NUTRIENT MANAGEMENT FOR PRODUCTIVITY ENHANCEMENT OF CASSAVA VAR. VELLAYANI HRASWA IN LOWLANDS

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"NUTRIENT MANAGEMENT FOR PRODUCTIVITY ENHANCEMENT OF CASSAVA VAR. VELLAYANI HRASWA IN LOWLANDS"** is a bonafide record of research work done by me during the course of research and 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.

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CERTIFICATE

Certified that this thesis entitled **"NUTRIENT MANAGEMENT FOR PRODUCTIVITY ENHANCEMENT OF CASSAVA VAR. VELLAYANI HRASWA IN LOWLANDS"** is a record of research work done independently by Ms. Pooja A. P (2016-11-027) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Pooja

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LIST OF ABBREVIATIONS

BCR	Benefit cost ratio
CD	Critical difference
cm	Centimetre
CTCRI	Central Tuber Crops Research Institute
et al	Co –workers/co-authors
DAP	Days after planting
day^{-1}	Per day
EC	Electrical conductivity
Fig	Figure
FYM	Farmyard manure
g	Gram
ha	Hectare
ha^{-1}	Per hectare
HI	Harvest index
ICAR	Indian Council of Agricultural Research
IFSRS	Integrated Farming System Research Station
K	Potassium
KAU	Kerala Agricultural University
kg	Kilogram

kg ha^{-1}	Kilogram per hectare
kg $plant^{-1}$	Kilogram per plant
LAI	Leaf area index
m	Metre
m^2	Square metre
MAP	Months after planting
mg kg^{-1}	Milligram per kilogram
mm	Millimetre
N	Nitrogen
NS	Not significant
P	Phosphorus
pH	Negative logarithm of H^+ ion concentration
$Plant^{-1}$	Per plant
PM	Poultry manure
RBD	Randomized Block Design
RH	Relative humidity
SEm	Standard error of means
TDMP	Total drymatter production
t ha^{-1}	Tonnes per hectare
var.	Variety

viz.	Namely
vs	Versus

LIST OF SYMBOLS

@	At the rate of
$^{\circ}C$	Degree Celsius
%	Per cent
₹	Rupees

INTRODUCTION

1. INTRODUCTION

Cassava (*Manihot esculenta* Crantz), belonging to the family Euphorbiaceae, is the king of tropical tuber crops as it occupies a dominant role in the global agricultural economy and trade amongst tuber crops. It is grown in about 90 countries of the world with majority of its production from Africa, Asia and South America. Besides its potential to produce high amount of food per unit area per unit time, cassava has the ability to combat biotic and abiotic stresses and adapt to marginal lands. Being climate resilient, cassava is branded as future crop for ensuring food and livelihood security of people. Apart from being an important food crop, it provides raw material for starch and animal feed industries.

In India, cassava is the second most important tuber crop after potato. It was brought to India by the Portuguese (during the 17^{th} century) who visited India for trade in spice and landed in the Malabar region which is presently part of Kerala state. As a food crop, it was popularized by Shri.Visakham Thirunal, the Maharaja of erstwhile Travancore, who ruled the state during AD 1880 to 1885. Cassava saved the people of erstwhile Travancore state when rice import was stopped from Myanmar (Burma) and at subsequent times of food scarcity. In India, it is grown in the states of Kerala and Tamil Nadu and to a marginal extent in Andra Pradesh and North Eastern states.

Cassava is the secondary staple food of Keralites. In the present scenario of acute rice shortage and dependence of Kerala on other states for foodgrains coupled with changing climatic conditions affecting the production of rice, it is necessary to give thrust to climate resilient crops like cassava for ensuring food security and stability. During the past two decades, cassava cultivation in uplands has declined in Kerala, whereas it has caught up in lowlands sequentially after main crop of rice or banana and vegetables. Short duration cassava can be grown in rice based cropping system for effective utilization of resources like land, moisture and nutrients as well as crop diversification and augmentation of farm income. Among the short duration varieties, the variety (var.) Vellayani Hraswa is becoming popular. Vellayani Hraswa is an early maturing (5 to 6 months duration) var. having good cooking quality acceptable to the Keralites (KAU, 2016). Since it cannot tolerate drought, it is more suited for cultivation in lowlands.

Although cassava is adapted to soils of low fertility, timely and proper nutrient management is necessary for realising higher yields. Considerable variations exist in the uptake and utilization of nutrients by different varieties of cassava (John, 2010). At present, there is no nutrient recommendation for short duration varieties of cassava in lowlands in the Package of Practices Recommendations of Kerala Agricultural University (KAU, 2016). Integrated nutrient management ensures higher crop productivity and sustains soil productivity. However, inadequate availability of farmyard manure (FYM) has necessitated the need for alternate sources of organic manure. Poultry manure (PM) is being commonly used by farmers in lowlands. Besides, green manuring *in situ* can add substantial quantity of organic manure which can reduce the dose of FYM as well as nitrogen (N) for the crop. Documented evidences revealed that phosphorus (P) is required in smaller quantities for tuber crops in general, compared to N and potassium (K). Hence, there is scope for reducing the dose of P for cassava especially in soils with high P. So it is necessary to explore the possibility of substituting FYM with PM and green manuring *in situ* and reducing the doses of N and P for short duration cassava in lowlands.

In the light of the above facts, the present investigation entitled "Nutrient management for productivity enhancement of cassava var. Vellayani Hraswa in lowlands" was undertaken

- To standardize the nutrient management for productivity enhancement of cassava var. Vellayani Hraswa in lowlands
- To work out the economics of cultivation.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Cassava, the king of tropical tuber crops, is the secondary staple food of Keralites. It is the fourth important source of food energy. Though rice is the staple food, its production over past ten years has stagnated. In the present scenario, rice cultivation in lowlands is being replaced by short duration cassava varieties. Increasing cassava production for food diversification would be a way to achieve food security of our people. Among the short duration varieties of cassava, Vellayani Hraswa is becoming popular due to its good cooking quality. Hence, the present study is undertaken to standardize the nutrient management for productivity enhancement of cassava var. Vellayani Hraswa in lowlands. The relevant literature on nutrient management of cassava are reviewed in this chapter.

2.1 EFFECT OF FARMYARD MANURE

Farmyard manure is the most readily available source of organic manure to farmers. It supplies both macro and micro nutrients as well improves physical, chemical and biological properties of soil. The nutrient content of FYM varies greatly depending upon source and condition and duration of storage. According to Tandon (1992), addition of one tonne of FYM can substitute 7.2 kg N, 3.6 kg P and 3.6 kg K. Meerabai and Raj (2001) reported that FYM @ 25 t ha^{-1} supplied 112 kg N, 56 kg P_2O_5 and 112 kg K_2O. According to Jayapal (2017), FYM contained 0.52 per cent N, 0.28 per cent P_2O_5 and 0.22 per cent K_2O.

The addition of organic sources could increase the yield through improving soil productivity and higher fertilizer use efficiency. Application of FYM loosens the soil, reduces crust formation and helps in better penetration and growth of the tuber crops (Annepu, 2011).

2.1.1 Effect on Growth Characters

Application of FYM @ 12.5 t ha^{-1} to cassava gave better response in terms of growth characters (Asokan and Sreedharan, 1977). Sankar *et al.* (1999) found that application of FYM @ 25 t ha^{-1} produced the highest plant biomass (9.54 kg $plant^{-1}$) and foliage weight (6.24 kg $plant^{-1}$) in cassava compared to the application of 12.5 t ha^{-1} and control (without FYM). Pamila (2003) reported that, among different organic manure treatments in lowland cassava, FYM produced significantly taller plants and higher leaf number. Application of FYM @ 12.5 t ha^{-1} produced better response in growth characters of cassava (KAU, 2016).

2.1.2 Effect on Yield Attributes and Yield

Saraswat and Chettiar (1976) recorded an yield of 32 t ha^{-1} when 66.6 per cent of N requirement was met by FYM application. Higher efficiency of FYM in producing higher yield of cassava compared to castor oilcake and urea was revealed by Gomes *et al.* (1983). Cassava showed an increase in yield of about 17.7 per cent (Mohankumar *et al.*, 1976) and 11.8 per cent (Gaur *et al.*, 1984) over control when FYM alone was applied. Basal application of FYM @ 12.5 t ha^{-1} increased the yield of cassava as revealed from studies conducted at ICAR - CTCRI and KAU (Mohankumar *et al.*, 1976; Asokan and Sreedharan, 1977; Pillai *et al.,* 1985; Ravindran and Balanambisan, 1987).

2.1.3 Effect on Tuber Quality

Application of FYM @ 12.5 t ha^{-1} enhanced the quality of cassava tubers as reported by Mohankumar *et al.* (1976) and Pillai *et al.* (1985). Application of FYM alone to cassava resulted in an increase in bitterness and cyanogen content of tubers. But when a mixture of ash and FYM was applied, bitterness was reduced (Kurien, 1976). An increase in HCN content of tuber was observed due to application of FYM alone or in combination with N as reported by Pillai *et al.* (1985) and John *et al.* (1998).

2.1.4 Effect on Soil Physio-chemical Properties

Mohankumar *et al.* (1976) and Pillai *et al.* (1985) reported the beneficial effect of FYM in conserving soil moisture and maintaining soil fertility for cassava. Application of FYM decreased bulk density (Khaleel *et al.,* 1981), increased infiltration rate (Acharya *et al.,* 1988) and improved soil structure and water retention capacity (Bhagat and Verma, 1991). Kumar *et al.* (2015) also observed a decreasing trend of soil bulk density with increasing FYM levels.

According to Patil *et al.* (2003), with each increment in FYM, the soil pH decreased from 7.99 to 7.65 and pH decreased significantly during decomposition due to the production of organic acids. However, Naramabuye (2006) and Kumar *et al.* (2015) reported that soil pH increased with increasing levels of FYM. An increase in EC of soil due to FYM application was also reported by Kumar *et al.* (2015).

FYM addition increased the organic carbon status and available N, P and K status of soil (Srivastava, 1985 ; More, 1994). Application of FYM continuously in tropical area improved organic carbon with balanced fertilization (Goyal *et al.,* 1993). FYM treated soils showed an increase in available P content than inorganically treated soils (Bharadwaj and Omanwar, 1994). FYM applied plots showed higher available N status in the soil compared to PM or coirpith applied plots (Pamila, 2003). John (2003) also observed increase in organic matter and available N content in soil due to FYM application. Mastol (2006) found an increase in soil organic carbon with the application of FYM. Increasing levels of FYM application increased the soil nutrient status as reported by Kumar *et al.* (2015).

2.2 EFFECT OF POULTRY MANURE

Poultry manure, which is a hot manure, is widely used by farmers in lowlands. It is a bulky organic manure which can substitute FYM. It has a narrow C: N ratio and comparatively higher content of mineralizable N (Singh *et al.,* 1973). PM is a rich organic manure since solid and liquid excreta are excreted together resulting in no urine loss. In fresh poultry excreta, uric acid or urate is the most abundant N compound (40 to 70% of total N) while urea and ammonium are present in small amounts (Krogdahl and Dahlsgard, 1981). In this, 60 per cent of N is present as uric acid, 30 per cent as more stable organic N forms and balance as mineral N (Srivastava, 1988). When entire quantity of PM is applied as basal, more than 60 per cent of its N, present as uric acid, rapidly changes to ammoniacal form. Pamila *et al.* (2006) suggested the suitability of PM as alternative to FYM for cassava cultivation in lowlands. Biratu *et al.* (2018) concluded that application of chicken manure significantly increased the yield and biomass production of cassava and was economically efficient.

2.2.1 Effect on Growth Characters

In lowland cassava, Pamila (2003) observed the effect of PM @ 5 t ha^{-1} could produce LAI and total dry matter on par with FYM @ 12.5 t ha^{-1}. Biratu *et al.* (2018) observed that, application of chicken manure @ 4.2 t ha^{-1} significantly influenced plant height, canopy diameter and leaf area index of cassava.

2.2.2 Effect on Yield Attributes and Yield

Pamila *et al.* (2006) reported that PM had superior response than FYM in improving the tuber weight $plant^{-1}$ of cassava. PM treated plants produced the highest tuber yield on par with FYM. Odedina *et al.* (2012) obtained an yield of 30.1 t ha^{-1} in cassava due to application of PM @ 5 t ha^{-1}. But, they obtained the highest tuber yield due to integrated application of poultry and goat manures which was comparable to that obtained with NPK fertilizers. Temegne and Ngome (2017) obtained the highest tuber yield (148.8% over control) due to application of PM @ 20 t ha^{-1} followed by application of 12:11:18 NPK fertilizers (65.1% over control). However, they suggested combined application of PM and chemical fertilizers to obtain a stable increase in cassava yields.

2.2.3 Effect on Tuber Quality

Among organic manures tried, PM resulted in the highest protein content of cassava tuber (Pamila, 2003). Also, PM applied plots showed the lowest HCN content followed by plots treated with FYM. However, different organic manures did not produce any significant variation in the starch content of tuber.

2.2.4 Effect on Nutrient Uptake

According to Pamila (2003), uptake of N, P and K did not vary due to application of FYM or PM. Higher uptake of nutrients due to application of composted PM either alone or with FYM was reported by Amanullah *et al.* (2007).

2.3 EFFECT OF GREEN MANURING

Green manuring is well known for improving soil productivity by increasing the organic carbon content and fertility level of soils, particularly by supplying nutrients available to the main plants, reducing erosion, preventing any pest and disease outbreak, and subsequently increasing the yield of the following crops as widely reported. Increasing organic matter in the soil by green manuring improves the soil physical properties through increasing the stability of soil aggregates and decreasing the soil bulk density (Fischler *et al.,* 1999; Basic *et al.,* 2004; Masri and Ryan, 2005).

Scarcity and higher cost of FYM necessitated studies on low cost soil fertility management practices for cassava like green manuring *in situ.* Hence, the feasibility of green manuring *in situ* to substitute FYM becomes important. (Nayar and Potty, 1996). Cassava responds well to application of chemical fertilizers and manures or to the incorporation of green manures (Howeler, 1996).

Cowpea is well adapted to the same ecological conditions as cassava and has been found to be a superior green manure in acid infertile soil of Columbia (CIAT, 1975). Paisancharoen *et al.* (1990) found, from a five year experiment, that cowpea was a promising green manure crop for improving the soil and increasing cassava yield.

Planting cowpea as a green manure crop and incorporating the plants before planting cassava resulted in increased tuber yield (Sasidhar and Sadanandan, 1976). Growing cowpea and incorporation of cowpea as green manure on the field before planting cassava produced maximum tuber yield compared to no green manuring (Howeler, 1981). However, growing of green manure before planting cassava was found to be impractical due to delay in planting cassava in the wet season leading to marked reduction in cassava yield (Howeler, 1995). Nayar *et al.* (1993) reported that green manuring *in situ* promoted greater dry matter accumulation in the storage roots and sustained productivity of cassava. They also observed an enhancement in organic carbon and available N, P and K contents in the soil due to green manuring *in situ.* Sittibusaya *et al.* (1995) obtained higher tuber yield when cowpea was incorporated as green manure before planting cassava. Nayar and Potty (1996) recorded higher uptake of N and K by cassava under green manuring. Incorporation of green manuring *in situ* produced the highest yield (42.98 t ha^{-1}) of cassava than fertilized fields (29.78 t ha^{-1}) (Tongglum *et al.*, 1998).

Prabhakar and Nair (1987) suggested that incorporation of cowpea as green manure *in situ* at the time of planting cassava was effective as the application of FYM for cassava and also reduced the N requirement by 50 per cent. Similar results of raising cowpea and incorporation in cassava fields under lowland situation has been reported by Mohankumar and Nair (1990). Green manuring *in situ* with cowpea could substitute FYM application to cassava and fertilizer N and P were saved by 50 per cent without hampering the root yields of cassava (Nayar and Potty 1996). Mohankumar (2000) suggested the possibility of interplanting green manure crops in between cassava rows and incorporating after 1.5 to 2 months or alternatively to seed the green manure about 1 to 2 months before cassava harvest and planting the next crop after incorporation of green manure. Suja (2001) also found that FYM application for white yam could be substituted with green manuring *in situ* (sun hemp) with equal efficiency. The study by Asok *et al.* (2013) observed that green manuring *in situ* with cowpea @ 50 kg ha^{-1} +

100 : 50 : 50 kg NPK ha^{-1} could produce cassava tuber yield on par with the application of FYM @ 10 t ha^{-1} + 100 : 50 : 50 kg NPK ha^{-1}.

2.4 EFFECT OF NITROGEN

Adequate N supply promotes growth, and hence yield, but excess N, either added or native to the soil, favours shoot growth at the expense of root yield (Oyekanmi, 2008; Obigbor, 2010).

2.4.1 Effect on Growth Characters

Higher levels of N invariably favoured the vegetative growth of cassava. Plant height, leaf number and leaf retention were higher with increasing N application as reported by Mandal *et al.* (1971). Plant height and weight increased with increase in N application in cassava var. M4 (Pillai and George, 1978). Ramanujam and Indira (1978) reported that the rate of leaf production was higher under higher levels of N and would produce about 10 to 12 functional leaves plant^{-1} week^{-1}. 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 N (50, 125 and 200 kg ha^{-1}) and reported maximum plant height, number of nodes and number of functional leaves at 200 kg N ha^{-1}, but enhancement in leaf area was attained only upto 125 kg N ha^{-1}. Increased rates of N application increased the plant height, nodes plant^{-1}, functional leaves plant^{-1} and LAI of cassava when intercropped in coconut garden (Nayar, 1986).

Pamila (2003) observed significant differences between N levels @ 50, 75 and 100 kg N ha^{-1} in their effects on growth characters in short duration varieties of cassava in lowlands. Application of N @ 75 kg ha^{-1} produced the tallest plants and highest leaf number and LAI at all growth stages. She also found that N @ 75 kg ha^{-1} is sufficient with any source of organic manure tried (FYM, PM and coirpith compost) to produce the highest leaf number and LAI of cassava in lowlands. But, Sekhar (2004) reported that different levels of N had no significant effect in plant height and LAI of cassava var. Vellayani Hraswa cultivated in uplands. But the highest dose of N increased leaf production at all growth stages. However, Abesuya (2010) and Deysil (2012) reported that shoot growth responded strongly and root growth moderately to applied N, resulting in high shoot / root ratio.

2.4.2 Effect on Yield Attributes and Yield

The mean number of cassava tubers plant^{-1} increased with increase in N application in varieties M4 and H-165 (Vjayan and Aiyer 1969). Ashokan and Sreedharan (1980) observed that N nutrition (@ 60, 120 and 180 kg ha^{-1}) had no significant effect on yield attributes of cassava. Nair (1982) observed that increase in N level caused significant increase in number and weight of tuber. But, Sekhar (2004) found no significance difference in tuber number and length of cassava var. Vellayani Hraswa under varying levels of N @ 50, 75 and 100 kg N ha^{-1}. However, the highest N level produced tubers with significantly higher girth of tuber.

Increase in tuber yield in response to higher rates of N application in cassava had been reported by many research workers. On acid laterite soils of Kerala, Mandal *et al.* (1971) obtained the highest yield of cassava due to N application upto 100 kg ha^{-1}. Saraswat and Chettiar (1976) inferred that, the most economic level of N for maximum tuber production in hybrid was 80 kg ha^{-1} while for local varieties, it was 40 kg ha^{-1} (Mohankumar and Mandal, 1977). However, the optimum dose was found to vary with location and varieties. According to Ashokan and Sreedharan (1980), cassava responded upto 180 kg N ha^{-1} in sandy loam soils of North Kerala. Studies by Nair (1982) revealed that the cassava hybrid var. Sree Sahya produced significantly higher tuber yield at 125 kg N ha^{-1}.

Pamila *et al.* (2006) reported that application of N @ 75 kg ha^{-1} recorded higher values of yield components in lowland cassava. She also reported that tuber yield significantly increased with an increase in N level from 50 to 75 kg ha^{-1} but decreased with further increase in N level. However, the top yield increased with increase in N level.

According to Vijayan and Aiyer (1969), varying levels of N had no significant difference in the tuber dry matter yield of cassava. Pamila (2003) obtained an increase in total dry matter production in short duration varieties of cassava in lowland with N level up to 75 kg ha^{-1} and a decrease at 100 kg N ha^{-1}. Sekhar (2004) obtained the highest dry matter production of cassava var. Vellayani Hraswa in uplands due to N application @ 75 kg ha^{-1} compared to other levels.

2.4.3 Effect on Tuber Quality

An increase in starch content of cassava due to nitrogen application upto 75 kg ha^{-1} was reported by Vijayan and Aiyer (1969) and Pamila (2003). The starch content decreased with the application of 100 kg N ha^{-1}. A similar improvement in starch content of cassava tuber as a result of higher rates of N application was reported by Mandal *et al.* (1971); Pillai and George (1978). But, according to Sekhar (2004), starch content of tuber was not affected by N levels.

Pillai (1975) observed that the crude protein content of cassava tuber (var. M4) increased with increase in N level up to 100 kg ha^{-1}. Similar increase in protein content of tuber with incremental dose of N was also observed by Nair (1982). Sekhar (2004) also observed higher protein content in tuber of cassava var. Vellayani Hraswa at the highest level (100 kg ha^{-1}) of N tried.

Increase in HCN content of tuber due to increase in N application has been reported by Vijayan and Aiyer (1969), Indira *et al.* (1972), Mohankumar and Maini, (1977), Nair (1982), Nayar (1986), Ashokan *et al.* (1988) and Sekhar (2004).

2.4.4 Effect on Nutrient Uptake

The highest uptake of nutrients by short duration cassava in lowlands was registered by 75 kg N ha^{-1} compared to 50 and 100 kg N ha^{-1} (Pamila, 2003).

2.4.5 Effect on Soil Physico-chemical Properties

According to Pamila (2003), different levels of N had no significant effect on available N and K contents in the soil after the experiment. But N @ 75 kg ha^{-1} registered the highest content of postharvest available P in the soil

2.5 EFFECT OF PHOSPHORUS

There are documented evidences which reveal that P is required in smaller quantities, for tuber crops in general, compared to N and K. Howeler (1981), Mohankumar *et al.* (1984), Kabeerathumma *et al.* (1987), Nair *et al.* (1988), Swadija and Sreedharan (1998) and John *et al.* (2005) reported the sufficiency of a lower dose of P for cassava.

Nair *et al.* (1988) observed the response of cassava to graded doses of P in acid laterite soil of high and low P status for five years (1980-85) in a high P soil (available P = 100.8 kg ha^{-1}) and for three years (1983-86) in a low P soil (available P = 8.9 kg ha^{-1}) to ascertain the effect of P skipping and application of graded doses of P respectively in these soils. It was observed that in high P soil, skipping of P for the first four years had no significant influence on the yield of tubers. In low P soil, even though cassava responded to 100 kg P_2O_5 ha^{-1} initially, the response gradually declined. From the response curves, it was observed that the optimum economic dose of P for cassava in laterite soil was 45 kg P_2O_5 ha^{-1}.

2.5.1 Effect on Growth Characters

According to Sekhar (2004), P levels had no significant effect on plant height and leaf number of cassava var. Vellayani Hraswa raised in uplands.

2.5.2 Effect on Yield Attributes and Yield

Application of N, P_2O_5 and K_2O in 2:1:2 ratio is recommended for getting the highest yield of cassava which shows low P requirement of the crop (Nguyen *et al.*, 2002). Phosphorus at the lowest level (50 kg P_2O_5 ha^{-1}) recorded the maximum tuber yield of cassava (Pamila, 2003). Sekhar (2004) obtained increase in number and length of tuber with increased P application for cassava. But, application of 50 kg P_2O_5 ha^{-1} resulted in the highest tuber yield and 100 kg P_2O_5 ha^{-1} resulted in the highest dry matter. However, Essien (2009) and Kim *et al.* (2013) observed that omission of P from fertilizer mixtures for cassava resulted in marked reduction in tuber yield. Asoro (2013) obtained a quadratic yield response and linear foliage response to application of P for cassava, thus indicating that foliage production is more responsive to P than tuber production.

2.5.3 Effect on Tuber Quality

Prema *et al.* (1975) reported an increase in dry matter, starch and crude protein contents of cassava at higher levels of P application. But John *et al.* (1997) reported that neither different levels nor sources of P had any significant influence on the starch content of cassava tubers. In contrast, Sekhar (2004) observed significant influence of P levels on the quality of tuber expressed in terms of starch, protein and HCN contents. Application of P @ 100 kg P_2O_5 ha^{-1} produced the highest starch and HCN contents of tuber while protein content was the highest for 50 kg ha^{-1}.

2.5.4 Effect on Nutrient Uptake

Asher *et al.* (1980) reported that at a tuber yield of 30 t ha^{-1}, the amount of major nutrients removed from the soil at harvest were 164 kg N ha^{-1}, 31 kg P ha^{-1} and 200 kg K ha^{-1}. Howeler (1981) reported that cassava being a tuber crop, its P requirement and consequently the P uptake were relatively low, compared to N and K. The increased dry matter accumulation in cassava due to higher doses of P fertilization and a consequent increase in P uptake have been reported by Mohankumar and Sadanandan (1990). According to Howeler (1991), cassava crop producing 35.7 t ha^{-1} removed 4.5 : 0.83 : 6.6 kg NPK per tonne of dry matter production. Mohankumar *et al.* (1996) found that cassava absorbed 6.45 kg N, 1.3 kg P and 8.62 kg K for the production of 1 tonne of dry matter. Swadija and Sreedharan (1998) reported that cassava var. M4 required 6.58 kg N, 2.37 kg P_2O_5 and 6.28 kg K_2O to produce one tonne of tuber. According to Mohankumar (2000), most of the cassava varieties that are capable of producing 30 t ha^{-1} of fresh tubers removed 180 - 200 kg N, 15 - 22 kg P and 160 kg K. Based on the data from literature, Howeler (2014) calculated the nutrient removal of cassava as 179.5 : 22.7 : 156.1 kg NPK ha^{-1} for producing 28.9 t ha^{-1} of tubers. He also made it clear that nutrient removal is not proportional to yield since plants with high root yield tend to have high nutrient concentration in the roots as well as in leaves and stems. However, Howeler (2017) found that when only roots are harvested, nutrients are removed in the ratio 2:1:4; when all plant parts including fallen leaves are harvested, nutrients are removed in the ratio 3:1:3.

2.6 EFFECT OF INTEGRATED NUTRIENT MANAGEMENT

Large number of experiments on manures and fertilizers conducted revealed that neither the inorganic chemical fertilizers, nor organic sources alone can achieve the production sustainability of soil as well as crops under high intensive cropping systems. High and sustained yield could be obtained with judicious and balanced fertilization combined with organic manures (Kang and Balasubramanian, 1990).

Integrated nutrient management is defined as the continuous improvement of soil productivity on long term basis through appropriate use of inorganic fertilizers and organic source of nutrients (Palniappan and Annadurai, 1999). Integration of both inorganic fertilizers and organic manure is important for obtaining good yield in cassava (Joseph and Abraham, 2004). John *et al.* (2005) reported that the combination of manure and chemical fertilizers resulted in higher net income than applying organic manure alone for cassava. According to Odenina *et al.* (2012), crop and soil productivity can be sustained with the integration of different manures as a viable alternative to the single application of either manure or inorganic fertilizer for cassava.

2.6.1 Effect on Growth Characters

Sankar *et al.* (1999) reported that application of FYM @ 12.5 t ha^{-1} + P @ 30 kg P_2O_5 ha^{-1} resulted in increased plant height, stem girth, root length and root girth in cassava. Growth characters of cassava *viz.* plant height, main and sub branches, leaf length, leaf breadth and fresh total biomass were significantly improved by combined application of organic manures, green manure and inorganic fertilizers (Mhaskar *et al.*, 2013).

2.6.2 Effect on Yield Attributes and Yield

It was observed that application of 12.5 t ha^{-1} of FYM and 100 kg each of N, P_2O_5 and K_2O ha^{-1} produced the highest tuber yield (Mandal and Mohankumar, 1973). Similar findings were reported by Mohankumar *et al.* (1976) and Pillai *et al.* (1985). Mohankumar *et al.* (1976) observed that the effect of fertilizers and FYM on tuber production was additive. Neither FYM nor any of the nutrients (N, P or K) applied individually could increase yield by more than 4 t ha^{-1} but the combined use of NPK + FYM produced a response four times higher. According to Kabeerathumma *et al.* (1987), continuous application of FYM + NPK resulted in the highest tuber yield of cassava. Nakviroj *et al.* (2002) reported that the fertilizer application @ 100 : 50 : 100 NPK kg ha^{-1} combined with 12.5 t ha^{-1} of municipal compost or 18 t ha^{-1} of incorporated cassava stalks resulted in better growth and higher yields of cassava than application of only chemical fertilizers. Amanullah (2007) also reported higher tuber yield of cassava due to integrated application of organic manure and chemical fertilizers. Integrated application of cattle manure or compost @ 12.5 t ha^{-1} as basal dose and NPK @ 100:50:100 kg ha^{-1} is usually recommended for high yielding cassava varieties. For M4 and local varieties, half the above dose is sufficient (John, 2010).

Application of PM @ 5 t ha^{-1} along with 200 kg ha^{-1} each of N, P and K produced an yield of 36.1 t ha^{-1} (Odedina *et al.*, 2012). Chaisri *et al.* (2013) obtained tuber yield of cassava due to application of chicken manure alone on par with chemical fertilizers alone. But, the treatments with chicken manure and chemical fertilizers together tended to give greater tuber yield. Mhaskar *et al.* (2013) noticed that yield attributes of cassava *viz.* length and girth of tubers, number of tubers, average tuber weight and tuber yield plant^{-1} were significantly improved by combined application of organic manures, green manure and inorganic fertilizers in cassava.

A fertilizer dose @ 100 : 25 : 50 kg NPK ha^{-1} was found to be the most suitable fertilizer dose for short duration cassava in rice based cropping system, if the preceding rice crop was raised by adopting all the recommended package of practices as reported by CTCRI (1990). According to Sekhar (2004), a fertilizer dose of 50:50:100 kg NPK ha^{-1} along with FYM at 12.5 t ha^{-1} was found optimum for short duration cassava var. Vellayani Hraswa which produced maximum tuber yield of 47.09 t ha^{-1} and a higher benefit cost ratio (BCR) of 3.32. Pamila *et al.* (2006) pointed out that application of FYM @ 12.5 t ha^{-1} or PM @ 5 t ha^{-1} along with 75:50:100 kg NPK ha^{-1} resulted in higher returns from short duration varieties of cassava cultivated in lowlands. Suja *et al.* (2010) reported that application of full recommended dose of FYM @ 12 .5 t ha^{-1} and NPK (100:22:83 kg ha^{-1}) resulted in the highest net income and BCR from short duration varieties of cassava in lowlands.

2.6.3. Effect on Tuber Quality

Nair *et al.* (1980) reported maximum starch content of cassava tubers upon application of NPK fertilizers in combination with FYM. Sankar *et al.* (1999) observed that application of FYM @ 12.5 t ha^{-1} + P @ 30 kg P_2O_5 ha^{-1} resulted in increased starch content in cassava. According to Pamila (2003), the different organic manures produced higher starch content with 75 kg N ha^{-1} than with 50 or 100 kg ha^{-1}. Balanced application of NPK @ 100:50:100 kg ha^{-1} along with FYM @ 12.5 t ha^{-1} was found to be effective in improving the starch content (20.68% on fresh weight basis) and decreasing the cyanogenic glucoside content of cassava tubers (88.16 μg g^{-1}) compared to the application of NPK singly or in two nutrient combination both alone and together with FYM (John *et al.*, 2005). John *et al.* (2007) reported that for cassava var. Sree Vijaya, application of 100:300:300 kg NPK ha^{-1} along with FYM @ 12.5 t ha^{-1} enhanced plant dry matter content and quality of tubers. Ramanandam *et al.* (2009) concluded, from two years of experimentation, that different INM treatments involving different organic manures, recommended dose of fertilizers and the biofertilizers. *Azospirillum* did not significantly affect starch and HCN contents of cassava tuber. Chaisri *et al.* (2013) observed that application of chicken manure or chemical fertilizers alone or in combination did not produce any significant difference in starch content of tuber as compared with control.

2.6.4 Effect on Nutrient Uptake

John *et al.* (2007) reported enhanced uptake of nutrients by cassava var. Sree Vijaya due to combined application of 100:300:300 kg NPK ha^{-1} and FYM @ 12.5 t ha^{-1}. Amanullah (2007) observed that integrated application of organic manures and chemical fertilizers registered higher uptake of NPK than chemical fertilizers alone. According to Suja e*t al.* (2010), application of full recommended dose of FYM + 100 per cent NPK significantly increased N uptake by short duration varieties of cassava in lowlands. Uptake of P and K was similar due to addition of 100 per cent NPK and fertilizer recommendation based on soil test data.

2.6.5 Effect on Soil Physio-chemical Properties

Nambiar and Abrol (1989) reported that combination of organic manure with inorganic fertilizer had a moderating effect on soil reaction particularly under acidic soils and improvement in sustained availability of N, P, K and S and the micronutrients particularly Zn . George *et al.* (2001) noticed that continuous cropping of cassava with only chemical fertilizers decreased the levels of Ca, Mg, Zn and Cu in the soil and lowered the pH. Results of a long term experiment in cassava revealed that integrated application of chemical fertilizers and organic manures maintained or improved the fertility status of soil compared to application of chemical fertilizers alone (Nakviroj, 2002). Amanullah (2007) reported higher available N, P and K in the soil after the harvest of cassava due to application of composted PM either alone or with FYM followed by PM + FYM, PM and FYM. Odedina *et al.* (2012) observed that nutrients were made most available when manures were integrated with inorganic fertilizers for cassava. The results clearly indicated the need for organic manure application to the soil along with inorganic fertilizers.

Short duration cassava can be grown in rice based cropping system for crop diversification, intensification and profit maximization (Suja *et al.*, 2010). Vellayani Hraswa is a short duration (5 to 6 months) var. more suited for cultivation in lowlands (KAU, 2016). A scan of literature emphasized the need for integrated use of organic manure and inorganic fertilizers for achieving higher yields of cassava and sustaining soil fertility. KAU (2016) recommends 50 to 100 kg NPK ha^{-1} along with 12.5 t ha^{-1} of FYM for cassava varieties with duration of 8 to 10 months. But there is no recommendation for short duration cassava in lowlands. Pamila (2003) suggested 75:50:100 kg NPK ha^{-1} along with 12.5 t ha^{-1} of FYM for obtaining higher yields from Sree Vijaya and Kariyilapothiyan, two short duration varieties of cassava in lowlands. But, Sekhar (2004) found that a fertilizer dose of 50:50:100 kg NPK ha^{-1} along with 12.5 t ha^{-1} of FYM was optimum for short duration cassava var. Vellayani Hraswa in uplands. Inadequate availability of sufficient quantity of FYM necessitates to explore the possibility of substituting FYM with other organic manures like PM. Pamila (2003) found that 12.5 t ha^{-1} of FYM could be substituted with 5 t ha^{-1} PM for fetching higher returns from cassava cultivated in lowlands. Studies at ICAR - CTCRI have also revealed the possibility of substitution of FYM and reduction in the dose of N and P with green manuring *in situ*. Hence the present investigation was undertaken to standardize the nutrient management including green manuring *in situ* for productivity enhancement of short duration cassava var. Vellayani Hraswa in lowlands.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present study entitled "Nutrient management for productivity enhancement of cassava var. Vellayani Hraswa in lowlands" was undertaken to standardize the nutrient management for productivity enhancement of cassava var. Vellayani Hraswa in lowlands and to work out the economics of cultivation. The materials used and the methods adopted for the study are presented in this chapter.

3.1 MATERIALS

3.1.1 Experimental Site

The field experiment was conducted at Integrated Farming System Research Station (IFSRS), Karamana, Thiruvananthapuram, Kerala. The station is located at 8° 28' 28" N longitude and 76° 57' 47" E longitude at an altitude of 29 m above mean sea level.

3.1.2 Soil

The soil of the experimental site is commonly known as brown hydromorphic soil and belongs to the taxonomic class of Typic Aquafluvent. The important physical and chemical properties of the soil are given in Table 1. The soil was clay loam in texture and acidic with a pH of 5.2. It was high in organic carbon and available P and medium in available N and K contents.

3.1.3 Cropping History of the Experimental Site

The experimental area was lying fallow for the previous three months after the harvest of vegetables.

3.1.4 Season

The field experiment was conducted from September 2017 to February 2018.

Table 1. Physico - chemical properties of the soil of the experimental field

Characteristics	Value	Method
Mechanical composition		
Clay (%)	39.5	International pipette method (Piper, 1966)
Silt (%)	20.0	
Fine sand (%)	8.5	
Coarse sand (%)	32.0	
Textural class	Clay loam	
pH	5.2 (Strongly acidic)	pH meter with glass electrode (Jackson, 1973)
Electrical conductivity (dS m^{-1})	0.19 (Safe)	Conductometry (Jackson, 1973)
Organic carbon (%)	2.5 (High)	Wet oxidation method (Walkley and Black, 1934)
Available N (kg ha^{-1})	249.91 (Medium)	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P (kg ha^{-1})	68.76 (High)	Bray's colorimetric method using ascorbic acid (Bray and Kurtz, 1964)
Available K (kg ha^{-1})	257.56 (Medium)	Neutral normal ammonium acetate method (Hanway and Heidal, 1952)

3.1.5 Weather Conditions

The experimental site, Karamana has a tropical humid climate. Data on maximum and minimum temperatures, relative humidity and rainfall during the entire crop season were collected and are presented as weekly averages in Appendix 1 and Fig 1.

3.1.6 Planting Material

Cassava var. Vellayani Hraswa released from College of Agriculture, Vellayani, Thiruvananthapuram, Kerala was used for the present study. It was brought through clonal selection of the germ plasm collection maintained at Instructional farm, Vellayani. The plant is of dwarf type with good branching characteristics. It has profuse foliation and high leaf retention till harvest. It is high yielding with five to six months duration. It has good cooking quality and contains 27.8 per cent starch and 53 mg kg^{-1} cyanogen (KAU, 2016). It cannot tolerate drought and hence, it is suited to lowlands and rice fallows. Cowpea var. Anaswara developed from College of Horticulture, Vellanikkara, KAU was used for green manuring *in situ.*

3.1.7 Manures and Fertilizers

The organic manures used in the experiment were FYM (0.58% N, 0.34% P_2O_5 and 0.39% K_2O) and PM (1.5% N, 0.42% P_2O_5 and 0.8% K_2O). The fertilizers used were urea (46% N), rajphos (20% P_2O_5) and muriate of potash (60% K_2O).

3.2 METHODS

3.2.1 Experimental Design and Layout

The details of the field experiment are given below. The lay out is depicted in Fig.2.

Design : RBD

Treatment combinations : 12 (3 x 2 x 2)

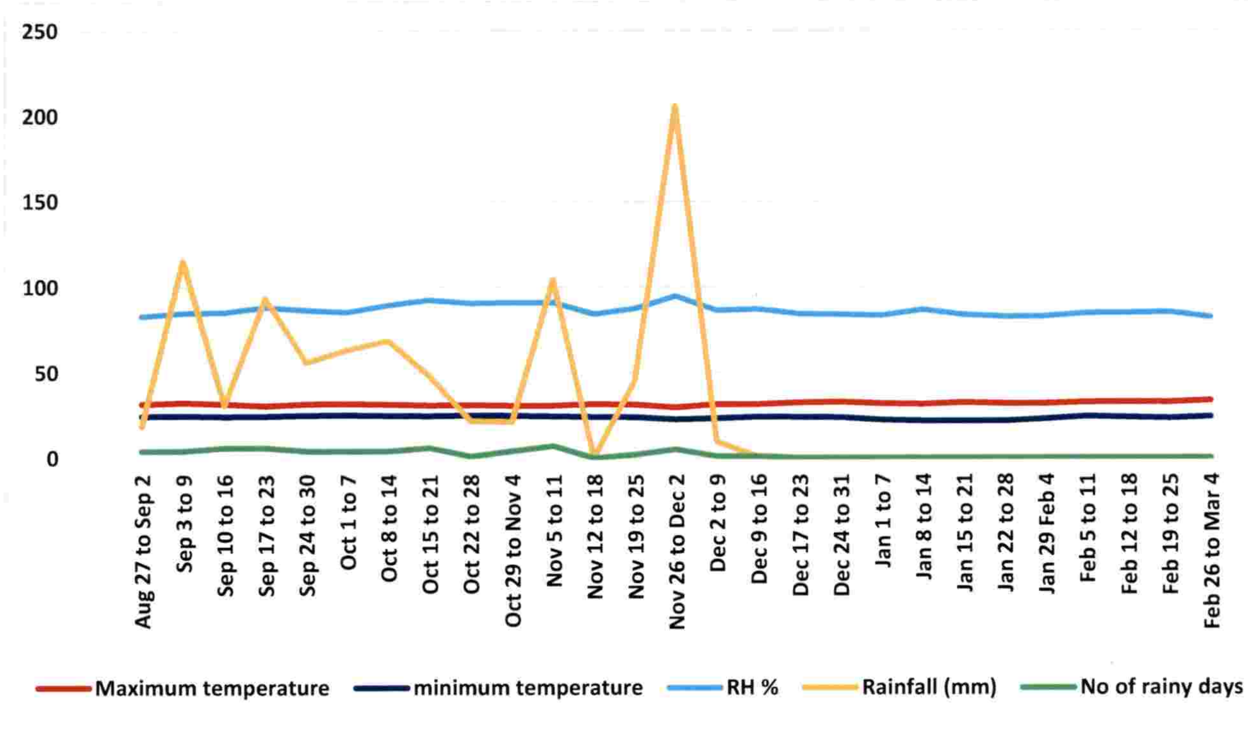

Fig 1. Weather data during the cropping period (September 2017 to February 2018)

Replications : 3

Variety : Vellayani Hraswa

Spacing : 90 cm x 90 cm

Plot size : 3.6 m x 3.6 m

3.2.2 Details of Treatments

The treatments consisted of factorial combinations of three sources of organic manure and two levels each of N and P.

A. Sources of organic manure (M) - 3

m_1 - FYM 12.5 t ha^{-1}

m_2 - FYM 6.25 t ha^{-1} + green manuring *in situ*

m_3 - Poultry manure 2.5 t ha^{-1} + green manuring *in situ*

B. Levels of Nitrogen (N) - 2

n_1 - 50 kg N ha^{-1}

n_2 - 75 kg N ha^{-1}

C. Levels of Phosphorus (P) - 2

p_1 - 25 kg P_2O_5 ha^{-1}

p_2 - 50 kg P_2O_5 ha^{-1}

Treatment combinations: 12

T_1 - $m_1n_1p_1$	T_5 - $m_2n_1p_1$	T_9 - $m_3n_1p_1$
T_2 - $m_1n_1p_2$	T_6 - $m_2n_1p_2$	T_{10} - $m_3n_1p_2$
T_3 - $m_1n_2p_1$	T_7 - $m_2n_2p_1$	T_{11} - $m_3n_2p_1$
T_4 - $m_1n_2p_2$	T_8 - $m_2n_2p_2$	T_{12} - $m_3n_2p_2$

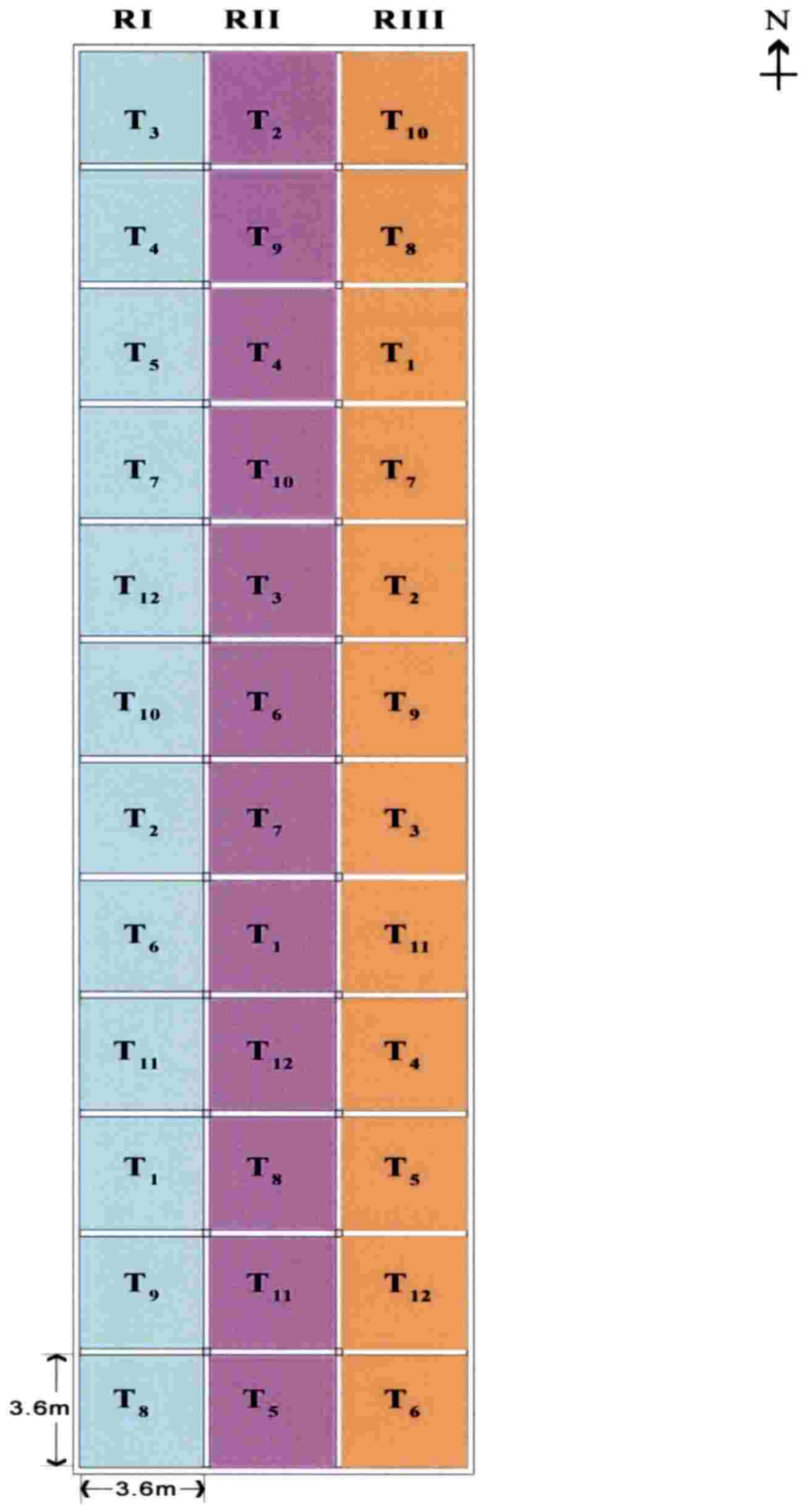

Fig. 2 Layout of the experimental field

Potassium @ 100 kg K_2O ha^{-1} was applied uniformly to all plots. Organic manures were applied at land preparation. Half the quantity of N and K and full dose of P were applied as basal dose for cassava. For green manuring *in situ*, cowpea @ 30 kg ha^{-1} was sown soon after planting cassava and was incorporated at flowering (50 days after sowing) along with the remaining half the dose of N and K for cassava.

3.2.3 Details of Cultivation

3.2.3.1 Field Preparation

The experimental area was ploughed and weeds and stubbles were removed. The field was laid out as per the design and in each plot, ridges to a height of 30 cm were taken 90 cm apart.

3.2.3.2 Application of Manures and Fertilizers

Dried and powdered FYM and PM were applied to the plots as per the treatment schedule and well incorporated into the soil.

Full dose of P and half dose each of N and K were applied as basal. Half the dose each of N and K was applied 50 days after planting (DAP) along with incorporation of cowpea as green manure.

3.2.3.3 Planting

The crop was planted on 1st September 2017. Setts of about 20 cm length were planted on the top of the ridges taken at a spacing of 90 cm x 90 cm, inserting about 5 cm of setts below the soil. Cowpea seeds @ 30 kg ha^{-1} were sown on the sides of the ridges after treating them with Rhizobium @ 250 g ha^{-1}. The seeds were dibbled in between cassava @ two seeds $hole^{-1}$ 15 cm apart, leaving 22.5 cm from the base of the cassava plant.

Plate 1. General view of the experimental field

3.2.3.4 After Cultivation

Dried and unsprouted setts were removed and gap filling was done with setts of longer size (about 40 cm) at 15 DAP. Excess sprouts were removed one month after planting (MAP) after retaining two healthy sprouts. Shallow digging and weeding were done 30 DAP and repeated at 50 DAP along with top dressing of the fertilizers and incorporation of cowpea as green manure as per the treatments followed by light earthing up. Third weeding and earthing up were done 20 days later.

3.2.3.5 Harvest

The crop was harvested on 26th February 2018 (6 MAP). Harvesting was done by digging out the tubers carefully and pulling out the stem. The tubers were separated from the stems. The border rows and sample plants were harvested separately from each plot. The tubers and top portions from the net plot were weighed separately and the weights were recorded.

3.3 BIOMETRIC OBSERVATIONS

Single row of plants bordering each plot was left out. Three plants were selected at random from each net plot and tagged as observational plants for recording biometric observations.

3.3.1 Growth Characters

Observations on growth characters were recorded from observational plants at bimonthly interval and averages worked out.

3.3.1.1 Height of the Plant

Height of the tallest stem of each observational plant was measured from the base of sprout to the terminal bud and the average expressed in cm.

3.3.1.2 Number of Branches Plant^{-1}

The number of branches present in each observational plant was recorded.

3.3.1.3 Total Number of Leaves Plant^{-1}

The total number of leaves in each observational plant was recorded by counting the number of fully opened leaves including the leaf scars from the base to the tip of both the stems.

3.3.1.4 Number of Functional Leaves plant^{-1}

The number of fully opened leaves present in each observational plant at the time of observation was counted.

3.3.1.5 Leaf Area Index (LAI)

The total leaf area of each observational plant was calculated by non-destructive method as suggested by Ramanujam and Indira (1978) and LAI was worked out using the following formula developed by Watson (1947).

$$\text{LAI} = \frac{\text{Leaf area plant}^{-1}\ (\text{cm}^2)}{\text{Land area occupied by the plant}\ (\text{cm}^2)}$$

3.3.2 Yield Components and Yield

The observational plants were harvested separately for recording the following observations and the mean values were calculated.

3.3.2.1 Number of Tubers plant^{-1}

The total number of tubers from each observational plant was recorded.

3.3.2.2 Percentage of Productive Roots Plant^{-1}

The percentage of productive roots plant^{-1} was calculated by dividing the number of tubers by the total number of roots including the number of tubers in each observational plant.

3.3.2.3 Tuber Weight Plant^{-1}

The total weight of tubers from each observational plant was recorded and expressed in kg plant^{-1}.

3.3.2.4 Mean Tuber Weight

Tubers from the observational plants were pooled, ten tubers were selected randomly, the weight of each tuber was recorded, the average worked out and expressed in kg.

3.3.2.5 Length of Tuber

The average length of tubers was worked out in cm by measuring the length of ten selected tubers.

3.3.2.6 Girth of Tuber

Girth measurements were recorded from the same tubers that were used for length measurements. Girth values were recorded at three places *viz.* one at the centre and the other two at half way between the centre and both the ends of the tuber. The average of these values, in cm, was taken as the tuber girth.

3.3.2.7 Rind to Flesh Ratio

Rind and flesh of the selected tubers were separated, weighed and the average rind to flesh ratio was computed.

3.3.2.8 Tuber Yield

The net plot was harvested separately, the tubers separated and cleaned to remove soil. The fresh weight was recorded and average tuber yield was expressed in t ha^{-1}.

3.3.2.9 Top Yield

The total weight of the stem and leaves of the plants from the net plot was taken at the time of harvest and converted to t ha^{-1}.

3.3.2.10 Dry Matter Production

Dry matter production was recorded at harvest. The observational plants uprooted were separated into stem, leaves and tuber. 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 70± 5°C to constant dry weight. Then the dry weight of each part was computed. Total dry matter production (TDMP) was worked out in t ha^{-1} by summing up the dry weights of all plant parts.

3.3.2.11 Harvest Index (UI)

It was worked out from the dry weight of tuber and top as given below.

$$\text{Harvest Index} = \frac{\text{Dry weight of tuber}}{\text{Dry weight of tuber + Dry weight of top (stem+ leaves)}}$$

3.3.2.12 Yield of Green Manure Cowpea

The cowpea plants were uprooted from each net plot, the fresh weight was recorded and green matter yield was recorded in t ha^{-1}. Sub samples were taken, dried in an oven at 70 ± 5°C to constant dry weight and the dry matter yield was computed in t ha^{-1}.

3.3.3 Quality Characters of Tuber

Fresh tuber samples were analysed for the content of starch, protein and hydro cyanic acid (HCN).

3.3.3.1 Starch Content

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

3.3.3.2 Protein Content

The N content of fresh samples of tuber flesh from each plot was estimated by modified micro kjeldahl method (Jackson, 1973). The N values were multiplied by the factor 6.25 to get the crude protein content of tuber in percentage. (Simmpson *et al.*, 1965).

3.3.3.3 Hydrocyanic Acid Content

The HCN content of fresh tuber sample was estimated colorimetrically by sodium picrate method (Indira and Sinha, 1969) and expressed as mg kg^{-1} on fresh weight basis.

3.5 OBSERVATIONS ON WEED

3.5.1 Weed Density m^{-2}

Number of weeds was recorded from the randomly selected area of 1.8 m x 0.45 m in each net plot at 30, 50 and 70 DAP just before each weeding and at monthly interval from 90 DAP till harvest and expressed as weed density m^{-2}.

3.5.2 Dry Weight of Weeds m^{-2}

Weed dry weight was recorded at 30, 50 and 70 DAP just before each weeding and at monthly interval from 90 DAP till harvest. The weeds in the specified area (1.8m x 0.45 m) in each plot were pulled out along with roots, washed, dried under shade and oven dried at 70 ± 5^{O}C to a constant weight. The weed dry weight was expressed in g m^{-2}.

3.6 CHEMICAL ANALYSIS

3.6.1 Plant Analysis

Samples of stem, leaves and tuber collected for chemical analysis were dried separately in an air oven at 70 ± 5^{O}C and ground to pass through 0.5 mm mesh. The N content of the samples was determined by modified micro kjeldahl method (Jackson, 1973). The P content was estimated colorimetrically (Jackson, 1973) and K content by flame photometric method (Piper, 1966).

3.6.2 Uptake Studies

The total uptake of N, P, and K at harvest were calculated by multiplying the respective nutrient content in the stem, leaf and tuber and their corresponding dry weight. The uptake was expressed in kg ha^{-1}.

3.6.3. Soil Analysis

Soil samples were taken from the experimental field area before and after the experiment. The composite sample from the experimental field before the experiment was analyzed for physical and chemical properties as given in Table 1. After the experiment, composite samples were collected from each plot, air dried, powdered and passed through 2 mm sieve and analyzed for available N, P, and K status using the standard procedures given in Table 1.

3.7 INCIDENCE OF PEST AND DISEASE

The incidence of pest and disease was monitored throughout the crop period.

3.8 ECONOMICS OF CULTIVATION

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

Net income (₹ ha^{-1}) = Gross income - Cost of cultivation

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

3.9 STATISTICAL ANALYSIS

The experimental data were analyzed statistically by applying the technique of analysis of variance (ANOVA) for 3 x 2 x 2 factorial RBD experiment and the significance was tested by F test (Cochran and Cox, 1965). Wherever F test was significant, the critical difference (CD) is provided. Correlation analysis of tuber yield versus (*vs*) LAI at 4 MAP and harvest, yield attributes and nutrient uptake as well as TDMP *vs* LAI at 4 MAP and harvest and nutrient uptake was also done.

RESULTS

4. RESULTS

The study entitled "Nutrient management for productivity enhancement of cassava var. Vellayani Hraswa in lowlands" was undertaken at College of Agriculture, Vellayani, Thiruvananthapuram. The field experiment was conducted from September 2017 to February 2018 at IFSRS, Karamana, Thiruvananthapuram to standardize the nutrient management for productivity enhancement of cassava var. Vellayani Hraswa in lowlands and to work out the economics of cultivation. The field was laid out in RBD with factorial combinations of three sources of organic manure and two levels each of N and P with three replications. The data collected were statistically analyzed and the results are presented in this chapter.

4.1. GROWTH CHARACTERS

Growth characters *viz.* plant height, number of branches plant^{-1}, number of leaves plant^{-1}, number of functional leaves plant^{-1} and LAI were recorded at 2 MAP, 4 MAP and harvest.

4.1.1 Height of the Plant

The data on effect of sources of organic manure and N and P levels and their interactions on plant height are presented in Table 2a, 2b and 2c. Height of the plant increased till harvest.

The plant height was significantly influenced by sources of organic manure at 4 MAP and harvest (Table 2a). At both stages, the tallest plant (116.7 cm and 153.18 cm respectively) was observed when PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) was applied. But, it was on par with FYM @ 6.25 t ha^{-1} + green manuring *in situ* (m_2) at harvest. The treatment m_2 was on par with FYM @ 12.5 t ha^{-1} (m_1) at both stages. Levels of N had no significant effect on plant height at 2 MAP. At 4 MAP and harvest, N @ 75 kg ha^{-1} (n_2) recorded the tallest plant (114.5 cm and 154.89 cm respectively). Levels

Table 2a. Effect of sources of organic manure and levels of N and P on plant height, cm

Treatments	2 MAP	4 MAP	Harvest
Sources of organic manure (M)			
m_1 - FYM @ 12.5 t ha^{-1}	56.99	98.96	135.10
m_2 - FYM @ 6.25 t ha^{-1} + GM *in situ*	60.66	103.03	147.77
m_3 - PM @ 2.5 t ha^{-1} + GM *in situ*	60.20	116.70	153.18
SEm±	1.95	3.22	4.45
CD (0.05)	NS	9.432	13.047
Levels of nitrogen (N)			
n_1 - 50 kg ha^{-1}	57.10	97.95	135.81
n_2 - 75 kg ha^{-1}	64.46	114.50	154.89
SEm±	1.59	2.63	3.63
CD (0.05)	NS	7.701	10.654
Levels of phosphorus (P)			
p_1 - 25 kg P_2O_5 ha^{-1}	60.54	105.47	143.34
p_2 - 50 kg P_2O_5 ha^{-1}	58.01	106.99	147.36
SEm±	1.59	2.63	3.63
CD (0.05)	NS	NS	NS

Table 2b. Interaction effects of sources of organic manure and levels of N and P on plant height, cm

Interactions	2 MAP	4 MAP	Harvest
M x N interaction			
m_1n_1	56.75	91.38	134.39
m_1n_2	57.21	106.53	135.83
m_2n_1	57.10	94.50	132.51
m_2n_2	64.21	115.55	163.05
m_3n_1	57.44	107.98	140.56
m_3n_2	62.96	125.43	165.81
SEm±	2.76	4.55	6.29
CD (0.05)	NS	NS	NS
M X P interaction			
m_1p_1	57.82	103.38	133.11
m_1p_2	56.14	94.53	137.11
m_2p_1	62.83	95.83	146.93
m_2p_2	54.49	110.22	148.62
m_3p_1	60.96	117.20	149.99
m_3p_2	59.44	116.22	156.36
SEm±	2.76	4.55	6.29
CD (0.05)	NS	NS	NS
N X P interaction			
n_1p_1	56.55	95.39	133.40
n_1p_2	57.64	100.52	136.23
n_2p_1	64.53	115.55	151.29
n_2p_2	58.39	113.46	158.49
SEm±	2.25	3.72	5.14
CD (0.05)	NS	NS	NS

Table 2c. Effect of M x N x P interaction on plant height, cm

Treatment combinations	2 MAP	4 MAP	Harvest
$m_1n_1p_1$	58.55	90.53	130.67
$m_1n_1p_2$	54.94	92.22	138.11
$m_1n_2p_1$	57.11	116.22	135.55
$m_1n_2p_2$	57.33	96.83	136.11
$m_2n_1p_1$	54.89	84.00	132.77
$m_2n_1p_2$	59.33	105.00	132.24
$m_2n_2p_1$	70.76	107.67	161.11
$m_2n_2p_2$	57.64	115.43	164.99
$m_3n_1p_1$	56.20	111.63	142.77
$m_3n_1p_2$	58.66	104.33	138.33
$m_3n_2p_1$	65.72	122.77	157.22
$m_3n_2p_2$	60.20	128.10	174.38
SEm±	3.90	6.44	8.90
CD (0.05)	NS	NS	NS

of P (25 and 50 kg P_2O_5 ha^{-1}) produced no significant difference in plant height at any growth stage of the crop.

It is observed from Table 2b that the interactions M x N, M x P and N x P had no significant influence on plant height at any growth stage.

M x N x P interaction (Table 2c) also had no significant effect on plant height at any growth stage.

4.1.2 Number of Branches Plant^{-1}

Table 3a, 3b and 3c shows the data on the effect of sources of organic manure and N and P levels and their interactions on number of branches plant^{-1}.

Significant variation in number of branches plant^{-1} was observed at 4 MAP and harvest due to sources of organic manure (Table 5a.). At 4 MAP and harvest, PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) recorded the highest number of branches (2.96 and 4.17 respectively). Levels of N had significant influence on number of branches at 4 MAP and harvest and 75 kg N ha^{-1} resulted in the highest number of branches at both stages (2.57 and 3.72 respectively). Levels of P had significant influence only at harvest. The treatment 50 kg P_2O_5 ha^{-1} (n_2) recorded the highest number of branches.

M x N interaction had significant influence on the number of branches at 4 MAP and harvest (Table 5b.). Application of PM @ 2.5 t ha^{-1} + green manuring *in situ* combined with application of 75 kg N ha^{-1} (m_3n_2) resulted in higher number of branches at both stages. M x P interaction had significant effect only at harvest. The treatment combinations m_3p_2 and m_2p_2 produced significantly higher number of branches and were on par. There was no significant variation in number of branches due to N x P interaction.

M x N x P interaction failed to produce significant variation in number of branches at any growth stage (Table 3c).

Table 3a. Effect of sources of organic manure and levels of N and P on number of branches $plant^{-1}$

Treatments	2 MAP	4 MAP	Harvest
Sources of organic manure (M)			
m_1 - FYM @ 12.5 t ha^{-1}	1.52	2.02	2.91
m_2 - FYM @ 6.25 t ha^{-1} + GM *in situ*	1.39	2.09	3.75
m_3 - PM @ 2.5 t ha^{-1} + GM *in situ*	1.28	2.96	4.17
SEm±	0.07	0.10	0.09
CD (0.05)	NS	0.305	0.251
Levels of nitrogen (N)			
n_1 - 50 kg ha^{-1}	1.34	2.15	3.41
n_2 - 75 kg ha^{-1}	1.45	2.57	3.72
SEm±	0.06	0.09	0.07
CD (0.05)	NS	0.244	0.217
Levels of phosphorus (P)			
p_1 - 25 kg P_2O_5 ha^{-1}	1.34	2.33	3.49
p_2 - 50 kg P_2O_5 ha^{-1}	1.45	2.39	3.72
SEm±	0.06	0.09	0.07
CD (0.05)	NS	NS	0.217

Table 3b. Interaction effects of sources of organic manure and levels of N and P on number of branches plant^{-1}

Interactions	2 MAP	4 MAP	Harvest
M x N interaction			
m_1n_1	1.39	1.95	2.60
m_1n_2	1.67	2.11	3.22
m_2n_1	1.39	2.05	3.83
m_2n_2	1.39	2.10	3.67
m_3n_1	1.28	2.45	3.77
m_3n_2	1.28	3.50	4.57
SEm±	0.10	0.15	0.12
CD (0.05)	NS	0.430	0.360
M X P interaction			
m_1p_1	1.56	2.10	2.89
m_1p_2	1.50	1.94	2.95
m_2p_1	1.33	1.95	3.22
m_2p_2	1.45	2.22	4.28
m_3p_1	1.11	2.94	4.39
m_3p_2	1.44	3.00	3.94
SEm±	0.10	0.15	0.12
CD (0.05)	NS	NS	0.360
N X P interaction			
n_1p_1	1.22	2.11	3.29
n_1p_2	1.48	2.18	3.51
n_2p_1	1.44	2.55	3.70
n_2p_2	1.44	2.59	3.92
SEm±	0.08	0.12	0.10
CD (0.05)	NS	NS	NS

Table 3c. Effect of M x N x P interaction on number of branches plant[-1]

Treatment combinations	2 MAP	4 MAP	Harvest
$m_1n_1p_1$	1.33	2.00	2.55
$m_1n_1p_2$	1.44	1.89	2.66
$m_1n_2p_1$	1.77	2.22	3.22
$m_1n_2p_2$	1.55	1.99	3.22
$m_2n_1p_1$	1.22	1.89	3.22
$m_2n_1p_2$	1.55	2.22	4.44
$m_2n_2p_1$	1.44	2.00	3.22
$m_2n_2p_2$	1.33	2.22	4.11
$m_3n_1p_1$	1.11	2.44	4.11
$m_3n_1p_2$	1.44	2.44	3.44
$m_3n_2p_1$	1.11	3.44	4.66
$m_3n_2p_2$	1.44	3.55	4.44
SEm±	0.14	0.21	0.18
CD (0.05)	NS	NS	NS

4.1.3 Total Number of Leaves Plant^{-1}

Total number of leaves plant as influenced by sources of organic manure and N and P levels and their interactions on number of leaves are given in Table 4a, 4b and 4c.

Total leaf number was significantly influenced by sources of organic manure only at 4 MAP and harvest (Table 4a). At 4 MAP and harvest, application of PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) recorded significantly higher number of leaves (68.17 and 125.22 respectively). But, it was on par with application of FYM @ 6.25 t ha^{-1} + green manuring *in situ* (m_2) at harvest. The leaf number was significantly influenced by the levels of N at all growth stages. Application of 75 kg N ha^{-1} resulted in the highest number of leaves at 2 MAP, 4 MAP and harvest (27.72, 64.28 and 120. 27 respectively). Levels of P had no significant effect on number of leaves at any of the growth stage.

Among M x N, M x P and N x P interactions, only N x P interaction had significant influence on number of leaves at 2 MAP and 4 MAP (Table 4b). The treatment combination n_2p_1 recorded the highest leaf number (30) at 2 MAP. At 4 MAP, it was on par with n_2p_2.

The interaction M x N x P had no significant effect on leaf number at any growth stage (Table 4c).

4.1.3. Number of Functional Leaves Plant^{-1}

The data on effect of sources of organic manure and N and P levels and their interactions on number of functional leaves are summarized in Table 5a, 5b and 5c.

There was significant influence of sources of organic manure on number of functional leaves at 4 MAP and harvest (Table 5a). The highest number of functional leaves at 4 MAP (63.33) and at harvest (112.2) were recorded by the application of PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3). Levels of N had significant influence on the

Table 4a. Effect of sources of organic manure and levels of N and P on total number of leaves $plant^{-1}$

Treatments	2 MAP	4 MAP	Harvest
Sources of organic manure (M)			
m_1 - FYM @ 12.5 t ha^{-1}	25.58	54.50	101.15
m_2 - FYM @ 6.25 t ha^{-1} + GM *in situ*	26.33	62.00	114.05
m_3 - PM @ 2.5 t ha^{-1} + GM *in situ*	26.67	68.17	125.22
SEm±	1.01	1.43	3.85
CD (0.05)	NS	4.181	11.278
Levels of Nitrogen (N)			
n_1 - 50 kg ha^{-1}	24.67	58.83	106.68
n_2 - 75 kg ha^{-1}	27.72	64.28	120.27
SEm±	0.83	1.17	3.14
CD (0.05)	2.426	3.416	9.209
Levels of Phosphorus (P)			
p_1 - 25 kg P_2O_5 ha^{-1}	26.61	61.78	116.68
p_2 - 50 kg P_2O_5 ha^{-1}	25.78	61.33	110.27
SEm±	0.83	1.17	3.14
CD (0.05)	NS	NS	NS

Table 4b. Interaction effects of sources of organic manure and levels of N and P on total number of leaves plant^{-1}

Interactions	2 MAP	4 MAP	Harvest
M x N interaction			
m_1n_1	25.33	52.83	92.39
m_1n_2	25.83	56.17	109.93
m_2n_1	24.17	60.50	104.49
m_2n_2	28.50	63.50	118.60
m_3n_1	24.50	63.17	118.17
m_3n_2	28.33	73.17	132.28
SEm±	1.43	2.02	5.44
CD (0.05)	NS	NS	NS
M X P interaction			
m_1p_1	26.57	55.83	101.78
m_1p_2	24.50	53.17	100.55
m_2p_1	25.67	62.00	115.45
m_2p_2	27.00	62.00	112.67
m_3p_1	27.50	67.50	132.83
m_3p_2	25.83	68.83	117.61
SEm±	1.43	2.02	5.44
CD (0.05)	NS	NS	NS
N X P interaction			
n_1p_1	23.22	57.22	109.44
n_1p_2	26.11	60.44	103.92
n_2p_1	30.00	66.33	123.92
n_2p_2	25.44	62.22	116.62
SEm±	1.17	1.65	4.44
CD (0.05)	3.427	4.830	NS

Table 4c. Effect of M x N x P interaction on total number of leaves plant^{-1}

Treatment combinations	2 MAP	4 MAP	Harvest
$m_1n_1p_1$	25.33	50.67	91.22
$m_1n_1p_2$	25.33	55.00	93.55
$m_1n_2p_1$	28.00	61.00	112.33
$m_1n_2p_2$	23.67	51.33	107.53
$m_2n_1p_1$	21.00	59.00	111.11
$m_2n_1p_2$	27.33	62.00	107.89
$m_2n_2p_1$	30.33	65.00	119.77
$m_2n_2p_2$	26.67	62.00	117.44
$m_3n_1p_1$	23.33	62.00	126.00
$m_3n_1p_2$	25.67	64.33	110.33
$m_3n_2p_1$	31.67	73.00	139.67
$m_3n_2p_2$	26.00	73.33	124.88
SEm±	2.02	2.86	7.691
CD (0.05)	NS	NS	NS

Table 5a. Effect of sources of organic manure and levels of N and P on number of functional leaves $plant^{-1}$

Treatments	2 MAP	4 MAP	Harvest
Sources of organic manure (M)			
m_1 - FYM @ 12.5 t ha^{-1}	22.33	50.50	88.08
m_2 - FYM @ 6.25 t ha^{-1} + GM *in situ*	24.25	58.00	99.33
m_3 - PM @ 2.5 t ha^{-1} + GM *in situ*	24.25	63.33	112.20
SEm±	1.14	1.15	3.95
CD (0.05)	NS	3.360	11.591
Levels of Nitrogen (N)			
n_1 - 50 kg ha^{-1}	22.11	54.89	91.23
n_2 - 75 kg ha^{-1}	25.11	59.67	104.50
SEm±	0.93	0.94	3.23
CD (0.05)	2.731	2.747	9.469
Levels of Phosphorus (P)			
p_1 - 25 kg P_2O_5 ha^{-1}	24.17	59.11	104.31
p_2 - 50 kg P_2O_5 ha^{-1}	23.06	55.44	95.43
SEm±	0.93	0.94	3.23
CD (0.05)	NS	2.747	NS

Table 5b. Interaction effects of sources of organic manure and levels of N and P on number of functional leaves plant^{-1}

Interactions	2 MAP	4 MAP	Harvest
M x N interaction			
m_1n_1	22.00	48.50	77.39
m_1n_2	22.67	52.50	98.78
m_2n_1	21.17	55.17	92.67
m_2n_2	26.33	60.83	105.10
m_3n_1	22.17	61.00	103.66
m_3n_2	26.33	65.67	120.71
SEm±	1.61	1.62	5.59
CD (0.05)	NS	NS	NS
M X P interaction			
m_1p_1	23.50	52.50	90.83
m_1p_2	21.17	48.50	85.33
m_2p_1	23.67	59.67	100.94
m_2p_2	24.83	56.33	97.72
m_3p_1	25.33	65.17	121.16
m_3p_2	23.17	61.50	103.21
SEm±	1.61	1.62	5.59
CD (0.05)	NS	NS	NS
N X P interaction			
n_1p_1	20.89	54.33	94.15
n_1p_2	23.33	55.44	88.33
n_2p_1	27.44	63.89	114.48
n_2p_2	22.78	55.44	105.52
SEm±	1.32	1.32	4.57
CD (0.05)	3.865	3.884	NS

Table 5c. Effect of M x N x P interaction on number of functional leaves plant^{-1}

Treatment combinations	2 MAP	4 MAP	Harvest
$m_1n_1p_1$	22.33	46.33	77.22
$m_1n_1p_2$	21.67	50.67	77.56
$m_1n_2p_1$	24.67	58.67	104.44
$m_1n_2p_2$	20.67	46.33	93.11
$m_2n_1p_1$	19.00	54.33	94.11
$m_2n_1p_2$	25.33	56.00	91.22
$m_2n_2p_1$	28.33	65.00	107.77
$m_2n_2p_2$	24.33	56.67	104.22
$m_3n_1p_1$	21.33	62.33	111.11
$m_3n_1p_2$	23.00	59.67	96.22
$m_3n_2p_1$	29.33	68.00	131.22
$m_3n_2p_2$	23.33	63.33	110.22
SEm±	2.28	2.29	7.91
CD (0.05)	NS	NS	NS

number of functional leaves at all stages. At all stages of observation, the highest number of functional leaves was recorded by the application of 75 kg N ha^{-1} (n_2). The number of functional leaves per plant varied significantly with P levels at 4 MAP and 25 kg P_2O_5 ha^{-1} (p_1) produced the highest number (59.11).

Among the interactions, only N x P had significant influence on the number of functional leaves at 2 MAP and 4 MAP. (Table 5b). The treatment combination n_2p_1 recorded the highest number.

M x N x P interaction had no significant influence on number of functional leaves at all growth stages (Table 5c).

4.1.5. Leaf Area Index (LAI)

The data on effect of sources of organic manure and N and P levels and their interactions on LAI are presented in Table 6a, 6b and 6c. In general, LAI increased upto harvest.

Sources of organic manure had significantly influenced LAI at 4 MAP and harvest. At both stages, LAI was the highest (1.82 at 4 MAP and 2.47 at harvest) when PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) was applied. At harvest, the treatments m_1 and m_2 were found on par. Application of 75 kg N ha^{-1} (n_2) recorded significantly higher LAI at all growth stages. Levels of P had significant influence on LAI only at 2 MAP when 25 P_2O_5 kg ha^{-1} resulted in higher LAI.

The effect of M x N interaction on LAI was found significant at 4 MAP and harvest. The treatment combination m_3n_2 recorded the highest value (2.20) at 4 MAP. At harvest also, m_3n_2 recorded the highest LAI (2.65), but was on par with m_2n_2. M x P interaction was found significant at 2 MAP and 4 MAP and the treatment combination m_3p_1 recorded the highest value at both stages. Leaf area index was found significantly influenced by N x P interaction at 2 MAP and 4 MAP. The treatment combination n_2p_1 recorded the highest value at each stage.

Table 6a. Effect of sources of organic manure and levels of N and P on LAI

Treatments	2 MAP	4 MAP	Harvest
Sources of organic manure (M)			
m_1 - FYM @ 12.5 t ha^{-1}	0.30	1.20	2.09
m_2 - FYM @ 6.25 t ha^{-1} + GM *in situ*	0.29	1.54	2.06
m_3 - PM @ 2.5 t ha^{-1} + GM *in situ*	0.28	1.82	2.47
SEm±	0.01	0.07	0.05
CD (0.05)	NS	0.196	0.141
Levels of Nitrogen (N)			
n_1 - 50 kg ha^{-1}	0.26	1.28	1.93
n_2 - 75 kg ha^{-1}	0.30	1.75	2.47
SEm±	0.08	0.05	0.04
CD (0.05)	0.023	0.153	0.113
Levels of Phosphorus (P)			
p_1 - 25 kg P_2O_5 ha^{-1}	0.31	1.60	2.32
p_2 - 50 kg P_2O_5 ha^{-1}	0.26	1.44	2.09
SEm±	0.08	0.05	0.04
CD (0.05)	0.023	NS	0.113

Table 6b. Interaction effects of sources of organic manure and levels of N and P on LAI

Interactions	2 MAP	4 MAP	Harvest
M x N interaction			
m_1n_1	0.29	1.14	1.86
m_1n_2	0.30	1.25	2.31
m_2n_1	0.27	1.27	1.65
m_2n_2	0.29	1.79	2.46
m_3n_1	0.25	1.44	2.27
m_3n_2	0.32	2.20	2.65
SEm±	0.01	0.09	0.07
CD (0.05)	NS	0.275	0.207
M X P interaction			
m_1p_1	0.29	1.10	2.30
m_1p_2	0.30	1.29	1.90
m_2p_1	0.30	1.63	2.17
m_2p_2	0.26	1.44	1.94
m_3p_1	0.34	2.04	2.50
m_3p_2	0.24	1.60	2.42
SEm±	0.01	0.09	0.07
CD (0.05)	0.039	0.275	NS
N X P interaction			
n_1p_1	0.26	1.25	2.04
n_1p_2	0.28	1.31	1.82
n_2p_1	0.37	1.93	2.60
n_2p_2	0.25	1.56	2.35
SEm±	0.01	0.08	0.06
CD (0.05)	0.031	0.225	NS

Table 6c. Effect of M x N x P interaction on LAI

Treatment combinations	2 MAP	4 MAP	Harvest
$m_1n_1p_1$	0.25	1.00	2.05
$m_1n_1p_2$	0.33	1.28	1.69
$m_1n_2p_1$	0.33	1.21	2.54
$m_1n_2p_2$	0.27	1.29	2.10
$m_2n_1p_1$	0.25	1.19	1.75
$m_2n_1p_2$	0.28	1.35	1.54
$m_2n_2p_1$	0.36	2.06	2.57
$m_2n_2p_2$	0.23	1.52	2.34
$m_3n_1p_1$	0.28	1.56	2.31
$m_3n_1p_2$	0.23	1.31	2.23
$m_3n_2p_1$	0.41	2.52	2.69
$m_3n_2p_2$	0.23	1.88	2.61
SEm±	0.02	0.13	0.10
CD (0.05)	NS	NS	NS

No significant variation in LAI was noticed due to M x N x P interaction at any growth stage of the crop (Table 6c).

4.2 YIELD ATTRIBUTES

The data on yield attributes like number of tubers plant^{-1}, percentage of productive roots plant^{-1}, tuber weight plant^{-1}, length and girth of tuber, mean tuber weight and rind to flesh ratio were summarized in Table 7a, 7b and 7c.

4.2.1 Number of Tubers Plant^{-1}

It can be seen from Table 7a that sources of organic manure significantly influenced the number of tubers plant^{-1} and the treatment PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) recorded the highest tuber number (5.19). Also, application of N @ 75 kg ha^{-1} resulted in significantly higher tuber number compared to 50 kg N ha^{-1}. Levels of P had no significant effect on numbers of tubers plant^{-1}.

M x N interaction had no significant effect on tuber number. But the interaction M x P was found significant and the treatment combination m_3p_1 recorded the highest number of tubers (5.67). The N x P interaction was also found significant and the treatment combination n_2p_1 resulted in the highest number of tubers (5.33) which was on par with n_2p_2.

No significant variation in tuber number was obtained due to M x N x P interaction.

4.2.2 Percentage of Productive Roots Plant^{-1}

Sources of organic manure produced significant variation in percentage of productive roots (Table 7a). Among the organic manure treatments, PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) produced 59.67 per cent productive roots plant^{-1} followed by FYM @ 6.25 t ha^{-1} + green manuring *in situ* (m_2) and FYM @ 12.5 t ha^{-1} (m_1) which were on par. Percentage of productive roots was influenced by levels of N also. Percentage of productive roots significantly increased when the N level was increased from 50 to 75 kg ha^{-1}. Levels of P had no significant effect on percentage of productive

Table 7a. Effect of sources of organic manure and levels of N and P on yield attributes

Treatments	Number of tubers plant^{-1}	Percentage of productive roots	Tuber weight plant^{-1} (kg)	Length of tuber (cm)	Girth of tuber (cm)	Mean tuber weight (kg)	Rind to flesh ratio
Sources of organic manure (M)							
m_1 - FYM @ 12.5 t ha^{-1}	4.26	50.85	2.22	31.00	13.73	0.57	0.25
m_2 - FYM @ 6.25 t ha^{-1} + GM *in situ*	4.73	53.12	2.56	35.30	13.79	0.62	0.29
m_3 - PM @ 2.5 t ha^{-1} + GM *in situ*	5.19	59.67	2.97	37.40	14.16	0.67	0.27
SEm±	0.17	1.89	0.01	1.24	0.76	0.003	0.01
CD (0.05)	0.514	3.655	0.034	2.576	NS	0.010	0.019
Levels of Nitrogen (N)							
n_1 - 50 kg ha^{-1}	4.38	45.93	2.47	32.83	13.19	0.59	0.26
n_2 - 75 kg ha^{-1}	5.06	63.15	2.70	36.29	14.59	0.63	0.27
SEm±	0.20	1.54	0.01	1.01	0.59	0.004	0.01
CD (0.05)	0.418	2.986	0.032	2.10	1.226	0.014	NS
Levels of Phosphorus (P)							
p_1 - 25 kg P_2O_5 ha^{-1}	4.77	53.76	2.64	35.54	14.64	0.62	0.26
p_2 - 50 kg P_2O_5 ha^{-1}	4.69	55.34	2.53	33.58	13.13	0.60	0.28
SEm±	0.20	1.54	0.01	1.01	0.59	0.004	0.01
CD (0.05)	NS	NS	0.032	NS	1.226	0.014	NS

roots although the percentage of productive roots increased when P level was increased from 25 to 50 kg P_2O_5 ha^{-1}.

Considering the interaction effects, only M x N interaction significantly influenced the percentage of productive roots (Table 7b). Higher percentage of productive roots was produced by the treatment combination m_3n_2 (71.61).

M x N x P interaction (Table 7c) failed to produce significant effect on this character.

4.2.3 Tuber Weight Plant^{-1}

The results (Table 7a) showed that there was significant difference in tuber weight plant^{-1} due to sources of organic manure and N and P levels. Application of PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) recorded the highest tuber weight per plant (2.97 kg) followed by FYM @ 6.25 t ha^{-1} + green manuring *in situ* (m_2). Nitrogen @ 75 kg ha^{-1} (n_2) produced the highest tuber weight plant^{-1} (2.70 kg). Application of lower level of P (25 kg P_2O_5 ha^{-1}) resulted in the highest tuber weight plant^{-1} (2.64 kg)

Among the interactions M x N, M x P and N x P, only M x N and M x P produced significant difference in tuber weight plant^{-1} (Table 7b). In the case of M x N interactions, the treatment combination m_3n_2 recorded the highest tuber weight plant^{-1} (3.11 kg). With respect to M x P interaction, the highest tuber weight plant^{-1} of 3.03 kg was registered by the treatment combination m_3p_1.

M x N x P interaction also produced significant effect on tuber weight plant^{-1} (Table 7c). The treatment combination $m_3n_2p_1$ resulted in the highest tuber weight plant^{-1} (3.23 kg).

4.2.4 Length of Tuber

As shown in Table 7a, sources of organic manure and N levels had significant influence on length of tuber. It can be seen that application of PM @ 2.5 t ha^{-1} + green manuring *in situ* recorded the longest tubers (37.4 cm) which was on par with m_2 (FYM

Table 7b. Interaction effects of sources of organic manure and levels of N and P on yield attributes

Interactions	Number of tubers $plant^{-1}$	Percentage of productive roots	Tuber weight $plant^{-1}$ (kg)	Length of tuber (cm)	Girth of tuber (cm)	Mean tuber weight (kg)	Rind to flesh ratio
M x N interaction							
m_1n_1	3.98	44.61	2.11	30.00	13.01	0.54	0.25
m_1n_2	4.56	57.10	2.32	32.00	14.45	0.59	0.28
m_2n_1	4.50	45.47	2.47	34.92	13.02	0.59	0.28
m_2n_2	4.95	60.75	2.66	35.67	14.56	0.64	0.29
m_3n_1	4.69	47.72	2.81	33.58	13.57	0.63	0.27
m_3n_2	5.69	71.61	3.11	41.20	14.75	0.68	0.27
SEm±	0.35	2.67	0.02	1.76	1.03	0.01	0.01
CD (0.05)	NS	5.166	0.058	3.645	NS	NS	NS
M X P interaction							
m_1p_1	4.08	49.85	2.24	31.50	14.06	0.58	0.25
m_1p_2	4.44	51.84	2.19	30.50	13.40	0.54	0.27
m_2p_1	4.55	50.48	2.62	36.00	14.62	0.63	0.28
m_2p_2	4.89	55.75	2.50	34.58	12.96	0.60	0.29
m_3p_1	5.67	60.93	3.03	39.12	15.26	0.68	0.28
m_3p_2	4.73	58.39	2.89	35.67	13.06	0.65	0.27
SEm±	0.35	2.67	0.02	1.76	1.03	0.01	0.01
CD (0.05)	0.722	NS	0.058	NS	NS	NS	NS
N X P interaction							
n_1p_1	4.20	46.38	2.50	33.44	13.77	0.60	0.27
n_1p_2	4.57	45.47	2.42	32.22	12.62	0.57	0.26
n_2p_1	5.33	61.12	2.77	37.63	15.52	0.65	0.27
n_2p_2	4.79	65.19	2.62	34.94	13.65	0.62	0.29
SEm±	0.29	2.18	0.02	1.03	1.03	0.004	0.01
CD (0.05)	0.597	NS	NS	NS	NS	NS	NS

@ 6.25 t ha^{-1} + green manuring *in situ*). Tuber length significantly increased when N level was increased from 50 kg ha^{-1} (n_1) to 75 kg ha^{-1} (n_2). But P levels had no significant influence on this character.

The tuber length was significantly affected by the interaction M x N but not by M x P and N x P interactions (Table 7b). The longest tuber (41.2 cm) was produced by the treatment combination m_3n_2 which was found significantly superior to other combinations.

Significant effect of M x N x P interaction was not observed for this character (Table 7c).

4.2.5 Girth of Tuber

The data on girth of tuber presented in Table 7a indicated that there was no significant effect due to source of organic manure, but the levels of N and P significantly influenced the girth of tuber. The girth of tuber increased due to application of higher level of N (75 kg ha^{-1}) and higher level of P (50 P_2O_5 kg ha^{-1}).

The interactions had no significant effect on girth of tuber as shown in Table 7b and Table 7c.

4.2.6 Mean Tuber Weight

Table 7a depicts the significant influence of sources of organic manure and levels of N and P on mean tuber weight. The treatment PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) recorded the highest mean tuber weight of 0.67 kg followed by m_2 (FYM @ 6.25 kg ha^{-1} + green manuring *in situ*). Higher levels of N (75 kg ha^{-1}) resulted in higher mean tuber weight of 0.63 kg and lower level of P (25 kg P_2O_5 ha^{-1}) produced higher mean tuber weight of 0.62 kg.

Mean tuber weight did not vary significantly due to interaction effects (Table 7b and 7c).

Table 7c. Effect of M x N x P interaction on yield attributes

Treatment combinations	Number of tubers plant^{-1}	Percentage of productive roots	Tuber weight plant^{-1} (kg)	Length of tuber (cm)	Girth of tuber (cm)	Mean tuber weight (kg)	Rind to flesh ratio
$m_1n_1p_1$	3.50	44.70	2.14	31.00	12.79	0.55	0.24
$m_1n_1p_2$	4.44	44.50	2.07	29.00	13.23	0.52	0.25
$m_1n_2p_1$	4.67	55.00	2.34	32.00	15.33	0.60	0.26
$m_1n_2p_2$	4.44	59.18	2.30	32.00	13.55	0.57	0.29
$m_2n_1p_1$	4.00	44.60	2.52	35.00	14.01	0.61	0.27
$m_2n_1p_2$	5.00	46.33	2.41	34.83	12.02	0.57	0.28
$m_2n_2p_1$	5.11	56.35	2.74	37.00	15.22	0.65	0.28
$m_2n_2p_2$	4.77	65.17	2.59	34.33	13.89	0.63	0.29
$m_3n_1p_1$	5.11	49.85	2.85	34.33	14.51	0.65	0.29
$m_3n_1p_2$	4.28	45.58	2.79	32.83	12.61	0.62	0.27
$m_3n_2p_1$	6.22	72.00	3.23	43.90	16.00	0.71	0.26
$m_3n_2p_2$	5.17	71.22	2.98	38.50	13.50	0.67	0.28
SEm±	0.49	3.78	0.03	1.45	1.45	0.01	0.28
CD (0.05)	NS	NS	0.079	NS	NS	NS	NS

4.2.7 Rind to Flesh Ratio

It can be seen that only sources of organic manure significantly influenced the rind to flesh ratio (Table 7a). Lower rind to flesh ratios were recorded by the treatment FYM @ 12.5 t ha^{-1} (m_1 - 0.25) and PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3 - 0.27) and were on par.

None of the interactions had significant effect (Table 7b and 7c).

4.3 YIELD

The data on the effect of sources of organic manure, levels of N and P and their interactions on tuber and top yields of cassava are given in Table 8a, 8b and 8c. The data on the treatments effects on dry matter production of cassava and harvest index are presented in Table 9a, 9b and 9c. The green matter and dry matter yields of green manure cowpea were also computed and shown in Table 10a, 10b and 10c.

4.3.1 Tuber Yield

A perusal of the data in Table 8a clearly indicated the significant influence of sources of organic manure on tuber yield. Poultry manure @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) resulted in the highest tuber yield of 33.85 t ha^{-1} followed by FYM @ 6.25 kg ha^{-1} + green manuring *in* situ (m_2). The treatment m_3 was superior to m_2 and m_1 while m_2 was superior to m_1 (FYM alone). The results pointed out the alternatives for FYM application. Tuber yield significantly increased from 29.33 to 32.21 t ha^{-1} when the N level was increased from 50 kg ha^{-1} (n_1) to 75 kg ha^{-1} (n_2). Levels of P had no significant influence on tuber yield. However, lower level of P (25 kg P_2O_5 ha^{-1}) registered higher tuber yield emphasizing low requirement of P for cassava.

The interactions, M x N and M x P had significant effect on tuber yield (Table 8b). Among M x N interaction, the treatment combination m_3n_2 (PM @ 2.5 t ha^{-1} + green manuring *in situ* along with 75 kg N ha^{-1}) recorded significantly higher tuber yield than other treatment combinations. In the case of M x P interaction, PM @ 2.5 t ha^{-1} +

Table 8a. Effect of sources of organic manure and levels of N and P on yield, t ha^{-1}

Treatments	Tuber yield	Top yield
Sources of organic manure (M)		
m_1 - FYM @ 12.5 t ha^{-1}	27.18	7.29
m_2 - FYM @ 6.25 t ha^{-1} + GM *in situ*	31.29	8.37
m_3 - PM @ 2.5 t ha^{-1} + GM *in situ*	33.85	9.64
SEm±	0.33	0.10
CD (0.05)	0.958	0.298
Levels of nitrogen (N)		
n_1 - 50 kg ha^{-1}	29.33	8.20
n_2 - 75 kg ha^{-1}	32.21	8.65
SEm±	0.27	0.08
CD (0.05)	0.782	0.233
Levels of phosphorus (P)		
p_1 - 25 kg P_2O_5 ha^{-1}	31.05	8.48
p_2 - 50 kg P_2O_5 ha^{-1}	30.49	8.39
SEm±	0.27	0.08
CD (0.05)	NS	NS

green manuring *in situ* along with 25 or 50 kg P_2O_5 ha^{-1} (m_3p_1 and m_3p_2 respectively) were on par and superior to other treatment combinations. No significant variation in tuber yield was observed due to N x P interaction.

M x N x P interaction significantly affected the tuber yield as indicated in Table 8c. It can be seen that the treatment combination $m_3n_2p_1$ recorded the highest tuber yield of 36.22 t ha^{-1}, which was superior to all other treatment combinations.

4.3.2 Top Yield

As shown in Table 8a, sources of organic manure and N levels had significant influence on top yield. Significantly higher top yield of 9.64 t ha^{-1} was obtained with the treatment PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3). Top yield significantly increased when N level was increased from 50 (n_1) to 75 kg ha^{-1}(n_2). However, P levels had no significant influence on top yield.

Table 8b revealed the significant effects of M x N and M x P interactions on top yield. With respect to M x N interaction, the treatment combination m_3n_1 (PM @ 2.5 t ha^{-1} + green manuring *in situ* along with 50 kg N ha^{-1}) produced the highest top yield which was on par with m_3n_2. In the case of M x P interaction, the treatment combination PM @ 2.5 t ha^{-1} + green manuring *in situ* along with 25 P_2O_5 ha^{-1} (m_3p_1) registered significantly higher top yield. However, N x P interaction had no significant effect on top yield.

As presented in Table 8c, M x N x P interaction had significant effect on top yield. The treatment combinations $m_3n_2p_1$, $m_3n_1p_2$ and $m_3n_1p_1$ were on par, but produced significantly higher top yield compared to other combinations.

4.3.3 Total Dry Matter Production

Sources of organic manure produced significant variation in TDMP as evident from Table 9a. Application of PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) recorded significantly higher TDMP (19.83 t ha^{-1}) than other treatments. Among N levels, 75 kg

Table 8b. Interaction effects of sources of organic manure and levels of N and P on yield, t ha^{-1}

Interactions	Tuber yield	Top yield
M x N interaction		
m_1n_1	24.93	6.64
m_1n_2	29.43	7.95
m_2n_1	29.97	8.27
m_2n_2	32.60	8.50
m_3n_1	33.09	9.73
m_3n_2	34.60	9.54
SEm±	0.46	0.14
CD (0.05)	1.351	0.417
M X P interaction		
m_1p_1	26.56	7.07
m_1p_2	27.80	7.53
m_2p_1	32.13	8.51
m_2p_2	30.46	8.25
m_3p_1	34.46	9.85
m_3p_2	33.21	9.42
SEm±	0.46	0.14
CD (0.05)	1.351	0.417
N X P interaction		
n_1p_1	29.68	8.28
n_1p_2	28.98	8.14
n_2p_1	32.41	8.66
n_2p_2	32.00	8.66
SEm±	0.38	0.12
CD (0.05)	NS	NS

Table 8c. Effect of M x N x P interaction on yield, t ha^{-1}

Treatment combinations	Tuber yield	Top yield
$m_1n_1p_1$	25.23	6.75
$m_1n_1p_2$	24.62	6.53
$m_1n_2p_1$	27.88	7.38
$m_1n_2p_2$	30.97	8.51
$m_2n_1p_1$	31.11	8.45
$m_2n_1p_2$	28.84	8.08
$m_2n_2p_1$	33.14	8.57
$m_2n_2p_2$	32.06	8.42
$m_3n_1p_1$	32.70	9.65
$m_3n_1p_2$	33.48	9.80
$m_3n_2p_1$	36.22	10.04
$m_3n_2p_2$	32.96	9.03
SEm±	0.65	0.20
CD (0.05)	1.916	0.587

Table 9a. Effect of sources of organic manure and levels of N and P on TDMP and harvest index

Treatments	TDMP ($t\ ha^{-1}$)	Harvest index
Sources of organic manure (M)		
m_1 - FYM @ 12.5 $t\ ha^{-1}$	14.76	0.70
m_2 - FYM @ 6.25 $t\ ha^{-1}$ + GM *in situ*	17.72	0.71
m_3 - PM @ 2.5 $t\ ha^{-1}$ + GM *in situ*	19.83	0.69
SEm±	0.16	0.005
CD (0.05)	0.483	NS
Levels of nitrogen (N)		
n_1 - 50 $kg\ ha^{-1}$	15.71	0.70
n_2 - 75 $kg\ ha^{-1}$	19.14	0.71
SEm±	0.13	0.004
CD (0.05)	0.392	NS
Levels of phosphorus (P)		
p_1 - 25 kg P_2O_5 ha^{-1}	17.79	0.69
p_2 - 50 kg P_2O_5 ha^{-1}	17.07	0.71
SEm±	0.13	0.004
CD (0.05)	0.392	NS

Table 9b. Interaction effects of sources of organic manure and levels of N and P on TDMP and harvest index

Interactions	TDMP (t ha^{-1})	Harvest index
M x N interaction		
m_1n_1	13.05	0.70
m_1n_2	16.45	0.71
m_2n_1	16.06	0.71
m_2n_2	19.38	0.70
m_3n_1	18.05	0.71
m_3n_2	21.61	0.70
SEm±	0.23	0.007
CD (0.05)	NS	NS
M X P interaction		
m_1p_1	14.72	0.70
m_1p_2	14.78	0.72
m_2p_1	18.36	0.70
m_2p_2	17.07	0.71
m_3p_1	20.30	0.70
m_3p_2	19.35	0.71
SEm±	0.23	0.01
CD (0.05)	0.673	NS
N X P interaction		
n_1p_1	15.82	0.70
n_1p_2	15.62	0.71
n_2p_1	19.77	0.70
n_2p_2	18.52	0.70
SEm±	0.20	0.01
CD (0.05)	0.557	NS

Table 9c. Effect of M x N x P interaction on TDMP and harvest index

Treatment combinations	TDMP (t ha^{-1})	Harvest index
$m_1n_1p_1$	13.14	0.70
$m_1n_1p_2$	12.96	0.71
$m_1n_2p_1$	16.29	0.70
$m_1n_2p_2$	16.62	0.72
$m_2n_1p_1$	16.41	0.70
$m_2n_1p_2$	15.71	0.71
$m_2n_2p_1$	20.30	0.70
$m_2n_2p_2$	18.45	0.70
$m_3n_1p_1$	17.89	0.69
$m_3n_1p_2$	18.19	0.72
$m_3n_2p_1$	22.72	0.70
$m_3n_2p_2$	20.50	0.69
SEm±	0.39	0.01
CD (0.05)	0.967	NS

N ha^{-1} (n_2) gave higher TDMP compared to 50 kg ha^{-1} (n_1). But application of lower level of P (25 kg P_2O_5 ha^{-1} - p_1) resulted in higher TDMP compared to 50 kg P_2O_5 ha^{-1} (p_2).

Only M x P and N x P interactions had significant effect on TDMP (Table 9b). Among M x P interaction, the treatment combination m_3p_1 registered the highest TDMP. With regard to N x P interaction, the treatment combination n_2p_1 recorded the highest TDMP.

The TDMP showed significant variation due to M x N x P interaction (Table 9c). Application of PM @ 2.5 t ha^{-1} + green manuring *in situ* along with 75 kg N ha^{-1} and 25 kg P_2O_5 ha^{-1} ($m_3n_2p_1$) was found superior to others, registering the highest TDMP of 22.72 t ha^{-1}.

4.3.4 Harvest index (HI)

. The treatments failed to produce any significant variation in HI as revealed from Table 9a. The interaction effects were also not significant with respect to this character (Table 9b and 9c).

4.3.5 Yield of Green Manure Cowpea

The data presented in Table 10a showed significant effects of treatments on green matter and dry matter yields of green manure cowpea. Plots given PM (m_3) recorded higher green matter and dry matter yields (11.3 and 1.52 t ha^{-1} respectively). Higher level of N (n_2 - 75 kg ha^{-1}) and lower level of P (p1 - 25 kg P_2O_5 ha^{-1}) registered higher green matter and dry matter yields.

With respect to M x N, M x P and N x P interactions (Table 10b), the treatment combinations m_3n_2, m_3p_1 and n_2p_1 respectively produced higher green matter and dry matter yields, although the effect of M x P interaction on dry matter yield was not significant.

Table 10a. Effect of sources of organic manure and levels of N and P yield of green manure cowpea, t ha^{-1}

Treatments	Green matter yield	Dry matter yield
Sources of organic manure (M)		
m_2 - FYM @ 6.25 t ha^{-1} + GM *in situ*	10.13	1.37
m_3 - PM @ 2.5 t ha^{-1} + GM *in situ*	11.30	1.52
SEm±	0.001	0.004
CD (0.05)	0.002	0.013
Levels of nitrogen (N)		
n_1 - 50 kg ha^{-1}	10.42	1.39
n_2 - 75 kg ha^{-1}	11.01	1.50
SEm±	0.001	0.004
CD (0.05)	0.002	0.013
Levels of phosphorus (P)		
p_1 - 25 kg P_2O_5 ha^{-1}	11.28	1.55
p_2 - 50 kg P_2O_5 ha^{-1}	10.15	1.35
SEm±	0.001	0.004
CD (0.05)	0.002	0.013

Table 10b. Interaction effects of sources of organic manure and levels of N and P on yield of green manure cowpea, t ha^{-1}

Interactions	Green matter yield	Dry matter yield
M x N interaction		
m_2n_1	9.66	1.28
m_2n_2	10.61	1.46
m_3n_1	11.19	1.50
m_3n_2	11.42	1.55
SEm±	0.005	0.009
CD (0.05)	0.016	0.027
M X P interaction		
m_2p_1	10.61	1.47
m_2p_2	9.65	1.27
m_3p_1	11.96	1.63
m_3p_2	10.65	1.42
SEm±	0.005	0.009
CD (0.05)	0.016	NS
N X P interaction		
n_1p_1	10.61	1.42
n_1p_2	10.22	1.36
n_2p_1	11.96	1.68
n_2p_2	10.07	1.33
SEm±	0.005	0.009
CD (0.05)	0.016	0.027

Table 10c. Effect of M x N x P interaction on yield of green manure cowpea, t ha^{-1}

Treatment combinations	Green matter yield	Dry matter yield
$m_2n_1p_1$	9.65	1.33
$m_2n_1p_2$	9.65	1.26
$m_2n_2p_1$	11.57	1.62
$m_2n_2p_2$	9.65	1.29
$m_3n_1p_1$	11.57	1.53
$m_3n_1p_2$	10.80	1.47
$m_3n_2p_1$	12.34	1.73
$m_3n_2p_2$	10.49	1.37
SEm±	0.005	0.015
CD (0.05)	0.014	NS

The M x N x P interaction had significant effect only on green matter yield (Table 10c). The treatment combination $m_3n_2p_1$ showed superior green matter yield of 12.34 t ha^{-1}.

4.4. QUALITY CHARACTERS OF TUBER

Quality characters of tuber such as starch, protein and HCN content as affected by sources of organic manure and levels of N and P are presented in Table 11a, 11b and 11c.

4.4.1. Starch Content

Table 11a shows the treatment effects on starch content. Sources of organic manure and P levels failed to produce significant effect on starch content. However, significantly higher starch content of 27.03 per cent was registered due to application of lower level of N (50 kg ha^{-1}).

None of interactions had significant effect on starch content (Table 11b and 11c.)

4.4.2. Protein Content

Among the treatments, only levels of N significantly influenced the protein content of tuber (Table 11 a). The protein content increased from 2.47 to 2.61 per cent when the N level was increased from 50 kg ha^{-1} (n_1) to 75 kg ha^{-1} (n_2).

The interaction effects were not significant for this character (Table 11b and 11c).

4.4.3. HCN Content

The HCN content of tuber was significantly influenced by source of organic manure and levels N and P (Table 11a). The treatment m_2 (FYM @ 6.25 t ha^{-1} + green manuring *in situ*) produced tubers with the lowest HCN. The HCN content significantly

Table 11a. Effect of sources of organic manure and levels of N and P on quality characters of tuber on fresh weight basis

Treatments	Starch content (%)	Protein content (%)	HCN content (mg kg^{-1})
Sources of organic manure (M)			
m_1 - FYM @ 12.5 t ha^{-1}	26.43	2.39	44.42
m_2 - FYM @ 6.25 t ha^{-1} + GM *in situ*	26.65	2.54	38.92
m_3 - PM @ 2.5 t ha^{-1} + GM *in situ*	26.99	2.54	47.92
SEm±	0.31	0.09	1.85
CD (0.05)	NS	NS	5.425
Levels of Nitrogen (N)			
n_1 - 50 kg ha^{-1}	27.03	2.47	39.83
n_2 - 75 kg ha^{-1}	26.35	2.61	47.63
SEm±	0.26	0.07	1.51
CD (0.05)	0.747	0.212	4.43
Levels of Phosphorus (P)			
p_1 - 25 kg P_2O_5 ha^{-1}	26.56	2.49	46.17
p_2 - 50 kg P_2O_5 ha^{-1}	26.82	2.49	41.33
SEm±	0.26	0.07	2.51
CD (0.05)	NS	NS	NS

Table 11b. Interaction effects of sources of organic manure and levels of N and P on quality characters of tuber on fresh weight basis

Interactions	Starch content (%)	Protein content (%)	HCN content (mg kg^{-1})
M x N interaction			
m_1n_1	27.02	2.33	42.83
m_1n_2	25.86	2.45	46.00
m_2n_1	26.90	2.45	33.83
m_2n_2	26.39	2.63	44.00
m_3n_1	27.18	2.33	42.83
m_3n_2	26.82	2.74	53.00
SEm±	0.44	0.13	2.62
CD (0.05)	NS	NS	NS
M X P interaction			
m_1p_1	26.29	2.39	47.67
m_1p_2	26.60	2.39	41.18
m_2p_1	26.79	2.51	40.83
m_2p_2	26.50	2.57	37.00
m_3p_1	26.61	2.57	50.00
m_3p_2	27.37	2.51	45.83
SEm±	0.44	0.13	2.62
CD (0.05)	NS	NS	NS
N X P interaction			
n_1p_1	26.91	2.33	41.89
n_1p_2	27.15	2.41	37.77
n_2p_1	26.22	2.64	50.44
n_2p_2	26.49	2.57	44.89
SEm±	0.36	0.10	2.14
CD (0.05)	NS	NS	NS

Table 11c. Effect of M x N x P interaction on quality characters of tuber on fresh weight basis

Treatment combinations	Starch content (%)	Protein content (%)	HCN content (mg kg^{-1})
$m_1n_1p_1$	26.41	2.33	44.33
$m_1n_1p_2$	27.62	2.33	41.33
$m_1n_2p_1$	26.15	2.45	51.00
$m_1n_2p_2$	25.57	2.45	41.00
$m_2n_1p_1$	27.39	2.33	36.00
$m_2n_1p_2$	26.41	2.57	31.67
$m_2n_2p_1$	26.20	2.68	45.67
$m_2n_2p_2$	26.58	2.57	42.33
$m_3n_1p_1$	26.93	2.33	45.33
$m_3n_1p_2$	27.43	2.33	40.33
$m_3n_2p_1$	26.31	2.80	54.67
$m_3n_2p_2$	27.33	2.68	51.33
SEm±	0.63	0.18	3.70
CD (0.05)	NS	NS	NS

increased when N level was increased from 50 (n_1) to 75 kg ha^{-1}(n_2). But, the levels of P had not significantly affected the HCN content.

No marked variation in HCN content of tuber was noticed due to M x N, M x P and N x P or M x N x P interactions (Table 11b and 11c).

4.5. OBSERVATIONS ON WEED

Observations on weed density and weed dry weight m^{-2} were recorded at 20 days interval from 30 DAP upto 90 DAP and then at monthly interval upto harvest. The data on weed density m^{-2} are summarized in Table 12a, 12b and 12c and that of weed dry weight m^{-2} are presented in Table 13a, 13b and 13c.

4.5.1 Weed Density m^{-2}

It can be seen from Table 12a that weed density m^{-2} varied significantly due to sources of organic manure. The plots without green manure (m_1) showed significantly higher weed density m^{-2} at all stages of observation except at 90 and 120 DAP when it was on par with plots given FYM @ 6.25 t ha^{-1} + green manuring *in situ* (m_2). The weed density m^{-2} was the lowest in plots given PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) at all stages of observation upto 150 DAP except at 30 and 150 DAP when it was on par with m_2. At harvest, no significant variation in weed density was observed due to sources of organic manure.

Levels of N significantly influenced weed density m^{-2} at all stages of observation except at 50 and 120 DAP (Table 12a). Lower weed density m^{-2} was observed in plots given lower level of N (n_1 - 50 kg ha^{-1}). Weed density was significantly influenced by P levels at 70 DAP, 120 DAP and harvest. At 70 and 120 DAP, P @ 50 kg P_2O_5 ha^{-1} recorded the lowest number of weeds. But at harvest, the weed density was found lower with 25 kg P_2O5 ha^{-1}.

Considering the interaction effects (Table 12b), M x N interaction had significant influence on weed density only at 30 and 70 DAP. At both stages, the

Table 12a. Effect of sources of organic manure and levels of N and P on weed density m^{-2}

Treatments	Weed density m^{-2}						
	30 DAP	50 DAP	70 DAP	90 DAP	120 DAP	150 DAP	Harvest
Sources of organic manure (M)							
m_1 - FYM @ 12.5 t ha^{-1}	56.03	41.92	40.50	25.18	32.88	32.40	18.70
m_2 - FYM @ 6.25 t ha^{-1} + GM *in situ*	35.91	27.68	30.36	26.26	33.01	20.59	16.20
m_3 - PM @ 2.5 t ha^{-1} + GM *in situ*	30.04	21.60	26.00	21.27	26.33	22.21	16.84
SEm±	1.79	1.31	1.28	1.00	1.15	1.61	0.77
CD (0.05)	5.259	3.840	3.762	2.298	3.371	4.711	NS
Levels of Nitrogen (N)							
n_1 - 50 kg ha^{-1}	37.85	29.52	30.11	21.45	30.02	24.80	15.57
n_2 - 75 kg ha^{-1}	43.47	31.28	34.46	27.00	31.46	25.34	18.93
SEm±	1.46	1.07	1.04	0.82	0.94	1.31	0.63
CD (0.05)	4.296	NS	3.075	2.393	NS	NS	1.842
Levels of Phosphorus (P)							
p_1 - 25 kg P_2O_5 ha^{-1}	40.95	30.02	33.89	23.09	31.19	25.29	16.34
p_2 - 50 kg P_2O_5 ha^{-1}	40.37	30.78	30.68	25.38	30.29	24.84	18.16
SEm±	1.46	1.07	1.04	0.82	0.94	1.31	0.63
CD (0.05)	NS	NS	3.075	NS	NS	NS	1.842

Table 12b. Interaction effects of sources of organic manure and levels of N and P on weed density m^{-2}

Interactions	Weed density						
	30 DAP	50 DAP	70 DAP	90 DAP	120 DAP	150 DAP	Harvest
M x N interaction							
m_1n_1	49.55	38.88	34.56	21.47	32.13	34.29	15.93
m_1n_2	62.51	44.96	46.44	28.89	33.62	30.51	21.45
m_2n_1	36.05	27.95	29.43	23.22	30.11	18.77	15.12
m_2n_2	35.78	27.41	31.28	29.30	35.91	22.41	17.28
m_3n_1	27.95	21.74	26.33	19.71	27.81	21.33	15.66
m_3n_2	32.13	21.47	25.69	22.82	24.84	23.09	18.03
SEm±	2.53	1.86	1.81	1.41	1.63	2.277	1.09
CD (0.05)	7.436	NS	3.762	NS	4.775	NS	NS
M X P interaction							
m_1p_1	55.08	42.53	41.99	24.84	32.27	34.83	18.23
m_1p_2	56.97	41.31	39.02	25.52	33.48	29.97	19.17
m_2p_1	36.32	26.06	31.46	24.17	36.45	20.12	15.39
m_2p_2	35.51	29.30	29.26	28.35	29.57	21.06	17.01
m_3p_1	31.46	21.47	28.22	20.25	24.84	20.93	15.39
m_3p_2	28.62	21.74	23.80	22.28	27.81	23.49	18.30
SEm±	2.53	1.86	1.81	1.41	1.63	2.27	1.09
CD (0.05)	NS	NS	NS	NS	4.775	NS	NS
N X P interaction							
n_1p_1	36.36	28.26	31.77	19.26	31.68	24.30	14.67
n_1p_2	39.33	30.78	28.44	23.67	28.35	25.29	16.47
n_2p_1	45.54	31.77	36.00	26.91	30.69	26.28	18.00
n_2p_2	41.40	30.78	32.93	27.09	32.22	24.39	19.85
SEm±	2.07	1.52	1.48	1.15	1.33	1.85	0.89
CD (0.05)	NS	NS	NS	NS	NS	NS	NS

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Table 12c. Effect of M x N x P interaction on weed density m^{-2}

Treatment combinations	Weed density						
	30 DAP	50 DAP	70 DAP	90 DAP	120 DAP	150 DAP	Harvest
$m_1n_1p_1$	44.82	38.07	35.91	20.52	30.78	31.86	15.39
$m_1n_1p_2$	54.27	39.69	33.21	22.41	33.48	36.72	16.47
$m_1n_2p_1$	65.34	46.98	48.06	29.16	33.75	37.80	21.06
$m_1n_2p_2$	59.67	42.93	44.82	28.62	33.48	23.22	21.87
$m_2n_1p_1$	35.10	24.30	30.51	19.98	32.40	19.71	14.04
$m_2n_1p_2$	36.99	31.59	28.35	26.46	27.81	17.82	16.20
$m_2n_2p_1$	37.53	27.81	32.40	28.35	40.50	20.52	16.74
$m_2n_2p_2$	34.02	27.00	30.16	30.24	31.32	24.30	17.82
$m_3n_1p_1$	29.16	22.41	28.89	17.28	31.86	21.33	14.58
$m_3n_1p_2$	26.73	21.06	23.76	22.14	23.76	21.33	16.74
$m_3n_2p_1$	33.75	20.52	27.54	23.22	17.82	20.52	16.20
$m_3n_2p_2$	30.51	22.41	23.82	22.41	31.86	25.65	19.85
SEm±	3.58	2.63	2.56	2.00	2.30	3.21	1.54
CD (0.05)	NS	NS	NS	NS	6.752	9.44	NS

treatment combinations, m_3n_1 and m_3n_2 registered lower weed density which were on par and superior to others. M x P interaction was significant only at 120 DAP and the treatment combinations m_3p_1 and m_3p_2 were on par and superior to others in recording lower weed density. N x P interaction had no significant effect on weed density.

The weed density varied significantly due to M x N x P interaction (Table 12c) only at 120 and 150 DAP. At 120 DAP, the treatment combinations $m_3n_2p_1$ and $m_3n_1p_2$ recorded lower weed density when compared to other combinations and were on par. At 150 DAP, lower weed density was observed with the treatment combinations $m_2n_1p_1$ and $m_2n_1p_2$ which were on par and significantly different from others.

4.5.2 Dry Weight of Weeds m^{-2}

It is evident from Table 13a that weed dry weight m^{-2} was significantly affected by the sources of organic manure at all stages of observation. The treatment FYM @ 12.5 t ha^{-1} (m_1) resulted in the highest weed dry weight at all stages. The treatment PM @ 2.5 t ha^{-1}+ green manuring in situ (m_3) recorded the lowest weed dry weight at all stages of observation except at 90 and 150 DAP. At 90 and 150 DAP, the treatment FYM @ 6.25 t ha^{-1} + green manuring *in* situ (m_2) registered the lowest weed dry weight.

Levels of N had significant effect on weed dry weight at 70, 90 and 120 DAP (Table 13a). At 70 and 90 DAP, the weed dry weight was the lowest with n_1 (50 kg ha^{-1}). But at 120 DAP, the weed density was the lowest with n_2 (75 kg N ha^{-1}). However, levels of P significantly affected the weed dry weight only at 120 DAP. Higher level of P (50 kg P_2O_5 ha^{-1}) recorded the lowest weed dry weight.

M x N interaction (Table 13b) had significant effect weed density m^{-2} at 30 DAP and harvest. The treatment combination m_3n_1 recorded the lowest weed dry weight at both stages but was on par with m_2n_1 at 30 DAP and m_3n_2 and $m_2n_1$at harvest. The interaction M x P was significant at 30 and 70 DAP. At 30 DAP, the weed dry weight was lower with the treatment combinations m_2p_1, m_3p_1 and m_3p_2 which were on par. The treatment combination m_3p_1 registered the lowest weed dry weight at 70 DAP. The

Table 13a. Effect of sources of organic manure and levels of N and P on weed dry weight, g m^{-2}

Treatments	Weed dry weight						
	30 DAP	50 DAP	70 DAP	90 DAP	120 DAP	150 DAP	Harvest
Sources of organic manure (M)							
m_1 - FYM @ 12.5 t ha^{-1}	68.55	64.50	70.39	74.60	30.31	25.52	17.32
m_2 - FYM @ 6.25 t ha^{-1} + GM *in situ*	25.31	37.46	62.45	53.47	23.25	17.12	15.72
m_3 - PM @ 2.5 t ha^{-1} + GM *in situ*	24.07	31.43	55.95	54.87	22.15	17.48	12.31
SEm±	0.70	2.26	2.74	2.01	0.96	1.83	0.58
CD (0.05)	1.934	6.642	0.933	5.897	2.807	5.374	1.688
Levels of Nitrogen (N)							
n_1 - 50 kg ha^{-1}	38.98	41.80	59.18	58.05	27.24	18.50	15.39
n_2 - 75 kg ha^{-1}	39.65	47.11	66.66	63.91	23.22	21.57	14.84
SEm±	0.538	1.85	0.76	1.64	0.78	1.50	0.47
CD (0.05)	NS	NS	2.235	4.815	2.290	NS	NS
Levels of Phosphorus (P)							
p_1 - 25 kg P_2O_5 ha^{-1}	39.56	42.42	62.91	61.91	26.94	19.37	15.01
p_2 - 50 kg P_2O_5 ha^{-1}	39.07	46.50	62.93	60.05	23.54	20.71	15.22
SEm±	0.538	1.85	0.76	1.64	0.78	1.50	0.47
CD (0.05)	NS	NS	NS	NS	2.290	NS	NS

Table 13b. Interaction effects of sources of organic manure and levels of N and P on weed dry weight, g m^{-2}

Interactions	Weed dry weight						
	30 DAP	50 DAP	70 DAP	90 DAP	120 DAP	150 DAP	Harvest
M x N interaction							
m_1n_1	71.28	59.40	66.39	71.96	31.05	25.65	19.58
m_1n_2	65.81	69.59	74.39	77.24	29.57	25.38	15.06
m_2n_1	22.88	35.98	58.73	49.47	25.44	14.64	14.58
m_2n_2	27.74	38.94	66.16	57.45	21.06	19.58	16.87
m_3n_1	22.74	30.03	52.45	52.69	25.25	15.18	12.02
m_3n_2	25.38	32.81	59.45	57.04	19.04	19.77	12.59
SEm±	0.93	3.20	1.32	2.84	1.35	2.59	0.81
CD (0.05)	2.735	NS	NS	NS	NS	NS	2.39
M X P interaction							
m_1p_1	71.22	60.68	72.22	77.58	32.54	25.79	16.34
m_1p_2	65.89	68.31	68.54	71.62	28.08	25.25	18.30
m_2p_1	23.42	33.76	63.15	52.66	25.65	15.67	16.41
m_2p_2	27.20	41.18	61.74	54.28	20.85	18.56	15.05
m_3p_1	24.04	32.81	53.37	55.48	22.61	16.67	12.29
m_3p_2	24.10	30.03	58.53	54.25	21.66	18.29	12.31
SEm±	0.93	3.20	1.32	2.84	1.35	2.59	0.81
CD (0.05)	2.735	NS	3.87	NS	NS	NS	NS
N X P interaction							
n_1p_1	37.76	39.06	57.78	56.52	28.94	18.99	15.12
n_1p_2	40.19	44.55	60.59	59.56	25.56	18.00	15.66
n_2p_1	41.36	45.77	68.04	67.29	24.93	19.76	14.90
n_2p_2	37.94	48.47	65.28	60.53	21.51	23.40	14.78
SEm±	0.76	2.61	1.08	2.32	1.10	2.12	0.64
CD (0.05)	2.23	NS	3.161	6.81	NS	NS	NS

Table 13c. Effect of M x N x P interaction on weed dry weight, g m^{-2}

Treatment combinations	Weed dry weight						
	30 DAP	50 DAP	70 DAP	90 DAP	120 DAP	150 DAP	Harvest
$m_1n_1p_1$	68.58	55.62	67.10	66.96	34.56	27.00	18.09
$m_1n_1p_2$	73.98	63.18	65.67	76.95	27.54	24.30	21.06
$m_1n_2p_1$	73.84	65.75	77.36	88.18	30.51	24.57	14.58
$m_1n_2p_2$	57.78	73.44	71.42	66.29	28.62	26.19	15.53
$m_2n_1p_1$	21.20	32.00	57.38	48.60	27.81	15.26	15.12
$m_2n_1p_2$	24.57	39.96	60.08	50.36	23.09	14.04	14.04
$m_2n_2p_1$	25.65	35.51	68.90	56.70	23.49	16. 07	17.69
$m_2n_2p_2$	29.84	42.39	63.40	58.19	18.63	23.09	16.07
$m_3n_1p_1$	23.49	29.57	48.87	54.00	24.44	14.72	12.15
$m_3n_1p_2$	22.01	30.51	56.03	51.38	26.06	15.66	11.88
$m_3n_2p_1$	24.57	36.05	57.86	56.97	20.79	18.63	12.42
$m_3n_2p_2$	26.19	29.57	61.02	57.11	17.28	20.93	12.75
SEm±	1.32	4.53	1.87	4.02	1.91	3.67	1.15
CD (0.05)	3.867	NS	NS	11.79	NS	NS	NS

weed dry weight was significantly influenced by N x P interaction at 30, 70 and 90 DAP and the treatment combination n_1p_1 recorded the lowest value at all these stages. But, it was on par with n_2p_2 at 30 DAP, n_1p_2 at 70 DAP and n_1p_2 and n_2p_2 at 90 DAP.

Weed dry weight was significantly influenced by M x N x P interaction (Table 13c) at 30 and 90 DAP only. At 30 DAP, the treatment combinations involving m_2 and m_3 except $m_2n_2p_2$ and $m_3n_2p_2$ registered lower weed dry weight and were on par. At 90 DAP, weed dry weight was lower with all treatment combinations involving m_2 and m_3.

4.6 UPTAKE OF NUTRIENTS

The effects of treatments on the uptake of N, P and K are summarized in Table 14a, 14b and 14c.

4.6.1 N Uptake

As depicted in Table 14a, uptake of N varied significantly due to source of organic manure and N and P levels. It can be seen that the treatment PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) resulted in higher N uptake and was significantly superior to others. When the N level was increased from 50 kg ha^{-1} (n_1) to 75 kg ha^{-1} (n_2), N uptake was also found to increase from 150.08 kg ha^{-1} to 181.57 kg ha^{-1}. However, lower level of P (25 kg P_2O_5 ha^{-1}) produced higher N uptake.

Among M x N, M x P and N x P interactions (Table 14b), only M x N was found significant and the treatment combination m_3n_2 could produce significantly higher N uptake.

M x N x P interaction did not produce any significant variation in N uptake (Table 14c).

4.6.2 P Uptake

Table 14a revealed the significant effect of sources of organic manure and levels of N on P uptake. Similar to N uptake, the treatment PM @ 2.5 t ha^{-1} + green manuring

Table 14a. Effect of sources of organic manure and levels of N and P on nutrient uptake, kg ha^{-1}

Treatments	N uptake	P uptake	K uptake
Sources of organic manure (M)			
m_1 - FYM @ 12.5 t ha^{-1}	112.58	46.55	140.81
m_2 - FYM @ 6.25 t ha^{-1} + GM *in situ*	167.62	53.56	175.74
m_3 - PM @ 2.5 t ha^{-1} + GM *in situ*	217.29	65.05	209.41
SEm±	2.36	1.00	2.49
CD (0.05)	6.924	2.931	7.291
Levels of Nitrogen (N)			
n_1 - 50 kg ha^{-1}	150.08	49.74	160.90
n_2 - 75 kg ha^{-1}	181.57	60.37	189.74
SEm±	1.93	0.82	2.03
CD (0.05)	5.659	2.393	5.953
Levels of Phosphorus (P)			
p_1 - 25 kg P_2O_5 ha^{-1}	170.36	55.60	174.11
p_2 - 50 kg P_2O_5 ha^{-1}	161.29	54.51	176.52
SEm±	1.93	0.82	2.03
CD (0.05)	5.659	NS	NS

Table 14b. Interaction effects of sources of organic manure and levels of N and P on nutrient uptake, kg ha^{-1}

Interactions	N uptake	P uptake	K uptake
M x N interaction			
m_1n_1	102.05	38.91	124.27
m_1n_2	123.10	54.18	157.33
m_2n_1	150.99	49.66	161.16
m_2n_2	184.24	57.47	190.32
m_3n_1	197.18	60.65	197.27
m_3n_2	237.40	69.46	221.54
SEm±	3.40	1.41	3.52
CD (0.05)	9.791	4.146	NS
M x P interaction			
m_1p_1	113.62	46.72	141.34
m_1p_2	111.53	46.37	140.27
m_2p_1	173.21	53.83	171.27
m_2p_2	162.00	53.30	180.22
m_3p_1	224.26	66.25	209.74
m_3p_2	210.32	63.85	209.08
SEm±	3.40	1.41	3.52
CD (0.05)	NS	NS	NS
N X P interaction			
n_1p_1	153.96	50.12	157.96
n_1p_2	146.19	49.36	163.84
n_2p_1	186.77	61.08	190.27
n_2p_2	176.38	59.66	189.21
SEm±	2.73	1.15	2.87
CD (0.05)	NS	NS	NS

Table 14c. Effect of M x N x P interaction on nutrient uptake, kg ha^{-1}

Treatment combinations	N uptake	P uptake	K uptake
$m_1n_1p_1$	103.66	39.20	125.00
$m_1n_1p_2$	100.45	38.62	123.55
$m_1n_2p_1$	123.56	54.25	157.68
$m_1n_2p_2$	122.62	54.12	157.00
$m_2n_1p_1$	158.54	50.08	155.06
$m_2n_1p_2$	143.43	49.24	167.26
$m_2n_2p_1$	187.90	57.58	187.48
$m_2n_2p_2$	180.58	57.36	193.17
$m_3n_1p_1$	199.68	61.08	193.84
$m_3n_1p_2$	194.69	60.22	200.71
$m_3n_2p_1$	248.85	71.42	225.64
$m_3n_2p_2$	225.93	67.49	217.45
SEm±	4.72	2.00	4.97
CD (0.05)	NS	NS	NS

in situ (m_3) registered the highest P uptake (65.05 kg ha^{-1}) . N@ 75 kg ha^{-1} resulted in higher P uptake compared to 50 kg ha^{-1}. No significant variation in P uptake was observed due to increase in P level.

In the case of M x N, M x P and N x P interactions, only M x N had significant effect on P uptake (Table 14b). The treatment combination m_3n_2 resulted in the highest P uptake followed by m_3n_1, which was on par with m_2n_2.

M x N x P interaction failed to produce any significant variation in P uptake (Table 14c).

4.6.3 K Uptake

It can be seen from Table 14a that K uptake varied significantly due to sources of organic manure. The treatment PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) recorded the highest K uptake. Significant variation in K uptake was also observed due to levels of N. Application of N @ 75 kg ha^{-1} recorded higher K uptake (189.74 kg ha^{-1}) than 50 kg ha^{-1}.

None of the interaction were significant with respect to K uptake (Table 14b and 14c).

4.7 SOIL ANALYSIS AFTER THE EXPERIMENT

The data on the effect of sources of organic manure and levels of N and P and their interactions on soil pH and organic carbon status in the soil after the experiment are presented in Table 15a, 15b and 15c. The data on post experiment soil available N, P and K status as influenced by sources of organic manure and levels of N and P are depicted in Table 16a, 16b and 16c.

Table 15a. Effect of sources of organic manure and levels of N and P on soil pH and organic carbon status in the soil.

Treatments	Soil pH	Organic Carbon (%)
Sources of organic manure (M)		
m_1 - FYM @ 12.5 t ha^{-1}	5.99	1.73
m_2 - FYM @ 6.25 t ha^{-1} + GM *in situ*	5.86	1.85
m_3 - PM @ 2.5 t ha^{-1} + GM *in situ*	6.28	1.95
SEm±	0.06	0.02
CD (0.05)	0.180	0.069
Levels of nitrogen (N)		
n_1 - 50 kg ha^{-1}	6.11	1.82
n_2 - 75 kg ha^{-1}	5.98	1.87
SEm±	0.05	0.02
CD (0.05)	NS	NS
Levels of phosphorus (P)		
p_1 - 25 kg P_2O_5 ha^{-1}	6.02	1.84
p_2 - 50 kg P_2O_5 ha^{-1}	6.05	1.85
SEm±	0.05	0.02
CD (0.05)	NS	NS

Table 15b. Interaction effects of sources of organic manure and levels of N and P on soil pH and organic carbon status in the soil

Interactions	Soil pH	Organic Carbon (%)
M x N interaction		
m_1n_1	6.07	1.69
m_1n_2	5.89	1.77
m_2n_1	5.91	1.86
m_2n_2	5.83	1.84
m_3n_1	6.33	1.92
m_3n_2	6.21	1.97
SEm±	0.09	0.03
CD (0.05)	NS	NS
M X P interaction		
m_1p_1	5.91	1.72
m_1p_2	6.06	1.74
m_2p_1	5.84	1.83
m_2p_2	5.90	1.90
m_3p_1	6.33	1.97
m_3p_2	6.22	1.93
SEm±	0.09	0.03
CD (0.05)	NS	NS
N X P interaction		
n_1p_1	6.10	1.81
n_1p_2	6.11	1.84
n_2p_1	5.95	1.86
n_2p_2	6.01	1.86
SEm±	0.07	0.03
CD (0.05)	NS	NS

Table 15c. Effect of M x N x P interaction on soil pH and organic carbon status in the soil.

Treatment combinations	Soil pH	Organic Carbon (%)
$m_1n_1p_1$	6.03	1.66
$m_1n_1p_2$	6.10	1.73
$m_1n_2p_1$	5.80	1.79
$m_1n_2p_2$	6.00	1.73
$m_2n_1p_1$	5.88	1.86
$m_2n_1p_2$	5.92	1.88
$m_2n_2p_1$	5.80	1.79
$m_2n_2p_2$	5.87	1.90
$m_3n_1p_1$	6.39	1.92
$m_3n_1p_2$	6.29	1.91
$m_3n_2p_1$	6.26	2.00
$m_3n_2p_2$	6.16	1.95
SEm±	0.12	0.05
CD (0.05)	NS	NS

4.7.1 Soil pH

Soil pH varied significantly due to sources of organic manure (Table 15a). The treatment PM @ 2.5 t ha^{-1} + green manuring *in situ* recorded the highest pH of 6.28. Levels of N and P had no significant effect on soil pH.

The interactions, M x N, M x P, N x P and M x N x P had no significant effect on soil pH (Table 15b and 15c.)

4.7.2 Organic Carbon

Table 15a reveals the effect of sources of organic manure and levels of N and P on soil organic carbon status. It can be seen that organic carbon varied significantly due to sources of organic carbon and the treatment PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) showed the highest content of organic carbon (1.95 %). Levels of N and P had no significant influence on organic carbon status.

None of the interactions had significant effect on organic carbon status in the soil. (Table 15b and 15c)

4.7.2 Available Nitrogen

As shown in Table 16a, only sources of organic manure had significant effect on available N status in the soil after the experiment. The treatment PM @ 2.5 t ha^{-1} + green manuring *in situ* recorded the highest available nitrogen (300.04 kg ha^{-1}). Neither the levels of N nor the levels of P had significant effect on available nitrogen.

The interaction effects were not significant for this character (Table 16b, 16c).

4.7.3 Available Phosphorus

The results (Table 16a) showed that there was significant difference available P due to sources of organic manure and levels of N and P. Among the sources of organic manure, PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) recorded the highest content of available P (64.17 kg ha^{-1}) which was superior to other treatments. Available P content

Table 16a. Effect of sources of organic manure and levels of N and P on available N, P and K status in the soil, kg ha^{-1}

Treatments	Available N	Available P	Available K
Sources of organic manure (M)			
m_1 - FYM @ 12.5 t ha^{-1}	251.92	58.54	204.67
m_2 - FYM @ 6.25 t ha^{-1} + GM *in situ*	284.43	56.20	216.29
m_3 - PM @ 2.5 t ha^{-1} + GM *in situ*	300.04	64.17	228.04
SEm±	6.15	1.23	5.63
CD (0.05)	18.049	3.569	16.516
Levels of nitrogen (N)			
n_1 - 50 kg ha^{-1}	274.59	56.26	218.75
n_2 - 75 kg ha^{-1}	283.00	63.02	213.90
SEm±	5.02	1.00	4.60
CD (0.05)	NS	2.918	NS
Levels of phosphorus (P)			
p_1 - 25 kg P_2O_5 ha^{-1}	276.03	55.37	221.21
p_2 - 50 kg P_2O_5 ha^{-1}	281.57	63.90	211.46
SEm±	5.02	1.00	4.60
CD (0.05)	NS	2.918	NS

Table 16b. Interaction effects of sources of organic manure and levels of N and P on available N, P and K status in the soil, kg ha^{-1}

Interactions	Available N	Available P	Available K
M x N interaction			
m_1n_1	242.52	54.06	200.53
m_1n_2	261.34	63.01	208.82
m_2n_1	273.88	54.37	225.92
m_2n_2	294.97	58.04	206.64
m_3n_1	307.40	60.34	229.83
m_3n_2	292.69	68.00	226.25
SEm±	8.70	1.73	7.96
CD (0.05)	NS	NS	NS
M X P interaction			
m_1p_1	250.88	55.65	209.97
m_1p_2	252.96	61.42	199.40
m_2p_1	280.24	52.54	221.25
m_2p_2	288.61	59.87	211.32
m_3p_1	296.95	57.90	232.42
m_3p_2	303.15	70.44	223.64
SEm±	8.70	1.73	7.96
CD (0.05)	NS	NS	NS
N X P interaction			
n_1p_1	271.83	53.63	227.29
n_1p_2	277.36	58.89	210.23
n_2p_1	280.21	57.10	215.14
n_2p_2	285.78	68.93	212.68
SEm±	7.10	1.42	6.50
CD (0.05)	NS	4.121	NS

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Table 16c. Effect of M x N x P interaction on available N, P and K status in the soil, kg ha^{-1}

Treatment combinations	Available N	Available P	Available K
$m_1n_1p_1$	238.34	53.04	207.87
$m_1n_1p_2$	246.70	55.08	193.20
$m_1n_2p_1$	263.42	58.26	212.06
$m_1n_2p_2$	259.24	67.76	205.58
$m_2n_1p_1$	271.79	51.70	232.33
$m_2n_1p_2$	275.97	57.05	219.50
$m_2n_2p_1$	288.69	53.39	210.15
$m_2n_2p_2$	301.24	62.69	203.15
$m_3n_1p_1$	305.37	56.14	241.66
$m_3n_1p_2$	309.42	64.52	217.98
$m_3n_2p_1$	288.51	59.65	223.20
$m_3n_2p_2$	296.87	76.35	229.30
SEm±	12.30	2.45	11.26
CD (0.05)	NS	NS	NS

significantly increased when N level was increased from 50 to 75 kg ha^{-1}. Higher level of P (50 kg P_2O_5 ha^{-1}) recorded significant increase in available P status.

Among the interactions in Table 16b, only N x P had significant effect on available P status. The treatment combination n_2p_2 recorded higher status of available P after the experiment and was superior to others.

The effect of the interaction M x N x P was not significant for this parameter (Table 16c).

4.7.4 Available Potassium

As presented in Table 15a, only source of organic manure had significant effect on available K status in the soil. The treatment PM @ 2.5 t ha^{-1} + green manuring *in situ* recorded the highest available K status in the soil (228.04 kg ha^{-1}) after the experiment.

None of the interactions were significant with respect to this parameter (Table 16b and 16c).

4.8 INCIDENCE OF PEST AND DISEASE

No incidence of pest and disease was noticed in the field during the cropping period. Though the var. Vellayani Hraswa is susceptible to cassava mosaic disease which is commonly found in Kerala, the crop of this study was free from that disease. The planting material for the present study was taken exclusively from mosaic free crop at IFSRS, Karamana, Thiruvananthapuram.

4.9 ECONOMICS OF CULTIVATION

The economics of cultivation was worked out in terms of net income and BCR considering the cost of inputs and price of produce during the cropping period as given in Appendix II. The data on the effect of source of organic manure and levels of N and P and their interactions on net income and BCR are summarized in Table 17a, 17b and 17c.

4.9.1 Net Income

It can be seen from Table 17a that net income varied significantly due to the sources of organic manure. Application of PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) recorded the highest net income of ₹ 336874 ha^{-1} followed by the application of FYM @ 6.25 t ha^{-1} + green manuring *in situ* (m_2). The data clearly indicated that the recommended dose of FYM could be partially substituted with green manuring *in situ* or fully substituted with PM @ 2.5 t ha^{-1} + green manuring *in situ*. Levels of N significantly influenced the net income. When the N level was increased from n_1 (50 kg ha^{-1}) to n_2 (75 kg ha^{-1}), the net income was increased from ₹ 271800 ha^{-1} to ₹ 314306 ha^{-1}. But the levels of P had no significant influence on net income.

Among the interactions, only M x N interaction and M x P interaction significantly influenced net income (Table 17b). The treatment combination m_3n_2 recorded the highest net income of ₹ 347828 ha^{-1}, which was superior to others. In the case of M x P interaction, the treatment combination m_3p_1 was found superior registering the highest net income of ₹ 347149 ha^{-1}.

Significant variation in net income was observed due to M x N x P interaction (Table 17c). Application of PM @ 2.5 t ha^{-1} + green manuring *in situ* along with 75 kg N ha^{-1} and 25 kg P_2O_5 ha^{-1} ($m_3n_2p_1$) recorded the highest net income of ₹ 373240 ha^{-1}.

4.9.2 Benefit Cost Ratio.

The data in Table 17a revealed the significant effect of sources of organic manure and N levels on BCR as in the case of net income. The highest BCR of 2.97 was obtained due to application of PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3). This was followed by the application of FYM @ 6.25 t ha^{-1} + green manuring *in situ* (m_2) indicating the feasibility of substitution of FYM. Similar to net income, BCR significantly increased from 2.61 to 2.87 when the N level was increased from 50 kg ha^{-1} (n_1) to 75 kg ha^{-1}(n_2). But, lower level of P (25 kg P_2O_5 ha^{-1}) resulted in higher BCR than P @ 50 kg P_2O_5 ha^{-1}.

Table 17a. Effect of sources of organic manure and levels of N and P on economics of cultivation

Treatments	Net income (₹ ha^{-1})	BCR
Sources of organic manure (M)		
m_1 - FYM @ 12.5 t ha^{-1}	245714	2.51
m_2 - FYM @ 6.25 t ha^{-1} + GM *in situ*	296571	2.72
m_3 - PM @ 2.5 t ha^{-1} + GM *in situ*	336874	2.97
SEm±	4894	0.03
CD (0.05)	14353	0.080
Levels of Nitrogen (N)		
n_1 - 50 kg ha^{-1}	271800	2.61
n_2 - 75 kg ha^{-1}	314306	2.87
SEm±	3996	0.02
CD (0.05)	11720	0.066
Levels of Phosphorus (P)		
p_1 - 25 kg P_2O_5 ha^{-1}	298178	2.77
p_2 - 50 kg P_2O_5 ha^{-1}	287928	2.69
SEm±	3996	0.02
CD (0.05)	NS	NS

Table 17b. Interaction effects of sources of organic manure and levels of N and P on economics of cultivation

Interaction effects	Net income (₹ ha^{-1})	BCR
M x N interaction		
m_1n_1	212299	2.32
m_1n_2	279130	2.73
m_2n_1	277180	2.60
m_2n_2	315962	2.83
m_3n_1	325921	2.91
m_3n_2	347828	3.04
SEm±	6921	0.04
CD (0.05)	20299	0.118
M X P interaction		
m_1p_1	237351	2.48
m_1p_2	254078	2.56
m_2p_1	310033	2.80
m_2p_2	283108	2.63
m_3p_1	347149	3.04
m_3p_2	326599	2.91
SEm±	6921	0.04
CD (0.05)	20299	0.118
N X P interaction		
n_1p_1	277995	2.66
n_1p_2	265604	2.57
n_2p_1	318360	2.89
n_2p_2	310252	2.83
SEm±	5651	0.03
CD (0.05)	NS	NS

Table 17c. Effect of M x N x P interaction economics of cultivation

Treatment combinations	Cost of cultivation (₹ ha^{-1})	Gross income (₹ ha^{-1})	Net income (₹ ha^{-1})	BCR
$m_1n_1p_1$	160690	378500	217810	2.36
$m_1n_1p_2$	162562	369350	206788	2.27
$m_1n_2p_1$	161308	418200	256892	2.60
$m_1n_2p_2$	163183	464550	301367	2.85
$m_2n_1p_1$	171483	466600	295117	2.72
$m_2n_1p_2$	173358	432600	259242	2.50
$m_2n_2p_1$	172101	497050	324949	2.89
$m_2n_2p_2$	173976	480950	306974	2.76
$m_3n_1p_1$	169492	490550	321058	2.89
$m_3n_1p_2$	171367	502150	330783	2.93
$m_3n_2p_1$	170110	527900	373240	3.19
$m_3n_2p_2$	171985	494400	322415	2.88
SEm±			9787	0.06
CD (0.05)			28706	0.161

The BCR significantly varied only due to M x N and M x P interaction effects (Table 17b). Among M x N interaction, the treatment combination m_3n_2 recorded the highest BCR (3.04). With respect to M x P interaction, the treatment combination m_3p_1 recorded the highest BCR (3.04) which was superior to others.

Table 17c revealed the significant effect of M x N x P interaction on BCR. Significantly higher BCR of 3.19 could be obtained by the application of PM @ 2.5 t ha^{-1} + green manuring *in situ* along with 75 kg N ha^{-1} and 25 kg P_2O_5 ha^{-1} ($m_3n_2p_1$) which also resulted in the highest net income.

4.10 CORRELATION ANALYSIS

Correlation analysis of yield *vs* LAI, yield components and nutrient uptake as well as TDMP *vs* LAI and nutrient uptake was done and data are presented in Table 18a and 18b.

It can be seen that tuber yield was significantly and positively correlated with LAI at 4 MAP and harvest, yield components *viz.* number and weight of tubers $plant^{-1}$ and mean tuber weight and NPK uptake (Table 18a).

It is observed from Table 18b that TDMP was significantly and positively correlated with LAI at 4 MAP and harvest and N, P and K uptake.

Table 18a. Correlation analysis of yield *vs* LAI, yield components and nutrient uptake

Variables correlated with tuber yield	Correlation coefficient (r)
LAI at 4 MAP	0.649**
LAI at harvest	0.538**
Number of tubers plant^{-1}	0.517**
Tuber weight plant^{-1}	0.899**
Mean tuber weight	0.675**
N uptake	0.888**
P uptake	0.877**
K uptake	0.665**

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

Table 18b. Correlation analysis of TDMP *vs* LAI and nutrient uptake

Variables correlated with TDMP	Correlation coefficient (r)
LAI at 4 MAP	0.809**
LAI at harvest	0.698**
N uptake	0.930**
P uptake	0.933**
K uptake	0.869**

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

DISCUSSION

5. DISCUSSION

The results of the experiment conducted to standardize the nutrient management for productivity enhancement of cassava var. Vellayani Hraswa in lowlands are discussed in this chapter.

5.1 GROWTH CHARACTERS

Growth characters of cassava *viz.* plant height, number of branches plant^{-1}, total number of leaves plant^{-1}, number of functional leaves plant^{-1} and LAI were recorded at bimonthly intervals from 2 MAP onwards. The crop was harvested at 6 MAP. In general, all the growth characters showed an increasing trend upto harvest (Table 2a to 6c). The number of functional leaves plant^{-1} (Table 5a, 5b and 5c) and LAI (Table 6a, 6b and 6c) were the highest observed at harvest with all the treatments, indicating higher leaf retention of the var. Vellayani Hraswa. Data on branch number (Table 3a, 3b and 3c) indicated good branching characteristics of the variety. No marked variation in growth characters due to treatments was observed at 2 MAP except the effects of N x P interaction on functional leaf number (Table 5b) and levels of N and P as well as M x P and N x P interactions on LAI (Table 6a and 6b). This showed that cassava took two months for establishment irrespective of the treatments.

Among the sources of organic manure, combined application of organic manure and green manure registered higher values of growth characters. Significant influence of combined application of organic manure, green manure and inorganic fertilizer on growth characters of cassava *viz* plant height, branch number and leaf length and breadth has been reported by Mhaskar *et al.* (2013). Regarding green manuring treatments in the present study, PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) produced taller plants with higher branch number, total and functional leaf number and LAI at 4 MAP and harvest (Fig. 3 to 7). But, it was on par with FYM @ 6.25 t ha^{-1} + green manuring *in situ* (m_2) in the case of plant height and total leaf number at harvest (Table 2a and 4a). Pamila (2003) has already suggested the suitability of PM as an alternative to FYM for cassava cultivation in lowlands. She observed that PM @ 5 t ha^{-1} could produce LAI and total dry matter on par with FYM @ 12.5 t ha^{-1}. In the present study, 50 per cent of the FYM dose for cassava (12.5 t ha^{-1}) was substituted with green manuring *in situ* (cowpea) in m_2 treatment and in m_3 treatment, the balance 6.25 t ha^{-1} of FYM has been substituted with 2.5 t ha^{-1} of PM in accordance with the findings of Nayar and Potty (1996) and Pamila (2003).

Significant influence of levels of N on plant height, number of branches $plant^{-1}$ and LAI at 4 MAP and harvest and leaf number $plant^{-1}$ at all growth stages was observed. In all these cases, application of 75 kg ha^{-1} (n_2) was found superior (Fig. 3 to 7). Pamila (2003) also obtained superior values of growth characters of short duration varieties of cassava in lowlands due to application of 75 kg N ha^{-1}. She also found that N @ 75 kg ha^{-1} was sufficient with any source of organic manure tried (FYM, PM and coirpith compost) to produce the highest leaf number and LAI of cassava in lowlands.

Levels of P had significant influence only on branch number at harvest (Table 3a), functional leaf number at 4 MAP (Table 5a) and LAI at 2 MAP (Table 6a) where in 50 kg P_2O_5 (p_2) registered higher branch number and 25 kg P_2O_5 (p_1) recorded higher functional leaf number and LAI. Sekhar (2004) also did not obtain significant effect of P levels on plant height and leaf number at any stage of cassava var. Vellayani Hraswa in uplands. It is evident that application of lower level of P (25 kg P_2O_5 ha^{-1}) is sufficient to improve growth characters of cassava in lowlands.

Considering interaction effects, M x N and M x P interactions had significant effect only on branch number and LAI at 4 MAP and harvest. In the case of M x N interaction, application of PM @ 2.5 t ha^{-1} + green manuring *in situ* along with 75 kg N ha^{-1} (m_3n_2) and with respect to M x P interaction, PM @ 2.5 t ha^{-1} + green manuring *in situ* along with 25 kg P_2O_5 ha^{-1} (m_3p_1) recorded the highest branch number (Table 3b) and LAI (Table 6b) at both the stages reflecting the main effects. Leaf characteristics *viz.* number, retention and LAI varied markedly due to N x P interaction

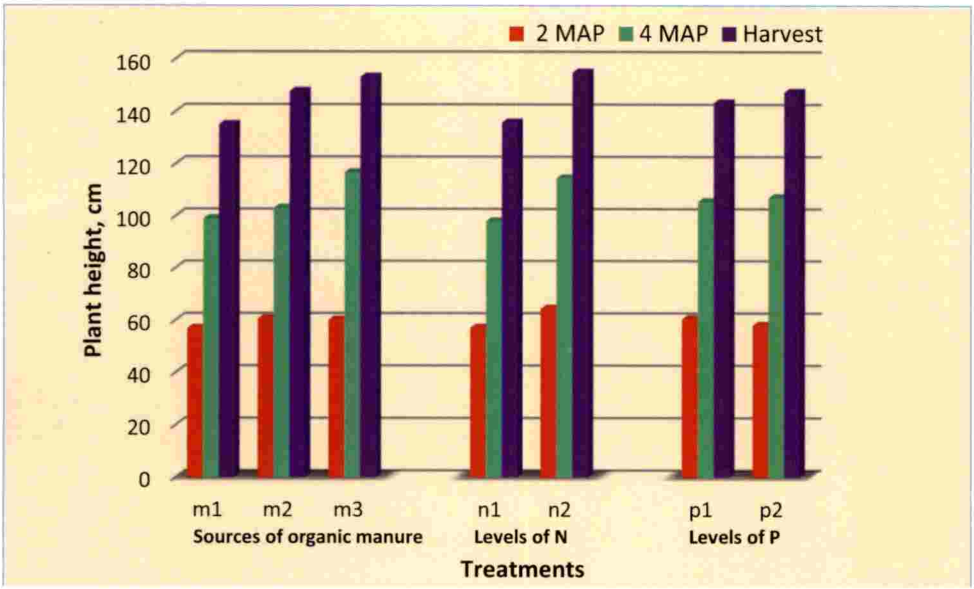


Fig. 3 Effect of sources of organic manure and levels of N and P on plant height, cm

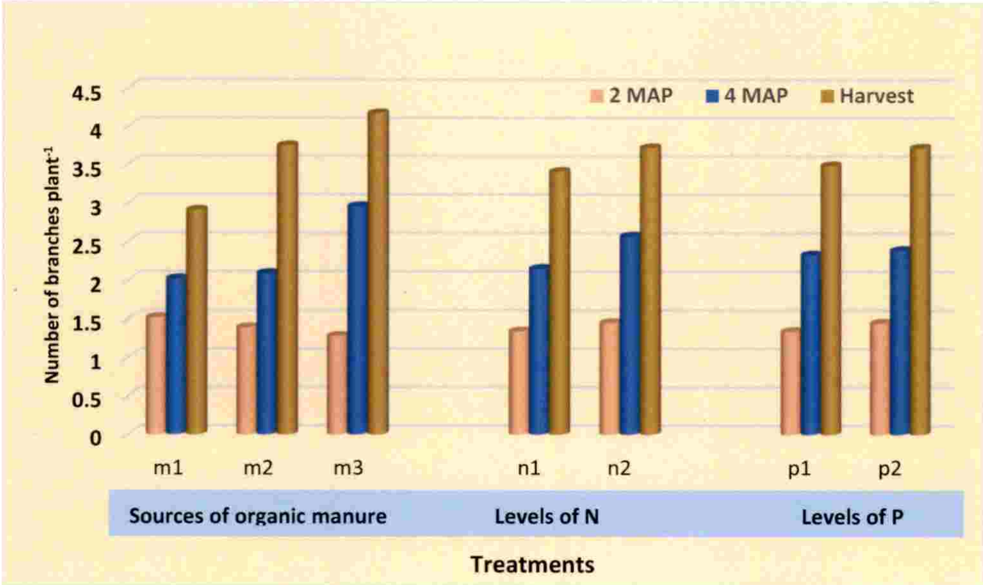


Fig. 4 Effect of sources of organic manure and levels of N and P on number of branches plant^{-1}

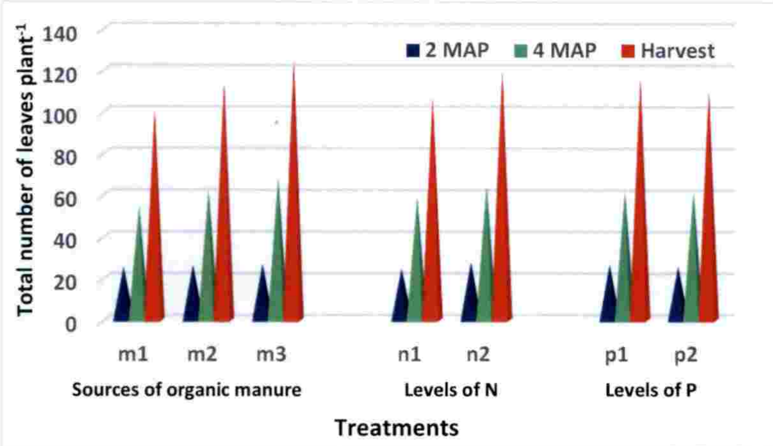


Fig. 5 Effect of sources of organic manure and levels of N and P on total number of leaves plant^{-1}

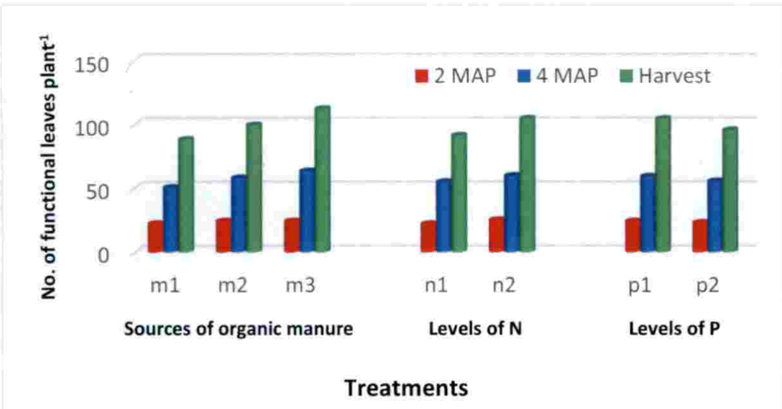


Fig. 6 Effect of sources of organic manure and levels of N and P on number of functional leaves plant^{-1}

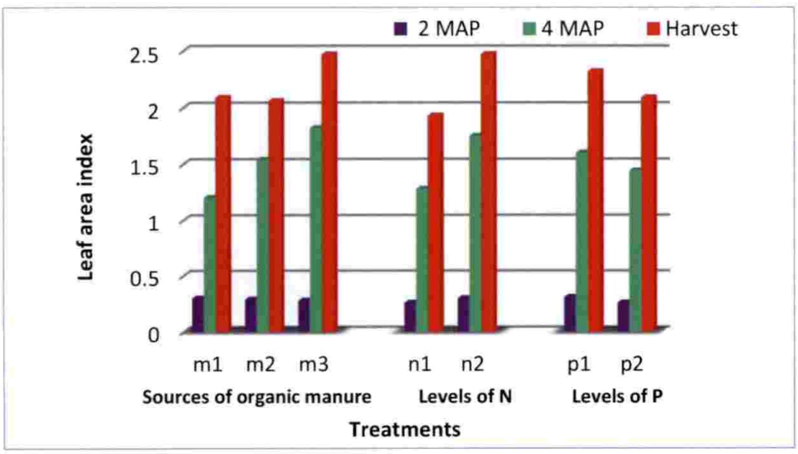


Fig. 7 Effect of sources of organic manure and levels of N and P on leaf area index

at 2 MAP and 4 MAP (Table 4b, 5b and 6b). Application of 75 kg N ha^{-1} + 25 kg P_2O_5 ha^{-1} (n_2p_1) registered the highest number and retention of leaves and LAI at both stages. M x N x P interaction failed to produce marked variation in growth characters.

5.2 YIELD ATTRIBUTES AND YIELD

Green manured plots showed significant improvement in yield attributes except tuber girth and rind to flesh ratio (Table 7a). Improvement in growth characters of cassava by green manuring *in situ* with cowpea culminated in the improvement in yield attributes. As in the case of growth characters, application of PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) registered higher number and weight of tubers $plant^{-1}$ (Fig. 8 and 11a), percentage of productive roots (Fig. 9) and length and mean weight of tuber (Fig. 10) and lower rind to flesh ratio. However, it was on par with FYM @ 6.25 t ha^{-1} + green manuring *in situ* (m_2) in tuber length and FYM @ 12.5 t ha^{-1} (m_1) in the case of rind to flesh ratio (Table 7a). Superior response of cassava, in terms of yield components, to application of PM than FYM, combined with fertilizers has been reported by Pamila *et al.* (2006).

The yield attributes except rind to flesh ratio markedly increased (Table 7a) when the level of N was increased from 50 (n_1) to 75 kg ha^{-1} (n_2).This is in agreement with the findings of Pamila (2003). However, levels of P had significant influence only on percentage of productive roots $plant^{-1}$, tuber weight $plant^{-1}$ and tuber girth (Table 7a). Application of 50 kg P_2O_5 ha^{-1} (p_2) produced higher percentage of productive roots $plant^{-1}$ (Fig. 9) and tuber girth while 25 kg P_2O_5 ha^{-1} (p_1) produced higher tuber weight $plant^{-1}$ (Fig 11a). The treatment combination $m_3n_2p_1$ registered significantly higher tuber weight $plant^{-1}$ (Fig. 11b) reflecting the main effects. Mhaskar *et al.* (2013) also obtained higher tuber yield $plant^{-1}$ due to combined application of organic manure, green manure and inorganic fertilizer in cassava.

The tuber yield was significantly and positively correlated with LAI at 4 MAP and harvest, number and weight of tubers $plant^{-1}$ and mean tuber weight (Table 18a).

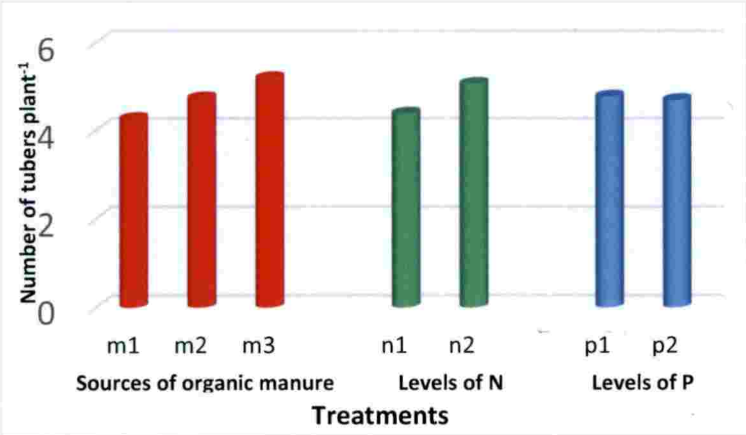


Fig. 8 Effect of sources of organic manure and levels of N and P on number of tubers plant^{-1}

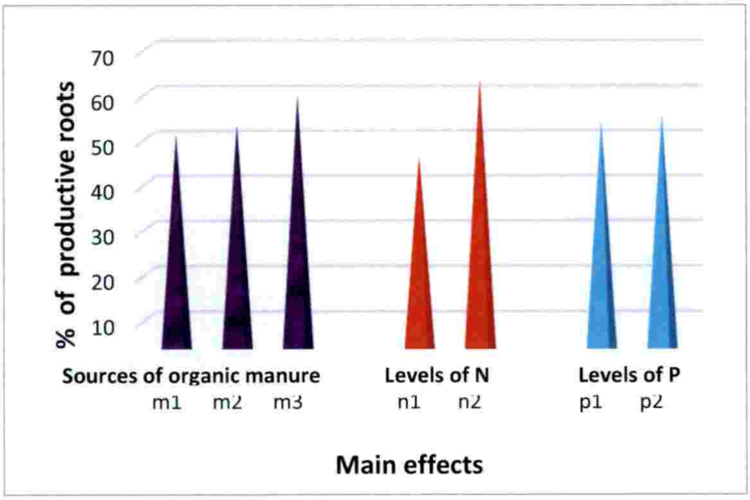


Fig. 9 Effect of sources of organic manure and levels of N and P on percentage of productive roots plant^{-1}

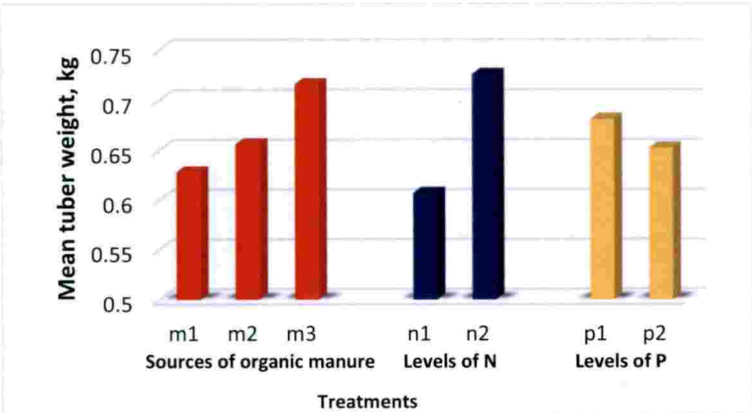


Fig. 10 Effect of sources of organic manure and levels of N and P on mean tuber weight, kg

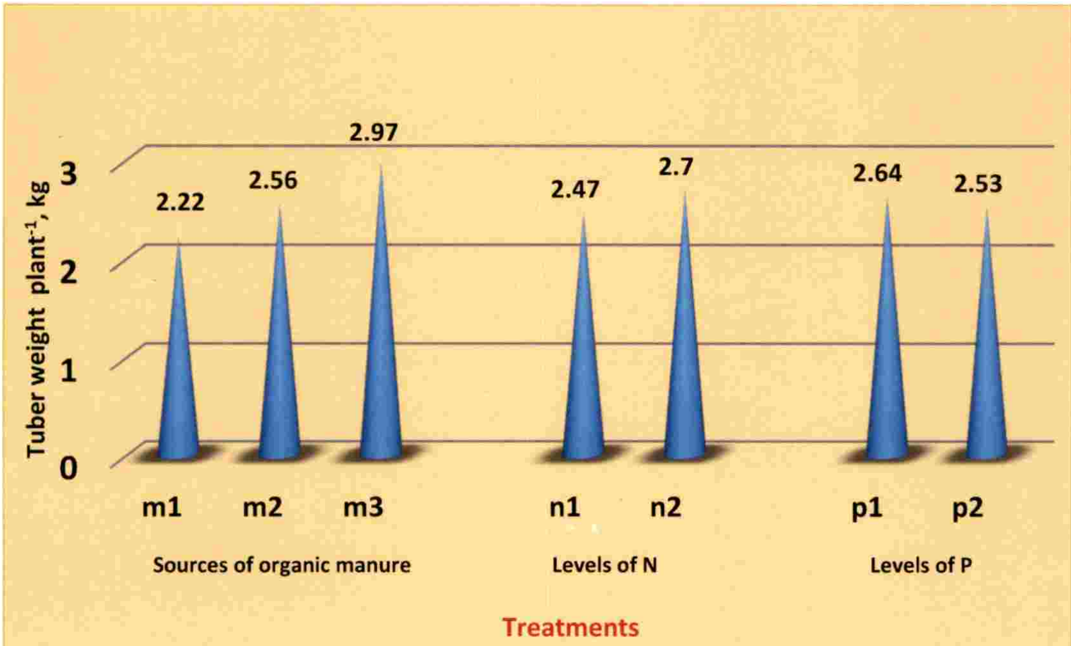


Fig. 11a Effect of sources of organic manure and levels of N and P on tuber weight plant^{-1}, kg

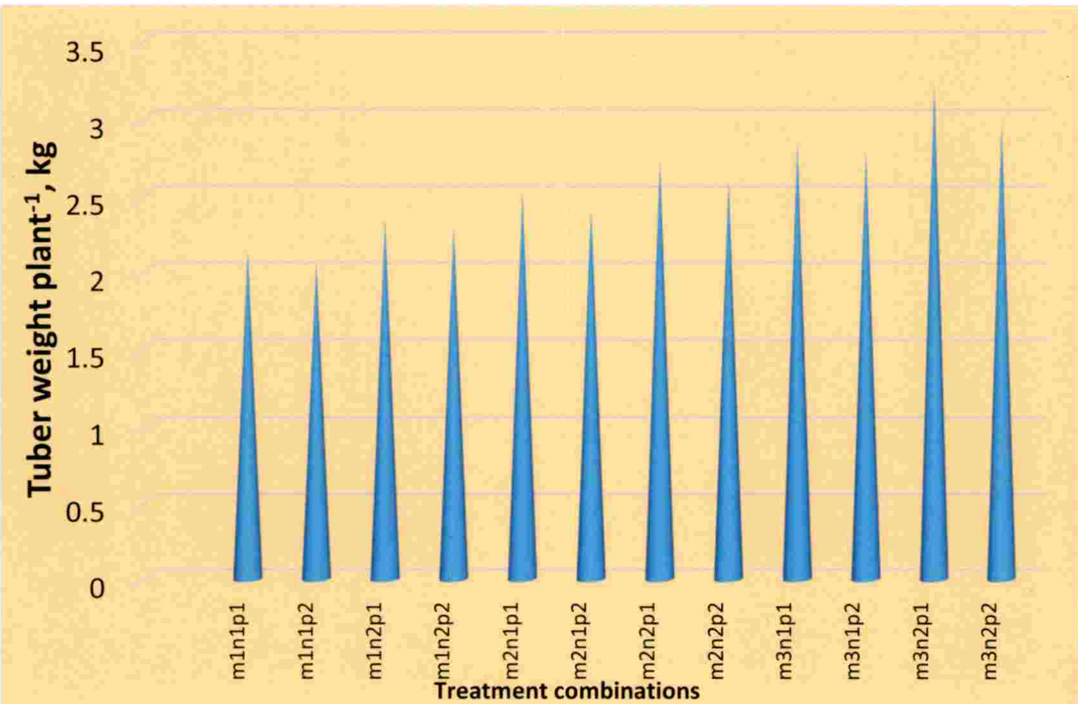


Fig. 11b Effect of treatment combinations on tuber weight plant^{-1}, kg

Regarding sources of organic manure, application of even recommended dose of FYM (12.5 t ha^{-1}) could produce an yield of 27.18 t ha^{-1} (Table 8a). However, higher tuber yields were obtained from green manured plots (Fig. 12a) which might be due to significant improvement in yield attributes by green manuring *in situ.* The feasibility of raising cowpea in between cassava and incorporation in the field under lowland situation has been reported by Mohankumar and Nair (1990) and Mohankumar (2000). Nayar and Potty (1996) and Asok *et al.* (2013) had reported the possibility of substitution of FYM with green manuring *in situ* (cowpea) along with recommended dose of NPK. Among green manuring treatments, the highest tuber yield of 33.85 t ha^{-1} (Table 8a) was produced by PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) followed by FYM @ 6.25 t ha^{-1} + green manuring *in situ* (m_2). Similar trend was observed in the case of top yield also. The results suggested PM and green manuring *in situ* as alternatives to FYM for cassava cultivation for enhanced tuber yield. Substitution of 50 per cent FYM with green manuring *in situ* registered 15 per cent increase and full substitution of FYM with PM + green manuring *in situ* recorded 24.5 per cent increase in tuber yield over FYM alone. Pamila *et al.* (2006) reported the highest tuber yield of cassava in lowlands with PM application compared to FYM. Odedina *et al.* (2012) obtained an yield of 30.1 t ha^{-1} in cassava by the application of PM @ 5 t ha^{-1}. Temegne and Ngome, (2017) suggested combined application of PM and chemical fertilizers to obtain a stable increase in cassava yields.

Significant increase in tuber yield as well as top yield was observed when N level was increased from 50 (n_1) to 75 kg ha^{-1} (n_2) as evident from Fig. 12a. This is in conformity of the findings of Pamila (2003). No marked variation in tuber and top yields was observed due to levels of P which might be due to high initial status of available P in the soil. Lower level of P (p_1 - 25 kg P_2O_5 ha^{-1}) recorded higher tuber and top yields emphasizing low requirement of P for cassava (Fig. 12a). However, omission of P from fertilizer mixtures for cassava may result in yield reduction as

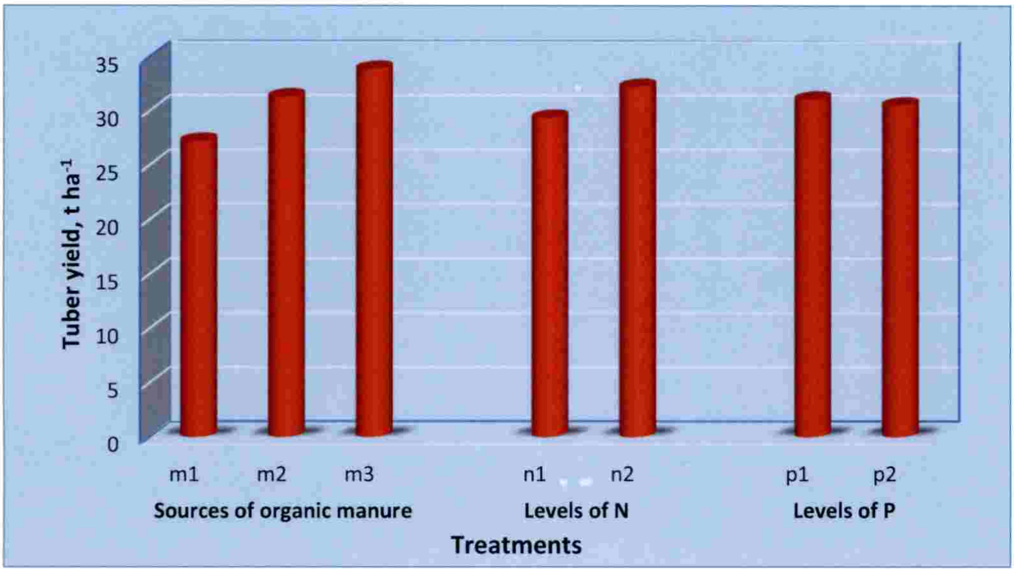


Fig. 12a Effect of sources of organic manure and levels of N and P on tuber yield, t ha^{-1}

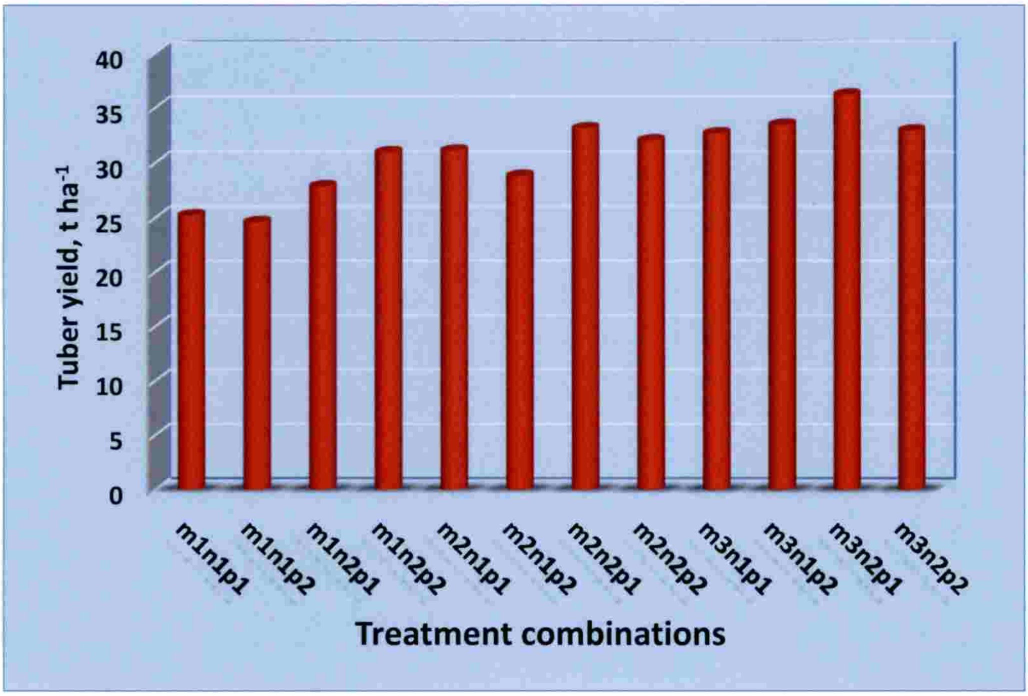
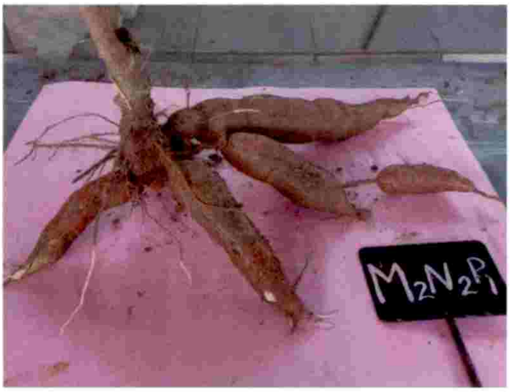


Fig. 12b. Effect of treatment combinations on tuber yield, t ha^{-1}

FYM @ 12.5 t ha^{-1} + 75 kg N + 25 kg P_2O_5



FYM @ 6.25 t ha^{-1} + GM *in situ* + n_2p_1

PM @ 2.5 t ha^{-1} + GM *in situ* + n_2p_1

Plate 2. Tuber yield as affected by sources of organic manure

observed by Essien (2009) and Kim *et al.* (2013). Hence, for sustaining the productivity of cassava, application of lower level of P is necessitated.

Significant influence of M x N, M x P and M x N x P interactions on tuber and top yields was observed (Table 8b and 8c), which reflected the main effects. Combined application of PM @ 2.5 t ha^{-1} + green manuring *in situ* + 75 kg N ha^{-1} + 25 kg P_2O_5 ha^{-1} ($m_3n_2p_1$) recorded the highest tuber yield of 36.22 t ha^{-1} (Fig. 12b) and top yield of 10.04 t ha^{-1} (Table 8c). The same treatment combination had produced the highest tuber weight $plant^{-1}$ also. However, with respect to top yield, the treatment combinations $m_3n_1p_2$, $m_3n_1p_1$ and $m_3n_2p_1$ could produce higher top yield without significant variation between them.

Combined application of PM @ 2.5 t ha^{-1}, 75 kg N ha^{-1} and 25 kg P_2O_5 ha^{-1} resulted in superior green matter yield of cowpea (12.34 t ha^{-1}), in green manured plots, reflecting the main effects (Fig. 13a and 13b). The same treatment combination had produced higher yield of cassava. Higher nutrient availability in green manured plots due to biological N fixation and improvement in physical condition of soil owing to incorporation of large quantity of green matter might have resulted in higher nutrient uptake and consequently higher tuber and top yields of cassava. Among green manured treatments, the superiority of the treatment involving PM might be due to higher green matter yield of cowpea from that treatment.

5.3. DRY MATTER PRODUCTION

Significant and positive correlation of dry matter production with LAI at 4 MAP and harvest were observed (Table 18b). The effects of treatments on tuber and top yields were evident in dry matter production also. Significantly higher TDMP was produced due to application of PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3), higher level of N (n_2 - 75 kg ha^{-1}) and lower level of P (p_1 - 25 kg P_2O_5 ha^{-1}) as shown in Fig. 14a. Higher uptake of nutrients due to higher availability of nutrients and better soil physical condition in green manured plots might have resulted in higher dry matter

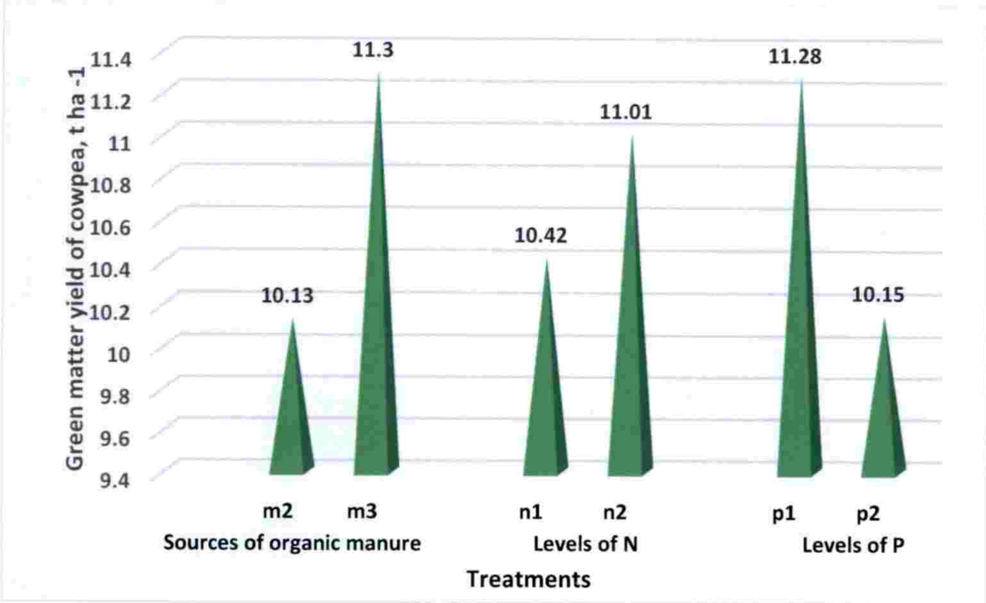


Fig. 13a. Effect of sources of organic manure and N and P levels on yield of green manure cowpea, t ha^{-1}

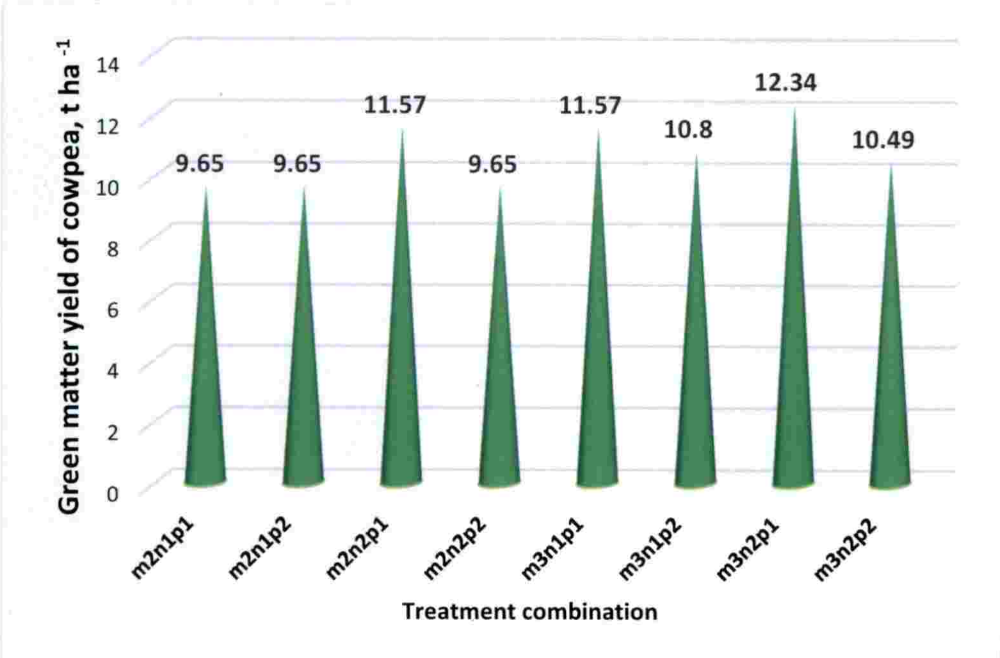


Fig. 13b. Effect of treatment combinations on yield of green manure cowpea, t ha^{-1}

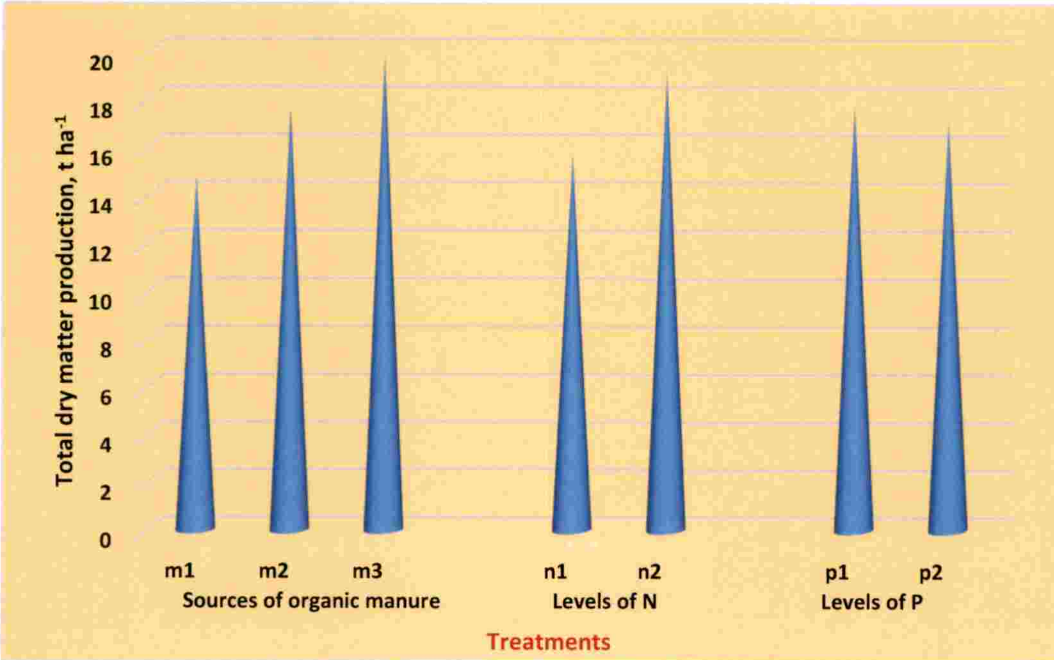


Fig. 14a Effect of sources of organic manure and levels of N and P on total dry matter production, t ha^{-1}

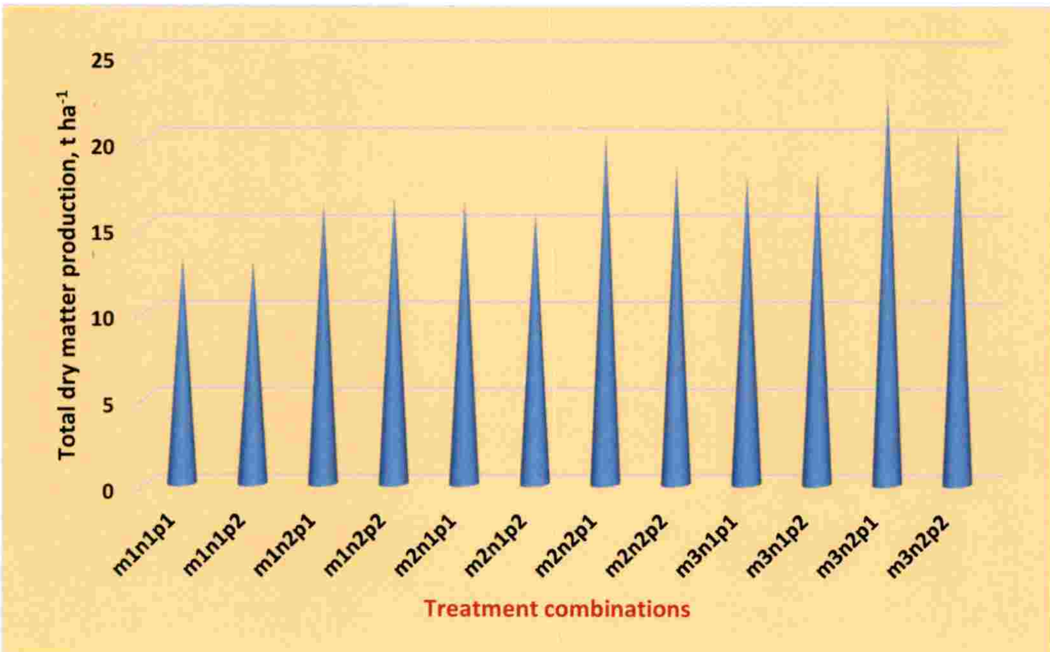


Fig. 14b. Effect of treatment combinations on total dry matter production, t ha^{-1}

production in those plots. Pamila (2003) and Sekhar (2004) also obtained the highest dry matter production of short duration variety of cassava in lowland and upland respectively with N application @ 75 kg ha^{-1}. As in the case of tuber and top yields, the treatment combination $m_3n_2p_1$ registered the highest TDMP of 22.72 t ha^{-1} (Fig 14b). However, the treatments failed to produce any conspicuous variation in harvest index, since the treatments which produced higher tuber yield also produced higher top (Table 8a, 8b and 8c).

5.4. QUALITY CHARCATERS OF TUBER

With regard to quality characters of tuber, sources of organic manure had significant influence only on HCN content (Table 11a). Tubers with the lowest HCN content (38.92 mg kg^{-1}) were produced by FYM @ 6.25 t ha^{-1} + green manuring *in situ* (m_2) which was on par with FYM @12.5 t ha^{-1} (m_1). Although PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) registered the highest HCN content of tuber, the values were within the permissible limits. The starch and protein contents of tuber did not vary markedly due to sources of organic manure again suggesting alternatives for FYM without sacrificing tuber quality.

Significantly higher starch content (27.03%) and lower HCN content (39.83 mg kg^{-1}) were registered due to application of lower level of N (50 kg ha^{-1}) as revealed from Table 10a. Increase in HCN content of tuber due to increase in N application has been reported by several workers including Sekhar (2004) in the var. Vellayani Hraswa itself. However, significantly higher protein content was recorded due to application of higher level of N (75 kg ha^{-1}). Improvement in protein content of cassava tuber as a result of higher rates of N application has been reported by Nair (1982) and Sekhar (2004).

Levels of P or interactions did not produce any marked variation in tuber quality characters as evident from Table 11a, 11b and 11c. John *et al.* (1997) also reported that different levels of P had no significant influence on the starch content of cassava tuber.

5.5 WEED INFESTATION

Lower weed infestation in terms of weed density and dry weight m^{-2} was noticed in green manured plots at all stages of observation (Fig. 15 and 16). This might be due to the competition from cowpea growing in the interspaces of cassava. Among green manured treatments, PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) was found more advantageous. Irrespective of treatments, weed density showed a decreasing trend from 30 DAP upto harvest as expected due to increased ground coverage by cassava with time restricting the resource availability for weed growth. Weed dry weight m^{-2} showed an increasing trend in all the plots upto three months` stage of cassava (90 DAP), which decreased towards harvest. However, in green manured plots, increasing trend in weed dry weight was observed upto 70 DAP only. The green manure cowpea was incorporated at flowering stage (50 days after sowing). Hence, in green manured plots, considerable increase in weed dry weight was observed at 70 DAP which showed a decreasing trend towards harvest. Reduction in weed dry weight from 90 DAP onwards might be due to increased ground coverage by cassava plants.

Weed density m^{-2} showed an increasing trend with increasing level of N at all stages, but significant increase was observed only during initial growth stages of cassava (upto 90 DAP). Weed dry weight m^{-2} also increased when N level was increased from 50 to 75 kg ha^{-1}. However, marked variation was observed only at 70 DAP, 90 DAP and 120 DAP. Levels of P registered no conspicuous variation in weed density m^{-2} at all stages except at 70 DAP and harvest when higher weed density at 70 DAP but lower at harvest were registered by lower level of P (25 kg P_2O_5 ha^{-1}).

5.6 UPTAKE OF NUTRIENTS

Tuber yield as well as dry matter production were significantly and positively correlated with N, P and K uptake (Table 18a and 18b). Conspicuous variation in NPK

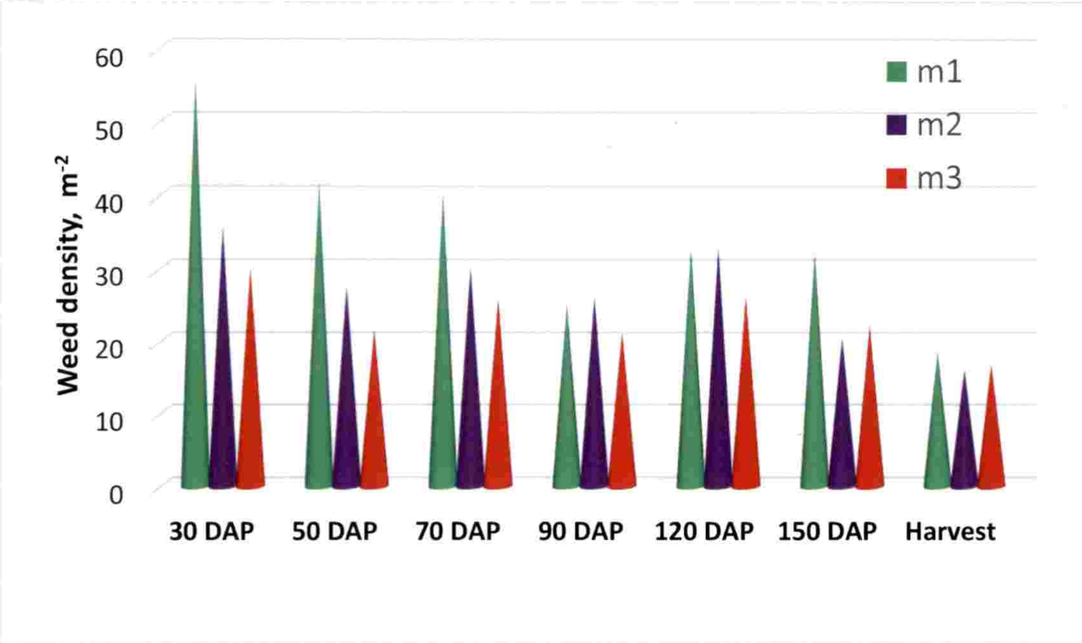


Fig. 15 Effect of sources of organic manure and levels of N and P on weed density m^{-2}

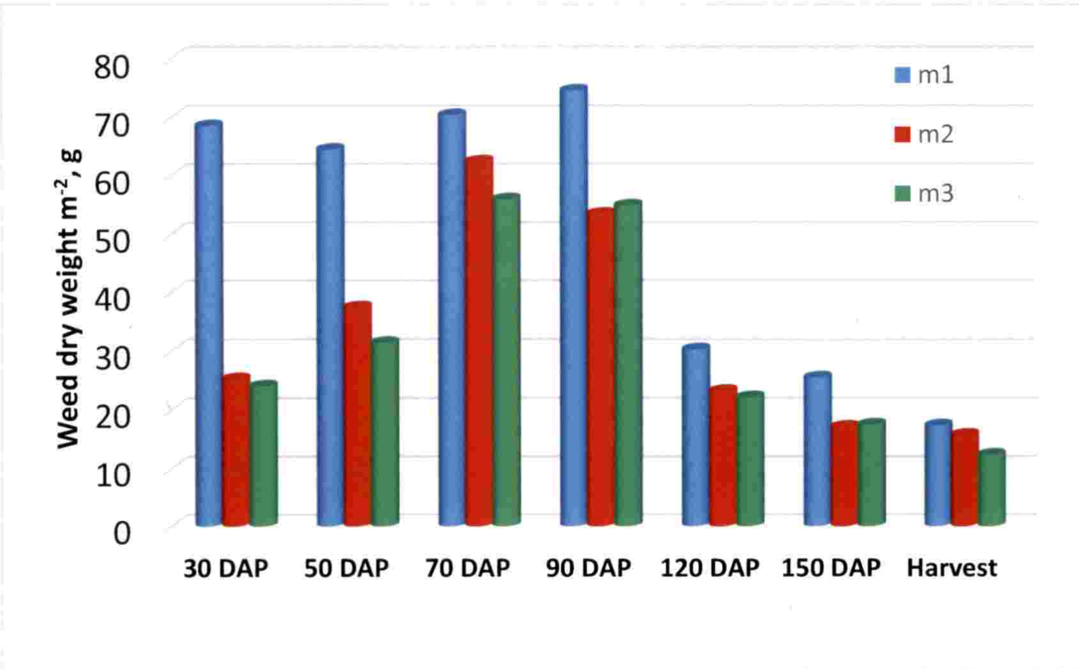


Fig. 16 Effect of sources of organic manure and levels of N and P on weed dry weight m^{-2}, g

Unweeded plot (without cowpea) at 50 DAP

Cassava + cowpea at 50 DAP

After weeding

After incorporation of cowpea

Plate 3. Weed infestation in cassava with and without cowpea

uptake has been observed between plots in which FYM alone was applied and green manured plots. Green manured plots showed higher N, P and K uptake (Fig.17). Higher availability of nutrients due to decomposition of cowpea might have contributed to higher uptake of N, P and K in green manured plots. Nayar and Potty (1996) also noticed higher uptake of N and K under green manuring. Among green manure treatments, the highest N, P and K uptake were recorded by PM @ 2.5 t ha^{-1} + green manuring *in situ*. Considering the effect on N, P and K uptake, Pamila (2003) opined that FYM could be substituted with PM as also observed in the present study.

Application of higher level of N (75 kg ha^{-1}) resulted in the highest N, P and K uptake (Fig. 17). Similar results were reported by Pamila (2003). Application of 25 kg P_2O_5 ha^{-1} registered significantly higher N uptake. It could also be inferred that application of 25 kg P_2O_5 is sufficient for higher P and K uptake. Swadija and Sreedharan (1998), Mohankumar *et al.* (2000) and Howeler (2014 and 2017) have noticed relatively lower uptake of P compared to those of N and K. Reduction in yield of cassava due to skipping of P application has been reported by Essien (2009) and Kim *et al.* (2013). The ratio of removal of N, P and K by cassava in the present study, in general, was in the ratio 3:1:3 in agreement with the findings of Swadija and Sreedharan (1998) and Howeler (2017).

5.7 SOIL ANALYSIS AFTER THE EXPERIEMENT

Compared to the initial status (Table 1), post experiment soil analysis revealed an increase in soil pH, improvement in available N, considerable reduction in organic carbon and available K and a slight reduction in available P status (Table 15a, 15b, 15c, 16a, 16b and 16c). Combination of organic manure with inorganic fertilizer had a moderating effect on soil reaction particularly under acidic soils and improvement in sustained availability of N, P and K as reported by Nambiar and Abrol (1989).Increase in soil pH due to addition of plant residues, cattle manure and PM in acid soil was also noticed by Naramabuye *et al.* (2006). Green manured plots showed higher post harvest

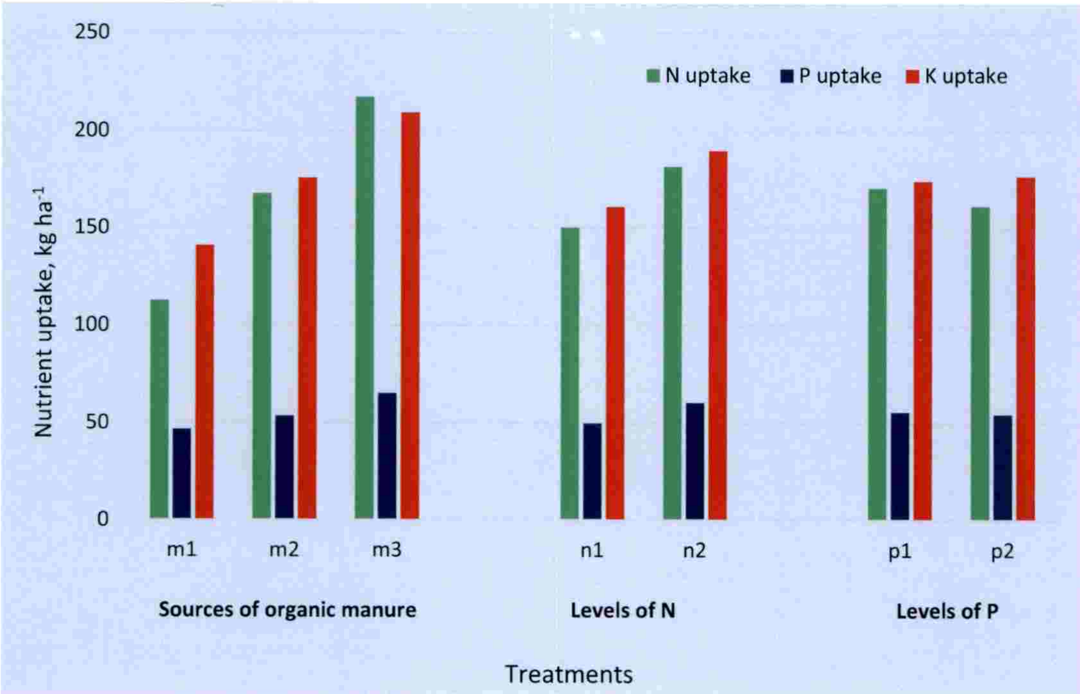


Fig. 17 Effect of sources of organic manure and levels of N and P on nutrient uptake, kg ha^{-1}

soil fertility and availability of nutrients especially N which might be due to higher biological N fixation of cowpea and release of nutrients on decomposition of incorporated cowpea. Improvement in soil productivity by increasing the soil nutrient status by green manuring is widely reported. Among the sources of organic manure, PM @ 2.5 t ha^{-1} + green manuring *in situ* recorded significantly higher pH and organic carbon and available N, P and K status in the soil after the experiment. Levels of N and P had significant influence only on available P status in the soil. Higher P status was registered by 75 kg N ha^{-1}. The result of the effect of levels of N on nutrient uptake corroborated with the findings of Pamila (2003). Available P status increased when the level of P was increased from 25 to 50 kg P_2O_5 ha^{-1} which might be due to reduced P uptake at higher level of P.

5.8 ECONOMICS OF CULTIVATION

The treatment effects on economics of cultivation in terms of net income and benefit cost ratio followed the same trend as in the case of tuber yield. Green manured plots resulted in higher productivity and profitability from cassava cultivation. Application of PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) recorded the highest net income of ₹ 336874 ha^{-1} (Fig.18a) and BCR of 2.97 (Fig.19a) followed by the application of FYM @ 6.25 t ha^{-1} + green manuring *in situ* (m_2). The results clearly suggested the possibility of substitution of FYM with other organic manures like PM and green manuring *in situ*. Significantly higher net income of ₹ 314306 ha^{-1} and BCR of 2.87 could be obtained by the application of 75 kg N ha^{-1} (n_2). However, higher net income and BCR were registered with lower level of P (p_1 - 25 kg P_2O_5 ha^{-1}).

Combined application of PM @ 2.5 t ha^{-1} + green manuring *in situ* along with 75 kg N ha^{-1} and 25 kg P_2O_5 ha^{-1} ($m_3n_2p_1$) resulted in the highest net income of ₹373240 ha^{-1} (Fig. 18b) and BCR of 3.19 (Fig. 19b). John *et al.* (2005) reported that the profitability of cassava cultivation could be increased due to integrated application of manure and chemical fertilizers. Pamila *et al*. (2006) noticed the feasibility of PM @ 5

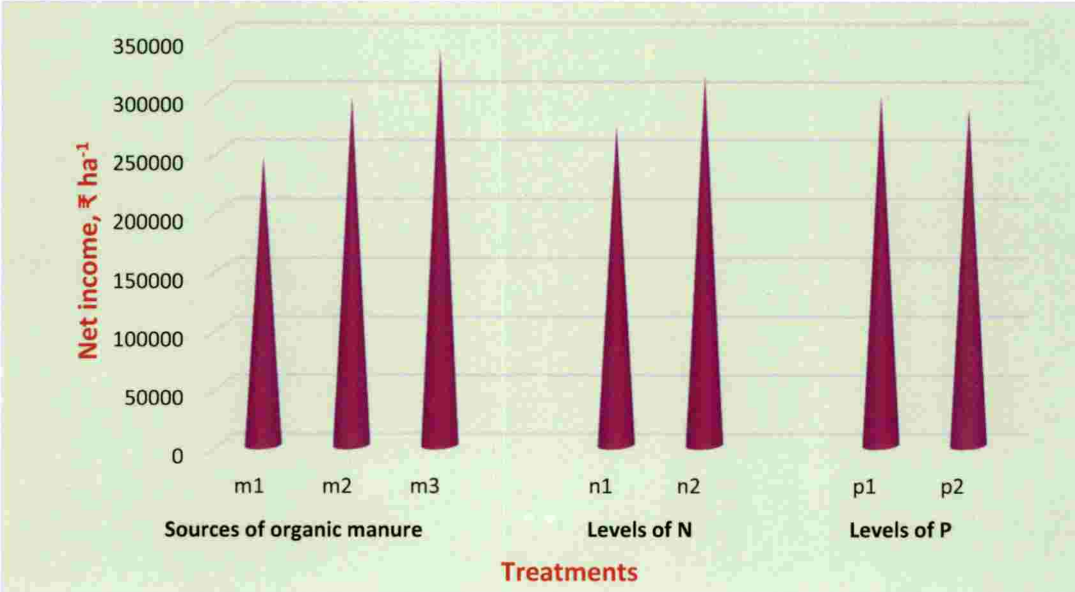


Fig. 18a Effect of sources of organic manure and levels of N and P on net income, ₹ ha^{-1}

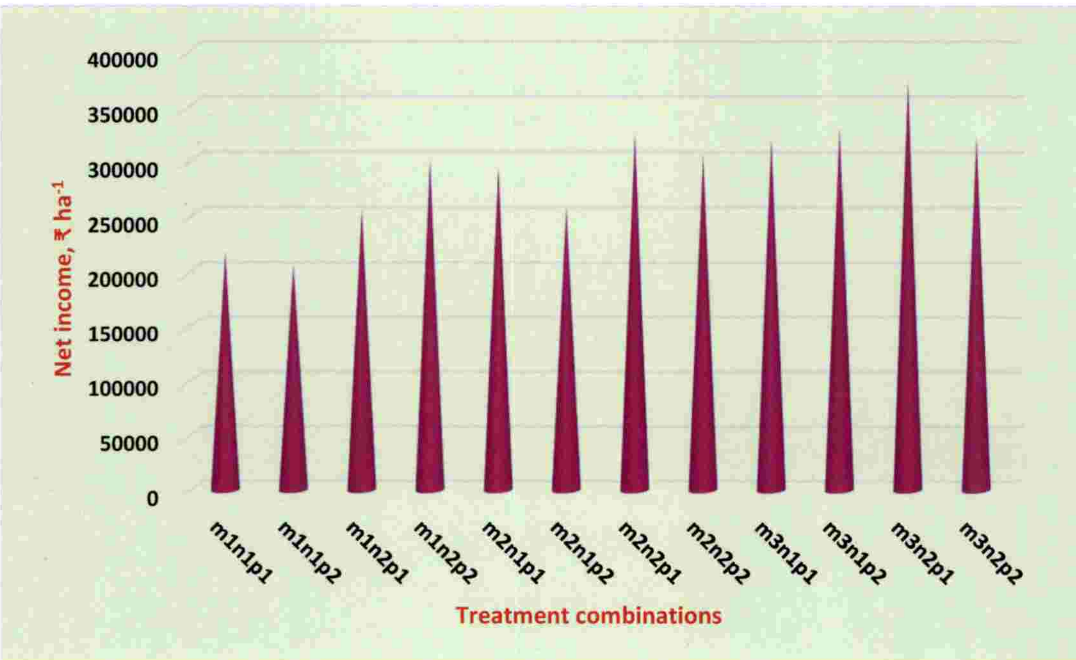


Fig. 18b. Effect of treatment combinations on net income, ₹ ha^{-1}

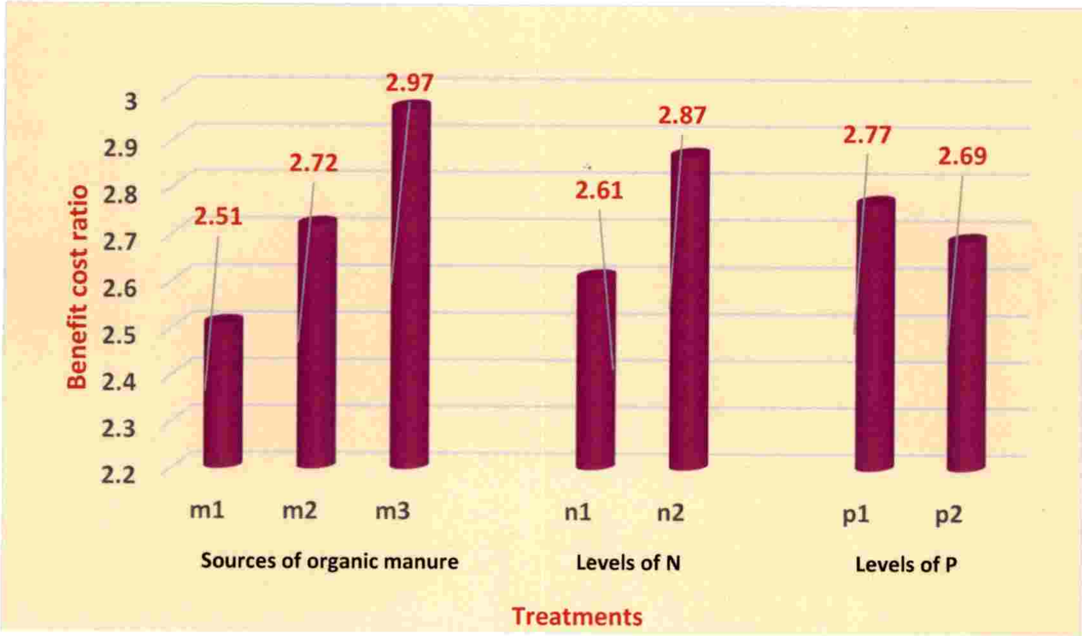


Fig. 19a Effect of sources of organic manure and levels of N and P on benefit cost ratio

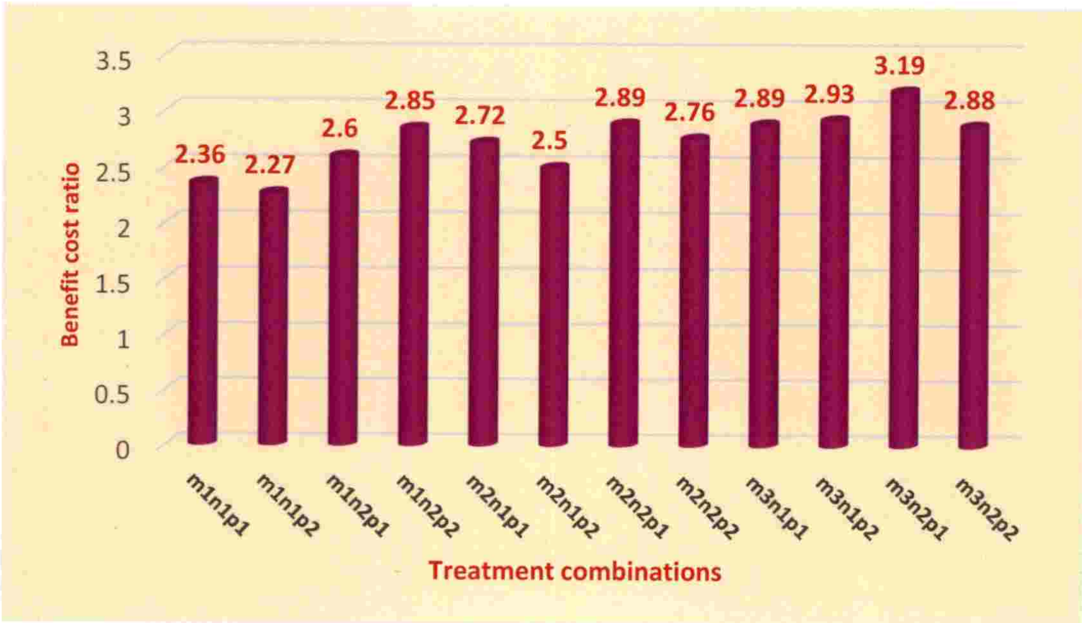


Fig. 19b. Effect of treatment combinations on benefit cost ratio

t ha^{-1} as an alternative to FYM @ 12.5 t ha^{-1} along with 75:50:100 kg NPK ha^{-1} for obtaining higher returns from short duration varieties of cassava cultivated in lowlands.

The results of the study clearly indicated the feasibility substitution of FYM with PM + green manuring *in situ* and sufficiency of a lower dose of P for cassava. The results also revealed that the highest yield, net income and BCR could be obtained from the cultivation of cassava var. Vellayani Hraswa in lowlands by the application of PM @ 2.5 t ha^{-1} + green manuring *in situ* with cowpea + 75 kg N ha^{-1} + 25 kg P_2O_5 ha^{-1} combined with 100 kg K_2O ha^{-1}.

SUMMARY

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6. SUMMARY

The present study entitled "Nutrient management for productivity enhancement of cassava var. Vellayani Hraswa in lowlands" was conducted at College of Agriculture, Vellayani, Thiruvananthapuram, Kerala to standardize the nutrient management for productivity enhancement of cassava var. Vellayani Hraswa in lowlands and to work out the economics of cultivation. The field experiment was conducted at IFSRS, Karamana, Thiruvananthapuram from September 2017 to February 2018.

The treatments consisted of three sources of organic manure (m_1 - FYM @ 12.5 t ha^{-1}, m_2 - FYM @ 6.25 t ha^{-1} + green manuring *in situ* and m_3 - PM @ 2.5 t ha^{-1} + green manuring *in situ*), two levels of N (50 and 75 kg ha^{-1}) and two levels of P (25 and 50 kg P_2O_5 ha^{-1}) along with a uniform dose of 100 kg K_2O ha^{-1}. The experiment was laid out as 3 x 2 x 2 factorial experiment with three replications in randomized block design. Organic manures were applied at land preparation as per the treatments. Cassava var. Vellayani Hraswa was planted on ridges at a spacing of 90 cm x 90 cm after applying ½ N + full P + ½ K of the fertilizer dose as per treatments. Cowpea @ 30 kg ha^{-1} was sown on the two sides of the ridges in between cassava plants for green manuring *in situ* and was incorporated 50 DAP. Interculture, weeding and earthing up were done at 30, 50 and 70 DAP in all the plots along with top dressing (½ N + ½ K) for cassava at 50 DAP. The crop was harvested at 6 MAP. The data collected were statistically analyzed and the results of the study are summarized in this chapter.

Growth characters *viz.* plant height, number of branches and leaves $plant^{-1}$ and LAI were recorded at 2 MAP, 4 MAP and harvest. In general, all the growth characters showed an increasing trend upto harvest.

Among the sources of organic manure, PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) produced taller plants with higher branch number, leaf number and LAI at 4 MAP and harvest. But it was on par with FYM @ 6.25 t ha^{-1} + green manuring *in situ*

(m_2) in the case of plant height and total leaf number at harvest. Levels of N profoundly influenced plant height, number of branches $plant^{-1}$ and LAI at 4 MAP and harvest and leaf number $plant^{-1}$ at all stages. In all these cases, application of 75 kg ha^{-1} (n_2) was found superior. Levels of P had significant influence only on branch number at harvest, functional leaf number at 4 MAP and LAI at 2 MAP when 50 kg P_2O_5 (p_2) registered higher branch number while 25 kg P_2O_5 (p_1)recorded higher functional leaf number and LAI.

Sources of organic manure had profound influence on yield attributes except tuber girth. Application of PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) registered higher number and weight of tubers $plant^{-1}$, percentage of productive roots and length and mean weight of tuber and lower rind to flesh ratio. However, it was on par with FYM @ 6.25 t ha^{-1} + green manuring *in situ* (m_2) in tuber length and FYM @ 12.5 t ha^{-1} (m_1) in the case of rind to flesh ratio. The yield attributes except rind to flesh ratio markedly increased when the level of N was increased from 50 (n_1) to 75 kg ha^{-1} (n_2). But levels of P had significant influence only on percentage of productive roots $plant^{-1}$, tuber weight $plant^{-1}$ and tuber girth. Application of 50 kg P_2O_5 ha^{-1} (p_2) produced higher percentage of productive roots $plant^{-1}$ and tuber girth while 25 kg P_2O_5 ha^{-1} (p_1) produced higher tuber weight $plant^{-1}$. The treatment combination $m_3n_2p_1$ registered significantly higher tuber weight $plant^{-1}$ reflecting the main effects.

The tuber yield was significantly and positively correlated with LAI at 4 MAP and harvest, number and weight of tubers $plant^{-1}$ and mean tuber weight. Higher tuber yields were obtained from green manured plots. The highest tuber yield of 33. 85 t ha^{-1} was produced by the treatment PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) followed by the treatment FYM @ 6.25 t ha^{-1} + green manuring *in situ* (m_2). Significant increase in tuber yield was observed when N level was increased from 50 (n_1) to 75 kg ha^{-1} (n_2). Lower level of P (p_1- 25 kg P_2O_5 ha^{-1}) recorded higher tuber yield emphasizing low requirement of P for cassava. Similar trend was observed in the case of top yield also. The tuber and top yields were significantly influenced by M x N, M x P and M x N x P interactions revealing the main effects. The treatment combination $m_3n_2p_1$ recorded the highest tuber yield of 36.22 t ha^{-1} and top yield of 10.04 t ha^{-1}.

Significantly higher TDMP was produced due to application of PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3), higher level of N (n_2 - 75 kg ha^{-1}) and lower level of P (p_1 - 25 kg P_2O_5 ha^{-1}). As in the case of tuber and top yields, the treatment combination $m_3n_2p_1$ registered the highest TDMP of 22.72 t ha^{-1}. However, the treatments failed to produce any significant variation in harvest index. Significant and positive correlations of dry matter production with LAI at 4 MAP and harvest were observed.

Higher green matter and dry matter yields of green manure cowpea were produced in the plots given PM (m_3), higher level of N (n_2 - 75 kg ha^{-1}) and lower level of P (p_1 - 25 kg P_2O_5 ha^{-1}). Combined application of PM @ 2.5 t ha^{-1}, 75 kg N ha^{-1} and 25 kg P_2O_5 ha^{-1} resulted in superior green matter yield of 12.34 t ha^{-1}.

With regard to quality characters of cassava tuber, sources of organic manure had significant influence only on HCN content. Tubers with the lowest HCN content (38.92 mg kg^{-1}) were produced by FYM @ 6.25 t ha^{-1} + green manuring *in situ* (m_2) which was on par with FYM @12.5 t ha^{-1} (m_1).Significantly higher starch content (27.03%) and lower HCN content (39.83 mg kg^{-1}) were registered due to application of lower level of N (50 kg ha^{-1}). However, significantly higher protein content was recorded by 75 kg N ha^{-1}. Levels of P or interactions did not produce any marked variation in tuber quality characters.

Lower weed infestation in terms of weed density and dry weight m^{-2} was noticed in green manured plots at all stages of observation and application of PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) was found more advantageous among the sources of organic manure. Significant increase in weed density was observed when N level was increased from 50 to 75 kg ha^{-1} at all stages except at 50 and 150 DAP.

Application of higher level of N (75 kg ha^{-1}) registered significantly higher weed dry weight at 70 DAP, 90 DAP and 120 DAP. Application of higher level of P reduced weed density at 70 DAP while increased the same at harvest. Significant influence of P level on weed dry weight was observed only at 120 DAP when higher level of P registered lower weed dry weight.

Application of PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) resulted in the highest N, P and K uptake. Significantly higher N, P and K uptake were recorded by 75 kg N ha^{-1}. Application of 25 kg P_2O_5 ha^{-1} registered significantly higher N uptake. Tuber yield as well as dry matter production were significantly and positively correlated with N, P and K uptake.

Compared to the initial status, an increase in soil pH and an improvement in available N status was observed after the experiment. However, considerable reduction in organic carbon and available K status and a slight reduction in available P status were noticed. Among the sources of organic manure, PM @ 2.5 t ha^{-1} + green manuring *in situ* recorded significantly higher pH and organic carbon and available N, P and K contents in the soil after the experiment. Levels of N and P had significant influence only on available P status in the soil and higher P status was registered by 75 kg N ha^{-1} and 50 kg P_2O_5 ha^{-1}.

No incidence of pest and diseases was noticed during the cropping period.

Application of PM @ 2.5 t ha^{-1} + green manuring *in situ* (m_3) recorded the highest net income of ₹ 336874 ha^{-1} and BCR of 2.97 followed by the application of FYM @ 6.25 t ha^{-1} + green manuring *in situ* (m_2). Significantly higher net income of ₹ 314306 ha^{-1} and BCR of 2.87 could be obtained due to application of 75 kg N ha^{-1} (n_2). However, higher net income and BCR were registered with lower level of P (p_1 - 25 kg P_2O_5 ha^{-1}). Regarding interaction effects, application of PM @ 2.5 t ha^{-1} + green manuring *in situ* along with 75 kg N ha^{-1} and 25 kg P_2O_5 ha^{-1} ($m_3n_2p_1$) resulted in the highest net income of ₹ 373240 ha^{-1} and BCR of 3.19.

The results of the study indicated the feasibility of substitution of FYM with PM + green manuring *in situ* and sufficiency of a lower dose of P for cassava. The results also revealed that the highest yield, net income and BCR from the cultivation of cassava var. Vellayani Hraswa in lowlands could be obtained by the application of PM @ 2.5 t ha^{-1} + green manuring *in situ* with cowpea + 75 kg N ha^{-1} + 25 kg P_2O_5 ha^{-1} combined with 100 kg K_2O ha^{-1}.

FUTURE LINE OF WORK

- The experiment may be repeated with different levels of K, biofertilizers, other short duration varieties of cassava and also in uplands.
- The feasibility of substitution of FYM with coir pith compost for cassava may be studied.
- Utilization of coir pith as soil amendment for cassava may be experimented.
- The residual effect of applied nutrients for cassava may be studied in the cropping system.

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NUTRIENT MANAGEMENT FOR PRODUCTIVITY ENHANCEMENT OF CASSAVA VAR. VELLAYANI HRASWA IN LOWLANDS

By

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ABSTRACT

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ABSTRACT

A study entitled "Nutrient management for productivity enhancement of cassava var. Vellayani Hraswa in lowlands" was conducted at College of Agriculture, Vellayani, Thiruvananthapuram, Kerala to standardize the nutrient management for productivity enhancement of cassava var. Vellayani Hraswa in lowlands and to work out the economics of cultivation. The field experiment was conducted at Integrated Farming System Research Station, Karamana, Thiruvananthapuram from September 2017 to February 2018. The treatments consisted of three sources of organic manure (m_1 - FYM @ 12.5 t ha^{-1}, m_2 - FYM @ 6.25 t ha^{-1} + green manuring *in situ* and m_3 - poultry manure (PM) @ 2.5 t ha^{-1} + green manuring *in situ*), two levels of N (50 and 75 kg ha^{-1}) and two levels of P (25 and 50 kg P_2O_5 ha^{-1}) along with a uniform dose of 100 kg K_2O ha^{-1}. The 3 x 2 x 2 factorial experiment was laid out in randomized block design with three replications. Organic manures were applied at land preparation as per the treatments. Cassava var. Vellayani Hraswa was planted on ridges at a spacing of 90 cm x 90 cm after applying ½ N + full P + ½ K of the fertilizer dose as per the treatments. Cowpea @ 30 kg ha^{-1} was sown on the two sides of the ridges in between cassava plants for green manuring *in situ* and was incorporated 50 days after planting along with top dressing (½ N + ½ K) for cassava.

Among the sources of organic manure, PM @ 2.5 t ha^{-1} + green manuring *in situ* produced taller plants with higher branch number, leaf number and leaf area index (LAI) at 4 months after panting (MAP) and harvest. Application of 75 kg N ha^{-1} registered taller plants and higher number of branches and LAI at 4 MAP and harvest and higher leaf number at all the stages. Application of 25 kg P_2O_5 ha^{-1} was found sufficient for improving growth characters.

Application of PM @ 2.5 t ha^{-1} + green manuring *in situ* registered the highest number and weight of tubers $plant^{-1}$, percentage of productive roots and length and mean weight of tuber and lower rind to flesh ratio. The yield attributes except rind to

flesh ratio were significantly higher with 75 kg N ha^{-1}. Application of 50 kg P_2O_5 ha^{-1} produced higher percentage of productive roots $plant^{-1}$ and tuber girth while 25 kg P_2O_5 ha^{-1} produced higher tuber weight $plant^{-1}$. The treatment combination $m_3n_2p_1$ registered significantly higher tuber weight $plant^{-1}$.

The tuber yield was significantly and positively correlated with LAI at 4 MAP and harvest, number and weight of tubers $plant^{-1}$ and mean tuber weight. Higher tuber yields were obtained from green manured plots. The highest tuber and top yields were produced by PM @ 2.5 t ha^{-1} + green manuring *in situ*, 75 kg N ha^{-1} and 25 kg P_2O_5 ha^{-1}. The treatment combination $m_3n_2p_1$ recorded the highest tuber yield of 36.22 t ha^{-1} and top yield of 10.04 t ha^{-1}. Similar trend was observed in dry matter production. The practice of green manuring *in situ* reduced weed infestation in cassava and improved its growth and yield.

The tubers with the lowest HCN content (38.92 mg kg^{-1}) were produced by FYM @ 6.25 t ha^{-1} + green manuring *in situ.* Nitrogen @ 50 kg ha^{-1} recorded higher starch (27.03%) and lower HCN (39.83 mg kg^{-1}) content while 75 kg N ha^{-1} registered higher protein content (2.61%).

Application of PM @ 2.5 t ha^{-1} + green manuring *in situ*, 75 kg N ha^{-1} and 25 kg P_2O_5 ha^{-1} resulted in the highest N, P and K uptake. Poultry manure @ 2.5 t ha^{-1} + green manuring *in situ* recorded significantly higher pH, organic carbon and available N, P and K status in the soil after the experiment. Levels of N and P had significant influence only on available P status in the soil and higher P status was registered by 75 kg N ha^{-1} and 50 kg P_2O_5 ha^{-1}.

Higher net income of ₹ 373240 ha^{-1} and benefit cost ratio of 3.19 could be obtained from the combined application of PM @ 2.5 t ha^{-1} + green manuring *in situ* along with 75 kg N ha^{-1} and 25 kg P_2O_5 ha^{-1} ($m_3n_2p_1$). The results indicated the feasibility of substitution of FYM with PM + green manuring *in situ.*

The results of the study revealed that higher yield, net income and benefit cost ratio could be realized from cassava var. Vellayani Hraswa in lowlands by the application of poultry manure @ 2.5 t ha^{-1} + green manuring *in situ* with cowpea + 75 kg N ha^{-1} + 25 kg P_2O_5 ha^{-1} combined with 100 kg K_2O ha^{-1}.

സംഗ്രഹം

''വയലിൽ കൃഷി ചെയ്യുന്ന വെള്ളായണി ഹ്രസ്വ എന്ന മരച്ചീനി ഇനത്തിന്റെ ഉത്പാദനക്ഷമത വർദ്ധിപ്പിക്കുന്നതിനു വേണ്ടിയുള്ള പോഷകപരിപാലനം'' എന്ന വിഷയത്തിൽ ഒരു പഠനം വെള്ളായണി കാർഷിക കോളേജിൽ നടത്തുകയുണ്ടായി. ഇതിനായുള്ള വിളഭൂമി പരീക്ഷണം തിരുവനന്തപുരത്ത് കരമനയിലുള്ള സംയോജിത കൃഷി സമ്പ്രദായ ഗവേഷണ കേന്ദ്രത്തിൽ 2017 സെപ്തംബർ മുതൽ 2018 ഫെബ്രുവരി വരെ നടത്തുകയുണ്ടായി. വയലിൽ കൃഷി ചെയ്യുന്ന വെള്ളായണി ഹ്രസ്വ എന്ന മരച്ചീനി ഇനത്തിന്റെ ഉത്പാദനക്ഷമത വർദ്ധിപ്പിക്കുന്നതിനുവേണ്ടി അനുയോജ്യമായ പോഷകപരിപാലനം കണ്ടെത്തുക, ഈ കൃഷിയുടെ സാമ്പത്തികവശം കണക്കാക്കുക എന്നിവയായിരുന്നു ഈ പഠനത്തിന്റെ ഉദ്ദേശ്യങ്ങൾ. മൂന്ന് ജൈവവള സ്രോതസ്സുകളും (ഹെക്ടറൊന്നിന് 12.5 ടൺ കാലിവളം; 6.25 ടൺ കാലിവളം + പച്ചിലവളപ്രയോഗം; 2.5 ടൺ കോഴിവളം + പച്ചിലവളപ്രയോഗം) രണ്ടു അളവുകളിൽ പാക്യജനകവും (ഹെക്ടറൊന്നിന് 50 ഉം 75 ഉം കിലോഗ്രാം വീതം) രണ്ടു അളവുകളിൽ ഭാവഹവും (ഹെക്ടറൊന്നിന് 25 ഉം 50 ഉം കിലോഗ്രാം വീതം) ചേർത്ത് 12 ട്രീറ്റുമെന്റുകൾ മൂന്നു പ്രാവശ്യം ആവർത്തിച്ച് മൊത്തം 36 പ്ലോട്ടുകളിലായി റാൻഡമൈസ്ഡ് ബ്ലോക്ക് ഡിസൈൻ എന്ന പഠനരീതി അവലംബിച്ച് വയലിൽ വെള്ളായണി ഹ്രസ്വ എന്നയിനം മരച്ചീനി കൃഷി ചെയ്യുകയുണ്ടായി. ഹെക്ടറൊന്നിന് 100 കിലോഗ്രാം വീതം പൊട്ടാഷ് എല്ലാ പ്ലോട്ടുകളിലും ഒരുപോലെ നൽകി.

വയലിൽ 90 സെന്റീമീറ്റർ അകലത്തിലും 30 സെന്റീമീറ്റർ പൊക്കത്തിലും വാരങ്ങളിൽ കോരി നിശ്ചയിക്കപ്പെട്ട അളവിൽ ജൈവവളങ്ങൾ ഇട്ടിളക്കി, മുഴുവൻ ഭാവഹവും പകുതിവീതം പാക്യജനകവും പൊട്ടാഷും നൽകി വാരങ്ങൾ 90 സെന്റീമീറ്റർ അകലത്തിൽ മരച്ചീനി നടുകയുണ്ടായി. പച്ചിലവള പ്രയോഗത്തിനായി ഹെക്ടറൊന്നിന് 30 കിലോഗ്രാം വീതം പയർ മരച്ചീനിക്കിടയിൽ നടുകയുണ്ടായി. നട്ട് ഒരു മാസമായപ്പോൾ കള പറിച്ചു. പയർ

പൂത്തുതുടങ്ങിയപ്പോൾ (നട്ട് 50 ദിവസമായപ്പോൾ) പിഴുതെടുത്ത് മരച്ചീനിക്ക് പച്ചിലവളമായി നൽകി. എല്ലാ പ്ലോട്ടുകളിലും കളയെടുത്ത് ബാക്കി പകുതി വീതം പാക്യജനകവും പൊട്ടാഷും മരച്ചീനിക്ക് നൽകി മണ്ണണച്ചു കൊടുത്തു. കൂടാതെ നട്ട് 70 ദിവസം ആയപ്പോഴും കളപറിച്ച് മണ്ണണച്ചു കൊടുക്കുകയുണ്ടായി. ആറു മാസമായപ്പോൾ മരച്ചീനി വിളവെടുത്തു.

പയർ കൊണ്ടുള്ള പച്ചിലവളപ്രയോഗത്തിനൊപ്പം ഹെക്ടറൊന്നിന് 2.5 ടൺ കോഴിവളവും 75:25:100 കിലോഗ്രാം പാക്യജനകം, ഭാവഹം, പൊട്ടാഷ് എന്നിവയും നൽകി വെള്ളായണി ഹ്രസ്വ എന്ന മരച്ചീനി ഇനം ആദായകരമായി വയലിൽ കൃഷി ചെയ്യാമെന്ന് ഈ പഠനത്തിൽ നിന്ന് വ്യക്തമായി.

APPENDICES

APPENDIX I

Weather data during the cropping period (September 2017 – February 2018)

Standard week	Date	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Rainfall (mm)	Number of rainy days
35	Aug 27 to Sep 2, 2017	31.5	24.4	82.75	18.6	4
36	Sep 3 to 9	32.3	24.6	84.70	114.9	4
37	Sep 10 to 16	31.5	24.2	85.10	30.6	6
38	Sep 17 to 23	30.4	24.4	88.00	93.3	6
39	Sep 24 to 30	31.6	24.9	86.35	55.8	4
40	Oct 1 to 7	31.7	25.1	85.25	63.2	4
41	Oct 8 to 14	31.4	24.8	89.40	68.6	4
42	Oct 15 to 21	30.7	24.6	92.35	48.1	6
43	Oct 22 to 28	31.0	24.9	90.50	21.7	1
44	Oct 29 to Nov 4	30.6	24.8	90.75	21.0	4
45	Nov 5 to 11	30.6	24.4	90.85	104.4	7
46	Nov 12 to 18	31.6	24.1	84.20	0	0
47	Nov 19 to 25	31.1	23.9	87.35	45.3	2
48	Nov 26 to Dec 2	29.5	22.5	94.55	205.9	5
49	Dec 2 to 9	31.3	23.2	86.25	9.4	1
50	Dec 9 to 16	31.4	24.1	87.00	0.9	1
51	Dec 17 to 23	32.3	23.8	84.20	0	0
52	Dec 24 to 31	32.6	23.7	83.70	0	0
1	Jan 1 to 7, 2018	31.8	22.1	83.25	0	0
2	Jan 8 to 14	31.3	21.7	86.60	0	0
3	Jan 15 to 21	32.2	21.6	83.50	0	0
4	Jan 22 to 28	31.7	21.5	82.40	0	0
5	Jan 29 Feb 4	31.7	22.8	82.65	0	0
6	Feb 5 to 11	32.4	24.2	84.50	0	0
7	Feb 12 to 18	32.6	23.7	84.75	0	0
8	Feb 19 to 25	32.5	23.1	85.00	0	0
9	Feb 26 to Mar 4	33.5	24.1	82.05	0	0

APPENDIX II

AVERAGE COST OF INPUTS AND MARKET PRICE OF PRODUCE

COST OF INPUTS

Planting material of cassava	- ₹ 3 stem^{-1}
Seed of cowpea var. Anaswara	- ₹ 800 kg^{-1}
Rhizobium	- ₹ 50 kg^{-1}
Farmyard manure	- ₹ 1000 t^{-1}
Poultry manure	- ₹ 2 kg^{-1}
Urea	- ₹ 9.50 kg^{-1}
Rajphos	- ₹ 15 kg^{-1}
Muriate of potash	- ₹ 17 kg^{-1}
Labour charge	- ₹ 741 labourer^{-1}

PRICE OF PRODUCE

Cassava tuber	- ₹ 15 kg^{-1}