350	1,680	4,580	4.770
8. 80 N+80 K_2O/ha + 15 t FYM/ha	18.50	196.6	73.1	0.48	9,250	2,180	5,080	4.170

[1)]FYM = farm yard manure (pig manure)

[2)]Prices: cassava dong 500/kg fresh roots
urea (45% N) 2,100/kg
KCl (60% K_2O) 2,300/kg
manure+application 100/kg

[3)]Cost of cassava cultivation: 2.8 mil. dong/ha; cost of chem. fert. application 0.10 mil. dong/ha

Source: *Nguyen The Dang, personal communication, 2002.*

Table 13. Effect of various fertilization alternatives on the yields of cassava, cv Faroka, and intercropped maize as well as gross and net income when grown in Jatikerto Station in Malang, East Java, Indonesia, in 2005/06. (2nd year)

Treatments N-P_2O-K_2O (kg/ha)	Organic (t/ha)	Maize yield[2)] (t/ha)	Cassava yield (t/ha)	Gross income[3)]	Fertil. costs[3)]	Prod. costs[4)]	Net income	Farmers preference ranking
				———(mil. Rp/ha———				
1. 0-0-0	0	1.10	10.96	4.72	0	4.10	0.62	
2. 135-0-0	0	1.93	35.60	13.52	0.45	7.01	6.51	2
3. 135-50-0	0	2.07	36.80	14.05	0.69	7.37	6.68	3
4. 135-50-100	0	2.10	37.47	14.30	1.27	8.02	6.28	4
5. 0-0-0	10 cattle manure	1.66	26.53	10.32	2.00	7.65	2.67	
6. 0-0-0	10 compost	1.63	22.67	9.05	1.00	6.27	2.78	
7. 135-0-0	5 cattle manure	2.26	35.63	13.89	1.45	8.01	5.88	1
8. 135-0-0	5 compost	1.97	39.33	14.75	0.95	7.88	6.87	5
9. 135-50-0	5 compost	1.87	39.07	14.56	1.19	8.10	6.46	
10. 135-0-0	5 sugar mud[1)]	1.67	33.73	12.63	0.95	7.32	5.31	

[1)] sugar mud = blotong = by-product of sugar mill

[2)] maize grain yield

[3)] Prices: cassava: Rp 320/kg fresh roots; KCl (60% K_2O) Rp 3,500/kg
maize 1,100/kg dry grain; cow manure 200/kg
urea (45% N) 1,500/kg; compost 100/kg
SP-36 (36% P_2O_5)) 1,700/kg; sugar mud 100/kg

[4)] Costs: cassava harvest+transport 100/kg
production costs, without fertilizers or cassava harvest, estimated at Rp 3 mil/ha

Source: *Wani Hadi Utomo, personal communication, 2006.*

7. Use of green manures to improve soil fertility

Leguminous intercrops, green manures and hedgerow species (used in "alley cropping") can improve the N status of the soil through N fixation. They do not supply P and K except by recycling these nutrients from the subsoil into the top soil through leaf fall or when their plant residues are incorporated into the soil.

When green manures are planted and incorporated into the soil before planting cassava, they may significantly increase cassava yields (**Table 14**). However, in this case farmers may have to plant cassava late in the wet season after the green manure crop, or they may have to wait planting cassava until the following year. The late planting is likely to result in low cassava yields (Howeler, 1995), while few farmers can afford to leave their land one year in an unproductive green manure crop. One way to overcome this problem is to plant the green manure as an intercrop between cassava rows and to pull out and mulch the green manure at 2-3 months after planting. **Table 15** shows that *Canavalia ensiformis* (sword bean) was the most effective of four green manures tested, increasing cassava yields from 17.6 to 26.9 t/ha. Alternatively, cassava can be planted late in the wet season after incorporating the green manure and harvested after 18 months; this method resulted in very high root yields (**Table 15**), but provides an income only once every two years. Farmers could plant the green manure and cassava in alternate years on half of their fields to obtain a more steady income.

Planting hedgerows of leguminous tree species may also help to improve soil fertility, if the hedgerows are cut back regularly and the prunings used as mulch between cassava plants. Both the hedgerows, when planted along the contour, and the mulch help to reduce erosion. **Table 16** shows that hedgerows of *Gliricidia sepium* and *Leucaena leucocephala* were very effective in increasing cassava yields, especially when no fertilizers had been applied. These alley crop treatments also resulted in the highest net incomes, both with or without applied fertilizers. However, the beneficial effect of these green manuring practices may become apparent only after several years of continuous cropping.

Table 14. Cassava root yield (t/ha) as affected by the incorporation of different green manures befour planting cassava at the Agric. Development Research Center (ADRC) in Khon Kaen, Thailand.

	Crop year					
Green manure	1	2	3	4	5	Means
Cowpea	10.23	17.58	16.24	19.14	14.64	15.57
Pigeon pea	5.44	12.91	14.16	13.25	14.18	11.99
Crotalaria juncea	5.88	13.43	14.94	17.21	15.20	13.33
No green manure	4.43	13.99	14.13	12.07	13.97	11.72
F-test	**	NS	NS	NS	NS	**
CV (%)	23.6	29.7	23.9	11.5	32.7	10.7

Source: *Sittibusaya et al., 1995.*

Table 15. The effect of green manures grown as in-situ production of manure cassava grown at RFCRC in Rayong, Thailand in 1994/95/96.

Treatment	Green manures (t/ha)	Total N (kg/ha)	Cassava root yield (t/ha)
1. Cassava +Fert. 13-13-21 (156 kg/ha)	-	-	17.56
2. Cassava + Fert. 13-13-21 (469 kg/ha)	-	-	29.78
3. Cassava + *Crotalaria juncea* (cut at 2 months)	1.92	44.75	23.75
4. Cassava + *Canavalia ensiformis* (cut at 2 months)	0.94	20.13	26.94
5. Cassava + Pigeon pea ICP 8094 (cut at 2 months)	1.09	27.00	21.39
6. Cassava +*Mucuna fospeada* (cut at 2 months)	-	-	20.28
7. Cassava + cassava (pulled out at 2 months)	0.36	11.75	18.25
8. Cassava + cassava (cut at 2 months)	0.09	1.69	12.00
9. Cassava + *Crotalaria juncea* (planted at 6-7 months)	9.89	262.13	8.75
10. Cassava + *Canavalia ensiformis* (planted at 6-7 months)	1.54	36.63	22.83
11. Cassava + Pigeon pea ICP 8094 (planted at 6-7 months)	8.92	221.69	15.86
12. Cassava + *Mucuna fospeada* (planted at 6-7 months)	-	-	17.25
13. *Crotalaria juncea*-Cassava (harvest at 18 months)	1.44	39.94	46.17
14. *Canavalia ensiformis*-Cassava (harvest at 18 months)	0.93	18.38	42.98
15. Pigeon pea ICP 8094-Cassava (harvest at 18 months)	1.05	25.63	38.81
16. *Mucuna fospeada*-Cassava (harvest at 18 months)	-	-	38.86
LSD (0.010	-	-	13.45
F-test	-	-	**
CV (%)	-	-	23.88

Note: Treatments 9-12: green manures were cut at 4.5 months (at harvest of cassava)
Treatments 6, 12 and 16: Mucuna fospeada failed due to poor germination
Treatments 3-16: 156 kg/ha of 13-13-21 were applied to cassava
Treatments 1-12: cassava was harvested at 12 months
Treatments 13-16: cassava was harvested at 18 months

Source: *Tongglum et al., 1998.*

8. Erosion control

Due to its wide plant spacing and slow initial growth, cassava may cause more serious erosion than other crops when planted on slopes without soil conservation measures (Putthacharoen *et al*., 1998). However, farmers can markedly reduce soil losses by erosion through the use of simple agronomic or soil conservation practices, such as minimum tillage, intercropping, contour ridging, closer plant spacing, fertilizer application, mulching and the planting of contour hedgerows of grasses, legumes or leguminous tree species. Numerous on-station experiments and farmer participatory research (FPR) trials have shown that on average planting contour hedgerows of vetiver grass, *Paspalum atratum*, lemon grass, *Tephrosia candida* and pineapple were most effective in reducing erosion, while closer plant spacing, fertilizer application and lemon grass or vetiver grass hedgerows were most effective in increasing cassava yields (Howeler, 2006). Once farmers see the beneficial effects of these practices in simple FPR trials on their own fields, they are willing to adopt those practices that are most suitable for their own conditions.

Table 16. Effect of planting intercrops, green manures and alley crops, with or without fertilizers, on cassava and intercrop yields, as well as on gross and net income obtained when cassava, KM 60, was grown for the 12th consecutive year at Hung Loc Agric. Research Center in Thong Nhat district, Dongnai, Vietnam in 2003/04.

	Root yield —(t/ha)—		Starch content ——(%)——		Gross income[3] —('000d/ha)—		Product. costs[4] —('000d/ha)—		Net income —('000d/ha)—	
Treatments[1]	-fert	+fert[2]	-fert	+fert	-fert	+fert	-fert	+fert	-fert	+fert
1. C monoculture	15.62	23.44	24.1	27.1	3,749	5,626	1,900	3,091	1,849	2,535
2. C+pigeon pea GM	15.66	23.02	21.4	25.0	3,758	5,525	2,800	3,991	958	1,534
3. C+*Mucuna* GM	11.25	20.44	22.6	24.7	2,700	4,906	2,800	3,991	-100	-915
4. C+peanut IC	18.12	24.75	23.3	26.4	4,349	6,585 [5]	2,800	3,991	1,549	2,594
5. C+cowpea IC	16.25	24.44	23.6	25.8	3,900	5,866	2,800	3,991	1,100	1,875
6. C+*Canavalia* GM	15.62	25.06	22.8	24.6	3,749	6,014	2,800	3,991	949	2,023
7. C+*Leucaena* AC	21.50	26.84	22.7	26.6	5,160	6,442	2,200	3,391	2,960	3,051
8. C+*Gliricidia* AC	23.58	30.96	23.7	26.4	5,659	7,430	2,200	3,391	3,459	4,039

[1] GM = green manure; IC = intercrop; AC = alley crop
[2] +fert = 80 kg N + 40 P_2O_5 + 80 K_2O/ha; -fert = no fertilizers
[3] Prices: cassava: dong 240/kg fresh roots (includes harvest + transport)
peanut 5,000/kg dry pods
[4] Costs: land preparation 500,000 d/ha
planting (8 md) 200,000 d/ha
weeding (48 md) 1,200,000 d/ha
seed intercrops 300,000 d/ha
planting/harvest intercrops (24 md) 600,000 d/ha
urea (45% N) 2,800 d/kg
SSP (17%P_2O_5) 1,000 d/kg
KCl (60% K_2O) 2,500 d/kg
labor 25,000 d/manday
fertilizer application (5 md) 125,000 d/ha
cutting alley crops 300,000 d/ha
[5] Peanut yield is 129 kg dry pods/ha
Source: *Nguyen Huu Hy, personal communication, 2004.*

9. Weeding

Cassava is a poor competitor and may suffer serious yield losses if the crop is not adequately weeded during the early stages of plant growth. In general, the crop should be weeded 2-3 times during the first three months or until canopy closure. Weeding is most often done by hoe, by animal-drawn cultivator or hand tractor, but can also be done by a tractor-mounted cultivator or with herbicides. Weed competition can also be reduced by adequate and early application of fertilizers to speed up canopy closure, by intercropping, and by planting in the early dry season when weed growth is less vigorous (**Table 17**). When herbicides are used it is recommended to apply metholachlor at 1.5 kg a.i./ha immediately after planting, followed by 1-2 hand weedings or spot application of Paraquat or Glyphosate, using a shield over the applicator to prevent damage to the cassava plants (Tongglum *et al.*, 2001). Alternatively, Nguyen Huu Hy *et al.* (2001) showed that application of 2.4 l/ha of Dual as a pre-emergence herbicide in Vietnam increased cassava yields and net income as compared to hand weeding.

Table 17. Cassava fresh root yield and weeding costs as effected by the frequency of hand weeding when cassava cutivars Rayong 3 and Rayong 60 were planted at Rayong Field Crops Research Center in Thailand in the beginning of the rainy and dry seasons of 1991.

Treatment	Rainy season		Dry season	
	Root yield (t/ha)	Weeding cost (US$/ha)	Root yield (t/ha)	Weeding cost (US$/ha)
Varieties				
-Rayong 3	21.44 b	111	22.88 b	57
-Rayong 60	28.00 a	94	30.81 a	53
F-test	*[1)]	-	*	-
Weeding times				
-No weeding	4.81 b	0	23.63	0
-1&2 months	26.69 a	77	24.88	9
-1, 2& 3 months	29.00 a	85	25.38	14
-1, 2, 3 &6 months	27.94 a	127	26.06	57
-1, 2, 3, 6 & 9 months	31.44 a	118	29.56	104
-As necessary	28.81 a	106	31.56	90
F-test	**[2)]	-	NS[3)]	-

[1)] and [2)] Mean within a column separated by DMRT at 0.05 and 0.01%, respectively.
[3)] NS = not significant
Source: *Tongglum et al., 1992.*

10. Harvest

Cassava can be harvested any time, but the roots are usually harvested between 6 and 18 months. Some early-maturing varieties can be harvested at 6 MAP for direct human consumption, but most industrial varieties are harvested between 8 and 12 MAP. **Table 6** indicates that root yields nearly tripled between 8 and 18 months and that starch contents increased substantially between 8 and 10 months. Harvesting cassava after 18 months provides an income only every 1½ years, but at a considerable saving in terms of production costs. Harvesting early, at 6-8 MAP, however, allows for double cropping cassava with a subsequent short-duration crop of rice, sweet corn or mungbean.

Cassava is usually harvested by removing the tops at 20-30 cm above the ground and using the remaining stump to pull up the roots. If the soil is too hard, the roots can be lifted out of the ground with a pointed metal bar or a metal fork attached to a wooden stick used as a lever. Roots can also be dug out with pick, hoe or shovel. In areas where labor is expensive or the soil is too hard during the dry season, farmers in Thailand now use a tractor-mounted cassava harvesting tool that loosens the soil and lifts up the roots for easy gathering by hand. In Malaysia a more sophisticated cassava harvesting machine will dig the roots and deposit them in an attached wagon. After pulling up the root clumps, the individual roots are cut off from the stump and packed in baskets or sacks for transport to the house, drying floor or starch factory. To prevent spoiling, fresh roots should be processed within 2-3 days after the harvest.

CONCLUSIONS

Cassava is an easy crop to grow, and in Southeast Asia it does not suffer from any serious pests or disease problems. It can grow in poor soils and in drought-prone areas with little risk of complete crop failure. However, to obtain high and sustainable yields, the crop should be well-managed; it should be planted at an optimum time of the year, weeded 2-3 times during the first 3-4 months, and fertilized with chemical fertilizers or manures to supply adequate amounts of all nutrients required by the crop, particularly K and N. Cassava will remain a highly competitive industrial crop only if farmers obtain high yields at low production costs by the use of high-yielding varieties and good production practices.

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