CASSAVA AGRONOMY RESEARCH AND ADOPTION OF IMPROVED PRACTICES IN INDIA - MAJOR ACHIEVEMENTS DURING THE PAST 30 YEARS

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ABSTRACT

Over the past 25-30 years, cassava agronomy research in India has made tremendous progress. In the recent past there has been a steady increase in the cultivation of cassava in non-traditional areas, despite the fact that cereals form the major crop and staple food of the country. There has been a marked increase in the number of cassava-based industries in states like Tamil Nadu and Andhra Pradesh, which is responsible for the expansion of the area under cassava in those states. Compared to 1980/81 the cassava area in Andhra Pradesh increased by 40% and in Tamil Nadu by 34%. In the state of Kerala, where cassava is traditionally grown for food, the cassava area decreased considerably (46%) due to farmers' preference for more remunerative plantation crops like rubber and coconut. A shift in the traditional cropping pattern, however, could also be noted in Kerala where rice in the lowlands is now being replaced by cassava, as the latter produces more income than the former. The yield of cassava has been almost static in the range of 19 to 23 t/ ha in Kerala, about 7 to 10 t/ha in Andhra Pradesh, and 36-37 t/ha in Tamil Nadu, which has the highest yield in the world.

Extensive research on cassava's nutritional requirements, agro-techniques, cropping systems and a long-term fertilizer trial have been conducted during the past three decades. Under rainfed conditions the best time of planting was found to be April-May; however, under irrigated conditions, it can be planted during any part of the year. Pit followed by mound has been identified as the best method for planting cassava stakes, using a spacing of 90x90 cm. Removing all but two healthy shoots on opposite sides of the stem has been found to increase yields. Investigations on the use of cassava plants as an alternate source for rearing eri silk worms revealed that the cassava root yield was adversely affected by this practice. Irrigating the crop at 25 per cent available soil moisture depletion level during the growth period could double the root yield. Supplementary irrigation at IW/CPE ratio=1.0 increased the root yield by 90 per cent over the rainfed crop.

Continuous application of NPK fertilizers did not significantly effect soil pH, but the available nutrient status of the soil was considerably enhanced, while the build-up of P was excessively high. An appreciable increase in the soil pH (4.7 to 6.1) was noticed in the treatment that received continuous applications of wood ash. Organic carbon content of the soil was found to increase in the plots that received farm-yard manure (FYM). When chemical fertilizers were applied regularly, the Cu and Zn status of the soil declined, but these deficiencies were not observed in plots that received FYM in addition to NPK. It was further revealed that the N and K requirement of the crop was in the ratio of 1:1. Liming at a rate of 2 t CaO/ha was found to be effective in increasing root yields in very acid soils. Application of sulfur resulted in an increase in starch and a decrease in the HCN content of roots. Significant responses to soil application of the micronutrients Zn, B and Mo were also observed.

Cropping systems research has shown that short-duration (seven months) cassava varieties can be grown successfully in a rice-based cropping system. Cowpea and groundnut were found quite remunerative as intercrops in cassava. Incorporation of cowpea as green manure *in situ* at time of planting cassava was found to be as effective as the application of FYM; in addition, it also reduced the N requirement by 50%.

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Cassava stems stored vertically gave better sprouting on planting as compared to those stored horizontally. Cassava stems of 7-11 months age and having a diameter of 2-4 cm were ideal as planting material. In non-traditional areas where rainfall is limited to 4-5 months per year, planting of cassava stakes in nursery beds at very close spacing, followed by transplanting at 20 DAP, was found to be quite effective in ensuring uniform establishment of the crop while also enhancing the eradication of cassava mosaic disease.

When cassava was grown on slopes, planting on staggered mounds reduced soil loss due to erosion by 40-50%. When cassava was grown in a multitier cropping system, its association with banana or coconut was found to be beneficial; however, when grown with eucalyptus or leucaena, the root yields were reduced by 60-80%.

Pruning the crop at eight months and thereafter retaining the crop for another eight months resulted in a two-fold increase in yield over the normal harvest.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) had been introduced into India by Portuguese merchants in the 17th century, and has since become a popular root crop. It is commonly known as tapioca in India. The crop has historical and sentimental value in Kerala state, which is indebted to her erstwhile ruler, King Visakham Thirunal, who was responsible for introducing the crop in India. Furthermore, this crop has saved many lives during an acute famine that gripped the state in the early part of the 20th century. The popularity of the crop later spread to neighboring states; however, not as a food crop but as a crop of industrial significance.

CLIMATE AND SOIL

In India, cassava cultivation is confined mainly to the southern states, which have a sub-tropical climate. Kerala receives a mean annual rainfall of about 3000 mm (**Figure 1**), well distributed over a period of 7-8 months, extending from April to November.

Nearly 60% of the annual precipitation is received during the southwest monsoon (May to Aug), and the rest during the northeast monsoon (Sept to Nov) (**Figure 2**). In the cassava-growing belt of Tamil Nadu, however, the annual rainfall on average is about 800-900 mm only. A major portion of this rainfall is received during the northeast monsoon.

Cassava is mainly grown on laterite soil (Ultisols) in Kerala, apart from forest soil (Mollisols) and red soil (Alfisols). In Tamil Nadu, the major soil groups under cassava are red soil (Alfisols) and black soil (Vertisols). In Andhra Pradesh, cultivation is mainly confined to the alluvial (Entisols) and red soils (Alfisols).

RESEARCH ACCOMPLISHMENTS

Extensive research has been done on cassava agronomy in India over the past three decades, mainly by the Central Tuber Crops Research Institute (CTCRI), located at Trivandrum in the major cassava-growing state of Kerala. The other leading institutions where cassava research is being carried out are the Kerala Agricultural University (KAU) and the Tamil Nadu Agricultural University (TNAU), Coimbatore. A brief review of the major research achievements is given below:

1. Planting

1.1 Time of planting

Cassava is mostly cultivated as a rainfed crop; however, if irrigated, it can be grown throughout the year. As a rainfed crop, the best time to plant cassava in Kerala is from April to May, with the onset of pre-monsoon showers. The next best season is from Aug to Sept, with the onset of the northeast monsoon. The effect of time of planting on root yield is presented in **Figure 2** (CTCRI, 1980).

1.2 Land preparation and planting

The physical conditions of the soil influence plant growth and development, and hence proper tillage is necessary for realizing the full yield potential of the crop. A study on the effect of deep and shallow tillage – either by tractor-plowing or by manual labor – did not show any significant difference in yield. One to three earthings up during weeding at monthly intervals, starting from 30 days after planting, significantly increased root yield as compared to the treatment where no earthing up was carried out (**Table 1**). Maximum root yield was obtained with three earthings up, but considering the cost involved, two earthings up at the second and third month stages of the crop were found to be more economical (Mandal and Mohankumar, 1973).

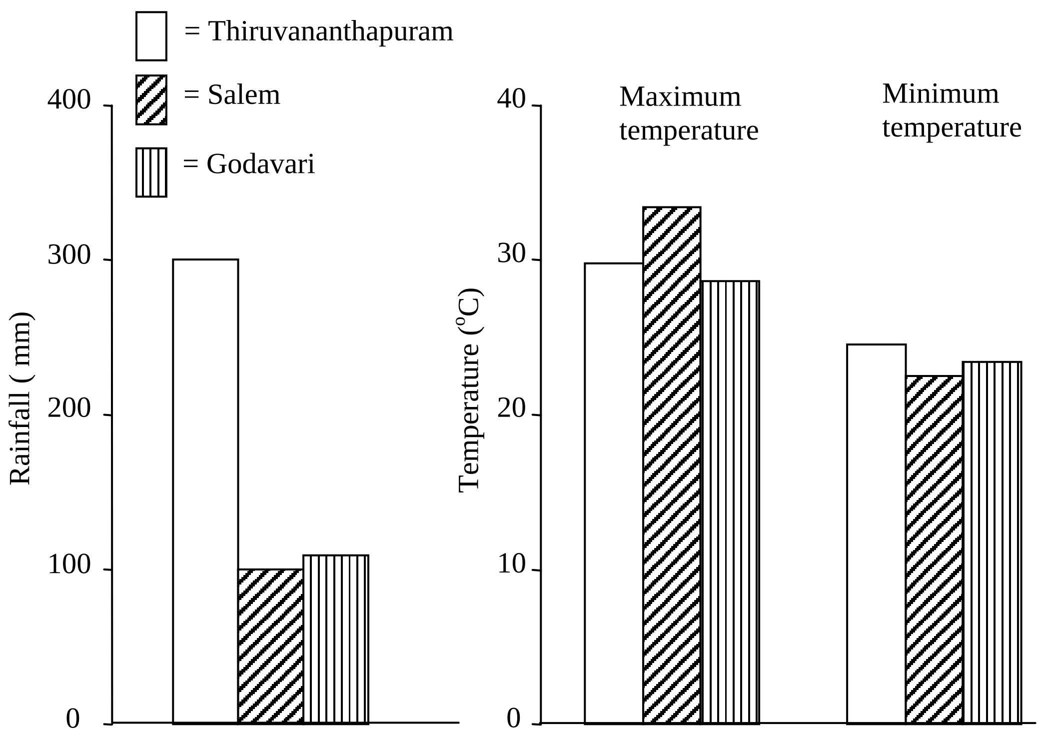

Figure 1 . Climatic characteristics of major cassava-growing states in India, i.e. Thiruvananthapuram in Kerala, Salem in Tamil Nadu and Godavari in Andhra Pradesh.

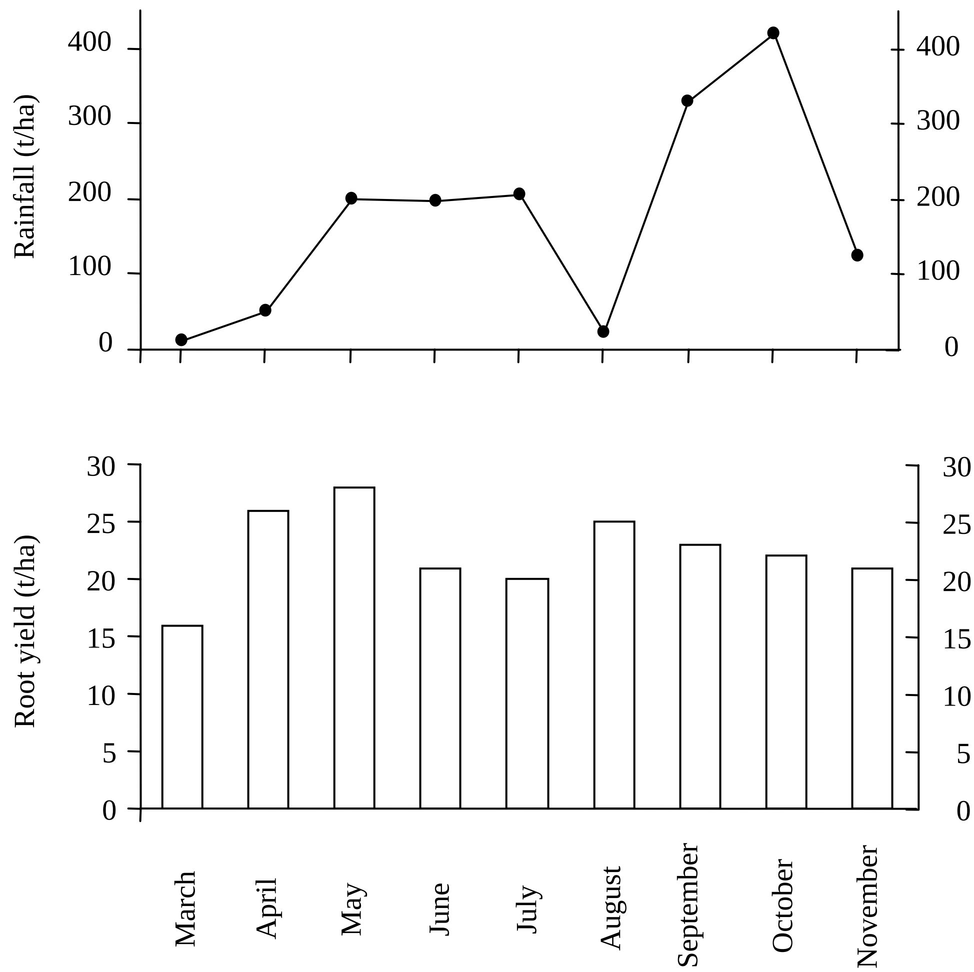

Figure 2. Effect of time of planting and rainfall on cassava root yield at CTCRI, Thiruvananthapuram, Kerala, India.

1.3 Method of planting

Different methods of land preparation, such as pit followed by mound, flat, mound and ridge methods did not show any significant differences in yield, although pit followed by mound recorded the maximum root yield (CTCRI, 1971) (**Figure 3**).

When planting on slopy land, the staggered mound method was found to be the most effective in reducing runoff losses. Runoff plot studies conducted at CTCRI on slopy land (8-9% slope) indicate that planting cassava on staggered mounds reduced soil loss due to erosion by 24% as compared to planting on flat beds (Kabeerathumma *et al*., 1996).

Table 1. Effect of tillage on cassava root yield (t/ha) at CTCRI, Trivandrum, India, in 1973.

Plowing/ digging	Number of earthings up*				Mean
	0	1	2	3	
Tractor plowing					
Once	16.2	22.1	24.2	25.1	**21.9**
Twice	18.1	22.6	23.5	24.0	**22.1**
Digging					
Once	14.4	21.6	23.4	25.3	**21.2**
Twice	12.7	20.4	25.3	25.6	**21.0**
Mean	**15.3**	**21.7**	**24.1**	**25.0**	
CD (0.05)	Plowing: NS		Earthing up: 2.51		

*Includes weeding
NS : not significant
Source: *Mandal and Mohakumar, 1973.*

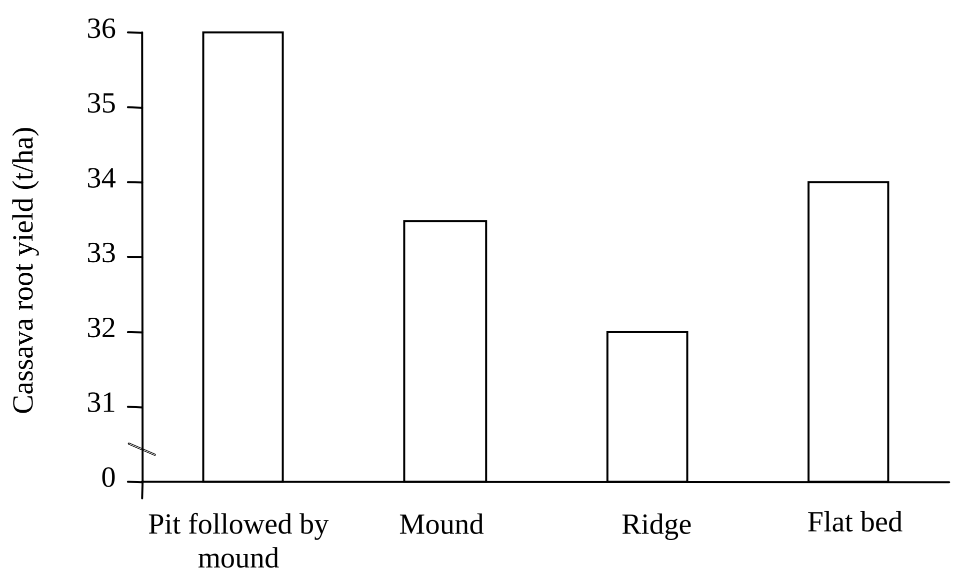

Figure 3. Effect of method of planting on cassava root yield at CTCRI, Thiruvananthapuram, Kerala, India.
Source: *CTCRI, 1971.*

1.4 Selection and preparation of planting materials

Disease-free planting material of 8-12 months' maturity with a stem girth of 2-3 cm has been found to be ideal for planting cassava (CTCRI, 1968). Stakes derived from the lower part of the stem had significantly higher survival rates than those from the immature top portion. It was observed that plant establishment was best when stakes were prepared by discarding one-third of the total length of the stem from the top end, and about 5 cm from the bottom end. Stakes with a smooth circular cut at its base resulted in uniform callus formation and root initiation. A stake length of 25-30 cm was found to be ideal for obtaining high root yield. A significant reduction in root yield was noticed when stakes of 10 cm length were used. Shallow planting facilitates the production of a large number of roots. When the soil is sufficiently loose and friable, stakes can be planted to a depth of 5-10 cm. Planting the stakes deeper resulted in swelling of the mother stem with consequent reduction in root size and yield.

1.5 Method of planting stakes

Different methods of planting the stakes, such as vertical, slanted (at a 45° angle) and horizontal, showed that vertical planting resulted in a more uniform distribution of callus tissue around the cut surface of the stake, which helped in the uniform bulking of roots all around the base of the plant (CTCRI, 1969; 1971).

1.6 Raising of young plants in the nursery

Planting of cassava stakes in traditional areas coincides with the onset of monsoon rains; however, in non-traditional areas where rainfall is very limited, nursery techniques have been developed for sprouting the stakes in the nursery first and then transplanting in the main field with the onset of rains. In the nursery, stakes are planted at a very close spacing of 4.5 x 4.5 cm under irrigated conditions during the first week of May (Mohankumar *et al*., 1998). The report further indicates that maximum root yields were obtained when 20-day old settlings were transplanted in the main field. The rooting media had no significant effect on root yields. High quality planting materials, free of disease, could be produced by this method.

1.7 Production of planting material

The rate of multiplication of planting material is only about ten times at harvest. A study undertaken to enhance the rate of multiplication revealed that spacings of 60x60 cm and 90x45 cm with one stake/hill were significantly superior to other treatments. Planting of two stakes/hill considerably reduced the number of high quality planting material under the different spacing (Mohankumar *et al*., 1980). Rapid multiplication of cassava stems by means of planting single-node cuttings was found to increase the multiplication rate to 647 stakes in one year (Kamalam *et al*., 1977).

1.8 Plant population

Experiments conducted to determine the effect of plant population and shoot number per plant for both branched and non-branched cultivars of cassava showed that a plant spacing of 90x90 cm for branched and a closer spacing of 75x75 cm for non-branched cultivars gave the highest yields (**Figure 4**).

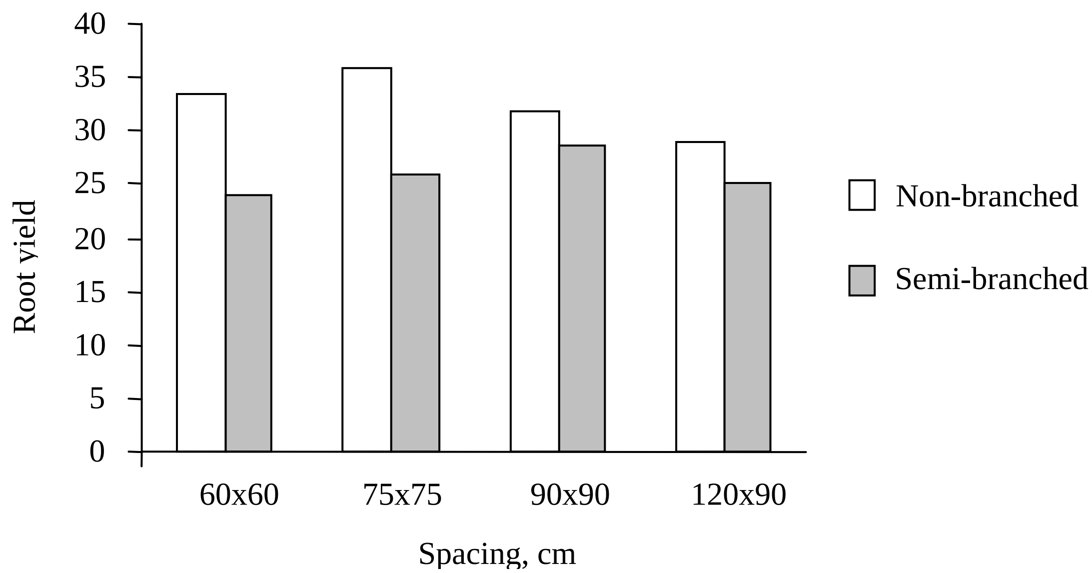

Figure 4. Effect of plant spacing on the root yields of a non-branched and semi-branched cassava variety at CTCRI, Trivandrum, India. in 1973. ***Source:*** *Mandal et al., 1973.*

Planting two stakes/hill for non-branched types produced better yields as compared to the normal practice of one plant/hill. However, despite an increase in root yield by this method, root size was considerably reduced, probably due to competition for light, nutrients and moisture.

1.9 Shoot number per hill

Under favorable conditions, the upper dominant buds produce sprouts. The sprouts emerging from the top buds are more vigorous than those emerging from the lower nodes of the same stake. Retaining two shoots at opposite sides was found to be better than retaining only one shoot. This practice helped in the production of a large number of uniformly sized roots all around the base of the plant (Mandal *et al.*, 1973). Thus, it was recommended that excess sprouts be removed at 10-15 days after sprouting, retaining only two sprouts per plant.

1.10 Gap filling

Establishment of stakes planted in the main field may turn out to be poor if low quality planting material is used or if weather conditions are adverse. Gap filling therefore becomes essential within a reasonable period of time for establishing a uniform crop stand, and to prevent economic loss. In an experiment conducted to identify the best time and method of gap filling, it was observed that using longer stakes of 40 cm at the 15th day after planting can produce 50% higher yield compared to normal stakes (of 20 cm length) used for gap filling (CTCRI, 1983).

1.11 Storage of planting material

Stems for planting material when stored for 15 days resulted in the highest percentage of sprouting (96%) as compared to planting fresh stakes (90%). Viability of the stems declined when stored beyond 60 days, as shown by the lowered percentage of sprouting (<75%) when planted.

2. Age at harvest

A study on the optimum age at harvest in cassava indicated that root yields increased progressively with a delay in harvesting time from the sixth to the tenth month of the crop. Maximum root yield was obtained at the tenth month (Mohankumar *et al*., 1985).

3. Pruning

Field experiments conducted for the June planting suggested that by close pruning (30 cm from the ground) at the eighth month after planting, the pruned plants could establish a fresh canopy during the drought period. The crop can then be further retained for a period of eighth months (total duration of 16 months), with a doubling of yield as compared to the normal crop of ten months. The quality of the roots was not affected by such pruning of cassava (Ramanujam, 1987).

4. Cropping systems

4.1 Intercropping in cassava

In a comparative study to evaluate the performance of some vegetables as intercrops with cassava, French bean (*Phaseolus vulgaris*), variety Contender, was found to be a successful intercrop (Thomas *et al*., 1982). Similar results were reported by Prabhakar *et al*. (1982).

Canopy spread and light penetration studies conducted in cassava fields, in which the stakes were planted at a spacing of 90x90 cm, showed that cassava canopies meet between the 45th and 75th day after planting, and with advancing age there was substantial canopy overlap. One hundred percent light penetration through the canopy at the interspace of 45 cm between two rows of cassava was observed up to the 45th day after planting. Thereafter, light penetration reduced to 50, 36 and 26% at 75, 90 and 120 days after planting, respectively (Ashokan *et al*., 1985).

An array of crops with duration not exceeding four months have been tested under irrigated conditions at Coimbatore in Tamil Nadu, and results show that onion (*Allium cepa*) was the most suitable intercrop with cassava, because bulb formation and maturity were completed within 85 days. Neither growth nor root yield of cassava were affected by onion (Muthukrishnan and Thamburaj, 1978).

Earlier reports suggested that intercropping legumes like peanut and cowpea with cassava caused a yield reduction in the main crop. Manipulation of spatial arrangements is one of the means to mitigate such yield losses. Experiments conducted by Meera Bai *et al*. (1991) showed that the paired-row system of planting cassava was beneficial in realizing higher yields of the main as well as the intercrops, i.e. peanut and cowpea (**Table 2**). Higher net income was also realized from the paired-row intercropping system.

Under lowland conditions, vegetable cowpea followed by cassava was found to be a feasible alternative to the use of farmyard manure. The yield reduction under such conditions was only 12% when compared to the control, where there was no preceding crop

Table 2. Yield of cassava and intercrops under different intercropping systems at Kerala Agricultural University, Kerala, India. 1990-1993.

Treatment	Cassava root yield (t/ha)	Yield of 1st intercrop		Yield of 2nd intercrop	
		Peanut (kg/ha)	Cowpea (kg/ha)	Cowpea (kg/ha)	Black gram (kg/ha)
Cassava monoculture (square planting)	19.46	-	-	-	-
C+P	21.77	819	-	-	-
C+CP	19.84	-	2,577	-	-
Cassava monoculture (paired-rows)	19.68	-	-	-	-
C+P	22.21	929	-	-	-
C+CP	22.22	-	2,145	-	-
C+P-CP	22.34	938	-	25	-
C+P-BG	21.55	908	-	-	negligible
C+CP-CP	20.45	-	1,501	35	-
C+CP-BG	20.48	-	1,770	-	7

C = cassava, P = peanut, CP = cowpea, BG = black gram
Source: *Meera Bai et al., 1991.*

of vegetable cowpea (**Figure 5**). The vegetative matter produced by the seasonal crop was sufficient to provide enough organic matter to cassava; however, under upland conditions, the cassava crop that followed the vegetable cowpea had a yield reduction of 30%. The significant reduction in yield was due to moisture deficiency as a result of late planting and subsequent drought, affecting the crop at the root bulking stage. When cassava was planted in May, there was no serious moisture stress up to the time of harvest in December.

4.2 Cassava as an intercrop in coconut plantations

A study on the growth and development of some cassava genotypes under coconut shade indicates that internodal elongation, thin leaves and absence of branching were the principal effects of shading. Most of the photosynthates produced by shade-grown cassava were utilized for shoot growth, leaving little resources for root development (**Table 3**) (Ramanujam *et al*., 1984).

4.3 Cassava-based multiple cropping system

In a cassava-based multiple cropping experiment, involving pure stands of perennials (banana, leucaena, eucalyptus and coconut), cassava and seasonal intercrops (peanut or cowpea), it was observed that inclusion of cassava and intercrops improved wood recovery in eucalyptus (**Table 4**). However, cassava intercropping adversely affected the yield of banana and the forage yield of leucaena. The perennials, especially eucalyptus, were also found to cause a serious reduction in cassava root yield. Intercropping with banana, however, increased cassava yields. A cost/return analysis showed that the highest net return was obtained for the crop combination of cassava + french bean or cowpea. The next best combination was banana + cassava + french bean or cowpea (Ghosh *et al*., 1987).

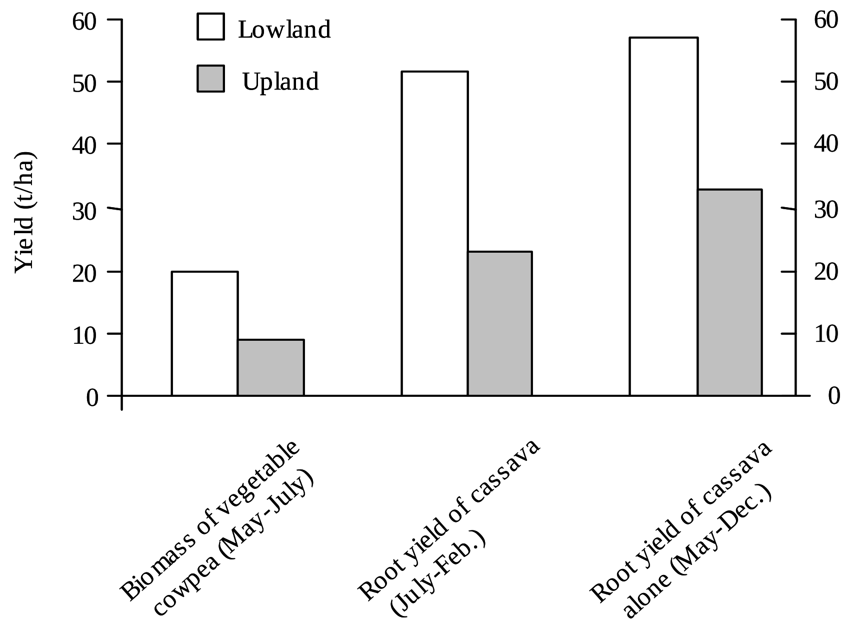

Figure 5. Biomass production of vegetable cowpea and cassava root yield (t/ha) of subsequently grown cassava as compared to the root yield of cassava grown without cowpea under upland and lowland conditions at CTCRI, Trivandrum, India, 1996.
Source: *Mohankumar and Nair, 1996.*

Table 3. Crop growth rate and yield of cassava genotypes under open conditions and under shade (in a coconut plantation) at CTCRI, Trivandrum, India. 1983-1985.

Clone	Crop growth rate ($g/m^2/day$)		Root yield (g/plant)		Yield reduction (%)
	Open	Shaded	Open	Shaded	
M-4	5.06	1.11	2,000	160	92
H-2304	6.40	2.61	2,500	506	79
H-1687	5.62	2.17	2,410	483	80
H-226	5.17	1.58	2,450	393	84
H-165	6.02	2.38	2,500	800	68
H-97	6.49	1.07	2,000	170	94

Source: *Ramanujam et al., 1984.*

Table 4. Wood yield of eucalyptus (t/ha) in various cassava-eucalyptus cropping Systems at CTCRI, Trivandrum, India. 1984-1987

Months after planting	Eucalyptus	Eucalyptus + cassava	Eucalyptus + cassava + peanut	Eucalyptus + cassava + cowpea
Side shoot removed at 18 months	0.52	0.36	0.40	0.33
Wood recovery at 33 months	30.11	28.05	40.40	43.53

Source: *Ghosh et al., 1987.*

In another study on root crop-based cropping systems for paddy fields in Kerala, cassava followed by rice was found to be an ideal crop sequence for obtaining maximum returns and for sustaining the fertility of the field (Mohankumar *et al*., 1985).

The root yield of cassava grown under the partial shade of coconut palms was poor (68%) compared to cassava grown in the open (**Table 5**). As shade was more or less uniform in the coconut garden, no significant differences in cassava root yield were observed from the various crop combinations (Ravindran, 1996).

Table 5. Root yield of cassava grown in various intercropping systems in a coconut garden, as compared to that of monoculture cassava grown in full sunlight at Kerala Agricultural University, Trivandrum, India. 1992-1994.

Cropping systems	Cassava root yield (t/ha)		
	1992-93	1993-94	Mean
Co+Ca	25.01	19.43	22.22
Co+Ca+Vcp	19.75	20.11	19.93
Co+Ca+EFY	29.79	31.56	30.67
Co+Ca+Ba	27.32	22.26	24.79
Co+Ca+Vcp+Ba	30.20	29.21	29.70
Mean	26.41	24.51	25.46
C.D. (0.05)	NS	NS	-
Standard error of mean	2.642	3.247	-
Cassava monoculture	35.38	30.23	32.80

Co=coconut, Ca=cassava, Vcp=vegetable cowpea, EFY=elephant foot yam, Ba=banana
Source: *Ravindran, 1996.*

5. Soil nutrient management

Substantial work has been done on soil nutrient/fertility management aspects of cassava for a sustainable and economic production of roots during the past two to three decades in India.

In order to formulate fertilizer recommendations for cassava on laterite soil, different promising clones were tested at different levels of organic manures and inorganic fertilizers. It was observed that application of 12.5 t/ha of farmyard manure (FYM) and 100 kg/ha of N, P_2O_5 and K_2O, respectively, produced the highest root yield (Mandal *et al*., 1973). Similar findings were reported by Pillai *et al*. (1985). Recent reports, however, suggests that the rate of phosphorus application can be reduced to 50 kg P_2O_5/ha (Kabeerathumma and Ravindran, 1996). This view has been endorsed by most of the recent findings.

Mohankumar and Nair (1996) reported that for the production of one tonne of total dry matter produced, cassava absorbed 6.45 kg N, 1.3 kg P and 8.62 kg K in the whole plant, whereas for a similar level of dry matter production, rice removed 6.6 kg N, 1.3 kg P and 8.62 kg K. This indicates that these two starch-producing crops behave almost identically with regard to total nutrient absorption per unit of dry product.

5.1 Effect of long-term cropping and fertilizer application on soil fertility

In order to study the effects of long-term cropping and fertilizer application to an acid Ultisol on the yield and quality of cassava and the consequent physico-chemical changes in the soil, an experiment has been conducted at CTCRI, Trivandrum for 13 years. Susan John *et al*. (1998) reported that in the 13th year the maximum root yield was obtained when N, P_2O_5 and K_2O were applied at 100 kg/ha each, along with 12.3 t/ha of FYM (**Table 6**). Root yields obtained with the FYM+NK and NPK treatments were, however, not significantly different from each other. Yield increases in these treatments were 400% more than the control (no fertilizer or manure). The lowest yield was recorded when P alone was applied. Ash and K alone as well as in combination increased the starch content and decreased the HCN content of roots, whereas FYM, N alone and FYM+N tended to increase the HCN content.

Table 6. Long-term effect of organic manures and fertilizers on root yield (t/ha) from 1978 to 1990 at CTCRI, Trivandrum, India.

Treatment[1)]	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
N	12.5	18.9	11.7	7.6	13.8	3.4	7.2	7.1	3.8	5.3	7.1	3.3	3.6
P	11.2	9.3	6.3	5.1	8.1	5.2	2.3	0.9	4.2	3.0	4.7	1.5	1.3
K	17.0	15.5	10.0	10.4	9.2	12.0	16.9	5.9	8.9	9.4	10.9	2.3	3.4
NP	22.4	18.2	13.7	12.2	15.7	7.6	9.7	3.1	4.9	6.3	4.1	4.1	1.6
NK	17.2	23.0	18.0	15.6	16.3	15.7	29.8	13.1	16.4	19.7	25.7	12.0	9.4
PK	13.7	12.4	8.7	6.4	9.9	9.8	9.8	2.1	9.9	9.5	10.4	3.9	5.4
NPK	20.0	22.1	18.5	21.8	26.0	25.6	28.0	14.6	18.7	29.0	34.0	18.7	22.3
FYM+N	19.5	20.0	14.0	10.6	16.3	17.6	23.3	6.6	15.6	23.0	28.8	5.0	11.0
FYM+P	16.2	14.5	7.5	6.8	11.7	12.8	14.4	5.5	11.7	12.8	20.7	4.3	9.8
FYM+K	13.8	17.1	9.1	10.1	13.4	21.5	20.6	6.4	14.4	17.4	20.8	9.7	10.9
FYM+NP	19.0	21.7	13.4	12.1	24.3	22.8	19.6	5.0	17.5	24.0	25.3	4.4	17.6
FYM+NK	22.9	22.9	13.7	17.9	25.1	31.2	33.5	13.0	21.3	30.0	39.8	14.3	21.9
FYM+PK	15.9	16.7	9.7	12.1	12.6	16.8	17.1	8.6	12.7	14.1	22.1	6.6	9.8
FYM+NPK	23.7	31.9	19.1	21.2	28.9	28.7	42.4	16.6	22.7	34.3	46.5	21.3	29.0
FYM	11.6	9.7	6.9	4.6	10.9	12.8	17.2	2.9	10.3	9.3	25.1	3.0	11.6
Ash	nd	nd	7.2	12.1	12.1	18.3	11.1	5.1	9.6	18.1	32.7	3.1	5.3
Ash+FYM	nd	nd	8.5	12.3	8.0	15.8	22.1	9.4	12.2	20.3	16.6	8.7	12.3
Control	11.3	9.6	5.0	4.4	5.7	6.0	2.8	1.4	4.3	2.4	1.6	1.7	1.0
C.D. (0.05)	6.35	8.53	6.35	4.96	5.69	6.12	11.2	4.55	4.47	4.00	6.13	3.29	6.73

[1)] N=100 kg N/ha; P=100 kg P_2O_5/ha; K=100 kg K_2O/ha; FYM=12.5 t farm-yard manure/ha; Ash=2.65 wood ash/ha; *nd=no data*

***Source:** Susan John et al., 1998.*

Combined application of FYM and NPK fertilizers increased the availability of N, P and K in the soil. Continuous application of ash was found to increase soil pH as well as the available K status in the soil, whereas FYM alone or in combination with inorganic fertilizers was found to increase the organic carbon status in the soil (**Table 7**). The build-up of P was very high (up to 280 kg/ha) when applied alone or in combination with FYM. A build-up of P even in non-treated plots was seen to be high, as the original soil was already high in P.

Table 7. Soil chemical characteristics at the end of the 13th cropping season in a long-term fertility trial studying the effects of applying organic manure and inorganic fertilizers at CTCRI, Trivandrum, India. 1990.

Treatment	pH	OC (%)	Ave. N	Ave. P	Ave. K	Ca	Mg	Zn	Cu
			------------(kg/ha)-----------			---(mg/100g)---		----(μg/g)----	
N	4.2	0.58	220.9	212.0	33.6	1.5	0.80	0.20	0.25
P	4.5	0.26	152.4	229.0	40.3	3.5	2.15	0.14	0.13
K	4.5	0.48	114.8	222.0	143.3	1.8	0.63	0.27	0.30
NP	4.4	0.39	144.8	296.8	48.2	2.3	1.57	0.24	0.37
NK	4.5	0.50	214.8	25.8	107.5	2.0	0.93	0.44	0.47
PK	4.5	0.41	227.7	282.0	183.7	3.0	2.14	0.57	0.32
NPK	4.5	0.60	234.8	263.0	96.3	2.0	0.90	0.30	0.24
FYM+N	4.4	0.91	315.1	112.0	53.8	2.5	2.10	0.68	0.34
FYM+P	4.5	0.83	304.2	330.0	60.5	4.8	4.13	0.78	0.40
FYM+K	4.6	0.75	277.6	64.4	164.6	3.2	5.43	0.75	0.45
FYM+NP	4.3	0.87	246.2	266.0	53.8	2.4	0.78	0.54	0.40
FYM+NK	4.4	0.91	249.1	61.6	105.8	2.0	2.13	0.68	0.45
FYM+PK	4.5	0.74	161.1	224.0	170.2	3.0	2.18	0.67	0.43
FYM+NPK	4.6	0.98	246.3	263.0	96.3	3.0	2.06	0.70	0.44
FYM	4.6	0.96	277.6	110.6	71.7	4.0	4.85	0.67	0.37
Ash	6.1	0.49	201.9	22.4	205.0	24.0	13.60	0.80	0.58
Ash+FYM	6.2	0.50	252.4	26.4	192.6	28.0	14.62	1.05	0.56
Control	4.3	0.23	201.9	22.5	41.4	1.6	0.98	0.22	0.16

FYM = farmyard manure, OC = organic carbon (%),
Ave. N, Ave. P and Ave. K are total N, available P and exchangeable K in kg/ha
Ca, Mg are exchangeable nutrients in mg/100 g
Zn, Cu are available nutrients in μg/g
Source: *Susan John et al., 1998.*

Continuous cropping of cassava with only chemical fertilizers decreased the levels of Ca, Mg, Zn and Cu in the soil and lowered the pH. The results clearly indicate the need for organic manure application to the soil along with inorganic fertilizers.

Planting cowpea as a green manure crop, and incorporating the plants before planting cassava, resulted in increased cassava yields (Sasidhar and Sadanandan, 1976). Prabhakar and Nair (1987) suggested that incorporation of cowpea as green manure *in situ* at the time of planting cassava could be as effective as the application of FYM; in addition, it also reduced the N requirement by 50%.

5.2 Substitution of KCl with sodium chloride

Studies conducted at the Kerala Agricultural University have shown that up to 50 per cent of the K requirement of cassava can be substituted by Na through the application of sodium chloride (NaCl), without any negative effect on yield (**Table 8**) (Sudharmai Devi, 1995; Mohankumar *et al*., 1998). Substitution of K by Na in varying levels also influenced the uptake of N at different stages of cassava growth (**Table 9**). Uptake of N showed an increasing trend in all the treatments up to six months after planting and thereafter a decline was noticed. At two and six months after planting, the treatment with 50 per cent substitution recorded the highest uptake of nitrogen.

Table 8. Effect of partial substitution of K[1] by Na application on the root yield of cassava at Kerala Agricultural University, Trivandrum, India. 1992-1994.

Treatment	Root yield (t/ha)		
	1992/93	1993/94	Mean
100% KCl	21.91	16.70	19.30
75% KCl + 25% NaCl	19.05	20.30	19.70
50% KCl + 50% NaCl	26.04	24.50	25.30
25% KCl + 75% NaCl	18.42	17.90	18.20
100% NaCl	11.43	15.30	13.40
50% wood ash + 50% NaCl	13.81	18.30	16.10
50% $KHCO_3$ + 50% $NaHCO_3$	16.19	17.80	17.00
C.D. (0.05)	7.87	6.55	3.44

[1] Rate of K application was 100 kg K_2O/ha; no control treatment.
Source: *Sudharmai Devi, 1995.*.

Table 9. Nitrogen uptake at different growth stages as affected by partial substitution of K[1] by Na application in cassava at Kerala Agricultural University, Trivandrum, India. 1992-1994.

Treatments	Nitrogen uptake (kg/ha)				
	2 MAP[2]	4 MAP	6 MAP	8 MAP	Harvest[3]
100% KCl	17.08	33.90	70.36	59.73	60.94
75% KCl + 25% NaCl	11.13	48.89	58.81	54.60	45.74
50% KCl + 50% NaCl	18.85	42.30	102.42	49.65	37.01
25% KCl + 75% NaCl	14.95	37.39	69.25	50.53	34.93
100% NaCl	10.20	43.32	66.48	53.58	23.97
50% wood ash + 50% NaCl	8.86	57.10	89.36	54.04	30.50
50% $KHCO_3$ + 50% $NaHCO_3$	11.20	33.18	77.25	49.54	36.93
C.D. (0.05)	4.16	NS	22.39	NS	28.40

[1] Rate of K application was 100 kg K_2O/ha; no control treatment.
[2] MAP= months after planting.
[3] At 10 MAP.
Source: *Sudharmai Devi, 1995.*

5.3 Response to N and K

A study on the response of two short-duration cassava varieties to application of N and K in a rice-based cropping system revealed that the application of N had a significant effect on root production (**Figure 6**). The highest yield was obtained at 75 kg N/ha, which was significantly superior to that at 50 kg N/ha. The former was, however, not significantly different from that at 100 kg N/ha. Application of K had a favorable effect on root yield. The highest yield was obtained with the application of 100 kg K_2O/ha, which was significantly higher than that at 50 or 75 kg K_2O/ha. The highest root yields of both varieties were obtained with 75 kg N and 100 kg K_2O/ha.

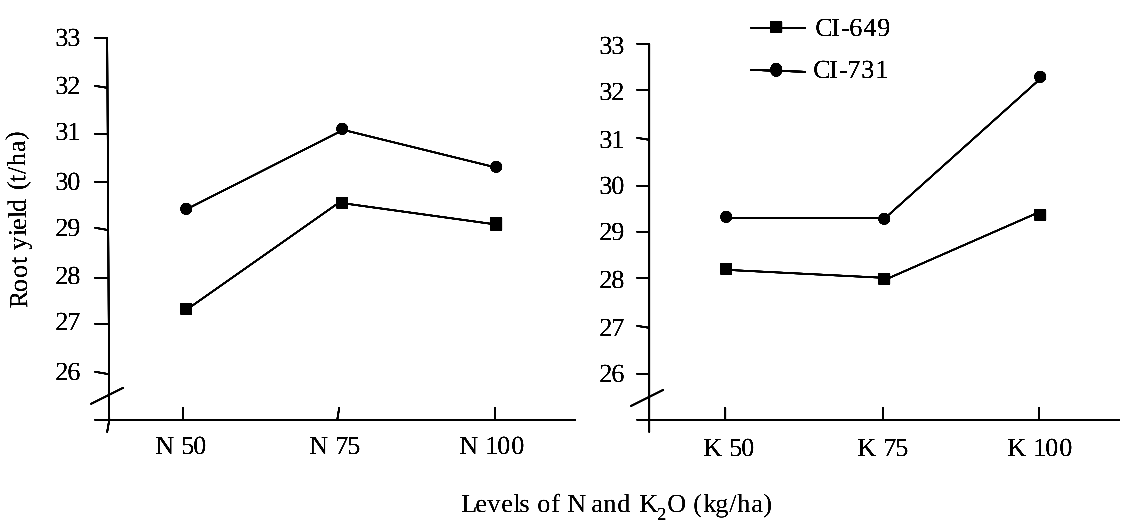

Figure 6. Effect of various rates of N and K application on the root yields (t/ha) of two short-duration lines of cassava grown in lowland soils at CTCRI, Trivandrum, India in 1991-1994.
Source: *Mohankumar, 1996.*

5.4 Soil amelioration with lime and sulfur

Amending an acid soil with lime is a common practice for reducing acidity and thereby making available more soil nutrients, which in turn benefit the crop and increases root production. A study conducted at CTCRI with different levels of lime, ranging from 0 to 2,000 kg CaO/ha in addition to the recommended dose of 100 kg/ha each of N, P_2O_5 and K_2O, revealed that the root yield was raised by as much as 35.6% with the application of 2,000 kg CaO/ha as compared to that of the control (**Table 10**). In addition to increasing root yield, lime application also improved the quality of roots by increasing the starch content and decreasing the level of HCN.

Table 10. Cassava root yield and quality as affected by different levels of lime application at CTCRI, Trivandrum, India. 1981-1984.

Level of lime (kg CaO/ha)	Root yield (t/ha)	Starch content (%, dry wt. basis)	HCN content (ppm, fresh wt. basis)
0	18.76	86.5	54.8
500	22.19	88.4	46.1
1,000	23.54	88.4	50.1
1,500	22.66	89.3	46.2
2,000	26.00	88.4	40.8
C.D. (0.05)	3.35	-	-

Source: *Mohankumar and Nair, 1985.*

A positive response in root yield to sulfur application in acid laterite soil of low available S (6.62 ppm) was obtained by Mohankumar and Nair (1985). They reported that application of S at the rate of 50 kg/ha increased the starch and methionine content but decreased the cyanogen content of roots, while the root yield increased 3.94 t/ha over the no-S treatment.

5.4 Effect of slow-release nitrogen fertilizers on cassava

Nitrogen fertilizers, especially urea, are subject to various losses under tropical conditions. An investigation into the effect of slow-release nitrogen fertilizers and nitrogen inhibitors on cassava was conducted by Vinod and Nair (1992). The N sources were urea, urea super-granule, neem cake-coated urea and rubber-coated urea, each applied at the rate of 50, 75, 100, 125 and 150 kg N/ha. Urea super-granule and neem cake-coated urea produced apparently higher yields and quality attributes as compared to other treatments (**Table 11**).

Table 11. Effect of four sources of nitrogen on the yield and quality attributes of cassava, cv. Sree Visakham, grown at the College of Agriculture, Trivandrum, India. 1989-1991.

Source	No. of roots/plant	Root yield (t/ha)	HCN content (ppm, fresh wt. basis)	Total dry matter (t/ha)
Urea	5.1	19.95	47.4	10.52
Neem-coated urea	5.8	22.59	46.8	12.13
Urea super-granule	5.9	25.65	48.4	13.97
Rubber cake-coated urea	4.9	17.76	48.2	10.40
	0.27	1.44	1.1	0.24
SE	0.55	2.96	-	0.49
CD (0.05)				

Source: *Vinod and Nair, 1992.*

5.6 Response to micronutrients

Cassava responded significantly to soil application of Zn, Mo and B at 12.5, 1.0 and 10.0 kg/ha as zinc sulfate, ammonium molybdate and borax, respectively, along with 100 kg/ha each of N, P_2O_5 and K_2O. Yield increases over the control of 4.0, 2.8 and 3.1 t/ha were obtained by the application of Zn, Mo and B at the rates mentioned (**Table 12**).

Table 12. Root yield, starch and HCN contents of cassava as influenced by micro-nutrient applications at CTCRI, Trivandrum, India. 1979–1982.

Treatment	Rate (kg/ha)	Root yield (t/ha)	Starch content (%)	HCN content (ppm, fresh wt. basis)
Mn	25 (Manganese sulfate)	26.8	27.0	101.7
Zn	12.5 (Zinc sulfate)	29.4	29.6	90.3
Cu	12.5 (Copper sulfate)	26.9	27.2	99.2
B	10 (Borax)	28.5	28.1	96.8
Mo	1.0 (Ammonium molybdate)	28.2	29.5	115.9
Control		25.4	29.2	110.5
C.D. (0.05)		1.6	27.6	119.6

Source: *Nair and Mohankumar, 1980.*

5.5 Response to mycorrhizal inoculation

Studies on the effect of inoculation with mycorrhizal fungi (VAMF) on field-grown cassava clearly showed that inoculation with *Glomus microcarpum* var. *microcarpum* in the nursery prior to transplanting to the field, enhanced total dry matter and root yields (**Figure 7**); inoculation also increased the concentrations of micronutrients, such as Zn and Cu, in the leaves.

6. Water management

Cassava is a drought tolerant crop, but to realize its potential yield it is essential that adequate soil moisture is available. Moisture stress at the time of root bulking drastically reduces root yield. Irrigation is thus essential in drought-prone areas like Tamil Nadu, Andhra Pradesh and Orissa. In the State of Kerala, where cassava is traditionally grown as a rainfed crop, reasonably high yields are obtained due to the good distribution of rain.

A study conducted at CTCRI revealed that irrigating the crop at the 25% available soil moisture depletion level throughout the growing period could double the root yield as compared to the control (no irrigation) (CTCRI, 1983). Another report indicated that supplemental irrigation at IW/CPE ratio=1.0, increased the cassava yield by 90% over the the rainfed crop (**Table 13**). The report further indicates that in order to fully realize the production potential of the crop, irrigation at IW/CPE=1.0 along with a fertilizer application of NPK at 150:100:150 kg/ha would be required.

7. Package of Cultural Practices

A summary of the recommended cultural practices for cassava production in India is given in **Table 14.**

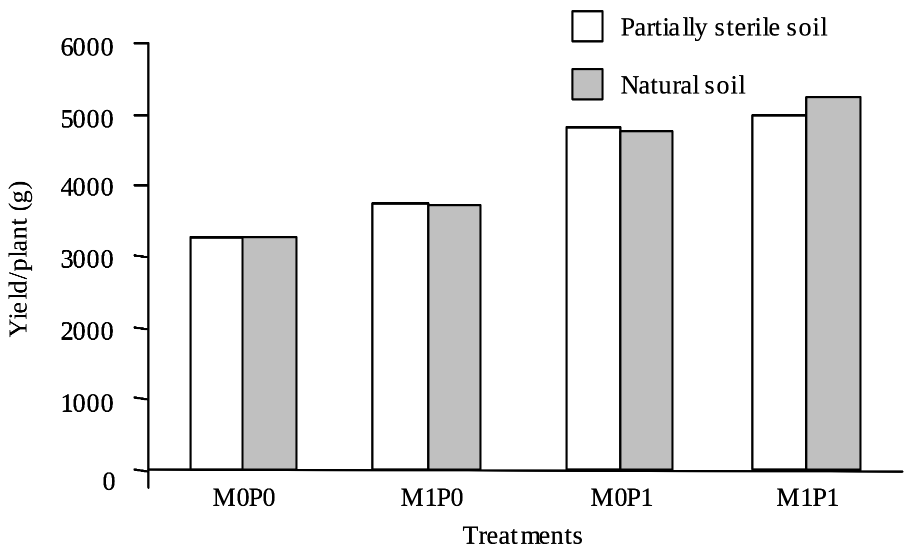

Figure 7. Influence of inoculation with mycorrhiza (M1) and application of P (P1) to nursery grown stakes on the yield of cassava grown in acid laterite soil at CTCRI, Trivandrum, India in 1996.
Source: *Potty, 1998.*

Table 13. Effect of various levels of supplemental irrigation and fertilizer application on root yield, and starch and HCN contents of cassava planted at CTCRI, Trivandrum, India. 1982-1985.

Treatments	Fresh root yield (t/ha)	Starch (% on dry wt. basis)	HCN (ppm on fresh wt. basis)
Levels of irrigation			
IW/CPE = 0 (rainfed)	20.8	72.7	55
IW/CPE = 0.25	24.5	72.9	41
IW/CPE = 0.50	30.8	74.5	41
IW/CPE = 0.75	34.8	75.2	33
IW/CPE = 1.0	39.7	75.0	22
C.D. (0.05)	4.8	-	-
Levels of NPK (kg/ha)			
50:100:50	23.3	75.9	37
100:100:100	28.9	75.2	37
150:100:150	33.4	71.1	39
200:100:200	34.9	74.0	46
C.D. (0.05)	2.6	-	-

[1)] Irrigation during drought periods (more than 7 days without rains); IW = irrigation water in mm, CPE = cumulative pan evaporation in mm. Fertilizers were applied 50% at planting and the rest at 45 days.

Source: *Nayar et al., 1985.*

Table 14. Recommended cultural practices adopted by cassava farmers in India

1. Cropping system:	Cultivated as monoculture in uplands and lowlands and also as an intercrop in plantation crops.
2. Variety:	M-4: Excellent as an edible variety H-97: High starch, good cooking quality H-165: Early (7 months) maturing, disease and pest resistant. H-226: Good cooking quality Sree Visakham: Good cooking quality, high yield Sree Sahya: High yield, drought resistant, high starch content Sree Prakash: Early maturing (6-7) months, good cooking quality Sree Rekha: A top cross hybrid line. Excellent cooking quality and high starch content Sree Prabha: A top cross hybrid line. Yellow flesh, high yield and high starch content Sree Harsha: A triploid variety. Very high starch and root yield Sree Jaya: Early maturing (6-7 months) Sree Vijaya: Early maturing (6-7 months), high root yield.
3. Planting time:	April/May or Sept/Oct.
4. Land preparation:	Two plowings followed by harrowing. Planting is done on mounds or on ridges of about 25-30 cm height.
5. Planting material:	Select and store disease-free cassava stems, 10-11 months old. For planting, cut the stems into stakes of 15-20 cm length.
6. Planting method:	Stakes planted vertically with buds facing up, 5 cm deep. Replant missing hills as early as possible.
7. Plant spacing:	90x90 cm for branching varieties and 75x75 cm for non-branching types. On sprouting, only two shoots are retained on either side.
8. Fertilization:	Farm-yard manure at 10-15 t/ha is applied at the time of land preparation. NPK recommended is 100 kg N, 50 kg P_2O_5 and 100 kg K_2O/ha. Half of N and K is applied at planting and the other half at 45-60 days after planting. Under lowland situation, FYM could be substituted with *in situ* planting of cowpea.
9. Weeding and hilling up:	At 45–60 days and 1-2 months later.
10. Intercropping:	Cassava could be intercropped with two rows of peanut or one row of cowpea.
11. Harvest:	Early maturing varieties are harvested at 6-7 months while the others at 9-10 months.
12. Storage of stems:	Stems are stored in vertical position under shade or in the open.

FUTURE THRUST

Future directions in agronomy research on cassava will focus on:

- The role of cassava in sequential and intercropping systems
- Development of an integrated nutrient management system for enhancing productivity of the crop and for sustaining soil fertility
- Irrigation requirements of cassava in low rainfall areas and nutrient management under such conditions
- Dynamics of applied nutrients in soil planted with cassava
- Physico-chemical transformations in the soil under long-term cassava cropping
- Chemical control of weeds
- Development of cassava models and simulation studies with these cassava models

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