CASSAVA AGRONOMY RESEARCH AND ADOPTION OF IMPROVED PRACTICES IN THAILAND - MAJOR ACHIEVEMENTS DURING THE PAST 35 YEARS

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ABSTRACT

This paper reviews the results of past research conducted from 1965 to 2000 in two major cassava growing areas, the northeastern and eastern parts of Thailand. This research was carried out by the Field Crops Research Institute, Department of Agriculture (DOA), in collaboration with Kasetsart University and the Centro Internacional de Agricultura Tropical CIAT). The major achievements are described under the following three topics:

Methods of cultivation, which tested and developed all the necessary components of cassava cultural practices, such as land preparation, planting time, age of harvest, spacing and plant population, planting method, stake size and storage, as well as weed control.

Cassava-based cropping systems, which showed the feasibility of intercropping cassava with short-duration crops such as mungbean, peanut, soybean and sweet corn.

Cassava soil conservation and fertility maintenance, which tested and developed appropriate production practices that both reduce soil loss by erosion and maintain high cassava yields. Long-term experiments on the effect of various fertilizer applications and soil management treatments showed the crop's nutritional requirements, and indicate soil/crop management practices that will maintain high levels of cassava productivity as well as adequate soil fertility.

INTRODUCTION

In 1976 the cassava planted area in Thailand was only 692,320 ha. Ten years later in 1985 the area had increased to 1,476,800 ha (OAE, 1985), and in 1997 this had slightly decreased again to 1,265,120 ha (OAE, 1998). Cassava replaced some other crops like kenaf and its area expanded greatly due to its ease of cultivation and tolerance to drought and infertile soils. Research on technologies for enhancing cassava production until the early 1990s was limited to the local variety Rayong 1, with most emphasis placed on agronomic practices for increasing yields. Since then the cassava breeding program has released several new high-yielding cultivars, and agronomy research has focused mainly on developing appropriate technologies, which could produce a high level of productivity of these varieties and maintain soil fertility in cassava growing areas. This paper reviews the results of many experiments in cassava agronomy which have been conducted from 1965 to 2000.

METHODS OF CULTIVATION

Agronomy research initially concentrated on the testing and development of the necessary components in cassava cultural practices:

1. Planting Time

In Thailand cassava can be planted all year round. A survey conducted in 1975 (Sinthuprama and Tiraporn, 1984) shows that 59% of cassava was planted in March to

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June, 15% during the heavy rains of July to Oct, and 26% during the dry season. However, an experiment conducted from 1965 to 1969 at Rayong Field Crops Research Center in the eastern part of Thailand to determine the appropriate planting time for cassava (**Table 1**), indicate that the highest root yields of cassava were obtained from planting in the rainy season (June to Oct); this resulted in higher root yields ranging from 22.9 to 28.7 t/ha. Planting either before or after the rainy season resulted in lower yields, ranging from 15.2 to 21.2 t/ha. The rainy season in Thailand lasts from May to Oct. **Table 2** shows that the average yield of cassava planted in the rainy season (May-Oct) was 25% higher than that obtained when planted in the dry season (Nov-April). Planting cassava before the rainy season (Feb-April) resulted in 10% higher yield than planting after the rainy season (Nov-Jan).

Table 1. Fresh root yield of Rayong 1 obtained when planted at various times at Rayong Field Crops Research Center, 1965-1969.

Month of planting	Average rainfall during 5 years (mm)[1)]	Fresh root yield (t/ha)
February	87	19.69
March	39	20.69
April	65	18.44
May	297	13.56
June	118	22.87
July	131	28.69
August	97	24.06
September	199	25.81
October	247	24.69
November	78	21.25
December	18	17.12
January	39	15.19

[1)]Average monthly rainfall from 1965 to 1969. Huaipong Meteorological Station, Rayong.
Source: *Field Crops Research Institute, Annual Reports 1965-1969.*

Table 2. Average fresh root yield when cassava was planted before, during and at the end of the rainy seasons at Rayong Field Crops Research Center, 1965-1969.

Planting periods	Fresh root yield (t/ha)	%
Before rainy season (February-April)	19.63	110
In rainy season (May-October)	23.31	130
After rainy season (November-January)	17.81	100
In dry season (November-April)	18.69	100
In rainy season (May-October)	23.31	125

Source: *Derived from Table 1.*

A similar trial conducted from 1975 to 1979 (**Table 3**) indicates that the highest yields were obtained by planting in the early rainy season (May-June), while yields decreased when planting was delayed to the later part of the wet season (Sinthuprama, 1980). The same studies were conducted using Rayong 2 and Rayong 3 in 1983-1985. **Figure 1** shows that the root yields of Rayong 2 and Rayong 3 were highest when planted in May. Root yields increased significantly when the age at harvest increased from 6 to 12 months. These results were similar to those observed with Rayong 1. Planting cassava early in the rainy season produced the highest yields, especially when the roots were harvested at 12 months.

Table 3. Fresh and dry root yield and starch yield of Rayong 1 when planted in different months during the rainy season at Rayong Field Crops Research Center, 1975-1979.

Planting time	Fresh root yield	Dry root yield	Starch yield
		(t/ha)	
May	38.75 a[1)]	14.00 a	8.00 a
June	39.81 a	14.56 a	8.12 a
July	36.19 b	12.94 b	7.44 b
August	31.38 c	10.69 c	6.00 c
September	27.00 d	9.62 d	5.31 d
October	22.19 e	8.12 e	4.81 e

Mean separation within each column: DMRT, 0.01
Source: *Sinthuprama et al., 1983.*

Rojanaridpiched *et al*. (1986) also studied the effect of planting time, planting in Feb, May and Nov of 1987 at Sri Racha Research Station. The results (**Table 4**) indicate that the highest yield was obtained from the Nov planting. These differences in results may be due to the high percentage of sand in the Mapbon soil found in Sri Racha. Land preparation in the dry season is possible in sandy soils but is very difficult in clay soils. Planting in the dry season tends to reduce erosion and weed problems. In 1987-1988 the optimum planting time for cassava was again studied using the new varieties Rayong 60 and Rayong 90. The results indicate the same trend as in the previous trials of Rayong 1 and Rayong 3. Planting Rayong 60 and Rayong 90 in the early to mid rainy season (June-Sept) resulted in higher yields than planting in the late rainy season or dry season (**Table 5**).

2. Age at Harvest

Although in Thailand cassava is harvested all year round (Sinthuprama and Tiraporn, 1984), the peak harvesting period is from Feb to May (53%), while less is harvested during the heavy rains of July to Oct due to a low root starch content and difficulty in drying for the chip factories. Experiments on optimum age at harvest were conducted from 1976 to 1978 at Rayong Field Crops Research Center. Results, shown in **Table 6**, indicate that the root yield increased with an increase in age at harvest from 8 to 18 months. However, if harvesting is delayed beyond 12 months the planting date for the next crop in the same area would be shifted and would no longer fit in the annual production cycle (Sinthuprama, 1980).

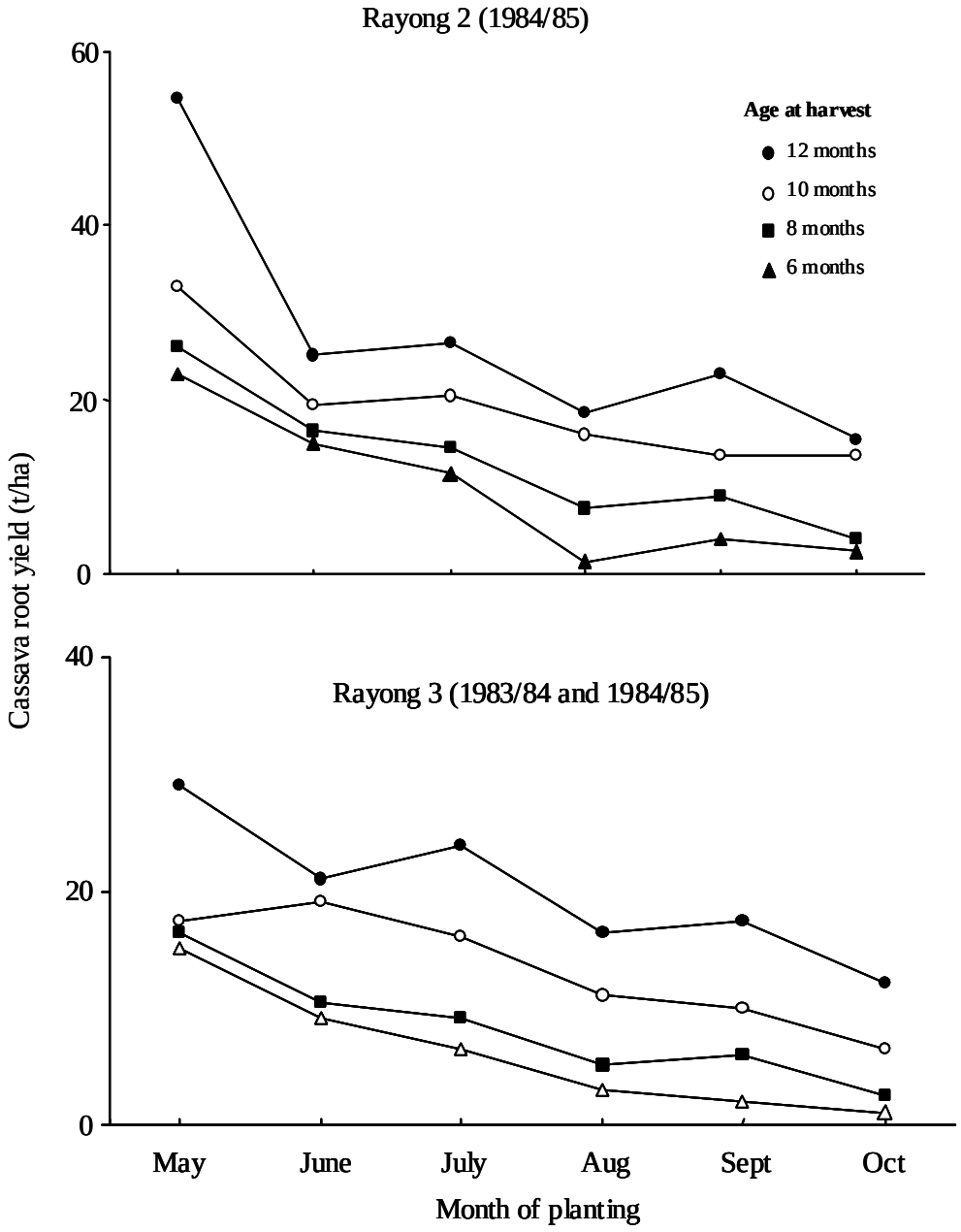

Figure 1. Effect of month of planting and age at harvest on root yields of cassava cultivars Rayong 2 and Rayong 3 planted at Rayong Field Crops Research Center in 1983-1985.

Source: *Field Crops Research Institute, Annual Report 1986.*

Table 4. Fresh and dry root yield and starch content of cassava planted in February, May or November at Sri Racha Research Station, 1987.

Planting time	Fresh root yield (t/ha)	Dry root yield (t/ha)	Root starch content (%)
February	23.11 b[1)]	7.91 b	20.24
May	27.59 b	6.99 b	15.90
November	34.28 a	11.12 a	19.75

[1)]Mean separation within each column: DMRT, 0.01

Source: *Rojanaridhipichet et al., 1986.*

Table 5. Fresh root yield (t/ha) of recommended cassava cultivars when planted in different periods at Rayong Field Crops Research Center, 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: *Field Crops Research Institute, Annual Report 1989.*

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

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

[1)]Mean separation within each column: DMRT, 0.01

Source: *Sinthuprama et al., 1983.*

The optimum age at harvest were also studied at Sri Racha Research Station during 1986-1994. The results reported by Rojanaridpiched *et al*. (1986) show that the root yield depended on rainfall; if there was no rainfall, delaying the harvest would not increase cassava yields (**Table 7**). Another trial by Vichukit *et al*. (1994) was conducted to determine the best harvest time for high root starch content. They reported that when four cassava varieties, i.e. Rayong 1, Sriracha 1, Kasetsart 50, and Rayong 60, were planted in May, the root starch content was still very low at four months after planting (MAP), increased in the late rainy and early dry season, reaching a maximum at 8-9 MAP in Jan-Feb. Since there were some rains in March, the starch content in March and April decreased due to sprouting of new leaves, but increased again in May as the dry period continued. The results indicate that the starch content increased with an increase in age at harvest up to 7-9 months, after which it would depend on the rainfall conditions during the last two months before harvest (**Table 8**).

Table 7. Fresh root yield (t/ha) of cassava planted in May, August, November and February and harvested at either 12 or 14 months at Sri Racha Research Station, 1986.

	Age at harvest (months)			Rainfall (mm) during the 2 months
Planting time	12	14	Yield increase	between harvests
May	27.88	36.45	8.57	272
September	29.39	40.73	11.34	619
November	30.18	30.34	0.16	0
February	16.26	18.51	2.25	22
Mean	25.93	31.51	5.58	-

Source: *Rojanaridhipichet et al., 1986.*

Table 8. Starch content (%) of four cassava varieties planted in May and harvested at monthly intervals at Sri Racha Research Station in 1990/1994. Numbers in parenthesis indicate the age (MAP) at harvest.

	Month at harvest								
Variety	Sept (4)	Oct (5)	Nov (6)	Dec (7)	Jan (8)	Feb (9)	Mar (10)	Apr (11)	May (12)
Rayong 1	9.4	16.7	19.4	19.4	19.8	22.2	14.7	10.6	12.0
Sriracha 1	12.5	18.0	21.5	22.0	23.7	23.0	18.4	15.8	19.1
Kasetsart 50	8.8	16.8	22.5	24.5	24.0	24.8	19.0	16.0	18.5
Rayong 60	10.6	14.0	18.2	19.9	17.2	21.3	13.1	9.2	10.2
Average	**10.3**	**16.4**	**20.4**	**21.4**	**21.2**	**22.8**	**16.3**	**12.9**	**14.9**

Source: *Vichukit et al., 1994.*

3. Land Preparation

On small farms, land preparation was usually done with animal traction at the beginning of the rainy season. On large farms, and presently on nearly all farms, land preparation is done by tractor; the land is plowed as soon as possible after the harvest of the previous crop. A major problem is the lack of tractors, which often results in delayed planting of cassava (Sinthuprama and Tiraporn, 1984). Several land preparation trials have been conducted at Rayong Field Crops Research Center since 1981. The preliminary studies in 1981, indicated that land prepared with the application of post-emergent herbicides but without any tillage gave a similar yield to that obtained with the traditionally prepared land, which includes one plowing by tractor followed by animal ridging (**Table 9**). The minimum tillage concept may be introduced to protect the soil from erosion and to reduce costs of cassava production.

Table 9. Effect of land preparation on the yield of cassava, Rayong 1, at Rayong Field Crops Research Center, 1981.

Treatments	Fresh root yield (t/ha)
No tillage; paraquat+hoeing	33.0
No tillage; paraquat+animal ridging	37.1
Animal plowing 2 times	36.2
Animal plowing 3 times	35.5
Plowing with 3 disc+animal ridging	34.7
Plowing with 3 disc+7 disc	31.6
Plowing with 3 disc+disc harrow	34.9
Plowing with 7 disc+animal ridging	35.2
Plowing with 7 disc 2 times	33.8
Plowing with 7 disc+disc harrow	35.4
Disc harrowing 2 times	34.4
Subsoiling+7 disc	35.8

Source: *Field Crops Research Institute, Annual Report 1982.*

During 1986-1987, trials with various land preparation treatments were also conducted, with the objective to determine the methods of land preparation which could result in high cassava yields and minimum production costs. In 1986 there were six treatments of land preparation, while in 1987 there were two additional treatments, shown in **Table 10**. No-tillage resulted in the same cassava yield as when land was prepared by tractor. However, during both years this treatment resulted in higher production costs per tonne of cassava produced, due to the higher cost of hand weedings. Land preparation with one pass of a tractor with a 7-disc harrow was found to result in the lowest cost per tonne of cassava produced in both years. This practice could be introduced to those areas where weeds are not a serious problem.

4. Plant Spacing and Population

Cassava is traditionally planted at various spacings with both row width and hill spacing ranging from 60 to 120 cm. The first cassava spacing studies were conducted in 1967-1969 at Rayong Field Crops Research Center, to find out the appropriate plant

Table 10. Effect of land preparation on cassava yield, gross income and cost of production, at Rayong Field Crops Research Center in 1986/87 and 1987/88.

Land preparation treatments	1986/87				1987/88			
	Root yield (t/ha)	Gross income (US$/ha)[1)]	Cost of production (US$/ha)	Cost of production (US$/t)	Root yield (t/ha)	Gross income (US$/ha)[1)]	Cost of production (US$/ha)	Cost of production (US$/t)
No tillage; (paraquat+hoeing)	16.31	489	377	23.1	16.38 ab	490	351	21.5
3 disc plow, once	12.94	388	371	28.7	18.06 ab	542	341	18.9
7 disc harrow, once	19.37	581	396	20.4	19.44 a	584	327	16.8
3 disc+7 disc	18.56	557	419	22.6	19.56 a	586	377	19.3
3 disc, twice+7 disc	18.81	565	446	23.7	-	-	-	-
Bullocks, twice	16.69	501	402	25.1	14.44 bc	432	442	30.6
7 disc harrow, twice (in planting strip only)	-	-	-	-	10.44 cd	311	316	30.3
7 disc harrow, twice (planting strip+ridging)	-	-	-	-	9.66 d	289	314	32.5
7 disc+subsoiler	-	-	-	-	16.59 ab	498	327	19.7
F-test	NS[2)]				**[3)]			

[1)]Price of cassava fresh root in 1986 and 1987 = 30 US$/tonne
[2)]Not significantly different.
[3)]Mean separation within a column: DMRT, 0.01
Source: *Tongglum et al., 1990.*

spacing and optimum population of cassava to produce high yields. The results (**Table 11**) indicate that there were no significant differences in yield among spacings ranging from 60x60 cm (27,777 plants/ha) to 120x120 cm (6,944 plants/ha). A wider spacing facilitated inter-cultivation; planting cassava at 1x1 m was recommended (Charoenrath, 1983).

Cassava spacing studies for Rayong 1 were repeated for another two years as component research for the introduction of the cropping system. The results are shown in **Table 12**. When the cassava population was maintained at 10,000 plants/ha, but arranged in various spacings (100x100, 150x66, 200x50 and 300x33 cm) this did not significantly affect the yield.

Research on the spacing of two new cultivars, Rayong 2 and Rayong 3, were also conducted during 1983-1985 at different locations in order to define the best spacings for these new cultivars (**Table 13**). The different yield responses were due to different edafo-climatic conditions at each location. However, the results indicate that both Rayong 2 and Rayong 3 could be planted at populations ranging from 10,000-15,000 plants/ha; plant arrangement may not be very important (Tongglum *et al*., 1987).

5. Planting Methods

Cassava was traditionally planted in various methods; horizontal planting prevailed, but vertical and inclined planting were also done. Various trials were conducted to evaluate these planting methods and to determine which would result in the highest yield. The results of experiments conducted in 1977 and 1978 (**Table 14**) indicate that root

yields were not different for cassava planted on ridges, on the flat, or on the flat followed by earthing-up at 30 days after planting. Horizontal planting gave a lower yield than vertical planting, mainly due to a lower survival rate in the former. Vertical and inclined planting did not result in significant differences in yield. Depth of planting (5, 10 and 15 cm) had no significant effect when planting was done either vertical or inclined (Sinthuprama and Tiraporn, 1984).

Table 11. Fresh root yield of Rayong 1 planted at different spacings at Rayong Field Crops Research Center, 1967-1969.

Spacings (cm)	Number of Plants/ha	Fresh root yield (t/ha)			
		1967	1968	1969	Mean
60 x 60	27,777	20.00	30.94	28.88	28.89
60 x 80	20,833	22.37	30.56	29.94	27.63
60 x 100	16,666	21.63	30.63	29.94	27.38
60 x 120	13,888	21.25	32.44	28.88	27.50
80 x 100	12,500	21.13	34.19	29.00	28.06
80 x 120	10,416	21.38	30.94	30.88	27.75
100 x 100	10,000	22.44	36.50	29.25	29.38
100 x 120	8,333	19.75	34.19	28.69	27.50
120 x 120	6,944	19.25	29.63	27.69	25.50
					NS[1)]

No significant interaction between year and spacing.
[1)]NS = Not significantly different.
Source: *Charoenrath, 1983.*

Table 12. Effect of plant spacings on yield of Rayong 1 (combined analysis for five locations[1)], 1979-1980).

Spacing (cm)	#Plants/ha	Root yield (t/ha)
100 x 100	10,000	29.87
150 x 66.7	10,000	27.06
200 x 50	10,000	26.25
300 x 33.3	10,000	25.06
		NS

[1)]Rayong, Loei, Sakon Nakon, Supanburi and Khon Kaen.
No significant interaction between location and spacing.
Source: *Tongglum et al., 1987.*

Table 13. Effect of plant population and spacing on yield (t/ha) of Rayong 2 and Rayong 3 in different locations, 1985.

#Plants /ha	Spacing (cm)	Rayong 2 cultivar				Rayong 3 cultivar			
		Location			Mean	Location			Mean
		Rayong	Khon Kaen	Banmai Samrong		Rayong	Khon Kaen	Banmai Samrong	
10,000	100x100	14.0	19.9	18.4	17.4	17.7	20.1	15.2	17.7
10,000	125x80	22.8	19.0	12.3	18.1	15.3	18.1	15.1	16.1
12,500	100x80	16.9	15.6	17.4	16.7	20.8	14.2	16.1	17.1
12,500	125x64	15.1	21.5	19.4	18.7	20.3	13.8	12.6	15.6
15,000	90x74	17.4	19.1	23.9	20.1	17.7	12.6	13.5	14.6
15,000	100x66	19.8	18.5	26.2	21.5	19.3	12.3	17.5	16.3
17,500	76x75	20.3	14.6	23.5	19.5	22.0	9.9	16.5	16.2
17,500	100x57	16.5	14.7	20.1	17.1	16.7	11.7	19.9	16.1

LSD (0.05) for spacing of Rayong 2 x location =7.23
LSD (0.05) for spacing of Rayong 3 x location =7.18
Source: *Tongglum et al., 1987.*

Table 14. Fresh root yield (t/ha) of Rayong 1 in different methods, positions and depths of planting at Rayong Field Crops Research Center, 1977-1978.

Treatments	Depth of planting (cm)			Mean
	5	10	15	
Method of planting				
-Ridge	27.75	29.44	28.62	28.62 a
-Flat	30.75	30.44	28.75	29.94 a
-Flat+earthing up	30.56	29.19	27.75	29.19 a
Planting position				
-Vertical	30.87	31.13	30.31	30.75 a
-Inclined	30.62	30.87	29.00	30.19 a
-Horizontal	27.56	27.00	25.81	26.81 b
Mean	29.69 a	29.68 a	28.37 a	

No interaction between methods, positions and depths of planting.
Mean separation: DMRT, 0.01
Source: *Tongglum et al., 1987.*

Farmers are harvesting and planting cassava more and more during the dry season when root starch content is highest and plenty of labor is available. The germination of stakes planted in the dry season is often poor due to low soil moisture content; planting deeper or vertically may improve this situation. Planting on ridges is often desirable in the wet season, but may not be necessary or desirable in the dry season. Two separate experiments were conducted during three consecutive years in the rainy and dry seasons at Rayong Field Crops Research Center in 1987-1989. The results, summarized in **Table 15**, show that in the rainy season (May-Aug) planting cassava stakes in a vertical or inclined

position, with 20 cm stake length and at 5-10 cm depth, resulted in significantly better yields than horizontal planting. Ridging had no significant effect on yield. In the dry season (Nov) planting cassava stakes in the vertical or inclined position also resulted in much higher yields than horizontal planting, and the use of 25 cm stakes planted at 15 cm depth resulted in significantly higher yields than planting 20 cm stakes or planting at shallow depths. Ridging was again not necessary. Planting on ridges may be more advantageous where the planting area is located on slopes or in low lying areas, in order to prevent soil erosion or flooding, respectively (Tongglum *et al*., 1990).

Table 15. Effect of stake position and planting method on cassava yield, planted in both the rainy and dry season at Rayong Field Crops Research Center (Average of 3 years, 1987-1989).

	Rainy season (May-August)				Early dry season (November)			
Treatments	Plants survived ('000/ha)	Plants harvested ('000/ha)	Root yield (t/ha)	Starch content (%)	Plants survived ('000/ha)	Plants harvested ('000/ha)	Root yield (t/ha)	Starch content (%)
Method of planting								
-Ridge	14.57 a	13.96 a	14.98 a	16.64 a	10.69 b	11.76 b	14.69 a	18.63 a
-No ridge	14.43 a	13.96 a	13.47 a	16.66 a	12.09 a	12.99 a	14.96 a	18.65 a
F-test	NS[3)]	NS	NS	NS	**	**	NS	NS
Stake position								
-Vertical	14.87 a	14.51 a	16.04 a	17.03 a	13.04 a	13.97 a	17.74 a	19.04 a
-Inclined	14.89 a	14.47 a	15.46 a	17.14 a	11.99 b	13.04 b	16.40 b	18.68 a
-Horizontal	13.74 b	12.91 b	11.08 b	15.85 b	9.31 c	10.09 c	10.32 c	18.17 b
F-test	**[1)]	**	**	**	**	**	**	**
Stake length (cm)								
-20	14.55 a	13.97 a	14.52 a	16.67 a	10.58 b	11.49 b	14.53 a	18.51 a
-25	14.41 a	13.95 a	13.54 b	16.69 a	13.02 a	14.14 a	15.41 a	18.87 a
F-test	NS	NS	*[2)]	NS	**	**	NS	NS
Planting depth (cm)								
-5-10	14.43 a	13.72 b	13.90 a	16.61 a	9.74 b	10.56 b	13.14 b	18.21 b
-15	14.56 a	14.15 a	14.43 a	16.73 a	12.71 a	13.83 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., 1990.*

6. Stake Size and Storage

Using cassava stems after the harvest for the next crop's planting has become a more serious problem because cassava is now preferably harvested in the dry season. After the harvest, cassava stems are collected and left in the field where they are exposed to the sun for a period of time; this causes the stems to dry up. When there is some rain, farmers start to plant but with poor cuttings the germination and plant survival is low. This problem markedly effects cassava production and also causes poor establishment of

cassava, which finally results in low yields, particularly in areas where cassava planting and harvesting is done in the dry season.

Research on cassava stake size and stem part were first conducted in 1974-1976 at Rayong Field Crops Research Center, in order to determine the best length of cutting and the best part of the stem from which to cut stakes which would result in the highest plant survival rate. The results (**Table 16**) reported by Chankam (1994) indicate that the highest plant survival rate was obtained from stakes of 15-20 cm length, which resulted in a plant survival rate ranging from 83.7 to 95.0%. Cuttings taken from the middle and lower parts of the stem gave higher plant survival rate, ranging from 73.7 to 92.8%, than those taken from the upper part of the stem. **Table 17** shows that the number of buds depends on the length of the stem. The number of cuttings obtained depends on the cutting length, and the longer cuttings would result in a higher plant survival rate than the shorter ones. Again, the cuttings taken from the middle and lower parts of the stem resulted in higher plant survival rates than those taken from the upper part of the stem. These results also indicate that the best age of stems used as planting material is about 10-12 months.

During 1976-1993 several studies were conducted on the effect of time and method of stem storage on plant survival of Rayong 1, Rayong 3, Rayong 60, Rayong 90 and Rayong 5. Results for Rayong 1, shown in **Table 18**, indicate that the survival rate of stakes taken from stems stored up to 30 days in the field was higher than 80%. Storage of stems under shade tends to be a better method than storage in full sun (Sinthuprama and Tiraporn, 1984).

Further studies were conducted separately with Rayong 1, Rayong 3 and Rayong 60 cultivars in 1989/1990, as well as with Rayong 90 and Rayong 5 cultivars in 1991/1993. The portion of the stems still available for cutting stakes, as well as the plant survival rate were quantified. The results of both experiments (**Table 19**) indicate that stems of all cultivars stored under shade resulted in a greater proportion of the stem available for use as planting material and better plant survival. It was found that stems of Rayong 1, Rayong 60, Rayong 5 and Rayong 3 could be stored up to 30 days, with a plant survival rate of

Table 16. Effect of stake length and part of stem from which stakes are cut on plant survival of Rayong 1 at 30 days after planting at Rayong Field Crops Research Center, 1974-1976.

Treatments	Survival (%)
Stake length (cm)	
5	59.93
10	72.73
15	83.67
20	95.00
Part of stem	
Upper	49.87
Middle	73.67
Lower	92.80

Source: *Tongglum et al., 1987.*

Table 17. Effect of stem age, stake length and part of stem from which stakes are cut on survival of Rayong 1 at Rayong Field Crops Research Center, 1974 -1976.

	Stem age (months)				
	4	6	8	10	12
Stem length (cm)	153	181	201	266	282
# Buds/stem	62	69	93	113	137
Stake length (cm)					Survival (%)
5					48.6
10					77.5
15					88.8
Part of stem					
Upper					58.7
Middle					92.1
Lower					98.6

Source: *Chankam, 1994.*

Table 18. Plants survival (%) from stakes stored under different conditions and for various periods at Rayong Field Crops Research Center, 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 et al., 1984.*

about 80%; longer stem storage resulted in lower plant survival rate in all cultivars. Since Rayong 3 is characterized by a branching plant type, the storability of Rayong 3's branches to be used as planting material was also studied. It was found that the primary branches of Rayong 3 could be stored for only 15 days; storage beyond 15 days decreased both the portion of available stem and plant survival (Chankam, 1994). A similar trend was observed in Rayong 90, the stored stems of which had a lower proportion available as planting material, and plant survival percentage decreased markedly when stems were stored beyond 15 days.

Table 19. Effect of storage time and method on available part (%) and plant survival (%) of Rayong 1, Rayong 3, Rayong 60 and Rayong 90 at 30 days after planting at Rayong Field Crops Research Center, 1989/90 and 1991-1993.

Storage time (days)	Storage method											
	1989/90								1991-1993			
	In sun				Under shade				In sun		Under shade	
	Rayong 1	Rayong 3 A	Rayong 3 B	Rayong 60	Rayong 1	Rayong 3		Rayong 60	Rayong 90	Rayong 5	Rayong 90	Rayong 5
	Available part (%)											
15	94	88	84	93	94	84	84	93	75	77	64	69
30	94	87	73	90	93	79	74	91	61	69	61	68
45	78	57	43	76	84	65	46	83	57	64	54	62
60	76	56	0	73	76	57	0	76	47	60	52	58
	Plant survival (%)											
15	83	66	31	78	86	59	26	80	76	85	77	95
30	97	88	46	82	94	83	50	80	75	79	66	90
45	91	68	20	93	97	70	44	88	57	65	63	70
60	64	14	0	47	64	0	0	50	45	64	50	67

A= main stem; B= branch of Rayong 3

Source: *Chankam, 1994; Rayong Field Crops Research Center, Annual Report 1993.*

In 1981/1982, various cassava cultural practices were tested in five farmers' fields, using a package of technology at two levels: 1) high technology which included the use of selected cuttings from the middle and lower parts of the stem, cut at 10-12 months, treated with both fungicide (Captan 600 gm/100 liters of water) and insecticide (Omethoated 100 cc/100 liters of water) to prevent damage of cuttings, ridging and application of chemical fertilizer 15-15-15, applied at 312 kg/ha; and 2) low technology, which included the use of selected cuttings as indicated above but without fungicide or insecticide treatment, planted on the flat without any fertilizer application; these two levels of technology were compared to the traditional practices used by farmers. The results (**Table 20**) indicate that with the high technology yields were 51% higher than with the traditional practices, while with low technology (only selected planting material), the yield was 16% higher than with the traditional practices.

Table 20. Effect of cassava cultural practices on yield and economic returns in farmers' field trials conducted in Rayong province in 1981/82 and in 1986/87.

	Average of five farmers' fields 81/82		Average of three farmers' fields 86/87				
Treatments	Root yield (t/ha)	Yield increase (%)	Root yield (t/ha)	Gross income (US$/ha)	Production costs (US$/ha)	Net income (US$/ha)	Unit cost (US$/t)
High technology	29.00	51	22.56	704.25	524.75	179.50	23.26
Low technology	22.19	16	14.50	453.25	298.00	155.25	20.55
Farmers' practice	19.13	-	11.50	358.75	249.00	109.75	21.65

Source: *Tongglum, 1991.*

These field tests were repeated in 1986/87 on three farmers' fields to further quantify the yield and the costs of cassava production. The results showed the same trends as those obtained in 1981/82. The farmers' practice resulted in the lowest cost of production, but this also resulted in the lowest net income. The results indicate that farmers can prevent considerable yield losses by practicing simple selection of planting material (Tongglum, 1991).

7. Root Storage

Tiraporn and Narintaraporn (1983) studied the effect of cassava root storage duration on root deterioration. The results, shown in **Table 21**, indicate that after harvest, roots can be stored for up to only two days. Longer storage caused a significant decrease in starch content and increase in root deterioration. Therefore, it is recommended that cassava growers and factories dealing with cassava prevent root damage by either selling or processing their roots within 2-4 days after harvest.

8. Weed Control

Cassava yields can be markedly reduced by competition from weeds. It has been reported that yields may be reduced 25-50% if weeds are not controlled, particularly at the early growth stage (Tirawatsakul, 1983). Traditionally weed control was done by animal

and hand labor, which accounted for 40% of total labor used in cassava production (Sinthuprama and Tiraporn, 1984). Due to the high cost and lack of labor, several experiments on weed control were conducted during 1987-1991 with the objective of minimizing the number of times and cost of weed control in cassava. The results, shown in **Table 22**, indicate that the pre-emergence herbicide Metholachlor, applied at a rate of 1.56 kg ai/ha, could control 90% of the weeds during the first three months after planting, and this treatment resulted in a high yield at the lowest production cost. Tongglum *et al*. (1992) also studied the effect of frequency of weeding on the yields of two recommended varieties, Rayong 3 and Rayong 60. The results show that two times of hand weeding, at 1 and 2 months after planting, gave the best results for both varieties (**Table 23**). The results also indicate that weeding costs varied according to the planting season, the cost being much higher when cassava was planted in the early rainy season than in the dry season.

During 1993-1995, additional experiments on weed control for cassava were conducted at Khon Kaen Field Crops Research Center in the northeast of Thailand. Rayong 1, Rayong 60 and Rayong 90 cultivars were planted in both the early and late rainy seasons. Plots were weeded for either 0, 2, 3 or 4 months as compared to a typical "farmer" practice of manual weeding only at 2 MAP and without fertilizer application. Results shown in **Table 24** indicate that weed control is extremely important during the first two months after planting, but weed control beyond 2 MAP did not significantly increase yield any further. The highest yields were obtained when plots were maintained weed-free for 3 MAP. Thus, when cassava is planted in either the early or late rainy season, these three cassava cultivars need to be free of weeds for about 2-3 months after planting to produce high yields.

CASSAVA-BASED CROPPING SYSTEMS

1. Intercropping Systems

Studies on land use efficiency and restoration of soil fertility through intercropping have been conducted since 1970, using peanut, mungbean and soybean as the intercrops. The most promising intercropping systems appeared to be the combination of cassava and peanut or cassava and mungbean (Sinthuprama *et al.*, 1983).

Table 21. Effect of root storage duration on root starch content and deterioration at Rayong Field Crops Research Center, 1976-1978.

Storage duration (days)	Starch content (%)	Deterioration (%)
0	23.84 a[1)]	0 d[1)]
2	23.01 a	0.61 d
4	20.08 b	8.25 c
6	10.89 c	27.00 b
8	7.12 d	40.12 a

[1)] Mean within each column separated by DMRT at 0.01% level.
Source: *Tiraporn et al., 1983.*

Table 22. Effect of various chemical weed control methods in cassava (Rayong 1) on yield and economic benefits at Rayong Field Crops Research Center, Rayong, Thailand, in 1987/1988.

Treatment	Root yield (t/ha)	Gross income (US$/ha)	Weeding cost (US$/ha)	Net income[1)] (US$/ha)
1. Metolachlor (1.56 kg a.i./ha); PE[2)]	26.82 a[3)]	955	230	725
2. Oxyfluorfen (1.56 kg a.i./ha); PE	21.26 b	757	234	523
3. Metolachlor (1.56 kg a.i./ha); PE-B +Paraquat (0.50 kg a.i./ha); ST	25.76 ab	917	234	683
4. Metolachlor (1.56 kg a.i./ha); PE +once bullock cultivation +Fluazifop-buty1(0.38 kg a.i./ha); PE	25.66 ab	914	268	646
5. Metolachlor (1.56 kg a.i./ha); PE +Fluazifop-buty1(0.38 kg a.i./ha); ST	27.00 a	961	258	703
6. Twice bullock cultivation +Paraquat (0.50 kg a.i./ha); ST	26.84 a	956	237	719
F-test	**	-	-	-

[1)] Root price = US$ 35.6/tonne
[2)] PE = Pre-emergence
PE-B = Pre-emergence, band spraying
ST = Spot treatment
Herbicide application rates are in kg active ingredient/ha.
[3)] Mean within a column separated by DMRT at 0.01% level.
Source: *Tirawatsakul et al., 1988.*

Table 23. 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 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.*

Table 24. Effect of weed control on the yields (t/ha) of three cassava varieties planted in the arly (ER) and late (LR) rainy seasons at Khon Kaen, Thailand, in 1993/94 and 1994/95.

	1993/94		1994/95		Average 2 years		Average
	ER	LR	ER	LR	ER	LR	2 seasons
Cultivars (C)							
-Rayong 1	28.33	19.53	10.86	17.23	20.97	18.38	19.67
-Rayong 60	23.33	27.68	15.11	14.59	19.22	21.13	20.18
-Rayong 90	25.03	21.88	11.33	12.25	18.18	17.06	17.62
F-test (C)	NS	*	*	NS	NS	*	NS
Weed-free period (W)							
-0 month (check)	2.61	13.48	4.49	5.63	5.83	9.56	7.69
-2 months	31.98	26.43	16.71	15.52	24.34	20.98	22.66
-3 months	34.71	26.03	13.84	19.20	24.28	22.61	23.44
-4 months	31.47	24.96	13.73	17.54	22.59	21.25	21.93
-farmers' practice[1)]	27.07	24.25	13.39	15.54	20.23	19.89	20.06
LSD (0.05) for W	6.73	7.38	4.97	5.82	5.51	4.70	3.56
F-test (W)	**	**	**	**	**	**	**
F-test (CxW)	NS	NS	**	NS	NS	NS	NS

[1)]Farmers' practice = manual weed control at 2 months with no fertilizer applied.
Source: *Khon Kaen Field Crops Research Center, Annual Report 1995.*

From 1976 to 1978, in order to improve the system, cassava was intercropped with each species of legume, planted in 1, 2 or 3 rows between cassava plants spaced at 1x1 m. The results indicate that increasing the number of rows of the intercrops reduced cassava yields. Two rows of intercrops was considered the best system (Charoenrath, 1983).

During 1982-1983, research on the effect of using a wider row spacing of cassava in combination with different patterns of intercropping indicate that root yields were reduced by the presence of the legumes and *vice versa*, but the Land Equivalent Ratios (LER) were always above 1.00, indicating that the intercropping system had a greater total productivity than cassava monocropping. The highest LER values were obtained when cassava was planted at a spacing of 125x80 cm, with two rows of either peanut or mungbean planted between cassava rows at a spacing of 20x10 cm (Tongglum *et al*., 1987).

In 1988-1989, a study on the spatial arrangement of cassava intercropped with mungbean, peanut and soybean was conducted to determine the optimum spacing for intercropped cassava, which would produce high yields of both the intercrops and cassava. Intercrops were arranged in four patterns with either 2 or 3 rows of legumes planted between cassava rows (spaced at 180 cm), while the intercrop rows were planted at either 45 or 60 cm from the cassava rows. All four intercropping patterns maintained the same legume population of 200,000 plants/ha as in legume monoculture, while both intercropped and monoculture cassava had a population of 10,000 plants/ha. The results indicate that intercropping cassava with any of the three grain legumes produced a higher gross income

than cassava grown in monoculture, while intercropping with peanut produced the highest gross income. Keeping the intercrops 60 cm from the cassava rows resulted in higher cassava yields and gross incomes than when intercrops were grown at 45 cm from the cassava rows (Tongglum *et al*., 1990).

Long-term cassava intercropping experiments have been conducted at Rayong Field Crops Research Center, Thailand, since 1975, to study the effect of the intercrops on soil nutrient depletion in continuously planted cassava. Short-duration crops such as sweet corn, mungbean, peanut and soybean were intercropped yearly with cassava, and each five years cassava was planted as a monocrop without fertilization. The results indicate that the yields of both cassava and the intercrops fluctuated due to different competitive effects with different climatic conditions each year. After the first five years the yield of monocropped cassava was not significantly affected by the previous intercropping treatments. It was concluded that the intercropped legumes had no long-lasting effect on soil productivity (Tongglum *et al*., 1987). The experiment was continued for two more 5-year periods (1981-1987 and 1988-1993). Similar fluctuating yields of cassava and intercropped legumes were obtained during these second and third 5-year periods (**Tables 25** and **26**). After six years of the second cassava intercropping period, the yield of monocropped cassava (in the 7^{th} year) without fertilizer application was significantly higher after continuous intercropping of cassava with soybean. These results seems to indicate a positive effect of the intercropped soybean, which might result in an increase in long-term cassava productivity. In the third cycle, after five more years of intercropping cassava, the yield of the cassava monocrop during the sixth year was not significantly affected by any of the previous intercropping treatments. Nevertheless, soil analysis of the long-term cassava intercropping experiment (**Figure 2**) shows an increasing trend in soil organic matter with the intercropped cassava treatments. Composite soil samples were taken at the beginning of the trial, and their analysis indicate an initial organic matter content of 1.01%. After the harvest of the first and second year, the intercropped treatments had higher organic matter contents than the monocropped cassava, especially those intercropped with soybean and peanut. Organic matter contents fluctuated depending on the climatic conditions each year, which affected the crops' growth. From the 12^{th} to the 24^{th} year of the trial, soil analysis results indicate a long-term positive effect on soil organic matter content, which increased by intercropping cassava with peanut and soybean. Cassava intercropping may take some time to show an increase in soil organic matter by the incorporation of the residues of the intercrops; this may contribute to improved soil fertility. Since the trial is a long-term study, the result still needs further confirmation with additional soil analyses and yield data of the cassava monocrop planted at the end of another intercropping cycle.

The results of long-term experiments on cassava intercropping with short-duration crops during 1975-1979, 1981-1986, 1988-1992 and 1994-1998 are summarized as the average for 21 years, in order to quantify the effect of intercropping cassava as compared to monocropped cassava. The results, shown in **Table 27**, indicate that all intercrops reduced cassava yields, ranging from 5 to 13%, as compared to monocropped cassava. Intercropping with sweet corn had the least effect on cassava yield. However, intercropping cassava with soybean, mungbean, peanut and sweet corn increased gross income 33, 35, 72 and 158%, respectively.

Table 25. Yield (t/ha) of cassava (C) and intercrop (INT) species in a long-term cassava intercropping trial conducted at Rayong Field Crops Research Centera, 1981-1987.

Intercropping patterns	Year												
	1981		1982		1983		1984		1985		1986		1987
	C	INT	C	INT	C	INT	C	INT	C	INT	C	INT	C
Cassava monoculture	29.2	-	15.2	-	5.9	-	25.1	-	17.4	-	19.9	-	22.5 bc[3)]
Cassava+sweet corn[1)]	31.3	27.2	19.2	18.8	9.9	17.8	26.3	9.7	14.5	0[2)]	21.9	13.9	25.7 ab
Cassava+mungbean	24.4	0.88	14.6	0.76	7.6	0.78	21.3	0.66	10.8	0	17.9	0.09	21.6 c
Cassava+peanut	23.5	1.35	13.4	1.28	8.9	1.24	21.2	0.92	11.8	0	21.4	0.31	24.6 abc
Cassava+soybean	29.1	0.63	14.1	1.52	8.9	0.58	18.7	0.93	11.9	0	17.4	0.63	26.8 a
F-test													*

[1)]Sweet corn yield in '000 cobs/ha.
[2)]Drought in 1985 caused complete intercrop yield loss
[3)]Means in a column separated by DMRT at 0.05%
Source: *Rayong Field Crops Research Center, Annual Report 1998.*

Table 26. Yield (t/ha) of cassava (C) and intercrop (INT) species in a long-term cassava intercropping trial conducted at Rayong Field Crops Research Center, 1988-1993.

Intercropping patterns	Year										
	1988		1989		1990		1991		1992		1993
	C	INT	C	INT	C	INT	C	INT	C	INT	C
Cassava monoculture	9.9	-	11.8	-	15.3	-	18.1	-	27.9	-	22.8
Cassava+sweet corn[1)]	10.2	9.8	13.4	12.7	14.9	0[2)]	15.6	15.3	30.7	20.1	26.2
Cassava+mungbean	9.1	0.33	13.6	0.16	13.4	0.19	17.5	0.55	32.9	0.23	26.4
Cassava+peanut	7.3	0.22	13.4	0.93	11.8	0.41	13.2	1.42	24.9	1.94	28.3
Cassava+soybean	5.9	0.33	12.3	0.56	10.4	0	12.0	0.47	27.2	0	27.2
F-test											NS

[1)]Sweet corn yield in '000 cobs/ha.
[2)]Drought in 1990 and 1992 caused complete yield loss of some intercrops
NS = not significantly different.
Source: *Rayong Field Crops Research Center, Annual Report 1998.*

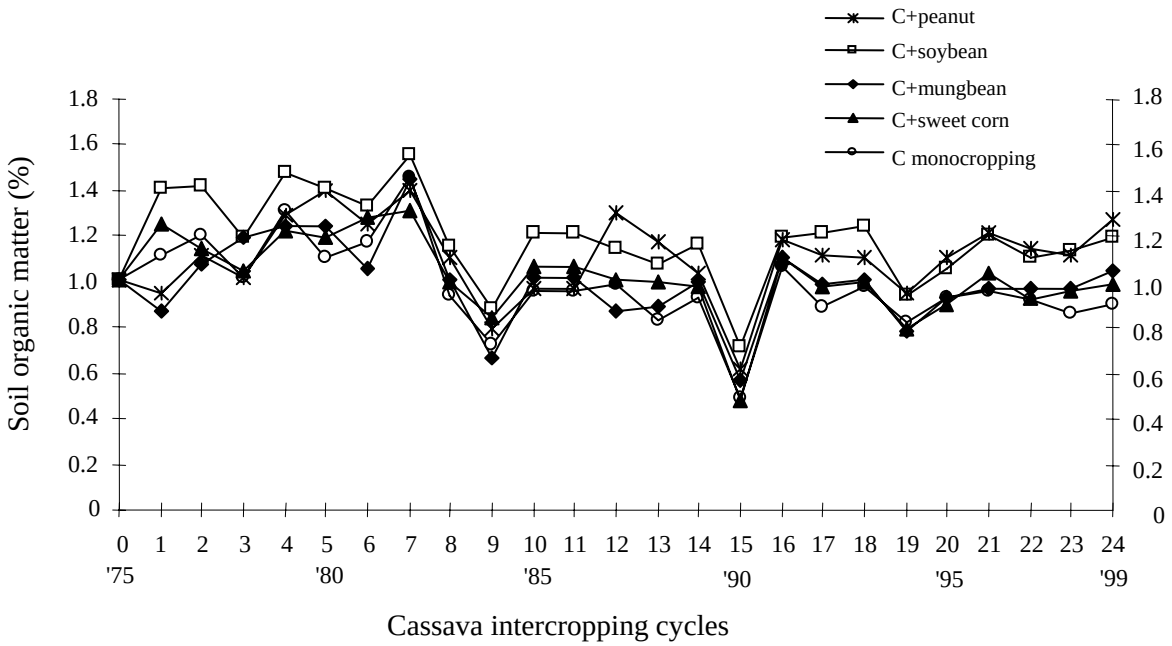

Figure 2. Percent organic matter as affected by different cassava intercropping patterns during 24 consecutive crops grown at Rayong Field Crops Research Center, Rayong, Thailand, from 1975 to 1999.
Source : *Rayong Field Crops Research Center, Annual Report 1999.*

Intercropping is a very intensive crop management system. Therefore, the system should be introduced to either small cassava growers who own their land and/or in areas located on slopes where adequate labor is still available.

CASSAVA SOIL CONSERVATION AND FERTILITY MAINTENANCE

1. Cultural Practices for Erosion Control

Cassava in Thailand is normally planted on flat or undulating land (0-10% slope) having soils with sandy loam and/or loamy sand texture. The rather wide spacing used as well as the slow growth during the first three months after planting results in the soil being exposed to the direct impact of raindrops, causing high soil loss due to erosion and a decrease in yield.

In 1988/89, the effect of soil and crop management on cassava yield and soil loss due to erosion was studied on 5% slope at Pluak Daeng in Rayong province, Thailand. **Table 28**, shows the effect of various land preparation and intercropping systems on the loss of soil and soil fertility. The results indicate that intercropping cassava with peanut, mungbean and soybean was very effective in reducing soil loss, with an average soil loss of 25.7 t/ha/year, as compared to 53.2 t/ha/year for the conventional monocropped cassava; this logically meant a much lower loss of soil fertility.

Table 27. Cassava (C) and intercrops (INT) species yield (t/ha) and gross income (US$/ha) in a long-term intercropping trial conducted at Rayong Field Crops Research Center during 1975-1979, 1981-1986, 1988-1992 and 1994-1998. Date are average values of 21 experiments.

Intercropping patterns	Yield (t/ha)		Relative cassava yield (%)	Gross income (US$/ha)		Total gross income	Relative gross income (%)
	C	INT		C	INT		
Cassava monoculture	20.15	-	100	55.16	-	55.16	100
Cassava + sweet corn[1)]	19.92	20.20	99	54.52	87.52	142.05	258
Cassava + mungbean	19.18	0.59	95	52.48	22.23	74.70	135
Cassava + peanut	17.96	1.08	89	49.15	45.50	94.65	172
Cassava + soybean	17.50	0.76	87	47.88	25.65	73.53	133

[1)]Sweet corn yield in '000 cobs/ha.

Price of crops : sweet corn 2.63 US$/100 cobs
mungbean dry grain 236.84 US$/tonne
peanut dry pods 263.16 US$/tonne
soybean dry grain 210.53 US$/tonne
cassava fresh roots 17.10 US$/tonne

Source: *Rayong Field Crops Research Center, Annual Report 1998.*

Table 28. Effect of various cassava intercropping systems on dry soil and soil fertility loss as compared to cassava monocropping using various land preparation practices on loamy sand with 5% slope at Pluak Daeng, Rayong, in 1988/89.

Treatment	Dry soil loss (t/ha)	Fertility loss (kg/ha)[1)]		
		OM	P	K
Intercropping systems (with fertilizers)				
-Cassava + peanut	28.63	241	0.69	1.75
-Cassava + mungbean	23.81	200	0.56	1.44
-Cassava + soybean	24.69	208	0.56	1.50
Average	**25.71**	**216**	**0.60**	**1.56**
Cassava monoculture				
-7 disc+7 disc, without fertilizers	69.81	586	1.63	4.31
-3 disc+7 disc, with fertilizers	34.94	293	0.81	2.13
-7 disc+7 disc, with fertilizers	47.81	402	1.13	2.94
-7 disc+7 disc, up/down ridges, with fertilizers	60.44	508	1.44	3.69
Average	**53.25**	**447**	**1.25**	**3.27**

[1)]loss of organic matter (OM), available P and exchangeable K based on analyses of soil sediments in the same experiment with on average 0.84% OM, 23.4 ppm available P and 61.3 ppm exchangeable K

Source: *Tongglum et al., 1994.*

Experiments were also conducted in cassava farmers' fields in Rayong province during 1994 to 1996 to determine the most appropriate cultural practices for erosion control which will reduce soil loss and maintain a high cassava yield. The results of two years of experiments, shown in **Table 29**, indicate that planting on contour ridges at closer spacing

of 0.8x0.8 m, and with application of 312 kg/ha of 15-15-15 chemical fertilizers, gave the best results, reducing soil erosion and increasing cassava root yields.

Table 29. Effect of various cultural practices on cassava yield and on soil erosion in on-farm trials conducted in four locations of Rayong province, Thailand, in 1994/95 and 1995/96. Data are average values of four locations in each year.

	1994/95				1995/96			
Treatment	Plants harvested /ha	Root yield (t/ha)	Starch content (%)	Total dry soil loss (t/ha)	Plants harvested /ha	Root yield (t/ha)	Starch content (%)	Total dry soil loss (t/ha)
1x1m, no ridges, no fertilizers	8,331 b	11.81 b	17.20	23.56	9,363 c	11.50 c	17.70	18.50 ab
1x0.6m, no ridges+fertilizers[1)]	14,088 a	14.56 ab	16.65	38.63	15,481 a	18.56 ab	17.73	26.75 a
1x0.6m, contour ridges+fert.	14,106 a	17.75 a	16.88	17.94	15,750 a	21.75 a	19.35	8.56 b
1x0.6m, no ridges, no fert.	14,631 a	11.75 b	19.25	24.75	15,269 a	13.00 bc	20.05	15.31 ab
0.8x0.8m, contour ridges+fert.	14,438 a	18.75 a	18.38	20.50	14,869 ab	22.75 a	20.30	10.25 b
Farmers' practices	14,306 a	15.38 ab	17.20	23.81	13,656 b	19.75 a	18.05	10.69 b
F-test	**[2)]	**	NS[3)]	-	**	**	NS	**
CV(%)	6.86	14.68	10.77	-	4.63	15.42	7.80	39.99

[1)]+fertilizers = 312.50 kg/ha of 15-15-15 compound fertilizers

[2)] Mean within each colomn separated by DMRT at 0.01%

[3)] NS = not significantly different

Source: *Tongglum et al., 1996; Rayong Field Crops Research Center, Annual Reports 1995 and 1996.*

2. Long-term Effect of Fertilizer Application

Sittibusaya *et al*. (1987) reported that during 1954-1980, many fertilizer trials were conducted on farmers' fields; it was found that if no fertilizers were applied to cassava, soil productivity steadily declined causing a decrease in root yields in three major cassava soils, i.e. Korat, Sattahip and Huaipong soil series. The decline in yields could be attributed mainly to the fact that cassava growers seldom fertilize the land sufficiently and to the methods of cultivation used, which caused severe soil erosion and nutrient loss. Much research has been conducted to try to solve this problem.

During 1975-1999 three experiments on the long-term effect of fertilizer application in cassava were conducted at Khon Kaen and Rayong Field Crops Research Centers and at Banmai Samrong Field Crops Research Station; these represent the major cassava growing areas in Thailand. The results of 23 years of continuous cassava cropping at Khon Kaen, and 24 years at Banmai Samrong and Rayong, shown in **Figures 3, 4** and **5**, respectively, indicate a clear response of cassava to annual fertilizer applications in all three locations. Without fertilizer application cassava yields declined over time, especially in Khon Kaen. The omission of K reduced cassava yields more than the omission of either P or N, while the annual incorporation of cassava tops after harvest resulted in a marked increase in cassava yields, especially in the absence of chemical fertilizers. The combined application of complete chemical fertilizers with municipal compost tended to result in the highest cassava yields. Based on these results, cassava growers have been recommended to apply chemical fertilizers that are high in K and N, and low in P, such as compound fertilizers in the ratio of 2:1:2 or 2:1:3.

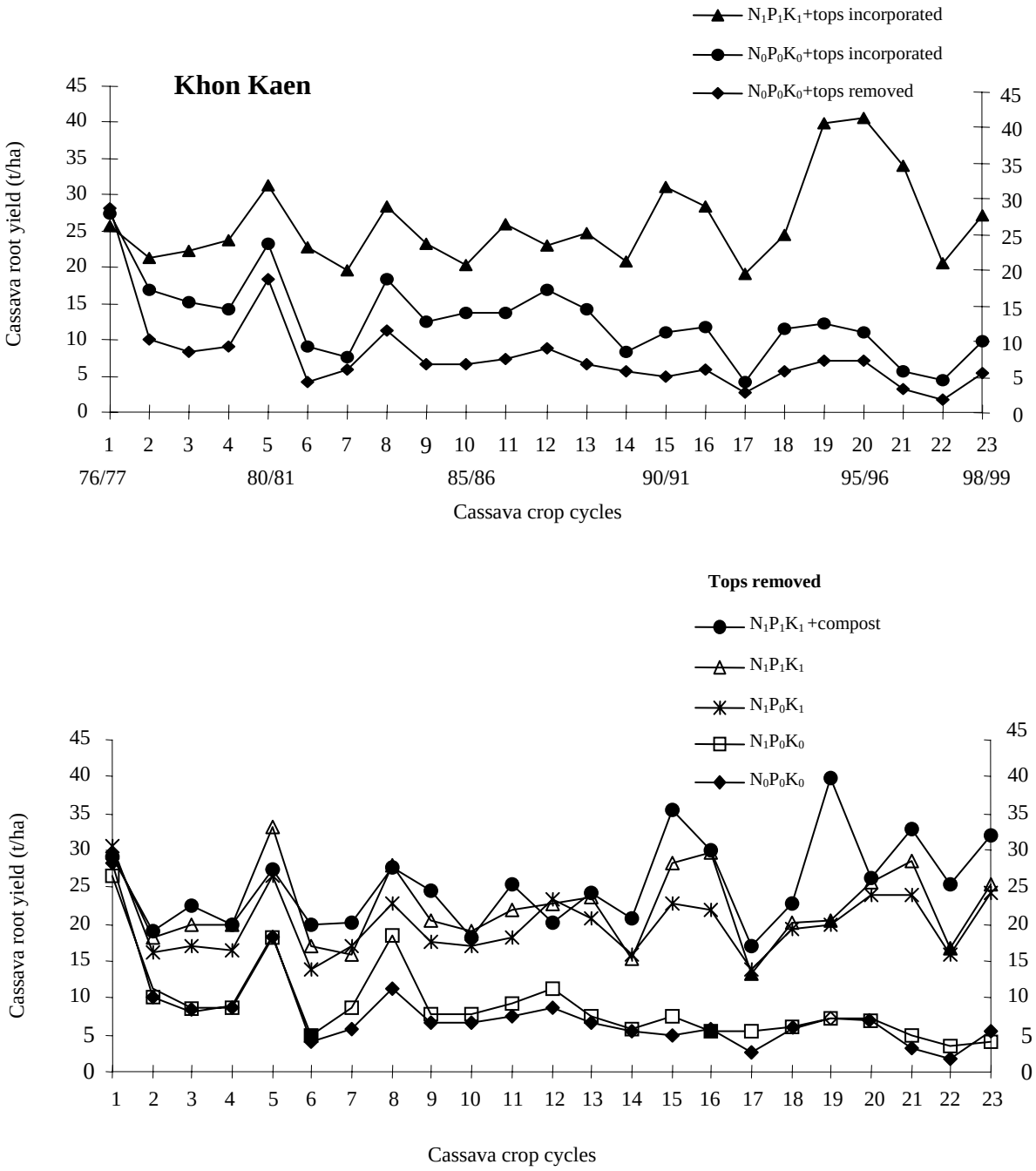

Figure 3. Effect of annual fertilizer application and crop residue management on cassava yields during 23 consecutive crops grown in Khon Kaen, Thailand.
Source : *Chumpol Nakviroj and Kobkiet Paisancharoen, Soils Division, DOA, Bangkok.*

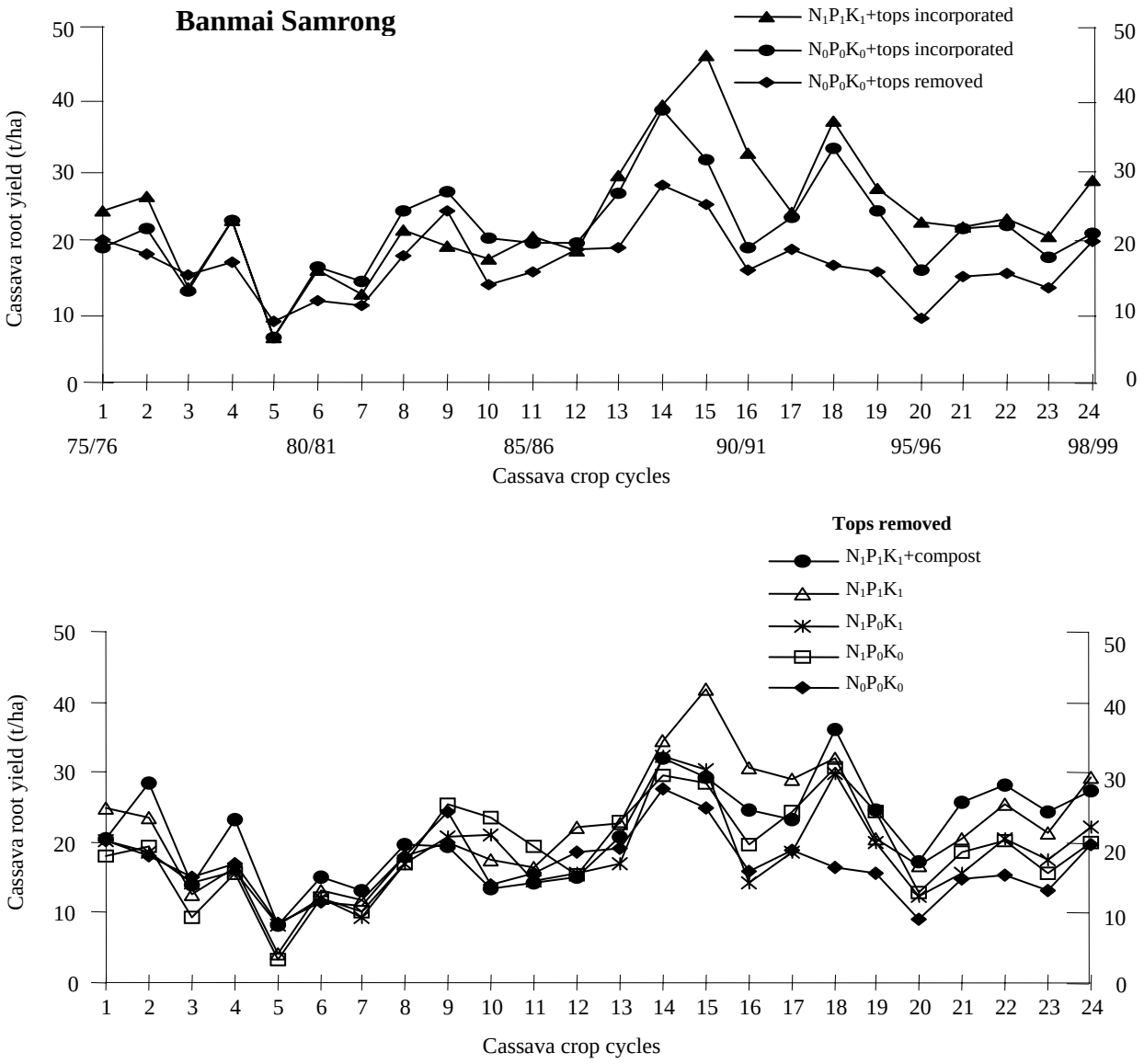

Figure 4. Effect of annual fertilizer application and crop residue management on cassava yields during 24 consecutive crops grown,in Banmai Samrong, Nakorn Ratchasima,Thailand.
Source: *Chumpol Nakviroj and Kobkiet Paisancharoen Soils Division,DOA,Bangkok.*

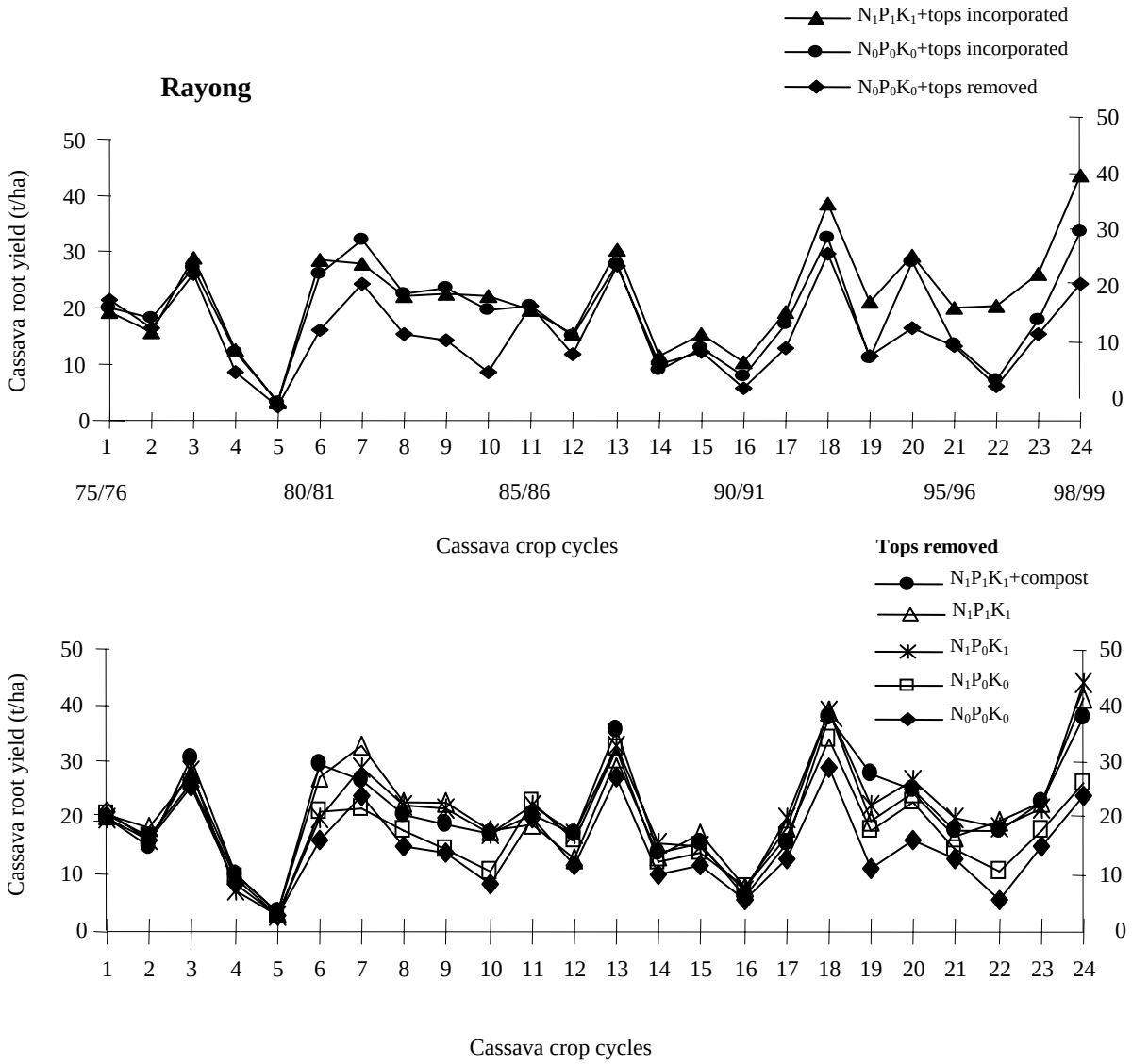

Figure 5. Effect of annual fertilizer application and crop residue management on cassava yields during 24 consecutive crops grown in Rayong, Thailand.
Source : *Chumpol Nakviroj and Kobkiet Paisancharoen, Soils Division, DOA, Bangkok*

3. Soil Management

Research on the long-term effect of various soil management practices on cassava production has been conducted at Khon Kaen Field Crops Research Center from 1980 to 1994. The objective of the trial was to determine the most appropriate soil management system to maintain soil fertility and sustain high cassava yields. Rayong 1 was used as the test cultivar. The results, shown in **Table 30**, indicate that cassava rotated with peanut-pigeon pea, and with either chemical fertilizer alone or in combination with soil

amendments, produced the highest cassava yields in the 19th year. These results should be complemented with soil analysis data to confirm the effect on soil fertility. Nevertheless, the results indicate that with suitable soil/crop management the long-term productivity of cassava can be sustained.

These results have led to better recommendation to cassava growers who plant cassava in areas located on either unfertile soil and/or on undulating land, and they are now more aware of the need for soil conservation and fertility maintenance.

Table 30. Long-term effect of various soil management treatments on the yield (t/ha) of cassava grown at Khon Kaen, Thailand from 1980 to 1999.

Treatments	Soil management				Average
	Check[1)]	Fertilizer[2)]	Soil amendment[3)]	Fertilizer+ soil amendment	
1st Year (1980)					
Continuous cassava monocropping	30.13	32.38	20.38	26.63	27.38
Cassava rotated with peanut-pigeon pea[4)]	27.88	26.81	18.63	22.88	24.05
Cassava intercropped with peanut[5)]	18.81	27.00	27.31	28.81	25.48
Average of 1st year	**25.61**	**28.73**	**22.11**	**26.11**	**25.64**
19th Year (1999)					
Continuous cassava monocropping	13.38	39.13	29.81	38.31	30.13
Cassava rotated with peanut-pigeon pea[4)]	15.00	42.88	33.50	38.44	32.44
Cassava intercropped with peanut[5)]	12.50	21.06	17.63	18.63	17.44
Average of 19th year	**13.63**	**34.38**	**27.00**	**31.81**	**26.69**
Relative to 1st year (%)	53.22	119.67	122.12	121.83	104.60

[1)]No fertilzers or soil amendments

[2)]Applied 50-50-50 kg/ha of N-P_2O_5-K_2O for cassava or 18.75-56.25-37.50 kg/ha of N-P_2O_5-K_2O for peanut in crop rotation treatment

[3)]Applied 1250 kg/ha of lime and rock phosphate (3% P_2O_5) with 18.75 t/ha of compost in 1st, 5th, 9th, 13th, 17th and 19th year (1980, 1984, 1988, 1992, 1996 and 1999).

[4)]Crop rotation by planting cassava and peanut-pigeon pea in alternate years; after harvest of the sequentionally planted legumes, the residues were incorporated into the soil before the following year's planting of cassava.

[5)]two rows of peanut were intercropped between cassava rows. After harvest of peanut the residue was used as mulch.

Source: *Chairoj Wongviwatchai, Khon Kaen Field Crops Research Center, Khon Kaen, Thailand.*

ADOPTION OF IMPROVED CULTURAL PRACTICES

During the past 35 years the Dept. of Agriculture and Kasetsart University have done intensive research on cassava breeding and agronomy with the objective of developing higher yielding varieties and cultural practices that would increase yield and protect the environment. Starting in the mid 1980s new varieties were released periodically together with information on recommended practices. In 1993 the area planted to a new variety, Rayong 3, reached 100,000 ha (Klakhaeng *et al*., 1995). With the active participation of the Dept. of Agric. Extension in varietal release sinds the early 1990s the area under new varieties and the number of farmers adopting improved cultural practices increased markedly. Data from the Dept of Agric. Extension (DOAE) revealed that in 1997 already 660,000 ha of cassava (63% of the total cassava area) were planted to newly released varieties.

Since 1994 both DOA and DOAE have been actively involved in the Nippon Foundation-supported Farmer Participatory Research (FPR) project, which involves the conducting of research by cassava farmers with the help of officials from both departments, not only on soil conservation but also on varieties, intercropping and fertilization practices.

In 1993, the recently founded Thai Tapioca Development Institute (TTDI) established a new 260 ha "Center for Cost Reduction in Cassava Production" in Huay Bong village of Nakhon Ratchasima province, with the initial objective of producing and distributing planting material of newly released varieties, and training of cassava farmers in improved cultural practices (Rojanaridpiched *et al*., 1998). From 1995 to 1999 a total of 23,413 cassava farmers had participated in 2-3 day training courses at TTDI. These courses covered all production aspects, from cassava varietal characteristics to fertilization and soil conservation. Many farmers also received planting material of new varieties. In 1999 a questionnaire was sent out by TTDI to 800 leaders of farmers groups in 32 provinces that had passed through these training courses. A total of 527 questionnaires were returned. **Table 31** summarizes the results. It is clear that many recommended practices have now been adopted, at least by the more progressive cassava farmers, including the planting of new varieties (79%), the application of chemical fertilizers (about 200 kg/ha of 15-15-15) and some organic or green manures, while about 31% of farmers used chemical weed control. Most (67%) of cassava was planted in the early dry season, and cassava was harvested on average at 10 MAP, producing a yield of 23.4 t/ha, about 50% higher than the average national cassava yield. In addition, in 2000 a total of 70 km of contour hedgerows of vetiver grass had been planted to control erosion by farmers in the FPR pilot sites. Thus, with active participation from many government departments, a non-governmental organization (TTDI) and farmers groups, the improved cassava production technologies have been widely disseminated and are now being adopted by many cassava farmers in Thailand, leading to a slow but steady increase in cassava yields, produced at highly competitive prices (**Table 32**). Unfortunately, due to the current (1999/2000) low price of cassava, this still does not produce much income for cassava farmers. But it leaves the Thai cassava farmer with at least the prospect of being able to compete in the future with other starch and animal feed raw materials on the world market.

Table 31. Agronomic practices used for cassava production in four regions of Thailand in 1999/2000, according to questionnaires returned by 527 farmers in 29 provinces.

	Northeast	Central	East	North	Whole country
1. Planting time (%)					
-early rainy season	65	65	40	80	67
-late rainy season	35	35	60	20	33
2. Harvest time					
-early rainy season planting	Dec-May	Dec-June	Dec-March	Jan-May	Dec-May
-most harvest	March	March	Jan	March	March
-late rainy season planting	Sept-Nov	July-Dec	Aug-Nov	Sept-Dec	Aug-Dec
-most harvest	Oct	Nov	Nov	Nov	Nov
3. Age at harvest (months after planting)	10.0	10.6	10.5	9.6	10.0
4. Use of new varieties (%)	79	73	91	78	79
5. Perceived use of chemical fertilizers (%)					
-most farmers use	79	44	57	77	76
-some farmers use	15	52	43	18	18
-very few farmers use	6	4	0	5	6
6. Rate of fertilizer application (kg/ha)	206	137	175	200	201
7. Type of chemical fertilizers					
-most used	15-15-15	15-15-15	15-15-15	15-15-15	15-15-15
-also used	16-8-8, 13-13-21 16-16-8, 46-0-0	16-20-0, 21-0-0 15-7-18, 13-13-21		16-20-0, 46-0-0 15-7-18, 13-13-21	16-8-8 15-7-18
8. Perceived use of organic fertilizers	some farmers	some farmers	some farmers	some farmers	some farmers
9. Type of organic fertilizers	chicken, buffalo green manure sugarcane residue	manures		manures, green manures, ami-ami	chicken manure green manures
10. Weeding (%)					
-hand labor	41	38	0	22	38
-hand labor + mechanical	32	15	29	31	31
-chemical	27	46	71	47	31
11. Average yield (t/ha)	23.3	22.7	25.0	24.3	23.4
12. Average starch content (%)	25.0	24.2	23.8	26.0	25.1
13. Sell (%)					
-fresh roots	94	91	83	69	91
-dry chips	6	9	17	31	9
14. Sell to (%)					
-drying floor	47	59	55	59	49
-local factory	53	41	45	41	51
15. Price (baht/kg)					
-fresh roots	0.66	0.64	0.65	0.62	0.65
-dry chips	1.41	1.85	1.50	1.51	1.45
Note: No. of farmers returning questionnaire	423	33	6	65	527

Source: *Adapted from TTDI, 2000.*

Table 32. Cassava production costs, gross and net income in four regions of Thailand in 1999/2000.

	Region[1]				Whole country
	Northeast	Central	East	North	
A. Production costs (baht/ha)					
1. land preparation	1,806	2,081	1,763	1469	1,781
2. planting	1,144	875	825	925	1,097
3. weeding	1,962	1,675	1,581	1,738	1,912
4. chem. fert. and application	1,806	1,281	2,125	1,450	1,733
5. other fertilizers	1,444	650	1,469	875	1,324
6. harvest	3,069	3,150	3,887	3,075	3,084
7. transport of harvest	2,625	2,344	2,856	2,575	2,604
Total variable costs	*13,856*	*12,056*	*14,506*	*12,107*	*13,535*
8. land rent	1,756	2,381	1,562	1,887	1,809
Total costs	15,612	14,437	16,068	13,994	15,344
B. Yield (t/ha)	23.29	22.67	25.00	24.30	23.40
C. Cost per tonne (baht)	670	637	643	576	656
(US$)[2]	18.12	17.21	17.37	15.56	17.72
D. Price fresh roots (baht/t)	660	640	650	620	654
E. Gross income (baht/ha)	15,371	14,509	16,250	15,066	15,304
F. Net income (baht/ha)	-241	72	182	1,072	-40

[1] Northeast: Nong Khay, Nakhon Phanom, Roy Et, Sri Saket, Mukdahaan, Khon Kaen, Chayaphum, Nakhon Ratchasima, Kalasin, Nong Bua Lamphu, Sakon Nakhon, Udon Thanii, Mahaasarakham, Buriram, Yasothon, Amnaat Charoen, Loey; Central: Suphanburii, Chainaat, Kanchanaburii, Uthay Thanii, Lopburii, Ratchaburi; East: Prachinburii, Sra Kaew; North: Pitsanulook, Utradit, Nakhon Sawan, Kamphaeng Phet

[2] in 1999/2000: 1 US$ - 37 baht

Source: *Adapted from TTDI, 2000.*

REFERENCES

Chankam, C. 1994. Stake quality and multiplication of cassava. *In*: Report of the Seminar on Cassava Production Problems, Utilization and Minimizing the Cost of Production, held in Pattaya, Chonburi, Thailand. Sept 1-3, 1994. pp. 132-148. (in Thai)

Charoenrath, S. 1983. Production of cassava in Thailand. Paper presented at the Intern. Seminar on Root Crops in Southeast Asia (ISRC-SEA).VISCA and UPLB, Philippines. Nov 8-16, 1983. 17 p.

Field Crops Research Institute. Department of Agriculture, Thailand. Annual Reports 1965-1969, 1982and 1989. (in Thai)

Khon Kaen Field Crops Research Center (KKFCRC). 1992-1995. Annual Reports for 1991-1994. Field Crops Research Institute, Department of Agriculture, Thailand. (in Thai)

Office of Agricultural Economics (OAE). 1985.Agricultural Statistics of Thailand-Crop Year 1984/ 1985. Agricultural Statistics No. 293. Ministry of Agriculture and Co-operatives, Bangkok, Thailand.

Office of Agricultural Economics (OAE). 1998. Agricultural Statistics of Thailand-Crop Year 1996/ 1997. Agricultural Statistics No. 18. Ministry of Agriculture and Co-operatives, Bangkok, Thailand.

Rayong Field Crops Research Center(RYFCRC). 1992-1999. Annual Reports for 1992-1999. Field Crops Research Institute, Department of Agriculture, Thailand. (in Thai)

Rojanaridpiched, C., P. Poolsanguan, S. Phutthacharoen, J. Jeamjamnanja, L. Srichandee and V. Saengkaewsuk. 1986. Effects of harvesting age and rate of fertilizer application on yield and quality of cassava. Paper presented at the 24th Kasetsart University Annual Conference, held at Kasetsart University, Bangkok, Thailand. Jan 27-29, 1986. (in Thai)

Sinthuprama, S. 1980. Cassava planting system in Asia. *In*:Cassava Cultural Practices: Proc. of a Workshop, held in El Salvador, Bahia, Brazil. Mar 18-21, 1980. IDRC, Ottawa, Ont., Canada. pp. 50-53.

Sinthuprama, S., C. Tiraporn and A. Tongglum. 1983. Cassava cultural practices and cropping systems. *In*: Cassava Monograph No.7, Department of Ariculture, Bangkok, Thailand. 163 p. (in Thai)

Sinthuprama, S. and C. Tiraporn. 1984. Improving the productivity of cassava in Thailand. *In*: Cassava in Asia, its Potential and Research Developement Needs. Proc. of a Regional Workshop, held in Bangkok, Thailand. June.5-8, 1984. pp. 277-287.

Sittibusaya, C., C. Narkviroj and D. Tunmaphirom. 1987. Cassava soils research in Thailand. *In*: R.H. Howeler and K. Kawano (Eds.). Cassava Breeding and Agronomy Research in Asia.Proc. 2nd Regional Workshop, held in Rayong, Thailand. Oct 26-28, 1987. pp. 145-156.

Thai Tapioca Development Institute (TTDI). 2000. Cassava production situation in the year 1999/ 2000. Summary report of data from questionnaires sent to leaders of farmers groups by TTDI. Oct, 2000. (in Thai)

Tiraporn, C. and K. Narintaraporn. 1983. Harvesting and storage. *In*: Cassava Monograph No.7, Department of Ariculture, Bangkok, Thailand. 163 p. (in Thai)

Tirawatsakul, M. 1983. Weed control in cassava. *In*: Cassava Monograph No.7, Department of Ariculture, Bangkok, Thailand. 163 p. (in Thai)

Tirawatsakul, M., C. Tiraporn and S. Katong. 1988. Effect of application of herbicides in combination with cultivation practices on weed control and cassava yield. *In*: Annual Report for 1988. Rayong Field Crops Research Center, Rayong, Thailand. (in Thai)

Tongglum, A. 1991. Review of literature on past agronomy research in cassava. *In*: Cassava Production Workshop, held in Pathumthanee, Thailand. Jan 16-18, 1991. Book 1. pp. 175-239. (in Thai)

Tongglum, A., C. Tiraporn and S. Sinthuprama. 1987. Cassava cultural practices research in Thailand. *In*: R.H. Howeler and K. Kawano (Eds.). Cassava Breeding and Agronomy Research in Asia.0 Proc. 2nd Regional Workshop, held in Rayong, Thailand. Oct 26-28, 1987. pp. 131-144.

Tongglum, A., V. Vichukit, S. Jantawat, C. Sittibusaya , C. Tiraporn , S. Sinthuprama and R.H. Howeler. 1990. Recent progress in cassava agronomy research in Thailand. *In*: R.H. Howeler (Ed.). Cassava Breeding, Agronomy and Utilization Research in Asia. Proc. 3rd Regional Workshop, held in Malang, Indonesia. Oct 22-27, 1990. pp. 199-223.

Tongglum, A., W. Phornpromprathaan, C. Tiraporn and S. Sinthuprama. 1992. Effect of time of manual weed control on yield, % starch and root dry yield of Rayong 3 and Rayong 60 in the rainy and dry season. *In*: Annual Report for 1992, Rayong Field Crops Research Center, Rayong, Thailand. (in Thai)

Vichukit, V., S. Phutthacharoen, E. Sarobol and C. Pedchalanuwat. 1994. Time of planting and harvesting of cassava. *In*: Report of a Seminar on Cassava Production Problems, Utilization and Minimizing the Cost of Production, held in Pattaya, Chonburi, Thailand. Sept 1-3, 1994. pp. 47-59. (in Thai)