Production Techniques for Sustainable Cassava Production in Asia

Reinhardt H. Howeler[1]

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.

Improved cultural practices, such as the use of chemical fertilizers and herbicides have been adopted in some regions or countries, such as in India (mainly in Tamil Nadu), Malaysia, Thailand, Indonesia and Vietnam (mainly fertilizers). Constraints to adoption are identified and the use of farmer participatory research methodologies are suggested to 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 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 that case 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). 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

[1] CIAT, Cassava Office for Asia; Dept. Agriculture, Chatuchak, Bangkok 10900, Thailand.

cassava, it does not suffer severe pest and disease problems, and it protects the soil from rainfall splash, thus reducing erosion.

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.

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).

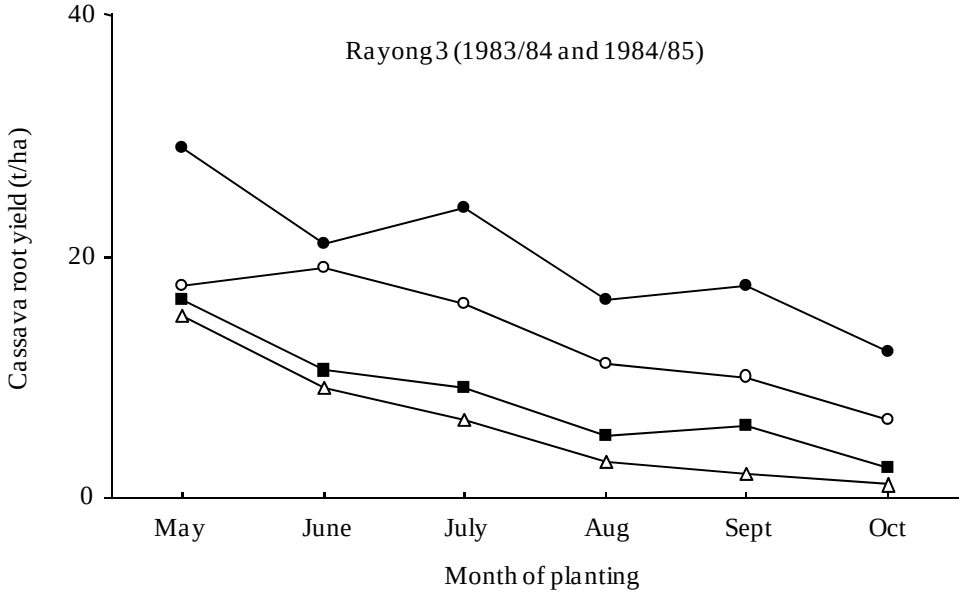

Figure 1. Effect of month of planting and age at harvest on root yields of cassava cultivars Rayong 3 planted at Rayong Field Crops Research Center, Thailand, in 1983-1985.
Source: *Tongglum et al., 2001.*

However, high yields may also be obtained when cassava is planted towards the end of the wet season. **Table 1** 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 1. 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 2** 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, while starch content was negatively correlated with temperature and rainfall during the last month before harvest (Howeler, 2001).

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.

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.

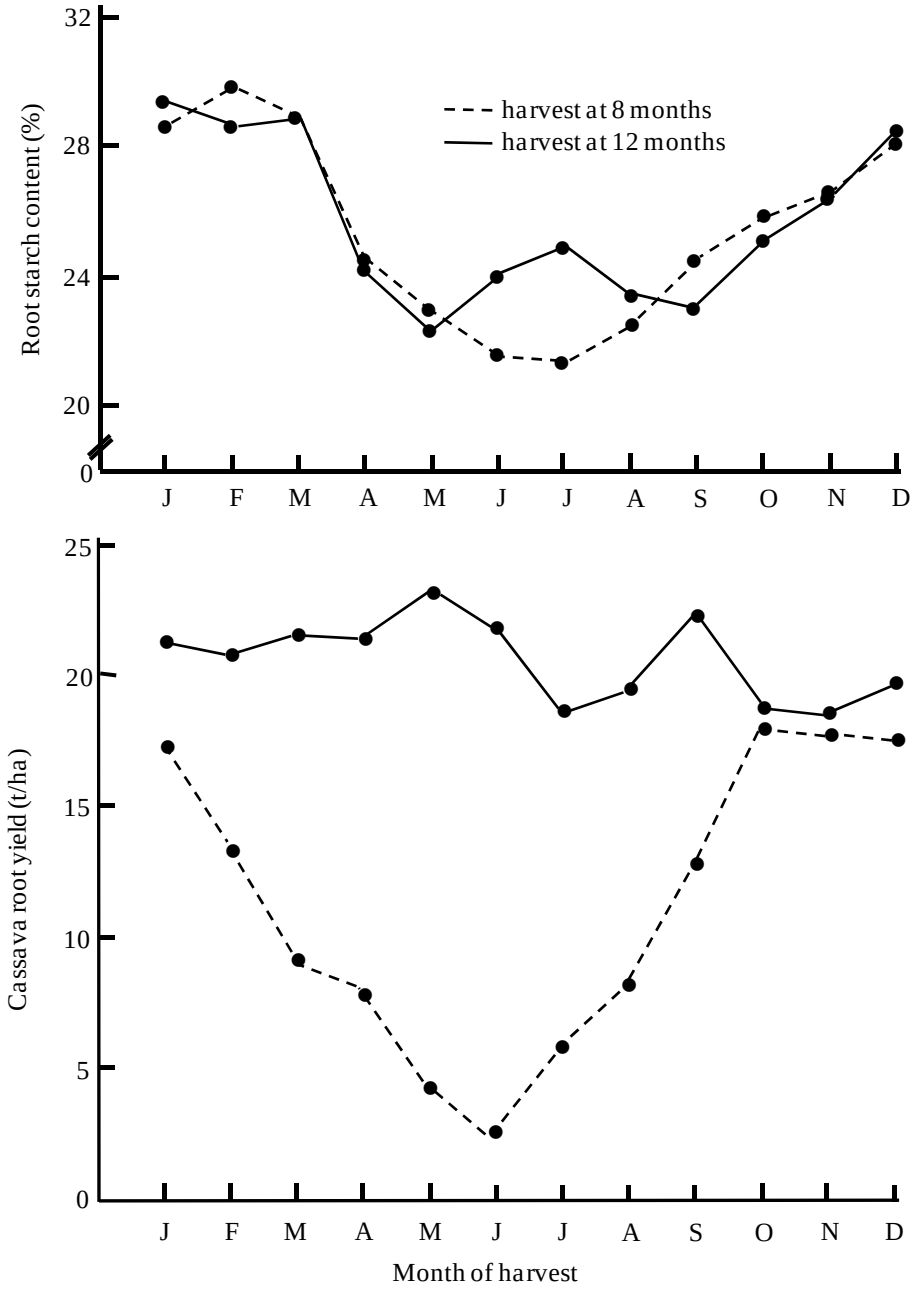

Figure 2. Cassava root starch content (top) and root yield (bottom) averaged over three varieties and three cropping cycles, when planted during different months of the year at CATAS, Danzhou, Hainan, China, and harvested after either 8 or 12 months.
Source: *Zhang Weite et al., 1998.*

Table 2 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 2. 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 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". The stems are normally cut when the mother plant is 8-12 months old. 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 (**Table 2**). 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.

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 2**); 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 (Zhang Weite *et al*., 1998).

6. Plant population and spacing

For maximum root production cassava is usually planted at a population of 10,000 plants/ha in fertile soil, and at about 16,000 plants/ha in infertile soil where plant growth is less vigorous. At 10,000 plants/ha, stakes are generally planted at 1.0x1.0 m for monoculture cassava or at wider row spacing (up to 2 m between rows) and closer in-the-row spacing (down to 0.5 m) for intercropping. The wider row spacing allows 1-3 rows of the intercrop to be planted between cassava rows. At a higher plant population of 16,000 plants/ha, cassava is generally planted in a square pattern of 0.8x0.8 m, but this can also vary to 1.2x0.52 m to allow for easy access by machinery or for intercropping. In general, the planting pattern can be varied somewhat without affecting yields as long as the plant population is maintained near the optimum level, depending on soil fertility and the branching habit of the variety. If some stakes do not germinate, the plant stand is reduced

As long as the plant stand is above 70-80% of maximum, yields may not be significantly affected as plants surrounding the open space will grow more vigorously and have higher yields, thus compensating for the lower plant stand. If possible, missing plants should be replaced by new stakes or transplants within 2-3 weeks from the original date of planting.

7. 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 gm 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 3** 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 4** shows the response of two cassava varieties to the annual application of various combinations of N, P and K during the 14th 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.

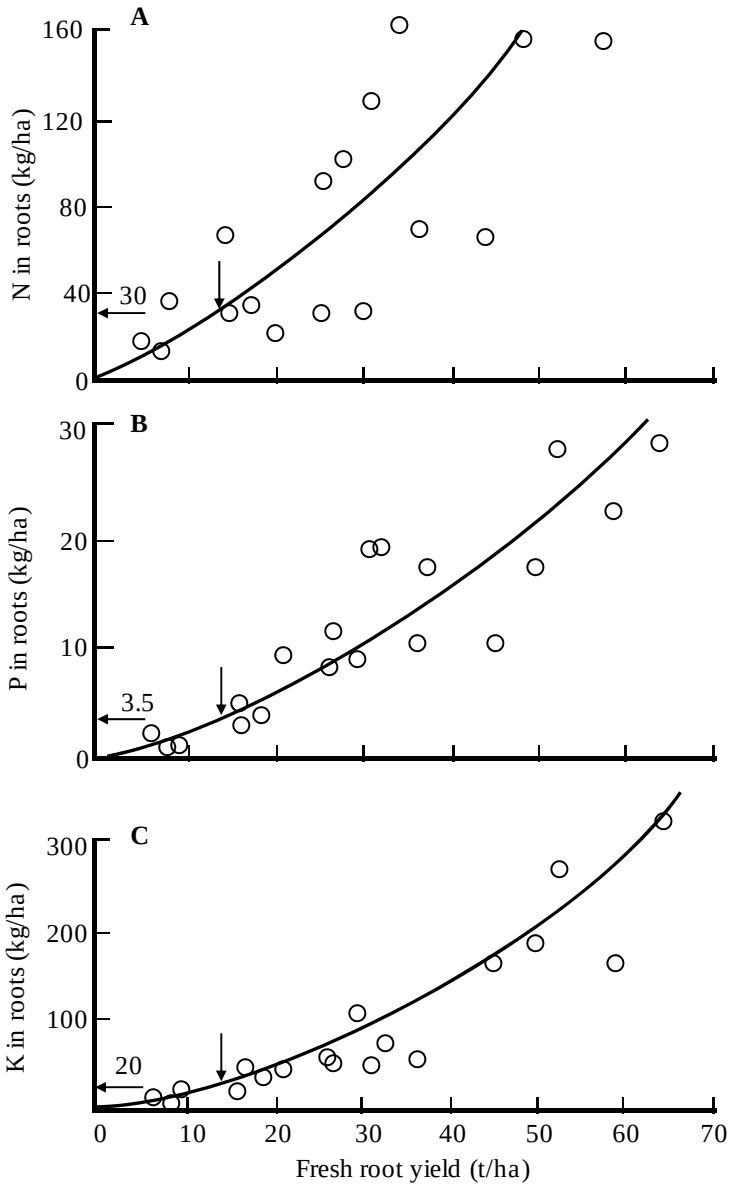

Figure 3. Relation between the amounts of N, P and K in cassava roots and the fresh root yields, as reported by various sources in the literature. Arrows indicate the approximate nutrient contents corresponding to a fresh root yield of 15 t/ha. ***Source:*** *Howeler et al., 2001.*

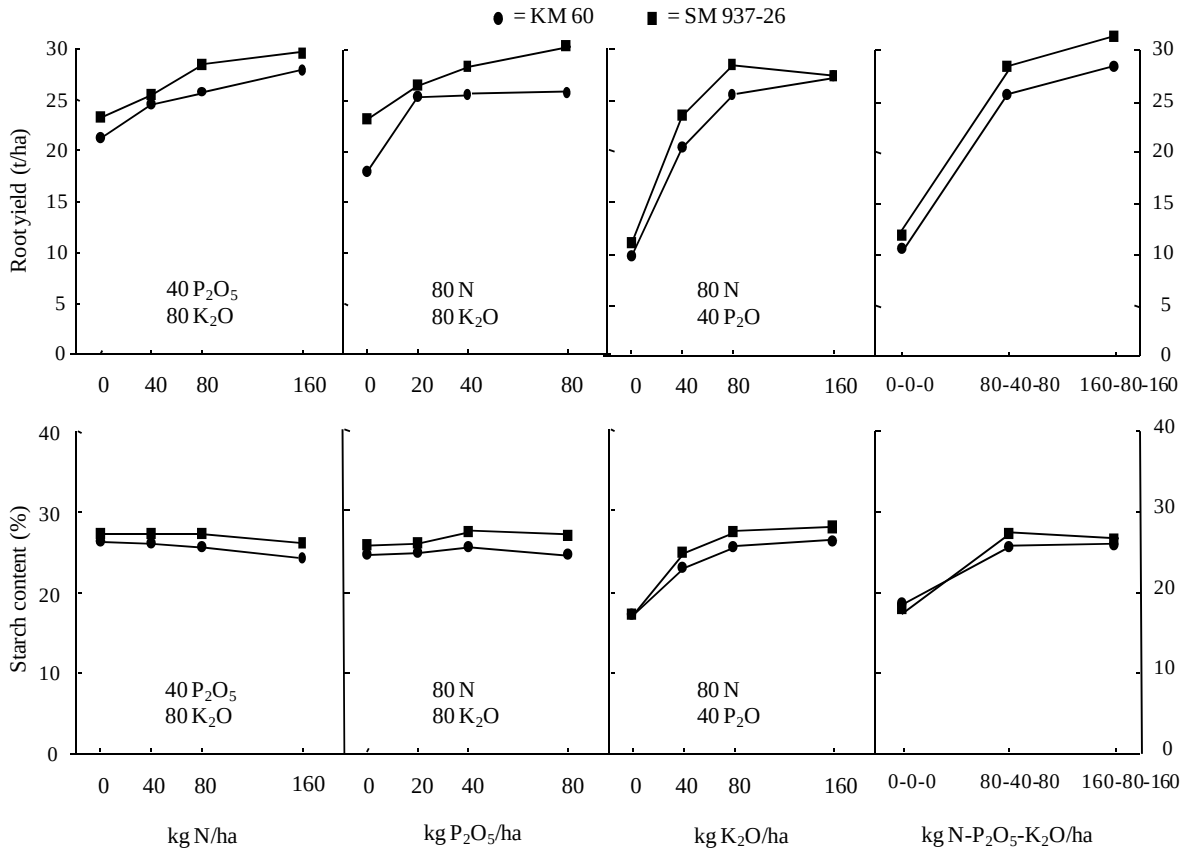

Figure 4. Effect of annual applications of various levels of N, P and K on the root yield and starch content of two cassava varieties grown at Hung Loc Agric. Research Center in Thong Nhat, Dong Nai, Vietnam in 2003/04 (14th year).

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

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. 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 and they tend to be too low in N and K as compared to P to be suitable for most cassava soils. **Tables 3** indicate that cassava yields were highest with either a well-balanced application of NPK fertilizers or a combination of a medium level (5/ha) of FYM supplemented with N and K. This combination of manure and chemical fertilizers, or of 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.

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.

Table 3. 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.*

8. 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 4**). 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 5** 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, 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.

9. 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, intercroppings, 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 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 4. 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 5. 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.*

10. 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. 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.

11. 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 mungbeans.

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.*

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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