FERTILIZER SCHEDULING FOR THE SHORT DURATION CASSAVA VARIETY "VELLAYANI HRASWA"

SEKAR, J.

Thesis submitted in partial fulfilment of the requirement for the degree of

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Department of Soil Science and Agricultural Chemistry
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM-695 522
KERALA, INDIA

DEDICATED TO

MY ever Loving
Gurukulam
(Sri.Balu Tuition Centre)

DECLARATION

I hereby declare that this thesis entitled "**Fertilizer scheduling for the short duration Cassava variety "Vellayani Hraswa"** " is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

Vellayani,
20. 10. 2004

SEKAR, J.
(2002-11-32)

CERTIFICATE

Certified that this thesis entitled **Fertilizer scheduling for the short duration Cassava variety "Vellayani Hraswa"** is a record of research work done independently by Mr. Sekar, J. (2002-11-32) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

Vellayani,
20.10.04

20.10.2004
Dr. K. HARIKRISHNANNAIR
(Chairman, Advisory Committee)
Associate Professor,
Department of Soil science and Agricultural Chemistry.
College of Agriculture, Vellayani.
Thiruvananthapuram-695 522

APPROVED BY

Chairman

Dr. K. HARIKRISHNANNAIR
(Chairman, Advisory Committee)
Associate Professor,
Department of Soil Science and
Agricultural Chemistry,
College of Agriculture, Vellayani,
Thiruvananthapuram-695 522

27.1.05

Members:

Dr. V. K. VENUGOPAL
Professor and Head,
Department of Soil Science and
Agricultural Chemistry,
College of Agriculture, Vellayani,
Thiruvananthapuram-695 522

27.1.05

Dr. C. R. SUDHARMAIDEVI
Associate Professor,
Department of Soil Science and
Agricultural Chemistry,
College of Agriculture, Vellayani,
Thiruvananthapuram-695 522

27/1/05

Dr. A. S. ANILKUMAR
Assistant Professor,
(Agronomy),
Instructional Farm,
College of Agriculture, Vellayani,
Thiruvananthapuram-695 522

27/1/05

EXTERNAL EXAMINER

27.1.2005
Dr. R. Govindasamy
Prof. & Head (Rtd.)
Dept. of Soil Sci. & Agrl. Chemistry
Annamalai University.

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J. SEKAR

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LIST OF ABBREVIATIONS

@	-	at the rate of
ADP	-	Adenosine di phosphate
ANOVA	-	Analysis of variance
ATP	-	Adenosine tri phosphate
BCR	-	Benefit cost ratio
CD	-	Critical difference
CEC	-	Cation exchange capacity
CIAT	-	Centro International De Agricultura Tropicale
cm	-	Centimetre
CTCRI	-	Central Tuber Crops Research Institure
$^{\circ}C$	-	Degree Celsius
$Cmol(p^{+})\ kg^{-1}$	-	Centi mole positive charge per kilo gram
dSm^{-1}	-	Deci Siemen per metre
Fig	-	Figure
FYM	-	Farmyard manure
g	-	gram
h	-	hours
i.e.,	-	that is
H_2SO_4	-	Sulphuric acid
$HClO_4$	-	Perchloric acid
HCN	-	Hydrogen cyanide
K	-	Potassium
KCl	-	Potassium chloride
$Kg\ ha^{-1}$	-	Kilogram per hectare
LAI	-	Leaf area index
M	-	Metre
MAP	-	Month after planting
Mgm^{-3}	-	Mega gram per metre cube
$\mu g\ g^{-1}$	-	Microgram per gram
N	-	Nitrogen
MOP	-	Muriate of potash
Na	-	Sodium
NS	-	Not significant
P	-	Phosphorus
%	-	Per cent
ppm	-	Parts per million
RBD	-	Randomized block design
scm^{-1}	-	Second per centimetre
TDMP	-	Total dry matter production
$t\ ha^{-1}$		tonnes per hectare
var.	-	Variety
viz.	-	Namely
Zn	-	Zinc

Introduction

1. INTRODUCTION

Cassava (*Manihot esculenta Crantz*), popularly known as tapioca; is one of the world's most important staple food crop. It ranks sixth among the major contributors of food in the world. The others being wheat, rice, maize, potato and barley (Ghosh *et al.* 1988). Approximately 60 per cent of the world's cassava production is used as human food serving as an important staple food for more than 500 million people (Mohankumar *et al.* 2000). It is a native of Brazil in Latin America and was introduced to India (Kerala) by the Portuguese in the 17^{th} century. Among the different tropical roots and tuber crops grown in India, cassava is of significance since it can produce more calories per unit area per unit time. Its importance in tropical agriculture is due to its drought tolerance and wide adaptability to adverse soil, nutrient and management conditions including time of harvest.

The crop pattern scenario has witnessed change especially in Kerala where plantation crops have started gaining prominence in uplands. Kerala being a food deficit state, cassava assumes importance as a supplementary food item and thus provides food security and avoids drain in our economy for the import of rice. Besides, cassava holds promise as an animal food and as a raw material for industries. But cassava area under traditional upland rainfed situation is declining gradually in Kerala. On the other hand, the area under low land situation is increasing with the gradual replacement of rice by cassava. Due to the high cost of labour and lack of timely availability of labour, the farmer shows interest to introduce cassava as a substitute for rice together with the crop cafeteria. Thus there is a need to develop scientific management strategies for cassava cultivation.

'Vellayani Hraswa' is a short duration variety of cassava released by the Kerala Agricultural University recently. Branching habit and short duration nature coupled with greater production potential make this variety physiologically unique and outstanding compared to other cassava varieties ever released. Due to its superior cooking quality and high yield, this variety may replace the other improved ones. These characters warrant for separate package in nutrient management. This experiment will enable to recommend a fertilizer schedule for sustainable land use and higher productivity through the efficient management of the available inputs especially, the costly fertilizers.

Keeping these views in mind, the experiment viz., Fertilizer scheduling for the short duration cassava variety "Vellayani Hraswa" was designed to achieve the objective of studying the influence of NPK fertilizers on the performance of short duration cassava variety "Vellayani Hraswa" and to arrive at a fertilizer recommendation for the variety.

Review of Literature

2. REVIEW OF LITERATURE

Cassava is a heavy feeder crop and requires a good amount of nitrogen, phosphorus and potash for higher yield. As cassava is an exhaustive crop that is highly efficient in nutrient absorption from a low fertile soil, apart from the availability of adequate quantities of nutrients in the soil, it is also important to have a proper balance between the nutrient constituents both in the soil and in plants. So the balanced application of nitrogen. phosphorus and potassium is particularly important in acid laterite soils. "Vellayani Hraswa", the shortest duration variety of cassava released recently by Kerala Agricultural University is characteristically a higher yielder .It may require reasonably high rate of the major nutrients and the same are to be standardized.

Hence, the review pertaining to the subject is presented broadly covering the influence of N, P, and K nutrients and their interactions on growth, yield and quality of cassava tubers.

2.1 GROWTH CHARACTERS

2.1.1 Plant Height

Higher level of nitrogen invariably favoured the vegetative growth of the plant. Significant increase in plant height, leaf number and leaf retention due to higher rates of nitrogen application was reported by Mandal *et al.* (1971). According to Natarajan (1975), nitrogen up to 150 kg ha^{-1} enhanced the plant height in cassava. Mandal *et al.* (1975) reported significant increases in plant height with added nitrogen. Pillai and George (1978 a) noticed increases in plant height and weight due to higher levels of nitrogen in M-4 variety of tapioca, but Muthukrishnan (1980) could not find any significant difference in foliage weight due to different rates of nitrogen application. Ramanujam and Indira (1978) reported that the rate of leaf production was higher for higher level of N and would produce about 10-12 functional leaves per plant per week. Similar increase in leaf production with incremental dose of N was noticed by Prabhakar *et al.* (1979).

Nair (1982) studied the influence of three levels of nitrogen (50,125 and 200 kg ha^{-1}) and recorded maximum plant height, number of nodes and number of functional leaves at 200 kg ha^{-1}, but enhancement in leaf area was attained only up to 125 kg N ha^{-1}.

Increasing rate of nitrogen application increased the plant height, number of nodes per plant, functional leaves per plant, and leaf area index of cassava when intercropped in coconut garden (Nayar 1986). Pamila (2003) reported that different levels of nitrogen showed significant influence on plant height and the maximum response was shown by nitrogen @ 75 kg ha^{-1} at all stages of growth which was on par with 100 kg nitrogen application. A quadratic nature of response was observed at the highest nitrogen dose in cassava. A number of workers have reported increase in plant height with increased doses of potassium. Several investigators could not get significant response to the levels of potassium on such growth characters as plant height, number of leaves and top yield (stems and leaves) of tapioca (Pushpadas and Aiyer, 1976; Ramaswamy and Muthukrishnan, 1980).

Pillai (1967) obtained significant increase in height of plant with K and Ca application in cassava. Increase in plant height with K application was recorded by Rajanna *et al.* (1987) in potato, Asokan *et al.* (1988) and Jimenez (1990) in cassava.

The effect of integrated nutrient management in cassava Cv. CO-3 was investigated in a field experiment conducted in Yethapur, Tamil Nadu, during 1998 by Rajamoni *et al.* (2001) and found that plant height was the highest (221.1cm) with the application of recommended dose of fertilizers (50:65:125) with N and K applied in three split doses along with Azospirillum and phosphobacteria. Nayar *et al.* (1998)

reported that the height of cassava plant enhanced significantly with higher level of NPK fertilizers.

2.1.2 Number of Leaves

Several research workers observed influence of nitrogen on leaf production and its retention in tapioca plants. Increased leaf growth due to higher levels of nitrogen application was also reported by CIAT (1976). Increase in plant height, leaf area and leaf sizes by increased dose of nitrogen were observed by Ngongi (1979).

Pillai and George (1978a) noticed increases in plant height and weight due to higher levels of nitrogen in M-4 variety of tapioca, but Muthukrishnan (1980) could not find any significant difference in foliage weight due to different rates of nitrogen application.

Queiroz (1980) also found significant increase in canopy yield by the application of adequate amount of nitrogen. They observed significant influence of nitrogen on leaf production and its retention in tapioca plants. Pamila (2003) observed significant differences between the nitrogen levels on this character at all growth stages. The treatment 75 kg nitrogen produced higher number of leaves at all growth stages and was significantly superior to 50 kg and 100 kg **N** ha^{-1}, which were on par.

Holmes and Wilson (1982) reported that high nitrogen supply stimulated leaf growth in cassava plants. Asokan and Sreedharan (1980) observed an increase in plant height and top yield at higher levels of potassium. Kang and Okeke (1984) reported a significant increase in plant top yield by nitrogen application.

2.2. YIELD AND YIELD COMPONENTS

2.2.1. Number of Tubers

Mandal and Singh (1970) observed yield increase due to nitrogen application and reported significant increase in the number of tubers per plant with increased level of nitrogen. Natarajan (1975) did not get any increase in tuber number, length, or girth due to higher levels of nitrogen. Mohankumar and Mandal (1977) observed significant increases in the number of tubers per plant with increased level of nitrogen. Vijayan and Aiyer (1969) found that mean number of tuber per plant was increased by increasing the rate of applied nitrogen from 0 to 75 kg ha^{-1} however, further increase of nitrogen decreased the tuber number in both varieties of tapioca, M4 and M-105.

Significant increase in tuber number of the hybrid H-165 was observed by Mandal and Mohankumar (1972) by raising the level of applied nitrogen from 40 kg to 80 kg ha^{-1} beyond which, there was not much difference. In another study to find out the effect of varying level of nitrogen on promising cassava hybrids, Mandal and Mohankumar (1972) found that the tuber number and average size of tuber were increased with increase in the levels of nitrogen in all the varieties tried. Pamila (2003) reported that the number of tubers significantly increased when the N level was increased from 50 to 75 kg ha^{-1} but decreased at 100 kg ha^{-1}. Nair (1982) recorded an increase in the tuber number at Kayamkulam and Vellayani at different rates of applied potassium and the incremental dose of K increased the tuber weight significantly up to the highest level.

2.2.2. Length And Girth of Tubers

Asokan *et al.* (1980) noticed that the length, girth and number of tubers did not vary significantly due to different levels of nitrogen (60,120 and 180 kg ha^{-1}) application in cassava. Pamila (2003) reported that cassava plants treated with 75 kg N ha^{-1} produced bigger tubers than those treated with 100 kg N and it was on par with 50 kg N treated plants while 75 kg N ha^{-1} treated plants produced longer tubers in cassava. Nair (1982) observed that the level of potassium did not influence the length and girth of tuber though there was an increase in the number of tubers per plant for different doses of applied potassium both at Vellayani and Kayamkulam.

Application of potash beyond 100 kg ha^{-1} had no significant influence on tuber size (Mohankumar and Hrishi, 1973). Length of tuber was not significantly influenced by K application in cassava variety H-97. But maximum girth of tubers was observed at 112.5 kg level of K. Asokan *et al.* (1988) found that the length of tuber was improved by combined application of N and K_2O.

Pamila (2003) found significant increase in weight of cassava tuber and the highest was obtained with 75 kg N ha^{-1}. Ofri (1976) observed that the tuber number and tuber weight were increased by K application.

Pillai and George (1978 b) showed that application of K increased the height of edible portion. Magalhaes *et al.* (1980) reported that the different levels of K_2O applied in cassava did not significantly affect the number of roots and weight. Incremental dose of K increased the tuber weight significantly up to the highest level (Nair, 1982)

2.2.3. Tuber Yield

Very few reports are available on the effect of higher levels of fertilizers on maximizing cassava tuber yield. Mandal and Singh (1970) reported significant yield increase due to nitrogen application up to 100 kg per hectare. Ramanathan *et al.* (1980) showed that application of nitrogen at higher levels did not significantly influence the fresh tuber yield although there was a numerical increase in yield at 120 kg N ha^{-1} in a field experiment conducted at Coimbatore and Bhavanisagar centers. On a very sandy loam soil (89 % sand, 0.70 % organic matter) in Santo Catarina, Brazil, two local varieties of cassava showed nearly linear response up to 150 kg N ha^{-1} and for both the varieties, highest yields were obtained with a split application of nitrogen with 1/3 each applied at 30,60 and 90 days after planting (Morae *et al.*1981).

Indira (1996) reported that the tuber yield was the highest when half the N was applied basally and the other half at one month after planting. Pamila (2003) reported that cassava tuber yield significantly increased with an increase in N level from 50 to 75 kg ha^{-1} but decreased with further increase in N.

According to Sittibusaya and Kurmarohita (1978), cassava was highly responsive to good fertility condition and required fairly high levels of fertilizer application to attain its high yield potential. When the plots were fertilized with higher rates of fertilizers, the nutrient removal increased to 235, 60, and 250 kg ha^{-1} of N, P, and K.

A scan through the various findings revealed that K had a definite role in boosting up the yield especially the tubers. As early in 1955, Malvotta *et al.* (1955) reported that the weight of roots decreased while that of shoot increased in the absence of K.

Jimenez (1990) found that the root yield tended to increase with increasing K rates where the agronomic and economic optimum points were fixed at 119 and 97 kg ha^{-1} K respectively with yield response at
97 kg K ha^{-1}.

Mohankumar *et al.* (1975) and Pushpadas and Aiyer (1975) separately tested the efficiency of K in enhancing the tuber yield in cassava and reported that enhanced rates of K application augmented the yield of cassava tubers.

Asokan and Sreedharan (1977) recorded a progressive increase in tuber yield up to 112.5 kg K_2O ha^{-1} and beyond which there was a significant reduction. Yield increase with increased rates of K application was also reported by Nair *et al.* (1980). But Rajanna *et al.* (1987) could not get any significant yield difference with increased levels of K_2O in potato. Hedge *et al.* (1986) and Chakrabarthy *et al.* (1993) obtained increased yield in sweet potato for K application. Asokan *et al.* (1984) noted a quadratic response to K in sweet potato tubers.

Ruiz *et al.* (1989) realized a yield potential of 32.6 t ha^{-1} with N @ 300 kg ha^{-1} yr^{-1}. In Hawaii, Manrique (1990) found that there was significant increase in top yield and total dry matter production but decreased the dry matter allocated to roots with increasing dose of applied nitrogen. Potassium not only increased the root yield of cassava plants, but also their starch content (Howeler, 1998). Maduakor (1997) found that storage root yield increased with increasing rates of K @ 105 kg ha^{-1} and 124 kg ha^{-1} for flat and ridge planting respectively. Goswami (2003) reported that the number of tubers and tuber weight per plant were significantly affected by K @ 125 kg ha^{-1}, but increased the tuber size and yield per plant.

Asokan *et al.* (1988) observed that the application of graded levels of N and K_2O @ 60,120 and 180 kg ha^{-1} each increased the tuber yield of local varieties by 35 per cent where as that of hybrid by 67 per cent. They found an increase in length of tuber due to combined effect of N and K_2O. Reports from the CTCRI (1990) further emphasized that continuous elimination of N and K was found to be deleterious to growth and yield, and reported that a fertilizer dose of 100 kg Nitrogen, 25 kg P_2O_5 and 50 kg K_2O per hectare was found to be the most suitable fertilizer dose for short duration cassava variety in paddy based cropping system, if the preceding crop rice was raised by adopting all the recommended package of practices. Thampatti and Padmaja (1995) found that application of muriate of potash @ 75 kg K_2O ha^{-1} with neem coated urea @ 50 kg ha^{-1} in two splits producted the highest tuber yield. Improvement in cassava tuber quality could be achieved by 50% substitution of K of muriate of potash by Na of common salt (Devi and Padmaja, 1996).

In North Vietnam, farmers obtained highest yield and net income with the application of 10 t ha^{-1} of pig manure in combination with 80 kg N and 80 kg K_2O ha^{-1} (Dang *et al.* 1998). Weite *et al.* (1998) found that the combined application of N, P and K was better than any other single nutrient and the application of N alone or N and K were better than that of P or K alone or in combination. Application of K in the presence of N and P increased the yield of cassava from about 14 t ha^{-1} to 22 t ha^{-1} (Howeler and Phien, 2000).

Hedge *et al.* (1990) was of the view that fertilizer treatment had no effect on number of tuber per plant, stem yield per plant, tuber length or tuber diameter.

Studies conducted at CTCRI revealed significant advantage for a fertilizer dose upto 150:100:150 kg NPK ha^{-1} (CTCRI, 1986) whereas an yield of 36 t ha^{-1} was obtained with NPK@ 200:100:200 kg ha^{-1} (CTCRI, 1987). Venkatachalam and Yasin (1991) reported significantly higher yields at a closer spacing of 75 cm x 75 cm at the lowest level of NPK @ 75:25:75 kg ha^{-1} for all the varieties of cassava. Wilson and Ovid (1994) studied the influence of fertilizers on cassava production under rainfed condition and application of 400 kg nitrogen + 200 kg P_2O_5 + 400 kg K_2O per hectare produced the highest yield of 63.1 t ha^{-1}, where the yield from unfertilized control was 7.1 t ha^{-1}. Cadavid *et al.* (1998) obtained significantly higher root yield and top biomass with the application of higher levels of N, P and K fertilizers.

Cordova *et al.* (1990) utilized two P sources for cassava cultivation in an ultisol and recommended the use of 160 kg P_2O_5 ha^{-1} in the form of rock phosphate because of high yield and returns, whereas Susan John *et al.* (1997) could not find any difference between the sources of P viz., single superphosphate and rock phosphate in terms of yield.

Mohankumar *et al.* (1996) worked out a fertilizer schedule of 100:25:100 kg NPK ha^{-1} for Sree Prakash, a short duration variety of cassava. CTCRI (1998) recommended a fertilizer dose of 75:75:75 kg NPK ha^{-1} for the variety Sree Vijaya.

A linear yield increase due to the application of N, P, K was obtained in colocasia by Pillai (1975). Significant responses to nitrogen have been observed more frequently in Asia than in Latin America. In nearly hundred NPK trails conducted by FAO on farmers field in

Thailand, there was mainly response to nitrogen followed by K and P (Hagen and Sittibusaya, 1990).

Higher tuber yield was recorded for the fertilizer level F_3 *viz.*, 100:50:100 kg NPK ha^{-1} which was significantly superior to F_1 level *viz.*, 50:50:50 kg NPK ha^{-1} but was on par with F_2 *viz.*, 75:50:75 kg NPK ha^{-1} (CTCRI, 2000). Geethakumari *et al.* (1997) recommended the application of NPK @ 50:70:70 kg ha^{-1} for cassava variety M-4 planted in October-November (Kannikappa).

Boonseng *et al.* (1998) recorded yield of 62.5 t ha^{-1} with NPK @ 313, 625, 1250 kg ha^{-1}. Susan John *et al.* (1998) reported that continuous application of NPK @ 100:50:100 kg ha^{-1} and FYM @ 12.5 t ha^{-1} individually as well as in combination over a period of 13 years was superior in maintaining tuber yield. Field experiments conducted by Imas and Bansal (2002) reported that a balanced N x K fertilizer application increased the tuber yield. Increasing K rates decreased the yield of small grade tubers and increased the proportion of large marketable tubers. Potassium application also dramatically decreased the incidence of late blight (*Phytophthora infestans*). In 1998, a maximum yield of 40.8 t ha^{-1} was obtained in Kufri (Shimla) when 180, 100 and 150 kg N, P_2O_5, K_2O ha^{-1} respectively were applied compared to a tuber yield of only 14.6 t ha^{-1} in the control plots without NPK application. It was concluded that high yields and enhanced quality tubers could only be sustained through the application of optimum rates in a balanced proportion.

Ngugen (1999) found that application of 80 kg N, 50 kg P_2O_5 and 100 kg K_2O with 5 to10 t ha^{-1} manure gave the highest net returns.

Pushpakumari and Geethakumari (1999) concluded that sweet potato crop is to be fertilized with 37.5 kg N, 25 kg P_2O_5 and 75 kg K_2O ha^{-1} combined with VAM inoculation for getting maximum yield.

Sethi *et al.* (2002) reported that the 500 g sett planted at 75 x 75 cm spacing and supplied with 125: 50:125 kg ha^{-1} NPK produced the highest yield (35.29 t ha^{-1}). Singh and Lal (2003) noticed that crop yield increased with a level of NPK @ 125: 50: 125 kg ha^{-1}.

2.2.4 Dry Matter Production

Vijayan and Aiyer (1969) mentioned that varying levels of N did not produce any difference in the dry matter yield of tubers. The total dry matter yield increased with N application and maximum was reached at approximately 40 to 80 kg N ha^{-1} (Keating and Evenson, 1981).

Pamila (2003) observed total dry matter production in cassava increased with N level up to 75 kg ha^{-1} and decreased at high level (100 kg ha^{-1}). Obigbesan (1973) recorded increase in tuber dry matter yield with higher rates of potassium application. Obigbesan and Agboola (1973) also reported similar results. It is generally known that K fertilizers improve vegetative growth and thereby dry matter accumulation in plants. In cassava also similar results were obtained by Pushpadas and Aiyer (1976). Again in 1977, Asokan and Sreedharan found that DMP in cassava (Variety H-97) was maximum at 112.5 kg level of K_2O ha^{-1}. Pillai and George (1978 a) reported an increase in dry matter content with K application.

Asokan and Sreedharan (1980) obtained maximum quantity of dry matter with 75 kg ha^{-1} of potassium application. In Potato, application of K up to 80 kg ha^{-1} enhanced the dry matter production, whereas higher levels of application decreased it (Sharma and Ezekiel, 1993).

Nayar *et al.* (1998) reported that total biomass production showed an increasing trend with higher level of NPK nutrition @ 100:50:100 kg ha^{-1}.

2.3. QUALITY ATTRIBUTES

2.3.1. Starch Content

The effect of potassium nutrition in enhancing the starch content of tuber was observed by several researchers (Obigbesan and Agboola, 1973; Natarajan, 1975; Muthuswamy and Rao, 1979; Muthukrishnan, 1980).

Pushpadas and Aiyer (1976) recorded highest starch yields per hectare with 250 kg K_2O ha^{-1}. Pillai and George (1978 b) also reported an increase in starch content by the application of potassium.

Linear increase in starch yield was recorded with higher rates of potassium application up to 200 kg ha^{-1} (CIAT, 1979).

Nair *et al.* (1980) noticed that increasing levels of K application resulted in an increase in starch content. Nair and Mohankumar (1982) noticed only a slight increase in starch content in cassava tubers due to potash application.

Relationship of soil K and leaf K with cassava yield and starch content were established in a trial conducted on an oxisol at the Malayan agricultural research and development in Malaya. Results showed that leaf K was a better indicator of starch yield than water-soluble soil K. The optimum leaf K for maximum starch yield was 2.11 per cent (Chan and Lee, 1982).

Nair and Aiyer (1986) observed an increase in edible portion, dry matter and starch content of tubers with the application of potassium. But Asokan *et al.* (1988) reported that fertilizer application reduced dry matter and starch percentage of cassava tubers.

P and Zn were also found to be beneficial in increasing the starch and dry matter production of tubers (CTCRI, 1977) whereas different sources of P had no significant influence on the starch content (Susan John *et al.* 1997).

Howeler (2002) reported that high dose of nitrogen application not only reduced the harvest index and root yield but also reduced the starch and increased interaction with each other and excessive application of one nutrient may induce a deficiency of another.

Sugito and Guritno (1991) found that combined application of N and K @ 50 to 100 kg N and 125 kg K ha^{-1} increased the starch content up to 27 per cent.

Tan and Mak (1995) stated that starch content was negatively correlated with high doses of nitrogen. Nair and Mohankumar (1984) could not get any significant increase in starch content due to NPK application.

Lujianwei *et al.* (2001) reported that adequate K input increased the yield and quality, assessed by measuring the average weight and starch content of tubers and also reported that the starch content of sweet potato tubers tended to be higher with adequate K_2SO_4 than with KCl. However, total starch content was higher with KCl due to higher fresh yield of tubers.

2.3.2. Protein Content

Crude protein content of cassava tuber (M-4 variety) was found to increase from 1.93 per cent with 50 kg N ha^{-1} to 2.13 per cent with 100 kg N ha^{-1} (Pillai, 1975). Nair (1982) found that crude protein content increased significantly with incremental doses of nitrogen at Kayamkulam and Vellayani.

Levels of potassium exerted no influence on the crude protein content of tubers (Mandal and Singh, 1970). But Natarajan (1975) noticed significant reduction in crude protein content of tubers by the application of higher levels of K. Similar results were obtained by Pushpadas and Aiyer (1976) and Pillai and George (1978 b) who had reported a decrease in crude protein content with K application. A decrease in crude protein content was also recorded by Nair (1982) due to potash application.

2.3.3. Cyanogenic Glucosides

The increase in HCN content in cassava tubers with high rates of N was reported by many researchers (Muthuswamy and Rao, 1981; Mohankumar and Nair, 1983; Asokan *et al.*, 1988; Obigbesan and

Fayemi, 1996). There are also reports on the effect of FYM alone or in combination with nitrogen in increasing the HCN content (Pillai *et al.* 1985 and Susan John *et al.* 1998). This may probably be due to the increased production of cyanogenic glucosides with high rates of nitrogen. Obigbesan and Fayemi (1996) could find a decrease in HCN in improved cultivars by nitrogen fertilization. Nair and Mohankumar (1982) studied the effect of different sources and levels of potassium on the yield and quality of tubers found that higher levels of potassium application resulted in a decrease in the HCN content. Ramanujam (1982) reported reduction in the HCN content of tubers and leaves of tapioca variety (H-2304) by potassium nutrition. The lower dose of K_2O (50 kg ha^{-1}) was not effective in reducing the HCN concentration. But by the application of potash beyond 100 kg K_2O ha^{-1}, the HCN content was reduced by 40 to 76 per cent as compared to the control.

Tan and Mak (1995) found a negative association between high soil N and Mg with HCN content of cassava tuber. Cadavid *et al.* (1998) under a long-term fertilizer trial in Colombia observed a reduction in HCN content by the combined application of NPK fertilizers. Susan John *et al.* (1998) reported that balanced application of NPK @ 100:50:100 kg ha^{-1} along with FYM @ 12.5 t ha^{-1} did not increase the HCN content of cassava tubers.

According to Mohankumar and Nair (1985) and George *et al.* (2000), lime application reduced HCN content.

P sources *viz.*, single superphosphate and rock phosphate also had not produced any significant difference in the HCN content (Susan John *et al.*, 1997) of tubers.

Indira *et al.* (1972) reported that application of nitrogen and phosphorus increased the HCN content while potassium alone or in combination with nitrogen reduced the HCN content of tapioca tubers.

2.3.4. Cooking Quality

Kurian *et al.* (1976) found that the quality of cassava tuber was improved by reducing bitterness by the application of wood ash alone or a mixture of cow dung and wood ash. In cassava (Variety H-97), application of K at the highest level of 150 kg ha^{-1} had resulted in an appreciable increase in cooking quality (Asokan and Sreedharan, 1977).

Remarkable improvement in cooking quality as measured by the bitterness of tuber at a higher rate of potassium nutrition (150 kg K_2O $ha^{-1}$was again observed by Asokan and Sreedharan (1980).

In agreement to the above findings, Nair *et al.* (1980) reported that the treatments without potash or half the normal quantity, in general, produced tubers with bitter taste. Nair (1982) reported a better cooking quality of tubers at Vellayani and Kayamkulam with potassium application. Improvement in cassava tuber quality could be achieved by 50 per cent substitution of K of muriate of potash by Na of common salt (Devi and Padmaja, 1996).

Cooking quality of tubers assessed by a taste panel was found to be reduced significantly by higher level of nitrogen as opined by Prema *et al.* (1975).

Nair (1976) observed a high percentage (75 %) of non-bitter tubers at 50 kg N ha^{-1} as compared to 63 per cent in the case of 75 kg N ha^{-1} and 69 per cent in the case of 100 kg N ha^{-1}. Nitrogen application at 75 kg ha^{-1} produced a higher percentage of soft textured tubers as against a lower percentage for nitrogen at the rate of 50 and 100 kg ha^{-1}.

A definite influence of the levels of nitrogen on the cooking quality of tubers could not be observed by Mohankumar and Maini (1977). Sheela (1981) also reported reduction in cooking quality of tuber due to higher levels of nitrogen application.

2.4.PHYSIOLOGICAL PARAMETERS

2.4.1. Leaf Area Index

Increase in plant height, leaf area, and leaf size by incremental doses of nitrogen were observed by Ngongi (1979). Kang and Okeke (1984) established that N application increased plant top yield and foliar N per cent with no significant effect on root yield. Indira (1996) reported that the leaf area index and tuber yield in cassava were influenced by the time of application of nitrogen.

Pamila (2003) reported that LAI increased with increase in N level from 50 to 75 kg and decreased at 100kg N level.

Ngongi (1979) reported increase in plant leaf area and leaf size with incremental dose of potash from 0 to 240 kg ha^{-1}. Nair (1982) also showed significant difference in plant height during the growth stages at two locations to different rates of potassium, but the effect of potassium was not significant on the number of leaves, and LAI. Ramanujam (1982) observed increase in plant height, number of leaves, leaf size and LAI by K fertilizer as compared to the control in cassava var-H-2304. But application of K beyond 50 kg K_2O ha^{-1} showed no appreciable change in LAI, crop growth rate and dry matter production. But maximum values of plant fresh weight and total dry matter were observed at low levels of potash application. LAI and LAD gradually increased in sweet potato cultivars up to 90 days with enhanced K levels (Chakrabarthy *et al.* 1993). Contrary to this, Singh *et al.* (1993) reported that increase in the level of K had no significant effect on leaf area per plant in potato.

Howeler (1985) opined that cassava has an optimal leaf area index (2.5 – 3.5) and that high rate of fertilization may lead to excessive leaf growth and an LAI > 4.

Nayar *et al.* (1998) reported that leaf area index especially at third month increased with increasing level of NPK@ 75:50:75 kg ha^{-1}.

2.4.2. Chlorophyll Content

The univalent cations exert a pronounced influence on the chlorophyll content of plants.

Devi and Padmaja (1997) observed an increase in chlorophyll content with an increase in the level of sodium substitution showing a possible role of sodium in chlorophyll biosynthesis in cassava.

2.5. UPTAKE OF MAJOR NUTRIENTS

There are different reports from various cassava-growing countries of the world on the uptake of nutrient by cassava. Greenstreet and Lambourne (1933) reported an uptake of 114 kg N, 25 kg P_2O_5 and 240 kg K_2O in tops and roots of cassava crop which yielded 28 t ha^{-1}.

Izawa and Okamoto (1959) observed that higher concentration of N (1.08%) in tuber at harvest was recorded with the treatment of 100 kg K_2O ha^{-1} applied as basal.

Most of the cassava varieties that are capable of producing 30 tons of fresh tubers per ha removed 180 to 200 kg N, 15 to 22 kg P and 160 kg K (CTCRI, 1983). Corrales and Guerra (1989) studied the NPK uptake and utilization coefficient in a leached brown sialitic soil and found highest uptake of 150, 61.3 and 195.3 kg NPK ha^{-1} and the utilization coefficients of N and P fertilizers were 18 and 2 percentage respectively. Garriga *et al.* (1989) observed a crop removal of 64 kg N, 28 kg P and 125 kg K per hectare for tuber yield of 29 t ha^{-1}. According to Howeler (1991), on the basis of per ton of dry matter in harvested product, cassava actually removed very much less N and P than most other crops but K in higher amounts. Mohankumar *et al.* (1996) found that cassava absorbed 6.45 kg N, 1.30 kg P and 8.62 kg K in the whole plant for production of one ton of total dry matter. Pellet and Elsharkawy (1997) was of the view that the proportion of total nutrient uptake translocated on storage root was the highest for K (67%) followed by P (45 %) and N (39 %). Suyamto (1998) estimated the typical N, P and K removal by the portion of cassava roots as 4.91, 1.08 and 5.83 kg ha^{-1} respectively. The NPK removal was found to increase with an increase in the level of manuring to a dose of 125:50:125 kg ha^{-1} (CTCRI, 2000).

Materials and Methods

3. MATERIALS AND METHODS

A field experiment to work out a fertilizer schedule for the short duration cassava variety, "Vellayani Hraswa" was conducted at the Instructional Farm, College of Agriculture, Vellayani during 2003. The details of the experimental site, cropping season and materials and methods adopted for the investigation are presented in this chapter.

3.1 EXPERIMENTAL SITE

3.1.1 Location

The Instructional Farm, Vellayani is located geographically at $8^0 30'$N latitude and $76^0 54'$ E longitude and at 29 m above MSL.

3.1.2 Soil

The soil of the experimental site is typical red loam classified as Rhodic Haplustox.

The physical and chemical characteristics of the soil where the field experiment was conducted are given in Table 1.

3.2 SEASON

The field experiment was laid out during the main cassava-planting season of June to December 2003. The crop was planted on 25^{th} June and harvested on 29^{th} December 2003.

3.2.1 Weather conditions

Vellayani enjoys a tropical humid climate. Data on maximum and minimum temperatures, relative humidity, rainfall and evaporation during the entire cropping season are collected and presented as weekly averages in Appendix I and Fig. 1.

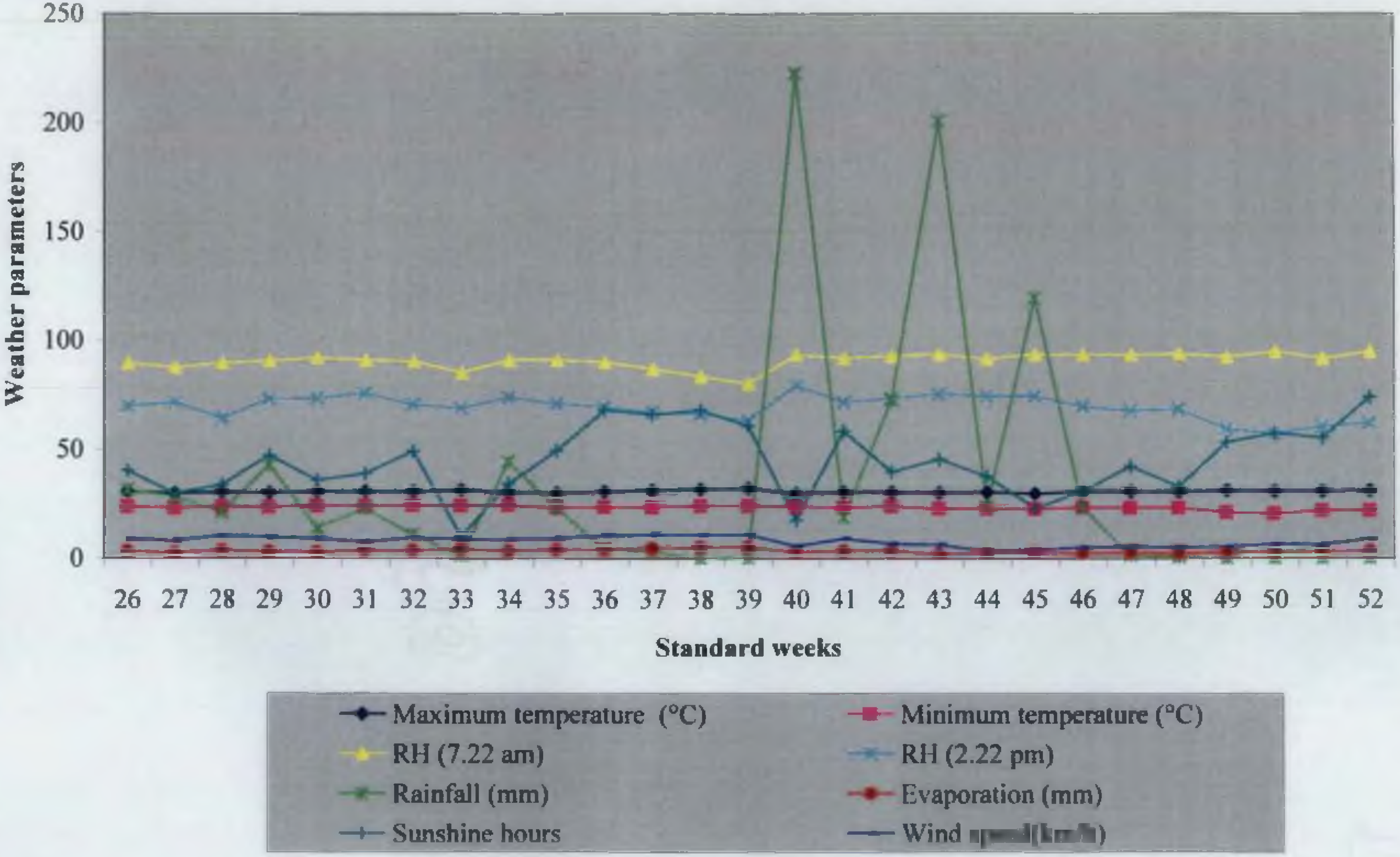

Fig. 1 Weather parameters during the cropping period (25th June to 31st December, 2003) – weekly averages

Table 1. Soil physical and chemical characteristics of the experimental field

Characteristics	Value	Method
Mechanical composition		International pipette method (Piper, 1966)
Clay	28.1 %	
Silt	20.9 %	
Fine sand	18.4 %	
Coarse sand	32.1 %	
Textural class	Sandy clay loam	
Bulk density	1.27 Mg m^{-3}	Undisturbed core method (Black *et al.* 1965
pH	5.3	pH meter with glass electrode (Jackson, 1973)
Electrical conductivity	< 0.06 dSm^{-1}	Conductivity meter (Jackson, 1973)
Cation exchange capacity	4.6 c mol (p^+) kg^{-1}	Ammonium saturation suing neutral normal ammonium acetate (Jackson, 1973)
Organic Carbon	0.71 %	Wet oxidation method (Walkley and Black, 1934)
Available N	237.1 kg ha^{-1}	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P_2O_5	43.2 kg ha^{-1}	Bray's colorimetric method using ascorbic acid (Bray and Kurtz, 1945)
Available K_2O	144.6 kg ha^{-1}	Neutral normal ammonium acetate method (Hanway and Heidal, 1952

3.3 MATERIALS

3.3.1 Planting Material and Variety Used

The planting material of the cassava var. "Vellayani Hraswa" was obtained from the Instructional Farm, College of Agriculture, Vellayani. Vellayani Hraswa is a branching type, evolved through clonal selection, due to its superior cooking quality it is a very popular culinary variety. It is a short duration variety of 6 months period.

3.3.2. Manures and Fertilizers

The organic manure used was FYM containing 0.4 % N, 0.3 % P_2O_5, and 0.3 % K_2O. The fertilizers used were urea (46 % N), Rajphos (20% P_2O_5) and muriate of potash (60 % K_2O).

3.3.3. Experimental design and layout

The study was laid out in a 3^3 Factorial RBD design with three levels each of N, P and K and two replications.(Plate 1)

The procedure followed for the allocation of various treatments to different plots was in accordance with Yates (1973). The lay out plan is depicted in Appendix. II.

The details of the lay out are furnished below.

3.4 METHODS

Design	: 3^3 Factorial experiment
Variety	: Vellayani Hraswa
Replication	: 2
Treatment combinations	: 27
Plot size	: 5.4 x 5.4 M
Net plot	: 3.6 x 3.6 M
Spacing	: 90 x 90 cm.

Factor A. Levels of N

n_1 - 50 Kg ha^{-1}

n_2 - 75 Kg ha^{-1}

Plate 1. General view of the experimental field

n_3 - 100 Kg ha^{-1}

Factor B. Levels of P

p_1 - 50 Kg ha^{-1}

p_2 - 75 Kg ha^{-1}

p_3 - 100 Kg ha^{-1}

Factor C. Levels of K

k_1 - 50 Kg ha^{-1}

k_2 - 75 Kg ha^{-1}

k_3 - 100 Kg ha^{-1}

Treatment combinations

No.	Treatment combination	No.	Treatment combination
1	$n_1p_1k_1$	15	$n_2p_2k_3$
2	$n_1p_1k_2$	16	$n_2p_3k_1$
3	$n_1p_1k_3$	17	$n_2p_3k_2$
4	$n_1p_2k_1$	18	$n_2p_3k_3$
5	$n_1p_2k_2$	19	$n_3p_1k_1$
6	$n_1p_2k_3$	20	$n_3p_1k_2$
7	$n_1p_3k_1$	21	$n_3p_1k_3$
8	$n_1p_3k_2$	22	$n_3p_2k_1$
9	$n_1p_3k_3$	23	$n_3p_2k_2$
10	$n_2p_1k_1$	24	$n_3p_2k_3$
11	$n_2p_1k_2$	25	$n_3p_3k_1$
12	$n_2p_1k_3$	26	$n_3p_3k_2$
13	$n_2p_2k_1$	27	$n_3p_3k_3$
14	$n_2p_2k_2$		

Organic manure @ 12.5 t ha^{-1} was applied to all the plots as per the Package of Practices Recommendations of Kerala Agricultural University (KAU 2002).

3.4.1. Cultivation Practices

3.4.1.1. Field Preparation

The experimental area was dug twice and weeds and stubbles were removed. The field was laid out into blocks and plots and then mounds were taken.

3.4.1.2. Fertilizer Application

The different nutrient levels of N, P and K were applied to the plots in the form of urea, rajphos and muriate of potash respectively in appropriate quantities according to the treatment schedule. Full dose of P, $1/3^{rd}$dose each of N and K were applied as basal dose. The $1/3^{rd}$dose each of N and K were applied at 30 days after planting and the balance $1/3^{rd}$dose at 60 days after planting.

3.4.1.3. Planting

Setts of about 20 cm length were planted on the top of the mounds taken at a spacing of 90 x 90 cm, inserting 4 cm of setts below the soil.

3.4.1.4. After cultivation

Dried and unsprouted setts were removed and gap filling with setts of longer size (about 40 cm) was done ten days after planting. Excess sprouts were removed one month after planting (MAP) after retaining two healthy sprouts. Shallow digging and weeding were done 60 days after planting along with top dressing of the fertilizers followed by light earthing up. A light raking, second weeding and earthing up were done two months later.

3.4.1.5. Harvest

The crop was ready for harvest by six months after planting. Harvesting was done by digging out the tubers and pulling out the stem. The tubers were separated from the shoot. The border rows and sample plants were harvested separately from each plot. The tubers and shoot portions from the net plot were weighed separately and the weights were recorded.

3.5 BIOMETRIC OBSERVATIONS

The following biometric observations of the plants under different treatments were recorded. Five plants were selected from each plot and observations were taken from those plants.

3.5.1 Height of Plant

Height of each plant was measured from the base of sprout to the terminal bud at monthly intervals.

3.5.2 Total number of leaves

Total number of leaves was recorded at monthly intervals by counting the number of fully opened leaves as well as the leaf scars from the base to the tip of the stems.

3.6 PHYSIOLOGICAL PARAMETERS

The following physiological parameters were also noted at the time of harvest.

3.6.1 Leaf area index

The total leaf area of each sample plant was calculated at 180th day after planting by adopting non-destructive method suggested by Ramanujam and Indira (1978) and LAI was worked out using the following formula developed by Watson (1947).

$$LAI = \frac{\text{Leaf area per plant } (cm^2)}{\text{Land area occupied by the plant } (cm^2)}$$

3.6.2 Stomatal conductance

Leaf stomatal conductance was measured by ΔT porometer of company ΔT, Cambridge, U. K.

3.6.3 Chlorophyll content

Chlorophyll content was determined by the colorimetric method as described by Arnon (1949).

3.7 YIELD AND YIELD COMPONENTS

3.7.1 Number of tubers per plant

The tubers from the observational plants were separated and counted.

3.7.2 Length of the tubers

Length of tubers from the observation plants were measured and the average worked out.

3.7.3 Girth of tubers

Girth measurements were recorded from the middle and end portions of the tubers and the average was calculated.

3.7.4 Weight of tuber per plant

Total weight of tubers from the sample plants were recorded and the average value was expressed as weight of tubers per plant.

3.7.5 Tuber yield per hectare

After the harvest of the crop, the tubers were separated, the soil adhering to the tubers were removed and the fresh weight of tuber from the net plot was recorded and expressed as t ha^{-1}.

3.7.6 Total dry matter production

One plant from each plot was carefully pulled out and separated out into stem, leaves and roots. Fresh weight of each part was recorded and sub samples were taken for estimating the dry weight. The sub samples were dried in an oven at $60 \pm 5^{O}C$ to constant dry weight. Thus the dry weight of each plant part was computed and recorded.

3.8 QUALITY ATTRIBUTES

3.8.1 Starch content

Starch content of the flesh was estimated by using potassium ferricyanide method (Aminoff *et al.* 1970). The values were expressed as percentage on fresh weight basis.

3.8.2 Protein content

The nitrogen content of the oven-dried samples of tuber flesh from each plot was estimated by micro kjeldahl method. The nitrogen values were multiplied by the factor 6.25 to get the crude protein content of tuber (A.O.A.C. 1969).

3.8.3 Hydrocyanic acid (HCN) content

The HCN content of fresh tuber samples was estimated by the colorimetric method suggested by Indira and Sinha (1969).

3.8.4 Cooking quality

The cooking quality of tuber was assessed by a taste panel (Prema *et al.* 1975) on a discrete scale with five points. The best taste was assessed as sweet and was allotted a score of four. The other scores in decreasing order of taste were powdery sweet (3), starchy (2), bitter (1) and watery bitter (0).

3.9 CHEMICAL ANALYSIS

3.9.1 Plant Analysis

Areal part and tuber samples were separately analyzed for the content of N, P, and K at the time of harvest.

Nitrogen was estimated by modified Kjeldahl method after digestion with H_2SO_4 (Jackson, 1973). Determination of other elements was done after digestion with HNO_3: $HClO_4$: H_2SO_4 mixture (Piper, 1966). Phosphorus was estimated by the vanado molybdate yellow colour method in a Klett Summerson Photoelectric colorimeter (Jackson, 1973). Potassium was estimated using the flame photometer.

3.9.2 Soil Analysis

Composite soil samples were collected from each plot, before planting and after the harvest of crop, air dried, powdered and passed through a 2 mm sieve and analyzed for available N, P and K using the methods given in Table 1.

3.10 ECONOMICS OF CULTIVATION

The economics of cultivation of the crop was worked out and the net income and benefit – cost ratio (BCR) were calculated as follows

Net income (Rs. ha^{-1}) = Gross income – Cost of cultivation.

$$BCR = \frac{\text{Gross income}}{\text{Cost of cultivation}}$$

3.11 STATISTICAL ANALYSIS

The experimental data were analyzed statistically by applying the technique of analysis of variance (ANOVA) for 3^3 factorial experiments and the significance was tested by F test (Cochran and Cox, 1965). Wherever F test was significant in ANOVA, the critical difference (CD) is provided. The results and discussion are based on 5 per cent level of significance.

Results

4. RESULTS

A field experiment was conducted at the Instructional Farm, College of Agriculture, Vellayani from 25th June to 25th December 2003 to workout a nutrient schedule for the short duration cassava var. "Vellayani Hraswa". The results of the investigations are presented in this chapter.

4.1 GROWTH CHARACTERS

4.1.1 Height of Plant

The data on the main effects of N, P, K and their interaction effects on the plant height at different growth stages are presented in Tables 2a, 2b and 2c.

There was no significant effect on the height of plant throughout the crop growth for both main and interaction effects of N, P and K. The lowest value (179.17 cm) was recorded for n_1 and the highest value for n_3 (182.94 cm). Among the P levels, p_2 recorded the lowest value (177.44 cm) and p_1, the highest value (182.50 cm). The lowest (177.06 cm) and the highest values (185.67 cm) for plant height were observed for k_1 and k_3 respectively. As for the interaction effects of N x P at 6 MAP, n_2p_2 and n_3p_1 respectively recorded the lowest (171.83 cm) and the highest (188.33 cm) values. Of the interactions between N and K, n_2k_1 and n_3k_3 resulted the lowest (172.50 cm) and the highest (191.67 cm) values while with P and K interactions, the lowest (172.50 cm) and the highest (187.83 cm) values were respectively for p_2k_1 and p_1k_3 interactions. Interactions, $n_2p_3k_1$ recorded the lowest (160.40 cm) and $n_2p_3k_3$, the highest (202.00 cm) values.

4.1 2 Number of Leaves Per Plant

The main effects of N, P, K and their interactions on the number of leaves per plant at different growth stages are presented in Tables 3a, 3b and 3c. Nitrogen had significant influence on the number of leaves

Table 2 a. Main effects of N, P and K on plant height (cm)

Main effects	1 MAP	2 MAP	3 MAP	4 MAP	5 MAP	6 MAP
n_1	14.19	29.00	86.78	117.00	142.82	179.17
n_2	13.06	31.11	87.61	118.00	141.61	178.39
n_3	14.17	30.72	86.06	117.33	143.83	182.94
F value	1.79	1.55	0.05	0.04	0.31	0.42
CD	NS	NS	NS	NS	NS	NS
p_1	14.44	29.94	85.22	117.06	142.89	182.50
p_2	13.92	28.94	84.94	115.17	144.22	177.44
p_3	15.06	31.90	40.28	120.11	141.17	180.56
F value	2.27	2.86	0.80	0.90	0.59	0.46
CD	NS	NS	NS	NS	NS	NS
k_1	14.50	29.89	87.17	117.17	142.06	177.06
k_2	14.39	31.00	83.66	118.94	144.00	177.78
k_3	14.47	29.44	89.61	119.22	142.22	185.67
F value	0.05	.048	0.80	1.17	0.25	1.61
CD	NS	NS	NS	NS	NS	NS

Table. 2 b. Interaction effects of NP, NK and PK on plant height (cm)

Interaction effects	1 MAP	2 MAP	3 MAP	4 MAP	5 MAP	6 MAP
n_1p_1	14.00	31.17	88.33	117.82	142.50	179.83
n_1p_2	13.42	26.00	77.67	110.00	145.50	180.17
n_1p_3	13.17	29.83	94.33	123.17	140.50	177.50
n_2p_1	13.33	29.83	80.33	115.33	141.33	179.33
n_2p_2	14.33	31.50	88.00	121.17	142.50	171.83
n_2p_3	15.50	32.02	94.50	117.50	141.00	184.00
n_3p_1	14.00	28.83	87.00	118.00	144.83	188.33
n_3p_2	14.00	29.33	89.17	114.33	144.67	180.33
n_3p_3	14.50	34.00	82.00	119.67	142.00	180.17
F Value	0.35	1.96	1.61	1.00	0.10	0.50
CD	NS	NS	NS	NS	NS	NS
$_1k_1$	14.50	28.33	89.67	115.33	146.67	181.50
n_1k_2	13.67	30.50	77.94	115.50	140.17	172.53
n_1k_3	14.42	28.17	92.83	120.17	141.67	141.17
n_2k_1	15.00	31.50	85.00	112.83	137.50	172.50
n_2k_2	15.50	31.00	89.00	121.50	145.67	181.50
n_2k_3	14.67	30.83	88.53	119.67	141.67	181.17
n_3k_1	14.17	29.83	86.83	114.33	147.00	178.17
n_3k_2	14.00	31.50	84.17	119.83	146.17	179.00
n_3k_3	14.33	30.83	87.17	117.83	143.33	191.67
F value	0.46	0.27	0.65	0.29	1.24	0.57
CD	NS	NS	NS	NS	NS	NS
p_1k_1	13.83	29.17	86.17	115.50	141.50	181.00
p_1k_2	14.33	30.33	83.00	116.67	144.83	178.67
p_1k_3	15.17	30.33	86.50	119.06	142.33	187.83
p_2k_1	15.17	29.17	78.33	107.67	145.00	172.50
p_2k_2	13.33	29.83	80.83	117.00	142.67	175.17
p_2k_3	13.25	27.83	95.67	120.83	145.00	184.67
p_3k_1	14.67	31.33	97.00	119.33	139.67	177.67
p_3k_2	15.50	32.83	87.17	123.17	144.50	179.50
p_3k_3	15.00	31.67	86.67	117.83	139.33	184.50
F value	2.08	0.09	1.47	0.78	0.41	0.09
CD	NS	NS	NS	NS	NS	NS

Table 2 c. Interaction effects of NPK on plant height (cm)

Treatments	1 MAP	2 MAP	3 MAP	4 MAP	5 MAP	6 MAP
$n_1p_1k_1$	13.50	29.50	93.50	124.00	148.40	172.50
$n_1p_1k_2$	14.00	33.50	82.50	109.50	139.50	174.50
$n_1p_1k_3$	14.50	30.50	89.00	120.00	140.00	192.50
$n_1p_2k_1$	14.00	25.00	73.50	93.00	146.50	171.50
$n_1p_2k_2$	12.50	28.00	61.00	116.00	141.50	173.00
$n_1p_2k_3$	13.75	25.00	98.50	121.00	148.50	196.00
$n_1p_3k_1$	16.00	30.50	102.00	129.00	145.50	197.50
$n_1p_3k_2$	14.50	30.00	90.00	121.00	139.50	171.00
$n_1p_3k_3$	15.00	29.00	91.00	119.50	136.50	164.00
$n_2p_1k_1$	15.00	30.50	81.00	113.50	134.50	187.00
$n_2p_1k_2$	15.50	28.50	79.50	122.00	147.00	174.00
$n_2p_1k_3$	15.00	30.50	80.50	110.50	142.50	177.00
$n_2p_2k_1$	14.00	31.00	79.00	114.50	144.50	170.50
$n_2p_2k_2$	14.00	32.00	89.00	121.00	143.50	180.50
$n_2p_2k_3$	15.00	31.50	96.00	128.00	139.50	164.50
$n_2p_3k_1$	15.00	33.00	95.00	110.50	133.50	160.40
$n_2p_3k_2$	17.00	32.50	98.50	121.50	146.50	190.00
$n_2p_3k_3$	14.50	30.50	90.00	120.50	143.00	202.00
$n_3p_1k_1$	13.00	27.50	84.00	109.00	142.00	183.50
$n_3p_1k_2$	13.50	29.00	87.00	118.50	148.00	187.50
$n_3p_1k_3$	15.50	30.07	90.00	126.50	144.50	194.00
$n_3p_2k_1$	16.50	31.50	82.50	115.50	144.00	175.50
$n_3p_2k_2$	13.50	29.50	92.50	114.00	143.00	172.00
$n_3p_2k_3$	12.00	27.00	92.50	113.50	147.00	193.50
$n_3p_3k_1$	13.00	30.50	94.00	118.50	140.00	175.50
$n_3p_3k_2$	15.00	36.00	73.00	127.00	147.50	177.50
$n_3p_3k_3$	15.50	35.00	79.00	113.50	138.50	187.50
F value	1.13	0.57	0.46	1.38	0.41	2.03
CD	NS	NS	NS	N S	NS	NS

Table 3 a. Main effects of N, P and K on number of leaves per plant

Main effects	1 MAP	2 MAP	3 MAP	4 MAP	5 MAP	6 MAP
n_1	8.00	35.33	58.00	120.39	159.67	184.28
n_2	12.56	45.78	65.00	117.61	161.72	185.94
n_3	12.67	43.12	78.83	156.44	178.39	205.50
F value	53.39**	8.01**	56.16**	14.94	11.91	25.76**
CD	1.06	5.58	4.11	16.30	8.65	6.76
P_1	9.89	40.00	63.06	121.67	159.89	190.56
p_2	11.78	4056	67.94	136.61	165.61	188.06
p_3	11.56	43.78	70.83	136.17	174.28	197.11
F value	8.03**	1.09	7.72**	2.30	5.53**	4.05*
CD	1.06	NS	4.11	NS	8.65	6.76
k_1	11.39	40.22	17.11	118.94	159.89	191.11
k_2	10.83	43.50	69.89	141.78	171.78	193.56
k_3	11.00	40.56	64.83	133.72	168.11	191.06
F value	0.61	0.88	3.20	4.28*	4.19*	0.38
CD	NS	NS	NS	16.30	8.65	NS

* Significant at 5% level ** Significant at 1% level

Table 3 b. Interaction effects of NP, NK and PK on number of leaves per plant

Interaction effects	1 MAP	2 MAP	3 MAP	4 MAP	5 MAP	6 MAP
n_1p_1	8.17	33.83	56.33	106.33	151.50	184.33
n_1p_2	8.33	32.90	57.82	101.50	155.33	177.50
n_1p_3	7.50	40.17	59.83	133.33	172.17	191.00
n_2p_1	10.83	44.67	55.00	104.67	154.50	186.00
n_2p_2	14.67	43.33	70.67	137.33	165.83	186.17
n_2p_3	12.17	49.33	69.33	110.83	164.83	185.67
n_3p_1	10.67	41.50	77.83	134.00	173.67	201.33
n_3p_2	12.33	46.33	75.33	151.00	175.67	200.50
n_3p_3	15.00	41.67	83.33	164.33	185.83	214.67
F value	6.98**	1.07	4.0*	1.68	0.85	1.33
CD	1.84	NS	7.12	NS	NS	NS
n_1k_1	8.17	33.17	53.67	97.83	144.00	181.33
n_1k_2	7.17	36.50	63.33	133.17	167.00	185.33
n_1k_3	8.67	36.33	57.00	130.17	168.00	186.17
n_2k_1	13.00	44.50	72.00	11.067	159.17	188.33
n_2k_2	12.33	51.17	63.00	132.83	170.17	188.00
n_2k_3	12.33	41.67	60.00	101.33	155.83	181.00
n_3k_1	13.00	43.00	75.67	148.33	176.50	203.17
n_3k_2	13.00	42.83	83.33	159.33	178.17	207.33
n_3k_3	12.00	43.67	71.50	161.67	180.50	206.00
F value	1.03	0.80	4.99**	1.10	2.51	0.73
CD	NS	NS	7.12	NS	NS	NS
p_1k_1	8.67	40.17	62.00	98.17	141.67	190.17
p_1k_2	9.50	37.17	66.17	133.33	170.83	192.33
p_1k_3	11.50	42.67	61.00	133.50	167.17	188.67
p_2k_1	13.67	38.00	69.67	140.00	168.50	190.50
p_2k_2	11.17	47.17	68.33	132.33	163.17	188.00
p_2k_3	10.50	36.50	65.83	137.60	165.17	185.67
p_3k_1	11.83	42.50	69.67	118.67	169.50	192.67
p_3k_2	11.83	46.17	75.17	159.67	181.33	199.83
p_3k_3	11.00	42.50	67.67	130.17	172.00	198.83
F value	6.14**	1.61	0.60	2.52	3.53*	0.59
CD	1.84	NS	NS	NS	14.98	NS

* Significant at 5% level ** Significant at 1% level

Table 3.c. Interaction effects of NPK on number of leaves per plant

Interaction effects	1 MAP	2 MAP	3 MAP	4 MAP	5 MAP	6 MAP
$n_1p_1k_1$	5.50	36.00	44.00	72.50	124.50	182.00
$n_1p_1k_2$	7.50	32.00	60.50	12.50	164.00	183.01
$n_1p_1k_3$	11.50	33.50	64.50	126.00	166.00	186.00
$n_1p_2k_1$	11.50	32.50	59.00	104.00	145.50	180.50
$n_1p_2k_2$	7.00	34.00	68.00	136.50	163.00	181.00
$n_1p_2k_3$	6.50	29.50	46.50	124.00	157.50	171.00
$n_1p_3k_1$	7.50	31.00	58.00	117.00	162.00	181.50
$n_1p_3k_2$	7.00	43.50	61.50	142.50	174.00	190.00
$n_1p_3k_3$	8.00	46.09	60.00	140.50	180.50	201.50
$n_2p_1k_1$	10.50	47.50	57.50	79.00	128.00	181.50
$n_2p_1k_2$	11.00	38.50	55.00	112.50	175.00	172.50
$n_2p_1k_3$	11.00	48.50	52.50	122.50	160.50	184.00
$n_2p_2k_1$	16.00	33.36	84.00	167.00	186.00	197.50
$n_2p_2k_2$	12.00	60.50	62.00	123.50	150.50	178.00
$n_2p_2k_3$	16.00	36.00	66.00	121.50	161.00	183.00
$n_2p_3k_1$	12.50	52.56	74.50	86.00	163.90	187.50
$n_2p_3k_2$	14.00	55.00	72.50	162.50	185.00	193.50
$n_2p_3k_3$	10.00	40.50	61.50	84.00	146.00	176.00
$n_3p_1k_1$	10.00	37.00	84.50	143.00	172.50	207.00
$n_3p_1k_2$	10.00	41.50	83.00	167.00	173.50	201.00
$n_3p_1k_3$	12.00	46.50	66.00	132.00	175.00	196.00
$n_3p_2k_1$	13.50	48.00	66.00	142.00	174.00	193.50
$n_3p_2k_2$	14.50	47.00	75.00	137.00	176.00	205.00
$n_3p_2k_3$	9.00	44.00	85.00	167.00	177.00	203.00
$n_3p_3k_1$	15.50	44.00	76.50	153.00	183.00	209.00
$n_3p_3k_2$	14.50	40.00	92.00	174.00	185.00	216.00
$n_3p_3k_3$	15.00	41.00	81.50	166.00	189.50	219.00
F value	3.96**	1.73	5.95**	1.55	2.29	1.54
CD	3.18	NS	12.34	NS	NS	NS

* Significant at 5% level ** Significant at 1% level

per plant at all the growth stages. In the first month after planting (I MAP), n_1 level recorded lowest value (8.00) and n_3, the highest (12.67). In the second MAP, the lowest value was recorded by n_1 (35.33) and highest value by n_2 (45.78). The least value (58.00) was recorded by n_1 and the highest value by n_3 (78.83) at 3 MAP. Similarly, in the fourth fifth and sixth MAP, n_1 and n_3 recorded the lowest and highest values respectively.

Except during the second and fourth MAP, there was significant influence on the number of leaves due to the main effects of phosphorus at different growth stages of the plant. In the first MAP, minimum value was obtained for p_1 level (9.89) and maximum value for p_2 (11.78). In the 3rd and 5th MAP, the least value was obtained for p_1 and maximum value for p_3. At 6 MAP, p_2 produced the lowest (188.06) number of leaves and p_3, the highest (197.11). Significant effect was noticed for the main effect of K at only 4 and 5 MAP. The interaction effects N x P showed significant influences during the first and third MAP. The n_1p_3 level recorded the lowest value (7.50) and n_3p_3, the highest value (15.00) at 1 MAP. The interaction n_2p_2 was on par with n_3p_3 while n_1p_2 and n_1p_1 were on par with n_1p_3. At 3 MAP, the n_2p_1 interaction recorded the lowest value (55.00) , which was on par with n_1p_1(56.33), n_1p_2 (57.63) and n_1p_3 (59.83) whereas the highest value for n_3p_3 (83.33). Among the N x K interactions, significant variation was obtained at 3rd MAP only. Here, n_1k_1 recorded minimum value (53.67) which was on par with n_1k_3 (57.00) and n_2k_3 whereas the highest value recorded was for n_3k_2 (83.33).

Significant effect for the P x K interactions was noticed for the 1st and 5th MAP. The p_1k_1 recorded the lowest (8.67) and p_2k_1, the highest values (13.67) at 1 MAP. The interactions p_3k_1, p_3k_2, p_1k_3, p_2k_2 and p_3k_3 were on par with each other while p_1k_2 and p_2k_3 were on par with the lowest value for p_1k_1. At 5 MAP, p_1k_1 recorded the lowest value (141.67) and p_3k_3 the highest value (181.33) which was on par with p_1k_2 (170.83), p_2k_1 (168.50), p_1k_3 (167.1), p_3k_1 (169.5) and p_3k_3 (172.00).

There was significant influence due to interactions NPK only at the 1st and 3rd MAP. At the 1st MAP, $n_1p_1k_1$ recorded the lowest value (5.50), which was on par with $n_1p_2k_2$, $n_1p_2k_3$, $n_1p_3k_1$, $n_1p_3k_2$ and $n_1p_3k_3$. The highest value (16.00) was obtained for $n_2p_2k_1$ and $n_2p_2k_3$, which were on par with $n_2p_2k_2$, $n_2p_3k_1$, $n_2p_3k_2$, $n_3p_1k_3$, $n_3p_2k_1$, $n_3p_2k_2$, $n_3p_3k_1$, $n_3p_3k_2$ and $n_3p_3k_3$. During the 3rd MAP, $n_1p_1k_1$ and $n_3p_3k_2$ respectively recorded the lowest (44.00) and highest (92.00) values. At 6 MAP, $n_1p_2k_3$ and $n_3p_3k_3$ registered the lowest (171.00) and highest (219.00) values respectively.

4. 2 YIELD AND YIELD COMPONENTS

The data on the main effects of N, P, K and their interactions on the yield and yield components are furnished in Tables 4a, 4b and 4c.

4.2.1 Number of Tubers

The levels of potassium showed significant influence on the number of tubers produced while the main effect of N and P did not produce significant effect on this character.

Among the K levels, k_1 recorded the lowest value (7.17) and k_3 the highest (9.04).

Interactions, N x P, N x K, P x K and NPK showed no significant influence on the number of tubers. However, as the dose of all the nutrients increased, the number of tubers also increased. Generally, the highest dose of K with nitrogen and phosphorus produced more number of tubers. The treatments, $n_2p_1k_1$ and $n_2p_1k_2$ produced the lowest (6.35) and highest (9.90) values respectively.

4.2.2 Length of Tuber

There was no significant difference on the length of tubers due to the main effect of N, P and K.

Interactions N x P, N x K, P x K and NPK had also no significant influence on the length of tubers. However, least value was recorded for $n_1p_1k_1$ (33.80 cm) and the highest value for $n_2p_1k_2$ (45.50 cm).

Table 4 a. Main effects of N, P and K on the yield and yield components at harvest

Main effect	Number of tubers plant^{-1}	Length of tubers (cm)	Girth of tubers (cm)	Tuber yield (t ha^{-1})	TDMP (t ha^{-1})
n_1	7.88	37.64	22.81	31.21	13.02
n_2	8.46	39.25	23.78	33.43	12.93
n_3	8.23	39.48	29.42	30.82	14.30
F value	1.53	1.19	14.45**	4.80*	4.91*
CD	NS	NS	2.53	1.87	1.00
p_1	8.45	38.65	25.97	33.78	11.89
p_2	8.08	38.54	26.47	29.72	13.78
p_3	8.08	39.18	25.56	31.95	14.60
F value	0.60	0.14	0.28	16.07**	16.42**
CD	NS	NS	NS	1.87	1.00
k_1	7.17	38.29	25.83	25.86	12.69
k_2	8.34	39.53	26.25	29.88	12.75
k_3	9.04	38.57	25.92	39.71	14.81
F value	16.25**	0.49	0.06	123.25**	12.29**
CD	0.69	NS	NS	1.87	1.00

* Significant at 5% level ** Significant at 1% level

Table. 4 b. Interaction effects of NP, NK and PK on yield and yield attributes of cassava at harvest

Interaction effects	Number of tubers plant^{-1}	Length of tubers (cm)	Girth of tubers (cm)	Tuber yield (t ha^{-1})	TDMP (t ha^{-1})
n_1p_1	7.87	36.57	23.92	32.25	10.36
n_1p_2	8.02	39.33	22.33	28.86	14.54
n_1p_3	7.75	37.03	22.17	32.51	14.16
n_2p_1	8.48	39.22	24.25	33.86	12.17
n_2p_2	8.20	37.68	26.00	31.94	11.65
n_2p_3	8.68	40.93	26.58	32.54	14.98
n_3p_1	8.85	40.25	29.25	33.24	13.09
n_3p_2	8.03	38.60	31.08	26.42	15.16
n_3p_3	7.78	39.68	27.92	30.80	14.65
F value	0.82	1.02	0.81	0.84	5.39**
CD	NS	NS	NS	NS	1.74
n_1k_1	7.12	39.43	24.58	24.66	11.99
n_1k_2	7.93	36.83	22.00	29.54	13.23
n_1k_3	8.58	36.67	21.83	39.43	13.84
n_2k_1	7.12	37.27	25.00	26.77	12.01
n_2k_2	8.95	42.00	26.25	32.57	12.40
n_2k_3	9.40	38.56	26.08	40.93	14.39
n_3k_1	7.28	38.18	27.97	16.16	14.08
n_3k_2	8.23	39.75	30.52	27.52	12.61
n_3k_3	9.15	40.50	29.83	38.78	16.21
F value	0.45	11.68	0.99	11.97	1.98
CD	NS	NS	NS	NS	NS
p_1k_1	6.28	35.52	26.08	25.58	12.19
p_1k_2	9.22	41.30	26.42	32.07	10.94
p_1k_3	9.30	39.22	25.42	43.43	12.49
p_2k_1	7.48	40.73	26.75	24.79	11.94
p_2k_2	7.62	38.08	26.08	29.70	14.45
p_2k_3	9.15	36.79	26.58	34.67	14.95
p_3k_1	7.35	38.63	24.67	27.22	13.95
p_3k_2	8.18	39.20	26.25	27.87	17.85
p_3k_3	8.72	39.72	25.75	40.77	17.00
F value	2.50	2.29	0.20	5.98**	4.93**
CD	NS	NS	NS	3.23	1.74

* Significant at 5% level ** Significant at 1% level

Table 4 c. Interaction effects of NPK on yield and yield components of cassava at harvest

Interaction effects	No. of tubers $Plant^{-1}$	Length of tubers (cm)	Girth of Tubers (cm)	Tuber yield ($t\ ha^{-1}$)	TDMP ($t\ ha^{-1}$)
$n_1p_1k_1$	6.50	33.80	24.50	23.11	9.52
$n_1p_1k_2$	7.95	36.90	23.75	26.25	9.27
$n_1p_1k_3$	9.15	39.96	28.60	47.09	12.30
$n_1p_2k_1$	7.40	45.00	20.50	23.31	12.89
$n_1p_2k_2$	7.50	38.00	25.25	30.55	16.47
$n_1p_2k_3$	9.15	35.00	22.25	32.72	14.26
$n_1p_3k_1$	7.45	39.50	25.00	27.54	13.57
$n_1p_3k_2$	8.35	36.60	21.75	31.52	13.96
$n_1p_3k_3$	7.45	36.40	19.75	38.48	14.67
$n_2p_1k_1$	6.35	34.50	26.50	26.83	13.67
$n_2p_1k_2$	9.90	45.50	25.00	37.65	11.68
$n_2p_1k_3$	9.20	37.65	22.75	40.21	11.16
$n_2p_2k_1$	7.35	34.15	25.75	25.17	9.83
$n_2p_2k_2$	7.65	36.50	26.25	31.39	11.62
$n_2p_2k_3$	9.60	37.38	26.00	39.05	13.50
$n_2p_3k_1$	7.65	38.15	22.75	28.31	12.52
$n_2p_3k_2$	7.00	44.00	27.50	25.79	13.90
$n_2p_3k_3$	9.40	40.65	29.50	37.40	18.52
$n_3p_1k_1$	7.20	38.25	27.25	26.79	13.39
$n_3p_1k_2$	9.80	41.50	30.50	29.10	11.87
$n_3p_1k_3$	9.25	40.00	22.00	37.40	14.02
$n_3p_2k_1$	7.70	38.05	30.25	23.88	13.10
$n_3p_2k_2$	7.70	39.75	31.50	27.15	15.27
$n_3p_2k_3$	8.70	38.00	31.50	32.23	17.11
$n_3p_3k_1$	6.95	38.25	26.25	25.81	15.76
$n_3p_3k_2$	7.20	38.00	29.50	26.32	10.68
$n_3p_3k_3$	9.20	40.50	26.00	40.28	17.50
F value	0.92	0.87	0.39	5.30**	2.67**
CD	NS	NS	NS	5.60	3.01

** Significant at 1% level

Plate 2. Influence of $N_1P_1K_1$ on tuber yield

Plate 3. Influence of $N_1P_1K_3$ on tuber yield

Plate 4. Influence of $N_2P_1K_3$ on tuber yield

4.2.3. Girth of Tuber

Different levels of nitrogen showed significant influence on the girth of tuber at the time of harvest. Here, n_1 level recorded the lowest value (22.81 cm) and n_3, the highest value (29.42 cm). The main effects of P and K did not produce any significant effect on this character. The interactions N x P, N x K, P x K and NPK also had no significant influence.

4.2.4. Tuber Yield

There was significant difference on tuber yield due to the different levels of N, P and K and their interactions. Among the levels of N, n_3 recorded minimum value (30.82 t ha^{-1}) and n_2, the maximum value (33.43 t ha^{-1}). With regard to the P levels, the least (29.72 t ha^{-1}) and the highest (33.78 t ha^{-1}) values were obtained for p_2 and p_1 respectively. Among K levels, k_1 recorded minimum yield (25.86 t ha^{-1}), whereas, k_3 recorded maximum yield (39.71 t ha^{-1})

Among the interactions, P x K alone had significant influence on the tuber yield. The tuber yield was minimum (24.79 t ha^{-1}) for p_2k_1, which was on par with the levels p_1k_1, p_3k_1 and p_3k_2. It was maximum (43.43 t ha^{-1}) for p_1k_3, which was on par with p_3k_3.

Interaction effects of NPK had significant influence on tuber yield. The minimum yield was recorded for (Plate.2) $n_1p_1k_1$ (23.11 t ha^{-1}), which was on par with $n_1p_2k_1$, $n_3p_2k_1$, $n_2p_2k_1$, $n_2p_3k_2$, $n_3p_3k_1$, $n_3p_3k_2$, $n_1p_1k_2$, $n_3p_1k_1$, $n_2p_1k_3$ $n_3p_2k_2$, $n_1p_3k_1$ and $n_2p_3k_1$. Whereas the maximum yield was recorded for (Plate. 3) $n_1p_1k_3$ (47.09 t ha^{-1}) followed by $n_3p_3k_3$ and $n_2p_1k_3$ (Plate. 4), the latter two were on par with each other.

4.2.5 Total Dry Matter Production

The main effects of N, P and K recorded significant difference on total dry matter production. Among N levels, n_1 recorded minimum value (13.02 t ha^{-1}) and n_3 recorded maximum value (14.30 t ha^{-1}). Among the different levels of P, p_1 had minimum value (11.89 t ha^{-1}) and

p_3, the maximum value (14.60 t ha^{-1}). As for potassium, the treatment k_1 produced minimum value (12.69 t ha^{-1}) and k_3, the maximum dry matter (14.81 t ha^{-1}).

The interactions N x P and P x K alone produced significant response on total dry matter yield. Here the lowest value was for n_1p_1 (10.36 t ha^{-1}) and the highest value for n_3p_2 (15.16 t ha^{-1}), which was on par with n_2p_3 (14.98 t ha^{-1}), n_3p_3 (14.65 t ha^{-1}) and n_1p_2 (14.54 t ha^{-1}). Between the P x K interactions, p_1k_2 recorded minimum value (10.94 t ha^{-1}) and p_3k_2, the maximum value (17.85 t ha^{-1}).

The NPK interactions showed significant influence on total dry matter production. The minimum value was recorded for $n_1p_1k_2$ (9.27 t ha^{-1}), which was on par with $n_1p_1k_1$, $n_2p_2k_1$, $n_3p_3k_2$, $n_2p_1k_3$, $n_2p_2k_2$, $n_2p_1k_2$, $n_3p_1k_2$ and $n_1p_1k_3$. The maximum value (18.52 t ha^{-1}) was obtained for $n_2p_3k_3$, which was on par with $n_3p_3k_3$, $n_3p_2k_3$, $n_1p_2k_2$, $n_3p_3k_1$ and $n_3p_2k_2$.

4.3 PHYSIOLOGICAL PARAMETERS

The data on the main effects of N, P, K and their interactions on the physiological parameters are furnished in Tables 5a, 5b and 5c.

4.3.1 Leaf Area Index (LAI)

There was no significant influence on the leaf area index due to the main effects and the interaction effects of N, P and K. Among the N levels, n_1 recorded minimum value (3.79) and n_3, the maximum value (4.32). The lowest (3.94) and highest values (4.12) were for p_1 and p_2 respectively. . Among the K levels, k_3 showed the lowest (3.85) and k_2, the highest (4.15) values. With regard to the N x P interactions, n_1p_1 recorded minimum value (3.53) and n_3p_2, the maximum value (4.51). As for as N x K interactions, n_1k_3 recorded the lowest value (3.44) and n_3k_1 recorded the highest value (4.49). In the P x K interactions, p_1k_1 recorded minimum vlue (3.66), and p_2k_1, the maximum value (4.36).

Table 5 a. Main effects of NPK on physiological parameters of cassava at harvest

Main effects	LAI	Stomatal conductance (s cm^{-1})	Chlorophyll content (ppm)
n_1	3.79	0.78	1.69
n_2	3.95	0.71	1.62
n_3	4.32	0.72	1.59
F value	1.55	0.53	0.33
CD	NS	NS	NS
p_1	3.94	0.64	1.49
p_2	4.12	0.77	1.72
p_3	4.01	0.79	1.70
F value	0.17	2.55	1.87
CD	NS	NS	NS
k_1	4.07	0.75	1.51
k_2	4.15	0.76	1.75
k_3	3.85	0.70	1.65
F value	0.58	0.48	1.56
CD	NS	NS	NS

Table 5 b. Interaction effects of NP, NK, PK on physiological parameters of cassava at harvest

Interaction Effects	LAI	Stomatal conductance (s cm^{-1})	Chlorophyll content (ppm)
n_1p_1	3.53	0.65	1.49
n_1p_2	3.83	0.79	1.93
n_1p_3	4.02	0.89	1.66
n_2p_1	4.11	0.68	1.62
n_2p_2	4.02	0.76	1.57
n_2p_3	3.72	0.67	1.68
n_3p_1	4.18	0.59	1.35
n_3p_2	4.51	0.75	1.67
n_3p_3	4.28	0.82	1.73
F value	0.36	0.67	0.87
CD	NS	NS	NS
n_1k_1	3.70	0.71	1.48
n_1k_2	4.25	0.85	1.76
n_1k_3	3.44	0.76	1.84
n_2k_1	4.03	0.80	1.56
n_2k_2	3.79	0.76	1.87
n_2k_3	4.03	0.60	1.44
n_3k_1	4.49	0.73	1.50
n_3k_2	4.40	0.71	1.61
n_3k_3	4.08	0.72	1.66
F value	0.58	0.76	0.98
CD	NS	NS	NS
p_1k_1	3.66	0.58	1.22
p_1k_2	4.32	0.65	1.76
p_1k_3	3.84	0.69	1.49
p_2k_1	4.36	0.87	1.74
p_2k_2	4.32	0.97	1.77
p_2k_3	3.68	0.51	1.66
p_3k_1	4.19	0.78	1.58
p_3k_2	3.81	0.71	1.71
p_3k_3	4.03	0.88	1.80
F value	0.79	3.66*	0.91
CD	NS	0.20	NS

* Significant at 5% level

Table 5 c. Interaction effects of NPK on the physiological parameters of cassava at harvest

Interaction effects	LAI	Stomatal conductance (s cm^{-1})	Chlorophyll (ppm)
$n_1p_1k_1$	3.11	0.50	1.06
$n_1p_1k_2$	4.07	0.68	1.55
$n_1p_1k_3$	3.42	0.78	1.86
$n_1p_2k_1$	4.05	0.83	1.92
$n_1p_2k_2$	3.96	0.98	1.91
$n_1p_2k_3$	3.48	0.61	1.95
$n_1p_3k_1$	3.93	0.81	1.46
$n_1p_3k_2$	4.71	0.96	1.80
$n_1p_3k_3$	3.43	0.90	1.73
$n_2p_1k_1$	4.05	0.70	1.43
$n_2p_1k_2$	4.58	0.62	2.05
$n_2p_1k_3$	3.69	0.74	1.38
$n_2p_2k_1$	4.15	0.97	1.57
$n_2p_2k_2$	3.76	0.88	1.68
$n_2p_2k_3$	4.15	0.45	1.46
$n_2p_3k_1$	3.88	0.74	1.68
$n_2p_3k_2$	3.03	0.66	1.88
$n_2p_3k_3$	4.27	0.62	1.48
$n_3p_1k_1$	3.82	0.54	1.16
$n_3p_1k_2$	4.31	0.66	1.68
$n_3p_1k_3$	4.42	0.57	1.23
$n_3p_2k_1$	4.89	0.83	1.73
$n_3p_2k_2$	5.23	0.96	1.56
$n_3p_2k_3$	3.42	0.47	1.71
$n_3p_3k_1$	4.75	0.81	1.61
$n_3p_3k_2$	3.68	0.51	1.45
$n_3p_3k_3$	4.40	1.13	2.17
F value	0.78	0.84	0.66
CD	NS	NS	NS

interactions of NPK, minimum value (3.11) was obtained for $n_1p_1k_1$ and maximum (5.23) was for $n_3p_2k_2$.

4.3.2 Stomatal Conductance

In general, the stomatal conductance did not vary significantly due to the different levels of nitrogen, phosphorus and potassium. Among the main effects, n_1, p_3 and k_2 showed comparatively higher stomatal conductance of 0.78, 0.79, and 0.76 s cm^{-1}.

Among the interactions, significant influence on stomatal conductance was noted for P x K. The lowest value (0.51 s cm^{-1}) was recorded for p_2k_3, which was on par with p_1k_1, p_1k_2 and p_1k_3. The highest value was noted for p_2k_2 (0.97 s cm^{-1}), which was on par with p_3k_3, p_2k_1 and p_3k_3.

Significant variation could not be noticed on stomatal conductance due to the third order interaction NPK.

4.3.3 Chlorophyll content

The main effects of N, P and K and their interactions did not influence the chlorophyll content of plant significantly. There was no significant effect on chlorophyll content due to NPK interactions. However, $n_1p_1k_1$ recorded minimum value (1.06 ppm) and $n_3p_3k_3$, the maximum value (2.17 ppm).

4.4 QUALITY ATTRIBUTES

The data on the quality attributes of cassava tubers due to the different levels of N, P, K and their interaction effects are given in Tables 6a, 6b and 6c.

4.4.1 Starch Content

There was significant variation on the starch content of cassava tubers only due to the different levels of phosphorus. The minimum value (31.84%) was recorded for p_1 and maximum value (35.74%) for p_3. With regard to K, an increasing trend on the starch content was noticed

Table 6 a. Main effects of N, P and K on the quality attributes of cassava tuber at harvest

Main effects	Starch (%)	Protein (%)	HCN ($\mu g g^{-1}$)	Cooking quality (Score 0 – 4)
n_1	31.88	1.81	9.68	2.83
n_2	34.16	2.06	12.37	2.54
n_3	33.65	2.26	15.15	2.44
F value	1.24	2391.6**	4712.8**	0.96
CD	NS	0.01	0.12	NS
p_1	31.84	2.06	12.57	2.39
p_2	32.11	2.04	11.89	2.67
p_3	35.74	2.03	12.74	2.78
F value	4.11	16.02**	127.60	0.96
CD	3.12	0.01	0.12	NS
k_1	32.07	2.07	13.53	1.94
k_2	33.30	2.04	16.64	3.00
k_3	34.32	2.03	12.03	2.89
F value	1.12	23.77**	631.19**	8.08**
CD	NS	0.01	0.12	0.59

** Significant at 1% level

Table 6 b Interaction effects of NP, NK and PK on the quality attributes of cassava tubers at harvest

Interaction effects	Starch (%)	Protein (%)	HCN (μg g^{-1})	Cooking quality (Score 0-4)
n_1p_1	30.04	1.90	10.17	2.33
n_1p_2	31.26	1.70	9.00	3.00
n_1p_3	34.36	1.83	9.89	3.17
n_2p_1	33.74	2.06	11.40	2.17
n_2p_2	32.21	2.13	13.01	2.83
n_2p_3	36.35	1.99	12.70	2.67
n_3p_1	31.75	2.23	16.14	2.67
n_3p_2	32.68	2.27	13.67	2.17
n_3p_3	36.52	2.27	15.64	2.50
F value	0.16	12.57**	232.6**	1.04
CD	NS	0.02	0.20	NS
n_1k_1	32.06	1.85	9.84	2.17
n_1k_2	32.29	1.77	9.61	3.67
n_1k_3	31.39	1.81	9.61	2.67
n_2k_1	34.98	2.04	12.44	2.00
n_2k_2	32.19	2.06	12.00	2.83
n_2k_3	35.32	2.08	12.66	2.83
n_3k_1	29.18	2.31	18.32	1.67
n_3k_2	33.43	2.27	13.30	2.50
n_3k_3	36.33	2.17	13.83	3.17
F value	12.11	38.89**	631.19**	1.48
CD	NS	0.02	0.20	NS
p_1k_1	29.94	2.05	12.05	1.50
p_1k_2	33.45	2.05	12.32	3.38
p_1k_3	32.13	2.10	13.32	2.33
p_2k_1	30.94	2.15	14.55	2.33
p_2k_2	31.05	1.98	10.78	2.83
p_2k_3	34.36	1.98	10.35	2.83
p_3k_1	35.35	2.00	13.99	2.00
p_3k_2	35.40	2.09	11.81	2.83
p_3k_3	36.48	2.01	12.42	3.50
F value	0.51	104.26**	427.30**	1.98
CD	NS	0.02	0.20	NS

** Significant at 1% level

Table 6 c. Interaction effects of NPK on the quality of cassava tubers at harvest

Treatments	Starch (%)	Protein (%)	HCN ($\mu g\ g^{-1}$)	Cooking quality (Score 0-4)
$n_1p_1k_1$	26.34	1.89	9.10	1.50
$n_1p_1k_2$	32.49	1.94	10.61	4.00
$n_1p_1k_3$	31.29	1.86	10.79	1.50
$n_1p_2k_1$	30.12	1.91	10.91	2.50
$n_1p_2k_2$	29.05	1.58	8.07	3.50
$n_1p_2k_3$	34.61	1.62	8.02	3.00
$n_1p_3k_1$	39.74	1.74	9.51	2.50
$n_1p_3k_2$	35.32	1.81	10.15	3.50
$n_1p_3k_3$	28.02	1.95	10.01	3.50
$n_2p_1k_1$	35.35	2.01	10.08	1.50
$n_2p_1k_2$	33.24	2.04	12.03	3.50
$n_2p_1k_3$	33.60	2.14	12.08	1.50
$n_2p_2k_1$	32.90	2.18	18.85	3.00
$n_2p_2k_2$	30.23	2.09	18.30	2.50
$n_2p_2k_3$	34.10	2.13	12.89	3.00
$n_2p_3k_1$	36.69	1.94	13.40	1.50
$n_2p_3k_2$	33.10	2.05	11.69	2.50
$n_2p_3k_3$	39.27	1.98	13.03	4.00
$n_3p_1k_1$	28.13	2.24	16.98	1.50
$n_3p_1k_2$	34.63	2.16	14.33	2.50
$n_3p_1k_3$	32.51	2.30	17.11	4.00
$n_3p_2k_1$	29.79	2.38	18.90	1.50
$n_3p_2k_2$	33.88	2.26	11.97	2.50
$n_3p_2k_3$	34.36	2.18	10.14	2.50
$n_3p_3k_1$	29.63	2.33	19.08	2.00
$n_3p_3k_2$	37.79	2.40	13.60	2.50
$n_3p_3k_3$	42.13	2.09	14.24	3.00
F value	1.49	61.68**	66.64**	1.50
CD	NS	0.04	0.35	NS

** Significant at 1% level

due to the increase in the level of K. Though the interaction effects did not influence significantly on this character, the highest level of NP, NK and PK interactions recorded the highest starch content. The NPK interactions were also insignificant on starch content. However $n_1p_1k_1$ registered minimum value (26.34%) and $n_3p_3k_3$, the maximum value (42.13%).

4.4.2 Protein Content

Significant difference on the protein content of tubers was observed due to different levels of N, P and K and their interactions. Among the N levels, n_1 recorded the lowest (1.81%) and n_3 the highest value (2.26%). In the P levels, p_3 obtained lowest value (2.03%) and p_1 the highest (2.06%). The minimum (2.03%) and maximum (2.07%) values were observed for k_3 and k_1 respectively.

Among the N x P interactions, n_1p_2 recorded the least value (1.70%) while n_3p_2 and n_3p_3 the highest (2.27%). In the N x K interactions, n_1k_2 registered the lowest value (1.77%) and n_3k_1, the highest value (2.31%). With regard to the P x K interactions, p_2k_3 and p_2k_2 resulted minimum value (1.98%), which was on par with p_3k_1 (2.00%)whereas p_2k_1, the maximum (2.15%). In the third order interactions, $n_1p_2k_2$ recorded the lowest value (1.58%) and $n_3p_3k_2$ the highest (2.40%).

4.4.3 Hydrocyanic Acid Content (HCN)

The main effect of N, P and K and their interactions produced significant influence on the Hydrocyanic acid content of tubers. Among the N levels, n_1 recorded the minimum value (9.68 $\mu g\ g^{-1}$) and n_3, the maximum (15.15 $\mu g\ g^{-1}$). In P levels, p_2 resulted the lowest value (11.89 $\mu g\ g^{-1}$) and p_3, the highest (12.74 $\mu g\ g^{-1}$). With regard to K levels, the lowest (12.03 $\mu g\ g^{-1}$) and highest (16.64 $\mu g\ g^{-1}$) values were obtained for k_3 and k_2 respectively.

In the N x P interactions, n_1p_2 recorded minimum value (9.00 $\mu g\ g^{-1}$) and n_3p_1 the maximum (16.14 $\mu g\ g^{-1}$). Among the N x K interactions, n_1k_2 and n_1k_3 showed lowest (9.61 µg g^{-1}) and n_3k_1 the highest value (18.32 µg g^{-1}). As for P x K interactions, p_2k_3 registered minimum (10.35 µg g^{-1}) and p_2k_1 the maximum value (14.55 µg g^{-1}). With regard to N x P x K interactions, $n_1p_2k_3$ recorded the lowest (8.02 µg g^{-1}), which was on par with $n_1p_2k_2$. Whereas, $n_3p_3k_1$ the highest value (19.08 µg g^{-1}) which was on par with $n_2p_2k_1$ and $n_3p_2k_1$.

4.4.4 Cooking quality

Among the main effects and their interactions, the different levels of K alone showed significant variation on the cooking quality of tuber. With regard to K, k_1 recorded minimum value (1.94) and k_2 the maximum value (3.00). Cooking quality was highest (4.00) for $n_1p_1k_2$, $n_2p_2k_3$ and $n_3p_1k_3$.

4.5 NUTRIENT CONTENT IN THE TUBERS

The data in Tables 7a, 7b and 7c show the main effect of N, P, K and their interaction effects on nutrient content in the tuber at the time of harvest.

4.5.1. Nitrogen Content

The main effect of N, P and K and their interactions have resulted significant influence on the nitrogen content of tubers.

Among the N levels, n_1 recorded minimum value (0.21%) and n_3 the maximum value (0.35%). In P levels, p_1 resulted the lowest value (0.26%) whereas p_2 and p_3 the highest value (0.28%). As far K, k_1 showed minimum value (0.26%) and k_2 and k_3 the maximum (0.28%). Among the N x P interactions, n_1p_1 recorded lowest value (0.20%), which was on par with n_1p_2 and n_1p_3 while n_3p_2 and n_3p_3 both registered the highest value (0.37%). Among the N x K interactions, the lowest value was obtained for n_1k_1 and n_1k_2 (0.20%), which was on par with n_1k_3, whereas n_3k_3 and n_3k_2 both resulted in the highest value (0.36%). As for P x K interactions, p_1k_1, p_1k_3 and p_2k_3 produced tubers with least (0.26%) N content which was on par with p_1k_2 and p_3k_1 whereas, p_3k_3 with

Table 7 a. Main effects of N, P and K on nutrient content in tuber at harvest.

Main effects	N (%)	P (%)	K (%)
n_1	0.21	0.16	1.16
n_2	0.26	0.18	0.94
n_3	0.35	0.18	0.92
F value	3747.64**	143.56**	9.38**
CD	0.01	0.01	0.12
p_1	0.26	0.17	0.98
p_2	0.28	0.18	0.94
p_3	0.28	0.18	1.04
F value	57.88**	8.91**	0.68
CD	0.01	0.01	NS
k_1	0.26	0.18	0.88
k_2	0.28	0.17	1.00
k_3	0.28	0.18	1.13
F value	84.02**	57.27**	8.30**
CD	0.01	0.01	0.12

** Significant at 1% level

Table 7 b. Interaction effects of NP, NK, PK on the tuber nutrient content at harvest

Interaction effects	N (%)	P (%)	K (%)
n_1p_1	0.20	0.12	1.11
n_1p_2	0.21	0.10	1.14
n_1p_3	0.21	0.17	1.22
n_2p_1	0.26	0.21	2.88
n_2p_2	0.26	0.14	0.98
n_2p_3	0.27	0.18	0.97
n_3p_1	0.33	0.19	0.95
n_3p_2	0.37	0.19	0.86
n_3p_3	0.37	0.17	0.95
F value	27.70**	718.53**	0.50
CD	0.01	0.01	NS
n_1k_1	0.20	0.18	1.06
n_1k_2	0.20	0.14	1.21
n_1k_3	0.21	0.18	1.20
n_2k_1	0.25	0.19	0.83
n_2k_2	0.27	0.16	0.92
n_2k_3	0.27	0.18	1.08
n_3k_1	0.34	0.17	0.78
n_3k_2	0.36	0.20	0.87
n_3k_3	0.36	0.18	1.11
F value	6.82**	232.5**	0.86
CD	0.01	0.01	NS
p_1k_1	0.26	0.16	0.89
p_1k_2	0.27	0.16	1.03
p_1k_3	0.26	0.21	1.02
p_2k_1	0.26	0.19	0.86
p_2k_2	0.28	0.19	0.99
p_2k_3	0.29	0.15	1.14
p_3k_1	0.27	0.18	0.91
p_3k_2	0.28	0.16	0.99
p_3k_3	0.30	0.18	1.24
F value	16.53**	334.89**	0.93
CD	0.01	0.01	NS

** Significant at 1% level

Table 7 c. Interaction effects of NPK on nutrient content in tuber at harvest

Treatment	N (%)	P (%)	K (%)
$n_1p_1k_1$	0.20	0.14	1.16
$n_1p_1k_2$	0.20	0.12	1.16
$n_1p_1k_3$	0.21	0.11	1.01
$n_1p_2k_1$	0.20	0.22	0.89
$n_1p_2k_2$	0.21	0.18	1.28
$n_1p_2k_3$	0.31	0.19	1.26
$n_1p_3k_1$	0.20	0.18	1.13
$n_1p_3k_2$	0.20	0.11	1.21
$n_1p_3k_3$	0.22	0.23	1.33
$n_2p_1k_1$	0.25	0.16	0.64
$n_2p_1k_2$	0.26	0.17	0.98
$n_2p_1k_3$	0.27	0.13	1.02
$n_2p_2k_1$	0.25	0.14	0.89
$n_2p_2k_2$	0.27	0.16	0.86
$n_2p_2k_3$	0.26	0.12	1.19
$n_2p_3k_1$	0.25	0.26	0.92
$n_2p_3k_2$	0.27	0.15	0.92
$n_2p_3k_3$	0.29	0.11	1.03
$n_3p_1k_1$	0.32	0.19	0.88
$n_3p_1k_2$	0.35	0.18	0.95
$n_3p_1k_3$	0.31	0.21	1.02
$n_3p_2k_1$	0.34	0.21	0.80
$n_3p_2k_2$	0.37	0.22	0.83
$n_3p_2k_3$	0.39	0.14	0.96
$n_3p_3k_1$	0.35	0.10	0.68
$n_3p_3k_2$	0.36	0.21	0.82
$n_3p_3k_3$	0.37	0.19	1.33
F value	12.30**	635.61**	1.44
CD	0.01	0.01	NS

** Significant at 1% level

highest value (0.30%) which was on par with p_2k_3 (0.29%). In the NPK interaction effects, $n_1p_1k_1$, $n_1p_1k_2$, $n_1p_2k_1$, $n_1p_3k_1$ and $n_1p_3k_2$ registered minimum value (0.20%), which was on par with $n_1p_1k_3$, and $n_1p_2k_2$ whereas $n_3p_2k_3$ recorded the maximum value (0.39%).

4.5.2 Phosphorus Content

The main effects of N, P, and K and their interactions produced significant effect on the P content in tuber. Among the N levels, n_1 recorded lowest value (0.16%) and both n_2 and n_3, the highest value (0.18%). In the P levels, p_1 resulted minimum value (0.17%) and both p_2 and p_3 the maximum value (0.18%). As for potassium, k_2 registered the lowest value (0.17%) whereas k_1 and k_3 both, the highest value (0.18%).

In the interaction between N and P, n_1p_2 recorded minimum value (0.10%) and n_2p_1, the maximum (0.21%). Among the interactions N x K, n_1k_2 showed lowest value (0.14%) and n_3k_2, the highest (0.20%) which was on par with n_2k_1 (0.19 %).

In the P x K interactions, p_2k_3 resulted minimum value (0.15%), which was on par with p_1k_1, p_1k_2 and p_3k_2 whereas p_1k_3 recorded the maximum value (0.21%).

In the third order interactions, $n_3p_3k_1$ recorded minimum value (0.10%) which was on par with $n_1p_1k_3$, $n_1p_3k_2$ and $n_2p_3k_3$, whereas $n_2p_3k_1$, the maximum (0.26%).

4.5.3 Potassium Content

The main effects of N, P and K showed significant influence on the potassium content of tuber. Among the N levels, n_3 showed the lowest value (0.92%) and n_1, the highest (1.16%). In the P levels, p_2 resulted minimum value (0.94%) and p_3, the maximum (1.04%). As for K, k_1 recorded minimum value (0.88%) and k_3, the maximum (1.13%).

The interactions N x P, N x K, P x K and NPK showed no significant effect on tuber potassium content.

4.6 NUTRIENT CONTENT IN THE TOP PORTION

The data in Tables 8a, 8b and 8c indicate the main and interaction effects of N, P and K on the nutrient content in the top portion of cassava plants.

4.6.1 Nitrogen Content

The main effects of N, P and K had significant influence on the nitrogen content in the top portion. The lowest value (1.16%) was recorded by n_1 and the highest by n_3 (1.42%). Among the P levels, p_1 registered minimum (1.22%) and p_3 maximum value (1.31%). In the K levels, k_1 recorded the lowest value (1.23%) whereas, k_3, the highest (1.31%).

Significant variation was observed due to the interactions, N x P, N x K and P x K on the nitrogen content in the top portion. Among the N x P interactions, n_1p_2 and n_1p_3 recorded minimum (1.14%) and n_3p_3, the maximum value (1.54%). In the N x K interactions, the lowest value was resulted for n_1k_2 (1. 13%) which was on par with n_1k_1, n_1k_3, n_2k_1 and n_2k_3 whereas, the highest (1.58%) for n_3k_3.

As far P x K interactions, p_1k_2 showed the lowest (1. 19%), which was on par with p_2k_1, p_2k_3 p_3k_1, p_1k_1, p_3k_2 and p_1k_3 whereas, p_3k_3, the highest value (1.43%), which was on par with p_2k_2. There was no significant difference on the nitrogen content in the top portion due to the interaction of NPK.

4.6.2 Phosphorus Content

The main effects of N, P, K and their interactions registered significant effect on the P content in the top portion. Among the N levels, both n_1 and n_3 recorded least value (0.30%) and n_2, the maximum value (0.31%). Among the P levels, p_1 resulted the least value (0.28%) and p_3, the highest (0.33%). In the K levels, k_1 and k_2 recorded minimum value (0.30%) and k_3, the maximum (0.31%). As for N x P interactions, n_2p_1 and n_3p_1 resulted the lowest (0.27%), which was on par with n_1p_2, whereas, n_1p_3, n_2p_3 and n_3p_3, the highest value (0.33%).

Table 8 a. Main effects of N, P and K on the nutrient content of Top portion plant at harvest

Main effects	N (%)	P (%)	K (%)
n_1	1.16	0.30	1.12
n_2	1.23	0.31	1.24
n_3	1.42	0.30	1.13
F value	36.77**	88.28**	3.26
CD	0.06	0.01	NS
p_1	1.22	0.28	1.13
p_2	1.27	0.29	1.11
p_3	1.31	0.33	1.25
F value	3.71*	3384.10**	5.18*
CD	0.06	0.01	0.10
k_1	1.23	0.30	1.08
k_2	1.26	0.30	1.06
k_3	1.31	0.31	1.35
F value	3.23	85.34**	21.98**
CD	NS	0.01	0.10

* Significant at 5% level ** Significant at 1% level

Table 8 b. Interaction effects of NP, NK and PK on nutrient content in the Top portion of plant at harvest

Interaction effects	N (%)	P (%)	K (%)
n_1p_1	1.18	0.29	1.05
n_1p_2	1.14	0.28	0.96
n_1p_3	1.14	0.33	1.15
n_2p_1	1.15	0.27	1.05
n_2p_2	1.30	0.32	1.20
n_2p_3	1.25	0.33	1.45
n_3p_1	1.33	0.27	1.08
n_3p_2	1.38	0.29	1.17
n_3p_3	1.54	0.33	1.16
F value	4.03*	278.32**	6.21**
CD	0.11	0.01	0.18
n_1k_1	1.19	0.32	1.06
n_1k_2	1.13	0.30	0.95
n_1k_3	1.14	0.28	1.35
n_2k_1	1.20	0.29	1.06
n_2k_2	1.29	0.31	1.26
n_2k_3	1.21	0.31	1.38
n_3k_1	1.31	0.29	1.11
n_3k_2	1.36	0.28	0.97
n_3k_3	1.58	0.30	1.32
F value	6.76*	624.25**	2.83*
CD	0.11	0.01	0.18
p_1k_1	1.26	0.29	1.07
p_1k_2	1.19	0.27	0.90
p_1k_3	1.23	0.27	1.41
p_2k_1	1.21	0.30	1.09
p_2k_2	1.33	0.29	1.11
p_2k_3	1.29	0.30	1.13
p_3k_1	1.23	0.32	1.07
p_3k_2	1.26	0.33	1.17
p_3k_3	1.43	0.35	1.52
F value	3.66*	289.58**	5.86**
CD	0.11	0.01	0.18

* Significant at 5% level ** Significant at 1% level

Table 8 c. Interaction effects of NPK on nutrient content of Top portion of plant at harvest

Interaction effects	N (%)	P (%)	K (%)
$n_1p_1k_1$	1.32	0.34	1.28
$n_1p_1k_2$	1.12	0.27	0.93
$n_1p_1k_3$	1.12	0.25	1.54
$n_1p_2k_1$	1.15	0.30	0.81
$n_1p_2k_2$	1.17	0.26	1.03
$n_1p_2k_3$	1.12	0.28	1.05
$n_1p_3k_1$	1.11	0.32	1.08
$n_1p_3k_2$	1.12	0.35	0.90
$n_1p_3k_3$	1.18	0.33	1.48
$n_2p_1k_1$	1.16	0.26	0.95
$n_2p_1k_2$	1.15	0.27	0.93
$n_2p_1k_3$	1.15	0.39	1.28
$n_2p_2k_1$	1.16	0.30	0.95
$n_2p_2k_2$	1.47	0.36	1.27
$n_2p_2k_3$	1.26	0.30	1.40
$n_2p_3k_1$	1.27	0.30	1.29
$n_2p_3k_2$	1.24	0.32	1.60
$n_2p_3k_3$	1.24	0.35	1.47
$n_3p_1k_1$	1.30	0.27	0.97
$n_3p_1k_2$	1.30	0.26	0.86
$n_3p_1k_3$	1.41	0.27	1.40
$n_3p_2k_1$	1.32	0.30	1.53
$n_3p_2k_2$	1.35	0.25	1.03
$n_3p_2k_3$	1.48	0.32	0.93
$n_3p_3k_1$	1.32	0.31	0.84
$n_3p_3k_2$	1.43	0.32	1.02
$n_3p_3k_3$	1.86	0.36	1.62
F value	1.57	345.29**	5.48**
CD	NS	0.01	0.30

** Significant at 1% level

The data in Tables 8a, 8b and 8c indicate the main and interaction effects of N, P and K on the nutrient content in the top portion of cassava plants.

4.6.1 Nitrogen Content

The main effects of N, P and K had significant influence on the nitrogen content in the top portion. The lowest value (1.16%) was recorded by n_1 and the highest by n_3 (1.42%). Among the P levels, p_1 registered minimum (1.22%) and p_3 maximum value (1.31%). In the K levels, k_1 recorded the lowest value (1.23%) whereas, k_3, the highest (1.31%).

Significant variation was observed due to the interactions, N x P, N x K and P x K on the nitrogen content in the top portion. Among the N x P interactions, n_1p_2 and n_1p_3 recorded minimum (1.14%) and n_3p_3, the maximum value (1.54%). In the N x K interactions, the lowest value was resulted for n_1k_2 (1. 13%) which was on par with n_1k_1, n_1k_3, n_2k_1 and n_2k_3 whereas, the highest (1.58%) for n_3k_3.

As far P x K interactions, p_1k_2 showed the lowest (1. 19%), which was on par with p_2k_1, p_2k_3 p_3k_1, p_1k_1, p_3k_2 and p_1k_3 whereas, p_3k_3, the highest value (1.43%), which was on par with p_2k_2. There was no significant difference on the nitrogen content in the top portion due to the interaction of NPK.

4.6.2 Phosphorus Content

The main effects of N, P, K and their interactions registered significant effect on the P content in the top portion. Among the N levels, both n_1 and n_3 recorded least value (0.30%) and n_2, the maximum value (0.31%).

Among the P levels, p_1 resulted the least value (0.28%) and p_3, the highest (0.33%). In the K levels, k_1 and k_2 recorded minimum value (0.30%) and k_3, the maximum (0.31%). As for N x P interactions, n_2p_1 and n_3p_1 resulted the lowest (0.27%), which was on par with n_1p_2, whereas, n_1p_3, n_2p_3 and n_3p_3, the highest value (0.33%).

In the N x K interactions, n_1k_3 recorded minimum value (0.25%), whereas n_1k_1, the maximum value (0.32%) and was on par with n_2k_2 and n_2k_3. Among P x K interactions, p_1k_2 and p_1k_3 showed minimum (0.27%) whereas p_3k_3, the maximum value (0.35%).

With regard to NPK interactions, the lowest value (0.25%) was recorded for $n_1p_1k_3$ and $n_3p_2k_2$ which were on par with $n_1p_2k_2$, $n_2p_1k_1$ and $n_3p_1k_2$ whereas, the highest (0.36%) for $n_2p_2k_2$ and $n_3p_3k_3$ which were on par with $n_1p_3k_2$ and $n_2p_3k_3$.

4.6.3 Potassium Content

There was significant difference on the potassium content in the top portion due to the main effects other than N. Among the P levels, p_2 recorded minimum value (1.11%) and p_3, the maximum (1.25%). In the levels of K, k_2 resulted the lowest (1.06) and k_3, the highest value (1.35%).

Among the N x P interactions, n_1p_2 showed minimum value (0.96%) which was on par with n_1p_1, n_2p_1 and n_3p_1 whereas n_2p_3, the highest value (1.45%).

With regard to the N x K interactions, n_1k_2 registered minimum (0.95%) which was on par with n_3k_2, n_2k_1, n_1k_1 and n_3k_1 whereas n_2k_3, the maximum value (1.38%) which was on par with n_1k_3, n_3k_3 and n_2k_2. In the P x K interactions, p_1k_2 resulted the lowest value (0.90%), which was on par with p_1k_1 and p_3k_1 while p_3k_3, the highest value (1.52%), which was on par with p_1k_3.

As for the NPK interactions, the minimum value (0.81%) was recorded for $n_1p_2k_1$ which was on par with $n_3p_3k_1$, $n_3p_1k_2$, $n_1p_3k_2$, $n_1p_1k_2$, $n_2p_1k_2$, $n_3p_2k_3$, $n_2p_1k_1$, $n_2p_2k_1$, $n_3p_1k_1$, $n_3p_3k_2$, $n_1p_2k_2$, $n_3p_2k_2$, $n_1p_2k_3$ and

$n_1p_3k_1$ whereas the maximum (1.62%), for $n_3p_3k_3$which was on par with $n_2p_3k_2$, $n_1p_1k_3$, $n_3p_2k_1$, $n_1p_3k_3$, $n_2p_3k_3$, $n_3p_1k_3$ and $n_2p_2k_3$.

4.7 SOIL AVAILABLE MAJOR NUTRIENTS AT THE TIME OF HARVEST

Data on the effects of N, P, K and their interactions on available major nutrients in the soil at the time of harvest are presented in Tables 9a, 9b and 9c.

4.7.1 Soil Organic Carbon

Both the main and interaction effects of N, P and K had significant influence on soil organic carbon content at the time of harvest. Among the N levels, n_3 recorded minimum value (0.70%) and n_2, the highest value (0.73%). Among the P levels, p_1 showed the least value (0.63%) and p_2 recorded the highest value (0.71%). With regard to K levels, k_2 recorded minimum value (0.65%) and k_1, the maximum value (0.73%). Among the N x P interactions, n_3p_2 recorded least value (0.45%) and n_1p_2 had the highest value (0.88%). As far N x K interactions, the lowest value (0.42%) was recorded for n_3k_3 and highest value (0.82%) for n_3k_1.

In the P x K interactions, p_1k_3 registered minimum (0.59%), which was on par with p_3k_2, p_1k_1 and p_2k_3 whereas, p_2k_1 had maximum value (0.84%).

With regard to NPK interactions, $n_3p_2k_3$, resulted the least value (0.26%) which was on par with $n_3p_3k_2$ and $n_3p_1k_3$ whereas $n_1p_2k_1$, the maximum value (0.93%) which was on par with $n_3p_1k_2$, $n_3p_3k_1$, $n_1p_2k_2$, and $n_2p_2k_1$.

4.7.2 Soil Available Nitrogen

Significant effect on soil available nitrogen could be noticed only for P levels. The main effects, p_3 recorded minimum value (222.38 kg ha^{-1}) and p_1, the maximum value (252.44 kg ha^{-1}). There was significant influence on soil available nitrogen due to the N x P

Table 9 a. Main effects of N, P and K on the available nutrients in the soil at harvest

Main effects	OC (%)	Available N (Kg ha^{-1})	Available P (Kg ha^{-1})	Available K (Kg ha^{-1})
n_1	0.71	239.49	37.96	140.28
n_2	0.73	239.31	41.83	125.24
n_3	0.70	246.55	47.27	160.89
F value	75.60	2.19	187.10**	22.33**
CD	0.02	NS	0.99	6.22
p_1	0.63	252.44	35.72	144.44
p_2	0.71	240.53	47.00	155.53
p_3	0.70	222.38	44.34	126.46
F value	26.05**	6.86	297.48**	31.60**
CD	0.02	66.80	0.99	6.22
k_1	0.73	240.06	41.32	133.25
k_2	0.65	243043	42.12	142.98
k_3	0.66	231.82	43.62	150.19
F value	23.31**	1.06	11.59**	3.38*
CD	0.02	NS	0.99	6.22

* Significant at 5% level ** Significant at 1% level

Table 9 b. Interaction effects of NP, NK and PK on the available nutrients in the soil at harvest,

Interaction effects	O.C (%)	Available N ($Kg\ ha^{-1}$)	Available P ($Kg\ ha^{-1}$)	Available K ($Kg\ ha^{-1}$)
n_1p_1	0.52	256.03	30.03	137.16
n_1p_2	0.88	237.22	39.23	153.40
n_1p_3	0.73	195.24	44.58	130.29
n_2p_1	0.69	258.14	36.75	126.91
n_2p_2	0.79	229.82	52.98	157.03
n_2p_3	0.72	229.98	35.77	91.79
n_3p_1	0.68	243.15	40.36	169.24
n_3p_2	0.45	254.56	48.77	156.14
n_3p_3	0.66	241.93	52.68	151.30
F value	107.39**	2.97*	117.80	22.33**
CD	0.04	29.10	1.72	10.78
n_1k_1	0.67	215.15	30.38	144.54
n_1k_2	0.71	232.15	44.55	143.62
n_1k_3	0.75	241.18	38.75	132.64
n_2k_1	0.69	247.31	37.35	120.52
n_2k_2	0.73	244.45	36.75	133.15
n_2k_3	0.78	226.18	31.37	122.06
n_3k_1	0.82	257.72	56.03	134.64
n_3k_2	0.52	253.68	45.05	152.17
n_3k_3	0.42	228.24	40.73	195.87
F value	84.71**	2.07	250.22**	31.60**
CD	0.04	NS	1.72	10.78
p_1k_1	0.61	245.68	34.91	130.28
p_1k_2	0.69	252.73	36.61	149.13
p_1k_3	0.59	258.91	35.62	153.90
p_2k_1	0.84	245.64	40.34	149.36
p_2k_2	0.65	253.74	46.13	159.85
p_2k_3	0.63	222.21	59.54	157.36
p_3k_1	0.73	228.86	48.71	120.11
p_3k_2	0.61	223.81	48.63	119.96
p_3k_3	0.77	214.42	35.68	139.31
F value	48.37**	1.29	243.56**	3.38*
CD	0.04	NS	1.72	10.78

* Significant at 5% level ** Significant at 1% level

Table 9 c. Interaction effects of NPK on the available nutrients in the soil at harvest.

Treatment	OC (%)	Available N (Kg ha^{-1})	Available P (Kg ha^{-1})	Available K (Kg ha^{-1})
$n_1p_1k_1$	0.40	120.84	28.96	156.59
$n_1p_1k_2$	0.51	248.41	30.88	123.62
$n_1p_1k_3$	0.66	298.84	30.27	131.27
$n_1p_2k_1$	0.93	243.15	31.77	158.08
$n_1p_2k_2$	0.86	261.21	37.01	159.79
$n_1p_2k_3$	0.84	207.29	49.01	142.35
$n_1p_3k_1$	0.68	181.48	31.01	119.11
$n_1p_3k_2$	0.76	186.83	65.77	147.47
$n_1p_3k_3$	0.76	217.40	36.97	124.29
$n_2p_1k_1$	0.60	282.25	36.97	98.66
$n_2p_1k_2$	0.70	265.35	37.94	140.85
$n_2p_1k_3$	0.78	226.80	35.34	141.21
$n_2p_2k_1$	0.86	235.59	40.86	162.01
$n_2p_2k_2$	0.74	236.07	43.17	169.33
$n_2p_2k_3$	0.79	217.79	74.90	139.76
$n_2p_3k_1$	0.62	224.09	34.22	100.88
$n_2p_3k_2$	0.76	231.90	29.22	89.27
$n_2p_3k_3$	0.78	233.96	43.87	85.22
$n_3p_1k_1$	0.84	233.96	28.81	135.60
$n_3p_1k_2$	0.88	244.40	41.03	182.91
$n_3p_1k_3$	0.33	251.08	41.25	189.22
$n_3p_2k_1$	0.74	258.18	48.39	128.00
$n_3p_2k_2$	0.36	263.95	48.21	150.44
$n_3p_2k_3$	0.26	241.55	84.73	189.98
$n_3p_3k_1$	0.88	231.00	80.90	140.33
$n_3p_3k_2$	0.32	252.70	50.91	123.13
$n_3p_3k_3$	0.77	192.10	26.22	208.41
F value	4.71*	2.57*	136.75**	3.38*
CD	0.07	50.40	2.98	18.67

* Significant at 5% level   ** Significant at 1% level

interactions only. The interactions, n_1p_3 recorded the least value (195.24 kg ha^{-1}) and n_2p_1, the highest value (258.14 kg ha^{-1}), which was on par with n_1p_1, n_3p_1, n_3p_2, n_3p_3, n_1p_2, n_2p_3 and n_2p_2. The NPK interactions had significant influence on soil available N. Here, $n_1p_1k_1$ registered minimum value (120.84 kg ha^{-1}) whereas $n_1p_1k_3$, the maximum (298.84 kg ha^{-1}) which was on par with $n_2p_1k_1$, $n_2p_1k_2$, $n_3p_2k_1$, $n_3p_3k_2$ $n_3p_2k_2$, $n_1p_2k_2$, $n_1p_1k_2$ and $n_3p_1k_3$.

4.7.3 Soil Available Phosphorus

There was significant effect on soil available phosphorus due to the main and interaction effects of N, P and K. Among N the levels, n_1 recorded minimum value (37.96 kg ha^{-1}) and n_3 the maximum value (47.27 kg ha^{-1}). With regard to the P levels, p_1 resulted least value (35.72 kg ha^{-1}) and p_2, the highest value (47.00 kg ha^{-1}). As far K levels, k_1 registered minimum value (41.32 kg ha^{-1}) and k_3, the maximum value (43.62 kg ha^{-1}). Among N x P interactions, n_1p_1 showed the lowest (30.03 kg ha^{-1}) and n_2p_2 the highest value (52.98 kg ha^{-1}) which was on par with n_3p_3. With regard to N x K interactions, n_1k_1 obtained least value (30.38 kg ha^{-1}) which was on par with n_2k_3 whereas n_3k_1, the highest (56.03 kg ha^{-1}). In the P x K interactions, p_1k_1 registered minimum value (34.91 kg ha^{-1}) which was on par with p_1k_3, p_3k_3 and p_1k_2 whereas, p_2k_3 the highest value (59.54 kg ha^{-1}).

Among the NPK interactions, $n_3p_3k_3$ recorded least value (26.22 kg ha^{-1}), which was on par with $n_1p_1k_1$ (28.96 kg ha^{-1}) whereas the highest value (84.73 kg ha^{-1}) was recorded for $n_3p_2k_3$.

4.7.4 Soil available potassium

Both the main effects and their interactions of N, P and K had significant influence on soil available potassium. Among the N levels, n_2 recorded minimum value (125.24kg ha^{-1}) and n_3, the maximum value (160.89 kg ha^{-1}). In the P levels, p_3 resulted minimum value (126.46 kg ha^{-1}) and p_2, the maximum value (155.53 kg ha^{-1}). As for K levels, k_1 registered least value (133.25 kg ha^{-1}) and k_3, the highest value (150.19 kg ha^{-1}).

In the N x P interactions, n_2p_3 showed minimum value (91.79 kg ha^{-1}) and n_3p_1 the maximum value (169.24 kg ha^{-1}). Among the N x K interactions, n_2k_1 recorded lowest value (120.52 kg ha^{-1}) which was on par with n_2k_3 (122.06 kg ha^{-1}) whereas n_3k_3, the highest value (195.87 kg ha^{-1}). With regard to the P x K interactions, p_3k_2 resulted minimum value (119.96 kg ha^{-1}) which was on par with p_3k_1 and p_1k_1 whereas p_2k_2, the maximum (159.85 kg ha^{-1}) which was on par with p_2k_3, p_1k_3, p_2k_1 and p_1k_2.

Due to the NPK interactions, $n_2p_3k_3$ registered the lowest (85.22 kg ha^{-1}) which was on par with $n_2p_3k_2$, $n_2p_1k_1$ and $n_2p_3k_1$ whereas $n_3p_3k_3$, the highest value (208.41 kg ha^{-1}).

4.7.5 UPTAKE OF MAJOR NUTRIENTS AT HARVEST

The data in Tables 10a, 10b and 10c show the main effects and interaction effects of N, P and K on the uptake of major nutrients.

4.7.5.1 Uptake of Nitrogen

The main effects of N, P and K had significant influence on the uptake of nitrogen at harvest. Among the N levels, n_2 recorded the least value (100.95 kg ha^{-1}) and n_3, the highest (137.51 kg ha^{-1}). Among the P levels, p_1 showed the lowest value (96.00 kg ha^{-1}) and p_3, the highest value (126.27 kg ha^{-1}). In the K levels, k_2 resulted least value (104.81kg ha^{-1}) and k_3, the highest value (122.96 kg ha^{-1}).

Among the interactions, the treatment P x K only influenced significantly the uptake of N. Here, p_1k_2 recorded the lowest value (85.19 kg ha^{-1}), which was on par with p_1k_3, p_2k_1 and p_3k_2 whereas; the highest value was recorded for p_3k_3 (152.98 kg ha^{-1}). The NPK interaction did not influence significantly on the uptake of nitrogen.

4.7.5.2 Uptake of Phosphorus

There was significant influence on the uptake of phosphorus due to the main effects of N, P and K. Among the N levels, lowest value

Table 10 a. Main effects of N, P and K on the uptake of nutrients by cassava at harvest

Main effects	N (Kg ha^{-1})	P (Kg ha^{-1})	K (Kg ha^{-1})
n_1	101.15	32.13	148.93
n_2	100.95	31.67	144.94
n_3	137.51	35.43	149.92
F value	16.65**	4.35*	0.24
CD	15.00	2.83	NS
p_1	96.00	27.83	124.80
p_2	117.34	33.31	147.22
p_3	126.27	38.27	171.58
F value	9.09**	28.79**	17.22**
CD	15.00	2.83	16.40
k_1	111.84	32.56	125.60
k_2	104.81	30.57	133.51
k_3	122.96	36.28	184.48
F value	3.15	8.87**	32.11**
CD	NS	2.83	1.40

** Significant at 1% level

Table 10 b. Interaction effects of NP, NK and PK on the uptake of nutrients by cassava at harvest

Interaction effects	N (Kg ha^{-1})	P (Kg ha^{-1})	K (Kg ha^{-1})
n_1p_1	82.22	23.00	122.89
n_1p_2	111.26	35.38	155.22
n_1p_3	109.98	38.58	168.68
n_2p_1	88.57	29.48	117.43
n_2p_2	92.60	26.81	129.65
n_2p_3	121.67	38.72	187.14
n_3p_1	117.20	31.03	134.07
n_3p_2	148.16	37.73	156.77
n_3p_3	147.17	37.52	158.92
F value	1.12	6.95*	2.55
CD	NS	4.90	NS
n_1k_1	105.05	32.98	125.20
n_1k_2	99.95	31.08	143.30
n_1k_3	98.45	32.91	178.29
n_2k_1	95.39	29.88	114.56
n_2k_2	99.69	30.21	140.61
n_2k_3	107.76	34.92	179.15
n_3k_1	135.09	34.83	137.04
n_3k_2	114.79	30.42	116.73
n_3k_3	162.64	41.03	196.00
F value	2.36	2.16	2.18
CD	NS	NS	NS
p_1k_1	111.54	30.10	119.32
p_1k_2	85.19	24.01	104.16
p_1k_3	91.26	29.39	150.91
p_2k_1	104.52	30.78	120.21
p_2k_2	122.87	34.66	153.34
p_2k_3	124.64	34.49	168.10
p_3k_1	119.47	36.80	137.28
p_3k_2	106.36	33.04	143.04
p_3k_3	152.98	44.98	234.43
F value	4.02*	4.91**	5.65**
CD	25.98	4.90	28.40

* Significant at 5% level ** Significant at 1% level

Table 10 c. Interaction effects of NPK on nutrient uptake by cassava at harvest

Treatment	N (Kg ha^{-1})	P (Kg ha^{-1})	K (Kg ha^{-1})
$n_1p_1k_1$	96.50	27.30	119.50
$n_1p_1k_2$	71.92	20.06	94.19
$n_1p_1k_3$	78.24	21.64	154.97
$n_1p_2k_1$	113.46	35.42	107.32
$n_1p_2k_2$	120.99	37.27	191.05
$n_1p_2k_3$	99.34	33.47	167.29
$n_1p_3k_1$	105.18	36.22	148.79
$n_1p_3k_2$	106.96	35.93	144.65
$n_1p_3k_3$	117.79	43.61	212.60
$n_2p_1k_1$	112.05	30.62	113.74
$n_2p_1k_2$	77.51	25.16	111.21
$n_2p_1k_3$	76.16	32.65	127.34
$n_2p_2k_1$	76.60	22.45	90.58
$n_2p_2k_2$	100.46	29.99	123.17
$n_2p_2k_3$	100.75	28.00	175.20
$n_2p_3k_1$	97.52	36.57	139.35
$n_2p_3k_2$	121.09	35.48	187.16
$n_2p_3k_3$	146.40	44.10	234.91
$n_3p_1k_1$	126.07	32.39	124.71
$n_3p_1k_2$	106.15	26.82	107.07
$n_3p_1k_3$	119.38	33.87	170.42
$n_3p_2k_1$	123.49	34.49	162.73
$n_3p_2k_2$	147.17	36.73	145.73
$n_3p_2k_3$	173.82	41.98	161.80
$n_3p_3k_1$	155.73	37.62	123.69
$n_3p_3k_2$	91.04	27.72	97.32
$n_3p_3k_3$	194.74	47.22	255.47
F value	1.26	0.50	2.72*
CD	NS	NS	49.19

* Significant at 5% level

(31.67 kg ha^{-1}) was recorded for n_2 and highest (35.43 kg ha^{-1}) for n_3. In the P levels, p_1 resulted least value (27.83 kg ha^{-1}) and p_3, the highest (38.27 kg ha^{-1}). As far K levels, k_2 registered minimum (30.57 kg ha^{-1}) and k_3, the maximum uptake (36.28 kg ha^{-1}). Among the interaction effects, there was significant response only for N x P and P x K interactions on P uptake. In the N x P interactions, n_1p_1 recorded minimum (23.00 kg ha^{-1}), which was on par with n_2p_2 whereas, highest value was recorded for n_2p_3 (38.72 kg ha^{-1}), which was on par with n_1p_3, n_3p_2, n_3p_3 and n_1p_2.

Among the P x K interactions, p_1k_2 recorded the lowest value (24.01 kg ha^{-1}) and p_3k_3, the highest value (44.98 kg ha^{-1}). The interactions of NPK had no significant effect on P uptake.

4.7.5.3 Uptake of Potassium

Among the main effects, P and K levels had only significant influence on K uptake. Due to the P levels, p_1 recorded the least (124.80 kg ha^{-1}) and p_3, the highest value (171.58 kg ha^{-1}). With regard to K levels, k_1 resulted the least value (125.60 kg ha^{-1}) and k_3, the highest vlue (184.48kg ha^{-1}).

Among the interaction effects, P x K and NPK interactions showed significant variation on K uptake. Here, p_1k_2 recorded lowest value (104.16 kg ha^{-1}) which was on par with p_1k_1 and p_2k_1 whereas p_3k_3 the highest (234.43 kg ha^{-1}). Among the NPK interactions, $n_2p_2k_1$ recorded the least value (90.58 kg ha^{-1}), which was on par with $n_1p_1k_2$, $n_3p_3k_2$, $n_3p_1k_2$, $n_1p_2k_1$, $n_2p_1k_2$, $n_2p_1k_1$, $n_1p_1k_1$, $n_2p_2k_2$, $n_3p_3k_1$, $n_3p_1k_1$, $n_2p_1k_3$ and $n_2p_3k_1$ whereas the highest (255.77 kg ha^{-1}) value was recorded for $n_3p_3k_3$ which was on par with $n_2p_3k_3$ and $n_1p_3k_3$.

4.8 ECONOMICS OF CULTIVATION

The data on the additional cost due to treatments, cost of cultivation, tuber yield, gross income, net income and the BCR resulted from various treatments are presented in Table 11. The additional cost

Table 11. Economic analysis

Treatment	Additional Cost due to treatment (Rs. ha^{-1})	Cost of cultivation (Rs. ha^{-1})	Tuber yield (kg ha^{-1})	Gross income (Rs. ha^{-1})	Net income (Rs. ha^{-1})	BCR
$n_1p_1k_1$	2100	42100	23112	29336	27236	1.64
$n_1p_1k_2$	2289	42289	26548	79644	37355	1.88
$n_1p_1k_3$	2479	42478	47091	141273	98795	3.32
$n_1p_2k_1$	2690	42690	23314	69942	27252	1.63
$n_1p_2k_2$	2879	42879	30554	91662	48783	2.13
$n_1p_2k_3$	3068	43068	32717	99815	55083	2.27
$n_1p_3k_1$	3279	43279	27544	82632	39353	1.90
$n_1p_3k_2$	3468	43468	31517	94551	51083	2.17
$n_1p_3k_3$	3657	43657	38477	115431	71774	2.64
$n_2p_1k_1$	2371	42371	26832	80496	38125	1.89
$n_2p_1k_2$	2560	42560	37650	112950	70390	2.65
$n_2p_1k_3$	2749	42749	40212	120636	77887	2.82
$n_2p_2k_1$	2961	42961	25173	75519	32558	1.76
$n_2p_2k_2$	3150	43150	31388	94164	51014	2.18
$n_2p_2k_3$	3339	43339	39053	117159	73820	2.70
$n_2p_3k_1$	3550	43550	28309	84927	41377	1.95
$n_2p_3k_2$	3739	43739	25799	77397	33658	1.77
$n_2p_3k_3$	3828	43928	37400	112200	68272	2.55
$n_3p_1k_1$	2641	42641	26792	80376	37735	1.88
$n_3p_1k_2$	2830	42830	29102	87306	44476	2.04
$n_3p_1k_3$	3019	43019	37400	112200	69181	2.60
$n_3p_2k_1$	3231	43231	25880	77640	34409	1.79
$n_3p_2k_2$	3420	43420	27153	81459	38039	1.88
$n_3p_2k_3$	3609	43609	32229	96687	53078	2.22
$n_3p_3k_1$	3820	43820	25813	77439	33619	1.77
$n_3p_3k_2$	4009	44009	26318	78954	34945	1.79
$n_3p_3k_3$	4198	44198	40279	120828	76630	2.73

Cost of cultivation except fertilizer = Rs.40,000/-
Cost of Cassava tubers = Rs. 3/- kg *
(*Sale Price fixed by the Instructional Farm, Vellayani)

due to treatments ranged from Rs.2,100 for the treatment with lowest dose of nutrients (50:50:50 kg NPK ha^{-1}) to Rs.4,198 for the treatment with the highest dose (100:100:100 kg NPK ha^{-1}). Accordingly, the cost of cultivation also varied from Rs.42,100 to Rs.44,198 for the treatments with lowest and highest doses of nutrients respectively. The tuber yield was maximum (47.09 t ha^{-1}) for the treatment $n_1p_1k_3$ (50:50:100 kg NPK ha^{-1}) resulting a gross income of Rs.1,41,273 and net income of Rs.98,795 ha^{-1}. The lowest BC ratio (1.63) was recorded by $n_1p_2k_1$ indicating the least rate of return from this treatment. The treatment $n_3p_1k_2$, $n_1p_1k_2$, $n_1p_3k_2$, $n_2p_2k_2$, $n_3p_2k_3$, $n_1p_2k_3$, $n_2p_3k_3$ $n_2p_2k_3$, $n_1p_3k_3$, $n_2p_1k_2$, and $n_3p_3k_3$ gave moderately high benefit cost ratio ranging from 2.04 to 2.73. Among the various treatments, $n_1p_1k_3$ resulted the highest BC ratio of 3.32 followed by $n_2p_1k_3$ (2.82) (Plate.4) and $n_3p_3k_3$ (2.73). Since the additional cost of fertilizer (Rs. 2,479) was less for the treatment $n_1p_1k_3$ (50:50:100 kg NPK ha^{-1}) which produced the highest tuber yield (47.09 t ha^{-1}) compared to the treatment $n_3p_3k_3$ (100:100:100 kg NPK ha^{-1}) which resulted the next highest yield (40.28 t ha^{-1}), the BC ratio for $n_1p_1k_3$ was the highest and hence it is most economical.

Discussion

5. DISCUSSION

The results generated from the studies on fertilizer scheduling for the short duration cassava variety "Vellayani Hraswa" are discussed in this chapter.

5.1 GROWTH CHARACTERS

Height and number of leaves produced by the plant were considered as the indicators of the growth of plant.

There was no significant difference on plant height at all the growth stages of the crop for the different levels of nitrogen, phosphorus and potassium. (Table 2 a). However, there was an increasing trend at 5^{th} and 6^{th} MAP due to higher dose of nitrogen at n_3 level (100 kg ha^{-1}). The plant height was maximum at 6 MAP. The positive influence due to nitrogen on the height of cassava plant was reported earlier by Mandal *et al.* (1971); Natarajan (1975); Pillai and George (1978 a); Muthukrishnan (1980); Nayar (1986) and Pamila (2003). Nayar *et al.* (1998) reported that the height of cassava plant increased significantly with higher levels of NPK fertilizers. Higher dose of N and P with lowest K level resulted maximum plant height at 6 MAP.

The highest level of nitrogen @ 100 kg ha^{-1} recorded maximum number of leaves per plant during the first and third MAP indicating the effect of this nutrient on the vegetative growth in the initial stage of crop growth. (Table.3b). It is a proven fact that an adequate supply of nitrogen promotes vegetative growth especially the leaf production and keeps the leaves functional for a long time (Russel, 1973 and Tisdale *et al.*, 1995). In general, there was more number of leaves per plant when the dose of N was increased. Stimulation of vegetative growth at higher rates of applied nitrogen was reported earlier in cassava by CIAT (1976); Ngongi (1979); Queiroz (1980) and Pamila (2003). At 6 MAP, the highest number of leaves per plant was recorded for the treatment with NPK @ 100: 100: 100 kg ha^{-1}. The leaf fall was found to be the minimum, retaining most of the leaves produced during the early vegetative phase till maturity though there is leaf production resulting the highest number of retained leaves at 6 MAP. During the peak vegetative period, i.e., 3rd MAP, N x K interaction showed significant influence on the leaf production (Table 3b). An enhanced rate of leaf production was resulted at increased levels of K due to increased uptake of N. The influence of K in promoting leaf retention was reported by Nair (1983). Further, the above observation was supported by Nayar (1986) with his findings that K had significant effect in producing maximum number of leaves at the active growth stage. According to Edward (1982), the beneficial effects of K on leaf retention may be due to the fact that K fertilization increased tolerance of plants to water stress. Generally, higher dose of P influenced the leaf production at higher levels almost throughout the growth stage of crop. Similarly, the influence of K was significant during the last stages of crop growth indicating the positive effect of K on the leaf production (Edward, 1982). Physiologically, the variety "Vellayani Hraswa" is short statured and is rather bushy type with branching characteristics when compared to other prominent varieties. The word "Hraswa" means short with respect to height and maturity period.

5.2. YIELD AND YIELD COMPONENTS

The number of tubers per plant, tuber length and girth are the major yield contributing components for cassava. There was significant influence only for potassium on the number of tubers produced (Table 4a) The positive role on the tuber production by potassium application (100 kg ha^{-1}) was observed by Nair (1982). Nitrogen and phosphorus had no significant influence on the number of tubers produced.

Among the interactions, n_3p_1, n_2k_3 and p_1k_3 recorded maximum number of tubers (Table 4b). The treatment $n_2p_1k_2$ registered the highest number of tubers followed by $n_3p_1k_2$ and $n_2p_2k_3$ (Table 4c). Significant increase in tuber number of the hybrid-165 was observed by Mandal and Mohankumar (1972) by raising the level of applied nitrogen from 40 kg to 80 kg ha^{-1} beyond which there was not much difference. Pamila (2003) reported that the number of tubers significantly increased when the N level was increased from 50 to 75 kg ha^{-1} but decreased at 100 kg N level. The variety responds well at lower levels of N and P and it prefers a 1: 1.5 NK ratio for better tuber production.

The main effects and interaction effects had no significant influence on the length of tubers (Table 4a, 4b). But, there was a progressive trend due to nitrogen and phosphorus levels. The interactions, n_2p_3; n_2k_2 and p_1k_2 resulted tuber with maximum length. The treatment with NPK @ 75:50:75 kg ha^{-1} produced tubers with maximum length (Table 4 c). Main effect of nitrogen did not influence significantly the length of tubers as observed by Asokan *et al.* (1980). There was significant difference only by different levels of nitrogen on girth of tubers. The highest dose of N (100 kg ha^{-1}) resulted in maximum girth of the tuber. Asokan *et al.* (1980) could not get significant influence on the length and girth of the tubers due to different levels of nitrogen @ 60, 120 and 180 kg ha^{-1}. Among the interactions, n_3p_2, n_3k_2, p_2k_1, $n_3p_2k_2$ and $n_3p_2k_3$ registered maximum girth of tuber, which indicates that higher dose of nitrogen, increased the girth of tubers. According to Pamila (2003), cassava plants treated with 100 kg nitrogen was on par with 50 kg nitrogen treated plants and the plants receiving 75 kg N ha^{-1} produced longer tuber. The girth of tuber was significantly influenced only by the different levels of nitrogen (Table 4a) indicating the role of nitrogen on bulking of tubers.

The tuber yield was significantly influenced by the main effects of nitrogen, phosphorus and potassium (Table 4a and Fig. 2). Here, nitrogen at medium level ((75 kg ha^{-1}) produced maximum tuber yield and this observation is in conformity with the findings of Asokan *et al.* (1988); Thampatti and Padmaja (1995) and Pamila (2003). Phosphorus at the lowest level (50 kg ha^{-1}) recorded maximum tuber yield for cassava.

The highest dose of K (100 kg ha^{-1}) produced the highest tuber yield (39.71 t ha^{-1}). The above observation was supported by Malvotta *et al.* (1955); Asokan and Sreedharan (1977); Mohankumar (1975), Sittibusaya and Kurmarohita (1978); Nair *et al.* (1980); Asokan *et al.* (1988); CTCRI (1990), Maduakor (1997); Howeler (1998); and Goswami (2003). An examination of tuber yield data indicated that interactions, n_2p_1, n_2k_3 and p_1k_3 were the most efficient in producing the highest yield (Table 4b.). The treatment, $n_1p_1k_3$ (Plate. 3) was the most efficient one in producing the highest tuber yield (47.09 t ha^{-1}) followed by $n_3p_3k_3$ (40.28 t ha^{-1}) and $n_2p_1k_3$ (40.21 t ha^{-1}) (Plate.4). The present findings are in agreement with the observations by Asokan *et al.* (1988), Asokan and Sreedharan (1977); Maduakor (1997); Dang *et al.* (1998); Weite *et al.* (1998); Cadavid *et al.* (1998); Mohankumar *et al.* (1996); CTCRI (1998) and Goswami (2003).

Wilson and Ovid (1994) reported that the conjoint use of higher levels of fertilizers could produce substantially higher yield, especially in low and medium fertile soils where they observed similar increase in yield to the tune of 63.1 t ha^{-1} in an acid inceptisol with 400 kg N, 200 kg P_2O_5 and 400 kg K_2O ha^{-1}. In the present study, the treatment $n_1p_1k_3$ produced the highest tuber yield (47.09 t ha^{-1}). The variety Vellayani Hraswa prefers a 1: 1: 3 ratio of NPK for maximum tuber yield under the present soil and climatic conditions.

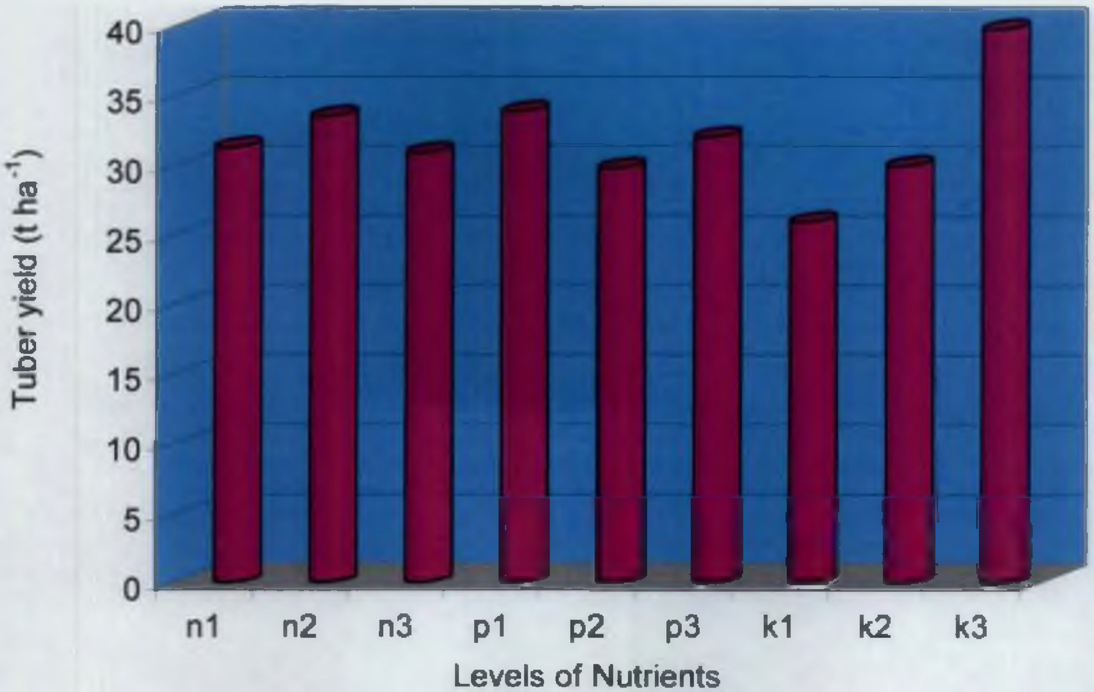

Fig. 2 Influence of N, P and K on Tuber yield

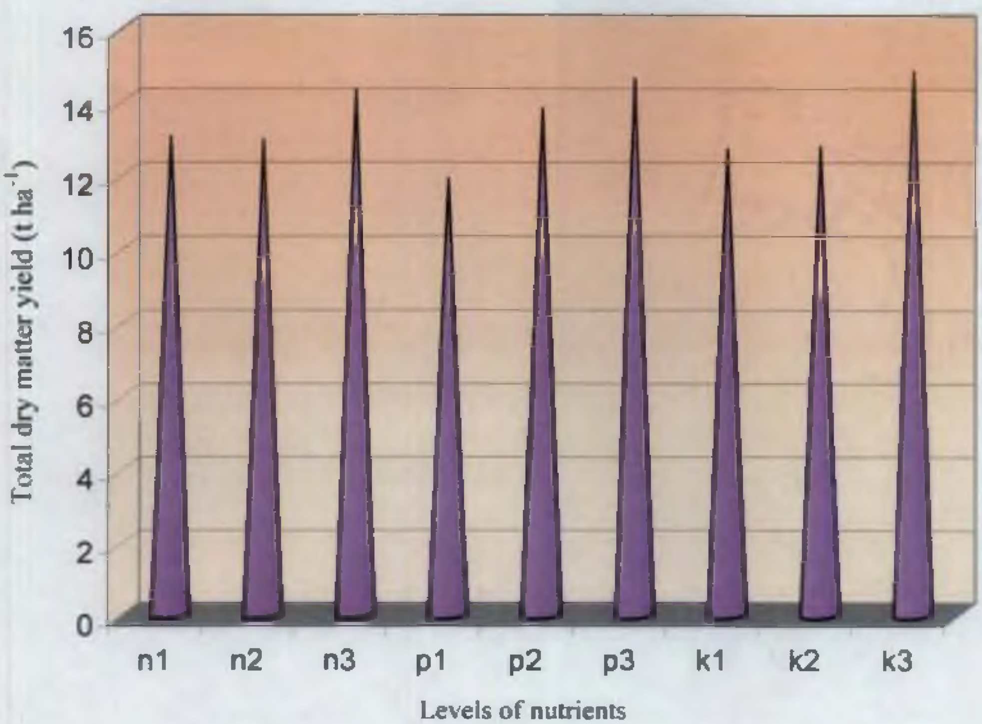

Fig. 3 Main effects of N, P and K on total dry matter production

There was significant influence on total dry matter production due to different levels of N, P and K (Table 4a and Fig.3). The N supply increased dry matter production. Adequate quantity of N is essential for effective partitioning of accumulated dry matter to the economic sink. The interaction effects of N, P and K are synergistic in affecting the dry matter yield. Similarly, the interaction effects of N and P cause N induced P absorption favouring growth stimulation and enhanced uptake of both elements. Among the main effects, nitrogen at the highest level (100 kg ha^{-1}) produced the maximum dry matter yield. This is in agreement with the observation by Susan John (2003). Application of N, P and K fertilizers significantly increased the aerial and total biomass as observed by Pellet and Elsharkawy (1993). N, P and K @ 100 kg ha^{-1} recorded maximum dry matter production. This observation is contrary to the report of Pamila (2003) and Vijayan and Aiyer (1969) but this is in conformity with the findings of Obigbesan (1973), Pushpadas and Aiyer (1976) and Pillai and George (1978 a) who reported an increase in tuber dry matter content with higher rates of potassium application.

Among the interaction effects of N x P, N x K, and P x K p_3k_2 produced the maximum dry matter yield. The treatment combination of $n_2p_3k_3$ (75:100:100 kg ha^{-1}) produced maximum dry matter yield (Table 4 c). The observations by Keating and Evenson (1981) also support the present findings.

5.3 PHYSIOLOGICAL PARAMETERS

Leaf area index (LAI), stomatal conductance and chlorophyll content of leaves were the physiological parameters considered here.

The main and interaction effects of N, P and K had no significant influence on LAI. (Tables 5a, 5b and 5c). But, there was an increasing trend due to higher dose of nitrogen whereas, P and K both @ 75 kg ha^{-1} produced maximum LAI. This is fairly supported by Ramanujam (1982). Ngongi (1979) reported increase in plant leaf area and leaf size with incremental dose of potash from 50 to 240 kg ha^{-1}. The treatment $n_3p_2k_2$ registered maximum leaf area index. Ramanujam (1982) also reported similar findings. Among the interactions, n_3p_2, n_3k_1 and p_2k_1 registered maximum LAI. But, there was no significant difference. The higher levels of nitrogen enhanced the leaf production and leaf area that led to maximum LAI for cassava as observed by Indira (1996).

In general, nitrogen, phosphorus and potassium had no significant effect on stomatal conductance (Table 5a). However, there was an increasing trend due to higher doses of nutrients, except for nitrogen. The nitrogen at lowest dose registered slightly high stomatal conductance and phosphorus at the highest dose obtained maximum stomatal conductance and potassium at 75 kg ha^{-1} increased stomatal conductance of the cassava leaves. The interaction, p_2k_2 increased the leaf stomatal conductance with significant variation (Table 5b). Phosphorus and potassium play a major role in increasing the stomatal conductance. Potassium maintains the cellular membrane and the protoplasm in a proper degree of hydration by stabilizing emulsions of highly colloidal particles. This helps in maintaining turgor pressure and eliminates the water imbalance in plants and regulates the osmotic pressure of plants. This may be the reason for significant increase on stomatal conductance in cassava leaves due to P and K both @ 75 kg ha^{-1}.

The main and interaction effects of N, P and K did not influence the chlorophyll content of cassava leaves significantly. However, there was an increasing trend in the chlorophyll content due to higher doses of nutrients. Nitrogen at low level @ 50 kg ha^{-1} produced rather high chlorophyll content in leaves. Potassium @ 75 kg ha^{-1} slightly increased the chlorophyll content. The interactions n_1p_2, n_2k_2 and p_3k_3 obtained maximum chlorophyll content. Among the NPK interactions, $n_3p_3k_3$ recorded maximum chlorophyll content in the leaves. This is in conformity with the findings of Collins and Duke (1981) who observed that a linear increase in chlorophyll concentration with increased the application of K in Alfalfa. Patil *et al.* (1987) reported that enhanced potash supply had a positive relation with chlorophyll content in tobacco. Devi and Padmaja (1997) revealed an increase in chlorophyll content with increase in the levels of sodium substitution showing a positive role of sodium on chlorophyll biosynthesis in cassava. This is because of univalent cation potassium exerts a pronounced influence on the chlorophyll content of plants. Nitrogen enhanced the concentration of chlorophyll content in the leaves. Nitrogen is an integral part of chlorophyll and is the primary absorber of light energy needed for photosynthesis. May be due to these reasons that the higher dose of nitrogen and potassium produced higher chlorophyll content.

5.4 QUALITY ATTRIBUTES OF CASSAVA

The quality of cassava tuber was assessed in terms of the starch, protein and HCN contents in addition to the cooking quality of tubers.

Starch content of tubers was influenced significantly by phosphorus. There was an increasing trend on tuber starch content due to higher dose of potassium (Table 6a). The effect of K in enhancing the starch content was observed by several workers (Obigbesan and Agboola, 1973; Natarajan, 1975; Muthuswamy and Rao, 1979 and Muthukrishnan, 1980) and their findings are in conformity with the present observations. Pushpadas and Aiyar (1976) recorded the highest starch yield with 250 kg K_2O ha^{-1}. Pillai and George (1978 b) reported increase in starch content by the application of K. Nair and Mohankumar (1984) noticed only a slight increase in the starch content in cassava tubers for potassium application. Nair and Mohankumar (1984) could not get any significant response in starch content of tubers due to NPK application. Among the main effects, P and K at the highest dose showed maximum starch content. In the interactions, n_3p_3, n_3k_3 and p_3k_3 produced tubers with maximum starch content. Similarly, the highest content of starch in cassava tubers was observed for the highest dose of NPK. This may be because of the significant contribution of potassium in the synthesis and translocation of assimilates from source to sink, which is an energy requiring process (Beringer, 1978). While the nutrient K encourages or promotes synthesis and translocation of starch, the role of N is reverse wherein, with increased levels of N and low potassium, there is reduction in starch content of tubers due to a decrease in the availability of carbohydrates (Black, 1973). This may be due to increase in the rate of protein synthesis and consequent increase in vegetative growth triggered by higher N supply with corresponding decrease in starch content. This was well documented by the observation of Tan and Mak (1995) that starch content is negatively correlated with high dose of nitrogen.

The crude protein content of cassava tubers was found to increase due to higher levels of nitrogen @ 100 kg ha^{-1} (Table 6a). When the N was increased from 50 to 75 kg ha^{-1}, the percent increase in crude protein content was 13.81 and further increase of N to 100 kg ha^{-1}, the increase in protein content was only 8.25 per cent i.e., the production of crude protein was not commensurate with the increase in the dose of nitrogen. (Fig.4). This is supported by the observations of Pillai and George (1978 b) and Nair (1982) that nitrogen at 100 kg ha^{-1}, phosphorus and potassium each at 50 kg ha^{-1} produced tubers with higher protein content.

Hydrocyanic acid content is the important limiting factor as far as quality of cassava tuber is concerned. The two cyanogenic glycosides, linamarin and lotaustralin, which are present in all parts of the cassava plants, are hydrolyzed by an endogenous β-glucosidase linamarase, forming cyanide which is toxic (Nambisan and Sundaresan, 1990). The data in the Table 6a and Fig.5 indicate that HCN content was maximum when the plants were treated with the highest dose of nitrogen @ 100 kg ha^{-1} whereas, the least for the lowest dose (50 kg ha^{-1}). This is well supported by the findings of Susan John (2003). The increase in HCN

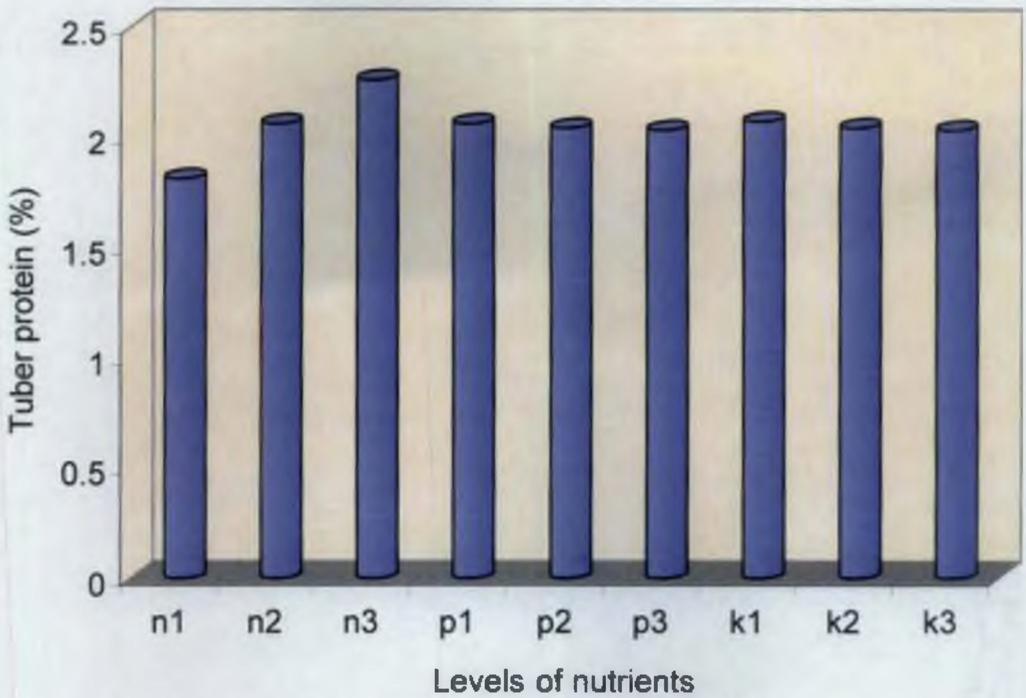

Fig. 4 Influence of N, P and K on tuber protein content

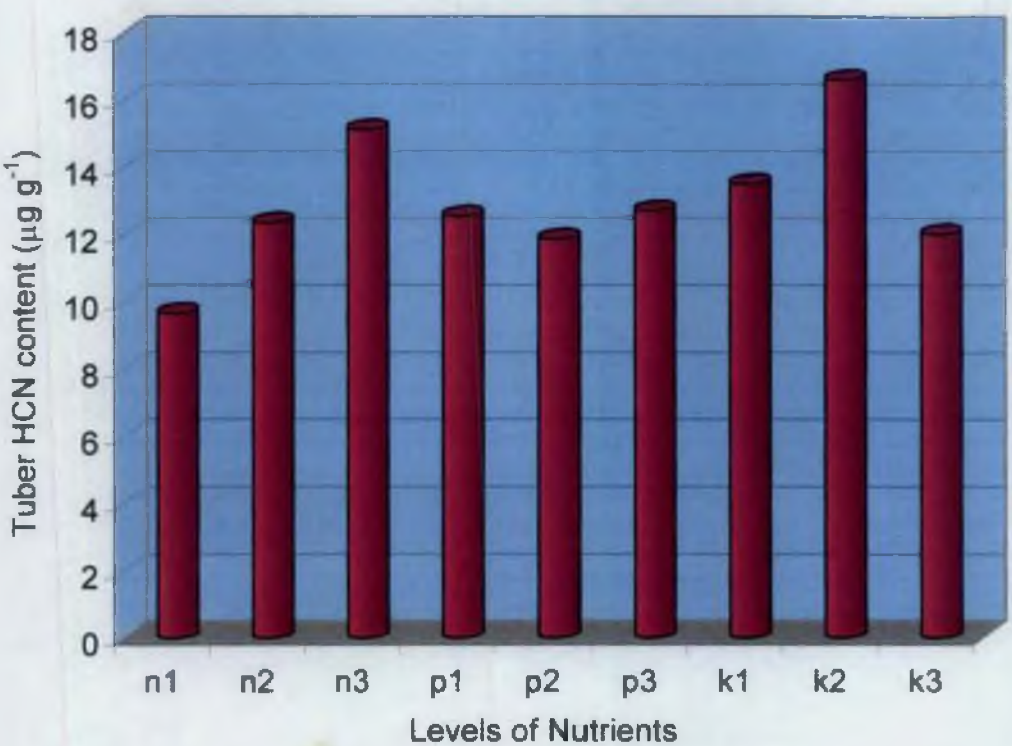

Fig. 5 Influence of N, P and K on Tuber HCN content

content in cassava tubers with high rates of nitrogen was reported by many researchers (Muthuswamy and Rao, 1981; Asokan *et al.*, 1988 Mohankumar *et al.* 1996 and Obigbesan and Fayemi, 1996). There are also reports on the effect of FYM alone or in combination with N in increasing the HCN content (Pillai *et al.*, 1985; and Susan John *et al.*, 1998). This may probably be due to the increased production of cyanogenic glucosides with high rate of nitrogen. There was a decline in the HCN content of tuber due to higher dose of Potassium. This agrees with the findings of Indira *et al.* (1972); Ramanujam (1982) Nair and Mohankumar (1982) and Susan John *et al.* (1998). Among the interactions, n_3p_1, n_3k_1, p_2k_1 resulted in maximum HCN content of cassava tubers. NPK @ 100:100:50 kg ha^{-1} produced maximum HCN content of tuber whereas the least was for $n_1p_2k_3$. This indicates that the HCN content was reduced to half when the dose of potassium was increased. This finding is in agreement with the observations by Susan John *et al.* (1998).

The cooking quality of the cassava tubers was influenced significantly due to different levels of potassium (Table 6a). The lowest dose of nitrogen and highest dose of phosphorus and medium level of potassium resulted in tubers with maximum cooking quality which indicates the effect of optimum dose of nutrients for better cooking quality. The taste and palatability of the cassava tubers were found to be maximum (3.0) for the treatment with 75 kg K ha^{-1}. This is supported by the findings of Asokan and Sreedharan (1980).

In agreement to the above observations, Nair (1982) reported a better cooking quality of tubers at Vellayani and Kayamkulam with potassium application. The improvement in the quality of tubers could be achieved by 50 per cent substitution of K of muriate of potash by Na of common salt (Devi and Padmaja, 1996). Cooking quality of tubers assessed by a taste panel was found to be reduced significantly by higher levels of nitrogen (Prema *et al.*, 1975). Nair (1976) observed a high percentage (75%) of non-bitter tubers at 50 kg ha^{-1} as compared to 63 per cent in the case of 75 kg ha^{-1} and 69 per cent in the case of 100 kg N ha^{-1}. Among the interaction effects, n_1p_3, n_1k_2 and p_3k_3 registered maximum cooking quality for the cassava tubers. This observation is supported by the above findings. Among NPK interactions, the treatments, $n_1p_1k_2$, $n_2p_3k_3$ and $n_3p_1k_3$ obtained almost higher cooking quality to the cassava tubers indicating a balanced fertilizer nutrient ratio for getting maximum tasty tubers. The treatment $n_1p_1k_3$, which produced the highest tuber yield also possessed near starch range for cooking quality.

5.5 NUTRIENT CONTENT IN TUBER

The main effects of N, P and K produced significant influence on the nitrogen content in tubers (Table 7 a). Among the interactions, n_3p_2 and n_3p_3, recorded the highest N content which were on par with n_3k_2 and n_3k_3. The treatment, $n_3p_2k_3$ registered the highest nitrogen content (0.39 %)in the tubers. These observations are in agreement with the findings by Izawa and Okamoto (1959); Knavel (1971) and Muthuswamy and Krishnamoorthy (1976) in sweet potato. Purcell *et al.* (1982) and Mukhopathyay *et al.* (1995) reported that high concentration of nitrogen (1.08) in tuber at harvest was recorded with the treatment of 100 kg K_2O ha^{-1} applied as basal in sweet potato.

N, P and K influenced phosphorus content in the tuber significantly. The interactions n_2p_1, and p_1k_3 recorded maximum P content in the cassava tubers whereas, the $n_2p_3k_1$ obtained the highest P concentrations, which indicate that higher dose of the nutrients, increased the P content of tubers. This is well supported by the findings of Leonard *et al.* (1949); Muthuswamy and Krishnamoorthy (1976) and Mukhopathyay *et al.* (1995) in sweet potato.

Significant difference on the potassium content in the tubers was noticed for the main effect of N and K only. Nitrogen @ 50 kg ha^{-1}

produced tubers with the highest K content (1.16%) while there was no significant influence of P on tuber K content. Maximum K content (1.13%) was registered by plants treated with the highest dose of K (100 kg ha^{-1}). However, $n_1p_3k_3$ and $n_3p_3k_3$ registered maximum K content in the cassava tubers. From the results it has been observed that the higher dose of potassium increased the K content in tubers. This agrees with the observations by Duncan *et al.* (1958); Knavel (1971) and Mukhopathyay *et al.* (1995) in sweet potato.

5.6 NUTRIENT CONTENT IN TOP PORTION

The higher levels of N, P and K increased the N content of top portion significantly. Among the interactions, n_3p_3, n_3k_3 and p_3k_3 increased the nitrogen content of top portion. The NPK interactions have no significant influence on top portion N content, however $n_3p_3k_3$ registered maximum N content for the top portion of cassava. This agrees with the research findings by Duncan *et al.* (1958); Izawa and Okamoto (1959); Mukhopathyay *et al.* (1995) in sweet potato.

The P content of top portion was significantly influenced by the optimum level of nitrogen and with higher dose of phosphorus and potash. Among the interactions, p_3k_3 registered the maximum P content in top portion of the cassava plant. In the NPK interactions, $n_2p_2k_2$ and $n_3p_3k_3$ recorded maximum P content in top portion with significant difference. This is supported by the reports of Leonard *et al.* (1949); Muthuswamy and Krishnamoorthy (1976) and Mukhopathyay *et al.* (1995) in sweet potato.

The medium level of nitrogen and the highest level of P and K nutrition increased the K content in the top portion of cassava. Among the interactions, p_3k_3 produced maximum K content in the top portions followed by n_2p_3. The treatment $n_3p_3k_3$ resulted maximum K content in the top portion with significant difference. This agrees with the observations of Leonard *et al.* (1949); Duncan *et al.* (1958); Knavel (1971) and Sharfuddin and Voican (1984) in sweet potato.

5.7 AVAILABLE MAJOR NUTRIENTS IN THE SOIL BEFORE AND AFTER THE EXPERIMENT

5.7.1 Organic Carbon

The data on soil chemical analysis after the harvest of the crops, (Table 9a) indicate that the organic carbon content of soil was positively influenced by nitrogen at 75 kg ha^{-1} which resulted in the highest soil organic carbon. Similarly P @ 75 kg ha^{-1} and K @ 50 kg ha^{-1} produced maximum organic carbon content in soil after the harvest of the crop (Fig.6). Among the interactions, n_1p_2, registered maximum organic carbon content in the soil (0.88 %) and is on par with p_2k_1 (0.84 %) and n_3k_1 (0.82 %), which are higher than the initial status of soil organic carbon. But the mean value of the organic carbon is somewhat low (0.68%) when compared to the initial status (0.71%) of the soil organic carbon. The variation with respect to the organic carbon content in the soil may be due to the difference on the rate of leaf fall on account of the treatments.

5.7.2 Available Nitrogen

Significant effect due to the treatments on the available N status in the soil after the experiment (Table 9a.) was observed. Nitrogen at the highest level, P at the lowest level and K at the medium level maintained maximum available nitrogen in soil (Fig. 7). Among the interactions, p_1k_3 recorded maximum available nitrogen in soil. The treatment $n_1p_1k_3$ which produced the highest tuber yield showed high available N in soil which was less than the initial status of the soil and also the mean value of the soil available N after the experiment. Crop removal of nitrogen at lower dose of nitrogen and phosphorus may be high bringing down the nitrogen content from the initial status. However, Maskina *et al.* (1990);

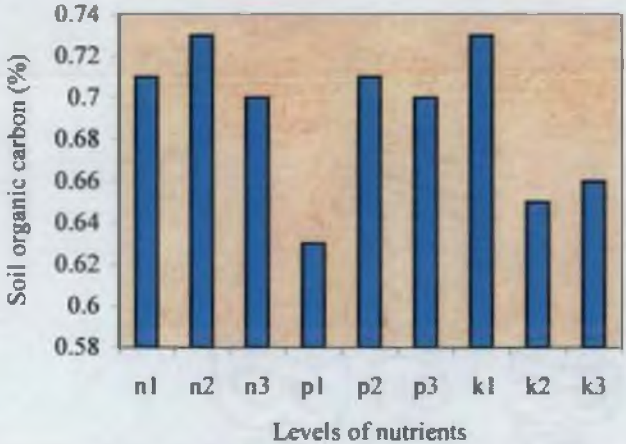

Fig. 6 Effect of N, P and K on soil organic carbon

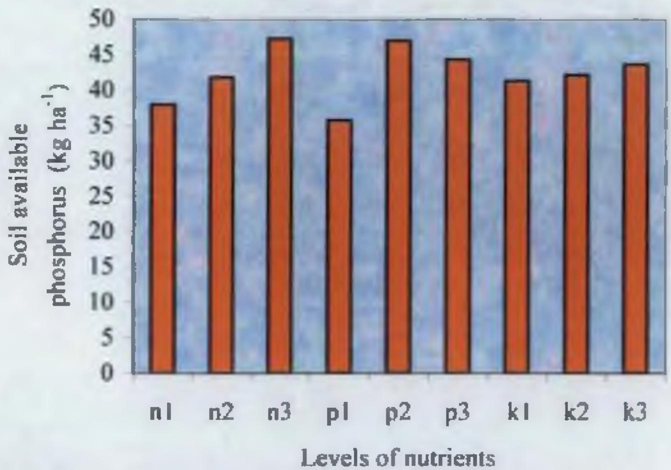

Fig. 8 Effect of N, P and K on soil available phosphorus

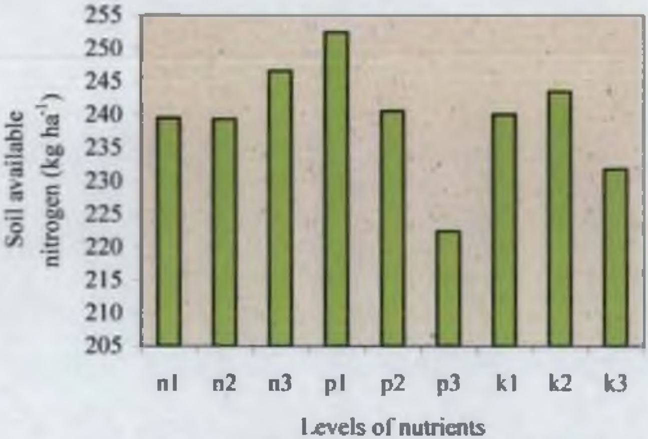

Fig. 7 Effect of N, P and K on soil available nitrogen

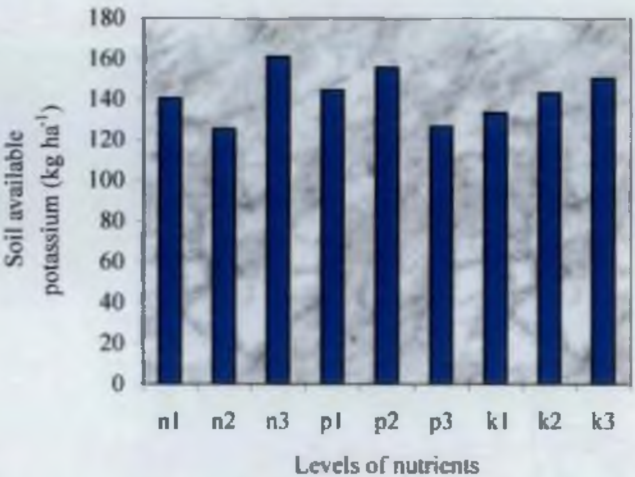

Fig. 9 Effect of N, P and K on soil available potassium

Udayasoorian *et al.* (1990) and Susan John (2003) could not get similar response.

5.7.3 Available Phosphorus

In the case of available P, the nitrogen at 100 kg ha^{-1}, phosphorus 75 kg ha^{-1} and potash at 100 kg ha^{-1} produced maximum available P in the soil with significant influence. Among the N x P, N x K and P x K interactions, n_2p_2, n_3k_1 and p_2k_3 registered maximum available P in the soil (Fig. 8). The treatment $n_3p_2k_3$ (100:75:100 kg ha^{-1}) produced maximum available P in the soil, which is higher than the initial status of the soil. This indicates the poor response to phosphorus at higher level of nutrient by this variety. The mean value for the P in the experimental plot is lower than the initial status. This might be associated with the crop removal of P due to enhanced dry matter production at higher levels of N, P and K. This conforms to the findings of Kabeerathumma *et al.* (1990) and Susan John *et al.* (1997) who reported that rock phosphate application increased the available P status in the soil. Substantial build up of available P with continuous use of phosphate fertilizers in the acid soil is due to their high P fixing capacity (Sharma *et al.* 1980) and low recovery of added P (Sharma *et al.*, 1987).

5.7.4 Available Potassium

Among the main effects, n_3, p_2 and k_3 levels resulted maximum available K in soil (Fig. 9). The treatment with 100:100:100 kg NPK ha^{-1} registered maximum available potassium in soil after the experiment, which is higher than the initial status of the soil available K. This agrees with the findings of Mohankumar *et al.* (1990) who observed that increased levels of K increased the availability of K in the soil.

5.8 UPTAKE OF MAJOR NUTRIENTS BY CASSAVA

The data on the nutrient uptake by plants are shown in Tables 10 a, 10b and 10c and Fig.10, 11 & 12 which indicate significant effect due

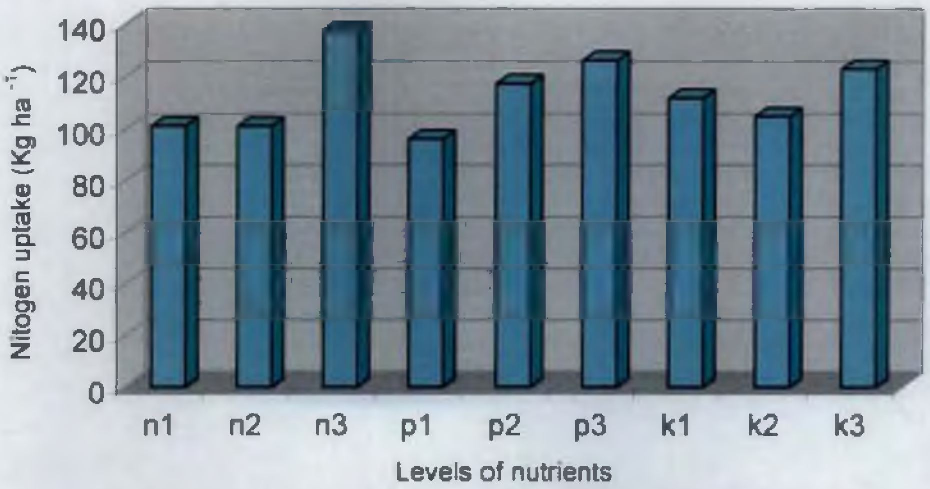

Fig. 10 Main effects of N, P and K on nitrogen uptake by cassava

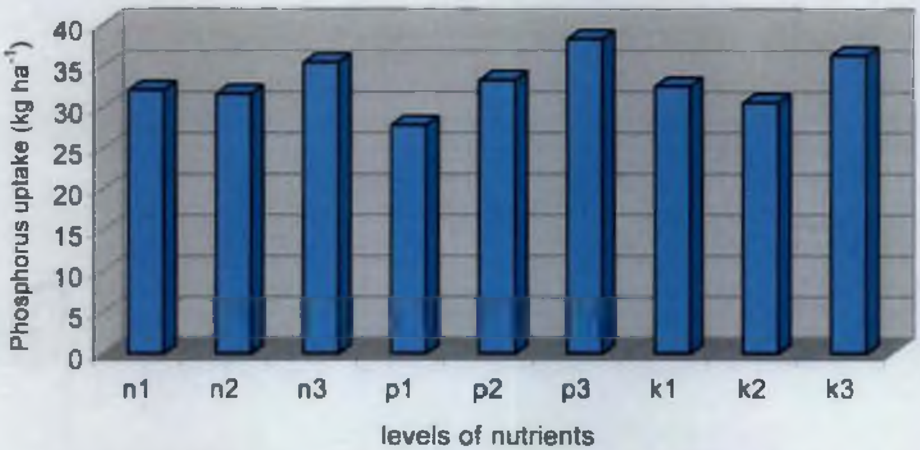

Fig. 11 Main effects of N, P and K on Phosphorus uptake by cassava

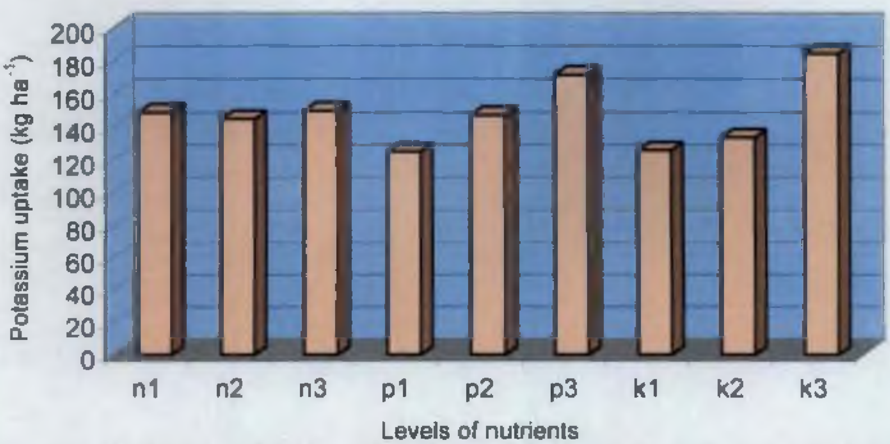

Fig. 12 Main effects of N, P and K on potassium uptake by cassava

to different doses of fertilizers. The dry matter yield and nutrient concentrations in various plant parts are taken into consideration for arriving at the nutrient uptake by the plants. The nutrient requirement of tuber crops is fairly high because of their high yield and dry matter production.

5.8.1 Nitrogen

There was an increase in the quantity of N absorbed as the dose of N increased (Fig. 10). This agrees with the findings of Muthuswamy and Rao (1981) who also reported that the N content of the plant increased with increase in the level of applied N. In the present study, the treatment $n_3p_3k_3$ had resulted in the highest uptake of 194.74 kg N ha^{-1} where the total dry matter production and tuber nutrient content were also the highest i.e., 17.50 t ha^{-1} and 0.37 per cent respectively. Due to an increase in the production of dry matter and also due to the higher nutrient content in the plant parts, the uptake of N was increased. There is a positive trend observed in the uptake of N at different levels of P. The increase in N uptake noted with increase in P levels can be ascribed to the enhanced root growth due to higher levels of P enabling higher uptake of N and also greater dry matter yield as given in Table 4a. When the K levels are increased there is an increase in N uptake.

5.8.2 Phosphorus

P uptake due to conjoint use of NPK in the present study ranged from 20.06 to 47.22 kg ha^{-1} for the various treatments (Table 10 a, 10 b and 10 c and Fig. 11). The highest P uptake was recorded for the highest dose of NPK. According to Howeler (1990), maximum P accumulation in the total biomass varied between 24 and 37 kg ha^{-1}. He attributed the low P requirement to the low intrinsic efficiency of P absorption by the root system. Though there is an increase in P uptake, which has only limited response to addition of P, which can be attributed to the reduced P uptake efficiency.

In cassava, the pattern of dry matter partitioning between top growth and storage root is a key factor in determining P uptake efficiency (Pellet and Elsharkawy, 1993). With increasing level of N, P and K, there is a corresponding increase in P uptake. At higher levels of N, significant enhancement in P uptake was noticed which may be due to the production of new tissues as a result of increased protein synthesis at higher rate of N nutrition. Protein biosynthesis involves energy rich phosphate compounds viz. ADP and ATP. Hence for the operation of the protein synthesis pathway, P is utilized in greater amounts at higher doses of nitrogen. Again, K promotes N uptake and protein synthesis, a highly energy dependant process that requires sufficient amount of P. Thus the higher rates of K also favoured P uptake (Pellet and Elsharkawy, 1993). According to Silberbush and Barber (1983), soil P concentration is one of the most important factors controlling P uptake by the roots. Low to medium level of P in the soil of the experimental site showed good response to applied P enabling a higher uptake.

In cassava, as in other crops, the growth of aerial biomass has priority over storage root growth (Cock *et al.*, 1979 and Wardlow, 1990). But with increase in P level, the corresponding increase in dry matter production of aerial part was much greater compared to the root dry matter production (Table 4a, 4b and 4 c).

5.8.3 Potassium

The uptake of potassium by the plants was higher for the higher dose of NPK treatments (Tables 10a, 10b and 10c and Fig. 12). There was significant influence on potassium uptake of plant only due to the different levels of phosphorus and potassium. But an increasing trend on plant K uptake due to higher dose of nitrogen application was also noticed among the main effects. Nitrogen at 100 kg ha^{-1} with P and K @ 100 kg ha^{-1} increased the K uptake by plants. Among the interactions of N x P, N x K and P x K , n_2p_3, n_3k_3 and p_3k_3 registered maximum uptake of K. The treatment $n_3p_3k_3$ showed maximum uptake of K by cassava plants. Higher levels of K may produce an increase in tuber number and its size resulting in higher tuber yield. (Table 10a). Rajendran *et al.* (1976) and Nair and Aiyer (1986) reported increased K uptake with an increase in the level of added nitrogen. With increasing levels of K application there was an increase in the K content of leaf, stem and tuber (Nair *et al.*, 1980 and Nayar, 1986). According to Wilson and Ovid (1994) nutrient assimilation, which coincided with storage root bulking, increased the storage root yield of cassava. Pellet and Elsharkawy (1997) was of the view that the proportion of total nutrient uptake translocated to the storage root was the highest for K (67%). However, this nutrient export and recycling are influenced by the mobility and partitioning of nutrient in the plant.

5.9 ECONOMIC ANALYSIS

The different economic parameters viz. additional cost due to treatments, cost of cultivation, tuber yield, gross income, net income and BCR were computed (Table. 11) for the meaningful analysis of the economics of various treatments and in turn the cultivation of the cassava variety " Vellayani Hraswa". The parameters indicate that the treatment $n_1p_1k_3$ (50:50:100 NPK ha^{-1}) as the best in terms of highest gross return (Rs. 1,41,273/-) and BCR (3.32). This may be due to highest tuber yield realized from this treatment (Table 11). Elsamma and Balakrishnan (1991) studied the cost benefit analysis of cassava cultivation in the southern zone of Kerala and reported the benefit cost ratio as 2.07. The high BCR value of 3.32 may be due to the high yield potential and low requirement of fertilizers, a favorable characteristic of the variety "Vellayani Hraswa". Since the yield obtained in response to the application of fertilizer for $n_2p_1k_3$ (75:50:100 NPK ha^{-1}) in terms of the net return per rupee invested in fertilizer was considerably higher, this treatment can also be considered as a better proposition. The lowest BC ratio (1.63) was recorded by $n_1p_2k_1$ indicating the least rate of returns from this treatment. Treatments $n_3p_1k_2$, $n_1p_2k_2$, $n_1p_3k_2$, $n_2p_2k_2$, $n_3p_2k_3$, $n_1p_2k_3$, $n_2p_3k_3$, $n_3p_1k_3$, $n_2p_2k_3$, $n_1p_3k_3$, $n_2p_1k_2$, and $n_3p_3k_3$ gave a moderately high benefit cost ratio ranging from 2.04 to 2.73. All the other treatments gave BCR above 1 but below 2, indicating the economic variability.

Since, the variety "Vellayani Hraswa" is a prolific yielder, which responds very well to fertilizer application, a comparatively high BCR value was obtained. Thus a fertilizer schedule of 50:50:100 kg NPK ha^{-1} is recommended for the cassava variety "Vellayani Hraswa" for its profitable cultivation. The shortest duration (about 6 months) coupled with high yield (about 40-50 t ha^{-1}) and with moderate fertilizer requirement (50:50:100 kg NPK ha^{-1}) may enable the variety to replace other existing cassava varieties.

Summary

6. SUMMARY

Cassava is grown in marginal environments and has shown good response to the application of fertilizers. It is a major contributor of food, nutrition and income of the world's poorest among the poor. Its biological efficiency and multi use characteristics warrant for scientific crop management strategies to meet with the challenges of the global population that may rise about 8 to 11 billion by 2040. The demographic changes and increased population growth exert strong and competing pressure on the shrinking natural resources. The Kerala Agricultural University released a short duration variety of cassava viz., "Vellayani Hraswa" recently. Branching habit and short duration coupled with greater production potential makes this variety physiologically different and outstanding compared to the other cassava varieties ever released. These characters warrant for separate package in nutrient management. Hence the experiment entitled "Fertilizer scheduling for the short duration cassava variety "Vellayani Hraswa" was designed to recommend a fertilizer schedule for sustainable land use and higher productivity through the efficient management of the available inputs especially, the costly fertilizers.

The results of the experiment are summarized as follows.

►There was no significant difference on the plant height at all the growth stages of the crop for the different levels of N, P and K applications.

►The highest dose of nitrogen increased the leaf production in cassava at all the growth stages. Variations with increased number of leaves at all the growth stages of the crop were noticed due to potassium. Similarly, the influence of K was significant during the last stages of crop growth indicating the positive effect of K on the leaf production.

In general, the leaf fall was found to be minimum retaining maximum number of leaves till harvest, a specific characteristic of the variety.

►Significant influence was noticed on the number of tubers produced due to potassium. Maximum number of tuber per plant was obtained for a dose of 100 kg K alone ha^{-1}.

►There was no significant difference on the length of tubers due to different levels of N, P and K applications. However, NPK @ 75:50:75 kg ha^{-1}produced tubers with maximum length.

►Different levels of nitrogen showed significant influence on the girth of tubers. Nitrogen @ 100 kg ha^{-1}, resulted maximum girth of tubers.

►The different levels of N, P and K significantly influenced the tuber yield in cassava. Nitrogen alone @ 75 kg ha^{-1}, phosphorus @ 50 kg $ha^{-1}$and potash @ 100 kg ha^{-1}produced maximum tuber yield. NPK @ 50:50: 100 kg ha^{-1} ($n_1p_1k_3$) produced the highest tuber yield (47.09 t ha^{-1}) in cassava. The variety "Vellayani Hraswa" prefers a 1:1:3 ratio of NPK for maximum tuber yield under the present soil and climatic conditions.

►Dry matter production of cassava was influenced significantly by the different doses of N, P and K. The interaction effects of N, P and K were synergistic in affecting the dry matter yield. The main effects of N, P and K each @ 100 kg ha^{-1}produced maximum dry matter, the third order interaction $n_2p_3k_3$ (75:100:100 kg ha^{-1}) produced the highest dry matter yield (18.52 t ha^{-1}).

►No significant influence was observed on leaf area index for the different levels of N, P and K and their interactions. But, there was an increasing trend due to the highest dose of nitrogen (100 kg ha^{-1}). The treatment $n_3p_2k_2$ registered maximum LAI.

►There was no significant response on stomatal conductance for N, P and K applications. But, an increasing trend was observed due to an increase in the phosphorus doses. Phosphorus and potassium @ 75 kg ha^{-1} (p_2k_2) increased stomatal conductance in cassava leaves with significant variation.

►Chlorophyll content of leaves was not influenced by the application of N, P and K. However, the treatment $n_3p_3k_3$ (100:100:100 kg ha^{-1}) produced maximum chlorophyll content.

►The treatment $n_3p_3k_3$ (100:100:100 kg ha^{-1}) produced tubers with highest starch content. Nitrogen and potash did not influence significantly on the tuber starch content in cassava. However, an increasing trend due to K up to 100 kg ha^{-1} was noticed. Phosphorus alone @ 100 kg ha^{-1} produced tuber with maximum starch content.

►Protein content of tubers was influenced significantly for the application of nitrogen @ 100 kg ha^{-1}. The main effect of P and K alone @ 50 kg ha^{-1}obtained tubers with highest protein content. The treatment $n_3p_3k_2$ (100:100: 75 kg ha^{-1}) produced tubers with maximum protein content.

►Hydrocyanic acid content, the important limiting factor as far as quality of cassava tuber is concerned, increased due to the high dose of nitrogen application @ 100 kg ha^{-1}. NPK @ 100:100:50 kg ha^{-1} produced tubers with the highest HCN content. The potassium at 100 kg ha^{-1} decreased the HCN content. HCN content was lowest for the treatment $n_1p_2k_3$.

►Cooking quality of tubers was influenced significantly due to different levels of potash. Potash @ 75 kg ha^{-1}produced tubers with maximum cooking quality. The treatment $n_1p_1k_2$, $n_2p_3k_3$ and $n_3p_1k_3$ resulted in the highest cooking quality for the cassava tubers whereas the treatment $n_1p_1k_3$ (50:50:100 kg ha^{-1}) which produced the highest tuber yield and the tubers were with nearest starchy (1.5) cooking quality.

►The different doses of N, P and K produced significant influence on the nitrogen content in the tuber. The treatment $n_3p_2k_3$ (100: 75: 100 kg ha^{-1}produced tubers with maximum nitrogen content.

►P content in tuber was influenced significantly by the treatments. N, P and K @ 75:100:50 kg ha^{-1}recorded the highest P content in tubers.

►Significant difference on the K content in tuber was noticed for the main effect of N and K only. However, NPK @ 100:100:100 and 50:100:100 kg ha^{-1}produced tubers with maximum K content.

►Organic carbon in the soil after the experiment was influenced significantly due to N, P and K levels. NPK @ 50:75:50 kg ha^{-1} treated plots recorded maximum organic carbon content in soil.

►Available N present in soil after the experiment was the highest due to the application of N, P and K @ 50:50:100 kg ha^{-1}.

►Available P status in soil after the experiment was the highest for the treatment of NPK @100: 75: 100 kg ha^{-1}, which was higher than the initial status of the soil available P.

►Nitrogen, phosphorus and potash influenced significantly on soil available potassium after the experiment. NPK @ 100:100:100 kg ha^{-1} obtained maximum available K in soil, which was higher than the initial status of soil available K.

►The uptake of N, P and K was influenced by different levels of NPK @ 100:100:100 kg ha^{-1} resulted in the highest uptake of N, P, and K by cassava.

►The application of N, P and K @ 50:50:100 Kg ha^{-1} produced the highest tuber yield and in turn the highest BC ratio of 3.32 followed by 75:50:100 kg NPK ha^{-1} which indicates the economic variability. Thus a fertilizer schedule of 50:50:100 Kg NPK ha^{-1} is recommended for the cassava variety "Vellayani Hraswa" for its profitable cultivation.

►It has to be concluded that the cassava variety "Vellayani Hraswa" is most economical due to its short duration (about 6 months), high yield (45 to 50 t ha^{-1}), good cooking quality (1.5) and moderate fertilizer requirement (50:50:100 kg NPK ha^{-1}).

Future line of research

The following aspects may be considered for further studies on this variety.

- On farm trials for confirmatory results on the outcome of research work at major industrial cassava growing areas under varied agro ecological situations.
- Integrated nutrient management studies
- Biotechnological aspects on the early bulking of tubers i.e., isolation and analysis of the genes responsible for this character and its further utilization.

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FERTILIZER SCHEDULING FOR THE SHORT DURATION CASSAVA VARIETY "VELLAYANI HRASWA"

SEKAR, J.

Abstract of the
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Department of Soil Science and Agricultural Chemistry
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM-695 522
KERALA, INDIA

ABSTRACT

Cassava (*Manihot esculenta* Crantz), popularly known as tapioca, is one of the world's most important staple food crops. It ranks sixth among the major contributors of food in the world. It has been a major contributor of food, nutrition and income especially for the poor. Its biological efficiency and multi use characteristics warrant for crop management strategies to exploit its production potential to the maximum. Due to the high cost of labour and lack of timely availability of labour, the farmers show interest to introduce cassava as a substitute for rice in his crop cafeteria. "Vellayani Hraswa" is a short duration variety of cassava released by the Kerala Agricultural University recently. Branching habit and short duration nature coupled with greater production potential make this variety physiologically unique and outstanding compared to other cassava varieties ever released. These characters warrant for separate package in nutrient management. Keeping these views in mind, an experiment entitled "Fertilizer scheduling for short duration cassava variety "Vellayani Hraswa" was conducted with the objective of studying the influence of NPK fertilizers on the performance of short duration cassava variety "Vellayani Hraswa" and to arrive at a fertilizer recommendation for the same. The experiment was laid out at the Instructional Farm, College of Agriculture, Vellayani during the period from 25th June to 25th December 2003 in a 3^3 Factorial Randomized Block Design (FRBD) with two replications and three factors (NPK) each with three levels (50,75 and 100 kg ha^{-1}). The crop was raised adopting the agronomic practices for cassava outlined in the Package of Practices Recommendation: Crops of Kerala Agricultural University KAU (2002). The results of the experiment are summarized as follows.

There was no significant difference on the plant height at all the growth stages of the plant due to the treatments. However, there was an increasing trend on the height of the plant as the dose of nitrogen increased. Higher dose of nitrogen increased the number of leaves produced in cassava at all the growth stages. At harvest stage, the plants retained maximum number of leaves for all the treatments which indicates that the leaf fall is minimum, a peculiar characteristic of the variety.

Tuber production was influenced significantly by all the treatments. Application of 100 kg K ha^{-1} resulted maximum tuber yield. NPK @ 50: 50: 100 kg ha^{-1} produced maximum tuber yield (47.09 t ha^{-1}). This variety favours a 1:1:3 NPK ratio for higher tuber production. Length of tubers was not influenced by different levels of N, P and K. However, NPK @ 75:50:75 kg ha^{-1} produced tubers with maximum length in cassava.

Girth of tubers was significantly increased due to the application of nitrogen alone @ 100 kg ha^{-1} in cassava. Application of NPK @ 75:100:100 kg ha^{-1} produced the highest quantity of dry matter. No significant influence on LAI due to the application of N, P and K fertilizers was observed. Stomatal conductance in cassava leaves was maximum due the application of P and K @ 75 kg ha^{-1} (p_2k_2) with significant effect.

Chlorophyll content of cassava leaves was not influenced significantly due to different levels of N, P, K application. The highest dose of NPK ($n_3p_3k_3$) recorded highest chlorophyll content.

Phosphorus has influenced significantly on tuber starch content. An increasing trend due to incremental doses of K up to 100 kg ha^{-1} was also observed. Treatment $n_3p_3k_3$ (100:100:100 kg ha^{-1}) recorded the highest starch content in tubers.

Crude protein content was significantly influenced by the nutrients NPK. Application of N @ 100 kg ha^{-1} registered the highest protein content NPK @ 100:100:75 kg ha^{-1} produced tubers with maximum protein content.

Hydrocyanic acid content was mainly affected by higher doses of nitrogen. Nitrogen alone @ 100 kg ha^{-1} produced maximum HCN content in the tuber. But there was significant decline in HCN content as the dose of K increased. When the treatment $n_3p_3k_1$ (100:100:50 kg ha^{-1}) produced tubers with the highest HCN content, the treatment $n_1p_2k_3$ produced tubers with lowest HCN content.

Cooking quality of tubers was significantly influenced by potash. Maximum cooking quality could be obtained when K was increased to 75 kg ha^{-1}. In general, the uptake of N, P and K by plants was maximum for the highest doses of N, P, K. A fertilizer dose of N, P, K @ 50:50:100 kg ha^{-1} produced maximum tuber yield (47.09 t ha^{-1}) with moderate cooking quality of tubers. The moderate fertilizer cost resulted high BC ratio of 3.32 for the treatment $n_1p_1k_3$, the best dose arrived at and to be recommended for the short duration cassava variety "Vellayani Hraswa".

It has to be concluded that the cassava variety "Vellayani Hraswa" is most economical due to its short duration (about 6 months), high yield (45-50 t ha^{-1}) good cooking quality (1.5) and moderate fertilizer requirement (50:50:100 NPK ha^{-1}).

Appendices

APPENDIX – I

Weather parameters during the cropping period (25th June to 31st December 2003) – weekly averages

Standard weeks	Maximum temperature (°C)	Minimum temperature (°C)	RH (7.22 am)	RH (2.22 pm)	Rainfall (mm)	Evaporation (mm)	Sunshine hours	Wind speed(km/h)
26	30.80	23.80	89.60	69.90	31.60	3.60	40.40	9.10
27	30.10	23.20	87.70	71.70	28.70	2.70	30.00	8.30
28	30.60	23.70	89.90	64.30	21.40	3.80	34.00	10.60
29	30.30	23.70	90.70	73.30	43.20	3.30	47.40	10.00
30	30.80	24.30	92.30	73.60	14.10	3.00	36.00	9.10
31	31.00	24.30	91.10	76.00	23.10	3.80	39.10	7.70
32	30.90	24.50	90.60	70.70	11.00	3.80	49.40	9.70
33	31.60	24.40	85.40	68.90	1.40	4.40	10.20	8.90
34	30.40	24.50	91.30	74.10	44.50	3.50	34.40	8.60
35	30.10	23.40	91.30	71.10	23.10	4.00	49.60	9.40
36	30.80	23.70	90.20	69.70	4.60	4.20	68.20	10.60
37	31.30	23.60	87.10	67.10	3.10	4.70	66.20	11.10
38	31.80	24.30	83.60	66.40	0.00	5.20	68.10	10.90
39	32.20	24.30	80.30	63.30	0.00	5.20	60.90	11.10
40	29.90	23.80	93.60	79.60	222.80	2.90	17.70	5.70
41	30.60	23.50	92.10	72.00	19.20	3.60	58.60	9.10
42	30.50	24.00	93.20	73.60	72.80	3.50	39.90	6.90
43	30.20	23.00	93.90	75.70	201.10	2.10	45.70	6.30
44	30.60	23.00	91.70	74.60	24.00	2.50	37.80	3.40
45	30.00	22.90	93.90	74.60	119.70	2.90	23.10	4.00
46	30.90	23.50	93.70	69.90	23.20	2.30	30.90	5.10
47	30.90	23.40	93.60	67.90	1.70	2.60	42.40	5.40
48	30.70	23.50	94.00	68.70	0.80	2.30	33.10	5.10
49	31.30	21.30	92.60	59.60	0.00	2.90	53.50	5.40
50	31.00	20.70	95.10	57.40	0.00	3.10	57.60	6.90
51	31.10	22.10	92.00	60.60	0.00	3.30	55.60	6.30
52	31.40	22.10	95.00	62.30	0.00	3.60	74.20	9.10

Appendix-II

N

S

Lay out plan of the experiment

Replication 1			Replication 2		
$n_1p_3k_1$	$n_3p_2k_2$	$n_2p_2k_2$	$n_2p_1k_3$	$n_2p_3k_3$	$n_1p_2k_3$
$n_1p_3k_3$	$n_2p_3k_2$	$n_1p_2k_2$	$n_1p_1k_3$	$n_2p_1k_2$	$n_3p_2k_2$
$n_2p_2k_3$	$n_2p_1k_1$	$n_3p_2k_1$	$n_2p_3k_2$	$n_1p_2k_1$	$n_3p_1k_3$
$n_1p_1k_2$	$n_2p_1k_3$	$n_3p_1k_2$	$n_1p_3k_1$	$n_3p_3k_3$	$n_2p_3k_1$
$n_2p_2k_1$	$n_1p_3k_2$	$n_3p_1k_1$	$n_2p_2k_1$	$n_3p_1k_1$	$n_1p_2k_2$
$n_2p_3k_1$	$n_1p_1k_1$	$n_3p_3k_2$	$n_1p_1k_2$	$n_3p_2k_1$	$n_2p_2k_2$
$n_3p_1k_3$	$n_2p_1k_2$	$n_1p_1k_3$	$n_3p_3k_2$	$n_1p_3k_2$	$n_3p_3k_1$
$n_1p_2k_3$	$n_3p_3k_3$	$n_3p_2k_3$	$n_2p_1k_1$	$n_3p_2k_3$	$n_2p_2k_3$
$n_3p_3k_1$	$n_2p_3k_3$	$n_1p_2k_1$	$n_3p_1k_2$	$n_1p_1k_1$	$n_1p_3k_3$