AGRONOMIC INTERVENTIONS FOR A SUSTAINABLE RICE BASED CROPPING SYSTEM IN PADDY FIELDS

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AGRONOMIC INTERVENTIONS FOR A SUSTAINABLE RICE BASED CROPPING SYSTEM IN PADDY FIELDS

by

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(2012-21-101)

THESIS

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2016

DECLARATION

I here by declare that this thesis entitled "**Agronomic interventions for a sustainable rice based cropping system in paddy fields**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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Vipitha V.P

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LIST OF ABBREVIATIONS

@	-	at the rate of

^oC	-	Degree Celsius
%	-	Per cent
B	-	Boron
BCR	-	Benefit Cost Ratio
C	-	Carbon
CD	-	Critical difference
CEC	–	Cation exchange capacity
CGR	-	Crop growth rate
CH_4	-	Methane
cm	-	Centimetre
cm^2	-	Square centimeter
cm^3	-	Cubic centimeter
C:N	–	Carbon : Nitrogen
cv.	-	Cultivar
DAS	-	Days after sowing
DAT	–	Days after transplanting
DAP	-	Diammonium phosphate
DMP	–	Dry matter production
$dS\ m^{-1}$	–	Deci semens per meter
et al.	-	And others
e.g.	-	Example
EC	–	Electrical conductivity
Fe	-	Iron
Fig.	-	Figure
FYM	-	Farmyard manure
g	–	Gram
$g\ plant^{-1}$	-	Gram per plant
ha	–	Hectare
HI	-	Harvest index
i.e.	-	That is
K	-	Potassium
K_2O	-	Potash
KCl	-	Potassium chloride
Kg	–	Kilogram
$kg\ plant^{-1}$	–	Kilogram per plant
$kg\ ha^{-1}$	-	Kilogram per hectare
L	–	Litre
LAI	–	Leaf area index
m	-	Metre
m^2	-	Square metre

LIST OF ABBREVIATIONS

MAP	-	Months after planting
mL	-	Millilitre
mm	–	Millimetre
mg	–	Milligram
Mg	-	Magnesium
mg m^{-3}	–	Milligram per cubic meter
mg 100 g^{-1}	–	Milligram per 100 gram
MJ	-	Mega joules
N	–	Nitrogen
Na	-	Sodium
NAR	-	Net assimilation rate
No.	-	Number
NS	-	Not significant
P	-	Phosphorus
P_2O_5	–	Phosphate
POP	–	Package of practices
ppm	-	Parts per million
q ha^{-1}	–	Quintal per hectare
RGR	-	Relative growth rate
REY	-	Rice equivalent yield
RH	-	Relative humidity
RDF	-	Recommended dose of
Rs	-	Rupees
S	-	Sulphur
SE	-	Standard Error
Sl.	–	Serial
Si	-	Silicon
SOP	-	Sulphate of potash
SPAD	-	Soil plant analysis
development		
t ha^{-1}	-	Tonnes per hectare
UI	-	Utilization index
var	-	Variety
viz.	–	Namely
WUE	–	Water use efficiency
Zn	-	Zinc

Introduction

1. INTRODUCTION

Rice, one of the most important cereal crops, provides food security and livelihood for millions of people across the globe. It is the main staple food crop of India. About 90 per cent of the world rice production originates from Asia. Further increase of agricultural production is urgently required to meet the growing demand of world population that is predicted to reach about 9 billion by 2050 (FAO, 2011).

During the past 50 years, the irrigated agricultural area has more than doubled (FAO, 2011). At present, irrigated rice utilizes approximately 40 per cent of the global irrigation water and 30 per cent of freshwater resources (IRRI, 2013). Water scarcity is likely to affect an estimated area of 15-20 m ha of irrigated rice by 2025 (Bouman and Lampayan, 2014). Transplanting of paddy seedling is common method of crop establishment in the irrigated rice systems of Asia, but it is labour intensive and consumes about 20-40 per cent of the total water required for growing the crop. Looming water crisis, water intensive nature of rice cultivation and escalating labour costs drive the search for alternative management methods to increase water productivity in rice cultivation. Upland rice has received much attention in this context because of its low input demand. Upland rice refers to rice grown on both flat and sloping fields that are not bunded, that were prepared and seeded under dry conditions and depends on rainfall for moisture. Through proper agronomic management practices productivity improvement in upland rice is possible.

Dry seeding on flat land or raised beds with successive saturated soil conditions reduces the amount of water needed for land preparation and thus overall water demand (Bouman and Tuong, 2001). In addition to higher economic returns, direct seeded rice crop is faster and easier to plant, less labour intensive and consumes less water (Bhushan *et al*., 2007; Jehangir *et al*., 2005), conducive to mechanization, matures 7–10 days earlier and have less methane emissions than transplanted crop. Yield in direct seeded rice is often lower than transplanted rice principally owing to poor crop stand and high weed infestation (Singh *et al*., 2005a).

Rice is an important component of varying cropping systems. In many rice cropping areas, two rice crops per year are grown sequentially as monoculture. The sustainability could be achieved by adopting new cropping and farming systems approach. The existing rice based cropping system diversified with the inclusion of tuber crops, oilseeds and pulses is more beneficial than continuous cultivation of cereals, and tackles the problem of water and labour scarcity, enhances total production and sustains the soil health (Kumpawat, 2001; Raskar and Bhoi, 2001).

Cropping systems research has shown that short duration cassava varieties could be grown successfully in rice based cropping systems. Cassava is the most important tuber crop of Kerala, which forms an integral part of most of the cropping systems. There is great scope for introducing this crop in rice fallows and thus including it as a major component crop in rice based cropping system. Since the development of cassava in initial stages is very slow, a sole crop of cassava does not efficiently use the available land, light, water and nutrient resources. Therefore a short duration crop can be integrated in the system to enable more efficient use of land and other resources. Bush type of groundnut was found to be the best intercrop of cassava and is adopted widely in Kerala condition.

In the present scenario of degradation of natural resources, the value of pulses is far more important (Singh *et al*., 2009). With the availability of high yielding and short duration varieties of important pulses, there is a need to include them in the rice based cropping system so as to improve the sustainability of the system and meet the future food grain demands without degradation of the natural resource base. The pulses have synergistic effect on the succeeding crop too. Bush cowpea is one of the most popular pulses grown in many parts of India. Because of the quick growth habit, it has become an essential component of sustainable agriculture in marginal lands of the tropics (Vavilapalli *et al*., 2013). Therefore, pulses have become viable alternative to improve the soil health and conserve the natural resources.

Experimental evidences show that a judicious integration of organic manures and inorganic fertilizers would help in better maintenance of long term soil fertility and sustain higher levels of productivity. Foliar formulations are gaining importance in crop production owing to its quick response to plant growth. Foliar feeding of nutrients is a viable supplement to conventional soil application and has proved to be the fastest way of curing nutrient deficiencies and boosting plant performances at specific physiological stages. Foliar fertilizer increases the uptake of soil applied fertilizer and because of higher uptake efficiency foliar supply of nutrients can increase photosynthetic efficiency (Tejada and Gonzalez, 2004). Recent interest in foliar nutrition is also due to the awareness of soil water pollution resulting from excessive soil fertilization and adverse soil conditions, which favours soil fixation of nutrients.

Energetics approach in cropping system is comparatively new and research efforts in this field gathered momentum through seventies due to global fossil fuel crisis. Non renewable energy reserves are exhaustible and research hunt is on to uncover new utilizable avenues of profitably capturable energy resources. Agriculture in a way is an energy conversion industry (Shekhar and Dave, 2014). Inclusion of suitable crops in diversification would reduce the energy production as they are poor converters of it. Therefore, suitable cropping systems need to be designed so that apart from higher productivity and profitability, it must be efficient converter of energy.

With this background, it is evident that the impact of modern agronomic management interventions on the productivity and sustainability of a diversified rice based cropping system needs detailed investigations. Therefore, this investigation was undertaken with the following objectives.

- To assess the impact of agronomic interventions on growth, productivity and sustainability of rice based cropping system

- To study the nutrient balance, energetics and economics of rice based cropping system

Review of Literature

2. REVIEW OF LITERATURE

Rice - cassava (intercropped with groundnut) – vegetable cowpea is one of the predominant rice based cropping systems in uplands of Kerala. The productivity of this crop sequence is more compared to the traditional rice-rice-fallow/cowpea system. As the literature pertaining to rice based system is limited, the available literature on related aspects of component crops are also included in this chapter.

2.1. UPLAND RICE

Upland rice differs from transplanted rice in terms of crop establishment as well as crop management practices. It offers many advantages such as more efficient water use, high tolerance to water deficit, less methane gas emission, reduced cultivation cost, prevents the formation of hard pan in sub soil and minimizes labour input (Balasubramanian and Hill, 2002). Direct seeding of rice refers to the process of establishing the crop from seeds sown in the field rather than by transplanting seedlings from the nursery (Farooq *et al.*, 2011). Dry direct seeded rice production is negligible in irrigated areas but it is practiced in most of the Asian countries in rainfed upland ecosystems (Sangeetha and Baskar, 2015).

2.1.1. Planting Methods in Upland Rice

Direct sowing is generally considered as a popular planting method of upland rice in many developing countries (Dawe, 2003). The yield levels realized by the farmers under upland situations are lower. Among many factors, method of sowing (Budhar and Tamilselvan, 2002, Singh *et al.*, 2002), seed rate (Kathiresan and Manoharan, 2002) and integrated nutrient management (Apurba and Gangwar, 2001) influenced the crop yield level greatly under upland situations. In rice, the planting methods have an impact on the growth and yield, besides cultivation cost and labour requirements (Rani and Jayakiran, 2010).

The direct seeding by dibbling or drilling had better plant establishment and was significantly higher than broadcasting of pre germinated seed and transplanting of seedlings. The tiller population in direct seeding on flat soil was at par with manually transplanted crop. It may be due to higher seed rates used at seeding time. Awan *et al.* (2005) discussed and reported similar results. In situations where labour is available and affordable, seedling transplanting could be chosen under upland condition, but where labour and time are limiting, it makes more economic sense to opt for direct dibbling method for rice under upland conditions (Laary *et al*., 2012).

Broadcast application of seeds @ 100 kg ha^{-1} produced the highest grain yield and it was at par with sowing of seeds @ 80 kg ha^{-1} in lines. Crop sown in lines 20 cm apart resulted in a net saving of 20 kg seed ha^{-1} without any reduction in the grain yield compared to broadcast sowing of 100 kg seed ha^{-1}, the later though had more panicles per unit area (Mankotia and Sekhar, 2006; Singh *et al*., 2004). Oyewole and Attah (2007) indicated that broadcasting generally depressed seed germination and thereby affected crop establishment due to seed loses through biotic and abiotic factors. The tiller population in direct seeding on flat soil was at par with manually transplanted crop. It might be due to higher seed rates used at seeding time (Hussain *et al*., 2013).

Line planting of rice *cv*. ADT 38 with higher fertilizer level registered higher rice grain yield compared to direct sowing or random transplanting in Tamil Nadu, India (Anbumani *et al*., 2000). Compared to transplanted rice, direct seeded rice on raised beds increased yield by 10 per cent, in trials at both experimental stations and on farm (Gupta *et al*., 2003). The direct seeded rice in moistened soil produced taller plants, more dry matter, lower chlorophyll contents, specific leaf weights, and more panicles and sterile spikelets than transplanted rice (Sarkar *et al*., 2003). Ali *et al*. (2006) observed that during both wet and dry seasons, direct seeded rice yielded the same as transplanted rice. The average grain yield of rice was statistically at par with the conventional puddled rice on flats (Kukal *et al*., 2009). The irrigation water productivity of rice on beds was significantly higher than that on puddled flat plots. Rana *et al*. (2014) reported that the rice variety BRRI dhan 39 gave the highest yield (4.96 t ha^{-1}) when grown with direct seeding of sprouted seed compared to transplanting.

Broadcasting of seeds registered the lowest gross returns of Rs 43545 ha^{-1} (Manjappai and Katarak, 2004). Ali *et al*. (2006) observed that during both wet and dry seasons, dry seeding had a higher benefit:cost ratio. Rana *et al*. (2014) reported that the highest net return (Rs 23,362 ha^{-1}) and benefit:cost ratio (1.49) were observed in direct seeding of the sprouted seeds. Direct seeding of sprouted seed was assessed as the best planting method as it reduced 19.94 per cent production cost due to the omission of seedling raising and transplanting operations as well as the reduction in the length of the crop cultivation period. The highest benefit:cost ratio (B:C) was obtained from drilled rice (Simerjeet and Surjit, 2015).

Gupta *et al.* (2003) reported that, direct seeded rice on raised beds decreased water use by 12–60 per cent. The research trials in the Indo-Gangetic Plain reported an irrigation water savings of 12–60 per cent for direct seeded rice on beds, with similar or lower yields in transplanted rice compared with puddle flooded transplanted rice (Bhushan *et al*., 2007).

Narasimman *et al*. (2000) reported that rice established through drum seeder produced significantly more number of panicles m^{-2} than transplanted rice. Gangwar *et al*. (2008) found that the rice plants grown by drum seeding (wet bed, unpuddled) had higher accumulation of dry biomass of shoot and root than manual and mechanical transplanting (puddled). Drum seeding resulted in saving of seeds. The saving of pre germinated rice seed was about 75 per cent and increase in yield was about 37 per cent in conical drum seeder as compared to manual broadcasting (Ratnayake and Balasoriya, 2013).

2.1.2. Straw Mulching in Upland Rice

Straw is an important source of micronutrients such as zinc (Zn) and silicon (Si) in rice. Incorporation of the crop stubbles and straw into the soil returns most of the nutrients and helps to conserve soil nutrient reserves in the long term. Where mineral fertilizers are used and straw is incorporated, reserves of soil nitrogen (N), phosphorus (P), potassium (K), and Si are maintained and may even be increased the soil fertility (Dobermann and Fairhurst, 2002).

New approaches of using rice straw for controlling weeds in different crops indicated that rice straw can be used for mulching, which benefits in reducing weed growth as well as supplies organic matter for nitrogen fixation by heterotrophic nitrogen fixing microorganism (Mendoza and Samson, 1999). Use of rice straw as manure as well as mulch for suppressing the weed growth due to its allelopathic potential can be a good approach to reduce the herbicide load. Application of rice straw mulch at the time of crop establishment in direct seeded rice results in suppressing growth and development of a wide range of weeds (Devasinghe *et al*., 2011). The crop residues like straw present on the soil surface significantly influenced weed and crop growth (Chauhan, 2012; Chauhan *et al*., 2012; Chauhan and Mahajan, 2012; Chauhan and Abugho, 2013). Straw mulching @ 4 t ha^{-1} reduced the weed density upto 20 days after sowing (DAS) (Reshma, 2014).

Lal *et al*. (1996) reported decrease in bulk density under straw mulch (1.42 g cm^{-3}) compared to bare soil (1.50 g cm^{-3}). Higher organic carbon content of soil was recorded with sunhemp mulch (0.71 per cent) followed by silkworm bed waste (0.68 per cent), paddy straw (0.66 per cent) mulched plots and least organic carbon content (0.48 per cent) in non mulched plot (Shashidhar *et al*., 2009). The increase in nutrient content in the 0 to 5 cm soil layer after five seasons of straw mulching were available K (7.64-15.33 per cent) > available P (7.52-10.03 per cent) > available N (7.30-8.74 per cent) > organic matter (6.08-7.53 per cent) (Ji *et al*., 2012).

Incorporation of rice residues showed beneficial effects on the yield of rice (Dhiman *et al*., 2000). Singh *et al.* (2003) observed that mulching increased the yield by 11.1 per cent. Compared with the non flooded cultivation without straw mulching treatment, straw mulching significantly increased leaf area plant^{-1}, main root length, gross root length and root dry weight plant^{-1} of rice. The highest grain yield under the non flooded cultivation with straw mulching treatment (6747 kg ha^{-1}) was close to the yield obtained from rice cultivated in flooded soil (6811.5 kg ha^{-1}) (Jiang-tao *et al.*, 2006). Kato *et al*. (2007) reported that deep tillage or mulching improved grain yield of rice under drought prone rainfed upland conditions in a temperate climate and their combination had more consistent and greater positive effects. The yield components of rice were significantly optimized under mulched situation, with straw mulching displaying an increase of effective panicle number and 9.59 per cent increase of total yield compared to the control (Yu-zhu *et al*., 2011). Straw mulching increased crop yield and the increase in mulching times and straw amount had a significant positive effect on crop yields (Ji *et al*., 2012). Xiaoning *et al*. (2014) observed that straw incorporation significantly stimulated methane (CH_4) emission in the transplanting, but not in the dry direct seeding. The results indicated that dry direct seeding along with straw incorporation gave an acceptable yield with a large reduction in green house gas emissions.

Studies on irrigation levels and mulching revealed that water use efficiency (WUE) was the least affected by irrigation levels, but increased by 12.3 per cent by straw mulching (Singh *et al*., 2003). Chakraborty *et al*. (2010) reported that rice straw mulch increased wheat grain yield, reduced crop water use by 3 to 11 per cent and improved WUE by 25 per cent compared with no mulch in rice-wheat cropping system. Mulch produced 40 per cent higher root length compared to no mulch in lower layers (>0.15 m), probably due to greater retention of soil moisture in deeper layers.

2.1.3. Mechanical Weeding in Upland Rice

The direct seeded rice fields are more species rich with greater diversity in weed flora than transplanted rice (Tomita *et al*., 2003). Yield in direct seeded rice is often lower than transplanted rice principally owing to poor crop stand and high weed infestation (Singh *et al*., 2005a). Moreover, cost for weed control is usually higher than transplanted rice. High weed infestation is a major constraint for broader adoption of direct seeded rice (Rao *et al*., 2007). So mechanical weeding is found to be effective in upland direct seeded rice cultivation.

The effective control of weeds through use of weeder was reported by Nair *et al*. (2002). Mechanical weeding at 15 and 30 DAS using finger weeder and wheel hoe supplemented with one hand weeding gave effective and economical weed control (Moorthy and Mishra, 2004). Effect of mechanical weeding in increasing the grain yield in direct seeded rice by suppressing the weed population was reported by Rao *et al*. (2007). They also reported that the development or adaptation of weeding devices helped to resolve the increased weed infestation in upland systems. Keen *et al*. (2012) stressed the importance of precision mechanical weeding under upland rice with increased weed occurrence. Based on the trials in aerobic rice, Reshma (2014) reported that mechanical weeding with cycle hoe and power weeder was beneficial and the total dry matter at 20 DAS was also significantly higher and on par with hand weeding at 20 DAS. The same treatments resulted in reasonably good yields (3.33 t ha^{-1} and 3.06 t ha^{-1} respectively), although less than the best treatments. Mechanical weeding with cycle hoe (Rs 5.02 ha^{-1}) and power weeder (Rs 4.51 ha^{-1}) also proved beneficial in terms of returns per rupee invested (Reshma, 2014).

2.1.4. Foliar Nutrition in Upland Rice

Foliar formulations are gaining importance in crop production owing to its quick response and better results in plant growth than soil application (Jamal *et al*., 2006). Shafiee *et al*. (2013) reported that foliar feeding stimulates plant roots to become more efficient in the uptake of all nutrient requirements. Furthermore, it is an economical way of supplementing plant nutrients when they are in short supply or unavailable from soils. They also reported that the efficiency of foliar application is three to five folds greater than soil applied fertilizers, and could significantly reduce the amount of fertilizer usage. Foliar nutrition is especially useful for micronutrients but can also be used for major nutrients like N, P, and K. However, as the amount applied at a time is small it requires several applications to meet the needs of a crop.

Tejada and Gonzalez (2004) reported the positive effects of foliar fertilization on chlorophyll a and b and carotenoids content of rice plant, which presumably favoured photosynthesis. Shayganya *et al*. (2011) reported that foliar application of different nutrients increased tiller number in direct seeded rice plants. Four sprays of $MnSO_4$ @ 0.5 per cent or $FeSO_4$ @ 1.0 per cent at 40, 50, 60 and 70 DAS were on par and produced significantly higher plant height, dry matter and leaf area index (LAI) of rice compared to control (Gill and Walia, 2013). Flag leaf nutrition with 19:19:19 @ 0.5 % produced significantly taller plants in rice at booting stage (Surya, 2015).

Foliar application of potassium chloride (KCl) @ 10 kg m^{-3} to rice at panicle initiation, boot leaf and 50 per cent flowering stages, significantly increased seed yield and improved quality (seed germination and 100 seed weight) (Jayaraj and Chandrasekharan, 1997). Splitting a total of 95 kg ha^{-1} of KCl to rice, one third at sowing in soil, one third as a foliar spray at flag leaf stage and one third as foliar spray at grain development gave higher yield than soil application of the entire at sowing (Narang *et al.*, 1997). In the Cauvery delta of Tamil Nadu, India, application of two foliar sprays of diammonium phosphate (DAP) @ 20 kg m^{-3} water with foliar application of 10 kg m^{-3} water of urea and KCl, one at panicle initiation and the other at flowering increased yield up to 0.75 t ha^{-1} (Nagarayan, 1999). Lin and Zhu (2000) reported that foliar spraying of nutrients at heading stage increased grain yield of rice compared to control.

Sarangi and Sharma (2004) reported that the yield attributes and yield of upland rice increased by 31-48 per cent with basal application of 15 kg $FeSO_4$ ha^{-1} + 1.0 per cent foliar spray (10 kg $FeSO_4$ ha^{-1}) at 35 DAS which was on par with foliar spray (0.1 per cent) of Fe-EDTA. Foliar spraying of *house green* (a combination of 20 per cent nitrogen + 20 per cent phosphorous + 20 per cent potassium + 0.5 per cent zinc + 0.5 per cent iron (Fe) + 0.5 per cent manganese (Mn) + 0.5 per cent copper (Cu) + 0.02 per cent boron (B) + 0.05 per cent molybdenum) in rice at 45 days after transplanting (DAT) enhanced grain weight $panicle^{-1}$ by 6 per cent and straw yield by 11 per cent compared to spraying at 15 DAT (Sharief *et al*., 2006). Ali *et al*. (2007) observed that foliar application of K_2SO_4 at 6 per cent concentration (equivalent to 48 kg K_2SO_4 ha^{-1}) and soil application of K_2SO_4 @ 50 kg K_2O ha^{-1} to rice crop produced the highest yield (3837 and 3874 kg ha^{-1} respectively). Four sprays of $MnSO_4$ @ 0.5 per cent or four sprays of $FeSO_4$ @ 1.0 per cent at 40, 50, 60 and 70 DAS were on par and produced significantly higher effective tillers m^{-2}, panicle length, spikelets $panicle^{-1}$, grains $panicle^{-1}$, 1000 seed weight, grain yield (3.8 and 3.6 t ha^{-1}) and straw yield (9.1 and 9.5 t ha^{-1}) (Gill and Walia, 2013). Surya (2015) reported that, the grain to straw ratio and harvest index were superior with 19:19:19 complex @ 0.5 %.

Foliar spray in bed planting method increased grain yield of transplanted *aman* rice up to 9.33 per cent over conventional method. Foliar nitrogen fertilizer application in bed planting method increased the number of panicle m^{-2}, number of grains $panicle^{-1}$, and 1000 grain weight of rice than the conventional method. Sterility percentage and weed infestation were lower at foliar nitrogen fertilizer application in bed planting method than the conventional method (Bhuyan *et al*., 2012). The zinc fertilizer application as foliar registered an average yield similar to foliar fertilizer application on soils with lower phosphorus levels, and higher yields for foliar fertilizer application on soils with high levels of phosphorus (Morais *et al*., 2013). Sandhya *et al.* (2014) observed that significantly higher grain yield (5611 kg ha^{-1}) was produced with recommended dose of fertilizer (RDF) along with foliar spray of 19:19:19 @ 2.5 kg ha^{-1} at tillering and panicle initiation stages along with top dressing of Muriate of potash (MOP) @ 80 kg ha^{-1} at panicle initiation stage.

Higher net returns and benefit:cost ratio was reported by Gill and Walia (2013) by the application of four sprays of $MnSO_4$ @ 0.5 per cent or four sprays of $FeSO_4$ @ 1.0 per cent at 40, 50, 60 and 70 DAS in rice compared to control. Gross returns and net returns were the highest with recommended dose of fertilizer (RDF) along with foliar spray of 19:19:19 @ 2.5 kg ha^{-1} at tillering and panicle initiation stages followed by RDF (160:80:80N:P_2O_5:K_2O kg ha^{-1}) (Sandhya *et al*., 2014).

2.2. CASSAVA GROUNDNUT INTERCROPPING SYSTEM

2.2.1. Intercropping in Cassava

In order to maintain soil fertility and crop yields, intercropping has been suggested as a common practice of small holder farmers. Besides improving soil fertility and stabilizing higher yield, the benefits associated with intercropping are reducing risk of crop failure, decreasing disease severity, controlling weed pressure and achieving more efficient utilization of environmental resources relative to the pure cropping system.

Among the various legume plants, groundnut is one of the recommended legume crops for intercropping with cassava. Groundnut (bunch type TMV 2 and TMV 7) was found to be the most promising and economical. Intercropping groundnut with cassava resulted in a positive impact on cassava yield and net income as well as decreased the soil erosion over the pure cassava (Howeler, 2002). Nyi *et al*. (2014) observed delayed growth of cassava in the cassava-groundnut intercropping system due to the interspecific competition of resources such as light and nutrients. They also observed that groundnut should be planted at the same time or not later than two weeks of planting cassava to maximize yields and economic returns in a cassava-groundnut intercrop.

Bridgit *et al.* (1992) reported that cassava leaf K content and K uptake plant^{-1} increased by intercropping with groundnut *var* TMV 2.

Cassava intercropped with groundnut produced the highest cassava yield of 17.8-25.1 t ha^{-1} with 94 kg N, 75 kg P_2O_5 and 94 kg K_2O ha^{-1}. In intercropped situation, groundnut produced the highest yield with 75 kg N, 75 kg P_2O_5 and 50 kg K_2O ha^{-1} (Sheela and Kunju, 1990). Bridgit *et al.* (1992) reported that cassava both under pure crop and intercropped condition, produced a tuber yield of 19.6 t ha^{-1} and 20.64 t ha^{-1} respectively and in intercropping, yield increase was observed with increased rate of N application and was the highest when N was applied at 15, 75 and 120 DAP (days after planting). Robinson (1997) reported that cassava growth and yield were higher when intercropped with groundnut than with rice. Eke-Okoro *et al*. (1999) observed that intercropping cassava with groundnut significantly produced the highest fresh root yield (13.6 t ha^{-1}). In a cassava -groundnut intercropping system, application of NPK @ 54:72:180 kg ha^{-1}, along with the biofertilizers *ie. Azospirillum* for cassava and *Rhizobium* for groundnut, promoted crop growth, increased yield and generated higher profits from the system (Thanunathan *et al*., 2000). Sole cassava treated with 7.5 t ha^{-1} FYM produced a stable tuber yield of about 13 t ha^{-1} and cassava intercropped with groundnut and cowpea gave yields of about 16 t ha^{-1}, implying complementary effects of legume intercropping (Islami *et al*., 2011). In cassava-groundnut intercropping system, groundnut produced 1000-1200 kg ha^{-1} dry pod yield (Ravindran *et al*., 2011). They also stated that the harvested haulms can be used for mulching cassava.

Sheela and Kunju (1990) reported that the highest net return was obtained when cassava was intercropped with groundnut by the application of 50 kg N, 62.5 kg P_2O_5 and 62.5 kg K_2O ha^{-1}. The highest gross return was obtained from cassava in wide rows intercropped with five rows of groundnut (Prabhakar and Nair, 1992). Among the intercropping systems, only the cassava groundnut intercrop generated more net income than the pure cassava crop (Karnik *et al*., 1993). Land equivalent ratio and combined economic value were much greater for intercropping patterns than those of the sole crops of both cassava and groundnuts as reported by Polthanee (1999). Ravindran *et al*. (2011) observed that the economic analysis of the cropping system was the maximum when groundnut was intercropped with cassava.

2.2.2. Minisett Planting of Cassava

A major problem in cassava production is the non availability of quality planting material. Rate of multiplication in most of the tuber crops including cassava is very low. Hence, it takes a long time for quality planting materials of high yielding and hybrid varieties to reach farmers. Cassava is also prone to the major viral disease, cassava mosaic disease (CMD), which causes enormous economical loss. Since, cassava is clonally propagated, it facilitates easy and fast spread of the disease. The ICAR - Central Tuber Crops Research Institute, Sreekaryam, Kerala have evolved a farmer friendly technique called Minisett Technique, by which it was proved that multiplication ratio in cassava could be significantly enhanced to 1:60 from the traditional 1:10. Hence, the technology could successfully address the twin problems of low multiplication ratio and CMD. The study also opened a new avenue for enhancing productivity and production from a unit area of land significantly over

thetraditionalmethod.
(http://www.cmtevents.com/eventdatas/120212/others/AbstractJamesGeorge.html**).**

Issac *et al*. (2011) reported that per plant yield from two noded minisetts (4.75 kg) was comparable to the yields from the normal setts (5.2 kg). They also stated that yield gap analysis recommended for technology verification trials in farmer's field revealed the superiority of minisett planting with two noded setts over the conventional practice on hectare basis owing to nearly double the plant population per unit area. In cassava, germination was earlier in minisetts than in the eight noded setts used. The yield and yield attributes of minisett cassava grown in bags were found more or less similar to normal setts. But per plant yield was comparatively higher than the conventional cassava planting (Issac *et al*., 2015).

The higher yield in two noded setts compensated for the additional cost incurred for preparation of minisetts and installation of the nursery resulting in higher net return and B:C ratio (Issac *et al*., 2011).

2.2.3. Foliar Nutrition in Cassava

The foliar fertilization with Zn, Mg and S on KU 50 cultivar gave the greater effect on fresh stem weight and fresh root weight, while HB 60 cultivar gave the highest fresh root yield (74.38 t ha^{-1}) and fresh root weight (370.10 g $root^{-1}$). The Zn and Mg treatment sprayed on HB 60 cultivar of cassava gave the highest fresh root yield (98.56 t ha^{-1}) and fresh root weight (442.45 g $root^{-1}$), but the HB 80 cultivar with Zn, Mg and S foliar fertilization gave the highest root starch content of 29.33 per cent (Panitnok *et al*., 2013).

2.2.4. Foliar Nutrition in Groundnut

Though groundnut is called as a self fertilizing crop, it is very exhaustive compared to other legumes as very little portion of the plant is left in the soil after harvesting. Soil application of fertilizer leads to losses of nutrients in the form of leaching, volatilization and fixation affecting the nutrient use efficiency (Veerabhadrappa and Yeledhalli, 2005).

El-Habbasha *et al.* (2013) reported that the highest N and K content in the seed and straw was observed under foliar application of Zn either at flowering or seed filling stages compared to control treatment. The highest values of available N, P, K and S were observed with the combined foliar application of S, Zn and B (Patro *et al.*, 2014).

Pod yields were significantly higher when basal and foliar applications were combined. The best results were achieved with foliar application of 1 per cent KCl together with a basal fertilization with 50 kg K_2O ha^{-1}. Response to K of crop harvest index (HI), quality parameters of protein and oil contents of seed was more consistent with foliar applied K_2SO_4 (Umar *et al*., 1999). Nassar (2005) reported that foliar spraying with 600 mg Fe, 600 mg Zn, 300 mg Mn and 150 mg B litre^{-1} gave the highest seed and pod yields of groundnut, achieving a balance between macro and micronutrients in the plants, and produced the highest seed nutrient, oil and protein contents. Pod yield of groundnut was 1,899 kg ha^{-1} in absolute control, which increased significantly to 2,059 kg ha^{-1} in the plots, which received only foliar spray of nutrient (1 per cent each of urea, single super phosphate and Muriate of potash) at 60 DAS. However, significantly higher pod yield (2,692 kg ha^{-1}) was observed due to application of 100 per cent RDF along with foliar spray of nutrient (1 per cent each of urea, single super phosphate and Muriate of potash) at 60 DAS and was significantly superior to all the other treatments (Veerabhadrappa and Yeledhalli, 2005).

Gobarah *et al*. (2006) observed that foliar spraying with different levels of zinc had a significant effect on groundnut growth, yield and its components as well as seed quality. It could be concluded that the highest yield of seed, oil and protein (1408, 633 and 368 kg ha^{-1} respectively), were obtained by application of 60 kg P_2O_5 ha^{-1} along with foliar spraying of 1 g $litre^{-1}$ Zn. Use of Zn as foliar application either at flowering or seed filling stages significantly increased number of pods $plant^{-1}$, weight of pods $plant^{-1}$, number of seeds $plant^{-1}$, weight of seeds $plant^{-1}$, 100 pod weight, 100 seed weight, pod, seed and haulm yield ha^{-1}, oil yield, seed protein content, compared to control treatment (El-Habbasha *et al*., 2013). El-Kader (2013) reported that application of sulphur (S) and foliar spraying with micronutrients (Zn and B) together had significant effect on yield attributes and yield of groundnut as well as seed quality. Foliar application of urea significantly influenced pod yield of groundnut. Foliar application of urea @ 2 per cent at 30 and 60 DAS resulted in the highest pod yield of 1350 kg ha^{-1}, which was 11.6 per cent higher than no foliar application (1210 kg ha^{-1}) (Patro *et al*., 2014).

2.3. COWPEA

2.3.1. Importance of Cowpea in Sequential Cropping System

In the present scenario of degradation of natural resources and International Year of Pulses (IYP 2016), the value of pulses is far more important. The beneficial effect of pulse crops in improving soil health and sustaining productivity has long been realized. On account of biological nitrogen fixation, addition of considerable amount of organic matter through root biomass and leaf fall, deep root systems, mobilization of nutrients, protection of soil against erosion and improving microbial biomass, the pulses keep soil productive and alive by bringing qualitative changes in physical, chemical and biological properties. As a result of this, the productivity of cereals following a preceding grain legume often increases and corresponds to a saving of 40-60 kg N equivalent. Besides this, the cost of production of such cropping systems significantly decreased and returns per rupee investment increased (Singh *et al*., 2009).

In sequential cropping involving pulses, the preceding pulse may contribute 18-70 kg N ha^{-1} to the soil and thereby considerable amount of nitrogen to succeeding crop (Ali and Mishra, 2000). Pulses are known for their soil fertility restoration value. By improving chemical, biological and physical environment in the soil, pulses in the system could arrest the declining trend in productivity of cereal-cereal system. Carry-over of N from biological nitrogen fixation, e.g. in roots and stover, can supply the N demand of subsequent non N fixing crops (Van Kessel and Hartley, 2000). Bationo *et al.* (2002) stated that yields of cereals succeeding cowpea could double compared to continuous cereal cultivation. Also with efficient soil fertility management, an increase of nitrogen use efficiency on the succeeding cereal crop from 20 per cent in the continuous cereal monoculture to 28 per cent when cereals are in rotation with cowpea could be obtained. Sorghum yields increased when sown after groundnut and cowpea (Ghosh *et al.*, 2007).

2.3.2. Foliar Nutrition in Cowpea

Spraying 2 per cent DAP at 20 and 30 DAS produced a good yield of cowpea similar to soil application of N and P and higher yields than 2 per cent urea spray (Srinivasan and Ramasamy, 1992). Parasuraman (2001) observed that soil application of recommended inorganic fertilizers + 2 per cent DAP spray twice (first at flowering and second at 15 days after first spray) resulted in the highest plant height, branches, pods $plant^{-1}$, seeds pod^{-1}, 100 seed weight, dry matter production (DMP), seed yield. Combined spraying of 0.5 per cent $FeSO_4$ and 0.5 per cent $ZnSO_4$ at 45 DAS was the most effective treatment as it increased the seed yield by 43.09 per cent compared to control, followed by combined spraying of 0.5 per cent $FeSO_4$ and 0.5 per cent $ZnSO_4$ at 25 DAS (40.14 per cent) (Anitha *et al.*,2005). Mavarkar *et al.* (2008) reported that foliar application of 1 per cent $ZnSO_4$ at 25 DAS resulted in the highest grain yield (1166 kg ha^{-1}), similar trends were also observed with respect to growth and yield attributes (plant height, number of leaves, number of pods plant^{-1}, number of seeds pod^{-1} and test weight).

Foliar sprays of 2 per cent DAP, 2 per cent urea and 2 per cent KCl remained at par and resulted in higher nitrogen, phosphorus and potassium content in seed and straw and total uptake of nitrogen, phosphorus and potassium over water sprayed control (Yadav and Choudhary, 2012).

Azarpour *et al.* (2011) observed significant interaction effect of humic acid and nitrogen fertilizer on seed yield, plant height, number of pods plant^{-1} and number of seeds pod^{-1} of cowpea. The highest seed yield was produced by spraying humic acid @ 50 mg L$^{\mathbf{-1}}$ along with 45 kg ha^{-1} nitrogen. Moraditochaee (2012) reported the effect of nitrogen fertilizer management with 4 levels (control (0 kg ha^{-1} pure nitrogen), 25 kg ha^{-1}, 50 kg ha^{-1}, 75 kg ha^{-1} pure nitrogen from source of urea (46 per cent) and also amino acid foliar spraying with 2 levels (control (without amino acid spraying), 2 g L^{-1} foliar spraying) on all measured traits, which was significant. The highest seed yield of cowpea was obtained among nitrogen levels, amino acid spraying treatments and interaction levels with 1360 kg ha^{-1}, 1166.8 kg ha^{-1} and 1736 kg ha^{-1} respectively. Foliar sprays of 2 per cent DAP, 2 per cent urea and 2 per cent KCl remained at par and resulted in higher seed yield and protein content over water sprayed control (Yadav and Choudhary, 2012). Foliar application of micronutrients complex fertilizer at 80 DAS had the highest impact on yield (3.7 t ha^{-1}) and produced the highest number of pods plant^{-1} (18.76) (Abbas *et al.*, 2013).

Parasuraman (2001) observed that soil application of recommended inorganic fertilizers along with 2 per cent DAP spray twice (first at flowering and second at 15 days after first spray) resulted in the highest net income and B:C ratio. The net return and B:C ratio was found highest in combined spraying of 0.5 per cent $FeSO_4$ and 0.5

per cent $ZnSO_4$ at 45 DAS compared to control, followed by combined spraying of 0.5 per cent $FeSO_4$ and 0.5 per cent $ZnSO_4$ at 25 DAS (Anitha *et al*., 2005).

2.4. RICE BASED CROPPING SYSTEM

2.4.1. Methods of Planting and Mulching in Rice Based Cropping System

Kavimani *et al*. (2000) observed that N, P and K removal by weeds was significantly lower in line sown rice and this method resulted in significantly higher uptake of nutrients by rice-rice-sesamum compared to broadcasting of rice seeds.

Rice grown under direct sowing, unpuddled conditions gave higher productivity than rice transplanted after puddling in rice – wheat cropping system (Sharma *et al*., 2005). The mean yield of hybrid rice was higher (8.52 t ha^{-1}) in different rice based cropping systems with drum seeding and remained on par with that of direct seeding and mechanical transplanting (puddled) compared with manual transplanting (puddled) and mechanical transplanting (unpuddled). The drum or direct seeded rice based cropping system not only produced higher grain yield of hybrid rice but also resulted in greater productivity of the subsequent crops (Gangwar *et al*., 2008). Bunna *et al*. (2011) found that seed drill produced better mungbean establishment and grain yield in rice – mungbean system compared to manual planting suggesting the suitability of driller to save the labour cost.

Among the different methods of planting in rice-wheat system, the output energy was the highest in drum seeded rice followed by direct seeded rice and the lowest was produced by manually transplanted rice in puddled condition. The direct and drum seeded rice required about 5 per cent less input energy and gave 8 to 9 per cent higher output energy as compared to manually transplanted rice in puddled field (Chaudhary *et al*., 2014).

Drum seeding fetched the highest mean net returns (Rs 47,040 ha^{-1}) in rice-wheat system, followed by rice-chickpea (Rs 42,336 ha^{-1}) and rice-mustard system (Rs. 39,774 ha^{-1}). The benefit:cost ratio was the highest in rice-chickpea (1.24) followed by rice-wheat (1.21) and rice-mustard systems (1.12) (Gangwar *et al*., 2008).

Mulching of rice straw @ 1.5 t ha^{-1} increased mungbean crop establishment from 72 to 83 per cent, reduced weed biomass from 164 to 123 kg ha^{-1} in rice–mungbean system at Mekong region (Bunna *et al*., 2011).

Bunna *et al.* (2011) reported that mulch was effective in conserving soil moisture in rice–mungbean system and even at maturity the mulched area had on average 1 per cent higher soil moisture content.

The application of 5 t ha^{-1} rice straw mulch increased soybean yield by 153 per cent in rice–legume cropping system was reported by Adisarwanto *et al.* (1995). Mulching with rice straw increased seed yield of mungbean grown after rice harvest at Philippines (Sanidad *et al*., 1995). Rautaray (2005) observed that the interaction between the winter crops (potato, tomato, radish, peas, toria, lentil, gram and coriander) grown after rice and mulching resulted in 29 per cent increase in yield in tomato followed by potato (21 per cent) among the different rice–winter crop systems. White clover with light rice straw mulching in rotation with rice produced moderate rice yield in no till, unfertilized, direct sown rice-based cropping systems (Son, 2005). Banik and Sharma (2008) reported that mulching with 10 t ha^{-1} rice straw resulted in significantly higher yield of winter season crops (mustard, lentil, barley and linseed) in rice based cropping system. Mulching of rice straw @ 1.5 t ha^{-1} increased mungbean yield by

104 kg ha^{-1} in rice–mungbean system at Mekong region (Bunna *et al*., 2011). Mulching of rice straw in rice based sequential cropping system registered higher yield for succeeding crops groundnut (35 per cent), mustard (26 per cent), pea (24 per cent) and french bean (18 per cent) over no mulched plot (Choudhary and Kumar, 2014).

2.4.2. Soil *vs* Foliar Fertilization in Rice Based Cropping System

Application of cowdung @ 5 t ha^{-1} once in a year at the time of *boro* transplanting supplemented 50 per cent of the fertilizer nutrients other than nitrogen (N) for the subsequent crop in rice based system (Saha *et al*., 2007). Geetha and Velayutham (2009) observed that all the growth parameters, NPK uptake and yield were significantly influenced when foliar spray of 2 per cent DAP + 1 per cent KCl was given at flowering and pod filling stages of black gram in rice-fallow-blackgram system. Interaction between fertilizer application and foliar spray was also significant for growth parameters and yield of black gram.

Application of FYM @12.5 t ha^{-1} along with 100 per cent RDF (150:75:75 kg NPK ha^{-1}) to maize and application of RDF (25:50:25 kg NPK ha^{-1}) to succeeding cowpea crop could be recommended for enhancing the growth as well as grain and haulm yield of succeeding cowpea in maize-cowpea cropping system (Stephen and Christopher, 2014).

2.4.3. Productivity of Rice Based Cropping System

Black gram as a fallow crop in rice based system produced more rice grain equivalent yield, followed by cotton and soybean (Anbumani *et al*., 2000). Saha *et al*. (2007) reported that the grain and straw yields were significantly increased as a result of the application of inorganic fertilizer and organic manure in rice based cropping system. Application of 100 per cent recommended dose of fertilizer (RDF: NPK

60:60:40 kg ha^{-1}) to rice followed by 50 per cent RDF to rapeseed produced the highest rice grain yield as well as system productivity (4.64 t ha^{-1}) in rice-rapeseed cropping sequence as observed by Munda *et al*. (2008). Among the different rice based systems tried, the highest total productivity was obtained under rice–potato–cowpea system (22.29 t ha^{-1}) (Shrikant *et al*., 2011). Rice (var. Kanchana)-short duration cassava (var. Sree Vijaya) + black gram (Co-7) resulted in higher tuber equivalent yield (38.86 t ha^{-1}) besides saving nutrients, half FYM and N and full P to short duration cassava in this system (CTCRI, 2016).

The relatively higher grain and straw yield were observed in rice that followed grain, vegetable and green manure crop of cowpea. This revealed the positive residual effect of incorporated cowpea on the subsequent crop yields (KAU, 2012). Kachroo *et al*. (2012) found that rice-garlic-cowpea resulted in the highest average rice equivalent yield (46.37 t ha^{-1}) followed by rice-potato-onion (33.96 t ha^{-1}) and rice-marigold-french bean (29.31 t ha^{-1}). The rice- groundnut-sesame system had the highest land use efficiency of 87.14 per cent whereas; rice-radish-greengram registered the highest production efficiency (61.54 kg ha^{-1} day^{-1}). Rice-frenchbean-greengram produced the highest rice equivalent yield (17.31 t ha^{-1}yr^{-1}) (Mishra *et al*., 2013). Intensification of rice–wheat system by inclusion of greengram grown in summer resulted in significantly higher rice equivalent grain yield than that of rice–wheat sequence (Prasad *et al*., 2013). Experiment involving sunhemp and cowpea for multiple uses in a rice based cropping system showed that raising green manure crop of sunhemp or cowpea significantly enhanced the yield of subsequent crop of rice. Growing grain or vegetable cowpea also resulted in a similar increase in rice yield (CSRC, 2013). The cropping system, rice (var. Aiswarya)-black gram (var. Co-6)-short duration cassava (var. Sree Vijaya) was productive, profitable and energy efficient. There was a possibility to save half FYM and N and full P to short duration cassava (23-24 t ha^{-1}) in this system (CTCRI, 2015).

2.4.4. Energetics of Rice Based Cropping System

Kachroo *et al.* (2012) reported that average energy productivity was the highest in rice-garlic-cowpea (1.29 kg MJ^{-1}) followed by rice-marigold-french bean (0.83 kg MJ^{-1}). Rice–french bean-greengram was the most sustainable with higher energy productivity (0.85 kg MJ^{-1}) (Mishra *et al.*, 2013). Among the different cropping systems, the highest energy output-input ratio of 10.73 was obtained from rice-chickpea followed by rice-linseed (8.78) and rice-wheat (8.39). The specific energy required was found the lowest in rice-chickpea cropping system having value of 2.81 MJ kg^{-1} followed by rice-wheat and rice-linseed, 3.54 and 3.64 MJ kg^{-1} respectively (Shekhar and Dave, 2014).

Walia *et al.* (2014) observed that **e**nergy productivity was the highest in groundnut–toria + gobhi sarson (0.82 kg MJ^{-1}) as compared to other cropping systems. The energy use efficiency was the maximum in groundnut–toria + gobhi sarson (16.3), but specific energy was lowest for the same treatment. The rice–greengram system produced the highest energy output (183,006 MJ ha^{-1}), which was on par with the energy production of the rice–toria–horsegram system (179,788 MJ ha^{-1}) (Lal *et al.*, 2015). The experiments conducted on various cropping systems at CTCRI (2016) reported that, rice (var. Kanchana)-short duration cassava (var. Sree Vijaya) + black gram (Co-7) system resulted in higher energy equivalent and production efficiency (107.94 kg ha^{-1} day^{-1}).

2.4.5. Nutrient Balance of Rice Based Cropping System

Nitrogen and phosphorous balance was found positive in rice-wheat–green gram and rice-potato-green gram cropping systems whereas, potassium balance was negative in these cropping systems (Sharma and Sharma, 2002). Ramachandra *et al*. (2006) reported that rice-cowpea, rice-soybean and rice-fallow sequences showed marginal, but positive N balance in soil at 50 per cent RDF and 50 per cent RDF + 5.0 t *Chromolaena odorata* compost. The crop sequences of rice-rice-cowpea and rice-rice-groundnut showed a positive nitrogen balance in the soil, the maximum being after rice-rice-groundnut crop sequence. Inclusion of groundnut and cowpea in rice based crop sequences increased the yield of the succeeding crop of rice due to the release of major nutrients (Pillai *et al*., 2007).

Saha *et al*. (2007) observed that there was an apparent positive balance of P, S and Zn in fertilized plots but a negative balance of N and K. This study showed that the addition of organic manure (cowdung, daincha) gave more positive balances. Inclusion of legumes in the cropping system and integrated nutrient management improved the organic carbon status of the soil. The biological nitrogen fixing ability of leguminous crops not only supplied additional nitrogen but also helped the plant to provide more macro and micronutrients through the increment in biological properties of soil (Azam *et al.*, 2008). Rice-groundnut-greengram sequence was found to be the most efficient user of N (138.8 kg yield ha^{-1} N applied) whereas, rice-groundnut -fallow used P and K more efficiently than other cropping sequences. The study further revealed that rice productivity could be enhanced by 19.1 per cent and 17.7 per cent by inclusion of oilseeds and pulses respectively than monocrop of rice (Mishra *et al*., 2013).

2.4.6. Residual Effect of Rice Based Cropping System

Irrespective of preceding crops in rice based cropping system, the mulch showed positive residual effect on rice yield (Mandal *et al*., 1988). Mitra and Mandal (2009) reported that in rapeseed–greengram-rice system of cropping, residual effect of mulch did not influenced the growth attributes significantly; however, it gave rise to higher values of LAI, crop growth rate (CGR) and higher dry matter yield of rice. Crop raised with residual effect of mulch resulted in higher grain yield irrespective of fertility levels. The increase in yield due to increased number of mature panicles and number of filled grains are attributed to the residual effect of legumes (preceding greengram) and organic mulches.

Yang *et al.* (2000) reported that the residual effect of soil application of boron (B) @ 1.1 kg ha^{-1} was fully effective in correcting B deficiency in oilseed rape for two years in intensively cropped rice based rotations. When boron application was increased to 1.65 kg ha^{-1}, the residual effect helped to correct B deficiency for at least three years. Foliar application of B fertilizer generally corrected B deficiency for oilseed rape but showed limited residual effect in the following years after application. The residual effect of the integrated nutrient treatment (NPK + green manure) applied to previous rice increased the grain yield and yield attributes of rice-fallow-blackgram (Subramani *et al.*, 2005). Latha and Murugappan (2007) found that considerable amounts of residual N, P and K were left in the soil following application of N, P and K fertilizers to the previous *kuruvai* (first crop) and *thaladi* (second crop) season rice crops in Tamilnadu. The same treatments enhanced the grain and haulm yield of succeeding blackgram in rice-rice-blackgram cropping system. A preceding crop of green manure could reduce the doses of phosphorus (P), potassium (K), sulphur (S), and zinc (Zn) to the second crop *aman* rice without reducing the yield, indicating the beneficial residual effect of fertilizer applied to the first crop (*boro* rice) of the cropping pattern (Saha *et al*., 2007).

Munda *et al*. (2008) reported the highest residual effect of organics on rapeseed seed yield when FYM @ 5 t ha^{-1} was applied to rice in rice-rapeseed cropping sequence. Phosphatic fertilizer and FYM contributed considerable residue in the soil, which is useful for subsequent crops. The residues left by potassium fertilizers were marginal.

Therefore, potassium availability to subsequent crop was increased by groundnut crop residues (Rana and Rana, 2011).

Rice–potato–greengram system produced higher grain and straw yield of rice, which could be attributed to the residual effect of nutrients by growing potato during *rabi* and the beneficial effect of legumes grown in summer season (Prasad *et al*., 2013). Succeeding rice showed significant response to residual fertilizer levels up to 100 per cent RDF in grain yield and up to 125 per cent in straw yield and registered 16.9 per cent and 25.4 per cent increase over the control, respectively in groundnut–rice cropping system (Chavan *et al*., 2014). Among the residual effect of different fertilizer levels and foliar sprays in maize, it was observed that grain and haulm yield of succeeding cowpea were significantly increased due to application of 100 per cent RDF to preceding maize compared to 75 per cent RDF to maize in irrespective of foliar spray applied (*i.e*. 1 or 2 per cent polyfeed) (Stephen and Christopher, 2014).

2.4.7. Profitability of Rice Based Cropping System

Munda *et al*. (2008) reported that application of 100 per cent recommended dose of fertilizer (RDF: NPK 60:60:40 kg ha^{-1}) to rice followed by 50 per cent RDF to rapeseed produced the maximum gross return, net return and benefit:cost ratio in rice-rapeseed cropping sequence. Among the various rice based systems, the highest net return (Rs 98,252 ha^{-1}) and benefit:cost ratio (2.40) was obtained under rice-brinjal-green manure. But over the years, rice-potato-cowpea sequence was found to be the most appropriate system in terms of profit as well as sustainability (Shrikant *et al*., 2011). When summer rice fallows are effectively utilized for vegetable production under rice based cropping system, the gross and net returns generated were many folds as compared to rice-rice-fallow reported by CSRC (2013).

Kachroo *et al*. (2012) found that rice-garlic-cowpea produced the highest B:C ratio of 2.59. Rice-frenchbean-greengram produced the highest net return and benefit: cost ratio (Mishra *et al*., 2013). Singh and Kumar (2014) reported that rice–potato–greengram cropping system produced the highest net return followed by rice–vegetable pea–vegetable french bean and rice–potato–vegetable cowpea system. The profitability and relative economic efficiency were higher under the rice–potato–greengram, rice–potato–vegetable cowpea and rice–vegetable pea–vegetable french bean cropping systems over the traditional rice–wheat system. The experiments conducted on various cropping systems at CTCRI (2016) reported that, rice (var. Kanchana)-short duration cassava (var. Sree Vijaya) + black gram (Co-7) system resulted in the higher profitability (added profit of Rs. 52,107 ha^{-1} over sole cassava).

In the present day scenario of climate change and food security, crop diversification including cereals, tubers and legumes like groundnut and cowpea is very much essential for a well sustainable and productive cropping system rather than monocropping. Increasing water scarcity and labour shortage necessitates the development of irrigated rice based systems along with various interventions like mechanization, foliar nutrition etc. The development of such systems needs the quantification of yield potential of each crop, residual study, nutrient balance and energetics.

Materials and Methods

3. MATERIALS AND METHODS

The present investigation entitled “Agronomic interventions for a sustainable rice based cropping system in paddy fields” was carried out to evaluate the impact of agronomic interventions on growth, productivity and sustainability of a rice based cropping system and to study the nutrient balance, energetics and economics of the cropping system. The materials used and the methods adopted for the investigation are briefly described below.

3.1. EXPERIMENTAL SITE

The experiment was carried out at Instructional farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala. The site is situated at 8^0 25’ 46.94” N latitude and 76^0 59’1.12” E longitude and at an altitude of 3 m above mean sea level (Plate 1).

3.1.1. Climate

The experimental site experiences a humid tropical climate. Data on weather parameters like temperature, rainfall and relative humidity were obtained from the Class B Agromet Observatory at College of Agriculture, Vellayani. The average values of weather parameters recorded during the cropping period are given in Appendix-I and Appendix-II and graphically presented in Fig 1 and Fig 2. The mean maximum temperature ranged between 28.9^{0}C to 32.4^{0}C and 29.8^{0}C to 32.7^{0}C during first and second years respectively, while the minimum temperature ranged between 21.5^{0}C to 25.4^{0}C and 21.9^{0}C to 25.5^{0}C during the first year and second year respectively. The mean relative humidity ranged from 88.5 per cent to 97.4 per cent and 88.4 per cent to 94.9 per cent during first and second years respectively. A total rainfall of 1518.1 mm and 2236.5 mm was recorded during the cropping period of first and second year respectively.

Plate 1. Location of the experimental field

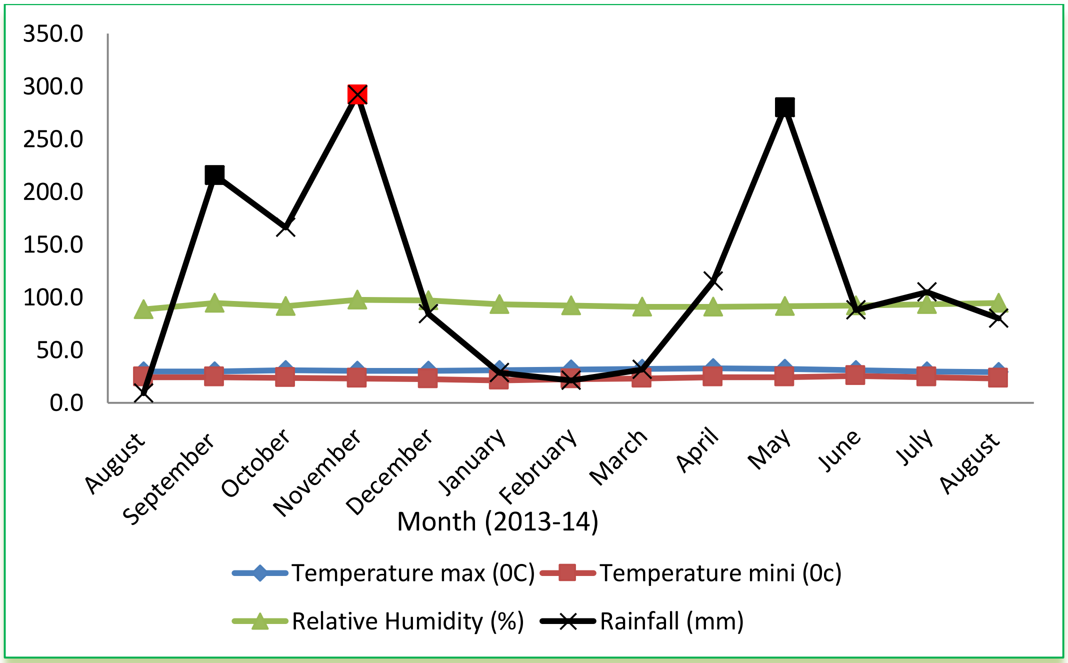


Fig 1. Weather data during the first year (2013-14) of experimentation

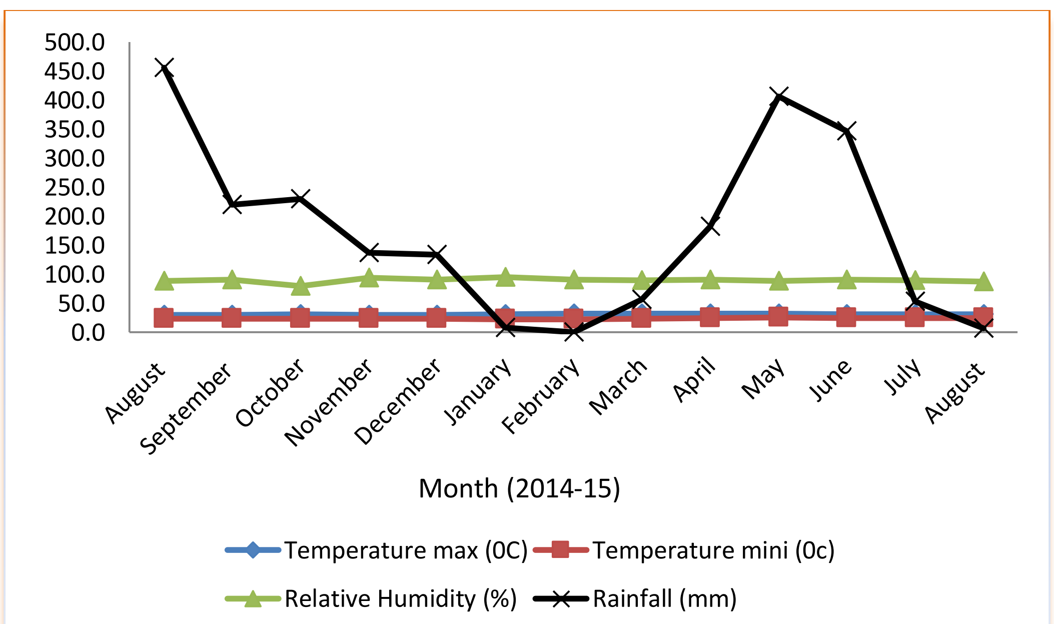


Fig 2. Weather data during the second year (2014-15) of experimentation

3.1.2. Cropping Season

The experiment was conducted during the period from August 2013 to August 2015. Rice crop was raised from August to November, cassava intercropped with groundnut was raised from December to May and cowpea was raised from May to August in both first (2013-14) and second (2014-15) year.

3.1.3. Soil

The soil of experimental field is sandy clay which belongs to the order Oxisol. The data on the mechanical composition and chemical nature of the soil of the experimental site are presented in Tables 1 and 2 respectively.

Table 1. Mechanical composition of the soil of the experimental site

Sl. No	Fractions	Content in soil (%)	Method adopted
1	Coarse sand	72.9	Bouyoucos Hydrometer Method (Bouyoucos, 1962)
2	Silt	7.1	
3	Clay	20	

Table 2. Chemical properties of the soil of the experimental site

Sl No	Parameter	Content	Rating	Methods adopted
1	pH	5.59	Acidic	pH meter with glass electrode (Jackson,1973)
2	EC ($dS\ m^{-1}$)	0.19	Normal	Conductivity meter (Jackson,1973)
3	Available N ($kg\ ha^{-1}$)	423.36	Medium	Alkaline potassium permanganate method (Subbiah and Asija,1956)
4	Available P ($kg\ ha^{-1}$)	63.84	High	Bray colorimeter method (Jackson,1973)
5	Available K ($kg\ ha^{-1}$)	352.80	High	Neutral normal ammonium acetate method

				(Jackson,1973)
6	Available S (ppm)	14.10	Sufficient	Morgan's extraction method (Chesnin and Yien, 1951)
7	Organic carbon (%)	1.89	High	Chromic acid wet digestion method (Walkley and Black, 1934)

3.2. MATERIALS

3.2.1. Crops and Varieties

Four crops and their varieties *viz*. rice (Aiswarya), cassava (Vellayani Hraswa), groundnut (TMV-2) and cowpea (Bhagyalakshmy) were selected for the investigation. The important varietal characters are given in Table 3.

Table 3. Varietal characteristics

Characteristics	Crops			
	Rice	Cassava	Groundnut	Cowpea
Variety	PTB 52 (Aiswarya)	Vellayani Hraswa	TMV-2	Bhagyalakshmy (VS 389)
Released from	RARS, Pattambi, Kerala	College of Agriculture, Vellayani, Kerala	Oilseed Research Station, Tindivanam, Tamilnadu	College of Horticulture, Vellanikkara, Kerala
Duration	105 to 110 days Medium duration	5 to 6 months Short duration	100 to 110 days	60 to 75 days
Special characters	Semi tall plants with long, bold grains and red kernel. Moderately	High yielding variety with 27.8 per cent starch and 53	Photoinsensitive variety	Early flowering and bushy nature with light green medium sized pods,

	resistant to blast, sheath blight, brown plant hopper and gall midge.	ppm cyanogen in tubers.		mottled seeds and white flowers in clusters. Used for vegetable purpose

3.2.2. Paddy Drum Seeder

The manually operated paddy drum seeder was used for sowing pre-germinated paddy seeds directly on levelled fields (Plate 3a). The seeder consists of a seed drum, baffles, main shaft, ground wheel, floats, and handle. Nine numbers of seed metering holes of 10 mm diameter are provided along the circumference of the drum at the both ends for a row to row spacing of 20 cm and plant to plant spacing of 15 cm.

3.2.3. Weeder

Power weeder used for the study was Microtiller MB-25H (four stroke OHV Honda G x 25; 1.1 HP petrol engine; four rotating tynes; approximately 10 kg weight; field capacity of one ha in 10 hours) (Plate 3c). Weeding was done at 20 and 40 DAS.

3.2.4. Straw Mulch

Paddy straw with a C:N ratio of 75:1 was used as the mulching material @ 3 t ha^{-1} (Plate 3d) containing 1.87% N, 0.74% P_2O_5 and 2.42% K_2O.

3.2.5. Manures and Fertilizers

Well decomposed cowdung (1.20% N, 0.38% P_2O_5 and 0.40% K_2O) was used as organic manure source. Urea, rockphosphate and Muriate of potash containing 46% N, 16% P_2O_5 and 60% K_2O respectively were used as the sources of N, P, and K nutrients. Water soluble complex fertilizers 19:19:19, diammonium phosphate (18-46-0) and sulphate of potash (0-0-50-18) were used as foliar nutrients and they were sprayed after mixing with an adjuvant stanowet @ 1mL L^{-1}.

3.3. METHODS

3.3.1. Design and Layout

The two year sequential cropping system experiment consisted of first crop of rice, second crop of cassava intercropped with groundnut and third crop of cowpea per year. In the second year, the same cropping system (Rice–cassava+groundnut–cowpea) was repeated for confirmatory results. The details of treatments are presented below and lay out plan of the experiment is given in Fig 4.

3.3.1.1. First Crop: Rice

Main Plot Treatments

Methods of planting and weed control measures (M)

M_1 – Broadcasting

M_2 –Dibbling (sprouted seeds with drum seeder along with weeding by power weeder)

M_3– Dibbling (sprouted seeds with drum seeder along with stubble mulching)

Sub Plot Treatments

Methods of fertilizer application (F)

F_1 - Broadcasting of POP recommendation (60:30:30 kg NPK ha^{-1} at 10 DAS, tillering and panicle initiation stage) for upland rice.

F_2 - Band placement (60:30:30 kg NPK ha^{-1} at 10 DAS, tillering and panicle initiation stage)

F_3 –Foliar spray of 19:19:19 (water soluble complex fertilizer) @ 0.5 per cent concentration (at tillering, panicle initiation and flowering stage)

F_4 –Foliar spray of diammonium phosphate (DAP) and sulphate of potash (SOP) each @ 2 per cent concentration (at tillering, panicle initiation and flowering stage)

F_5 – Control (without any fertilizer and organic manure)

*Farm yard manure @ 5 t ha^{-1} was applied uniformly in all treatments except control.

Treatment Combinations

m_1f_1	m_1f_2	m_1f_3	m_1f_4	m_1f_5
m_2f_1	m_2f_2	m_2f_3	m_2f_4	m_2f_5
m_3f_1	m_3f_2	m_3f_3	m_3f_4	m_3f_5

3.3.1.2. Second Crop: Cassava (Planted with Minisett Seedlings) Intercropped with Groundnut

Recommended dose of nutrients (FYM @ 12.5 t ha^{-1} and NPK @ 110:120:120 kg ha^{-1}) along with 0.5 per cent foliar spray of 19:19:19 at 30 days interval up to three weeks before harvest (both cassava and groundnut) was applied uniformly to all plots.

3.3.1.3. Third Crop: Vegetable Cowpea (Bush Type)

Recommended dose of nutrients (FYM @ 20 t ha^{-1} and 20:30:10 kg NPK ha^{-1}) along with 0.5 per cent foliar spray of 19:19:19 at 14 days interval (up to one week before first harvest) was applied uniformly to all plots.

Design : Split Plot Design

Main Plot treatments : 3

Sub Plot treatments : 5

Replications : 5

Plot size : 12 m x 2 m

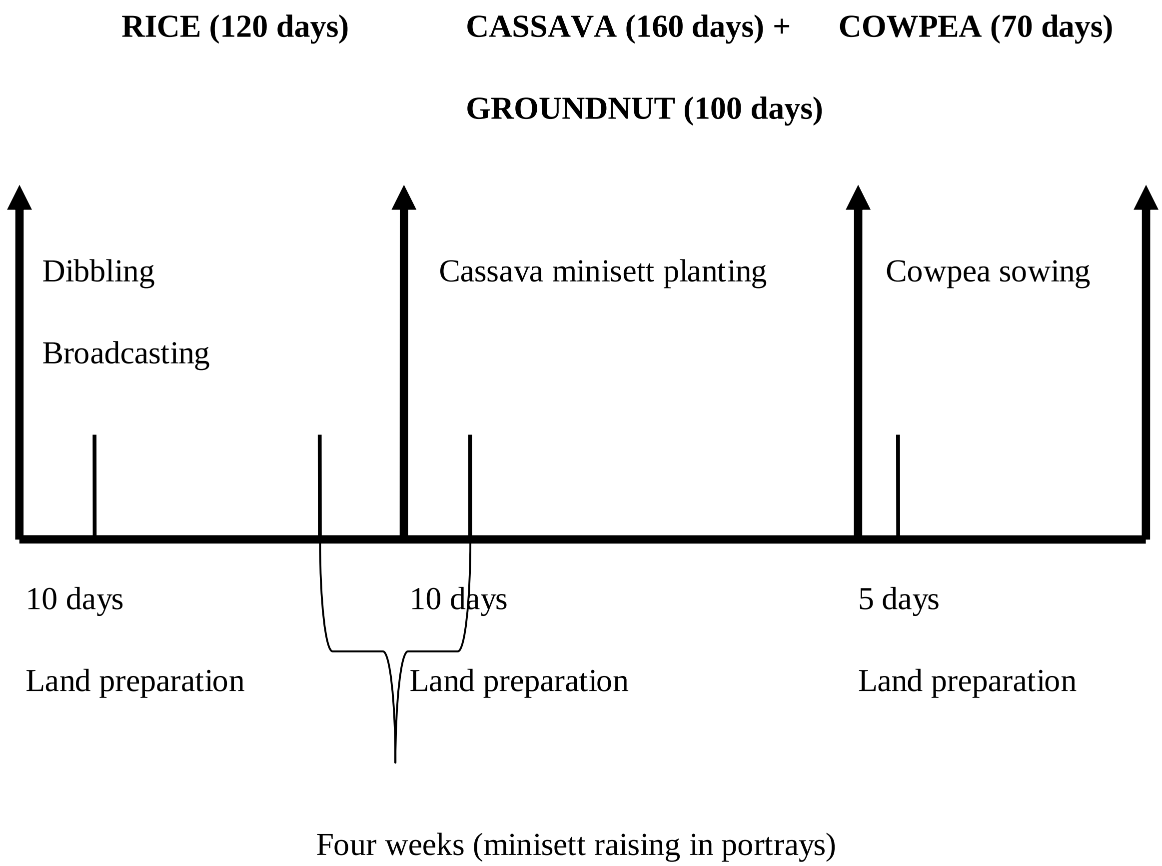
3.4. DETAILS OF CULTIVATION

Summary of the experiment is given in Table 4 and Fig 3. Lay out of the experimental field is depicted in Plate 2.

Table 4. Summary of the experiment

Particulars	2013-2014			2014-2015		
	Crop-I	Crop-II	Crop-III	Crop-I	Crop-II	Crop-III
Crop	Rice	Cassava+ groundnut	Cowpea	Rice	Cassava+ groundnut	Cowpea
Spacing (cm^2)	20 x 15	90 x90 (cassava) 30 x 20 (groundnut)	30 x 15	20 x 15	90 x90 (cassava) 30 x 20 (groundnut)	30 x 15
Plot size (m^2)	12 x 2	12 x 2	12 x 2	12 x 2	12 x 2	12 x 2
Date of sowing	8-8-2013 to	13-12-2013 to 25-5-2014	29-5-2014 to 5-8-2014	9-8-2014 to	15-12-2014 to 27-5-2015	30-5-2015 to 8-8-2015

and harvest	27-11-2013			29-11-2014		



120 days (rice) + **160 days** (cassava) + **70 days** (cowpea) = **350 days** (total number of days required for the cropping system in one year period of study)

Fig 3. Rice – Cassava+ Groundnut – Cowpea cropping system

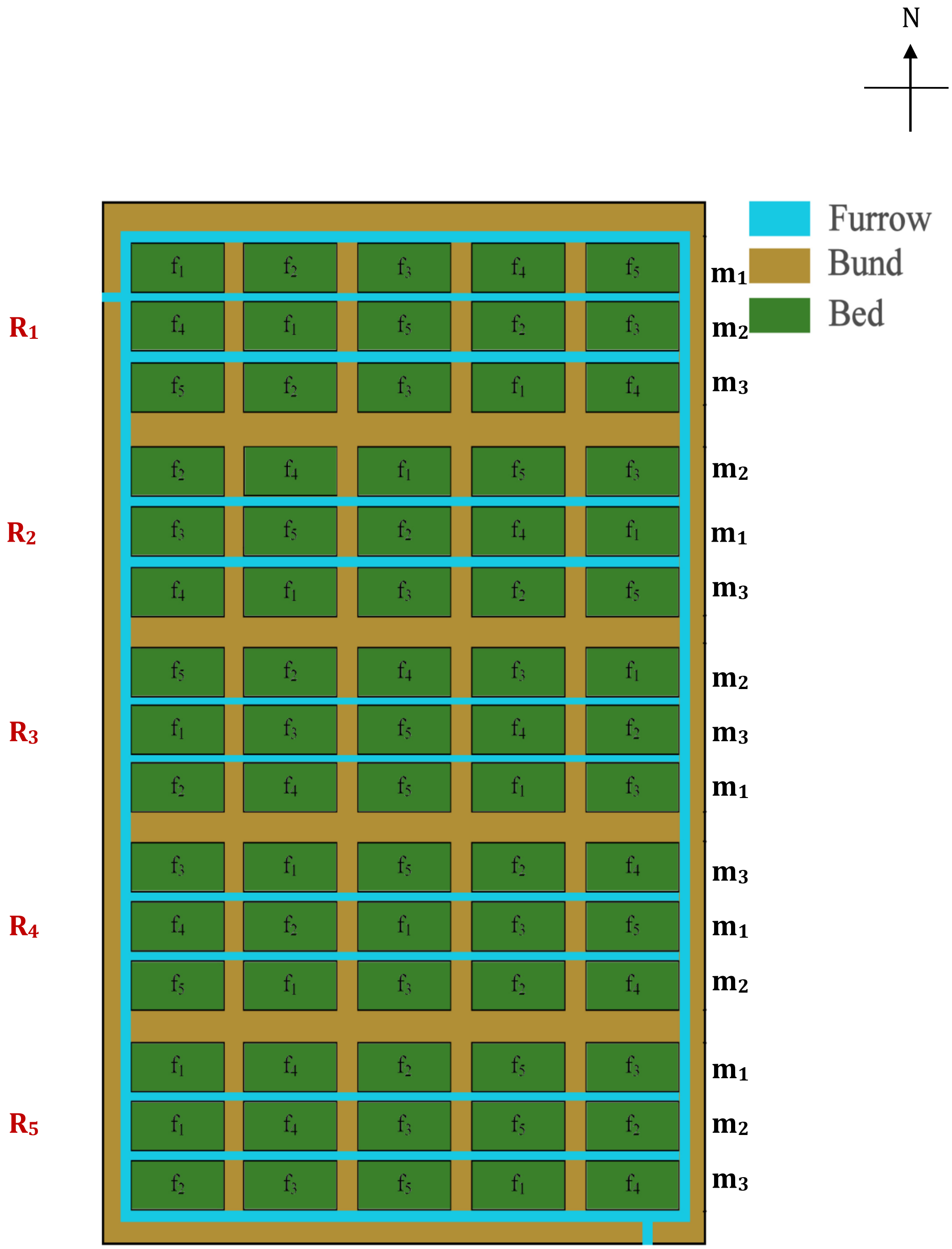


Fig 4. Lay out plan of the experiment (2013-14 and 2014-15)

Plate 2. Lay out of the experimental field (broad bed and furrow)

3.4.1. First Crop: Rice

3.4.1.1. Field Preparation

The experimental area was well ploughed, levelled and brought to a fine tilth. The plots of size 12 m x 2 m were laid out in five blocks with 15 plots each. The plots were prepared by adopting broad bed furrow system. Broad beds of two meter width were separated by furrows of 30 cm width. Proper irrigation facilities and drainage channels were provided.

3.4.1.2. Seeds and Sowing

Seeds were soaked for 24 hours and the pregerminated seeds were dibbled and broadcasted on the next day in the respective plots according to the treatment. The field was irrigated for a week for the seeds to emerge out from the soil.

3.4.1.3. After Cultivation

Almost uniform germination was obtained. Gap filling and thinning were done two weeks after sowing. General view of rice crop is given in Plate 4.

3.4.1.4. Application of Manures and Fertilizers

Farm yard manure @ 5 t ha^{-1} was applied basally to all the plots except absolute control at the time of land preparation. A nutrient recommendation of NPK @ 60:30:30 kg ha^{-1} was adopted for upland rice (KAU, 2011). Urea, Mussorie rock phosphate and Muriate of potash were applied to the respective plots as per the treatments to supply N, P_2O_5 and K_2O. In band placement, small channels were taken in between two rows of plants and the fertilizers were band placed in these channels.

a. Dibbling of sprouted seeds using drum seeder

b. Broadcasting of sprouted seeds

c. Power weeder

d. Straw mulching

Plate 3. Agronomic interventions practiced in rice field



Plate 4. General view of rice crop in the experimental field

The complex fertilizer 19:19:19 @ 0.5 per cent, diammonium phosphate and sulphate of potash @ 2 per cent each were applied as foliar spray at tillering, panicle initiation and flowering stage. The entire recommended dose of phosphorus and one third dose of nitrogen and half the dose of potassium were applied 10 DAS. The remaining two third dose of nitrogen was applied in two equal splits, at maximum tillering and panicle initiation stages respectively and the remaining half dose of potash was applied at panicle initiation stage.

3.4.1.5. Weed Management

Two hand weedings were done at 20 and 40 DAS (days after sowing). Weeding using power weeder was also done at 20 and 40 DAS in the respective treatment plots.

3.4.1.6. Water Management

The soil moisture was maintained at field capacity uniformly in all the treatments. During non rainy period, irrigation was given once in two days till the panicle initiation stage and from panicle initiation stage onwards the crop was irrigated daily. One week prior to harvest, irrigation was stopped for ensuring uniform maturity of the grains.

3.4.1.7. Plant Protection

The pests such as rice bug and leaf roller were managed by spraying Malathion @ 2 mL L^{-1} at the time of incidence.

3.4.1.8. ***Harvest***

The crop was harvested when the straw just turned yellow. The net plots were harvested separately, threshed, winnowed and the weight of straw and grain were recorded separately from the individual plots. The sample plants and border rows were harvested separately.

3.4.2. Second Crop: Cassava Intercropped with Groundnut

3.4.2.1. Minisett Preparation of Cassava

The two noded minisett cuttings of Vellayani Hraswa was prepared and planted in protrays filled with potting mixture. Potting mixture was prepared by mixing sand and soil @ 1:1 ratio. Minisetts sprouted in a week and it was transplanted to main field after 25 to 30 days (Plate 5).

3.4.2.2. Field Preparation

The main field was thoroughly ploughed and brought to a fine tilth. Farmyard manure @ 12.5 t ha^{-1} was spread in the field. Mounds of 30 cm height were taken. Proper irrigation facilities and drainage channels were provided.

3.4.2.3. Setts/Seeds and Planting/Sowing

Minisetts were planted on mounds taken at a spacing of 90 cm x 90 cm and the plants established within a week.

The groundnut seeds were soaked in water for one to two hours and sown at a spacing of 30 cm x 20 cm in between two rows of mounds @ 2 seeds $hole^{-1}$. The seeds germinated within one week.

Two noded sett

Three to four weeks old minisett seedling

Protray raised minisett seedlings

Plate 5. Minisett preparation of cassava in protrays

3.4.2.4. After Cultivation

Gap filling was done ten days after planting in cassava and one week after sowing in groundnut. For cassava, excess sprouts were removed retaining only two healthy and vigorous shoots. Earthing up was done at two months after planting. General view of cassava intercropped with groundnut is given in Plate 6.

3.4.2.5. Application of Manures and Fertilizers

Farmyard manure @ 12.5 t ha^{-1} was applied basally to all the plots at the time of land preparation. Urea, Mussorie rock phosphate and Muriate of potash were applied to the plots to supply N, P_2O_5 and K_2O. The complex fertilizer 19:19:19 @ 0.5 per cent was applied as foliar at 30 days interval up to three weeks before harvest. A basal dose of 50:100:50 kg N: P_2O_5: K_2O ha^{-1} was given uniformly to both cassava and groundnut. One month after sowing of groundnut, 20 kg each P_2O_5 and K_2O and 10 kg N ha^{-1} was given to groundnut along with earthing up. After the harvest of groundnut pods, the haulms were incorporated in the soil along with a top dressing of 50 kg each of N and K_2O ha^{-1} for cassava. Lime @ 1 to 1.5 t ha^{-1} was applied at the time of flowering of groundnut and mixed with soil by light hoeing or raking in order to facilitate pegging of groundnut. General view of cassava alone after the harvest of groundnut in the field is given in Plate 7.

3.4.2.6. Weed Management

One weeding at 30 days after transplanting and a light hoeing or raking at the time of application of lime was given to groundnut. Second weeding along with earthing up was given to cassava after harvest of groundnut and the bhusa was also incorporated.

Plate 6. General view of cassava intercropped with groundnut in the field

Cassava tubers

Groundnut pods

Plate 7. General view of cassava alone after the harvest of groundnut in the field

3.4.2.7. Plant Protection

None of the diseases and pests was observed above the economic threshold level thereby warranting no control measures.

3.4.2.8. Harvest

Cassava was harvested by uprooting the whole plant and the weight of fresh tubers were recorded from the individual plots separately.

Groundnut was harvested when the leaves just turned yellow. The plants were uprooted and the pods were separated from the plants.

3.4.3. Third Crop: Cowpea

3.4.3.1. Field Preparation

The field was thoroughly ploughed and brought to a fine tilth. Farmyard manure @ 20 t ha^{-1} was spread in the field. Proper irrigation facilities and drainage channels were provided.

3.4.3.2. Seeds and Sowing

The seeds were sown @ 3 seeds $hole^{-1}$ and the seeds germinated within one week.

3.4.3.3. After Cultivation

Gap filling and thinning were done one week after sowing. Hoeing was done at the time of application of second dose of N (20 DAS) and along with that weeding was also done. General view of vegetable cowpea in the field is given in Plate 8.

Cowpea pods

Plate 8. General view of vegetable cowpea (bush type) in the field

3.4.3.4. Application of Manures and Fertilizers

Farmyard manure was applied basally to all the plots at the time of land preparation. A fertilizer dose of 20:30:10 kg ha^{-1} was applied uniformly to all plots. Half the quantity of N, full dose of phosphorous and potash was applied at the time of final ploughing. The remaining nitrogen was applied 15-20 DAS. The complex fertilizer 19:19:19 @ 0.5 per cent was applied as foliar at 14 days interval up to one week before first harvest.

3.4.3.5. Water Management

Since there was sufficient rain during the early stages, irrigation was given only at later stages (four to five days interval).

3.4.36. Plant Protection

None of the diseases and pests was observed above the economic threshold level warranting no control measures.

3.4.3.7. Harvest

Picking of pods for vegetable purpose was commenced at 50 DAS. Subsequent harvests were done at weekly intervals.

3.5. OBSERVATIONS

3.5.1. Rice

Two rows of plants were left as border on all the sides and observations were taken from the net plot area. Observations were taken on important parameters associated with growth and yield of paddy. Five hills were selected at random from the net plot area of each plot and tagged. The observations such as plant height, leaf area index, dry matter production, relative growth rate, crop growth rate, net assimilation rate were recorded from the sample plants from five hills and all other observations were recorded from the net plot area and the mean values were worked out during both the years.

3.5.1.1. Biometric Observations

3.5.1.1.1. Plant Height

Plant height was recorded at maximum tillering and at harvest stages using the method described by Gomez (1972). The height was measured from the base of the plant to the tip of the longest leaf or tip of the longest ear head, whichever was longer and the average was recorded in cm.

3.5.1.1.2. Leaf Area Index

LAI was computed at maximum tillering and harvest stage using the method described by Gomez (1972). The maximum width ‘w’ and length ‘l’ of all the leaves of central tiller of the hills from the sample plants were recorded and LAI was calculated using the relationship.

Leaf area of a single leaf = l x w x k

k - Adjustment factor (0.75 at maximum tillering and 0.67 at harvest stage)

$$\text{LAI} = \frac{k\,(l \times w) \times \text{Number of leaves plant}^{-1} \times \text{Number of tillers plant}^{-1}}{\text{Land area occupied by the plant}}$$

3.5.1.1.3. Number of Tillers m^{-2}

Tiller count was taken from the hills in the net plot area at maximum tillering and harvest stages and the mean was worked out and expressed as number of tillers m^{-2}.

3.5.1.1.4. Dry Matter Production (DMP)

The observational plants were uprooted at harvest, washed and initially air dried and later oven dried at 70°C to a constant weight. The values were recorded on moisture free basis and computed as kg ha^{-1}.

3.5.1.1.5. Relative Growth Rate (RGR)

Five randomly selected plants were uprooted from each plot at maximum tillering and harvest stages. These uprooted plants were then washed and dried to a constant weight. The amount of growing material per unit dry weight of plant per unit time expressed as g g^{-1} day^{-1} gave the Relative Growth Rate of the crop, as given by the following formula (Evans, 1972).

$$RGR = \frac{\log_e Wn_2 - \log_e Wn_1}{t_2 - t_1} \quad g\ g^{-1}\ day^{-1}$$

Where $\log_e W_2$ and $\log_e W_1$ are the logarithmic value of dry weight of crop at two stages n_2 and n_1 respectively and t_2 and t_1 are duration in days between the crop growth stages.

3.5.1.1.6. Crop Growth Rate (CGR)

Five randomly selected plants were uprooted from each plot at maximum tillering and harvest stages. These uprooted plants were then washed and dried to a constant weight. Crop growth rate was calculated following the formula suggested by Watson (1958).

$$CGR = \frac{Wn_2 - Wn_1}{t_2 - t_1} \times \frac{1}{A} \quad g\ m^{-2}\ day^{-1}$$

Where Wn_2 is weight of crop at stage n_2 (g), Wn_1 is weight of crop at stage n_1 (g), t_2 is days after transplanting at stage n_2, t_1 is days after transplanting at stage n_1 and A is ground area.

3.5.1.1.7. Net Assimilation Rate (NAR)

Five randomly selected plants were uprooted from each plot at maximum tillering and harvest stages. These uprooted plants were then washed and dried to a constant weight. The mean net assimilation rate was worked out as suggested by Enyi (1962).

$$NAR = \frac{(\log_e L_2 - \log_e L_1)\ (W_2 - W_1)}{(L_2 - L_1)\ \ (t_2 - t_1)} \quad g\ cm^{-2}\ day^{-1}$$

Where

W_1 and W_2	Initial and final dry weight of plant materials per unit ground area respectively.
t_1 and t_2	Initial and final day of observation respectively

L_1 and L_2 Initial and final leaf area of a period of observation respectively

3.5.1.1.8. Chlorophyll Content

Chlorophyll content was recorded with the help of SPAD meter (Konica Minolta Model SPAD 502). The SPAD meter was obtained from the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani.

The SPAD meter readings were collected from top most fully expanded leaf. From each plot, five leaves from five randomly selected sample plants were selected. The SPAD readings were recorded at maximum tillering and harvest stage and the mean value at each stage was calculated.

3.5.1.2. Yield and Yield Attributes

3.5.1.2.1. Number of Productive Tillers m^{-2}

At harvest the number of productive tillers m^{-2} area in the net plot was noted and expressed as number of productive tillers m^{-2}.

3.5.1.2.2. Length of Panicle

The length of the panicles were taken from hills in the net plot and the mean value was computed and expressed in cm.

3.5.1.2.3. Weight of Panicle

At harvest the weight of panicle was noted from hills in the net plot and the mean was expressed in g.

3.5.1.2.4. Grain Weight Panicle^{-1}

At harvest the weight of grains per panicle was noted from hills in the net plot and the mean was expressed in g panicle^{-1}.

3.5.1.2.5. Number of Grains Panicle^{-1}

The number of grains collected from the hills in net plot was counted and the mean value was expressed as number of grains panicle^{-1}.

3.5.1.2.6. Thousand Grain Weight

Thousand grains were counted from the cleaned and dried produce from the observational plants and the weight was recorded in g.

3.5.1.2.7. Sterility Percentage

Sterility percentage was worked out using the following relationship.

$$\text{Sterility percentage} = \frac{\text{Number of unfilled grains panicle}^{-1}}{\text{Total number of grains panicle}^{-1}} \times 100$$

3.5.1.2.8. Grain Yield

The net plot area was harvested separately, threshed, cleaned and dried to 14 per cent moisture level and the weight was recorded. Grain yield was expressed in kg ha^{-1}.

3.5.1.2.9. Straw Yield

Straw harvested from the net plot of each treatment was dried under sun to a constant weight and the weight was expressed as kg ha^{-1}.

3.5.1.2.10. Harvest Index (HI)

From grain and straw yield values, the harvest index was worked out using the following equation as suggested by Donald and Hamblin (1976).

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}}$$

3.5.2. Cassava

3.5.2.1. Pre Harvest Observations

Observations on growth characters were recorded from three plants selected at random from each plot at three and six months after planting in both the field experiments.

3.5.2.1.1. Plant Height

Height of the tallest stem was measured from the base of the sprout to the terminal bud and the mean value was computed and expressed in cm.

3.5.2.1.2. Number of Functional Leaves $Plant^{-1}$

The total number of leaves were recorded by counting fully opened leaves as well as the leaf scars from the base to the tip of the stem and the mean value was computed.

3.5.2.1.3. Number of Branches Plant^{-1}

The mean value of number of primary and secondary branches were computed from the observational plants.

3.5.2.1.4. Leaf Area Index (LAI)

Leaf area was worked out using the length x width method suggested by Gomez (1972). The leaf area index was calculated by the following formula.

$$LAI - \frac{k\,(l \times w) \times \text{Number of leaves plant}^{-1}}{\text{Land area occupied by the plant}}$$

k- adjustment factor (0.44)

l- leaf length in cm

w- leaf width in cm

3.5.2.1.5. Dry Matter Production

During harvest, the sample plants from each plot was carefully uprooted and separated into leaf, stem and tuber to record their fresh weight. Samples were dried in an oven at 70^{o}C for estimating dry matter content. The distribution of dry matter in each part was computed and expressed in t ha^{-1}.

3.5.2.2. Post Harvest Observations

The following post harvest observations were made from the observational plants and the mean values were calculated.

3.5.2.2.1. Number of Tubers Plant^{-1}

The total number of fully developed tubers from the sample plants were recorded and average number plant^{-1} was worked out.

3.5.2.2.2. Tuber Weight Plant^{-1}

The mean tuber weight of the sample plants was computed and expressed in kg.

3.5.2.2.3. Top Yield

The total weight of stems and leaves of the plants from the net plot was recorded soon after the harvest and expressed on hectare basis (t ha^{-1}).

3.5.2.2.4. Total Tuber Yield

From the net plot area, the plants were carefully uprooted, the tubers were separated, cleaned and the fresh weight recorded. The tuber yield was computed and expressed on hectare basis (t ha^{-1}).

3.5.2.2.5. Utilization Index (UI)

The ratio of total root weight to the weight of stem and leaves on fresh weight basis was worked out (Obigbesan, 1973).

3.5.2.2.6. Marketable Tuber Yield ha^{-1}

Weight of the marketable tubers from the net plot was recorded and the average was worked out and expressed in t ha^{-1}.

3.5.3. Groundnut

3.5.3.1. Pod Yield

Pod yield from net plot of groundnut was recorded after sun drying the pods and expressed in kg ha^{-1}.

3.5.3. 2. Haulm Yield

The haulm after separating the pods was dried and weighed, expressed in kg ha^{-1}.

3.5.3.3. Kernel Yield

The dried pods obtained from the net plot were deshelled and bold kernels separated. The kernel weight was recorded and expressed in kg ha^{-1}.

3.5.3.4. Biomass Yield

After carefully pulling out the plants, the weight of the whole plant from each net plot was recorded and expressed in kg ha^{-1}.

3.5.4. Cowpea

3.5.4.1. Biometric Observations

The following biometric observations were recorded from the five sample plants at 30 days after sowing and the mean values were calculated during both the years.

3.5.4.1.1. Plant Height

Height of plant was taken from the base of the plant to the terminal leaf bud and expressed in cm. The mean value of height of five randomly selected observational plants from each plot was computed at 30 days after sowing.

3.5.4.1.2. Number of Branches Plant^{-1}

The mean value of number of primary branches was computed from five observational plants at 30 days after sowing.

3.5.4.1.3. Dry Matter Production (DMP)

The observational plants were uprooted from each plot carefully without damaging the roots. The plants were dried under shade and then oven dried at 70^{o}C till constant weight was obtained. The dry weight of the plants were found out and expressed in kg ha^{-1}.

3.5.4.2. Yield and Yield Attributes

3.5.4.2.1. Number of Pods Plant^{-1}

Average of the total number of pods collected from five observational plants during the cropping period.

3.5.4.2.2. Pod Yield

Total yield of tender pods from the net plot was recorded and yield per hectare was worked out and expressed in kg ha^{-1}.

3.5.5. Plant Analysis

3.5.5.1. Nutrient Uptake

Nutrient uptake by the component crops of the system were calculated by using the following formula (Jackson, 1967) and expressed in kg ha^{-1}.

$$\text{Uptake of N or P or K} = \frac{\text{N or P or K (\%)} \times \text{drymatter (kg ha}^{-1}\text{)}}{100}$$

3.6. SOIL ANALYSIS

Composite soil samples were collected before the start of the experiment for analyzing the physico-chemical properties. After the harvest of the crops, soil samples were taken from each plot separately and analyzed for available N, P_2O_5, and K_2O.

3.6.1. Chemical Properties

3.6.1.1. Soil Reaction (pH)

The pH was determined in a 1:2.5 soil water suspension using ELICO digital pH meter (Jackson, 1973).

3.6.1.2. Electrical Conductivity

The EC of soil was determined in a 1:2.5 soil water suspension using conductivity meter (Jackson, 1973).

3.6.1.3. Available Nitrogen

Available nitrogen content of the soil was estimated by alkaline permanganate method (Subbiah and Asija, 1956) and expressed as kg ha^{-1}.

3.6.1.4. Available Phosphorus

Available phosphorus in soil was determined by Bray I method as described by Jackson (1973) and readings were taken in spectrophotometer and expressed as kg ha^{-1}.

3.6.1.5. Available Potassium

Available potassium was determined in the neutral normal ammonium acetate extract and estimated using flame photometer (Jackson, 1973) and expressed as kg ha^{-1}.

3.6.1.6. Organic Carbon

The wet digestion method suggested by Walkley and Black (1934) was employed for the estimation of organic carbon using ferroin as indicator. It was expressed as percentage (%).

3.6.1.7. Nutrient Balance Sheet of the Soil

Nutrient balance sheets were worked out for available N, P and K in post-harvest soil on the basis of the following parameters, adopting the procedure outlined by Sadandan and Mahaptra (1973).

1. Initial status of nutrient in soil (A)
2. Total amount of nutrient added through manures and fertilizers (B)
3. Amount of nutrient removed by the crop or uptake (C)

4. Expected nutrient balance (D) = (A+B) -C

5. Available nutrient of soil after the experiment (E)

6. Actual loss (-) or gain (+) = (E - A) kg ha^{-1}

3.7. MAIN YIELD EQUIVALENT (MYE)

Main yield equivalent (rice) or Rice equivalent yield of the cropping system was calculated using the formula

$$\text{Rice equivalent yield} = \text{Rice grain yield} + \frac{(\text{tuber yield} \times \text{price of cassava}) + (\text{pod yield} \times \text{price of groundnut}) + (\text{pod yield} \times \text{price of cowpea})}{\text{Price } kg^{-1} \text{ of rice}}$$

3.8. ECONOMICS OF CULTIVATION

The economics of cultivation was worked out based on the costs of various inputs, labour and produce at the time of experimentation. The details regarding the costs of various inputs and produce are presented in Appendix III.

3.8.1. Net Returns (Rs ha^{-1})

Net returns was computed using the formula,

Net returns = Gross returns – Cost of cultivation

3.8.2. Benefit:Cost Ratio (BCR)

Benefit:cost ratio was computed using the formula,

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

3.9. ENERGY BUDGETING OF CROPPING SYSTEM

The direct energy input and output were calculated in terms of Mega joules per hectare (MJ ha^{-1}) based on energy equivalent values for the various inputs and outputs. The details regarding the energy equivalents of inputs and outputs are presented in Appendix IV.

3.9.1. Energy Efficiency

Energy efficiency was worked out by dividing the energy output by the energy input as suggested by Devasenapathy *et al.* (2008).

$$\text{Energy Efficiency} = \frac{\text{Energy output (MJ ha}^{-1}\text{)}}{\text{Energy input (MJ ha}^{-1}\text{)}}$$

3.9.2. Specific Energy

Specific energy was calculated in terms of energy required to produce one kilogram of main product and expressed in MJ kg^{-1} as suggested by Dazhong and Pimental (1984).

Total system input (MJ ha^{-1})

$$\text{Specific Energy} = \frac{}{\text{Rice equivalent yield (kg ha}^{-1})}$$

3.9.3. Energy Productivity

Energy productivity describes the quantity of physical output obtained for every unit of input and expressed in kg MJ^{-1} as suggested by Dazhong and Pimental (1984).

$$\text{Energy Productivity} = \frac{\text{Rice equivalent yield (kg ha}^{-1})}{\text{Total system input (MJ ha}^{-1})}$$

3.9.4. Energy Intensity

Energy intensity (economic terms) is the ratio between energy output and cost of cultivation and expressed in MJ Rs^{-1} as suggested by Devasenapathy *et al.* (2008).

$$\text{Energy Intensity} = \frac{\text{Energy output (MJ ha}^{-1})}{\text{Cost of cultivation (Rs ha}^{-1})}$$

3.10. STATISTICAL ANALYSIS

The data generated from field trials were subjected to analysis of variance (ANOVA) as applied to Split Plot Design (Panse and Sukhatme, 1985). Pooled analysis was done by taking data of both years. Wherever significant difference among treatments were observed, CD values at 5 per cent level of significance were provided for effective comparison of means.

Results

4. RESULTS

An investigation was conducted to assess the impact of agronomic interventions on the growth, productivity and sustainability of a rice based cropping system and to study the nutrient balance, energetics and economics of the cropping system. The experiment consisted of rice based cropping system comprised of rice followed by cassava (intercropped with groundnut) and cowpea, was conducted during 2013-14 (first year) and 2014-15 (second year). The data on various observations were statistically analyzed and presented in this chapter.

4.1. EFFECT OF TREATMENTS ON RICE [2013-14 (FIRST YEAR) AND 2014-15 (SECOND YEAR)]

4.1.1. Growth Attributes

4.1.1.1. Plant Height

The data on plant height of rice recorded at maximum tillering and harvest stage during 2013-14 and 2014-15 are presented in Table 5. Among the methods of planting and weed control measures, the plant height at maximum tillering stage did not show any variation in the first year and was significantly different in the second year. During 2014-15, the greatest plant height of 68.78 cm was produced in M_3 at maximum tillering, which was significantly superior to the other two treatments. At harvest stage, the treatments were not significant during both the years.

Among the nutrient application methods, foliar spraying of 19:19:19 complex fertilizer (F_3) produced the tallest plants of 93.30 cm at maximum tillering during 2013-14. The treatment F_2 showed the highest value (71.00 cm) during 2014-15, which was on par with F_1. At harvest stage, in the first year F_3 resulted in the highest

Table 5. Effect of treatments on plant height of rice (cm)

Treatments	Maximum tillering		Harvest	
	2013-14	2014-15	2013-14	2014-15
Main plot (M)				
M_1	88.12	64.61	109.73	90.87
M_2	89.39	65.09	110.04	87.32
M_3	88.74	68.78	112.29	92.50
SEm	0.346	0.796	0.816	1.300
CD (0.05)	NS	2.595	NS	NS
Sub plot (F)				
F_1	90.70	69.52	110.83	90.48
F_2	88.99	71.00	110.74	94.54
F_3	93.30	66.84	114.60	91.76
F_4	90.89	62.86	113.73	87.47
F_5	80.39	60.57	103.54	86.89
SEm	0.453	0.775	0.907	1.332
CD (0.05)	1.289	2.205	2.578	3.789
m x f				
m_1f_1	89.96	70.86	109.11	95.20
m_1f_2	87.27	64.40	104.83	89.93
m_1f_3	90.20	68.82	111.57	91.13
m_1f_4	90.82	61.85	116.70	89.92
m_1f_5	82.37	57.09	106.47	88.15
m_2f_1	90.80	67.35	110.91	83.68
m_2f_2	89.84	70.04	113.36	92.70
m_2f_3	94.00	64.02	112.62	87.29
m_2f_4	91.95	63.18	110.71	87.49
m_2f_5	80.36	60.86	102.62	85.42
m_3f_1	89.77	70.34	112.47	92.56
m_3f_2	89.87	78.57	114.05	100.98
m_3f_3	95.72	67.69	119.62	96.84
m_3f_4	89.91	63.54	113.78	85.00
m_3f_5	78.45	63.75	101.56	87.11
SEm	0.786	1.343	1.570	2.308
CD (0.05)	2.234	3.819	4.460	6.564

plant height and in the second year, the highest plant height was produced in F_2. The treatment F_3 was on par with F_4 (2013-14) and F_2 was on par with F_3 (2014-15).

The interaction effect of treatments revealed that during the first year, m_3f_3 produced the highest plant height of 95.72 cm (maximum tillering) and it was on par with m_2f_3 and m_2f_4. In the second year, the highest plant height of 78.57 cm was resulted in m_3f_2, which was significantly superior to all the other interactions. At harvest stage, the highest plant height was observed in m_3f_3 and m_3f_2 for the first and second year respectively. The combined effect were significantly different from all the other treatments, except m_1f_4 (2013-14) and m_1f_1 and m_3f_3 (2014-15) which were on par.

4.1.1.2. Leaf Area Index

Data presented in Table 6 depicts the influence of treatments on LAI of rice at maximum tillering and harvest stage for the two years of study. Among the methods of planting and weed control measures during both the years, M_2 resulted in significantly the highest LAI compared to M_3, which were on par with M_1 at maximum tillering. At harvest stage, M_2 produced significantly the highest LAI of 3.88 and was on par with M_3 (2013-14). But the treatments were not significant during the second year.

Considering the effect of fertilizer application methods it was observed that, all treatments except control were on par at both the stages and both the years.

The interactions were significant only at the harvest stage during 2013-14 and at other stages during both the years, the treatment combinations were not significant.

Table 6. Effect of treatments on leaf area index of rice

Treatments	Maximum tillering		Harvest	
	2013-14	2014-15	2013-14	2014-15
Main plot (M)				
M_1	3.89	3.91	3.26	3.60
M_2	3.92	3.91	3.88	3.61
M_3	3.58	3.63	3.55	3.48
SEm	0.070	0.031	0.102	0.043
CD (0.05)	0.222	0.102	0.332	NS
Sub plot (F)				
F_1	3.97	4.06	3.78	3.79
F_2	4.01	4.04	3.78	3.81
F_3	4.04	4.04	3.74	3.75
F_4	3.96	4.02	3.66	3.77
F_5	3.01	2.95	2.85	2.69
SEm	0.114	0.107	0.114	0.101
CD (0.05)	0.325	0.303	0.323	0.287
m x f				
m_1f_1	4.00	4.03	3.58	3.68
m_1f_2	4.11	4.15	2.83	3.76
m_1f_3	4.48	4.45	3.65	4.09
m_1f_4	3.81	3.90	3.61	3.71
m_1f_5	3.06	3.04	2.61	2.77
m_2f_1	4.23	4.28	3.96	3.96
m_2f_2	4.08	4.09	4.17	3.88
m_2f_3	3.91	3.97	3.83	3.70
m_2f_4	4.23	4.25	4.15	3.95
m_2f_5	3.15	2.96	3.28	2.54
m_3f_1	3.69	3.80	3.81	3.73
m_3f_2	3.83	3.87	4.34	3.79
m_3f_3	3.72	3.74	3.74	3.47
m_3f_4	3.85	3.90	3.22	3.63
m_3f_5	2.82	2.84	2.65	2.76
SEm	0.198	0.185	0.197	0.175
CD (0.05)	NS	NS	0.560	NS

The combination m_3f_2 was significantly superior to all the other treatments, except m_2f_1, m_2f_2, m_2f_3, m_2f_4 and m_3f_1, which were on par.

4.1.1.3. Number of Tillers m^{-2}

Data furnished in Table 7 indicated significant variation among the treatments in the number of tillers m^{-2} at both the stages during 2013-14 and 2014-15. During the first year, M_1 and second year, M_3 produced the higher number of tillers m^{-2} (409.47 and 435.71 respectively) at maximum tillering, which was significantly different from the other two treatments. At harvest stage, the treatments were not significant in the first year, while in the second year, M_3 produced significantly the highest number of tillers m^{-2}.

The methods of fertilizer application were significantly different during the years of study. The highest number of tillers m^{-2} was observed in F_4 during the first year (436.81) and F_2 during the second year, which was on par with F_1 at maximum tillering. At harvest stage during 2013-14, F_4 produced the highest tiller production of 388.18 tillers m^{-2} and in the second year the highest value was resulted in F_2 and F_1.

The treatment combinations were not significant during the first year. During the second year, m_3f_1 produced the highest number of tillers m^{-2}, which was significantly different from all other combinations, except m_3f_2, at maximum tillering. At harvest stage, also the similar trend was observed in both the years.

4.1.1.4. Chlorophyll Content

Chlorophyll readings using SPAD meter recorded at maximum tillering and harvest stages during both the years are presented in Table 8. During both the years

Table 7. Effect of treatments on number of tillers m^{-2} of rice

Treatments	Maximum tillering		Harvest	
	2013-14	2014-15	2013-14	2014-15
Main plot (M)				
M_1	409.47	343.96	342.50	303.08
M_2	387.20	414.48	357.64	388.58
M_3	373.85	435.71	351.08	406.72
SEm	4.188	5.817	3.753	5.407
CD (0.05)	13.658	18.971	NS	17.631
Sub plot (F)				
F_1	408.79	429.17	361.85	395.16
F_2	401.08	444.99	370.19	408.09
F_3	405.55	397.28	360.83	362.89
F_4	436.81	398.80	388.18	369.79
F_5	298.66	320.01	271.00	294.71
SEm	5.306	7.604	5.567	6.446
CD (0.05)	15.090	21.627	15.832	18.333
m x f				
m_1f_1	439.78	316.91	361.26	280.02
m_1f_2	420.78	361.02	362.86	317.52
m_1f_3	429.62	350.57	358.86	309.68
m_1f_4	454.50	351.65	380.00	314.80
m_1f_5	302.72	339.65	249.52	293.36
m_2f_1	399.38	450.82	363.02	419.12
m_2f_2	393.36	463.36	370.14	425.14
m_2f_3	403.92	443.08	362.48	414.72
m_2f_4	436.18	405.69	392.46	390.13
m_2f_5	303.16	309.46	300.10	293.78
m_3f_1	387.20	519.78	361.26	486.34
m_3f_2	389.10	510.59	377.58	481.60
m_3f_3	383.10	398.20	361.14	364.26
m_3f_4	419.76	439.06	392.08	404.43
m_3f_5	290.10	310.92	263.38	296.98
SEm	9.190	13.171	9.642	11.165
CD (0.05)	NS	37.459	NS	31.753

Table 8. Effect of treatments on chlorophyll content of rice

Treatments	Maximum tillering		Harvest	
	2013-14	2014-15	2013-14	2014-15
Main plot (M)				
M_1	31.38	32.52	27.69	27.81
M_2	31.34	32.50	27.80	27.83
M_3	31.37	32.40	27.74	27.91
SEm	0.024	0.082	0.086	0.087
CD (0.05)	NS	NS	NS	NS
Sub plot (F)				
F_1	31.45	33.22	27.69	27.93
F_2	31.31	33.62	28.03	28.89
F_3	31.43	32.35	28.18	27.88
F_4	31.35	32.05	27.57	27.44
F_5	31.27	31.12	27.23	27.12
SEm	0.034	0.120	0.070	0.132
CD (0.05)	0.136	0.339	0.281	0.377
m x f				
m_1f_1	31.42	32.72	27.66	28.00
m_1f_2	31.12	33.92	27.82	28.66
m_1f_3	31.78	32.70	27.96	27.94
m_1f_4	31.26	32.24	27.82	27.28
m_1f_5	31.32	31.00	27.18	27.18
m_2f_1	31.48	33.72	27.46	27.66
m_2f_2	31.50	33.50	28.46	29.00
m_2f_3	31.22	32.16	28.46	27.88
m_2f_4	31.28	31.94	27.44	27.44
m_2f_5	31.20	31.20	27.18	27.18
m_3f_1	31.46	33.22	27.94	28.12
m_3f_2	31.28	33.44	27.82	29.00
m_3f_3	31.28	32.18	28.12	27.82
m_3f_4	31.52	31.98	27.46	27.60
m_3f_5	31.30	31.16	27.34	27.00
SEm	0.059	0.206	0.121	0.229
CD (0.05)	0.235	0.588	0.487	NS

at various stages, the methods of planting and weed control measures were not significant.

Among the methods of fertilizer application, during the first year F_1, F_3 and F_4 (31.45, 31.43 and 31.35 respectively) were on par and significantly different from the other two treatments and during the second year, F_2 had the highest chlorophyll content at maximum tillering. At harvest stage, F_3 had significantly the highest chlorophyll content and it was on par with F_2. During second year, F_2 was significantly superior to all the other treatments.

The interaction effect of treatments revealed that during the first year m_1f_3 had the highest chlorophyll content at maximum tillering, which was significantly higher than all the other combinations. During the second year, m_1f_2 had the highest chlorophyll content, which was on par with m_2f_1, m_2f_2 and m_3f_2. At harvest stage, the highest chlorophyll content of 28.46 was produced in m_2f_2 and m_2f_3 (2013-14) which was significantly superior to all the other treatment combinations, except m_3f_3, which was on par. The interaction was not significant in the second year.

4.1.1.5. Crop Growth Rate (CGR)

The data summarized in Table 9 showed significant difference among treatments on crop growth rate from maximum tillering to harvest stage during both the years. Considering the effect of methods of planting and weed control measures, it was observed that, M_1 resulted in the highest CGR of 11.31 g m^{-2} day^{-1} (2013-14), which was on par with M_3. During the second year, M_1 resulted in the highest value followed by M_3 and M_2.

Among the methods of fertilizer application, F_3 produced higher values of 13.60 g m^{-2} day^{-1} and 22.62 g m^{-2} day^{-1} during the first and second years respectively, which was on par with F_2 in both the years.

Among the treatment combinations, the highest crop growth rate was registered in m_1f_2, which was significantly different from the rest and on par with m_1f_3, during the first year. During the second year, the interaction m_1f_3 produced the highest value for crop growth rate, which was significantly superior to all the other treatments, except m_1f_2, which was on par. The lowest value was produced in m_2f_5 (10.52 g m^{-2} day^{-1}).

4.1.1.6. Relative Growth Rate (RGR)

Data furnished in Table 9 revealed significant difference among treatments on relative growth rate from maximum tillering to harvest stage. During 2013-14, M_2 and M_3 produced higher values of RGR, which were significantly superior to M_1. During the second year, M_1 resulted in significantly the highest value and the lowest relative growth rate was recorded in M_3.

Among the methods of fertilizer application, F_1, F_2 and F_3 resulted in significantly higher relative growth rate of 0.0085, 0.0085 and 0.0086 g g^{-1} day^{-1} respectively in the first year. During 2014-15, it was observed that foliar spray of 19:19:19 complex fertilizer was significantly superior to all the other treatments. The lowest values were produced in absolute control in both the years.

During both the years, the combinations were significant. During 2013-14, m_2f_3 resulted in the highest value and it was on par with m_1f_1, m_2f_4 and m_3f_2. In the second year, the treatment combination of m_1f_3 proved superior. The lowest relative growth rate was recorded in m_3f_5.

4.1.1.7. Net Assimilation Rate (NAR)

The net assimilation rate produced during 2013-14 and 2014-15 presented in Table 9 showed the significant variation only at the main plot level in the first year, while all the treatments were significant during the second year. Among the methods of planting and weed management practices, M_3 resulted in the higher net assimilation rate of 0.063 g cm^{-2} day^{-1}, which was on par with M_1 during the first year, while in the second year, M_1 was observed to be significantly superior to the other main plot treatments.

Among the different methods of fertilizer application, F_3 resulted in the highest net assimilation rate during the second year which was on par with F_2 and F_4. The lowest NAR of 0.065 g cm^{-2} day^{-1} was produced in absolute control.

Comparing the treatment combinations, m_1f_2 and m_1f_3 produced the higher net assimilation rates in the second year and was significantly superior to all other treatment combinations, but interaction effect was not significant during the first year.

4.1.1.8. Dry Matter Production

The methods of planting and weed management practices significantly influenced the dry matter production during 2013-14 (Table 10). The highest dry matter of 6166.93 kg ha^{-1}was produced in M_3, which was on par with M_2 (6062.62 kg ha^{-1}) in the first year.

Table 9. Effect of treatments on crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR) of rice (maximum tillering to harvest)

Treatments	CGR (g m^{-2} day^{-1})		RGR (g g^{-1} day^{-1})		NAR (g cm^{-2} day^{-1})	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Main plot (M)						
M_1	11.31	20.76	0.0078	0.0076	0.057	0.080
M_2	9.30	15.68	0.0082	0.0070	0.056	0.073

M_3	11.20	16.43	0.0084	0.0065	0.063	0.075
SEm	0.388	0.695	0.00011	0.00005	0.001	0.001
CD (0.05)	1.267	2.269	0.00036	0.00017	0.006	0.004
Sub plot (F)						
F_1	8.68	15.04	0.0085	0.0069	0.059	0.070
F_2	12.83	21.27	0.0085	0.0073	0.061	0.079
F_3	13.60	22.62	0.0086	0.0080	0.059	0.086
F_4	8.96	16.96	0.0082	0.0065	0.059	0.081
F_5	8.96	12.23	0.0068	0.0065	0.058	0.065
SEm	0.594	0.861	0.00012	0.00021	0.001	0.003
CD (0.05)	1.690	2.449	0.00034	0.00058	NS	0.008
m x f						
m_1f_1	7.61	14.23	0.0088	0.0067	0.060	0.061
m_1f_2	17.09	29.13	0.0082	0.0080	0.066	0.100
m_1f_3	14.92	29.50	0.0079	0.0100	0.055	0.100
m_1f_4	7.42	15.74	0.0076	0.0069	0.058	0.080
m_1f_5	9.53	15.18	0.0066	0.0064	0.058	0.061
m_2f_1	8.18	14.94	0.0084	0.0075	0.055	0.070
m_2f_2	7.28	18.76	0.0080	0.0074	0.055	0.072
m_2f_3	13.65	15.72	0.0093	0.0075	0.061	0.074
m_2f_4	8.74	18.47	0.0088	0.0059	0.058	0.083
m_2f_5	8.67	10.52	0.0064	0.0067	0.050	0.067
m_3f_1	10.26	15.95	0.0084	0.0066	0.063	0.080
m_3f_2	14.13	15.93	0.0092	0.0065	0.060	0.066
m_3f_3	12.23	22.63	0.0086	0.0065	0.063	0.084
m_3f_4	10.71	16.66	0.0083	0.0066	0.062	0.080
m_3f_5	8.69	10.97	0.0075	0.0063	0.065	0.066
SEm	1.029	1.492	0.00021	0.00035	0.003	0.005
CD (0.05)	2.927	4.243	0.00058	0.00101	NS	0.013

The dry matter was not influenced by methods of fertilizer application in the first year, while in the second year, F_2 resulted in the highest dry matter, which was significantly superior to all other treatments. The lowest dry matter production of 6348.46 kg ha^{-1} was obtained in the absolute control.

The different treatment combinations showed significant variation in dry matter production in both the years. During 2013-14, m_2f_2 resulted in the highest dry matter, which was on par with m_1f_3 and significantly superior to all other combinations. The highest and lowest dry matter production of 8306.03 kg ha^{-1} and 5337.13 kg ha^{-1} was produced in m_2f_2 and m_2f_5 respectively in the second year.

4.1.2. Yield and Yield Attributes

4.1.2.1. Number of Productive Tillers m^{-2}

It is evident from Table 11 that treatments had significant effect on number of productive tillers m^{-2} during both the years. Among the main plot treatments, M_3 produced significantly the highest value (293.64) during the first year, which was on par with M_2. In the second year, M_2 and M_3 resulted in the higher number of productive tillers m^{-2} (324.66 and 333.43 respectively) which was significantly superior to M_1.

Among the fertilizer application methods, the highest number of productive tillers m^{-2} was resulted in F_2 in the first year (310.14), which was on par with F_3 and F_4. In the second year, F_2 was on par with F_1, which were significantly different from all the other fertilizer application methods. The lowest values were produced in absolute control during both the years.

Table 10. Effect of treatments on dry matter production of rice

Treatments	Dry matter production (kg ha^{-1})	
	2013-14	2014-15
Main plot (M)		
M_1	5195.99	6708.52
M_2	6062.62	7405.02
M_3	6166.93	6771.96
SEm	100.397	233.563

CD (0.05)	327.410	NS
Sub plot (F)		
F_1	5710.44	6630.25
F_2	6065.88	7860.39
F_3	6028.63	6969.86
F_4	5566.70	7000.20
F_5	5670.92	6348.46
SEm	197.667	251.924
CD (0.05)	NS	716.461
m x f		
m_1f_1	4789.53	6073.33
m_1f_2	5140.84	7425.18
m_1f_3	6644.96	7315.78
m_1f_4	4229.45	5571.60
m_1f_5	5175.16	6985.85
m_2f_1	6445.27	7277.37
m_2f_2	7580.56	8306.03
m_2f_3	4944.66	8092.29
m_2f_4	6336.77	8180.09
m_2f_5	5293.53	5337.13
m_3f_1	5896.51	6537.05
m_3f_2	5548.06	7931.47
m_3f_3	6417.16	5501.49
m_3f_4	6133.88	7167.41
m_3f_5	6544.07	6722.38
SEm	342.370	436.345
CD (0.05)	973.686	1240.946

Among the interactions, m_3f_2 and m_2f_2 produced significantly higher number of productive tillers m^{-2} (341.73 and 319.95 respectively) in the first year. During the second year, the higher values were recorded in m_3f_1 and m_3f_2. During 2013-14, the lowest value was recorded in m_1f_5 and during the second year, m_1f_1 produced the least tiller production of 244.33.

4.1.2.2. Length of Panicle

Among the different methods of planting and weed control measures, dibbling of sprouted seeds along with stubble mulching (M_3) produced significantly the higher panicle length of 18.95 cm and 19.13 cm in the first and second years respectively and it was on par with M_2 (Table 11).

Comparing the fertilizer application treatments, the highest length of panicle was resulted in F_2 in both the years. The treatment was on par with F_3 and F_4 during 2013-14 and with F_3 in the second year.

Among the treatment combinations, m_2f_2 produced the highest panicle length during both the years and was significantly different from other treatments. It was on par with m_2f_3 with panicle length of 19.94 cm in the first year. During 2014-15, the treatment combination was on par with m_2f_3, m_3f_1 and m_3f_2.

4.1.2.3. Grain Weight Panicle^{-1}

The data presented in Table 11 revealed that the methods of planting, weed and nutrient management practices significantly influenced grain weight panicle^{-1} in both the years, while the main plot treatments were not significant.

Among the methods of fertilizer application, the highest grain weight panicle^{-1} was recorded in F_3 (1.36 g) and it was on par with F_1 and F_4 during the first year. During second year, F_1 resulted in the highest grain weight panicle^{-1}, which was significantly different from the other treatments but on par with F_3 and F_4.

The treatment combinations significantly influenced the grain weight panicle^{-1} and m_2f_4 produced the highest value of 1.71 g and was on par with m_3f_3 in the first year. The combination m_2f_3 resulted in the highest grain weight panicle^{-1} of 1.41 g, which was on par with m_1f_2, m_1f_3, m_2f_1, m_2f_4 and m_3f_1 (second year).

4.1.2.4. Weight of Panicle

The data on weight of panicle is presented in Table 12. The main plot treatments were observed to be not significant on panicle weight in both the years.

Comparing the different fertilizer application treatments, F_4 produced the highest panicle weight of 1.71g during 2013-14 which was on par with F_1 and F_3. During the second year, F_3 resulted in significantly the highest panicle weight of 1.76 g, which was on par with F_2 and F_4. The lowest value was recorded in the absolute control.

Among the treatment combinations, during the first year, m_2f_4 resulted in the highest panicle weight of 2.04 g panicle^{-1} which was significantly superior to all the other treatments. During 2014-15, m_1f_2 registered the highest panicle weight, which was significantly differing from all other combinations, except m_1f_3, m_2f_3 and m_2f_4 which were on par.

Table 11. Effect of treatments on number of productive tillers m^{-2}, length of panicle and grain weight panicle^{-1} of rice

Treatments	Number of productive tillers m^{-2}		Length of panicle (cm)		Grain weight panicle^{-1}	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Main plot (M)						

M_1	268.05	262.72	17.42	17.85	1.09	1.26
M_2	287.85	324.66	18.69	18.97	1.39	1.28
M_3	293.64	333.43	18.95	19.13	1.19	1.20
SEm	3.967	3.189	0.289	0.252	0.083	0.036
CD (0.05)	12.938	10.400	0.324	0.823	NS	NS
Sub plot (F)						
F_1	292.14	322.12	17.63	18.73	1.22	1.33
F_2	310.14	336.78	18.95	19.43	1.14	1.24
F_3	297.34	304.78	18.49	19.29	1.36	1.30
F_4	298.19	306.85	18.59	18.74	1.28	1.26
F_5	218.08	264.16	18.10	17.08	1.12	1.13
SEm	5.122	6.554	0.229	0.228	0.054	0.024
CD (0.05)	14.565	18.639	0.652	0.647	0.154	0.069
m x f						
m_1f_1	268.28	244.33	15.66	17.93	1.09	1.30
m_1f_2	282.15	263.25	17.58	18.27	1.27	1.40
m_1f_3	300.04	267.21	16.48	18.29	1.20	1.32
m_1f_4	285.90	275.19	19.06	18.35	1.00	1.17
m_1f_5	203.87	263.62	18.32	16.41	0.91	1.13
m_2f_1	288.20	354.33	17.89	18.41	1.34	1.37
m_2f_2	319.95	353.01	20.59	20.50	1.25	1.27
m_2f_3	298.65	333.29	19.94	20.26	1.39	1.41
m_2f_4	302.87	326.61	17.91	18.68	1.71	1.36
m_2f_5	242.98	256.07	17.10	17.03	1.27	1.00
m_3f_1	306.53	367.68	19.33	19.84	1.24	1.31
m_3f_2	341.73	394.08	18.67	19.50	0.91	1.05
m_3f_3	293.33	313.85	19.06	19.33	1.49	1.15
m_3f_4	305.80	318.73	18.81	19.18	1.11	1.26
m_3f_5	207.39	272.79	18.87	17.80	1.19	1.25
SEm	12.545	16.053	0.561	0.558	0.133	0.059
CD (0.05)	25.228	32.283	1.129	1.121	0.267	0.119

4.1.2.5. Number of Grains Panicle^{-1}

Among the methods of planting and weed control measures, the highest number of grains panicle^{-1} was recorded in M_2 (86.50) and it was significantly higher than other two treatments in the first year (Table 12). The treatments were not significant in the second year.

Among the fertilizer application methods, the treatment F_3 produced the highest number of grains panicle^{-1} of 84.93 in the first year and was on par with F_2. During 2014-15, the highest number of grains panicle^{-1} was produced in F_3, which was significantly superior to all the other treatments except F_2 and F_4 which were on par.

Comparing the interactions, m_2f_4 produced significantly the highest number of grains panicle^{-1} in 2013-14 and it was on par with m_2f_2. The highest number of grains panicle^{-1} of 98.22 was registered in m_2f_3 and was significantly different from all the other interactions except m_2f_2 and m_2f_4 (second year), which were on par.

4.1.2.6. Thousand Grain Weight

It is evident from Table 12 that treatments had significant effects on thousand grain weight. But the main plot treatments in the second year and sub plot treatments in the first year were not significant. During the first year, M_2 and M_3 registered higher thousand grain weight of 26.50 g and 26.49 g respectively and the lowest thousand grain weight was produced in M_1.

Among the fertilizer application methods, the highest thousand grain weight was recorded in F_4 and F_2, which was significantly different from the other treatments during the second year.

Comparing the treatment combinations, m_2f_2 was significantly superior to all the other treatments except in m_2f_1, m_3f_3 and m_3f_4 (2013-14). During the second year, the treatment combination of m_3f_4 was significantly higher than the other combinations, but on par with m_1f_2, m_2f_1, m_2f_2, m_2f_3, m_2f_4, m_3f_1 and m_3f_5.

4.1.2.7. Sterility Percentage

The treatments significantly influenced the sterility percentage except main plot treatments in both the years and the results are depicted in Table 12.

Absolute control (F_5) resulted in higher sterility percentage during both the years which was significantly different from all other fertilizer application methods. The lowest values were recorded by F_2 in the first year and F_3 in the second year.

Among the treatment combinations, the highest sterility percentage was recorded in m_2f_5 during 2013-14 which was on par m_1f_5 and m_3f_5. In the second year, the highest sterility of 30.01 per cent was recorded by m_2f_5 which was significantly superior to all the other combinations. The lowest values were produced in m_1f_3 and m_2f_4 in the first and second years respectively.

4.1.2.8. Grain Yield

The data presented in Table 13 showed the effect of different treatments on grain yield of rice during 2013-14 and 2014-15. The different methods of planting and weed management showed significant difference in grain yield during the first year but was not significant during the second year. Dibbling of seeds along with power weeding (M_2) produced the higher grain yield of 2085.42 kg ha^{-1} which was on par with dibbling of seeds along with stubble mulching (m_3) with a grain yield of 2068.18 kg ha^{-1} in the first year. The lowest value was resulted in M_1.

Table 12. Effect of treatments on weight of panicle, number of grains panicle^{-1}, thousand grain weight and sterility percentage of rice

Treatments	Weight of panicle (g)		Number of grains panicle^{-1}		Thousand grain weight (g)		Sterility percentage	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Main plot (M)								

M_1	1.58	1.71	70.95	73.50	24.33	23.77	34.78	24.11
M_2	1.78	1.67	86.50	84.92	26.50	25.25	36.84	23.04
M_3	1.56	1.63	78.26	78.73	26.49	25.58	35.33	24.92
SEm	0.066	0.035	1.760	2.823	0.409	0.578	0.660	0.622
CD (0.05)	NS	NS	5.742	NS	1.335	NS	NS	NS
Sub plot (F)								
F_1	1.63	1.60	75.28	74.19	26.09	24.73	34.52	24.45
F_2	1.61	1.73	83.05	85.27	25.65	25.46	30.27	23.13
F_3	1.63	1.76	84.93	85.37	25.60	25.25	31.23	22.90
F_4	1.71	1.72	76.76	80.55	26.01	26.51	35.18	23.50
F_5	1.60	1.54	75.28	69.86	25.51	22.38	41.07	26.14
SEm	0.030	0.030	1.631	2.256	0.288	0.397	0.787	0.490
CD (0.05)	0.086	0.084	4.638	6.416	NS	1.130	2.238	1.393
m x f								
m_1f_1	1.58	1.64	52.09	61.83	24.34	21.46	38.61	27.26
m_1f_2	1.69	1.92	64.29	85.62	23.78	25.92	27.46	20.15
m_1f_3	1.49	1.80	71.79	78.56	23.88	24.63	27.29	22.26
m_1f_4	1.49	1.63	79.33	74.58	24.34	25.00	34.76	24.81
m_1f_5	1.63	1.59	87.24	66.91	25.30	21.84	40.81	26.07
m_2f_1	1.73	1.50	82.91	76.46	27.56	27.18	32.20	21.96
m_2f_2	1.65	1.73	98.36	95.06	28.26	25.55	36.09	22.66
m_2f_3	1.84	1.88	81.87	98.22	24.82	26.53	32.36	20.44
m_2f_4	2.04	1.85	99.33	89.61	25.82	27.15	35.29	20.13
m_2f_5	1.65	1.38	70.04	65.26	26.04	19.85	42.23	30.01
m_3f_1	1.59	1.68	83.54	84.27	26.38	25.56	32.75	24.13
m_3f_2	1.50	1.52	86.49	75.14	24.92	24.92	30.14	25.89
m_3f_3	1.57	1.61	83.65	79.34	28.10	24.58	31.16	26.70
m_3f_4	1.60	1.68	69.07	77.46	27.86	27.40	35.47	25.56
m_3f_5	1.52	1.64	68.57	77.43	25.18	25.46	41.16	22.33
SEm	0.052	0.051	2.825	3.908	0.498	0.688	1.241	0.848
CD (0.05)	0.149	0.145	8.033	11.113	1.416	1.958	3.516	2.413

Among the methods of fertilizer application, during 2013-14 the treatments were not significant for grain yield and during the second year, the highest grain yield was resulted in foliar spray of 19:19:19 complex fertilizer @ 0.5 per cent (F_3) (2747.76 kg ha^{-1}) which was on par with all the other treatments except F_1 and F_5. Absolute control (F_5) produced the lowest grain yield of 2228.58 kg ha^{-1}.

During the first year, the treatment combination of m_2f_2 (2927.97 kg ha^{-1}) was significantly superior to all the other treatments. The data revealed that m_2f_3 produced significantly the highest grain yield and was on par with m_1f_2, m_1f_3, m_2f_2 and m_2f_4 in the second year. The lowest grain yield of 1878.24 kg ha^{-1} was recorded in m_2f_5 during 2014-15.

The pooled data on grain yield revealed that the main plot and sub plot treatments were not significant (Table 13). Comparing the interactions, m_2f_2 resulted in the maximum grain yield of 2979.97 kg ha^{-1}, which was significantly superior to all the other combinations.

4.1.2.9. Straw Yield

The data summarized in Table 13 showed the effect of different treatments on straw yield of upland rice in both the years. The different main plot treatments showed significant variation in straw yield during the first year which was not significant in the second year. In the first year, the highest straw yield was registered in M_3 which was significantly higher and on par with M_2.

Among the fertilizer application treatments, during the first year, straw yield was not influenced by the treatments and during the second year, F_2 (band placement of 60:30:30 NPK kg ha^{-1}) produced the highest straw yield of 5210.86 kg ha^{-1}, which was significantly superior to all the other treatments.

Comparing the treatment combinations, m_1f_3 (4917.00 kg ha^{-1}) was significantly superior to all the other treatments except m_2f_1, m_2f_2 and m_3f_5 in the first year. During 2014-15, the highest straw yield was resulted in m_3f_2 (5712.96 kg ha^{-1}) which was on par with m_1f_5, m_2f_2, m_2f_3 and m_2f_4.

The pooled data showed the significant difference of treatments on straw yield of rice in the interaction only (Table 13). The individual effects were not significant. Among the treatment combinations similar to grain yield data, the highest straw yield was also registered in m_2f_2 (4963.33 kg ha^{-1}). It was significantly superior and on par with m_1f_3, m_1f_5, m_2f_1, m_2f_4, m_3f_2, m_3f_4 and m_3f_5.

4.1.2.10. Harvest Index (HI)

Data on harvest Index furnished in Table 13 revealed that the treatments were not significantly influenced by various methods of planting as well as weed management in both the years. Among the methods of fertilizer application, foliar spray of complex fertilizer DAP and SOP each @ 2 per cent (F_4) produced significantly the highest harvest index of 0.36 in the first year. The treatments were significantly different from all the other treatments except F_1 and F_2. The higher harvest index values of 0.39 and 0.38 were resulted in F_3 and F_4 respectively during the second year, which was significantly superior to all the other methods of fertilizer application.

The interaction effect showed significant variation among treatments. The highest harvest index of 0.40 was produced in the treatment combination of m_1f_4 during 2013-14 which was on par with m_2f_2 and m_3f_3. In the second year, the highest HI was registered in the treatment combination of m_1f_3 (0.41). It was significantly superior to all the other combinations except m_1f_4, m_2f_2, m_2f_3, m_3f_3 and m_3f_5 which were on par.

Treatments	Grain yield (kg ha^{-1})		Pooled	Straw yield (kg ha^{-1})		Pooled	Harvest index (HI)	
	2013-14	2014-15		2013-14	2014-15		2013-14	2014-15
Main plot (M)								
M_1	1654.31	2436.29	2045.30	3541.68	4272.22	3906.95	0.33	0.36
M_2	2085.42	2697.09	2391.26	3977.22	4707.93	4342.57	0.34	0.37
M_3	2068.18	2422.70	2245.44	4098.75	4349.26	4224.00	0.34	0.36
SEm	46.282	104.819	52.603	99.463	130.555	120.315	0.008	0.004

CD (0.05)	150.931	NS	NS	324.363	NS	NS	NS	NS
Sub plot (F)								
F_1	1922.27	2332.84	2127.56	3788.17	4297.41	4042.79	0.34	0.35
F_2	2053.26	2649.53	2351.40	4012.62	5210.86	4611.74	0.34	0.34
F_3	1981.30	2747.76	2364.53	4047.33	4222.10	4134.71	0.33	0.39
F_4	1996.92	2634.77	2315.85	3569.78	4365.43	3967.61	0.36	0.38
F_5	1726.07	2228.58	1977.33	3944.84	4119.88	4032.36	0.31	0.36
SEm	79.956	86.373	67.908	152.855	187.453	155.325	0.008	0.006
CD (0.05)	NS	245.642	NS	NS	533.108	NS	0.025	0.019
m x f								
m_1f_1	1679.16	1928.89	1804.03	3110.37	4144.44	3627.41	0.35	0.32
m_1f_2	1598.62	2779.62	2189.12	3542.22	4645.56	4093.89	0.31	0.37
m_1f_3	1727.97	2949.11	2338.54	4917.00	4366.67	4641.83	0.27	0.41
m_1f_4	1693.80	2201.23	1947.52	2535.65	3370.37	2953.01	0.40	0.40
m_1f_5	1572.00	2151.78	1861.89	3603.15	4834.07	4218.61	0.30	0.31
m_2f_1	2207.12	2683.30	2445.21	4238.15	4594.07	4416.11	0.34	0.37
m_2f_2	2927.97	3031.96	2979.97	4652.59	5274.07	4963.33	0.39	0.38
m_2f_3	1603.84	3109.33	2356.59	3340.82	4982.96	4161.89	0.32	0.38
m_2f_4	2221.96	2950.46	2586.21	4114.81	5229.63	4672.22	0.35	0.36
m_2f_5	1753.81	1878.24	1816.03	3539.72	3458.89	3499.30	0.33	0.35
m_3f_1	1880.54	2383.35	2131.95	4015.97	4153.70	4084.84	0.32	0.36
m_3f_2	1705.00	2218.51	1961.76	3843.06	5712.96	4778.01	0.31	0.28
m_3f_3	2533.00	2184.83	2358.92	3884.16	3316.67	3600.41	0.39	0.40
m_3f_4	2075.00	2671.11	2373.06	4058.88	4496.30	4277.59	0.34	0.37
m_3f_5	1852.41	2655.72	2254.07	4691.66	4066.67	4379.16	0.29	0.40
SEm	138.488	149.603	117.620	264.752	324.678	269.032	0.016	0.011
CD (0.05)	393.854	425.464	349.260	752.943	923.369	798.863	0.044	0.032

Table 13. Effect of treatments on grain yield, straw yield and harvest index of rice

4.1.3. Economics of Cultivation

4.1.3.1. Net Return

The results presented in Table 14 indicates the effect of methods of planting, weed as well as nutrient management practices on net return of rice during 2013-14 and 2014-15. The highest net return was produced in m_2f_2 (Rs 25938.40 ha^{-1}) in the first year and m_2f_3 (Rs 44062.78 ha^{-1}) in the second year.

4.1.3.2. Benefit:Cost Ratio

The data presented in Table 14 showed that during the first year, dibbling of seeds + power weeding along with band placement of 60:30:30 kg NPK ha^{-1} (m_2f_2) resulted in the highest benefit cost ratio. During 2014-15, the highest benefit cost ratio of 2.38 was produced in the treatment combination m_2f_3.

4.1.4. Energy Budgeting

4.1.4.1. Energy Efficiency

The results presented in Table 15 indicated that the treatments and their interaction had significant effect on the energy efficiency of rice in both the years. Among the methods of planting and weed management practices, the highest energy efficiency was registered significantly in M_2 (dibbling of seeds + power weeding), which it was on par with M_1 in both the years. The lowest value was registered in M_3.

The energy efficiency of various fertilizer application methods revealed that even though the highest value was produced in F_5 (control), while comparing the four fertilizer application treatments, the highest energy efficiency was registered in F_3 during both the years.

Table 14. Effect of treatments on economics of cultivation of rice

Treatments	Net return (Rs. ha^{-1})	Benefit:Cost (B:C)	Net return (Rs. ha^{-1})	Benefit:Cost (B:C)
	2013-14		2014-15	
m_1f_1	2235.36	1.06	15150.78	1.42
m_1f_2	1289.04	1.03	35543.52	1.98
m_1f_3	13192.46	1.35	37255.66	2.12

m_1f_4	2095.00	1.05	18851.62	1.55
m_1f_5	11638.60	1.37	31280.32	2.17
m_2f_1	17707.76	1.45	32040.68	1.92
m_2f_2	25938.40	1.65	36440.44	2.05
m_2f_3	6111.40	1.17	44062.78	2.38
m_2f_4	19376.52	1.52	42699.80	2.30
m_2f_5	15195.46	1.50	21395.88	1.82
m_3f_1	3440.60	1.07	17326.10	1.41
m_3f_2	-1634.76	0.97	20596.02	1.49
m_3f_3	22819.10	1.52	13256.62	1.34
m_3f_4	9007.52	1.20	25771.18	1.64
m_3f_5	14078.02	1.37	30321.64	1.90

Comparing all the interactions, m_1f_3 resulted in the highest energy efficiency in the first year and during 2014-15, the highest efficiency was registered in m_2f_3 which was on par with m_1f_3 and m_2f_4. Both the years, the highest value was recorded without considering the combinations which consists of control.

4.1.4.2. Energy Productivity

The results on the energy productivity of rice as affected by the methods of planting and weed management measures, fertilizer application and their interactions are presented in Table 15. The highest energy productivity was registered significantly in M_2 (dibbling of seeds + power weeding) which was on par with M_1 in both the years.

The energy productivity of the various fertilizer application methods revealed that even though the highest value was produced in F_5 (control), while comparing the four fertilizer application treatments, the highest energy productivity of 0.52 kg MJ^{-1} and 0.67 kg MJ^{-1} were registered in F_3 in the first and second year respectively.

Among the treatment combinations, m_1f_3 had the highest energy productivity in the first year and during 2014-15, the highest productivity was registered in m_2f_3 since these combinations produced the highest yield. Both the years, the highest value was presented without considering the combinations which consists of control even though they recorded the highest values.

Table 15. Effect of treatments on energy budgeting of rice

Treatments	Energy Efficiency		Energy Productivity (kg MJ^{-1})	
	2013-14	2014-15	2013-14	2014-15
Main plot (M)				
M_1	8.18	10.40	0.53	0.68

M_2	8.75	10.84	0.57	0.71
M_3	1.89	2.05	0.12	0.13
SEm	0.175	0.444	0.011	0.029
CD (0.05)	0.569	1.449	0.037	0.095
Sub plot (F)				
F_1	3.65	4.30	0.24	0.28
F_2	3.95	5.06	0.26	0.33
F_3	8.02	10.22	0.52	0.67
F_4	6.53	8.47	0.43	0.56
F_5	9.22	10.76	0.60	0.70
SEm	0.283	0.387	0.018	0.025
CD (0.05)	0.805	1.100	0.052	0.072
m x f				
m_1f_1	4.02	5.11	0.26	0.33
m_1f_2	4.32	6.36	0.28	0.42
m_1f_3	12.68	13.87	0.83	0.91
m_1f_4	7.13	9.42	0.47	0.62
m_1f_5	12.77	17.25	0.83	1.13
m_2f_1	5.35	6.04	0.35	0.40
m_2f_2	6.05	6.69	0.40	0.44
m_2f_3	9.19	15.00	0.60	0.98
m_2f_4	10.50	13.69	0.69	0.90
m_2f_5	12.65	12.75	0.83	0.83
m_3f_1	1.59	1.75	0.10	0.11
m_3f_2	1.49	2.14	0.10	0.14
m_3f_3	2.19	1.79	0.14	0.12
m_3f_4	1.97	2.29	0.13	0.15
m_3f_5	2.24	2.28	0.15	0.15
SEm	0.490	0.670	0.032	0.044
CD (0.05)	1.394	1.905	0.091	0.124

4.1.5. Uptake of Major Nutrients

4.1.5.1. Nitrogen Uptake

Nitrogen uptake data furnished in Table 16 revealed that the treatment effect was significant during both the years. The different methods of planting and weed control measures showed that M_3 and M_2 produced significantly the higher nitrogen uptake during 2013-14 and 2014-15 respectively, compared to M_1.

Comparing the different methods of fertilizer application, during 2013-14 F_2 resulted in the highest uptake of 128.97 kg ha^{-1} which was on par with F_1 and F_3. During 2014-15, the highest uptake was registered in F_3 (191.80 kg ha^{-1}), which was significantly superior to all the other fertilizer application methods.

The different treatment combinations showed significant variation on nitrogen uptake during both the years. In the first year, m_2f_2 resulted in the highest nitrogen uptake of 183.67 kg ha^{-1} and was found superior to all the other treatment combinations. The highest nitrogen uptake during 2014-15 was produced in m_1f_3 and the minimum uptake was produced in m_1f_1.

4.1.5.2. Phosphorous Uptake

It is evident from Table 16 that the treatments had significant effect on phosphorous uptake except the main plot treatments which was not significant during 2014-15. During the first year, M_3 recorded the highest P uptake of 16.56 kg ha^{-1} which was significantly superior to other two methods of planting and weed management practices.

Among the fertilizer application methods, the highest uptake was registered in F_1 during the first year and F_2 during the second year. The treatments showed significant difference in all the treatments, except F_3 (2013-14) and F_4 (2014-15) which were on par with each other.

During the first year, the treatment combination of m_2f_1 was significantly superior to all the other combinations except m_1f_3, m_3f_1 and m_3f_3. The combination of m_2f_4 resulted in the highest phosphorous uptake of 31.52 kg ha^{-1} and was on par with m_1f_2, m_2f_2 and m_2f_3 during the second year.

4.1.5.3. Potassium Uptake

All the treatments except subplot treatments in the first year significantly influenced the potassium uptake (Table 16). Among the methods of planting and weed control measures, the highest potassium uptake was recorded in M_3 in the first year and in the second year, M_2.

During 2014-15, the highest potassium uptake was registered in F_2 (167.16 kg ha^{-1}) and was significantly superior to all other fertilizer application methods.

Comparing the interaction, m_1f_3 was found superior to other combinations except m_2f_1, m_2f_2, m_2f_4, m_3f_1 and m_3f_2 during the first year. In the second year, m_2f_1 resulted in significantly the highest potassium uptake and was on par with m_1f_2, m_2f_2, m_2f_4 and m_3f_4.

4.1.5.4. Sulphur Uptake

The data presented in Table 16 revealed that the treatments influenced the uptake of sulphur. In the first year and second year, the highest S uptake of 5.86 and

Table 16. Effect of treatments on uptake of major nutrients in rice

Treatments	Nitrogen	Phosphorous	Potassium	Sulphur

	(kg ha^{-1})		(kg ha^{-1})		(kg ha^{-1})		(kg ha^{-1})	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Main plot (M)								
M_1	106.13	150.19	13.15	23.85	89.18	138.33	4.37	5.45
M_2	120.36	179.36	15.16	26.27	102.29	160.12	5.86	7.64
M_3	123.25	163.98	16.56	23.47	105.10	137.61	4.86	6.47
SEm	2.148	5.337	0.282	0.771	2.145	4.365	0.078	0.226
CD (0.05)	7.006	17.404	0.920	NS	6.996	14.236	0.256	0.736
Sub plot (F)								
F_1	125.21	167.94	17.28	23.60	107.59	143.42	5.39	5.95
F_2	128.97	152.75	12.96	27.45	101.44	167.16	4.43	7.08
F_3	119.23	191.80	16.87	24.58	96.01	136.26	5.73	6.64
F_4	109.82	164.62	14.59	25.15	93.44	144.90	5.42	7.41
F_5	99.66	145.45	13.08	21.87	95.81	135.03	4.19	5.51
SEm	3.900	5.700	0.520	0.955	3.775	5.684	0.182	0.173
CD (0.05)	11.093	16.211	1.481	2.716	NS	16.165	0.520	0.493
m x f								
m_1f_1	114.31	107.62	11.61	22.06	86.53	120.88	4.20	4.27
m_1f_2	91.03	131.42	11.35	27.55	69.93	178.42	3.49	6.74
m_1f_3	111.82	235.89	20.33	25.98	127.08	139.66	5.86	5.19
m_1f_4	127.04	109.88	9.54	19.30	68.50	89.15	4.70	5.89
m_1f_5	86.44	166.12	12.93	24.35	93.89	163.53	3.61	5.16
m_2f_1	133.25	205.07	21.31	25.29	117.49	196.25	6.52	8.42
m_2f_2	183.67	165.73	15.83	28.10	120.34	170.89	6.62	7.40
m_2f_3	94.35	201.31	11.48	28.66	67.36	129.74	5.80	8.50
m_2f_4	98.36	207.21	16.60	31.52	118.13	170.93	6.27	8.20
m_2f_5	92.17	117.49	10.56	17.80	88.12	132.79	4.10	5.66
m_3f_1	128.06	191.11	18.92	23.46	118.73	113.14	5.47	5.15
m_3f_2	112.22	161.09	11.68	26.69	114.04	152.17	3.18	7.12
m_3f_3	151.53	138.19	18.80	19.12	93.58	139.37	5.54	6.21
m_3f_4	104.05	176.79	17.63	24.63	93.69	174.61	5.28	8.14
m_3f_5	120.37	152.73	15.76	23.46	105.44	108.77	4.86	5.70
SEm	6.756	9.873	0.902	1.654	6.539	9.845	0.317	0.301
CD (0.05)	19.213	28.079	2.565	4.705	18.595	27.998	0.900	0.854

7.64 kg ha^{-1} respectively were recorded in M_2 which was superior to all other methods of planting and weed control measures.

Comparing the different fertilizer application methods, the highest S uptake of 5.73 kg ha^{-1} was recorded in F_3 (2013-14) which showed the superiority compared to other treatments except F_1 and F_4. The highest uptake of S was registered in F_4 during the second year which was on par with F_2.

Among the interactions, m_2f_2 recorded significantly the highest S uptake and was on par with m_1f_3, m_2f_1, m_2f_3 and m_2f_4 in the first year. The highest uptake of S was recorded in m_2f_3 with a value of 8.50 kg ha^{-1} which was on par with m_2f_1, m_2f_4 and m_3f_4.

4.1.6. Chemical Properties of the Soil

4.1.6.1. pH

Treatments exerted significant effect on pH of soil as revealed from Table 17. During 2013-14, M_1 recorded the highest pH (5.48) followed by M_3 and M_2. In the second year, M_3 resulted in the highest pH of 5.98 and the minimum pH was recorded in M_2.

Among the fertilizer application methods, the highest pH was registered in F_5 (2013-14) which was significantly different from all other treatments. The highest pH was observed in F_4 (6.01) during the second year and was on par with F_1.

The results on interaction revealed that m_3f_5 recorded significantly the highest pH of 6.03 during the first year which was slightly acidic. During 2014-15, the highest pH was recorded in m_3f_4 and the minimum was observed in m_3f_3 which were significantly different from the other treatment combinations.

4.1.6.2. EC

The highest EC was registered in M_3 in the first and second year with the values of 0.42 and 0.27 dS m^{-1} respectively (Table 17). The main plot treatment M_3 was found significantly superior to other two methods of planting and weed control measures.

Comparing the fertilizer application treatments, F_3 recorded the highest EC compared to the other treatments and the lowest EC value was recorded in F_1 and F_4 in the first year. During 2014-15, the treatment which showed highest EC value was F_2 (0.28 dS m^{-1}) followed by F_4, F_3, F_5 and F_1.

Among the treatment combinations, significantly highest EC was registered in m_3f_3 in the first year which was significantly superior to all other combinations. During 2014-15, m_3f_2 resulted in the highest EC of 0.32 dS m^{-1} which showed the significant difference from all the other combinations except m_1f_3, m_3f_4 and m_3f_5.

4.1.6.3. Organic Carbon

Data presented in Table 17 indicates the effect of various treatments on organic carbon content of soil during 2013-14 and 2014-15. Among the methods of planting and weed management measures, M_2 resulted in the highest organic carbon content of 1.22 per cent (2013-14) which was significantly different from M_1 (1.14 per cent) and M_3 (1.15 per cent). In the second year, M_1 resulted in significantly higher organic carbon content, which was on par with M_3.

Table 17. Effect of treatments on pH, EC and organic carbon content in soil

Treatments	pH		EC (dS m^{-1})		Organic carbon (%)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Main plot (M)						
M_1	5.48	5.85	0.36	0.23	1.14	1.01

M_2	5.42	5.71	0.37	0.21	1.22	0.98
M_3	5.45	5.98	0.42	0.27	1.15	1.00
SEm	0.003	0.016	0.004	0.002	0.001	0.004
CD (0.05)	0.010	0.052	0.013	0.006	0.003	0.014
Sub plot (F)						
F_1	5.24	5.96	0.35	0.20	1.20	1.06
F_2	5.44	5.72	0.36	0.28	1.20	0.97
F_3	5.56	5.71	0.47	0.24	1.13	0.90
F_4	5.29	6.01	0.35	0.25	1.13	1.12
F_5	5.72	5.82	0.39	0.24	1.20	0.91
SEm	0.009	0.026	0.003	0.003	0.002	0.006
CD (0.05)	0.026	0.075	0.008	0.008	0.005	0.017
m x f						
m_1f_1	5.22	5.94	0.17	0.14	1.05	1.18
m_1f_2	5.71	5.70	0.30	0.28	1.11	0.91
m_1f_3	5.95	6.06	0.44	0.30	1.25	0.87
m_1f_4	5.28	5.91	0.39	0.21	1.10	1.14
m_1f_5	5.25	5.64	0.49	0.23	1.19	0.92
m_2f_1	5.24	6.04	0.50	0.22	1.26	0.88
m_2f_2	5.55	5.55	0.35	0.23	1.25	1.13
m_2f_3	5.14	5.62	0.40	0.20	1.08	1.05
m_2f_4	5.29	5.62	0.32	0.24	1.28	1.02
m_2f_5	5.88	5.71	0.29	0.18	1.23	0.83
m_3f_1	5.25	5.91	0.39	0.22	1.28	1.13
m_3f_2	5.05	5.92	0.44	0.32	1.23	0.89
m_3f_3	5.60	5.46	0.57	0.22	1.06	0.77
m_3f_4	5.29	6.50	0.33	0.31	1.02	1.21
m_3f_5	6.03	6.10	0.39	0.30	1.18	0.99
SEm	0.016	0.045	0.005	0.005	0.003	0.010
CD (0.05)	0.045	0.129	0.013	0.015	0.009	0.029

The various fertilizer application treatments F_1, F_2 and F_5 recorded an organic carbon content of 1.20 per cent in the soil which was significantly higher compared to other two treatments in the first year. In the second year, the highest organic carbon content was registered in F_4 and it was on par with F_1.

Comparing the interactions, the highest organic carbon content was recorded in m_2f_4 and m_3f_1 with similar values of 1.28 per cent and lowest in m_3f_4 (1.02 per cent) during 2013-14. In the second year, m_1f_1 and m_3f_4 resulted in the highest organic carbon contents and was significantly superior to all the other combinations.

4.1.5. Available Nutrient Content in Soil

4.1.5.1. Available Nitrogen

The data on available nitrogen content of soil are furnished in Table 18. The treatments significantly influenced the available N content of soil during 2013-14 and 2014-15. Comparing the methods of planting and weed control measures, the higher available nitrogen content of 393.51 kg ha^{-1} and 225.14 kg ha^{-1} was recorded in M_1 during the first and second years respectively. In the second year, M_1 was on par with M_3.

Among the different fertilizer application methods, during 2013-14 the highest available nitrogen was registered in F_3 which was superior to all the other treatments. During the second year, the treatment F_4 recorded the highest available nitrogen content of 251.43 kg ha^{-1} and was significantly superior to all the other fertilizer application methods.

During the first year, the treatment combination, m_1f_1 was significantly superior to all the other combinations. The minimum content was observed by the combination m_2f_2 (299.44 kg ha^{-1}). The combination m_3f_4 resulted in significantly the highest available nitrogen content of 270.74 kg ha^{-1} and was on par with m_1f_1 in the second year.

4.1.5.2. Available Phosphorous

The data presented in Table 18 clearly depicts the significant influence of treatments on available phosphorous content in soil. The highest P content in soil was noticed in M_3 and was significantly superior to the other methods of planting and weed control measures in both the years. The minimum content was registered in M_2 (2013-14) and M_1 (2014-15).

Comparing the different fertilizer application methods, the highest P content was registered in F_1 (105.35 kg ha^{-1}) and on par with F_3 (101.52 kg ha^{-1}) during 2013-14 which was significantly superior to all other treatments. The treatment F_4 recorded the highest available phosphorous content in the second year and was significantly superior to all the other treatments.

The combination of m_3f_1 resulted in the highest available P content during the first year with a value of 141.45 kg ha^{-1}. During 2014-15, the highest P content was recorded in m_2f_2, which was on par with m_3f_4 and superior to all the other combinations.

4.1.5.3. Available Potassium

The treatments significantly influenced the available potassium content in soil during both the years (Table 18). In the first year, M_3 resulted in the highest available potassium content of 371.69 kg ha^{-1} which was significantly higher than other two methods of planting and weed control measures. The treatment M_1 recorded significantly the highest available K content during the second year.

The highest available K content of 388.53 kg ha^{-1} was observed in F_2 in the first year which was significantly superior to other fertilizer application methods. During 2014-15, F_3 resulted in the highest K content and the minimum content was recorded in F_2.

Among the treatment combinations, m_3f_1 recorded the highest available K content of 534.06 kg ha^{-1} and was significantly different from all other combinations (2013-14). During 2014-15, m_2f_3 and m_1f_1 resulted in significantly the higher K contents compared to other interactions.

4.1.5.4. Available Sulphur

The data presented in Table 18 revealed that treatments significantly influenced the available sulphur content in soil. In the first year available S content of 19.42 ppm was recorded in M_1 which was superior to all the other methods of planting and weed control measures. The treatment M_2 resulted in the higher S content in the second year.

Comparing the different fertilizer application methods, the highest available S content was recorded in F_3 during both the years which showed the superiority compared to other treatments. In second year, F_3 was on par with F_2 and F_4 and significantly different from all the others. The interaction effects showed that m_3f_3 recorded the highest S content and the lowest content was observed in m_2f_1 during the first year. In the second year, the highest available S content in soil was recorded in m_2f_2 with a value of 25.00 ppm which was significantly different from all the other treatment combinations.

Table 18. Effect of treatments on available nitrogen, phosphorous, potassium and sulphur content in soil

Treatments	Nitrogen (kg ha^{-1})		Phosphorous (kg ha^{-1})		Potassium (kg ha^{-1})		Sulphur (ppm)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Main plot (M)								
M_1	393.51	225.14	85.86	117.68	270.91	355.76	19.42	13.31
M_2	359.19	219.46	85.70	140.86	272.19	350.24	15.14	15.92

M_3	376.87	223.64	102.51	159.68	371.69	194.78	17.64	14.40
SEm	0.074	0.995	1.876	0.305	0.515	0.257	0.074	0.196
CD (0.05)	0.243	3.245	6.117	0.995	1.680	0.838	0.239	0.639
Sub plot (F)								
F_1	386.82	238.44	105.35	137.95	337.05	290.21	12.58	10.91
F_2	335.10	218.18	92.34	161.66	388.53	282.94	17.48	15.90
F_3	422.60	201.30	101.52	125.47	255.87	322.96	23.64	15.91
F_4	359.85	251.43	91.54	164.36	258.40	294.25	20.42	15.64
F_5	378.25	204.39	66.03	107.59	284.80	310.94	12.88	14.37
SEm	0.351	1.310	2.729	0.709	0.534	0.350	0.221	0.272
CD (0.05)	0.997	3.724	7.761	2.017	1.517	0.994	0.629	0.772
m x f								
m_1f_1	485.50	265.22	69.77	97.17	268.34	393.69	17.01	14.16
m_1f_2	387.09	202.94	60.30	121.44	300.88	323.46	16.90	12.03
m_1f_3	447.03	195.93	119.86	124.03	260.10	362.35	22.04	11.22
m_1f_4	340.43	255.96	97.94	148.15	284.98	354.61	22.02	15.83
m_1f_5	307.50	205.63	81.44	97.59	240.25	344.67	19.11	13.32
m_2f_1	360.70	196.22	104.82	138.37	208.74	361.79	7.70	9.19
m_2f_2	299.44	252.67	113.64	203.10	340.10	291.30	16.71	25.00
m_2f_3	358.62	234.60	108.42	150.22	298.36	394.24	22.13	18.43
m_2f_4	322.70	227.58	52.71	142.33	283.80	350.89	20.65	11.91
m_2f_5	454.48	186.22	48.89	70.27	229.95	352.97	8.52	15.07
m_3f_1	314.27	253.87	141.45	178.30	534.06	115.14	13.04	9.37
m_3f_2	318.76	198.91	103.09	160.42	524.62	234.05	18.83	10.66
m_3f_3	462.16	173.38	76.28	102.16	209.13	212.29	26.73	18.09
m_3f_4	416.41	270.74	123.98	202.59	206.42	177.25	18.60	19.18
m_3f_5	372.75	221.31	67.76	154.91	384.20	235.18	11.02	14.73
SEm	0.607	2.268	4.727	1.228	0.924	0.606	0.383	0.470
CD (0.05)	1.726	6.451	13.443	3.493	2.628	1.722	1.089	1.337

4.2. RESIDUAL EFFECT OF TREATMENTS OF RICE ON SUCCEEDING CROP OF CASSAVA [2013-14 (FIRST YEAR) AND 2014-15 (SECOND YEAR)]

4.2.1. Growth Attributes

4.2.1.1. Plant Height

Data presented in Table 19 represents the residual effect of various treatments of rice on plant height of cassava at 3 and 6 months after planting (MAP) during 2013-

14 and 2014-15. The results on residual effect of different methods of planting and weed management revealed that the highest plant height was produced in M_1 at 3 MAP in both the years. At 6 MAP (2013-14), the residual effect of M_2 resulted in the highest plant height of 198.51 cm and during the second year, the highest plant height was registered in M_1 (133.71 cm), which was significantly superior to all the other treatments.

Comparing the methods of fertilizer application at 3 MAP, the residual effect of F1 produced taller plants of 80.28 cm and 77.03 cm in the first and second years respectively, which was on par with F_3 and F_4 during the first year. At 6 MAP, the highest plant height was produced in F_5 in 2013-14, while during 2014-15, F_2 was significantly different from all the other methods of fertilizer application.

Among the interactions, m_1f_1 produced the highest plant height at 3 MAP in both the years. During 2013-14 at 6 MAP, the highest plant height was produced in m_2f_5 and in the second year, m_1f_1 produced significantly the highest plant height of 140.75 cm, which was on par with m_3f_2.

Table 19. Residual effect of treatments of rice on plant height (cm) of cassava

Treatments	3 MAP		6 MAP	
	2013-14	2014-15	2013-14	2014-15
Main plot (M)				
M_1	81.38	73.39	169.49	133.71
M_2	75.86	70.92	198.51	125.68
M_3	78.13	70.04	176.21	126.78
SEm	0.447	0.247	0.663	0.767
CD (0.05)	1.458	0.808	2.161	2.499
Sub plot (F)				
F_1	80.28	77.03	181.06	126.18

F_2	78.16	67.98	178.33	133.62
F_3	78.73	68.21	177.19	129.21
F_4	79.92	69.41	178.46	127.24
F_5	75.18	74.61	191.98	127.38
SEm	0.650	0.595	2.343	0.433
CD (0.05)	1.89	1.692	6.662	1.231
m x f				
m_1f_1	86.96	87.81	163.50	140.75
m_1f_2	81.74	64.38	164.56	128.59
m_1f_3	80.22	69.69	184.38	136.31
m_1f_4	80.74	65.84	184.06	130.97
m_1f_5	77.22	79.22	150.94	131.94
m_2f_1	77.82	73.94	201.25	130.75
m_2f_2	78.33	71.75	212.56	131.63
m_2f_3	72.78	65.56	167.81	121.00
m_2f_4	77.01	67.72	185.63	117.19
m_2f_5	73.37	75.63	225.31	127.81
m_3f_1	76.06	69.34	178.44	107.03
m_3f_2	74.42	67.81	157.88	140.63
m_3f_3	83.19	69.38	179.38	130.31
m_3f_4	82.02	74.66	165.69	133.56
m_3f_5	74.94	69.00	199.69	122.38
SEm	1.126	1.030	4.057	0.750
CD (0.05)	3.202	2.930	11.539	2.131

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

The data on number of functional leaves plant^{-1} of cassava influenced by the residual effect of treatments of rice is presented in Table 20. Comparing the methods of planting and weed management, number of functional leaves plant^{-1} showed significant difference only at 6 MAP and were not significant at 3 MAP in both the years. At 6 MAP, the residual effect of M_3 produced 207.92 leaves plant^{-1} in the first year and M_1 produced 116.99 functional leaves plant^{-1} in the second year, which were the highest.

At 3 MAP, the highest number of functional leaves plant^{-1} was registered in F_3, which was on par with F_1 and was significantly superior to all the other fertilizer application methods in the first year. In the second year, the residual effect of F_1 was significantly superior to all the other treatments. The residual effect of F_4 and F_1 resulted in the highest number of functional leaves plant^{-1} of 214.24 and 121.44 in the first and second years respectively at 6 MAP.

Among the treatment combinations, at 3 MAP the highest number of functional leaves plant^{-1} of cassava was registered in m_1f_2 during 2013-14. During 2014-15, at 3 MAP, m_2f_1 and m_3f_1 produced significantly the higher number of functional leaves plant^{-1}. At 6 MAP, the residual effect of m_3f_1 was found significantly superior to all the other treatments in the first year and the second year, m_1f_1 produced the highest no of functional leaves plant^{-1}.

4.2.1.3. Number of Branches Plant^{-1}

The residual effect of treatments of rice on the number of primary and secondary branches plant^{-1} at 3 and 6 MAP is presented in Table 21. At 3 MAP secondary branches were not developed. The methods of planting and weed

Table 20. Residual effect of treatments of rice on number of functional leaves plant^{-1} of cassava

Treatments	3 MAP		6 MAP	
	2013-14	2014-15	2013-14	2014-15
Main plot (M)				
M_1	74.25	35.04	190.60	116.99
M_2	71.31	35.28	181.71	100.39
M_3	71.97	35.44	207.92	107.54
SEm	0.764	0.530	1.316	0.397
CD (0.05)	NS	NS	4.292	1.295
Sub plot (F)				
F_1	76.56	42.63	202.84	121.44
F_2	73.67	33.20	210.52	113.17
F_3	77.85	36.57	170.33	113.89
F_4	69.50	32.13	214.24	103.04
F_5	64.99	31.75	169.13	90.00
SEm	0.934	0.598	1.968	1.056
CD (0.05)	2.656	1.701	5.597	3.005
m x f				
m_1f_1	73.27	40.31	169.94	156.94
m_1f_2	93.91	29.81	190.94	102.81
m_1f_3	70.39	37.19	195.47	125.19
m_1f_4	71.67	32.84	231.00	96.56
m_1f_5	62.03	35.06	165.66	103.44
m_2f_1	81.04	44.94	166.06	113.88
m_2f_2	58.67	33.69	225.31	116.50
m_2f_3	79.85	36.06	143.44	95.69
m_2f_4	67.92	31.88	224.53	96.50
m_2f_5	69.07	29.81	149.22	79.38
m_3f_1	75.38	42.63	272.50	93.50
m_3f_2	68.42	36.09	215.31	120.19
m_3f_3	83.30	36.47	172.08	120.78
m_3f_4	68.91	31.66	187.19	116.06
m_3f_5	63.87	30.38	192.50	87.19
SEm	1.617	1.036	3.408	1.830
CD (0.05)	4.600	2.946	9.694	5.204

management measures showed the significant effect on number of branches plant^{-1} in both the years. At 3 MAP, residual effect of M_1 resulted in the highest primary branches of 3.00 and 2.51 plant^{-1} in the first and second years respectively and it was on par with M_2 (2013-14). At 6 MAP, M_3 and M_1 resulted in significantly the highest number of primary branches plant^{-1} during 2013-14 and 2014-15 respectively, which was superior to all the other main plot treatments. The number of secondary branches plant^{-1} was the highest in M_2 (7.07) in the first year and M_1 (5.91) in the second year.

Comparing the fertilizer application methods, the number of primary branches plant^{-1} did not show any significant variation in the first year at 3 MAP. During 2014-15, the residual effect of F_3 produced the highest number of primary branches plant^{-1} which was significantly different from all the other treatments except, F_1 at 3MAP. At 6 MAP, the significantly highest number of primary branches plant^{-1} was registered in F_1 and F_3 in the first and second years respectively. The residual effect of treatments was significantly superior to all others except F_2 (2014-15). At 6 MAP during 2013-14, the number of secondary branches plant^{-1} was not significant. In the second year, F_1 resulted in the highest number of secondary branches plant^{-1} of 6.09, which was on par with F_2.

Among the treatment combinations, the higher number of primary branches plant^{-1} was produced in m_1f_1 during 2013-14 and m_1f_1 and m_1f_3 during 2014-15 at 3 MAP. The interactions were on par with all other combination, except m_2f_5, m_3f_1, m_3f_2, m_3f_4 and m_3f_5 in the first year and m_1f_2, m_2f_4, m_2f_5, m_3f_1, m_3f_4 and m_3f_5 in the second year. At 6 MAP, the residual effect of m_3f_1 and m_1f_3 produced the higher number of primary branches plant^{-1} which was significantly superior to all the other interactions during the first and second years respectively. The results on number of secondary branches plant^{-1} revealed that m_2f_5 (2013-14) and m_1f_1 (2014-15) registered the higher values which was on par with m_3f_1 (2013-14) and m_1f_2 (2104-15).

Table 21. Residual effect of treatments of rice on number of branches plant^{-1} of cassava

Treatments	3 MAP		6 MAP			
	Primary branches		Primary branches		Secondary branches	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Main plot (M)						
M_1	3.00	2.51	3.00	3.05	5.96	5.91
M_2	2.98	2.06	3.00	2.66	7.07	4.36
M_3	2.83	2.26	3.05	2.68	6.73	5.14
SEm	0.027	0.010	0.010	0.076	0.045	0.054
CD (0.05)	0.088	0.032	0.032	0.247	0.145	0.176
Sub plot (F)						
F_1	2.94	2.59	3.18	2.74	6.78	6.09
F_2	2.94	2.11	3.00	2.91	6.44	5.92
F_3	3.02	2.69	2.91	2.92	6.58	4.70
F_4	2.95	1.97	3.00	2.74	6.43	4.40
F_5	2.90	2.02	3.00	2.66	6.70	4.57
SEm	0.036	0.120	0.030	0.037	0.098	0.097
CD (0.05)	NS	0.3414	0.087	0.104	NS	0.275
m x f						
m_1f_1	3.15	3.00	3.00	3.00	5.47	6.97
m_1f_2	3.00	1.07	3.00	3.00	5.53	6.77
m_1f_3	3.00	3.00	3.00	3.23	6.27	5.80
m_1f_4	3.00	2.73	3.00	3.00	6.77	3.53
m_1f_5	3.06	2.73	3.00	3.00	5.77	6.47
m_2f_1	3.00	2.50	3.00	2.50	7.27	5.77
m_2f_2	3.00	2.77	3.00	3.00	6.53	5.27
m_2f_3	3.06	2.53	3.00	2.53	7.00	3.03
m_2f_4	3.00	1.17	3.00	2.77	6.53	4.97
m_2f_5	2.85	1.33	3.00	2.50	8.03	2.77
m_3f_1	2.67	2.27	3.53	2.73	7.60	5.53
m_3f_2	2.82	2.50	3.00	2.73	7.27	5.73
m_3f_3	3.00	2.53	3.00	3.00	6.47	5.27
m_3f_4	2.85	2.00	3.00	2.47	6.00	4.70
m_3f_5	2.79	2.00	3.00	2.47	6.30	4.47
SEm	0.062	0.208	0.053	0.063	0.170	0.163
CD (0.05)	0.177	0.591	0.151	0.180	0.485	0.475

4.2.1.4. Leaf Area Index

The residual effect of treatments of rice on leaf area index of cassava showed significant variation among treatments in both the years (Table 22). The residual effect of M_1 produced the higher LAI of 0.32 and 0.10 at 3 MAP during the first and second years respectively which was on par with M_3 (2013-14). During 2013-14 at 6 MAP, the highest LAI was registered in M_3 and was significantly superior from the other two methods of planting and weed management. In the second year, the residual effect of M_1 resulted in the highest LAI of 0.36 and the minimum value was recorded in M_2.

Among the fertilizer application methods, the residual effect of F_1 and F_3 recorded significantly superior values of LAI compared to all the other treatments at 3 MAP in both the years. At 6 MAP during 2013-14, the highest LAI of 0.84 was registered in F_5, which was on par with F_2 and during 2014-15, F_2 and F_3 produced higher values, which was significantly different from all other treatments.

The higher LAI was produced in the treatment combinations of m_1f_2 and m_1f_3, at 3 MAP in the first and second years respectively, which was significantly superior to all the other combinations, except m_2f_1 during 2014-15. Significant results were recorded at 6 MAP in m_3f_1 during the first year and m_1f_1 in 2014-15. The first year interaction was on par with m_1f_3 and m_3f_5.

4.2.1.5. Dry Matter Production

Data furnished in Table 22 indicated that the significant variation among treatments in the dry matter production of cassava. During 2013-14, the methods of planting and weed control measures were found significant in which the highest dry matter production was produced in M_1 (16.39 t ha^{-1}) and in the second year, the dry matter production was found not significant.

Table 22. Residual effect of treatments of rice on leaf area index and dry matter production (t ha^{-1}) of cassava

Treatments	Leaf area index				Dry matter production (t ha^{-1})	
	3 MAP		6 MAP			
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Main plot (M)						
M_1	0.32	0.10	0.78	0.36	16.39	8.70
M_2	0.30	0.09	0.76	0.32	13.73	8.75
M_3	0.31	0.09	0.83	0.33	15.16	8.77
SEm	0.003	0.001	0.006	0.004	0.049	0.143
CD (0.05)	0.010	0.003	0.020	0.011	0.159	NS
Sub plot (F)						
F_1	0.34	0.11	0.79	0.35	17.14	10.69
F_2	0.32	0.09	0.80	0.39	16.82	8.93
F_3	0.34	0.11	0.76	0.38	14.19	7.54
F_4	0.28	0.07	0.76	0.31	13.67	8.09
F_5	0.28	0.09	0.84	0.26	13.65	8.44
SEm	0.005	0.003	0.016	0.004	0.215	0.153
CD (0.05)	0.015	0.007	0.044	0.012	0.612	0.434
m x f						
m_1f_1	0.30	0.10	0.64	0.48	21.28	9.89
m_1f_2	0.46	0.09	0.78	0.37	20.21	8.49
m_1f_3	0.31	0.13	1.01	0.39	12.55	7.57
m_1f_4	0.30	0.08	0.88	0.29	14.05	9.04
m_1f_5	0.24	0.10	0.60	0.28	13.87	8.50
m_2f_1	0.39	0.12	0.65	0.32	13.53	10.49
m_2f_2	0.24	0.09	0.90	0.37	13.39	11.11
m_2f_3	0.32	0.09	0.50	0.33	14.92	6.91
m_2f_4	0.25	0.08	0.81	0.33	14.28	6.58
m_2f_5	0.31	0.08	0.92	0.24	12.55	8.65
m_3f_1	0.35	0.10	1.06	0.25	16.61	11.70
m_3f_2	0.26	0.10	0.72	0.44	16.86	7.18
m_3f_3	0.38	0.10	0.77	0.41	15.12	8.13
m_3f_4	0.29	0.07	0.59	0.32	12.68	8.68
m_3f_5	0.29	0.09	1.00	0.25	14.54	8.18
SEm	0.009	0.004	0.026	0.007	0.373	0.264
CD (0.05)	0.026	0.013	0.076	0.021	1.060	0.751

Comparing the fertilizer application methods, the residual effect of F_1 produced the significantly higher dry matter production of 17.14 t ha^{-1} and 10.69 t ha^{-1} during 2013-14 and 2014-15 respectively, except F_2 which was on par in the first year.

The results of treatment combinations revealed that the residual effect of m_1f_1 resulted in the highest dry matter production which was significantly superior to all the other treatments during 2013-14. During the second year, the highest dry matter of 11.70 t ha^{-1} was produced in m_3f_1 and was significantly different from all other combinations except m_2f_2 which was on par. The lowest dry matter was recorded in m_2f_4.

4.2.2. Yield and Yield Attributes

4.2.2.1. Number of Tubers Plant^{-1}

Data on number of tubers $plant^{-1}$ recorded during 2013-14 and 2014-15 are presented in Table 23 and was influenced by the residual effect of treatments of rice. During the first year, the residual effect of M_1 resulted in the highest number of tubers $plant^{-1}$ (7.62) and in the second year, M_3 produced the highest value and was on par with M_2.

Among the methods of fertilizer application, the residual effect of F_4 produced the highest number of tubers $plant^{-1}$ (7.82), which was on par with F_1 and F_2 in the first year. The higher number of tubers $plant^{-1}$ of 7.08 and 7.00 were recorded in F_1 and F_2 respectively which was significantly superior to all the other treatments in the second year.

Comparing the treatment combinations during 2013-14, the residual effect of m_1f_2 resulted in the highest number of tubers $plant^{-1}$. The highest number of tubers $plant^{-1}$ (8.06) was registered in m_3f_1 (2014-15), which was significantly superior to all the other treatments. The lowest number of tubers plant^{-1} was produced in m_2f_3 and m_1f_4 in the first and second years respectively.

4.2.2.2. Tuber Weight Plant^{-1}

The data in Table 23 showed significant variation due to treatments on tuber weight plant^{-1}. The residual effect of M_2 resulted in the highest tuber weight plant^{-1} in both the years which was significantly superior to all other methods of planting and weed management. The lowest value was observed in M_1 in both the years.

The residual effect of F_3 resulted in the highest tuber weight of 3.69 kg plant^{-1} in the first year. In the second year, F_2 produced the highest tuber weight of 2.69 kg plant^{-1} which was significantly superior to all other fertilizer application methods.

Significantly highest tuber weight of 4.33 kg plant^{-1} was produced in m_2f_2 and the least value was produced in m_1f_1 during 2013-14. During the second year, the highest tuber weight plant^{-1} was registered in m_3f_1 and m_2f_5, which were on par and significantly superior to all other combinations.

4.2.2.3. Marketable Tuber Yield

The two year experiment results showed that marketable tuber yield of cassava was influenced by the residual effect of treatments of rice (Table 24). Among the methods of planting and weed control measures, the highest marketable tuber yield of 25.38 t ha^{-1} was registered in M_3 which was significantly different from the other two treatments during 2013-14. The marketable tuber yield was not influenced by the treatments in the second year.

Table 23. Residual effect of treatments of rice on number of tubers plant^{-1} and tuber weight plant^{-1} of cassava

Treatments	Number of tubers plant^{-1}		Tuber weight (kg plant^{-1})	
	2013-14	2014-15	2013-14	2014-15
Main plot (M)				
M_1	7.62	6.09	3.07	2.38
M_2	6.81	6.68	3.42	2.53
M_3	7.35	6.87	3.30	2.41
SEm	0.054	0.070	0.019	0.022
CD (0.05)	0.175	0.227	0.062	0.071
Sub plot (F)				
F_1	7.58	7.08	2.91	2.54
F_2	7.69	7.00	3.41	2.69
F_3	6.89	6.73	3.69	2.21
F_4	7.82	5.69	3.39	2.22
F_5	6.33	6.23	2.93	2.54
SEm	0.107	0.066	0.061	0.038
CD (0.05)	0.303	0.187	0.173	0.109
m x f				
m_1f_1	7.00	6.28	2.43	2.00
m_1f_2	9.11	6.72	3.13	2.64
m_1f_3	8.17	7.19	3.57	2.64
m_1f_4	7.63	4.44	3.47	2.36
m_1f_5	6.21	5.84	2.77	2.28
m_2f_1	7.42	6.91	2.70	2.47
m_2f_2	6.88	7.56	4.33	2.78
m_2f_3	6.14	6.28	3.92	2.14
m_2f_4	7.38	6.06	3.08	2.17
m_2f_5	6.22	6.56	3.08	3.06
m_3f_1	8.32	8.06	3.61	3.14
m_3f_2	7.08	6.72	2.75	2.64
m_3f_3	6.35	6.72	3.58	1.86
m_3f_4	8.44	6.56	3.61	2.14
m_3f_5	6.57	6.28	2.94	2.28
SEm	0.185	0.114	0.105	0.066
CD (0.05)	0.525	0.323	0.300	0.189

Among the fertilizer application methods, the residual effect of F_2 recorded the highest marketable tuber yield in the first year which was on par with F_1 and in the second year F_1 proved superior. The lowest marketable tuber yield was recorded in F_5 in the first year and F_3 in the second year.

Comparing the interaction, the residual effect of m_3f_1 resulted in significantly the highest marketable tuber yield of 29 t ha^{-1} which was on par with m_1f_1 (2013-14). In the second year, m_3f_1 and m_3f_4 resulted in the higher marketable tuber yield of 16.54 t ha^{-1} and 15.81 t ha^{-1} respectively.

4.2.2.4. Total Tuber Yield

The residual effect of methods of planting and weed management treatments of rice on total tuber yield of cassava showed significant variation among treatments in the first year and during the second year the treatments were found not significant (Table 24). The highest total tuber yield of 30.86 t ha^{-1} was registered in M_3 and the lowest yield was produced in M_2 in the first year.

Among the fertilizer application methods, the residual effects of F_1 and F_2 were on par but superior in 2013-14 compared to other treatments. During 2014-15, the highest total tuber yield of 18.63 t ha^{-1} was registered in F_1 and was significantly superior to other treatments except F_4 which was on a par.

The result on treatment combinations showed that, the residual effect of m_3f_1 produced the highest total tuber yield of 36.69 t ha^{-1} (2013-14) and 20.27 t ha^{-1} (2014-15). These interactions were significantly superior to all the other combinations, except m_1f_1 in the first year and m_3f_4 in the second year, which were on par.

4.2.2.5. Top Yield

Among the methods of planting and weed management, the residual effect of treatments had significant influence on top yield during the first year and was not significant during 2014-15 (Table 24). In the first year, M_3 recorded the highest top yield of 15.28 t ha^{-1} which was significantly superior to the other treatments.

Comparing the fertilizer application treatments, in the first year the highest top yield was registered in F_4 (15.60 t ha^{-1}) which was on a par with F_3. In the second year, the value was highest in F_1 (12.78 t ha^{-1}), which was on par with F_2. The least values were recorded in F_2 and F_3 for the first and second years respectively.

The treatment combination results indicated that the residual effect of m_3f_3 produced the highest top yield of 21.09 t ha^{-1} during 2013-14. During 2014-15, the highest top yield of 13.38 t ha^{-1} was recorded in m_2f_1, which was significantly superior to all the other treatments except m_2f_2, m_2f_5, m_3f_1 and m_3f_4 which were on par.

4.2.2.6. Utilization Index (UI)

The effect of treatments on utilization index is given in Table 24. The residual effect of methods of planting and weed management showed that M_1 resulted in the highest UI of 2.23 in the first year and it was on par with M_2. In the second year the treatments were found not significant.

The highest UI was registered in F_2 (first year) which was significantly superior to the other methods of fertilizer application except F_1 which was on par. During the second year, the treatments were observed not significant.

Table 24. Residual effect of treatments of rice on marketable tuber yield, total tuber yield, top yield, and utilization index of cassava

Treatments	Marketable tuber yield (t ha^{-1})		Total tuber yield (t ha^{-1})		Top yield (t ha^{-1})		Utilization index	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Main plot (M)								
M_1	23.68	14.15	30.31	17.49	14.09	11.50	2.23	1.53
M_2	23.65	13.09	29.10	16.43	13.28	12.06	2.22	1.41
M_3	25.38	13.83	30.86	17.10	15.28	12.02	2.11	1.47
SEm	0.203	0.318	0.073	0.292	0.103	0.233	0.027	0.035
CD (0.05)	0.661	NS	0.237	NS	0.336	NS	0.088	NS
Sub plot (F)								
F_1	25.96	15.00	31.90	18.63	13.59	12.78	2.38	1.47
F_2	26.18	13.84	31.68	16.90	13.13	12.15	2.43	1.49
F_3	22.76	12.52	27.82	15.63	15.50	11.30	1.97	1.44
F_4	24.84	14.05	29.88	17.78	15.60	11.67	1.97	1.49
F_5	21.43	13.04	29.18	16.10	13.26	11.33	2.19	1.47
SEm	0.453	0.216	0.617	0.245	0.198	0.290	0.047	0.043
CD (0.05)	1.289	0.614	1.756	0.696	0.563	0.889	0.132	NS
m x f								
m_1f_1	27.44	14.54	33.67	18.23	14.48	11.60	2.53	1.56
m_1f_2	25.13	15.02	31.38	18.91	13.80	11.81	2.27	1.61
m_1f_3	21.23	14.14	26.48	17.85	9.85	11.33	2.68	1.60
m_1f_4	23.43	12.78	28.39	15.35	19.06	11.27	1.49	1.37
m_1f_5	19.60	14.28	28.13	17.13	13.26	11.28	2.10	1.54
m_2f_1	22.85	13.93	28.13	17.39	10.94	13.38	2.55	1.34
m_2f_2	25.98	15.06	30.00	18.69	13.70	13.05	2.20	1.44
m_2f_3	24.72	12.05	29.27	15.13	15.55	10.81	1.89	1.43
m_2f_4	24.63	13.54	30.31	16.44	12.97	10.63	2.33	1.56
m_2f_5	20.07	10.84	27.81	14.48	13.23	12.45	2.12	1.29
m_3f_1	29.00	16.54	36.69	20.27	15.36	13.36	2.83	1.52
m_3f_2	26.04	11.44	30.39	15.74	11.90	11.60	1.98	1.41
m_3f_3	22.33	11.37	27.71	13.92	21.09	11.77	1.33	1.31
m_3f_4	26.45	15.81	30.94	19.06	14.76	13.12	2.10	1.45
m_3f_5	24.62	13.99	31.61	16.69	13.29	11.00	2.33	1.57
SEm	0.785	0.374	1.069	0.424	0.342	0.502	0.081	0.074
CD (0.05)	2.233	1.064	3.042	1.205	0.974	1.428	0.229	0.213

Among the treatment combinations, the residual effect of m_3f_1 produced significantly the highest UI in the first year (2.83) and m_1f_2 in the second year (1.61).

During 2013-14, the interaction was on par with m_1f_3. In the second year, the interaction was on par with all the other treatment combinations except m_1f_4, m_2f_1, m_2f_5, m_3f_2 and m_3f_3.

4.2.3. Uptake of Major Nutrients

4.2.3.1. Nitrogen Uptake

Nitrogen uptake data furnished in Table 25 revealed that the residual effect of treatments were significant in both the years. The different methods of planting and weed control measures showed that, the residual effect of M_3 recorded the highest nitrogen uptake during 2013-14 and during 2014-15, the highest uptake of 126.13 kg ha^{-1} was recorded in M_1.

Comparing the methods of fertilizer application during 2013-14 and 2014-15, the residual effect of F_1 resulted in the higher N uptake of 235.04 kg ha^{-1} and 155.93 kg ha^{-1} respectively which was significantly superior to all the other fertilizer application methods and was on par with F_2 (2013-14).

The residual effect of different treatment combinations showed significant variation in nitrogen uptake in both the years. In the first year, m_3f_1 resulted in the highest nitrogen uptake of 271.13 kg ha^{-1} and was found superior to all the other treatment combinations except m_1f_1 and m_3f_2. The residual effect of m_2f_1 resulted in the highest nitrogen uptake during 2014-15 and the lowest uptake was recorded in m_2f_4.

4.2.3.2. Phosphorous Uptake

It is evident from the data in Table 25 that the residual effect of treatments had significant effect on phosphorous uptake. The residual effect of M_3 recorded the highest P uptake during both the years, which was on par with the other methods of planting and weed management practices, except M_2 (2013-14) and M_1 (2014-15).

Among the fertilizer application methods, the highest uptake was registered by F_1 (95.43 and 53.29 kg ha^{-1}) during the first and second years respectively. The residual effect of treatments showed significant difference for all the treatments and the lowest uptake was recorded in F_5 (2013-14) and F_3 (2014-15).

The different treatment combinations showed significant variation in P uptake during both the years. In the first year, the residual effect of m_1f_1 resulted in the highest phosphorous uptake of 114.09 kg ha^{-1} which was superior to all the other treatment combinations except m_3f_1. The combination m_3f_1 resulted in the highest phosphorous uptake of 65.44 kg ha^{-1} in the second year.

4.2.3.3. Potassium Uptake

The treatments significantly influenced the potassium uptake and the results are presented in Table 25. Among the methods of planting and weed control measures, the highest potassium uptake was recorded in M_3 in the first year and M_2 in the second year which was significantly superior to the other main plot treatments.

During both the years, among the fertilizer application methods, the highest potassium uptake was registered in F_1 (217.03 and 213.80 kg ha^{-1} respectively) and was significantly superior to all the other application methods, except F_3 and F_4 which were on par with F_1 (2013-14).

Comparing the interactions, the residual effect of treatments observed significant variation in the uptake of potassium. The residual effect of m_2f_3 was significantly superior to all the other combinations with a potassium uptake of 274.38 kg ha^{-1} in the first year except m_1f_1 which was on par with m_2f_3. In the second year, m_2f_5 resulted in significantly the highest potassium uptake and was on par with m_2f_1.

4.2.4. Chemical Properties of Soil

4.2.4.1. pH

Data presented in Table 26 shows the residual effect of treatments on pH of the soil. In the first year, the main plot treatments did not impart any change in soil pH. In the second year, M_3 resulted in the highest pH of 5.99 and the lowest pH was recorded in M_2 which was significantly superior to all the other methods of planting and weed management measures.

Among the fertilizer application methods, the highest pH was registered in F_5 (2013-14) which was on par with the other treatments except F_2. In second year, the highest pH was observed in F_3 (6.35), which was superior to all the other fertilizer application methods.

The interaction results revealed that the residual effect of m_3f_5 recorded significantly the highest pH of 5.29 during the first year and was on par with the others except m_1f_3, m_1f_4, m_2f_2, m_3f_1 and m_3f_2. During 2014-15, the highest pH was recorded in m_2f_3 and the lowest was observed in m_2f_2 which was significantly different from all the other treatment combinations.

Table 25. Residual effect of treatments of rice on the uptake of major nutrients in cassava

Treatments	Nitrogen ($kg\ ha^{-1}$)		Phosphorous ($kg\ ha^{-1}$)		Potassium ($kg\ ha^{-1}$)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Main plot (M)						
M_1	209.70	126.13	80.49	42.15	204.17	169.09
M_2	185.37	116.14	66.26	45.14	179.17	193.96
M_3	227.59	118.07	80.87	47.87	217.86	165.26
SEm	1.336	2.243	0.351	0.856	1.767	2.599
CD (0.05)	4.357	7.315	1.145	2.791	5.762	8.477
Sub plot (F)						
F_1	235.04	155.93	95.43	53.29	217.03	213.80
F_2	226.27	113.79	81.65	46.36	196.57	168.06
F_3	208.10	109.11	67.56	39.95	216.47	146.94
F_4	212.27	106.60	70.24	41.81	205.92	170.34
F_5	156.10	115.14	64.49	43.86	166.01	181.36
SEm	3.548	2.213	1.549	0.897	4.394	3.738
CD (0.05)	10.089	6.292	4.405	2.549	12.497	10.629
m x f						
m_1f_1	263.32	153.58	114.09	37.32	265.07	211.96
m_1f_2	241.49	114.69	95.18	39.93	217.30	146.87
m_1f_3	124.25	112.89	47.34	39.77	131.71	141.87
m_1f_4	232.18	120.74	76.90	48.70	249.12	175.47
m_1f_5	187.27	128.74	68.95	45.05	157.65	169.26
m_2f_1	149.45	167.12	60.73	57.11	141.75	224.03
m_2f_2	192.48	129.46	67.10	59.62	144.02	199.12
m_2f_3	249.98	94.47	77.87	41.68	274.38	138.86
m_2f_4	190.56	87.26	71.83	24.57	183.18	174.41
m_2f_5	144.38	102.41	53.76	42.73	152.51	233.36
m_3f_1	271.13	147.08	111.47	65.44	244.28	205.42
m_3f_2	266.05	97.23	82.67	39.55	228.38	158.18
m_3f_3	250.07	119.98	77.47	38.40	243.33	160.09
m_3f_4	214.06	111.80	61.99	52.15	185.45	161.15
m_3f_5	136.64	114.26	70.75	43.81	187.87	141.47
SEm	6.144	3.832	2.683	1.553	7.611	6.474
CD (0.05)	17.474	10.898	7.629	4.415	21.646	18.411

4.2.4.2. EC

The highest EC was observed in M_2 in the first and second years with the values of 0.35 and 0.49 dS m^{-1} respectively (Table 26) in which M_2 and M_3 had similar values in 2013-14.

Comparing the fertilizer application methods, the residual effect of F_1 recorded significantly the highest EC and the lowest EC was recorded in F_4 in the first year. During 2014-15, the treatment which showed the highest EC value was recorded in F_3 (0.43 dS m^{-1}) followed by F_2, F_1, F_4 and F_5.

Among the treatment combinations, the highest EC was noticed in m_1f_1 in the first year, which was significantly superior to all the other combinations except m_2f_5, m_3f_2 and m_3f_3. During 2014-15, m_2f_1 resulted in the highest EC of 0.64 dS m^{-1}.

4.2.4.3. Organic Carbon

Data presented in Table 26 indicates the residual effect of various treatments on organic carbon content of soil during 2013-14 and 2014-15. Among the methods of planting and weed management measures, the residual effect of M_2 resulted in the highest organic carbon content of 1.34 per cent (2013-14) which was significantly superior to M_1 (1.24 per cent) and M_3 (1.31 per cent). The treatment, M_1 was significantly superior to M_2 and M_3 in the second year. The fertilizer application treatment F_3 recorded significantly the highest organic carbon content of 1.50 per cent and 1.72 per cent in the soil in the first and second years respectively.

Comparing the interactions, the significantly highest organic carbon content was recorded in m_2f_4 during 2013-14, which was on par with m_1f_3. In the second year, the residual effect of m_3f_3 resulted in the highest organic carbon content and was significantly superior to all other combinations.

Table 26. Residual effect of treatments of rice on pH, EC and organic carbon content in soil

Treatments	pH		EC (dS m^{-1})		Organic carbon (%)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Main plot (M)						
M_1	5.18	5.92	0.34	0.31	1.24	1.56
M_2	5.19	5.89	0.35	0.49	1.34	1.49
M_3	5.21	5.99	0.35	0.33	1.31	1.47
SEm	0.017	0.004	0.001	0.001	0.004	0.008
CD (0.05)	NS	0.013	0.003	0.004	0.014	0.026
Sub plot (F)						
F_1	5.20	6.31	0.36	0.36	1.30	1.61
F_2	5.14	5.65	0.34	0.38	1.17	1.51
F_3	5.21	6.35	0.35	0.43	1.50	1.72
F_4	5.18	5.85	0.33	0.36	1.40	1.30
F_5	5.24	5.52	0.35	0.34	1.11	1.38
SEm	0.023	0.006	0.002	0.001	0.009	0.006
CD (0.05)	0.067	0.019	0.006	0.003	0.026	0.018
m x f						
m_1f_1	5.25	6.30	0.39	0.22	1.35	0.93
m_1f_2	5.21	5.72	0.34	0.44	1.15	1.82
m_1f_3	5.15	6.30	0.33	0.20	1.57	1.99
m_1f_4	5.11	5.58	0.32	0.24	1.15	0.98
m_1f_5	5.19	5.72	0.33	0.44	0.98	2.07
m_2f_1	5.21	6.39	0.37	0.64	1.30	1.95
m_2f_2	5.06	5.15	0.31	0.42	1.20	1.76
m_2f_3	5.24	6.54	0.33	0.58	1.46	0.91
m_2f_4	5.19	6.21	0.35	0.42	1.67	2.02
m_2f_5	5.24	5.19	0.38	0.39	1.07	0.81
m_3f_1	5.14	6.24	0.32	0.22	1.26	1.95
m_3f_2	5.15	6.07	0.38	0.29	1.16	0.94
m_3f_3	5.25	6.22	0.38	0.51	1.46	2.27
m_3f_4	5.25	5.77	0.32	0.42	1.39	0.91
m_3f_5	5.29	5.65	0.34	0.19	1.29	1.25
SEm	0.041	0.011	0.004	0.002	0.016	0.011
CD (0.05)	0.116	0.032	0.011	0.005	0.045	0.031

4.2.5. Available Nutrient Content in Soil

4.2.5.1. Available Nitrogen

The data on available nitrogen content of soil are furnished in Table 27. The treatments significantly influenced the available N content of soil during 2013-14 and 2014-15. Comparing the methods of planting and weed control measures, the highest available nitrogen content of 379.73 kg ha^{-1} was produced in M_3 in the first year. In the second year, the residual effect of treatment M_1 was found significantly superior to the other two methods of planting and weed management practices.

Among the fertilizer application methods during 2013-14, the highest available nitrogen was registered in F_2, which was superior to all the other treatments. During the second year, the treatment F_3 resulted in the significantly highest available nitrogen content of 385.83 kg ha^{-1} which was significantly different from all the other fertilizer application methods.

During the first year, the residual effect of treatment combination of m_3f_2, was significantly superior to all the other combinations. The lowest content was observed in the combination of m_1f_1 (240.44 kg ha^{-1}). The combination of m_3f_3 resulted in significantly the highest available nitrogen content of 508.18 kg ha^{-1} in the second year.

4.2.5.2. Available Phosphorous

The data presented in Table 27 clearly indicates the significant influence of treatments on available phosphorous content in soil. The residual effect of treatment M_1 resulted in the highest P content in soil which was significantly superior to the other methods of planting and weed control measures during both the years. It was on par with M_3 (2013-14).

Comparing the fertilizer application methods, the highest P content was registered by F_1 (60.55 kg ha^{-1}) and F_3 (155.81 kg ha^{-1}) during 2013-14 and 2014-15 respectively.

The interactions imparted significant influence of treatments on the available P content. The combinations m_1f_4 and m_3f_1 were on par with each other but with higher available P content during the first year (72.93 and 72.32 kg ha^{-1} respectively). During 2014-15, the highest P content was recorded in m_2f_3, which was superior to all the other combinations.

4.2.5.3. Available Potassium

The residual effect of treatments significantly influenced the available potassium content in soil during both the years (Table 27). In the first year, the residual effect of M_2 resulted in the highest available potassium content of 239.97 kg ha^{-1} which was significantly different from other two methods of planting and weed management measures. The treatment M_1 recorded significantly the highest available K content during the second year.

The significantly highest available K content was observed in F_5 in both the years which were significantly superior to other fertilizer application methods. During 2013-14, F_5 was on par with F_1 with a K content of 245.44 kg ha^{-1} in the soil.

Among the treatment combinations, the residual effect of m_2f_1 and m_2f_5 recorded the highest available K content which was significantly different from all the other combinations (2013-14). During 2014-15, m_2f_4 resulted in significantly the highest potassium content of 421.00 kg ha^{-1}, compared to the other interactions and the lowest content was observed in m_3f_4.

Table 27. Residual effect of treatments of rice on available nitrogen, phosphorous and potassium content in soil

Treatments	Nitrogen (kg ha^{-1})		Phosphorous (kg ha^{-1})		Potassium (kg ha^{-1})	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Main plot (M)						
M_1	302.96	348.84	55.85	145.54	183.31	365.27
M_2	356.89	333.25	52.80	138.81	239.97	354.79
M_3	379.73	328.44	55.72	140.60	227.64	284.78
SEm	0.477	1.763	0.439	0.212	3.207	0.453
CD (0.05)	1.555	5.750	1.431	0.692	10.459	1.479
Sub plot (F)						
F_1	325.57	360.39	60.55	136.08	245.44	344.55
F_2	384.06	337.84	51.21	148.36	189.64	330.33
F_3	292.05	385.83	47.48	155.81	212.82	341.05
F_4	373.01	291.75	58.22	124.72	189.74	307.59
F_5	357.92	308.42	56.49	143.27	247.22	351.22
SEm	0.928	1.393	0.540	0.255	4.567	0.530
CD (0.05)	2.638	3.961	1.535	0.725	12.990	1.507
m x f						
m_1f_1	240.44	207.27	60.16	149.31	219.57	354.40
m_1f_2	262.75	408.28	43.10	167.20	142.30	372.17
m_1f_3	292.90	445.91	38.07	126.63	203.88	396.22
m_1f_4	362.23	219.22	72.93	124.75	159.24	293.61
m_1f_5	356.47	463.53	64.97	159.80	191.57	409.96
m_2f_1	318.40	436.20	49.15	132.90	293.06	372.74
m_2f_2	392.75	393.79	60.57	99.35	214.72	314.55
m_2f_3	326.25	203.39	53.85	210.83	216.39	309.12
m_2f_4	449.40	451.88	54.15	105.84	189.32	421.00
m_2f_5	297.63	180.99	46.26	145.11	286.34	356.52
m_3f_1	417.89	437.70	72.32	126.03	223.69	306.51
m_3f_2	496.66	211.46	49.94	178.51	211.90	304.27
m_3f_3	256.99	508.18	50.52	129.96	218.21	317.79
m_3f_4	307.41	204.14	47.56	143.57	220.66	208.17
m_3f_5	419.68	280.75	58.25	124.90	263.75	287.17
SEm	1.607	2.412	0.935	0.442	7.911	0.918
CD (0.05)	4.569	6.860	2.659	1.256	22.499	2.610

4.3. RESIDUAL EFFECT OF TREATMENTS OF RICE ON SUCCEEDING CROP OF GROUNDNUT INTERCROPPED IN CASSAVA [2013-14 (FIRST YEAR) AND 2014-15 (SECOND YEAR)]

4.3.1. Yield and Yield Attributes

4.3.1.1. Pod Yield

The data presented in Table 28 shows the significant influence of treatments on pod yield of groundnut as influenced by the residual effect of treatments of preceding rice. The highest pod yield was observed in M_3 during both the years were significantly superior to other two methods of planting and weed control measures.

Comparing the fertilizer application methods, the residual effect of F_1 resulted in the highest pod yield of 789.06 kg ha^{-1} in the first year which was on par with F_5 (708.85 kg ha^{-1}). During the second year, F_4 produced significantly the highest pod yield of 1370.73 kg ha^{-1} which was significantly superior to other fertilizer application methods.

The residual effect of treatment combination, m_3f_1 was found to record the highest pod yield which was significantly different from the other treatment combinations during the first year, except m_1f_5 and m_3f_3. The pod yield was significantly higher in m_3f_4 and m_1f_4 (1433.60 kg ha^{-1} and 1410.38 kg ha^{-1} respectively) in the second year which was significantly superior to other interactions.

4.3.1.2. Kernel Yield

The kernel yield of groundnut was influenced by the residual effect of treatments of rice (Table 28). Among the methods of planting and weed control measures, the highest kernel yield was observed in M_3 during both the years which were significantly different from other two treatments.

The methods of fertilizer application results revealed that, the residual effect of F_1 resulted in the highest kernel yield of 550.22 kg ha^{-1} in the first year which was on par with F_5. During the second year, F_4 produced the significantly highest kernel yield of 959.51 kg ha^{-1}. The treatments were significantly superior to other fertilizer application methods.

Among the interactions during 2013-14, the residual effect of m_3f_1 was significantly superior to all other combinations except m_1f_5 and m_3f_3 which were on par with m_3f_1. During 2014-15, significantly higher kernel yield was obtained from m_3f_4 (1003.52 kg ha^{-1}) and m_1f_4 (987.26 kg ha^{-1}) which was significantly different from all other interactions.

4.3.1.3. Haulm Yield

It is evident from Table 29 that the residual effect of treatments had significant effect on haulm yield of groundnut during 2013-14 and 2014-15. The residual effect of M_3 resulted in the highest haulm yield of 1858.67 kg ha^{-1} and 3209.53 kg ha^{-1} in the first and second years respectively which was significantly different from other two methods of planting and weed management measures.

Comparing the methods of fertilizer application during 2013-14, the residual effect of F_1 resulted in the highest haulm yield and was significantly superior to all other treatments except F_3. During 2014-15, the highest haulm yield was produced in F_4 (3343.99 kg ha^{-1}), which was significantly superior.

Table 28. Residual effect of treatments of rice on pod yield and kernel yield of groundnut

Treatments	Pod yield (kg ha^{-1})		Kernel yield (kg ha^{-1})	
	2013-14	2014-15	2013-14	2014-15
Main plot (M)				
M_1	600.00	1056.77	418.73	739.74
M_2	552.19	1028.65	386.53	720.05

M_3	817.19	1182.37	572.03	827.66
SEm	17.119	4.348	12.366	3.043
CD (0.05)	55.826	14.179	40.326	9.925
Sub plot (F)				
F_1	789.06	958.765	550.22	671.14
F_2	626.04	1107.20	438.23	775.04
F_3	560.94	1005.27	392.66	703.69
F_4	597.40	1370.73	418.18	959.51
F_5	708.85	1004.35	496.20	703.04
SEm	28.970	7.703	20.299	5.392
CD (0.05)	82.391	21.907	57.729	15.335
m x f				
m_1f_1	815.63	721.35	564.56	504.95
m_1f_2	451.56	1118.49	316.09	782.94
m_1f_3	434.38	981.77	304.06	687.24
m_1f_4	332.81	1410.38	232.97	987.26
m_1f_5	965.63	1028.64	675.94	720.05
m_2f_1	521.88	786.46	365.31	550.52
m_2f_2	764.06	1018.23	534.84	712.76
m_2f_3	360.94	904.95	252.66	633.46
m_2f_4	779.69	1268.23	545.78	887.76
m_2f_5	334.38	1165.37	234.06	815.76
m_3f_1	1029.69	1368.49	720.78	957.94
m_3f_2	662.50	1184.90	463.75	829.43
m_3f_3	887.50	1129.08	621.25	790.36
m_3f_4	679.69	1433.60	475.78	1003.52
m_3f_5	826.56	819.03	578.59	573.32
SEm	50.178	13.343	35.158	9.340
CD (0.05)	142.705	37.945	99.989	26.561

Among the treatment combinations in rice in both the years, the significantly highest haulm yield was observed in m_3f_3 (3033.32 kg ha^{-1} and 3860.19 kg ha^{-1} respectively) which was significantly superior to all other combinations.

4.3.1.4. Biomass Yield

It is evident from Table 29 that treatments had significant effects on biomass yield of groundnut during 2013-14 and 2014-15. The highest biomass yield for the first and second year was registered in M_3 which was superior to other two methods of planting and weed management.

The residual effect of methods of fertilizer application in rice on the biomass yield of succeeding groundnut revealed that F_1 resulted in the highest biomass yield (2619.05 kg ha^{-1}) which was significantly superior to other treatments in the first year. During 2014-15, F_4 was found to register the highest value and was significantly different from other treatments.

Comparing the treatment combinations, the residual effect of m_3f_3 produced the highest biomass yield in both the years, which was on par with m_3f_1 (second year). The combinations m_1f_4 (2013-14) and m_1f_1 (2014-15) produced the lowest biomass yield.

4.3.1.5. Harvest Index (HI)

The results (Table 29) indicated that the HI of groundnut was influenced by the residual effect of treatments of preceding rice. Comparing the methods of planting and weed management treatments, the highest HI was observed in M_3 in both the years, which was on par with M_2 (2013-14).

Table 29. Residual effect of treatments of rice on haulm yield, biomass yield and harvest index of groundnut

Treatments	Haulm yield (kg ha^{-1})		Biomass yield (kg ha^{-1})		Harvest index	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Main plot (M)						

M_1	1441.56	2923.81	2041.56	3980.58	0.29	0.26
M_2	1219.82	3050.17	1772.01	4078.81	0.31	0.25
M_3	1858.67	3209.53	2675.86	4391.91	0.32	0.27
SEm	60.465	12.222	77.101	11.042	0.004	0.001
CD (0.05)	197.184	39.859	251.437	36.008	0.013	0.005
Sub plot (F)						
F_1	1829.99	3124.63	2619.05	4083.40	0.31	0.23
F_2	1293.05	3057.96	1919.09	4165.17	0.32	0.27
F_3	1735.07	3030.35	2296.00	4035.62	0.26	0.25
F_4	1233.49	3343.99	1830.89	4714.72	0.32	0.29
F_5	1441.82	2748.91	2150.68	3753.26	0.32	0.27
SEm	64.629	32.691	78.579	34.810	0.011	0.002
CD (0.05)	183.805	92.970	223.476	98.998	0.029	0.007
m x f						
m_1f_1	2277.50	2198.44	3093.13	2919.79	0.27	0.25
m_1f_2	1153.75	3468.23	1605.31	4586.71	0.28	0.24
m_1f_3	1085.94	2872.16	1520.31	3853.93	0.29	0.25
m_1f_4	1967.19	3250.29	1300.00	4683.88	0.26	0.31
m_1f_5	1723.44	2829.96	2689.06	3858.60	0.36	0.27
m_2f_1	1108.73	3627.18	1630.61	4413.63	0.32	0.18
m_2f_2	1397.91	2768.71	2161.97	3786.94	0.35	0.27
m_2f_3	1085.94	2358.71	1446.88	3263.66	0.26	0.28
m_2f_4	1419.13	3469.96	2198.81	4738.19	0.35	0.27
m_2f_5	1087.40	3026.28	1421.78	4191.65	0.24	0.28
m_3f_1	2103.75	3548.28	3133.44	4916.77	0.32	0.28
m_3f_2	1327.48	2936.96	1989.98	4121.85	0.34	0.29
m_3f_3	3033.32	3860.19	3920.82	4989.28	0.23	0.23
m_3f_4	1314.16	3311.72	1993.84	4722.09	0.34	0.30
m_3f_5	1514.63	2390.51	2341.19	3209.54	0.35	0.26
SEm	111.942	56.621	136.103	60.293	0.018	0.004
CD (0.05)	318.359	161.029	387.072	171.469	0.052	0.011

During 2013-14 all the treatments, except F_3 proved superior. During the second year, the highest HI of 0.29 was observed in F_4 and was significantly different from all other fertilizer applications.

Among the treatment combinations, the residual effects of m_1f_5 and m_1f_4 resulted in the higher HI of 0.36 and 0.31 in the first and second years respectively. They were significantly different from the other interactions except m_2f_1, m_2f_2, m_2f_4, m_3f_1, m_3f_2, m_3f_4 and m_3f_5 in the first year and m_3f_2 and m_3f_4 in the second year, which were on par.

4.3.2. Uptake of Major Nutrients

4.3.2.1 Nitrogen Uptake

Nitrogen uptake data furnished in Table 30 revealed that the residual effect of treatments were significant during both the years. Among the different methods of planting and weed control measures, M_3 produced significantly higher nitrogen uptake of 85.49 kg ha^{-1} and 161.54 kg ha^{-1} during 2013-14 and 2014-15 respectively.

Comparing the methods of fertilizer application, the residual effect of F_1 resulted in the higher uptake of nitrogen during 2013-14 and 2014-15, which was significantly superior to all the other fertilizer application methods and was on par with F_5 (first year).

The different treatment combinations exerted significant effect on nitrogen uptake in both the years. In the first year, the residual effect of m_3f_3 resulted in the highest nitrogen uptake which was found superior to all the other treatment combinations, except m_1f_1 and m_3f_1 which were on par. The treatment combination m_3f_1 had significantly the highest nitrogen uptake of 201.52 kg ha^{-1} during 2014-15.

4.3.2.2. Phosphorous Uptake

It is evident from Table 30 that the treatments had significant effect on phosphorous uptake. In the first year, the highest P uptake was produced in M_3, followed by M_1 and M_2. During the second year, the residual effect of M_1 recorded the highest P uptake (11.59 kg ha^{-1}) which was significantly superior to the other methods of planting and weed management practice.

Among the fertilizer application methods, the highest uptake was recorded in F_1 (7.34 kg ha^{-1}) during the first year which was significantly superior to all others and F_4 (13.14 kg ha^{-1}) in the subsequent year.

The different treatment combinations showed significant variation in phosphorous uptake in both the years. In the first year, the residual effect of m_3f_3 resulted in the highest P uptake of 9.83 kg ha^{-1} which was superior to all the other treatment combinations, except m_1f_1 which was on par. The combination, m_3f_4 resulted in the highest phosphorous uptake in the second year.

4.3.2.3. Potassium Uptake

The residual effect of treatments significantly influenced the potassium uptake and the results are presented in Table 30. Among the methods of planting and weed control measures, the significantly highest potassium uptake was recorded in M_3 in both the years.

In the first year among the fertilizer application methods, the highest potassium uptake was registered in F_1 and was significantly superior to all other application methods. The treatment F_4 resulted in the highest K uptake during the second year (44.90 kg ha^{-1}).

Table 30. Residual effect of treatments of rice on uptake of major nutrients in groundnut

Treatments	Nitrogen (kg ha^{-1})		Phosphorous (kg ha^{-1})		Potassium (kg ha^{-1})	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Main plot (M)						
M_1	66.74	134.77	6.12	11.59	14.47	36.32
M_2	61.61	142.75	5.07	8.72	12.83	31.01
M_3	85.49	161.54	7.20	11.06	19.25	37.93
SEm	2.869	0.448	0.240	0.044	0.563	0.195
CD (0.05)	9.358	1.463	0.781	0.143	1.835	0.636
Sub plot (F)						
F_1	82.42	161.96	7.34	8.87	19.33	34.09
F_2	67.61	135.81	5.51	11.12	13.57	31.97
F_3	69.65	143.08	6.24	10.52	16.70	36.77
F_4	61.75	154.58	5.04	13.41	12.81	44.90
F_5	74.98	136.35	6.52	8.35	15.16	27.71
SEm	2.870	1.214	0.279	0.098	0.632	0.668
CD (0.05)	8.163	3.452	0.793	0.280	1.798	1.850
m x f						
m_1f_1	98.33	107.52	9.27	7.15	22.84	30.91
m_1f_2	54.77	150.51	4.28	14.63	11.62	30.92
m_1f_3	57.33	125.77	5.04	12.81	10.48	41.15
m_1f_4	40.59	136.77	3.64	15.08	8.06	46.64
m_1f_5	82.68	153.29	8.38	8.25	19.36	32.00
m_2f_1	51.45	176.82	4.45	8.51	12.44	37.50
m_2f_2	72.36	128.44	6.19	8.27	14.15	24.82
m_2f_3	42.52	112.04	3.84	7.60	10.10	26.69
m_2f_4	81.62	152.68	6.17	9.53	17.42	40.39
m_2f_5	60.11	143.77	4.71	9.68	10.02	25.65
m_3f_1	97.47	201.52	8.31	10.96	22.71	33.87
m_3f_2	75.69	128.49	6.07	10.46	14.95	40.17
m_3f_3	109.10	191.43	9.83	11.16	29.53	42.47
m_3f_4	63.05	174.28	5.32	15.60	12.94	47.68
m_3f_5	82.16	111.98	6.48	7.13	16.10	25.47
SEm	4.972	2.103	0.483	0.170	1.095	0.575
CD (0.05)	14.139	5.980	1.374	0.485	3.114	1.635

Comparing the interactions, the residual effect of treatments observed significant variation, m_3f_3 (29.53 kg ha^{-1}) was significantly superior to all the other combinations in the first year. In the second year, m_1f_4 and m_3f_4 resulted in the higher potassium uptake (46.64 kg ha^{-1} and 47.68 kg ha^{-1} respectively), which were on par.

4.4. RESIDUAL EFFECT OF TREATMENTS OF RICE ON THE THIRD CROP OF COWPEA [2013-14 (FIRST YEAR) AND 2014-15 (SECOND YEAR)] IN THE SYSTEM

4.4.1. Growth Attributes

4.4.1.1 Plant Height

Data furnished in Table 31 indicates significant variation among treatments on the plant height of cowpea as influenced by the residual effect of treatments of rice. Comparing the methods of planting and weed control measures, the residual effects of M_2 and M_3 produced the higher plant height, which were significantly superior to M_1, during both the years.

Among the methods of fertilizer application, during the first year, the residual effect of F_2 resulted in the taller plants (59.95 cm), while in the second year, F_3 resulted in the taller plants of 70.14 cm.

The residual effect of treatment combinations, m_2f_1 and m_3f_2 resulted in significantly the higher plant height in the first year. During 2014-15, the significantly highest plant height was observed in m_2f_3 (72.29 cm) which was significantly superior to all other combinations.

4.4.1.2. Number of Branches Plant^{-1}

The residual effect of various treatments of rice on number of branches plant^{-1} in cowpea (Table 31) revealed that, the residual effect of M_3 produced the highest number of branches plant^{-1} (5.33 and 5.69 for the first and second year respectively) which was significantly superior to the other methods of planting and weed management except M_2, during 2013-14.

Comparing the fertilizer application methods, the residual effect of F_2 resulted in the highest number of branches plant^{-1} (5.38 and 5.43 for the first and second year respectively). The fertilizer application method F_2 was significantly superior and on par with F_3 and F_4 during 2013-14 and F_1 during 2014-15.

The residual effects of m_3f_3 and m_3f_1 produced higher number of branches plant^{-1} for the first and second year respectively. The combinations were found significantly superior to the other treatments, except m_1f_2, m_1f_3, m_2f_2, m_2f_4, m_3f_1, m_3f_2 and m_3f_4 (first year) and m_2f_2, m_3f_1 and m_3f_3 (second year) which were on par.

4.4.1.3. Dry Matter Production

Dry matter production of cowpea was influenced by the residual effect of treatments in the first crop of rice during both the years (Table 31). During 2013-14, the dry matter was found not significant and in second year, the residual effect of M_3 was significantly superior to other two methods of planting and weed management.

Among the fertilizer application methods, the residual effect of F_1 produced the highest dry matter (921.99 kg ha^{-1}) in the first year and F_2 in the second year. The treatment F_1 was on par with F_3 in the first year and F_2 was on par with F_1 and F_5 in the second year.

Table 31. Residual effect of treatments of rice on plant height, number of branches plant^{-1} and dry matter production of cowpea

Treatments	Plant height (cm)		Number of branches plant^{-1}		Dry matter production (kg ha^{-1})	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Main plot (M)						
M_1	56.97	63.03	5.04	4.56	696.24	774.92
M_2	57.83	64.91	5.14	5.24	985.34	1101.37
M_3	58.56	64.19	5.33	5.69	800.36	1668.49
SEm	0.359	0.257	0.064	0.081	134.789	22.637
CD (0.05)	1.170	0.839	0.206	0.265	NS	73.823
Sub plot (F)						
F_1	58.05	62.63	4.88	5.30	921.99	1173.86
F_2	59.95	63.71	5.38	5.43	749.41	1233.65
F_3	57.25	70.14	5.37	5.07	861.25	1148.23
F_4	56.57	62.56	5.25	5.02	794.44	1127.01
F_5	57.13	61.17	4.98	5.01	809.48	1225.22
SEm	0.424	0.479	0.100	0.062	23.847	27.901
CD (0.05)	1.205	1.361	0.283	0.177	67.819	79.350
m x f						
m_1f_1	52.44	65.22	4.36	4.52	835.88	670.24
m_1f_2	59.95	55.18	5.36	4.72	873.05	882.46
m_1f_3	59.54	68.76	5.39	4.69	526.05	920.35
m_1f_4	56.04	68.93	5.03	4.22	584.45	522.83
m_1f_5	56.86	57.04	5.09	4.68	661.77	878.73
m_2f_1	60.96	65.53	5.00	5.44	955.84	1184.36
m_2f_2	58.93	67.73	5.41	5.67	677.72	1284.82
m_2f_3	53.14	72.29	5.08	4.80	1075.22	953.67
m_2f_4	57.92	59.11	5.15	5.18	1086.56	1068.38
m_2f_5	58.23	59.87	5.07	5.13	1131.37	1015.64
m_3f_1	60.74	57.13	5.27	5.93	974.27	1666.99
m_3f_2	60.97	68.22	5.38	5.90	697.46	1533.67
m_3f_3	59.07	69.38	5.63	5.73	982.47	1570.68
m_3f_4	55.74	59.62	5.58	5.66	712.30	1789.81
m_3f_5	56.30	66.60	4.77	5.21	635.31	1781.31
SEm	0.734	0.829	0.173	0.108	41.304	48.326
CD (0.05)	2.088	2.357	0.490	0.307	117.466	137.437

The interaction effects also showed significant difference. The residual effect of the combination of m_2f_5 produced the highest dry matter which was on par with m_2f_3 and m_2f_4 in the first year. During 2014-15, m_3f_1, m_3f_4 and m_3f_5 recorded the higher values of dry matter production which were on par, but superior to all the other combinations.

4.4.2. Yield and Yield Attributes

4.4.2.2. Number of Pods Plant^{-1}

The data presented in Table 32 depicts the influence of treatments on number of pods plant^{-1} of cowpea as influenced by the residual effect of treatments of preceding rice. Number of pods plant^{-1} was not influenced by the different methods of planting and weed control measures during the first year, while in the second year, M_3 resulted in the highest pods plant^{-1} (89.87).

Comparing the fertilizer application methods, the residual effect of F_3 (foliar spray of complex fertilizer 19:19:19 @ 0.5 per cent) produced the highest number of pods plant^{-1} (56.35), which was on par with F_1 in the first year. The pod number was not influenced by the treatments in the second year.

The interaction effect was observed to be significant during both the years. During 2013-14, the residual effect of m_2f_4 resulted in the highest number of pods plant^{-1} which was on par with m_2f_3 and m_2f_5. In the second year, m_3f_4 produced the highest pod number, which was on par with m_3f_1, m_3f_3 and m_3f_5.

4.4.2.3. Pod Yield

During 2013-14, the pod yield was not influenced by treatments. In the second year, the residual effect of M_3 produced significantly the highest pod yield of 1127.35

kg ha^{-1} compared to other two methods of planting and weed management measures (Table 32).

Among the methods of fertilizer application, the highest pod yield was observed in F_1 (618.38 kg ha^{-1}), which was on par with F_3 in the first year. During 2014-15, the residual effect of F_2 registered the highest pod yield of 833.54 kg ha^{-1} which was on par with other treatments, except F_1 and F_3.

Among the treatment combinations, m_2f_4 resulted in the highest pod yield during the first year, which was on par with the other treatments except m_2f_3 and m_2f_5. During the second year, the highest pod yield was obtained from which m_3f_4, was significantly superior to all other treatments, except m_3f_1 and m_3f_5 which were on par with the best treatment.

4.4.3. Uptake of Major Nutrients

4.4.3.1 Nitrogen Uptake

Nitrogen uptake data furnished in Table 33 revealed that, the different methods of planting and weed control measures was not significant in 2013-14 while M_3 recorded significantly the highest nitrogen uptake of 78.65 kg ha^{-1} followed by M_2 and M_1 in the subsequent year.

Comparing the methods of fertilizer application, the residual effect of F_1 resulted in significantly the highest uptake of 54.75 kg ha^{-1} which was superior to all the other fertilizer application methods during 2013-14. In the second year, F_5 (absolute control) was observed to be significantly superior to all the other treatments (59.92 kg ha^{-1}) which was on par with F_2.

Table 32. Residual effect of treatments of rice on yield and yield attributes of cowpea

Treatments	Number of pods plant^{-1}		Pod yield (kg ha^{-1})	
	2013-14	2014-15	2013-14	2014-15
Main plot (M)				
M_1	43.32	55.05	454.16	523.55
M_2	60.87	69.58	660.37	744.18
M_3	51.43	89.87	540.78	1127.35
SEm	6.614	1.025	95.952	15.287
CD (0.05)	NS	3.341	NS	49.852
Sub plot (F)				
F_1	55.45	70.02	618.38	761.48
F_2	47.85	74.11	497.34	833.54
F_3	56.35	71.60	577.43	775.85
F_4	52.02	68.84	532.27	793.07
F_5	47.69	72.93	533.44	827.85
SEm	1.095	1.619	16.654	18.849
CD (0.05)	3.114	NS	47.364	53.606
m x f				
m_1f_1	48.46	47.55	551.00	452.63
m_1f_2	49.11	61.70	576.38	596.25
m_1f_3	40.17	61.90	341.94	621.88
m_1f_4	39.23	44.73	381.38	353.25
m_1f_5	39.61	59.38	420.13	593.75
m_2f_1	57.92	75.03	645.84	800.25
m_2f_2	46.13	76.73	444.41	868.13
m_2f_3	67.11	60.63	734.16	644.38
m_2f_4	68.74	68.90	750.94	721.88
m_2f_5	64.47	66.63	726.50	686.25
m_3f_1	59.99	87.48	658.28	1126.34
m_3f_2	48.33	83.90	471.25	1036.25
m_3f_3	61.78	92.28	663.84	1061.29
m_3f_4	48.08	92.90	481.28	1209.33
m_3f_5	38.98	92.78	429.25	1203.55
SEm	1.341	2.803	28.845	32.647
CD (0.05)	5.394	7.971	82.036	92.848

The residual effect of different treatment combinations showed significant variation in nitrogen uptake. In the first year, m_2f_4 resulted in the highest nitrogen uptake which was superior to all the other treatment combinations except m_2f_3 and m_2f_5. The residual effect of m_3f_4 resulted in the highest nitrogen uptake (87.80 kg ha^{-1}) during 2014-15.

4.4.3.2. Phosphorous Uptake

It is evident from Table 33 that the main plot treatments did not show any significant variation in the first year. During the second year, the residual effect of M_3 recorded the highest P uptake (12.51 kg ha^{-1}) which was significantly superior to the other methods of planting and weed management practice.

Among the fertilizer application methods, the highest uptake was registered in F_3 (6.23 kg ha^{-1}) in the first year which was on par with F_1 and F_5. During 2014-15, F_5 recorded the highest phosphorous uptake.

The different treatment combinations showed significant effect on phosphorous uptake during both the years. In the first year, the residual effect of m_3f_3 resulted in the highest P uptake (9.10 kg ha^{-1}) which was superior to all the other treatment combinations, except m_2f_5, which was on par. The combination of m_3f_4 resulted in significantly the highest phosphorous uptake and was on par with m_3f_5 in the second year.

4.4.3.3. Potassium Uptake

The treatments significantly influenced the potassium uptake and the results are depicted in Table 33. Among the methods of planting and weed control measures, during 2013-14, the treatments were not significant. The highest potassium uptake was recorded in M_3 in the second year, which was followed by M_2 and M_1.

In the first year among the fertilizer application methods, the higher potassium uptake was registered in F_1, F_3 and F_5 which were significantly superior to the other two methods of application. The residual effect of F_1 resulted in the highest K uptake during the second year (41.29 kg ha^{-1}).

Comparing the interactions, m_2f_5 was significantly superior to all the other combinations in the first year except m_2f_3 and m_3f_3 which were on par. In the second year, m_3f_1 resulted in the highest potassium uptake (58.66 kg ha^{-1}) and the minimum was observed in m_1f_4.

4.4.4. Chemical Properties of Soil

4.4.4.1. pH

The residual effect of treatments on pH of the soil is presented in Table 34. In the first year, M_3 resulted in the highest pH of 5.46 and was significantly superior to all other methods of planting and weed management measures. The treatment M_2 recorded the highest pH followed by M_1 and M_3 during the subsequent year.

Among the fertilizer application methods, the significantly highest pH was registered in F_3 in the first and second years which was slightly acidic and was found superior to all other fertilizer application methods.

The results on treatment combinations revealed that, the residual effects of m_3f_3 recorded significantly the highest pH during the first year. During 2014-15, the highest pH was recorded in m_2f_3 which was significantly different from the other treatment combinations.

Table 33. Residual effect of treatments of rice on uptake of major nutrients in cowpea

Treatments	Nitrogen ($kg\ ha^{-1}$)		Phosphorous ($kg\ ha^{-1}$)		Potassium ($kg\ ha^{-1}$)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Main plot (M)						
M_1	43.06	37.71	4.96	6.04	34.95	24.86
M_2	55.59	52.30	5.92	6.96	45.01	36.00
M_3	45.42	78.65	6.13	12.51	36.73	44.45
SEm	8.192	1.044	1.010	0.077	6.706	0.568
CD (0.05)	NS	3.403	NS	0.252	NS	1.852
Sub plot (F)						
F_1	54.75	55.52	5.72	7.33	43.30	41.29
F_2	46.52	57.39	5.49	8.61	32.69	31.22
F_3	45.22	53.52	6.23	8.45	39.69	37.72
F_4	46.38	54.76	4.87	8.10	36.47	28.02
F_5	47.25	59.92	6.04	10.03	42.33	37.27
SEm	1.496	1.353	0.243	0.197	1.367	0.898
CD (0.05)	4.252	3.850	0.693	0.558	3.887	2.554
m x f						
m_1f_1	57.66	36.11	5.76	5.60	39.45	25.85
m_1f_2	56.20	42.50	7.14	6.59	41.47	27.65
m_1f_3	26.83	38.91	3.56	7.11	21.01	31.87
m_1f_4	34.38	27.59	3.18	3.10	28.96	12.71
m_1f_5	40.24	43.42	5.18	7.78	43.85	26.20
m_2f_1	49.49	60.00	6.22	8.61	46.22	39.34
m_2f_2	36.51	53.80	3.82	6.63	29.62	36.45
m_2f_3	62.46	45.39	6.03	6.10	51.42	39.00
m_2f_4	66.61	48.87	5.30	5.83	44.78	30.75
m_2f_5	62.86	53.41	8.21	7.65	53.01	34.46
m_3f_1	57.10	70.45	5.19	7.76	44.23	58.66
m_3f_2	46.85	75.85	5.50	12.62	26.97	29.57
m_3f_3	46.37	76.25	9.10	12.16	46.63	42.28
m_3f_4	38.15	87.80	6.13	15.37	35.66	40.61
m_3f_5	38.65	82.92	4.72	14.67	30.14	51.14
SEm	2.590	2.345	0.422	0.340	2.367	1.556
CD (0.05)	7.365	6.668	1.200	0.967	6.732	4.424

4.4.4.2. EC

The highest EC was observed in M_3 in the first and second years (0.43 and 0.30 dS m^{-1} respectively) (Table 34) in which M_3 and M_2 had similar values during 2014-15. The main plot treatment M_3 was significantly superior to the other two methods of planting and weed control measures (2013-14).

Comparing the fertilizer application methods, the residual effect of F_4 recorded the highest EC compared to the other treatments and the lowest EC values were recorded in F_1 and F_3 in the first year. During 2014-15, the treatment which showed the highest EC value was F_3 (0.32 dS m^{-1}) followed by F_5, F_4, F_2 and F_1.

Among the treatment combinations, the highest EC was registered in m_2f_4 in the first year which was significantly superior to all the other combinations except m_1f_2 and m_3f_4. During 2014-15, the residual effect of m_2f_3 resulted in the highest EC of 0.43 dS m^{-1} which was significantly superior to all other combinations.

4.4.4.3. Organic Carbon

Data presented in Table 34 represents the residual effect of various treatments on organic carbon content of soil during 2013-14 and 2014-15. Among the methods of planting and weed management measures, the residual effect of M_1 resulted in the highest organic carbon content of 1.06 per cent (2013-14), which was significantly superior to M_2 (0.98 per cent) and M_3 (0.87 per cent). The treatment M_3 was significantly superior to M_2 and M_3 in the second year.

Table 34. Residual effect of treatments of rice on pH, EC and organic carbon content of the soil

Treatments	pH		EC (dS m^{-1})		Organic carbon (%)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Main plot (M)						
M_1	5.40	5.68	0.36	0.26	1.06	1.30
M_2	5.40	5.72	0.40	0.30	0.98	1.29
M_3	5.46	5.63	0.43	0.30	0.87	1.34
SEm	0.002	0.004	0.001	0.002	0.005	0.001
CD (0.05)	0.008	0.012	0.004	0.006	0.015	0.003
Sub plot (F)						
F_1	5.39	5.54	0.32	0.25	1.22	1.30
F_2	5.34	5.55	0.45	0.27	0.99	1.36
F_3	5.56	6.11	0.32	0.32	0.86	1.29
F_4	5.46	5.57	0.56	0.29	0.79	1.30
F_5	5.35	5.60	0.34	0.30	0.99	1.30
SEm	0.005	0.001	0.004	0.002	0.011	0.001
CD (0.05)	0.015	0.005	0.012	0.007	0.033	0.003
m x f						
m_1f_1	5.27	5.27	0.26	0.29	1.17	1.40
m_1f_2	5.26	5.52	0.68	0.20	0.95	1.22
m_1f_3	5.56	5.96	0.11	0.24	1.00	1.38
m_1f_4	5.49	5.96	0.30	0.34	1.00	1.33
m_1f_5	5.40	5.67	0.47	0.25	1.17	1.20
m_2f_1	5.31	5.71	0.40	0.18	1.28	1.30
m_2f_2	5.30	5.68	0.16	0.30	1.29	1.33
m_2f_3	5.41	6.37	0.52	0.43	0.84	1.27
m_2f_4	5.67	5.42	0.69	0.29	0.81	1.23
m_2f_5	5.32	5.41	0.23	0.29	0.68	1.33
m_3f_1	5.59	5.63	0.31	0.28	1.21	1.21
m_3f_2	5.46	5.47	0.52	0.31	0.73	1.53
m_3f_3	5.70	6.00	0.33	0.30	0.75	1.22
m_3f_4	5.22	5.32	0.68	0.25	0.55	1.33
m_3f_5	5.34	5.71	0.32	0.35	1.10	1.38
SEm	0.009	0.003	0.007	0.004	0.020	0.001
CD (0.05)	0.026	0.008	0.021	0.012	0.057	0.005

The residual effect of treatment F_1 recorded significantly the highest organic carbon content of 1.22 per cent in the soil during the first year. In the second year, F_2 registered the highest organic carbon, which was superior to all the other fertilizer application methods.

Comparing the interactions the higher organic carbon content was recorded in m_2f_2 during 2013-14, which was on par with m_2f_1 and significantly different from all the other combinations. In the second year, m_3f_2 resulted in the significantly highest organic carbon content and was significantly superior to all other combinations.

4.4.5. Available Nutrient Content in Soil

4.4.5.1. Available Nitrogen

The data on available nitrogen content of soil are furnished in Table 35. Various treatments significantly influenced available N content of soil during 2013-14 and 2014-15. Comparing the methods of planting and weed control measures, the highest available nitrogen content of 468.59 kg ha^{-1} was recorded in M_2 in the first year. In the second year, the residual effect of treatment M_3 was significantly superior to the other two methods of planting and weed management practices.

Among the fertilizer application methods during 2013-14 as well as 2014-15, the highest available nitrogen was registered in F_3, which was superior to all the other treatments.

During the first year, the residual effect of treatment combinations, m_2f_2, m_3f_1 and m_3f_3 was on par and significantly superior to all the other combinations. The minimum content was observed by the combination m_2f_1 (299.28 kg ha^{-1}). The combination m_3f_3 resulted in significantly the highest available nitrogen content of 539.98 kg ha^{-1} in the second year.

4.4.5.2. Available Phosphorous

The data presented in Table 35 clearly explains the significant influence of treatments on available phosphorous content in soil. The residual effect of M_3 recorded the highest P content in soil in the first year which was significantly different from other methods of planting and weed control measures in the first year. During 2014-15, the available P content recorded by M_1 was significantly superior.

Comparing the fertilizer application methods, the highest P content was registered in F_4 (161.90 kg ha^{-1}) during 2013-14, which was significantly superior to all the other treatments. The absolute control resulted in significantly the highest available P content, which was followed by F_3, F_4, F_1 and F_2.

The interactions significantly influenced the available P content. The residual effect of combination of m_1f_4 resulted in the highest available P content during the first year (203.59 kg ha^{-1}). During 2014-15, the highest P content was recorded in m_1f_5, which was superior to all the other combinations.

4.4.5.3. Available Potassium

The treatments significantly influenced the available potassium content in soil in both the years (Table 35). In the first and second years, the residual effect of M_3 had significantly the highest available potassium content which was significantly different from other two methods of planting and weed management measures.

The highest available K content was observed in F_2 which was significantly superior to the other fertilizer application methods during 2013-14. During 2014-15, F_3 with a potassium content of 186.56 kg ha^{-1} was observed in the soil and was significantly superior.

Table 35. Residual effect of treatments of rice on available nitrogen, phosphorous and potassium content in soil

Treatments	Nitrogen ($kg\ ha^{-1}$)		Phosphorous ($kg\ ha^{-1}$)		Potassium ($kg\ ha^{-1}$)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Main plot (M)						
M_1	425.59	291.74	128.28	174.05	299.40	163.19
M_2	468.59	309.11	126.09	169.23	279.34	173.24
M_3	446.03	330.36	149.68	156.46	301.82	181.83
SEm	0.906	3.468	0.960	0.175	0.427	1.375
CD (0.05)	2.954	11.311	3.132	0.569	1.393	4.485
Sub plot (F)						
F_1	392.50	305.23	130.54	148.43	304.14	176.12
F_2	425.81	254.44	140.97	135.01	307.69	169.79
F_3	532.70	377.36	136.81	184.69	289.22	186.56
F_4	436.43	323.44	161.90	174.64	284.89	179.06
F_5	446.26	291.55	103.19	190.14	281.66	152.22
SEm	1.148	4.928	0.715	0.441	0.462	1.768
CD (0.05)	3.264	14.015	2.032	1.256	1.315	5.029
m x f						
m_1f_1	319.73	312.85	97.73	169.03	317.64	202.76
m_1f_2	394.06	272.38	158.41	110.31	254.09	104.11
m_1f_3	529.39	308.37	89.56	185.58	315.59	195.65
m_1f_4	515.72	297.17	203.59	185.20	382.40	164.97
m_1f_5	369.06	267.90	92.09	220.14	227.30	148.44
m_2f_1	299.28	291.50	104.01	120.88	289.52	155.33
m_2f_2	559.78	298.37	131.50	187.27	376.67	192.79
m_2f_3	506.79	283.73	191.98	174.07	267.16	152.25
m_2f_4	427.12	374.77	127.78	168.76	228.11	257.03
m_2f_5	550.00	297.17	75.15	195.14	235.22	108.80
m_3f_1	558.48	311.34	189.88	155.37	305.26	170.26
m_3f_2	323.60	192.57	132.99	107.45	292.30	212.48
m_3f_3	561.93	539.98	128.89	194.41	284.93	211.79
m_3f_4	366.45	298.37	154.32	169.95	244.17	115.19
m_3f_5	419.71	309.57	142.32	155.14	382.46	199.44
SEm	1.988	8.536	1.237	0.764	0.801	3.063
CD (0.05)	5.654	24.274	3.520	2.175	2.278	8.711

Among the treatment combinations, the residual effect of m_1f_4 and m_3f_5 recorded the higher available K content and were significantly different from all other combinations (2013-14). During 2014-15, m_2f_4 resulted in significantly the highest potassium content compared to the other interactions.

4.5. DIRECT AND RESIDUAL EFFECT OF TREATMENTS ON RICE – CASSAVA + GROUNDNUT - COWPEA SYSTEM [2013-14 (FIRST YEAR) AND 2014-15 (SECOND YEAR)]

4.5.1. Rice Equivalent Yield of Cropping System

The data presented in Table 36 revealed the significant influence of treatments on the rice equivalent yield of rice – cassava+groundnut - cowpea system. In the first year and second year, direct and residual effect of M_3 resulted in the highest rice equivalent yield of 31.62 t ha^{-1} and 21.81 t ha^{-1} respectively, which were significantly superior to other two methods of planting and weed management measures.

Comparing the fertilizer application methods, the highest rice equivalent yield was produced in F_2 (foliar spray of water soluble complex fertilizer 19:19:19 @ 0.5 per cent) during both the years and it was on par with F_1 (2013-14) and F_4 (2014-15).

Among the treatment combinations, direct and residual effect of m_3f_1 produced the highest rice equivalent yield of 34.61 t ha^{-1} during 2013-14 and 24.82 t ha^{-1} during 2014-15 which was on par with m_3f_4 in both the years.

The pooled data over years presented in Table 36 showed the significant influence of direct and residual effect of treatments on rice equivalent yield of the rice – cassava+groundnut - cowpea system. The significantly highest rice equivalent yield was registered in M_3 which was significantly superior to all other methods of

Table 36. Direct and residual effect of treatments on rice equivalent yield of rice – cassava + groundnut - cowpea system

Treatments	Rice equivalent yield (t ha^{-1})		Pooled
	2013-14	2014-15	
Main plot (M)			
M_1	28.12	19.91	24.02
M_2	29.03	20.32	24.68
M_3	31.62	21.81	26.71
SEm	0.382	0.236	0.525
CD (0.05)	1.246	0.769	2.337
Sub plot (F)			
F_1	30.96	20.73	25.85
F_2	31.01	21.78	26.02
F_3	27.75	19.73	23.75
F_4	29.31	21.45	25.80
F_5	28.81	19.72	24.26
SEm	0.582	0.245	0.677
CD (0.05)	1.657	0.696	2.423
m x f			
m_1f_1	30.04	16.66	23.35
m_1f_2	30.03	22.52	26.27
m_1f_3	25.52	21.39	23.46
m_1f_4	26.94	18.96	22.95
m_1f_5	28.09	20.03	24.06
m_2f_1	28.24	20.70	24.47
m_2f_2	30.32	22.55	26.44
m_2f_3	28.41	19.16	23.78
m_2f_4	30.84	21.15	25.99
m_2f_5	27.34	18.06	22.70
m_3f_1	34.61	24.82	29.71
m_3f_2	30.44	20.27	25.36
m_3f_3	29.36	18.65	24.01
m_3f_4	31.74	24.24	28.09
m_3f_5	30.99	21.06	26.02
SEm	1.009	0.424	1.173
CD (0.05)	2.870	1.205	3.484

planting and weed management measures. The highest rice equivalent yield was produced in F_2 which was on par with the other methods of fertilizer application, except F_3 and F_5. The direct and residual effect of treatment combination, m_3f_1 (dibbling of seeds + stubble mulching along with broadcasting of 60:30:30 kg NPK ha^{-1}) registered significantly the highest rice equivalent yield of 29.71 t ha^{-1} which was superior to all the other combinations, except m_3f_4 (dibbling of seeds + stubble mulching along with foliar spray of water soluble complex fertilizer DAP and SOP each @ 2 per cent).

4.5.2. Economic Analysis of Cropping System

4.5.2.1. Net Return

Data presented in Table 37 represents the direct and residual effect of various treatments on net return of rice – cassava+groundnut - cowpea system. The highest net return was registered in m_3f_1 followed by m_3f_2 in the first year and m_3f_4 in the second year.

The results of pooled analysis presented in Table 37 revealed the treatment variation in net return of the rice – cassava+groundnut - cowpea system. The highest net return of 3,17,358.35 Rs ha^{-1} was registered in direct and residual effect of treatment combination m_3f_1 (dibbling of seeds + stubble mulching along with broadcasting of 60:30:30 kg NPK ha^{-1}), which was followed by m_3f_4.

4.5.2.2. Benefit Cost Ratio

The data presented in Table 37 showed that during the first year, direct and residual effect of dibbling of seeds + stubble mulching along with broadcasting of 60:30:30 kg NPK ha^{-1} (m_3f_1) resulted in the highest benefit: cost ratio. During the

Table 37. Direct and residual effect of treatments on economic analysis of rice – cassava + groundnut - cowpea system

Treatments	Net return (Rs. ha^{-1})	Benefit:Cost (B:C)	Net return (Rs. ha^{-1})	Benefit:Cost (B:C)	Pooled Net return (Rs. ha^{-1})	Pooled B:C
	2013-14		2014-15			
m_1f_1	305118.56	2.23	127902.78	1.52	216510.67	1.88
m_1f_2	305474.64	2.23	178927.12	1.73	242200.88	1.98
m_1f_3	233813.26	1.95	161519.66	1.67	197666.46	1.81
m_1f_4	248880.60	2.01	112943.62	1.47	180912.11	1.74
m_1f_5	281387.00	2.18	145493.92	1.62	213440.46	1.90
m_2f_1	278734.56	2.13	148727.08	1.61	213730.82	1.87
m_2f_2	316645.20	2.28	183388.84	1.75	250017.02	2.02
m_2f_3	281027.00	2.15	125353.98	1.52	203190.49	1.84
m_2f_4	326948.52	2.34	161272.20	1.67	244110.36	2.00
m_2f_5	268126.26	2.13	105028.68	1.45	186577.47	1.79
m_3f_1	421177.40	2.66	213539.30	1.85	317358.35	2.26
m_3f_2	341133.24	2.34	136686.02	1.54	238909.63	1.94
m_3f_3	292890.70	2.17	102039.42	1.41	197465.06	1.79
m_3f_4	311914.32	2.24	211122.38	1.85	261518.35	2.04
m_3f_5	330828.42	2.35	153942.84	1.64	242385.63	1.99

second year, the highest benefit: cost ratio of 1.85 was produced in both the treatment combinations of m_3f_1 and m_3f_4.

On pooled analysis (Table 37), direct and residual effect of m_3f_1 produced the highest benefit : cost ratio of 2.26, which was followed by the treatment combination of m_3f_4 (dibbling of seeds + stubble mulching along with foliar spray of water soluble complex fertilizer DAP and SOP each @ 2 per cent).

4.5.3. Energy Budgeting of Cropping System

4.5.3.1. Energy Efficiency

The results presented in Table 38 indicated that the direct and residual effect of treatments and their interaction had significant effect on the energy efficiency of cropping system in both the years. Among the methods of planting and weed management practices, the highest energy efficiency was registered in M_1 which was on par with M_2 (2013-14). During the second year (2014-15), direct and residual effect of M_2 (dibbling of seeds + power weeding) resulted in the higher energy efficiency of 29.17 which was significantly different from the other treatments, except M_1.

The energy efficiency of the various fertilizer application methods was assessed and it was found that though the highest value was produced in F_5, the highest energy efficiency was registered in F_3 which was on par with F_5 in the first year. In the second year, the highest energy efficiency of 28.86 was observed in F_4, which produced the highest yield and was on par with F_3 and F_5.

Comparing the interactions, the direct and residual effect of m_2f_4 resulted in the highest energy efficiency during both the years without considering the control since the treatment produced the higher yield compared to control.

4.5.3.2. Energy Productivity

The results on the energy productivity of the cropping system as affected by the direct and residual effect of methods of planting, weed and nutrient management measures are presented in Table 38. Direct and residual effect of broadcasting of seeds (M_1) as well as dibbling of seeds with power weeding (M_2) produced significantly the highest value of energy productivity as compared to M_3 in the first year. During the second year, M_2 resulted in the highest energy productivity of 0.39 kg MJ^{-1} and it was on par with M_1.

The highest energy productivity was recorded in F_4 with a value of 0.45 kg MJ^{-1} which was on par with F_5 during 2013-14. In the second year, the direct and residual effect of F_4 resulted in significantly the highest energy productivity which was on par with other fertilizer application methods, except F_1 and F_2.

Among the treatment combinations, the direct and residual effect of m_1f_1 and m_2f_4 produced the higher energy productivity (0.54 kg MJ^{-1}) in the first year which was significantly different from all the other combinations, except m_1f_5. In the second year, the highest energy productivity was registered in m_1f_3 and was on par with m_1f_5 and m_2f_4.

4.5.3.3. Specific Energy

Data summarized in Table 38 showed that the direct as well as residual effect of treatments and their combinations had significant effect on specific energy of the cropping system. During both the years, direct as well as residual effect of M_3 (dibbling of seeds with stubble mulching) resulted in significantly the higher values of specific energy which was significantly superior to other two methods of planting and weed control measures.

The direct as well as residual effect of various fertilizer application methods did not show any significant variation in the first year. During 2014-15, the highest specific energy was registered in F_1 which was on par with F_2.

The specific energy was not influenced by the different treatment combinations during 2013-14. In the second year, the direct and residual effect of m_3f_2 produced significantly the highest value which was superior to all the other interactions, except m_3f_3 which was on par.

4.5.3.4. Energy Intensity

The results pertaining to the energy intensity of the cropping system are presented in Table 38. Comparing the methods of planting and weed control practices, direct as well as residual effect of M_2 resulted in significantly the highest energy intensity value in the first and second years (4.19 and 5.08 MJ Rs^{-1} respectively). The treatment was on par with M_3 in the first year (2013-14).

Table 38. Direct and residual effect of treatments on energy budgeting of rice – cassava + groundnut - cowpea system

Treatments	Energy Efficiency		Energy Productivity (kg MJ^{-1})		Specific Energy (MJ kg^{-1})		Energy Intensity (MJ Rs^{-1})	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Main plot (M)								

M_1	22.31	28.22	0.49	0.38	2.10	2.68	3.85	4.71
M_2	22.26	29.17	0.49	0.39	2.12	2.61	4.19	5.08
M_3	18.61	22.17	0.31	0.24	3.32	4.24	4.10	4.37
SEm	0.276	0.507	0.007	0.003	0.079	0.037	0.045	0.105
CD (0.05)	0.899	1.652	0.022	0.010	0.260	0.122	0.147	0.341
Sub plot (F)								
F_1	20.25	23.24	0.42	0.30	2.58	3.45	4.04	4.26
F_2	18.21	24.15	0.41	0.32	2.59	3.35	4.00	4.91
F_3	22.94	28.17	0.43	0.35	2.53	3.18	3.98	4.63
F_4	20.51	28.86	0.45	0.36	2.41	2.88	3.83	4.89
F_5	23.83	28.17	0.45	0.35	2.48	3.02	4.38	4.91
SEm	0.407	0.399	0.007	0.004	0.080	0.035	0.093	0.114
CD (0.05)	1.159	1.133	0.019	0.012	NS	0.099	0.263	0.323
m x f								
m_1f_1	23.09	19.87	0.54	0.28	1.90	3.54	3.98	3.78
m_1f_2	17.93	26.28	0.46	0.38	2.27	2.62	3.58	4.93
m_1f_3	23.23	31.49	0.46	0.44	2.25	2.28	4.13	4.92
m_1f_4	19.32	28.71	0.47	0.38	2.12	2.63	3.08	4.33
m_1f_5	27.10	34.73	0.52	0.43	1.98	2.35	4.50	5.58
m_2f_1	17.72	25.55	0.43	0.35	2.41	2.88	4.10	4.60
m_2f_2	20.47	25.13	0.46	0.38	2.23	2.62	4.70	5.20
m_2f_3	22.49	30.42	0.51	0.39	2.01	2.56	3.58	5.28
m_2f_4	25.45	33.66	0.54	0.42	1.91	2.36	4.50	5.61
m_2f_5	25.16	31.10	0.51	0.38	2.06	2.62	4.06	4.71
m_3f_1	19.95	24.31	0.30	0.25	3.42	3.94	4.04	4.39
m_3f_2	16.23	21.04	0.31	0.21	3.26	4.82	3.73	4.57
m_3f_3	23.09	22.61	0.31	0.21	3.33	4.69	4.21	3.70
m_3f_4	16.76	24.21	0.32	0.27	3.20	3.67	3.91	4.73
m_3f_5	17.02	18.67	0.33	0.25	3.41	4.08	4.60	4.45
SEm	0.706	0.690	0.012	0.008	0.139	0.060	0.161	0.197
CD (0.05)	2.007	1.963	0.034	0.021	NS	0.171	0.456	0.559

Comparing the methods of fertilizer application, during the first year, the highest energy intensity was registered in F_1 without considering the control (F_5), since F_1 produced the highest system yield than control. In the second year, the direct and residual effect of F_2 resulted in the higher value and was on par with all the other treatments except F_1.

The direct as well as residual effect of m_2f_2 resulted in the highest energy intensity (4.70 MJ Rs^{-1}) and was significantly superior to all the other interactions except m_1f_5, m_2f_4 and m_3f_5 which were on par with m_2f_2 in the first year. During 2014-15, the highest energy intensity was recorded in the treatment combination of m_2f_4, which was on par with m_1f_5, m_2f_2 and m_2f_3.

4.5.4. Nutrient Balance Sheet of Cropping System

The results on the balance sheet of available nitrogen, phosphorous and potassium content in soil for each crop in the rice – cassava + groundnut – cowpea system for two years (2013-14 and 2014-5) are given below.

4.5.4.1. Nitrogen Balance Sheet

Data summarized in Table 39 and 40 showed the direct and residual effect of treatments on nitrogen balance sheet during the two years in rice. The gain in available nitrogen was recorded in the treatment combinations of m_1f_1, m_1f_3, m_2f_5 and m_3f_3. All the other combinations registered a negative balance of available nitrogen in the first year. The highest build up of 62.14 kg ha^{-1} over the initial soil level was in the treatment where seeds were broadcast along with broadcasting of 60:30:30 kg NPK ha^{-1} (m_1f_1). In the second year of rice, all the treatments showed a negative balance of available nitrogen content in soil.

The data on the balance sheet of available nitrogen for cassava intercropped with groundnut in both the years (Table 41 and 42) revealed that the direct and residual effect of treatments, m_1f_4, m_1f_5, m_2f_2, m_2f_4, m_3f_1, m_3f_2 and m_3f_5 showed an actual positive balance of nitrogen during 2013-14. All other treatments produced a negative balance with the lowest value in m_2f_3 (dibbling of seeds with power weeding along with foliar spray of water soluble complex fertilizer 19:19:19 @ 0.5 per cent). Compared to the first crop of rice more treatments showed a gain in available nitrogen in the first year of cassava. During 2014-15, most of the treatment combinations resulted in an actual positive balance, except m_1f_1, m_1f_4, m_2f_3, m_2f_5 and m_3f_4 which showed an actual loss in available nitrogen content in soil. The available nitrogen content showed a positive balance after the second year in cassava compared to the first year.

The results on the nitrogen balance sheet of first and second year cowpea as affected by the direct and residual effect of methods of planting and weed management measures and fertilizer application are presented in Table 43and 44. The highest build up of 304.93 kg ha^{-1} was in the treatment (m_3f_3) where seeds were dibbled with stubble mulching and foliar application of water soluble complex fertilizer 19:19:19 @ 0.5 per cent was followed. All the treatments recorded a positive balance of available nitrogen in the first year crop of cowpea, except the treatments of m_2f_1, m_2f_4 and m_3f_2 which showed an actual loss of nitrogen. Compared to first year, in the second year cowpea more treatments showed a reduction in the available nitrogen content, but the reduction was less in foliar treatment combinations whereas some of the combinations showed a positive balance.

Table 39. Direct and residual effect of treatments on nitrogen balance sheet (kg ha^{-1}) of rice (2013-14)

Treatments	Initial (A)	Added (B)	Crop uptake (C)	Expected balance D =(A+B)-C	Soil available (E)	Actual gain/loss (E-A/A-E)
m_1f_1	423.36	120.00	114.31	429.05	485.50	62.14
m_1f_2	423.36	120.00	91.03	452.33	387.09	-36.27
m_1f_3	423.36	61.40	111.82	372.94	447.03	23.67
m_1f_4	423.36	65.40	127.04	361.72	340.43	-82.93
m_1f_5	423.36	0.00	86.44	336.93	307.50	-115.86
m_2f_1	423.36	120.00	133.25	410.11	360.70	-62.66
m_2f_2	423.36	120.00	183.67	359.69	299.44	-123.92
m_2f_3	423.36	61.40	94.35	390.41	358.62	-64.74
m_2f_4	423.36	65.40	98.36	390.40	322.70	-100.66
m_2f_5	423.36	0.00	92.17	331.19	454.48	31.12
m_3f_1	423.36	120.00	128.06	415.30	314.27	-109.09
m_3f_2	423.36	120.00	112.22	431.14	318.76	-104.60
m_3f_3	423.36	61.40	151.53	333.23	462.16	38.80
m_3f_4	423.36	65.40	104.05	384.71	416.41	-6.95
m_3f_5	423.36	0.00	120.37	302.99	372.75	-50.61

Table 40. Direct and residual effect of treatments on nitrogen balance sheet (kg ha^{-1}) of rice (2014-15)

Treatments	Initial (A)	Added (B)	Crop uptake (C)	Expected balance D =(A+B)-C	Soil available (E)	Actual gain/loss (E-A/A-E)
m_1f_1	319.73	120.00	107.62	332.10	265.22	-54.51
m_1f_2	394.06	120.00	131.42	382.64	202.94	-191.11
m_1f_3	529.39	61.40	235.89	354.90	195.93	-333.47
m_1f_4	515.72	65.40	109.88	471.24	255.96	-259.76
m_1f_5	369.06	0.00	166.12	202.94	205.63	-163.43
m_2f_1	299.28	120.00	205.07	214.20	196.22	-103.05
m_2f_2	588.81	120.00	165.73	543.08	252.67	-336.14
m_2f_3	506.79	61.40	201.31	366.88	234.60	-272.19
m_2f_4	427.12	65.40	207.21	285.31	227.58	-199.53
m_2f_5	585.90	0.00	117.49	468.41	186.22	-399.68
m_3f_1	558.48	120.00	191.11	487.37	253.87	-304.62
m_3f_2	323.60	120.00	161.09	282.51	198.91	-124.69
m_3f_3	561.93	61.40	138.19	485.13	173.38	-388.55
m_3f_4	366.45	65.40	176.79	255.07	270.74	-95.71
m_3f_5	419.71	0.00	152.73	266.98	221.31	-198.40

Table 41. Direct and residual effect of treatments on nitrogen balance sheet (kg ha^{-1}) of cassava (2013-14)

Treatments	Initial (A)	Added (B)	Crop uptake (C)	Expected balance D =(A+B)-C	Soil available (E)	Actual gain/loss (E-A/A-E)
m_1f_1	485.50	252.40	263.32	474.58	240.44	-245.07
m_1f_2	387.09	252.40	241.49	398.00	262.75	-124.34
m_1f_3	447.03	252.40	124.25	575.19	292.90	-154.14
m_1f_4	340.43	252.40	232.18	360.65	362.23	21.79
m_1f_5	307.50	252.40	187.27	372.63	356.47	48.96
m_2f_1	360.70	252.40	149.45	463.65	318.40	-42.30
m_2f_2	299.44	252.40	192.48	359.36	392.75	93.31
m_2f_3	358.62	252.40	249.98	361.03	326.25	-32.36
m_2f_4	322.70	252.40	190.56	384.54	449.40	126.70
m_2f_5	454.48	252.40	144.38	562.51	297.63	-156.86
m_3f_1	314.27	252.40	266.05	300.62	417.89	103.62
m_3f_2	318.76	252.40	271.13	300.03	496.66	177.90
m_3f_3	462.16	252.40	250.07	464.49	256.99	-205.16
m_3f_4	416.41	252.40	214.06	454.76	307.41	-109.00
m_3f_5	372.75	252.40	136.64	488.52	419.68	46.92

Table 42. Direct and residual effect of treatments on nitrogen balance sheet (kg ha^{-1}) of cassava (2014-15)

Treatments	Initial (A)	Added (B)	Crop uptake (C)	Expected balance D =(A+B)-C	Soil available (E)	Actual gain/loss (E-A/A-E)
m_1f_1	265.22	252.40	153.58	364.04	207.27	-57.94
m_1f_2	202.94	252.40	114.69	340.65	408.28	205.33
m_1f_3	195.93	252.40	112.89	335.44	445.91	249.98
m_1f_4	255.96	252.40	120.74	387.62	219.22	-36.74
m_1f_5	205.63	252.40	128.74	329.30	463.53	257.90
m_2f_1	196.22	252.40	167.12	281.50	436.20	239.98
m_2f_2	252.67	252.40	129.46	375.62	393.79	141.12
m_2f_3	234.60	252.40	94.47	392.54	203.39	-31.21
m_2f_4	227.58	252.40	87.26	392.72	451.88	224.30
m_2f_5	186.22	252.40	102.41	336.21	180.99	-5.23
m_3f_1	253.87	252.40	147.08	359.19	437.70	183.83
m_3f_2	198.91	252.40	97.23	354.08	211.46	12.54
m_3f_3	173.38	252.40	119.98	305.80	508.18	334.81
m_3f_4	270.74	252.40	111.80	411.34	204.14	-66.60
m_3f_5	221.31	252.40	114.26	359.45	280.75	59.43

Table 43. Direct and residual effect of treatments on nitrogen balance sheet (kg ha^{-1}) of cowpea (2013-14)

Treatments	Initial (A)	Added (B)	Crop uptake (C)	Expected balance D =(A+B)-C	Soil available (E)	Actual gain/loss (E-A/A-E)
m_1f_1	240.44	262.40	58.44	444.40	319.73	79.29
m_1f_2	262.75	262.40	56.85	468.30	394.06	131.30
m_1f_3	292.90	262.40	27.36	527.93	529.39	236.49
m_1f_4	362.23	262.40	35.05	589.58	515.72	153.49
m_1f_5	356.47	262.40	41.70	577.17	369.06	12.60
m_2f_1	318.40	262.40	49.49	531.31	299.28	-19.12
m_2f_2	392.75	262.40	37.18	617.97	588.81	196.06
m_2f_3	326.25	262.40	62.46	526.20	506.79	180.53
m_2f_4	449.40	262.40	66.61	645.19	427.12	-22.28
m_2f_5	297.63	262.40	63.38	496.65	585.90	288.27
m_3f_1	417.89	262.40	57.10	623.19	558.48	140.60
m_3f_2	496.66	262.40	46.85	712.21	323.60	-173.06
m_3f_3	256.99	262.40	46.37	473.02	561.93	304.93
m_3f_4	307.41	262.40	38.15	531.67	366.45	59.04
m_3f_5	419.68	262.40	38.65	643.42	419.71	0.03

Table 44. Direct and residual effect of treatments on nitrogen balance sheet (kg ha^{-1}) of cowpea (2014-15)

Treatments	Initial (A)	Added (B)	Crop uptake (C)	Expected balance D =(A+B)-C	Soil available (E)	Actual gain/loss (E-A/A-E)
m_1f_1	207.27	262.40	36.11	433.57	312.85	105.58
m_1f_2	408.28	262.40	42.50	628.17	272.38	-135.89
m_1f_3	445.91	262.40	38.91	669.40	308.37	-137.54
m_1f_4	219.22	262.40	27.59	454.03	297.17	77.95
m_1f_5	463.53	262.40	43.42	682.51	267.90	-195.63
m_2f_1	436.20	262.40	60.00	638.60	291.50	-144.70
m_2f_2	393.79	262.40	53.80	602.39	298.37	-95.42
m_2f_3	203.39	262.40	45.39	420.41	283.73	80.34
m_2f_4	451.88	262.40	48.87	665.41	374.77	-77.11
m_2f_5	180.99	262.40	53.41	389.98	297.17	116.18
m_3f_1	437.70	262.40	70.45	629.64	311.34	-126.36
m_3f_2	211.46	262.40	75.85	398.01	192.86	-18.60
m_3f_3	508.18	262.40	76.25	694.33	539.89	31.71
m_3f_4	204.14	262.40	87.80	378.74	298.37	94.23
m_3f_5	280.75	262.40	82.92	460.23	309.57	28.82

4.5.4.2. Phosphorus Balance Sheet

The results on the balance sheet of available phosphorus content in the soil after rice during 2013-14 and 2014-15 are presented in Table 45 and 46. The available phosphorus content after the first year rice resulted in a positive balance of all the combinations, except the treatments, m_1f_2, m_2f_5 and m_2f_4 which showed negative phosphorus content over the initial soil level. During 2014-15, the direct and residual effect of most of the treatments showed depletion in available phosphorous content after the rice crop. The treatment of m_2f_2 (dibbling of seeds with power weeding and band placement of 60:30:30 kg NPK ha^{-1}) recorded a build up of available phosphorus content (71.59 kg ha^{-1}) in the second year rice crop.

Data depicted in Table 47 showed a depletion of available phosphorus content in the soil after first year cassava, except the treatment m_2f_4 (dibbling of seeds with power weeding and foliar spray of water soluble complex fertilizer DAP and SOP each @ 2 per cent) which produced an actual gain of 1.45 kg ha^{-1}. During the second year (Table 48), the phosphorus balance sheet of the treatment combinations after cassava resulted in a build up (m_3f_3, m_1f_2, m_1f_3, m_1f_5, m_2f_3, m_2f_5, m_3f_2 and m_1f_1) compared to the first year cassava, while the other treatments produced a negative balance.

The results presented in Table 49 and 50 indicated that the direct and residual effect of treatments had influenced the balance sheet of available phosphorus content in the soil after cowpea over two years (2013-14 and 2014-15). In the first year, all the treatment combinations resulted in an actual gain in available phosphorus content

Table 45. Direct and residual effect of treatments on phosphorous balance sheet of rice (kg ha^{-1}) (2013-14)

Treatments	Initial (A)	Added (B)	Crop uptake (C)	Expected balance D =(A+B)-C	Soil available (E)	Actual gain/loss (E-A/A-E)
m_1f_1	63.84	49.00	11.61	101.23	69.77	5.93
m_1f_2	63.84	49.00	11.35	101.49	60.30	-3.54
m_1f_3	63.84	20.40	20.33	63.91	119.86	56.02
m_1f_4	63.84	32.80	9.54	87.11	97.94	34.10
m_1f_5	63.84	0.00	12.93	50.91	81.44	17.60
m_2f_1	63.84	49.00	21.31	91.53	104.82	40.98
m_2f_2	63.84	49.00	15.83	97.01	113.64	49.80
m_2f_3	63.84	20.40	11.48	72.76	108.42	44.58
m_2f_4	63.84	32.80	16.60	80.04	52.71	-11.13
m_2f_5	63.84	0.00	10.56	53.28	48.89	-14.95
m_3f_1	63.84	49.00	18.92	93.92	141.45	77.61
m_3f_2	63.84	49.00	11.68	101.16	103.09	39.25
m_3f_3	63.84	20.40	18.80	65.45	76.28	12.44
m_3f_4	63.84	32.80	17.63	79.01	123.98	60.14
m_3f_5	63.84	0.00	15.76	48.08	67.76	3.92

Table 46. Direct and residual effect of treatments on phosphorous balance sheet of rice (kg ha^{-1}) (2014-15)

Treatments	Initial (A)	Added (B)	Crop uptake (C)	Expected balance D =(A+B)-C	Soil available (E)	Actual gain/loss (E-A/A-E)
m_1f_1	97.73	49.00	22.06	124.67	97.17	-0.56
m_1f_2	158.41	49.00	27.55	179.86	121.44	-36.97
m_1f_3	89.56	20.40	25.98	83.98	124.03	34.48
m_1f_4	203.59	32.80	19.30	217.09	148.15	-55.44
m_1f_5	92.09	0.00	24.35	67.74	97.59	5.49
m_2f_1	104.01	49.00	25.29	127.72	138.37	34.36
m_2f_2	131.50	49.00	28.10	152.41	203.10	71.59
m_2f_3	191.98	20.40	28.66	183.72	150.22	-41.76
m_2f_4	127.78	32.80	31.52	129.06	142.33	14.55
m_2f_5	75.15	0.00	17.80	57.35	70.27	-4.89
m_3f_1	189.88	49.00	23.46	215.43	178.30	-11.58
m_3f_2	132.99	49.00	26.69	155.31	160.42	27.43
m_3f_3	128.89	20.40	19.12	130.18	102.16	-26.73
m_3f_4	154.32	32.80	24.63	162.49	202.59	48.27
m_3f_5	142.32	0.00	23.46	118.86	154.91	12.58

Table 47. Direct and residual effect of treatments on phosphorous balance sheet of cassava (kg ha^{-1}) (2013-14)

Treatments	Initial (A)	Added (B)	Crop uptake (C)	Expected balance D =(A+B)-C	Soil available (E)	Actual gain/loss (E-A/A-E)
m_1f_1	69.77	149.90	114.09	105.58	60.16	-9.61
m_1f_2	60.30	149.90	95.18	115.02	43.10	-17.19
m_1f_3	119.86	149.90	47.34	222.42	38.07	-81.79
m_1f_4	97.94	149.90	76.90	170.94	72.93	-25.01
m_1f_5	81.44	149.90	68.95	162.40	64.97	-16.48
m_2f_1	104.82	149.90	60.73	194.00	49.15	-55.67
m_2f_2	113.64	149.90	67.10	196.44	60.57	-53.07
m_2f_3	108.42	149.90	77.87	180.46	53.85	-54.57
m_2f_4	52.71	149.90	71.83	130.78	54.15	1.45
m_2f_5	48.89	149.90	53.76	145.03	46.26	-2.63
m_3f_1	141.45	149.90	111.47	179.88	72.32	-69.13
m_3f_2	103.09	149.90	82.67	170.32	49.94	-53.14
m_3f_3	76.28	149.90	77.47	148.71	50.52	-25.76
m_3f_4	123.98	149.90	61.99	211.89	47.56	-76.41
m_3f_5	67.76	149.90	70.75	146.91	58.25	-9.51

Table 48. Direct and residual effect of treatments on phosphorous balance sheet of cassava (kg ha^{-1}) (2014-15)

Treatments	Initial (A)	Added (B)	Crop uptake (C)	Expected balance D =(A+B)-C	Soil available (E)	Actual gain/loss (E-A/A-E)
m_1f_1	97.17	149.90	37.32	209.76	149.31	52.14
m_1f_2	121.44	149.90	39.93	231.42	167.20	45.76
m_1f_3	124.03	149.90	39.77	234.16	126.63	2.60
m_1f_4	148.15	149.90	48.70	249.35	124.75	-23.40
m_1f_5	97.59	149.90	45.05	202.44	159.80	62.22
m_2f_1	138.37	149.90	57.11	231.16	132.90	-5.47
m_2f_2	203.10	149.90	59.62	293.38	99.35	-103.74
m_2f_3	150.22	149.90	41.68	258.44	210.83	60.61
m_2f_4	142.33	149.90	24.57	267.66	105.84	-36.49
m_2f_5	70.27	149.90	42.73	177.44	145.11	74.85
m_3f_1	178.30	149.90	65.44	262.76	126.03	-52.27
m_3f_2	160.42	149.90	39.55	270.78	178.51	18.09
m_3f_3	102.16	149.90	38.40	213.66	129.96	27.80
m_3f_4	202.59	149.90	52.15	300.34	143.57	-59.01
m_3f_5	154.91	149.90	43.81	261.00	124.90	-30.01

Table 49. Direct and residual effect of treatments on phosphorous balance sheet of cowpea (kg ha^{-1}) (2013-14)

Treatments	Initial (A)	Added (B)	Crop uptake (C)	Expected balance D =(A+B)-C	Soil available (E)	Actual gain/loss (E-A/A-E)
m_1f_1	60.16	108.40	5.78	162.78	97.73	37.57
m_1f_2	43.10	108.40	7.19	144.31	158.41	115.31
m_1f_3	38.07	108.40	3.59	142.88	89.56	51.48
m_1f_4	72.93	108.40	3.22	178.11	203.59	130.66
m_1f_5	64.97	108.40	5.25	168.12	92.09	27.12
m_2f_1	49.15	108.40	6.22	151.34	104.01	54.85
m_2f_2	60.57	108.40	3.87	165.10	131.50	70.94
m_2f_3	53.85	108.40	6.03	156.22	191.98	138.13
m_2f_4	54.15	108.40	5.30	157.26	127.78	73.63
m_2f_5	46.26	108.40	8.25	146.42	75.15	28.89
m_3f_1	72.32	108.40	5.19	175.53	189.88	117.56
m_3f_2	49.94	108.40	5.50	152.85	132.99	83.05
m_3f_3	50.52	108.40	9.10	149.82	128.89	78.37
m_3f_4	47.56	108.40	6.13	149.83	154.32	106.76
m_3f_5	58.25	108.40	4.72	161.93	142.32	84.07

Table 50. Direct and residual effect of treatments on phosphorous balance sheet of cowpea (kg ha^{-1}) (2014-15)

Treatments	Initial (A)	Added (B)	Crop uptake (C)	Expected balance D =(A+B)-C	Soil available (E)	Actual gain/loss (E-A/A-E)
m_1f_1	149.31	108.40	5.60	252.11	169.03	19.72
m_1f_2	167.20	108.40	6.59	269.01	110.31	-56.89
m_1f_3	126.63	108.40	7.11	227.92	185.58	58.95
m_1f_4	124.75	108.40	3.10	230.05	185.20	60.45
m_1f_5	159.80	108.40	7.78	260.43	220.14	60.33
m_2f_1	132.90	108.40	8.61	232.69	120.88	-12.02
m_2f_2	99.35	108.40	6.63	201.12	187.27	87.92
m_2f_3	210.83	108.40	6.10	313.13	174.07	-36.76
m_2f_4	105.84	108.40	5.83	208.41	168.76	62.93
m_2f_5	145.11	108.40	7.65	245.87	195.14	50.03
m_3f_1	126.03	108.40	7.76	226.67	155.37	29.34
m_3f_2	178.51	108.40	12.62	274.30	107.45	-71.06
m_3f_3	129.96	108.40	12.16	226.20	194.41	64.45
m_3f_4	143.57	108.40	15.37	236.61	169.95	26.38
m_3f_5	124.90	108.40	14.67	218.63	155.14	30.24

with the highest build up of 138.13 kg ha^{-1} in the treatment m_2f_3 (dibbling of seeds with power weeding and foliar spray of water soluble complex fertilizer 19:19:19 @ 0.5 per cent). In the second year, combinations of m_1f_2, m_2f_1, m_2f_3 and m_3f_2 registered a negative phosphorus balance compared to all other combinations which showed a gain over the initial soil level.

4.5.4.3. Potassium Balance Sheet

Data presented in Table 51 and 52 indicates the direct and residual effect of various treatments on potassium balance sheet of rice during 2013-14 and 2014-15. The potassium balance was positive in treatments m_3f_1 with a highest build up of 181.26 kg ha^{-1}, m_3f_2 and m_3f_5 whereas, all the other combinations resulted in the depletion of available potassium in the first year in rice. In the second year, the direct and residual effect of most of the treatments recorded an actual gain in potassium content compared to the first year. But m_1f_4, m_2f_2 and all the methods of fertilizer application in combination with dibbling of seeds with stubble mulching showed a depletion of potassium in rice for the period of 2014-15.

The direct and residual effect of various treatments on available potassium content in soil of cassava during both the years (Table 53 and 54) showed that all the treatments resulted in a negative potassium balance, except the treatments m_2f_1, m_2f_5, m_3f_3 and m_3f_4 which showed an actual gain over the initial soil level in the first year. During second year in cassava, all the combinations recorded a build up of available potassium content in soil with a value of 191.37 kg ha^{-1} (m_3f_1) compared to first year cassava. However, the treatments of m_1f_1, m_1f_4 and m_2f_3 showed a negative balance but the rate of depletion was very less compared to the initial soil status.

Table 51. Direct and residual effect of treatments on potassium balance sheet of rice (kg ha^{-1}) (2013-14)

Treatments	Initial (A)	Added (B)	Crop uptake (C)	Expected balance D =(A+B)-C	Soil available (E)	Actual gain/loss (E-A/A-E)
m_1f_1	352.8	50.00	86.53	316.27	268.34	-84.46
m_1f_2	352.8	50.00	69.93	332.87	300.88	-51.92
m_1f_3	352.8	21.40	127.08	247.13	260.10	-92.70
m_1f_4	352.8	35.00	68.50	319.30	284.98	-67.82
m_1f_5	352.8	0.00	93.89	258.92	240.25	-112.55
m_2f_1	352.8	50.00	117.49	285.31	208.74	-144.06
m_2f_2	352.8	50.00	120.34	282.46	340.10	-12.70
m_2f_3	352.8	21.40	67.36	306.84	298.36	-54.44
m_2f_4	352.8	35.00	118.13	269.67	283.80	-69.00
m_2f_5	352.8	0.00	88.12	264.69	229.95	-122.85
m_3f_1	352.8	50.00	118.73	284.07	534.06	181.26
m_3f_2	352.8	50.00	114.04	288.76	524.62	171.82
m_3f_3	352.8	21.40	93.58	280.62	209.13	-143.67
m_3f_4	352.8	35.00	93.69	294.11	163.29	-189.51
m_3f_5	352.8	0.00	105.44	247.36	384.20	31.40

Table 52. Direct and residual effect of treatments on potassium balance sheet of rice (kg ha^{-1}) (2014-15)

Treatments	Initial (A)	Added (B)	Crop uptake (C)	Expected balance D =(A+B)-C	Soil available (E)	Actual gain/loss (E-A/A-E)
m_1f_1	317.64	50.00	120.88	246.76	393.69	76.05
m_1f_2	254.09	50.00	178.42	125.66	323.46	69.37
m_1f_3	315.59	21.40	139.66	197.33	362.35	46.76
m_1f_4	382.40	35.00	89.15	328.24	354.61	-27.79
m_1f_5	227.30	0.00	163.53	63.77	344.67	117.37
m_2f_1	289.52	50.00	196.25	143.27	361.79	72.27
m_2f_2	376.67	50.00	170.89	255.78	291.30	-85.37
m_2f_3	267.16	21.40	129.74	158.81	394.24	127.09
m_2f_4	228.11	35.00	170.93	92.18	350.89	122.79
m_2f_5	235.22	0.00	132.79	102.42	352.97	117.76
m_3f_1	305.26	50.00	113.14	242.13	115.14	-190.12
m_3f_2	292.30	50.00	152.17	190.13	234.05	-58.24
m_3f_3	284.93	21.40	139.37	166.95	212.29	-72.63
m_3f_4	244.17	35.00	174.61	104.56	177.25	-66.92
m_3f_5	382.46	0.00	108.77	273.69	235.18	-147.28

Table 53. Direct and residual effect of treatments on potassium balance sheet of cassava (kg ha^{-1}) (2013-14)

Treatments	Initial (A)	Added (B)	Crop uptake (C)	Expected balance D =(A+B)-C	Soil available (E)	Actual gain/loss (E-A/A-E)
m_1f_1	268.34	152.40	265.07	155.68	219.57	-48.78
m_1f_2	300.88	152.40	217.30	235.98	142.30	-158.57
m_1f_3	260.10	152.40	131.71	280.79	203.88	-56.23
m_1f_4	284.98	152.40	249.12	188.26	159.24	-125.74
m_1f_5	240.25	152.40	157.65	235.00	191.57	-48.68
m_2f_1	208.74	152.40	141.75	219.40	293.06	84.32
m_2f_2	340.10	152.40	144.02	348.47	214.72	-125.38
m_2f_3	298.36	152.40	274.38	176.38	216.39	-81.98
m_2f_4	283.80	152.40	183.18	253.02	189.32	-94.48
m_2f_5	229.95	152.40	152.51	229.84	326.39	96.44
m_3f_1	534.06	152.40	244.28	442.18	223.69	-310.37
m_3f_2	524.62	152.40	228.38	448.64	211.90	-312.72
m_3f_3	209.13	152.40	243.33	118.21	218.21	9.08
m_3f_4	163.29	152.40	185.45	130.24	220.66	57.38
m_3f_5	384.20	152.40	187.87	348.73	290.66	-93.54

Table 54. Direct and residual effect of treatments on potassium balance sheet of cassava (kg ha^{-1}) (2014-15)

Treatments	Initial (A)	Added (B)	Crop uptake (C)	Expected balance D =(A+B)-C	Soil available (E)	Actual gain/loss (E-A/A-E)
m_1f_1	393.69	152.40	211.96	334.14	354.40	-39.29
m_1f_2	323.46	152.40	146.87	328.98	372.17	48.72
m_1f_3	362.35	152.40	141.87	372.88	396.22	33.87
m_1f_4	354.61	152.40	175.47	331.54	293.61	-61.00
m_1f_5	344.67	152.40	169.26	327.81	409.96	65.29
m_2f_1	361.79	152.40	224.03	290.16	372.74	10.95
m_2f_2	291.30	152.40	199.12	244.59	314.55	23.25
m_2f_3	394.24	152.40	138.86	407.78	309.12	-85.12
m_2f_4	350.89	152.40	174.41	328.88	421.00	70.11
m_2f_5	352.97	152.40	233.36	272.01	356.52	3.55
m_3f_1	115.14	152.40	205.42	62.13	306.51	191.37
m_3f_2	234.05	152.40	158.18	228.27	304.27	70.21
m_3f_3	212.29	152.40	160.09	204.61	317.79	105.50
m_3f_4	177.25	152.40	161.15	168.50	208.17	30.92
m_3f_5	235.18	152.40	141.47	246.12	287.17	51.98

Table 55. Direct and residual effect of treatments on potassium balance sheet of cowpea (kg ha^{-1}) (2013-14)

Treatments	Initial (A)	Added (B)	Crop uptake (C)	Expected balance D =(A+B)-C	Soil available (E)	Actual gain/loss (E-A/A-E)
m_1f_1	219.57	92.40	40.02	271.95	317.64	98.07
m_1f_2	142.30	92.40	42.02	192.69	254.09	111.78
m_1f_3	203.88	92.40	21.42	274.86	315.59	111.71
m_1f_4	159.24	92.40	29.58	222.06	382.40	223.16
m_1f_5	191.57	92.40	44.57	239.40	227.30	35.73
m_2f_1	293.06	92.40	46.22	339.24	289.52	-3.54
m_2f_2	214.72	92.40	30.18	276.94	376.67	161.95
m_2f_3	216.39	92.40	51.42	257.36	267.16	50.77
m_2f_4	189.32	92.40	44.78	236.94	228.11	38.78
m_2f_5	326.39	92.40	53.44	365.35	235.22	-91.18
m_3f_1	223.69	92.40	44.23	271.86	305.26	81.57
m_3f_2	211.90	92.40	26.97	277.33	292.30	80.40
m_3f_3	218.21	92.40	46.63	263.98	284.93	66.72
m_3f_4	220.66	92.40	35.66	277.40	244.17	23.51
m_3f_5	290.66	92.40	30.14	352.92	382.46	91.80

Table 56. Direct and residual effect of treatments on potassium balance sheet of cowpea (kg ha^{-1}) (2014-15)

Treatments	Initial (A)	Added (B)	Crop uptake (C)	Expected balance D =(A+B)-C	Soil available (E)	Actual gain/loss (E-A/A-E)
m_1f_1	354.40	92.40	25.85	420.95	202.76	-151.64
m_1f_2	372.17	92.40	27.65	436.92	104.11	-268.06
m_1f_3	396.22	92.40	31.87	456.75	195.79	-200.44
m_1f_4	293.61	92.40	12.71	373.30	164.97	-128.64
m_1f_5	409.96	92.40	26.20	476.16	148.44	-261.52
m_2f_1	372.74	92.40	39.34	425.80	155.33	-217.42
m_2f_2	314.55	92.40	36.45	370.50	192.79	-121.76
m_2f_3	309.12	92.40	39.00	362.53	152.25	-156.87
m_2f_4	421.00	92.40	30.75	482.65	257.03	-163.97
m_2f_5	356.52	92.40	34.46	414.46	108.80	-247.73
m_3f_1	306.51	92.40	58.66	340.25	170.26	-136.25
m_3f_2	304.27	92.40	29.57	367.10	212.48	-91.78
m_3f_3	317.79	92.40	42.28	367.91	211.79	-106.00
m_3f_4	208.17	92.40	40.61	259.96	115.19	-92.98
m_3f_5	287.17	92.40	51.14	328.43	199.44	-87.73

The results on the potassium balance sheet of first and second year cowpea are presented in Table 55 and 56. The highest build up of 223.16 kg ha^{-1} was in the residual effect of treatment (m_1f_4) where seeds were broadcasted along with foliar spray of water soluble complex fertilizer DAP and SOP each @ 2 per cent applied to the first year in rice. All the treatments, except m_2f_1 and m_2f_5 recorded a positive potassium balance in the first year cowpea. In the second year, all the combinations showed depletion in available potassium content in soil, but the rate of depletion was less in foliar fertilizer applied combinations compared to the other treatments.

Discussion

5. DISCUSSION

A cropping system experiment on rice – cassava intercropped with groundnut – cowpea was conducted at College of Agriculture, Vellayani during 2013-14 and 2014-15 in upland condition to assess the impact of agronomic interventions on growth, productivity and sustainability of the cropping system, nutrient balance, energetics and economics.

The experiment comprised of three main plot treatments, which included methods of planting in combination with weed control measures [M_1- broadcasting of sprouted seeds, M_2 - dibbling (sprouted seeds with drum seeder along with weeding by power weeder) and M_3 - dibbling (sprouted seeds with drum seeder along with stubble mulching)] and five methods of fertilizer application as sub plot treatments [F_1- broadcasting (60:30:30 kg NPK ha^{-1}), F_2- band placement (60:30:30 kg NPK ha^{-1}), F_3- foliar spray of water soluble complex foliar fertilizer 19:19:19 @ 0.5 per cent, F_4- foliar spray of diammonium phosphate (DAP) and sulphate of potash (SOP) each @ 2per cent, F_5- control] for upland rice. These treatments were replicated five times. For cassava intercropped with groundnut, and cowpea, recommended dose of fertilizers along with 0.5 per cent foliar spray of 19:19:19 was applied at 30 (up to three weeks before harvest) and 14 days (up to one week before first harvest) interval respectively. The results of the study are briefly discussed in this chapter.

5.1. EFFECT OF TREATMENTS ON GROWTH AND PRODUCTIVITY OF RICE IN RICE BASED CROPPING SYSTEM

5.1.1. Effect of Methods of Planting and Weed Control Measures

5.1.1.1. Growth Parameters

In rice, planting methods have direct impact on the growth, productivity and economics of rice cultivation. In this experiment the different methods of planting and weed control measures had significant effect on most of the growth parameters of rice. The various growth characters recorded at maximum tillering and harvest stage revealed that the plant height showed significant variation only at tillering stage in the second year. The leaf area index (LAI) was significantly higher in M_2 (dibbling of seeds using drum seeder + power weeding) at both the stages in the first year and at maximum tillering in the second year. At harvest stage, during second year, there was no significant variation among the three methods of planting and weed control measures. The power weeding might have resulted in the reduction in weed population. Dibbling of seeds using drum seeder resulted in the proper spacing, which helped the plants to utilize maximum sunlight without any competition. Thus combined effect of power weeding as well as dibbling might have helped to produce more number of leaves with maximum area.

Among the methods of planting and weed control practices, broadcasting of seeds showed significant variation in number of tillers m^{-2} only at maximum tillering during the first year. During 2014-15, dibbling of seeds using drum seeder + stubble mulching resulted in higher number of tillers m^{-2} at both the stages. Dibbling might have resulted in maintaining better plant population through proper spacing which led to better utilization of resources resulting in maximum number of tillers m^{-2}. Stubble mulching might have helped in conservation of moisture and release of nutrients more efficiently for the production of maximum number of tillers m^{-2}. Laary *et al.* (2012) reported that direct seeding by dibbling and drilling had better plant establishment and was significantly better than broadcasting of pre-germinated seed. The results of this study are in accordance to that of Ji *et al.* (2012). The chlorophyll content was not influenced significantly by the different methods of planting and weed control practices.

The growth analysis parameters such as crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR) are the measures of photosynthetic efficiency and the factors responsible for higher paddy yield (Thakur and Patel, 1998). In this experiment these parameters varied significantly among the methods of planting and weed control measures. During the first year, dibbling of seeds using drum seeder + stubble mulching produced maximum CGR, RGR and NAR from maximum tillering to harvest stage. Lu *et al.* (2000) also reported similar results. During the second year, broadcasting of seeds produced maximum CGR, RGR and NAR from maximum tillering to harvest stage.

5.1.1.2. Yield and Yield Attributes

The methods of planting and weed control practices significantly influenced most of the yield parameters of rice. The highest grain yield of 2085.42 kg ha^{-1} was recorded in M_2 (dibbling of seeds using drum seeder + power weeding) and was on par with M_3 (dibbling of seeds using drum seeder + stubble mulching) with a yield of 2068.18 kg ha^{-1}, compared to broadcasting of seeds during the first year. Similar results were reported by Mankotia and Shekar (2006). The straw yield was also observed to be higher in treatments M_2 and M_3 (3977.22 and 4098.75 kg ha^{-1} respectively). Mechanical weeding as well as stubble mulching contributed to enhance yield characters by suppressing the weeds, conserving the nutrient reserves and the moisture in soil. Covering or mulching the soil surface could prevent weed seed germination or physically suppress seedling emergence (Bhardwaj, 2013). Better performance of these treatments during first year could be attributed to uniform plant stand and significantly higher number of productive tillers m^{-2}, panicle length, number of grains $panicle^{-1}$, thousand grain weight and dry matter production (DMP). Narasimman *et al.* (2000) reported that rice established through drum seeder produced significantly more number of panicles m^{-2} than transplanted rice. The cumulative beneficial effect of growth and yield attributing characters was finally reflected in higher grain and straw yield.

During the second year the results indicated that the methods of planting and weed control measures did not have any significant effect on the grain yield, straw yield and HI (harvest index) of rice. Even though the yield attributes such as number of productive tillers m^{-2} and panicle length were significant and higher for the treatments M_2 and M_3, all the other attributes were not significant.

5.1.1.3. Uptake of Nutrients

During the first and second years, the highest N, K and S uptake was recorded in the treatment, where dibbling of seeds using drum seeder + power weeding was adopted. This treatment also resulted in highest dry matter production in the first year. Increase in uptake of nutrients was due to the cumulative effect of total dry matter produced and nutrient concentration. These results are in close confirmity with the findings of Gautam *et al.* (2012). But during 2014-15, the yield characters and dry matter production were not significant.

5.1.2. Effect of Methods of Fertilizer Application

5.1.2.1. Growth Parameters

In the first year, foliar spray of water soluble complex fertilizer 19:19:19 @ 0.5 per cent produced the highest plant height at both the stages. In the second year, significantly higher plant height was resulted in band placement of 60:30:30 kg NPK ha^{-1} at both the stages (maximum tillering and harvest). Similar results were reported by Slaton *et al.* (2010). The results on LAI revealed that, all the four methods of fertilizer application were significantly produced higher LAI which were on par compared to absolute control (lowest). Therefore, soil as well as foliar application of fertilizer showed an equal effect on LAI of rice at maximum tillering and harvest stage.

The highest number of tillers m^{-2} was produced in foliar spray of DAP and SOP each @ 2 per cent during 2013-14 at both the stages and however in the second year, number of tillers m^{-2} was significantly higher in the band placement of 60:30:30 kg NPK ha^{-1} at maximum tillering and harvest stage. Foliar spray of nutrients might have helped in better absorption of nutrients within a short period in the absence of soil applied nutrients. Komosa (1990) reported that under conditions of low nutritional status of plants, absorption rates of leaf applied nutrients were higher as compared to those of plants well supplied with nutrients via the roots. But in the second year, soil application helped in producing more number of tillers m^{-2} due to the more availability of nutrients in the root zone area. Similar results were observed in the chlorophyll content (SPAD meter reading) also. In the first year, the highest chlorophyll content was observed in foliar sprayed rice plants and in the second year, significantly the highest chlorophyll content was observed in soil applied plants. Chlorophyll content is an important aspect which determines the photosynthetic efficiency of rice (Kumar *et al*., 2001) and thereby it produced more number of tillers m^{-2} by the synthesis of more assimilates. Highest chlorophyll content was observed in rice plants treated with 19:19:19 complex was also reported by Surya (2015).

The growth analysis parameters such as CGR, RGR and NAR were found significantly superior in the treatment F_3 (19:19:19 @ 0.5 %) which was on par with band placement of 60:30:30 kg NPK ha^{-1} from maximum tillering to harvest stage. Surya (2015) also reported a similar finding, in which, at flowering stage of rice 19:19:19 complex significantly produced the highest NAR of 2.58 mg cm^{-2} day^{-1}. Since, these parameters also influence the rate of photosynthesis which cumulatively resulted in the better utilization of nutrients for higher productivity of rice.

5.1.2.2. Yield and Yield Attributes

The results of the present study indicated significant variation in yield and yield attributes of rice. During 2013-14, the effect of fertilizer application on the grain yield and straw yield of rice was not significant. The highest number of productive tillers m^{-2} and panicle length were recorded in band placement of 60:30:30 kg NPK ha^{-1}. The foliar spray of water soluble complex fertilizer 19:19:19 @ 0.5 per cent resulted in the highest grain weight $panicle^{-1}$ and number of grains $panicle^{-1}$ during the first year. The foliar fed nutrients were possibly efficiently absorbed by the plant at a faster rate leading to the differentiation into more yield attributing characters. Sarangi and Sharma (2004) also reported similar findings. The highest panicle weight and HI were observed in the treatment F_4 and the sterility percentage was highest in absolute control.

During 2014-15, the grain yield, straw yield and HI were significantly influenced by the different methods of fertilizer application and also the yield was comparatively higher compared to the first year. This was due to the higher yield attributes and lower sterility percentage in the second year. The highest grain yield was in F_3 (foliar spray of 19:19:19 @ 0.5 %) with an increase of 3.71 and 4.29 per cent compared to that of F_2 and F_4 respectively. Better performance of these treatments could be attributed to significantly higher productive tiller count, panicle length, panicle weight, number of grains $panicle^{-1}$ and thousand grain weight recorded. The nutrients applied through foliage would be easily available and translocated in the plants without any loss (Srinivasan and Ramaswamy, 1992). The highest straw yield was registered in F_2, which was significantly higher than all the other treatments. This was due to the higher dry matter produced in the treatment F_2.

5.1.2.3. Uptake of Nutrients

Among the fertilizer application methods in the first year, though the yield characters were not significant, the nutrient uptake was significant, except for potassium. The significantly highest N uptake was recorded in F_2, P uptake in F_1 and S uptake in F_3. In the second year, the uptake of P, K and S was significantly higher in band placement of 60:30:30 kg NPK ha^{-1} (F_2). This was due to the higher dry matter produced in the treatment F_2. The foliar spray of 19:19:19 @ 0.5 per cent resulted in the significantly highest N uptake of 191.80 kg ha^{-1} and the reason might be that, foliar fertilizer helps in more N availability at reproductive stage, which enhanced the total nitrogen uptake.

5.1.3. Interaction Effect

5.1.3.1. Growth Parameters

Among the interaction of methods of planting, weed control practices and methods of fertilizer application, the maximum plant height was noticed in m_3f_3 in the first year, at both the stages. Significantly higher plant height was produced in m_3f_2 at both the stages during 2014-15. Interaction effect did not significantly influence the LAI of rice at both the stages during the years of experiment, except at harvest stage, in the first year. The treatment combination of m_3f_2, had a higher LAI of 4.34, which produced more number of leaves with broader leaf area. This might be due to the better uptake of soil applied nutrients as well as enhanced moisture availability through stubble mulching.

The number of tillers m^{-2} did not show any significant variation due to the interaction effect in the first year. During the second year, dibbling of seeds using drum seeder + stubble mulching along with soil application of fertilizers produced higher number of tillers m^{-2} at both the stages, which is the cumulative effect of higher plant height and LAI. In the first year, at maximum tillering, the highest chlorophyll content was produced in m_1f_3. At harvest stage, it was higher in m_2f_2 and m_2f_3. During the second year, the chlorophyll content was significant only at maximum tillering stage. The highest chlorophyll content might have led to increased photosynthetic rate, which resulted in better yield.

During 2013-14, all the growth analysis parameters such as CGR and RGR except NAR, were significantly different. The highest CGR was observed in m_1f_2 and the treatment combinations, m_1f_1, m_2f_3, m_2f_4 and m_3f_2 showed similar and higher RGR compared to the others from maximum tillering to harvest stage. In the second year, the combination of m_1f_3 (broadcasting of seeds along with foliar spray of 19:19:19 @ 0.5 %) produced higher values for CGR, RGR and NAR from maximum tillering to harvest stage. These results are in agreement with those of Alexander (1986).

5.1.3.2. Yield and Yield Attributes

Dibbling of seeds using drum seeder + power weeding along with band placement of 60:30:30 kg NPK ha^{-1} (m_2f_2) produced the highest grain yield (2927.97 kg ha^{-1}), straw yield (4652.50 kg ha^{-1}) and HI (0.39) during the first year. The highest straw yield was recorded in m_1f_3 and HI in m_1f_4, which were on par with m_2f_2 (Fig. 5). Better performance of the treatment combination of m_2f_2 during first year could be attributed to significantly higher number of productive tillers m^{-2}, panicle length, number of grains $panicle^{-1}$, thousand grain weight and dry matter production. The stubble mulch used as a weed control measure was not able to significantly influence the grain yield and the reason might be that straw mulch could effectively control weeds only during the early stage of crop growth. This finding justifies the implication of critical period of crop weed competition in aerobic rice as reported by Anwar *et al.* (2013).

During 2014-15 comparing the methods of planting and weed control practices along with fertilizer application methods, the highest grain yield of 3109.33 kg ha^{-1} with a straw yield and HI of 4982.96 kg ha^{-1} and 0.38 respectively was obtained in m_2f_3 (dibbling of seeds using drum seeder + power weeding along with foliar spray of 19:19:19 @ 0.5 %) (Fig. 6). The combination of m_2f_3 resulted in the highest panicle length, grain weight $panicle^{-1}$, weight of panicle and number of grains $panicle^{-1}$, which ultimately resulted in higher grain and straw yield. The beneficial effect of cowpea grown as third crop in the sequence might have contributed sufficient nutrients through nitrogen fixation, which in turn helped to enhance the yield parameters and yield of rice along with foliar nutrition. Kumar *et al.* (1993) reported similar results, pointing out the superiority of cowpea and groundnut in increasing the yield of the first crop of rice in the system. Similar findings were also reported by Quayyam and Maniruzzaman (1996).

5.1.3.3. Economics of Cultivation

The treatment combination of m_2f_2 (dibbling of seeds using drum seeder + power weeding along with band placement of 60:30:30 kg NPK ha^{-1}) resulted in the highest B:C ratio of 1.65 in the first year (Fig. 7). During the second year, the highest B:C ratio of 2.38 was observed in dibbling of seeds using drum seeder + power weeding along with foliar spray of 19:19:19 @ 0.5 per cent (m_2f_3) (Fig. 8). The higher yield produced in these treatments during the first and second years resulted in the highest B:C ratio. The combination containing stubble mulching and hand weeding resulted in high cost in terms of input (straw) as well as labour cost, which ultimately led to low B:C ratio.

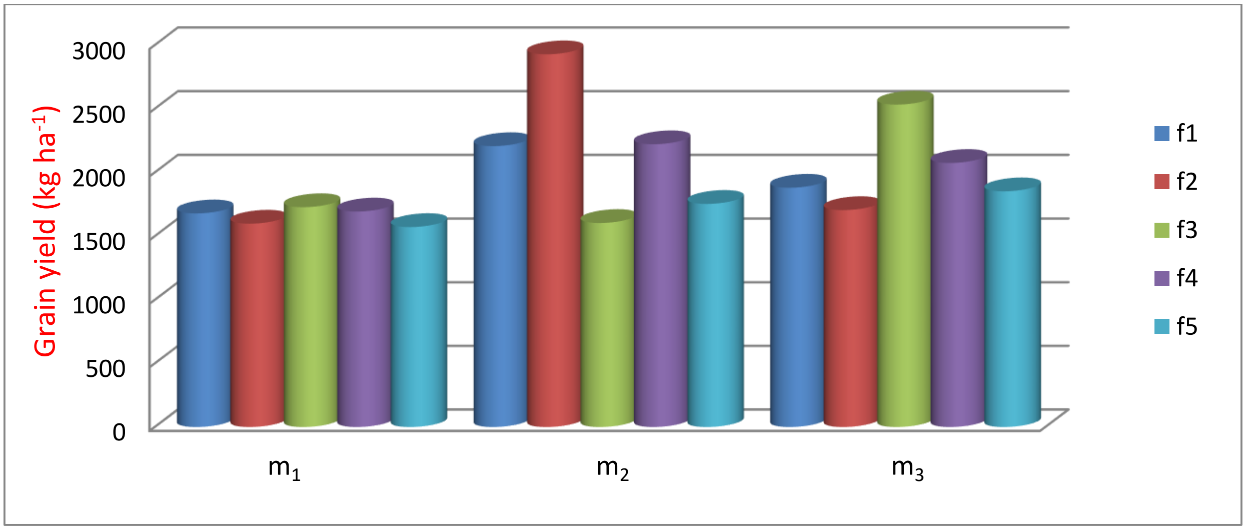


Fig 5. Effect of treatments on grain yield of rice in rice- cassava + groundnut – cowpea cropping system (2013-14)

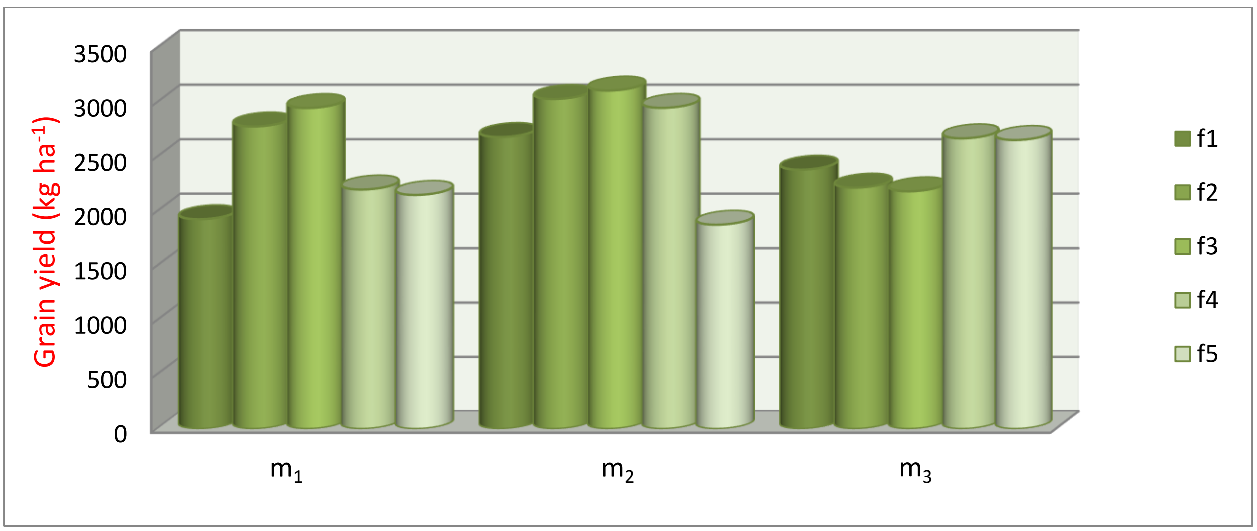


Fig 6. Effect of treatments on grain yield of rice in rice- cassava + groundnut – cowpea cropping system (2014-15)

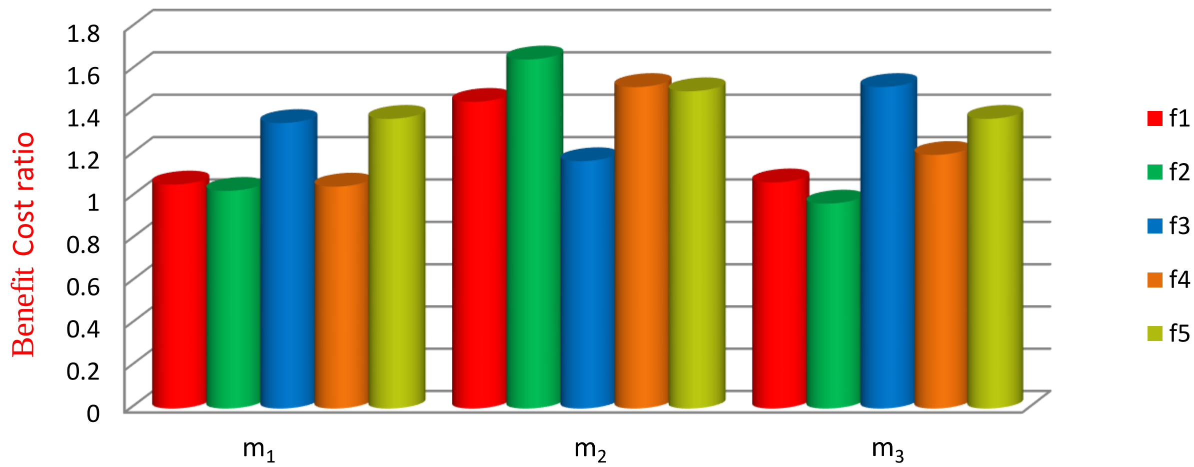


Fig 7. Effect of treatments on benefit cost ratio of rice in rice- cassava + groundnut – cowpea cropping system (2013-14)

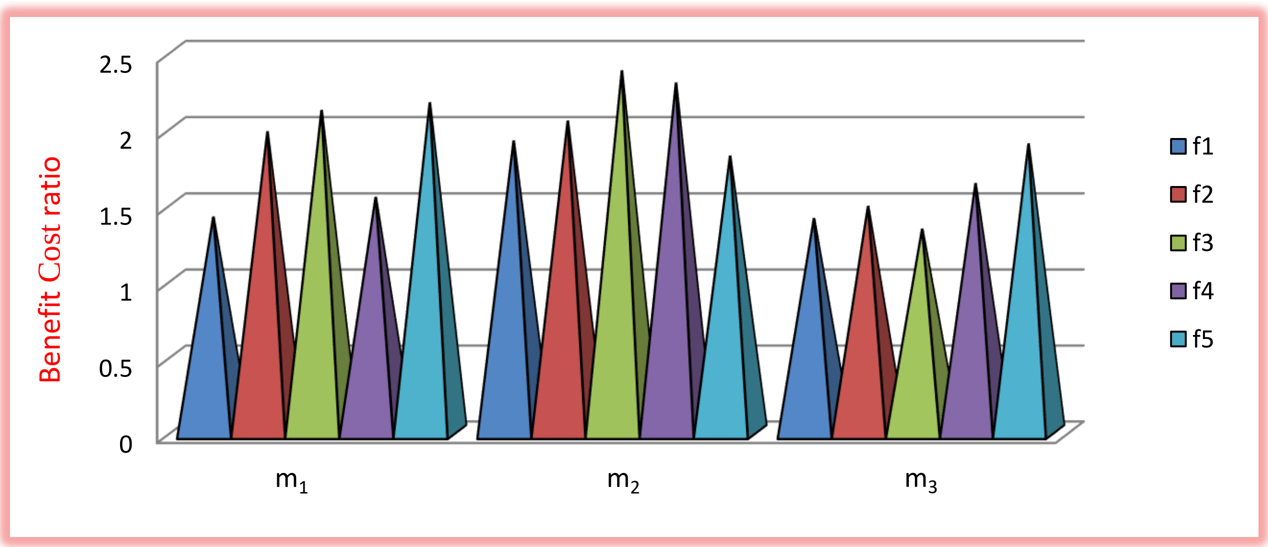


Fig 8. Effect of treatments on benefit cost ratio of rice in rice- cassava + groundnut – cowpea cropping system (2014-15)

5.1.3.4. Uptake of Nutrients

The highest N, K and S uptake was recorded in dibbling of seeds using drum seeder + power weeding along with band placement of 60:30:30 kg NPK ha^{-1} (m_2f_2) which might be due to the highest dry matter produced in the treatment combination m_2f_2. During 2014-15, dibbling of seeds using drum seeder + power weeding along with foliar spray of 19:19:19 @ 0.5 per cent resulted in the highest P and S uptake and this might have also resulted in the highest grain yield and HI during that period.

5.2. RESIDUAL EFFECT OF TREATMENTS OF RICE ON GROWTH AND PRODUCTIVITY OF CASSAVA INTERCROPPED WITH GROUNDNUT IN RICE BASED CROPPING SYSTEM

Since the treatments were imposed to rice crop only, the impact of treatments of rice on the residual effect of available soil nutrient content after each crop on the succeeding components crops in the system was assessed. The yield of individual crops after rice in the sequence was correlated with the soil nutrient status of the preceding crops during both the years. The results on available nutrient status after first crop rice in two years revealed that during the first year, the treatment combination of m_1f_1 resulted in the highest available nitrogen content and m_3f_1 produced the highest P and K content. During 2014-15, m_3f_4 resulted in the highest available N and P content and m_2f_3 produced the higher K content.

5.2.1. Residual Effect of Methods of Weed Control Measures

5.2.1.1. Growth and Productivity

Residual effect of the treatments applied to first crop rice was observed in the growth and yield of succeeding cassava intercropped groundnut in both the years. Among the main plot treatments, the highest tuber yield, marketable tuber yield and top yield was recorded under residual effect of stubble mulching (M_3) and the increase in yield was 1.81 and 6.05 per cent compared to M_1 and M_2 respectively during first year. The treatment M_3 resulted in higher number of functional leaves plant^{-1} at 6 MAP (months after planting), number of branches plant^{-1} at 6 MAP and LAI at 3 and 6 MAP, which cumulatively resulted in better total tuber yield. The residual effect of highest available P and K content after the first crop rice might have enhanced the yield attributes of succeeding cassava. LAI is related to the biologic and economic yield and increase in LAI resulted in higher yield (Singh *et al.*, 2009). The carry over effect of stubble mulching and the intercrop grown might have helped in increasing the soil moisture content as well as reduced the weeds and might have fixed some amount of nitrogen by groundnut at the time of incorporation. These results are supported by the findings of Robinson (1997). In the second year, the total tuber yield was not significant and this might be due to the not significance of the yield characters such as dry matter production, marketable tuber yield and top yield. The reason might be that during the second year the rainfall obtained in the initial period of crop establishment was less compared to the first year and this might have led to lower vegetative growth of cassava, which ultimately reduced the yield. At harvest stage of cassava in the second year, heavy rainfall was received, which might have resulted in rotting of some of the tubers and finally lower yield was obtained in cassava during 2014-15.

The residual effect of stubble mulching using rice straw (M_3) resulted in the highest haulm yield, kernel yield, pod yield, biomass yield and HI of groundnut during both the years, which was significantly different from the carry over effect of the other two methods of weed control practices in rice. The pod yield was reduced by 47.99 per cent and 13.00 per cent in M_2 compared to M_3 during the first and second years respectively. The residual effect of available soil nutrient content after the rice crop might have enhanced the yield attributes of succeeding groundnut.

5.2.1.2. Uptake of Nutrients

Among the methods of planting and weed control practices significantly higher N, P and K uptake of cassava were registered in M_3 (residual effect of stubble mulching) during 2013-14 and in the second year, the highest N, P and K uptake were recorded in M_1, M_3 and M_2 respectively. The highest N, P and K uptake of groundnut was recorded in the residual effect of stubble mulching in both the years. This might be due to the maximum dry matter produced by the treatment in groundnut. These results are in conformity with those of Rahman *et al*. (2005).

5.2.2. Residual Effect of Methods of Fertilizer Application

5.2.2.1. Growth and Productivity

The growth characters which attributed to the better yield of cassava in both the years were the highest plant height at 3 MAP, number of functional leaves plant^{-1} at 3 and 6 MAP, number of primary and secondary branches at 6 MAP and LAI at 3 and 6 MAP. During 2013-14, the tuber yield of 31.90 and 31.68 t ha^{-1} was significantly higher under the residual effect of soil application of 60:30:30 kg NPK ha^{-1} through broadcasting as well as band placement respectively. The highest dry matter production, number of tubers plant^{-1}, marketable tuber yield and utilization index (UI) might have contributed to higher total tuber yield in both the treatments. The residual effect of highest available P (F_1) and K (F_2) content was observed in soil after the rice. It might have also enhanced the yield attributes of succeeding cassava (Fig 11). In the second year, the residual effect of application of 60:30:30 kg NPK ha^{-1} as broadcasting (F_1) and foliar spray of DAP and SOP each @ 2 per cent (F_4) produced the higher total tuber yield of 18.63 and 17.78 t ha^{-1} respectively. The improvement in the number of tubers plant^{-1} and dry matter production might have resulted in better productivity in the treatment of F_1. Moreover, the high residual soil nutrients of the previous rice along with the nutrients (soil and foliar) applied to cassava as well as the nutrients supplied from the incorporated groundnut have contributed to higher yield. The residual effect of highest available N, P and S content was recorded in F_4 after the rice which might have also enhanced the yield attributes of succeeding cassava in the second year.

Among the methods of fertilizer application, the haulm yield, kernel yield, pod yield, biomass yield and HI of groundnut were significantly higher under the residual effect of broadcast application of 60:30:30 kg NPK ha^{-1} to the rice in the first year. During 2014-15, the highest pod yield was resulted in the residual effect of DAP and SOP each @ 2 per cent foliar spray with an increase of 23.08 per cent compared to F_2. The yield characters which attributed to the highest pod yield were the kernel yield, biomass yield and HI of groundnut. Improvement in vegetative growth led to better yield. The higher yield obtained in the soil as well as foliar application of fertilizers might be due to the added residual effect of nutrients by soil application and better uptake of nutrients in foliar spray which caused the plant to pump more sugars and other exudates from its roots into the rhizosphere and increase the availability of nutrients as suggested by Kuepper (2003).

5.2.2.2. Uptake of Nutrients

The highest uptake of N, P and K was observed in the residual effect of broadcast application of 60:30:30 kg NPK ha^{-1} in both the years in cassava. This better uptake of nutrients resulted in the maximum yield and yield attributes of cassava. The residual effect of soil application of 60:30:30 kg NPK ha^{-1} as broadcast in the preceding crop of rice produced the highest N, P and K uptake in the first year and the residual effect of foliar spray of DAP and SOP each @ 2 per cent resulted in the highest P and K uptake of groundnut in the second year. The nutrient uptake is a function of yield and nutrient concentration in the plant. Thus, significant improvement in uptake of N, P and K might be attributed to higher yield and increased concentration in pod and haulm. The findings confirm the results of Kumar *et al*. (2000) and Yadav *et al*. (2009).

5.2.3. Residual Effect of Interaction

5.2.3.1. Growth and Productivity

The residual effect of stubble mulching along with broadcast application of 60:30:30 kg NPK ha^{-1} (m_3f_1) resulted in the highest tuber yield during both the years and it was on par with m_3f_4 (residual effect of stubble mulching along with foliar spray of DAP and SOP each @ 2 %) during the second year (Fig. 9 and 10). The highest number of functional leaves plant^{-1} at 3 MAP, number of tubers plant^{-1}, DMP, tuber weight plant^{-1}, marketable tuber yield, top yield and UI in the second year, which might have resulted in better yield of m_3f_1 and m_3f_4. In the first year at 6 MAP, the highest number of functional leaves plant^{-1}, number of primary and secondary branches and LAI also contributed to the maximum productivity of the best treatment (m_3f_1) in cassava. The residual effect of available P and K content was highest in m_3f_1 (2013-14) (Fig. 11) and N and P content in m_3f_4 during 2014-15 (Fig 12) after the rice crop might have also enhanced the yield attributes of succeeding cassava.

Comparing the treatment combinations, the higher pod yield of groundnut was found in the residual effect of stubble mulching along with broadcasting of 60:30:30 kg NPK ha^{-1} and was on par with m_1f_5 and m_3f_3 in the first year (Fig. 13). During 2014-15, the highest pod yield of 1433.60 kg ha^{-1} was observed in the residual application of stubble mulching along with foliar spray of DAP and SOP each @ 2 per cent (Fig. 14). The similar results were observed by Singh and Singh (2014), where foliar application of DAP twice met out N and P requirement at the critical stages of the chick pea crop due to ensured and prompt delivery of mineral nutrients to the site of photosynthesis, which leads to higher yield. Similar to cassava the

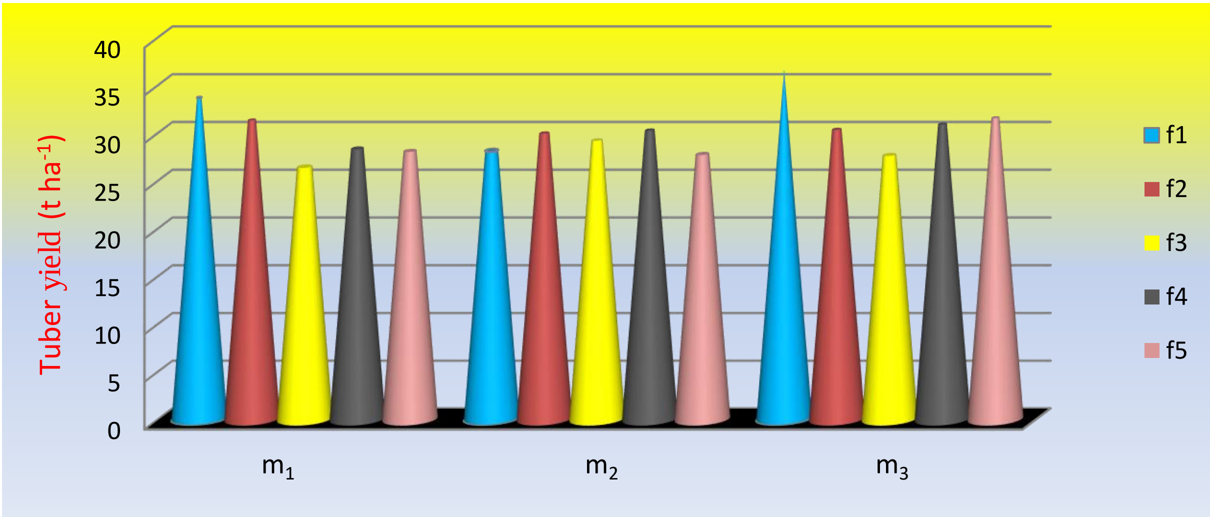


Fig 9. Residual effect of treatments of rice on total tuber yield of cassava in rice-cassava + groundnut – cowpea cropping system (2013-14)

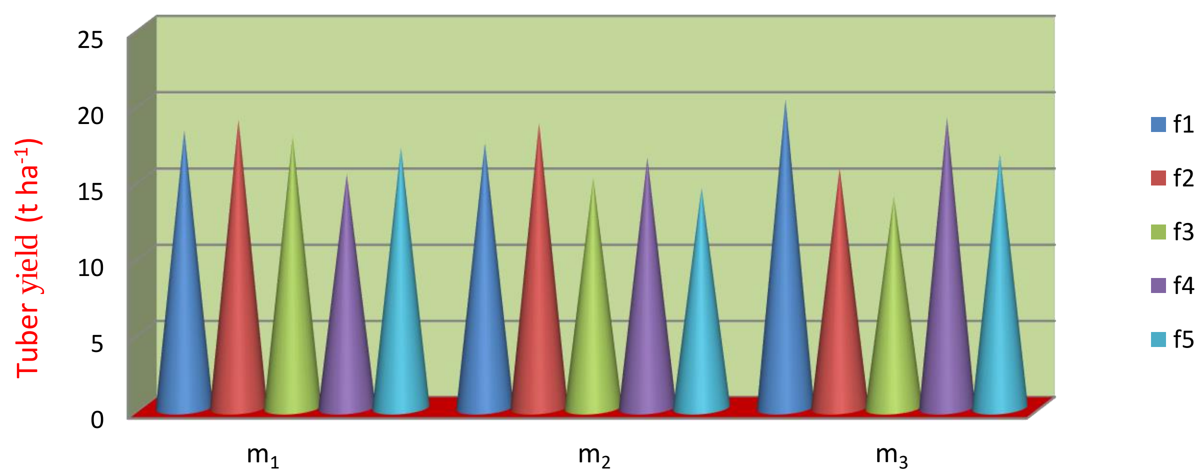


Fig 10. Residual effect of treatments of rice on total tuber yield of cassava in rice-cassava + groundnut – cowpea cropping system (2014-15)

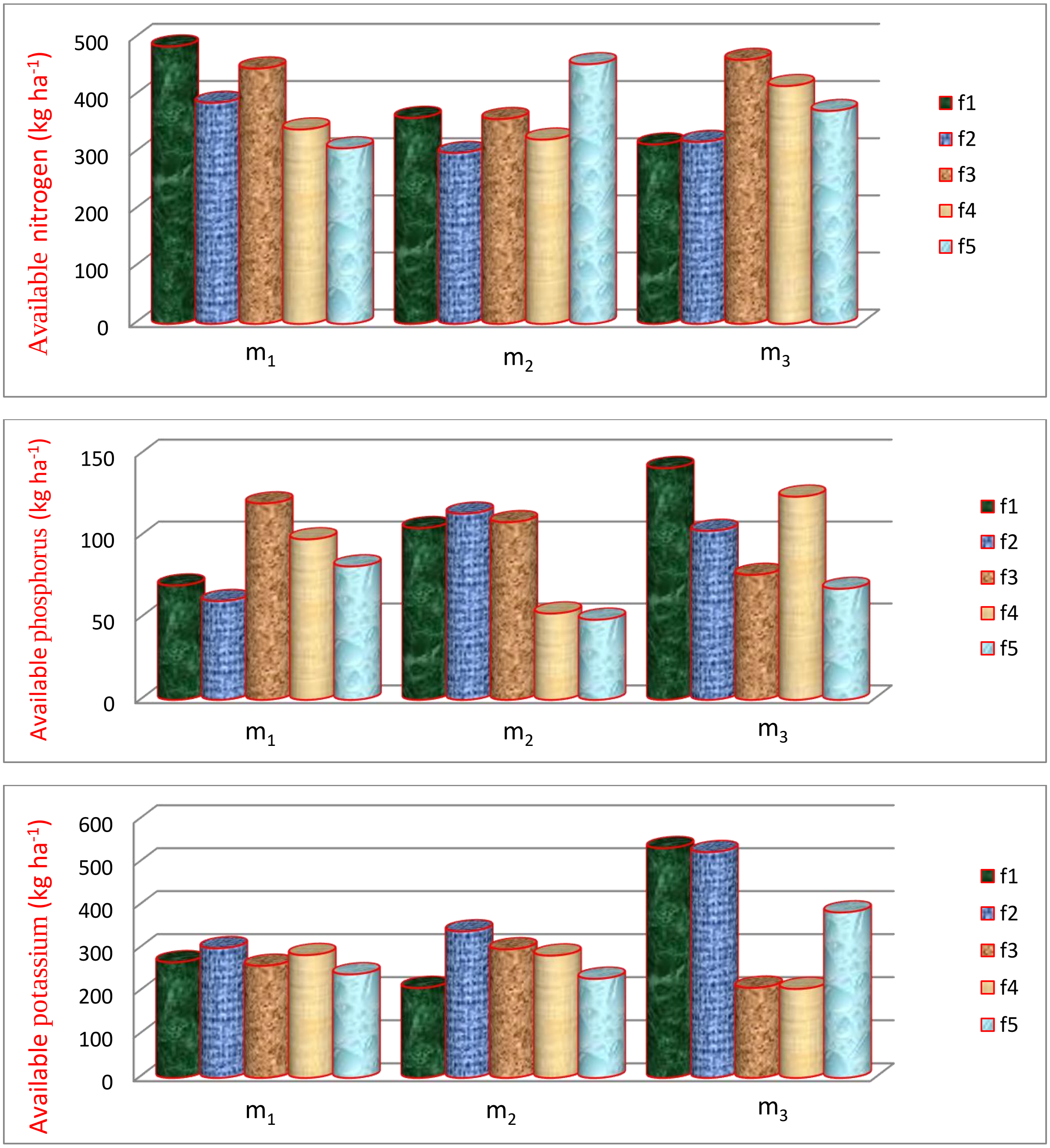


Fig 11. Effect of treatments on available nitrogen, phosphorus and potassium content in soil after first year rice

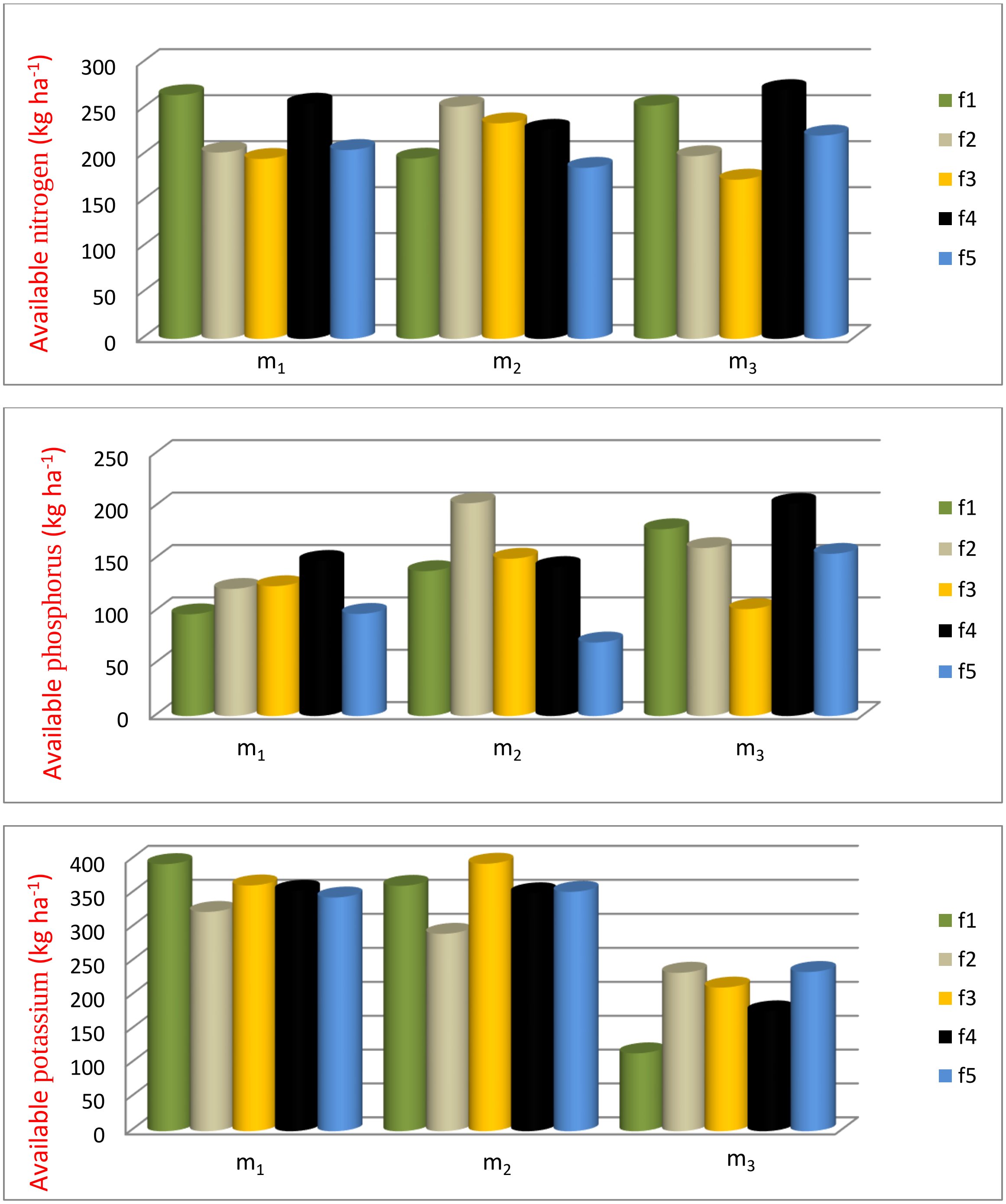


Fig 12. Effect of treatments on available nitrogen, phosphorus and potassium content in soil after second year rice

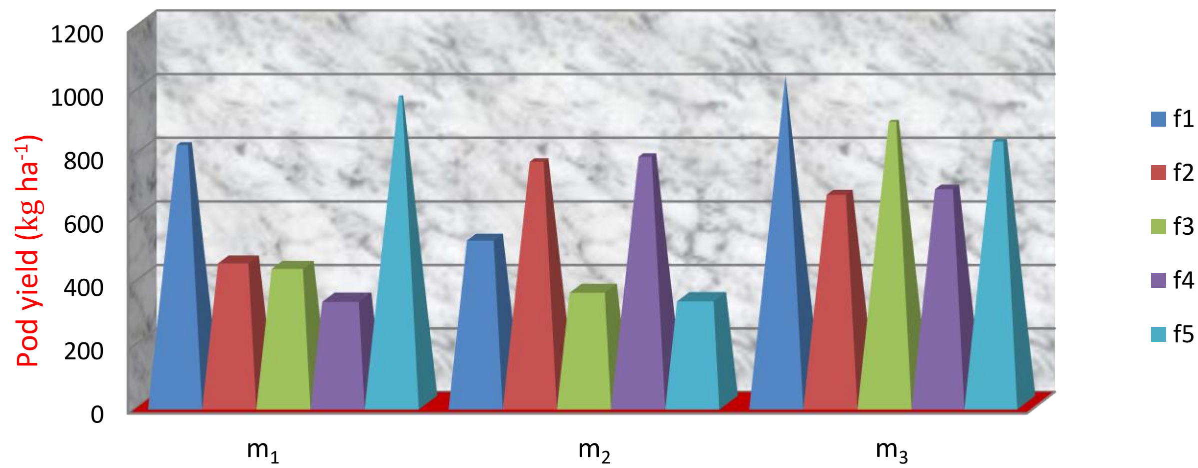


Fig 13. Residual effect of treatments of rice on pod yield of groundnut in rice-cassava + groundnut – cowpea cropping system (2013-14)

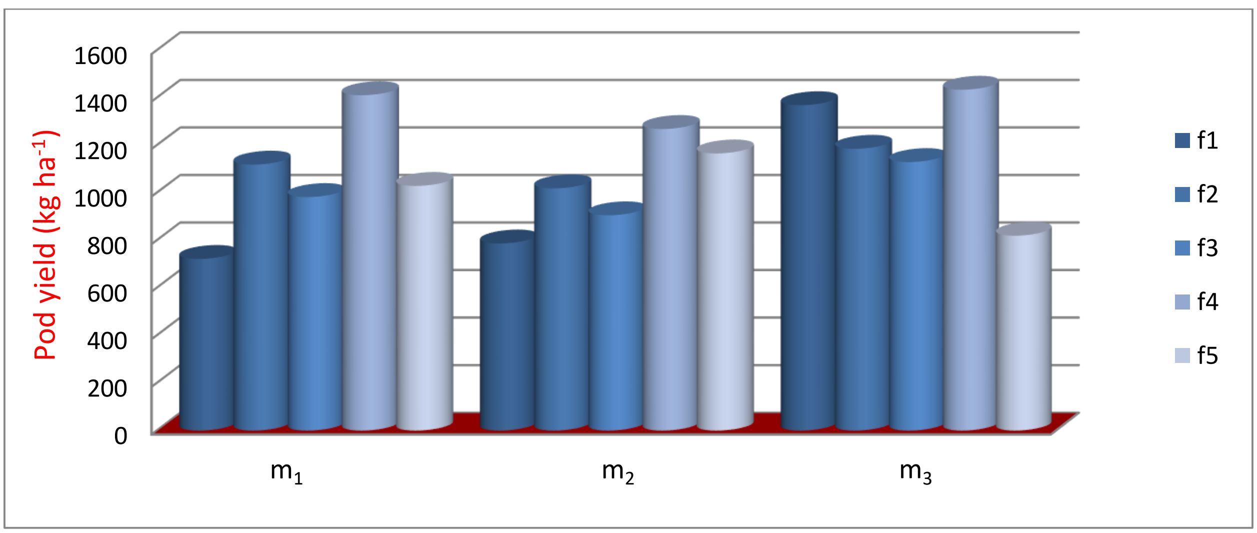


Fig 14. Residual effect of treatments of rice on pod yield of groundnut in rice-cassava + groundnut – cowpea cropping system (2014-15)

residual effect of available nutrient content after the rice crop had a positive influence in groundnut also (Fig. 11and 12).

5.2.3.2. Uptake of Nutrients

In cassava, the N and P uptake was higher in m_3f_1 which was on par with m_1f_1 and m_3f_2 for N and m_1f_1 for P in the first year. The dry matter was also highest in m_1f_1. The highest K uptake was registered in m_2f_3. During 2014-15, the highest N uptake was recorded in m_2f_1, P uptake was registered in m_3f_1 and K uptake was recorded in m_2f_5. Comparing the treatment combinations, the interaction m_3f_1 was found to record the highest N uptake in groundnut in both the years and the highest P and K uptake was registered in m_3f_3 in the first year. The highest dry matter was produced in the combination of m_3f_1 and m_3f_3 which might have led to the increased uptake of nutrients in groundnut. During 2014-15, P and K uptake was higher in m_3f_4, which resulted in yield attributes and yield of groundnut.

5.3. RESIDUAL EFFECT OF TREATMENTS OF RICE ON GROWTH AND PRODUCTIVITY OF COWPEA IN RICE BASED CROPPING SYSTEM

The results on available nutrient status after the second crop cassava in two years revealed that during the first year, the highest available nitrogen, phosphorus and potassium content were recorded in the combinations of m_3f_2, m_3f_1 and m_2f_1 respectively. During 2014-15, m_3f_3 resulted in the highest available N content, m_2f_3 recorded the highest P content and m_2f_4 recorded the highest K content.

5.3.1. Residual Effect of Methods of Weed Control Measures

5.3.1.1. Growth Parameters

The residual effect of treatments of rice had significant influence on the growth attributes such as plant height and number of branches plant^{-1} of cowpea in both the years. In the first and second years, the growth characters were higher in the residual effect of stubble mulching applied to the preceding first crop rice (M_3). Holland (2004) also reported that mulched soil environment increased soil biota and improved nutrient cycling and organic matter. The residual effect of soil available nutrients (N and P in the first year) after the harvest of cassava might also have contributed to more nutrient release, which ultimately resulted in better growth characters.

5.3.1.2. Yield and Yield Attributes

In the first year, the residual effect of various weed control measures did not have any significant influence on the dry matter production, number of pods plant^{-1} and pod yield. The weed control method such as straw mulch applied in the first crop rice later got degraded and the nutrients were made available to the subsequent cowpea crop in the initial stage only. When the crop reached the reproductive phase, the nutrients may not have been sufficient for the growth and development of pods. Therefore the direct effect of nutrients applied to cowpea was more influential than the residual effect of nutrients.

In the second year, the residual effect of stubble mulching (M_3) showed significant effect on the dry matter production, number of pods plant^{-1} and pod yield of cowpea. The treatment M_3 produced 33.99 per cent higher pod yield compared to M_2. This might be due to the availability of the residual nutrients and the fixation of nitrogen by the cowpea in the first year and groundnut in the second year to the succeeding third crop of cowpea.

5.3.1.3. Uptake of Nutrients

The nutrient uptake was found not significant in the first year. In the second year, the maximum N, P and K uptake was observed in M_3 and this might be due to enhanced dry matter production in this treatment.

5.3.2. Residual Effect of Methods of Fertilizer Application

5.3.2.1. Growth Parameters

Among the methods of fertilizer application, the residual effect of soil application (band placement of 60:30:30 kg NPK ha^{-1}) of fertilizers to the rice (F_2) produced the highest plant height in the first year. While during the second year, the residual effect of foliar application of 19:19:19 @ 0.5 per cent (F_3) to rice was produced the highest plant height in cowpea. In both the years, the number of branches $plant^{-1}$ was found significantly higher in the carry over effect of band placement of 60:30:30 kg NPK ha^{-1} in rice. The available nutrient content in the soil after the second crop of cassava was the highest in the treatment F_2, which might have lead to the better uptake of nutrients. Along with that the direct effect of nutrients supplied through soil and foliage might have contributed to the better growth of cowpea in the cropping system.

5.3.2.2. Yield and Yield Attributes

Comparing the various methods of fertilizer application, the higher dry matter production, number of pods $plant^{-1}$ and pod yield was observed in the residual effect of soil application of nutrients in rice (F_1) in the first year. The available nutrient content in the soil after the harvest of cassava in the first year showed the highest P and K content in F_1, which might have resulted in the higher yield and yield attributes of cowpea.

While in the second year, the residual effect of F_2 (band placement of 60:30:30 kg NPK ha^{-1} applied to rice) resulted in the highest dry matter production and pod yield of 833.54 kg ha^{-1}. The highest uptake of N and K was observed in F_2 might have contributed to the yield improvement in cowpea.

5.3.2.3. Uptake of Nutrients

Comparing the residual effect of soil as well as foliar application of fertilizers, the highest uptake of N, P and K was recorded in the treatment F_1, which was found the best treatment in terms of dry matter production (2013-14). During 2014-15, the N and P uptake was observed to be significantly higher in the residual effect of F_5 (control) and it was on par with F_2 in N uptake. The highest K uptake was observed in F_2. The highest dry matter observed in F_2 might have resulted in the maximum uptake of nutrients by cowpea in the second year.

5.3.3. Residual Effect of Interaction

5.3.3.1. Growth Parameters

The residual effect of combination of stubble mulching along with band placement of 60:30:30 kg NPK ha^{-1} in rice (m_3f_2) resulted in significantly higher plant height during 2013-14. In the second year, the highest plant height of 72.29 cm was recorded in the carry over effect of mechanical weeding along with foliar spray of 19:19:19 @ 0.5 per cent in rice. The reason for the first year result was already been discussed in the individual effects.

While in the second year, the mechanical weeding in rice might have reduced the weed population in the first crop rice in which the nutrients were not depleted compared to other methods of weed control. Therefore the residual as well as direct effect of nutrients applied to cowpea might have helped in enhancing the plant height.

The residual effect of stubble mulching along with foliar spray of 19:19:19 @ 0.5 per cent (m_3f_3) and broadcasting of 60:30:30 kg NPK ha^{-1} (m_3f_1) in rice resulted in the highest number of branches $plant^{-1}$ in the first and second years respectively.

5.3.3.2. Yield and Yield Attributes

The combination of weed control practices and fertilizer application methods significantly influenced the yield and yield attributes of cowpea in both the years of study. The residual effect of mechanical weeding along with foliar spray of DAP and SOP each @ 2 per cent resulted in the highest number of pods $plant^{-1}$ and pod yield in the first year (Fig. 15). The highest DMP was recorded in m_2f_5, which might be due to the residual effect of higher available K in the soil after the first year cassava (Fig. 17). The direct effect of soil as well as foliar nutrients applied to cowpea also might have a positive influence on the yield.

During 2014-15, the DMP, number of pods $plant^{-1}$ and pod yield (1209.33 kg ha^{-1}) were higher in the residual effect of stubble mulching along with foliar spray of DAP and SOP each @ 2 per cent (Fig. 16). The residual effect of the available N, P and K content after second year cassava did not influence the yield characters of cowpea (Fig. 18). The direct effect of applied nutrients and nitrogen fixation by cowpea and groundnut as well as the nutrient released by the decomposition of straw in rice might have contributed to higher yield in the best treatment. The higher uptake of N and P also might have led to the better growth and yield attributes of cowpea in the second year.

5.3.3.3. Uptake of Nutrients

The highest N, P and K uptake was observed in the residual effect of the treatments m_2f_4, m_3f_3 and m_2f_5 respectively. The highest N uptake might have also

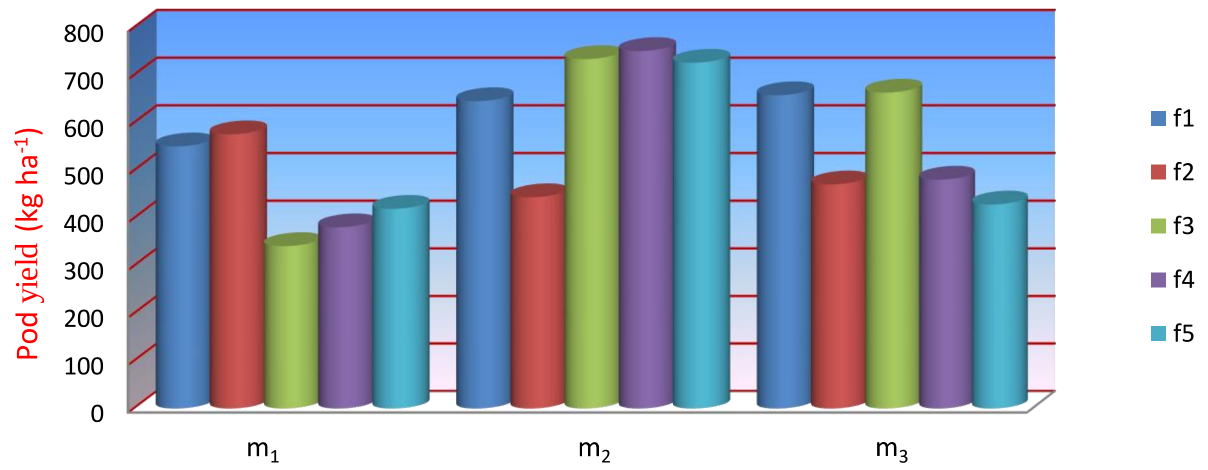


Fig 15. Residual effect of treatments of rice on pod yield of cowpea in rice- cassava + groundnut – cowpea cropping system (2013-14)

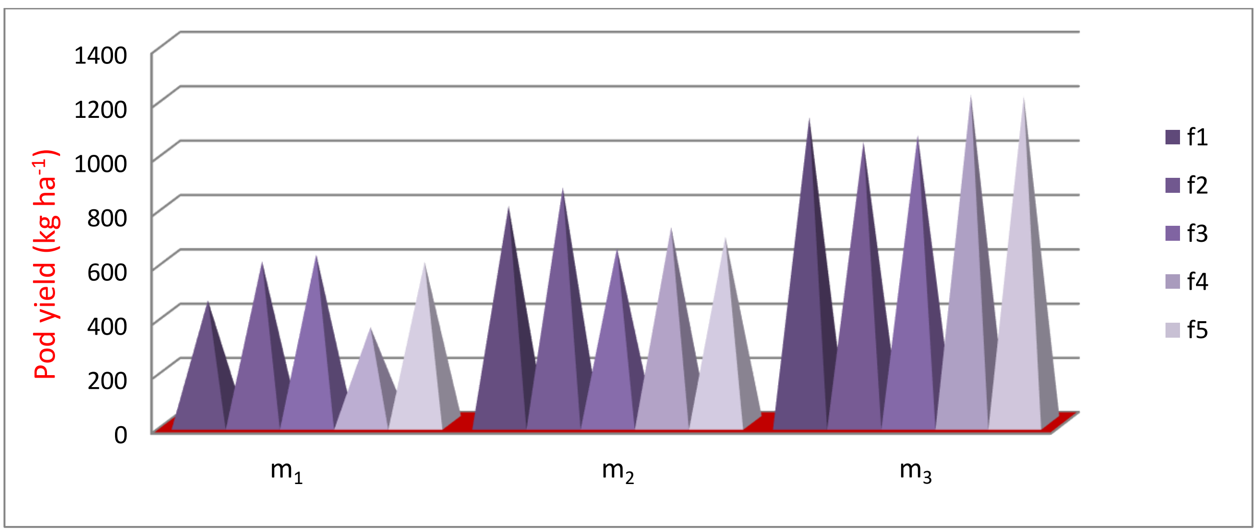


Fig 16. Residual effect of treatments of rice on pod yield of cowpea in rice- cassava + groundnut – cowpea cropping system (2014-15)

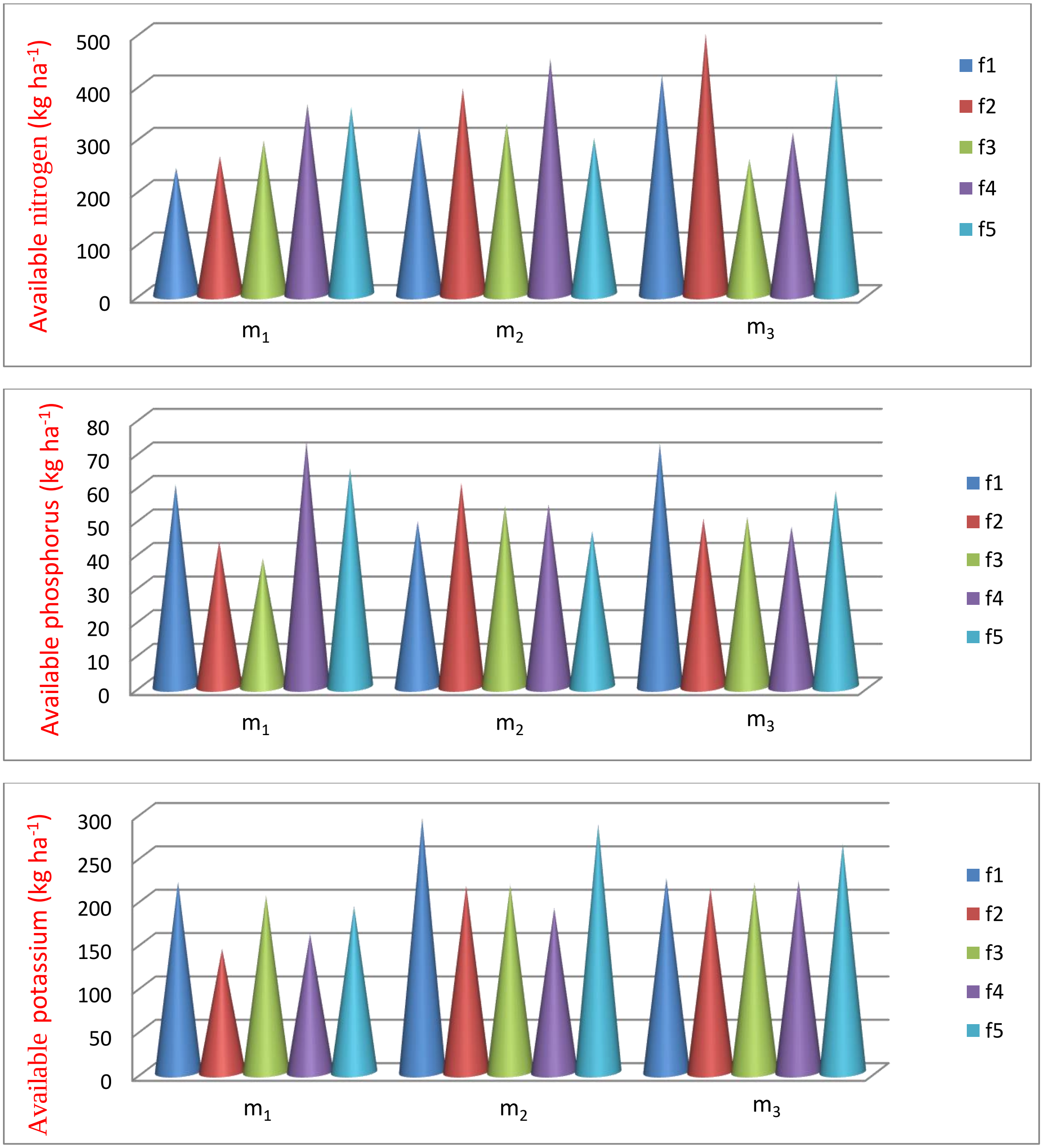


Fig 17. Residual effect of treatments on available nitrogen, phosphorus and potassium content in soil after first year cassava

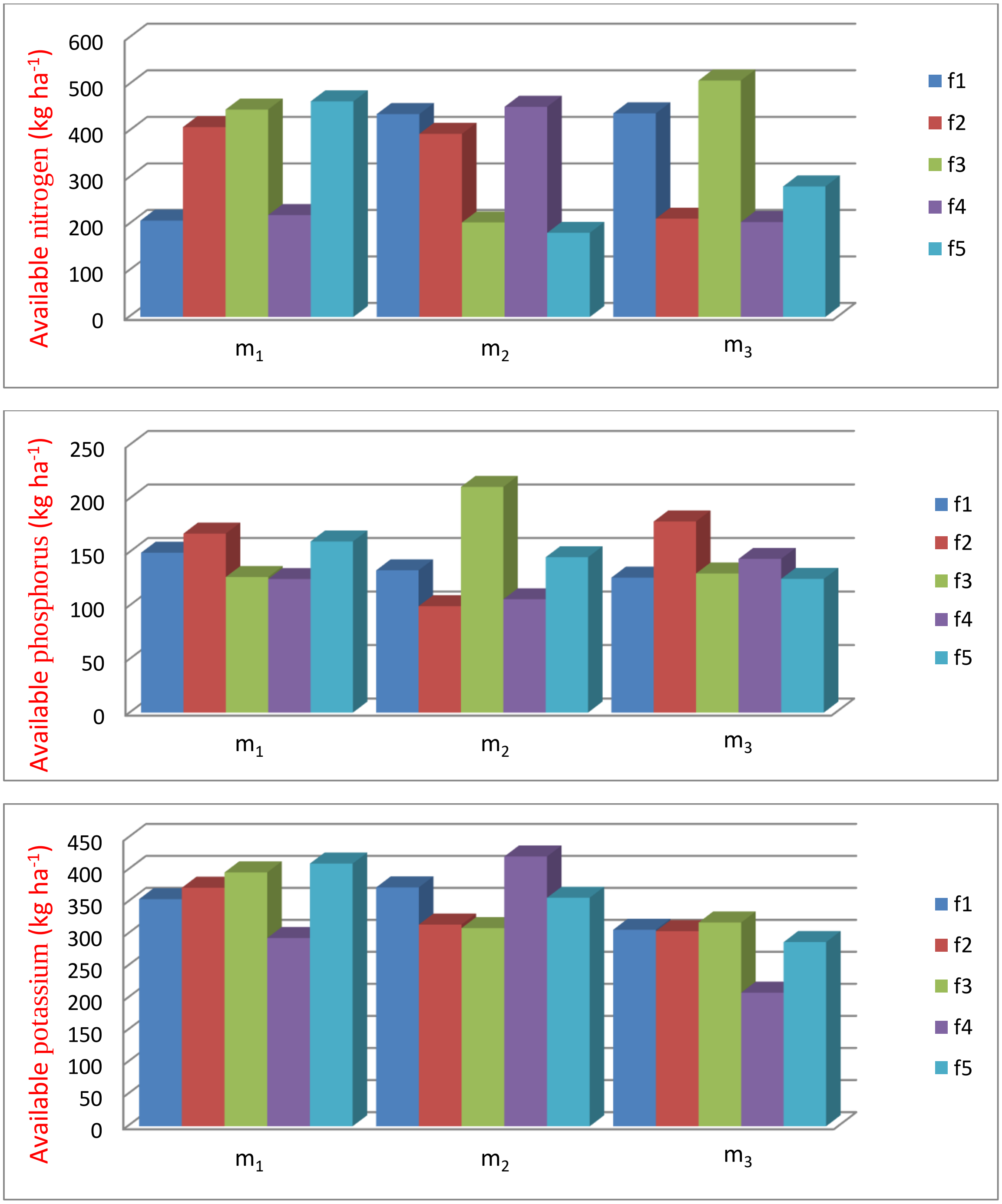


Fig 18. Residual effect of treatments on available nitrogen, phosphorus and potassium content in soil after second year cassava

contributed to the better yield and yield characters of first year cowpea. In the second year, the highest N and P uptake was registered in the combination of residual effect of stubble mulching along with foliar spray of DAP and SOP each @ 2 per cent and the reason might be due to the higher dry matter production of the combination. The highest K uptake was observed in m_3f_1 and it was on par with the best treatment of second year cowpea.

5.4. DIRECT AND RESIDUAL EFFECT OF TREATMENTS OF RICE ON THE PERFORMANCE OF RICE BASED CROPPING SYSTEM

5.4.1. Direct and Residual Effect of Methods of Planting and Weed Control Practices

5.4.1.1. Rice Equivalent Yield (REY)

The three methods of planting and weed control practices exhibited significant variation in REY during both the years of experimentation. Direct and residual effect of dibbling of seeds using drum seeder + stubble mulching (M_3) produced significantly higher REY during both the years. The treatment, M_3 had 8.07 per cent and 8.93 per cent more REY than M_1 and M_2 respectively during the first year of study. In the second year, M_3 had 9.54 per cent and 7.33 per cent more REY than M_1 and M_2 respectively. Long term effect of the residue recycling might have improved physical, chemical and biological health of soil. Since crop residues such as straw contain significant quantities of plant nutrients; continuous application of straw as mulch had positive effect on fertilizer control in rice-wheat system was reported by Singh and Sidhu (2014).

The pooled analysis results showed significant variation in REY among the various methods of planting and weed control measures. The pooled data of REY also produced the highest value (8.23 per cent) in the direct and residual effect of M_3 compared to that of the next best treatment M_2.

5.4.1.2. Energy Budgeting

Energetics of the cropping system includes various parameters such as energy efficiency, energy productivity, specific energy and energy intensity. Direct and residual effect of methods of planting and weed control practices significantly affected various parameters of the energetics in both the years. The highest energy efficiency, energy productivity and energy intensity was resulted in the direct and residual effect of dibbling of seeds using drum seeder + power weeding during both the years of experimentation. The mechanical weeding might have helped to reduce the labour and weed population and thereby the energy utilized for each unit of labour was reduced. Each unit of energy might have been effectively utilized for the production of yield attributes and yield of the cropping system. Specific energy gives an indication of energy required per unit quantity of economic produce. It is always essential to have lower specific energy for higher efficiency. In the system under study, M_2 (dibbling of seeds using drum seeder + power weeding) resulted in the lowest value which might be due to the less energy utilized for labour in sowing and weeding.

5.4.2. Direct and Residual Effect of Methods of Fertilizer Application

5.4.2.1. Rice Equivalent Yield (REY)

The REY varied significantly among the direct and residual effect of different fertilizer application methods during the two years of study. In the first year, the direct as well as residual effect of soil application of fertilizer (broadcast (F_1) and band placement (F_2)) in rice was produced higher REY of 7.46 per cent and 7.64 per cent respectively compared to that of control (F_5). While in the second year, the direct and residual effect of soil (band placement of 60:30:30 kg NPK ha^{-1} (F_2)) as well as foliar application of fertilizer (foliar spray of DAP and SOP each @ 2 %) resulted in higher REY of 21.78 t ha^{-1} and 21.45 t ha^{-1} respectively.

In a cropping sequence, first crop hardly utilized 30–50, 15–20 and 60–80 per cent of N, P and K, respectively (Hegde *et al.*, 2007) leaving much of the nutrients for use by the succeeding crop. Shivakumar and Ahlawat (2008) and Singh *et al.* (2012) reported similar findings. During both the years, soil application resulted in higher rice equivalent yield, while in the second year, soil as well as foliar application was observed on par with each other. Foliar application cannot be considered as a substitute to soil application. The results confirm the need for better soil nutrient status for increased benefit for supplemental nutrition through foliar. In this experiment sufficient build up of soil nutrients by incorporation of groundnut and cowpea along with lower quantities of nutrients as foliar spray resulted in higher rice equivalent yield.

The pooled data on REY was significantly higher in band placement of 60:30:30 kg NPK ha^{-1} in rice with a yield of 26.02 t ha^{-1}. The direct and residual effect of the nutrients added to the soil by growing cowpea and incorporation of groundnut in the system also might have contributed to the highest system yield which was on par with F_1 and F_4. Intensification of rice–wheat system by inclusion of greengram grown in summer intensified the system to add yield and consequently resulted in significantly higher REY than that of rice–wheat sequence as reported by Prasad *et al.* (2013).

5.4.2.2. Energy Budgeting

Among the direct and residual effects of four methods of fertilizer application, the highest energy efficiency and energy productivity were resulted in the foliar application of fertilizers 19:19:19 @ 0.5 per cent (F_3) and DAP and SOP each @ 2 per cent (F_4) in both the years respectively. Even though the specific energy was found not significant in the first year, the direct and residual effect of foliar spray of both the fertilizers was significantly influenced the specific energy of the cropping system.

Specific energy values should be lower because it is the energy produced for each unit of crop yield obtained. Compared to the soil applied fertilizers, foliar spray of nutrients produced lower specific energy in both the years indicating that higher yield could be obtained in this treatment with lower energy input. Energy intensity was also significantly higher in the soil as well as foliar treatments. The foliar application of both the fertilizers was found to efficiently utilize all the energy parameters. This might be due to the fact that only less energy was utilized for the production of each unit of output in the cropping system. Another reason might be that the quantity of nutrients given through foliar was less and also sufficient to meet the nutrient needs of crop compared to soil application method.

5.4.3. Direct and Residual Effect of Interaction

5.4.3.1. Rice Equivalent Yield (REY)

The combination of all the treatments showed significant influence on REY in both the years of experimentation. The direct and residual effect of dibbling of seeds using drum seeder, stubble mulching and broadcast application of 60:30:30 kg NPK ha^{-1} (m_3f_1) in rice based cropping system produced the highest REY in both the years. In the second year, the best treatment (m_3f_1) was on par with m_3f_4 (dibbling of seeds using drum seeder, stubble mulching and foliar spray of DAP and SOP each @ 2%). This could be attributed to nutrient release from mulching of rice and easiness in nutrient availability from foliar fertilizers. Foliar nutrition is ideally designed to provide many elements to crop that may be limiting production at a time when nutrient uptake from the soil is inefficient (Hiller, 1995). However mulching using straw may provide sufficient moisture as well as conserve the soil nutrients without any leaching losses and during the period of subsequent crop growth, the decomposed straw might have also supplied some nutrients for the better system productivity. Incorporated rice residue *i.e.* straw lost about 80 per cent of its initial mass at the end of decomposition cycle, leading to a decomposition rate that was about three times as fast as that in the surface placed residue. About 50-55 per cent of the rice residue placed at the soil surface was not decomposed at the time of wheat harvest in wheat – rice cropping system (Singh and Sidhu, 2014).

The pooled data over years showed the significant influence of direct and residual effect of treatments on rice equivalent yield of the rice – cassava+groundnut - cowpea system (Fig. 19). The direct and residual effect of treatment combination of m_3f_1 (dibbling of seeds + stubble mulching along with broadcasting of 60:30:30 kg NPK ha^{-1}) produced the highest rice equivalent yield of 29.71 t ha^{-1}, which was superior to all the other combinations, except m_3f_4 (dibbling of seeds + stubble mulching along with foliar spray of water soluble complex fertilizer DAP and SOP each @ 2 %) with an increase of 5.77 per cent compared to m_3f_4. Favourable individual effect of these treatments on yield of component crops in the system enhanced the rice equivalent.

5.4.3.2. Energy Budgeting

All the energy parameters were found to perform better in the combination of direct and residual effect of dibbling of seeds using drum seeder + power weeding along with foliar spray of DAP and SOP each @ 2 per cent during 2013-14 and 2014-15 period of study. The reasons have already been discussed in the individual effects and that holds well in cumulative effect.

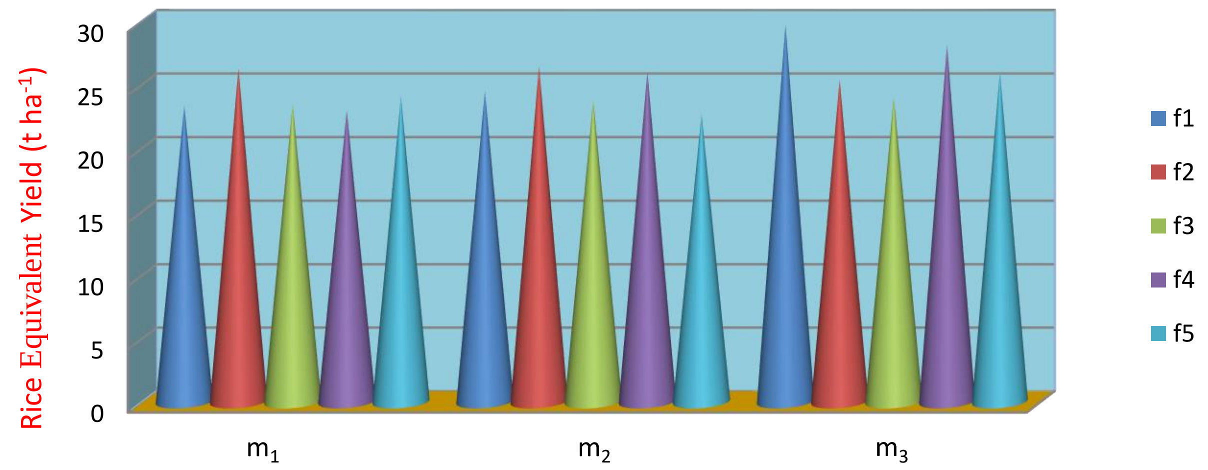


Fig 19. Direct and residual effect of treatments of rice on rice equivalent yield of rice-cassava + groundnut – cowpea cropping system (pooled data)

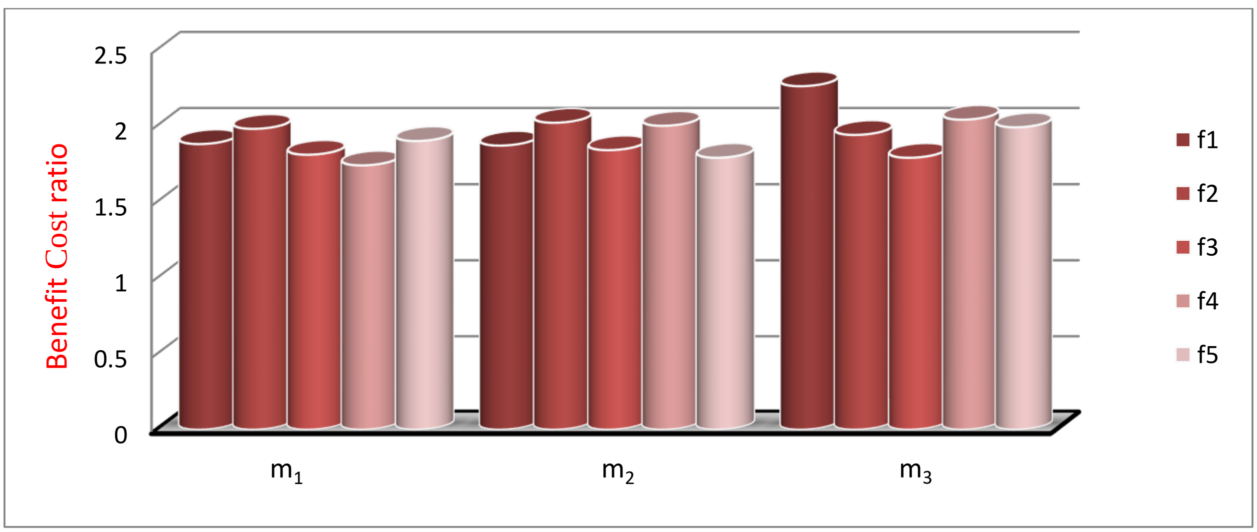


Fig 20. Direct and residual effect of treatments of rice on benefit cost ratio of rice-cassava + groundnut – cowpea cropping system (pooled data)

5.4.3.3. Economics of Cultivation

During the first year of experimentation (2013-14), the highest net returns and B:C ratio were resulted in the direct and residual effect of dibbling of seeds using drum seeder + stubble mulching along with soil application of 60:30:30 kg NPK ha^{-1} as broadcasting to rice (m_3f_1). In the second year also, the combination of m_3f_1 resulted in the highest net returns and B:C ratio, which was followed by the direct and residual effect of m_3 along with foliar spray of DAP and SOP each @ 2 per cent (f_4) with a net returns of Rs. 2,11,122.00 ha^{-1}. The B:C ratio of 1.85 was observed in both the combinations, m_3f_1 and m_3f_4. The higher rice equivalent yield produced in these combinations led to increased net returns. In addition, drum seeding reduced the labour cost leading to higher returns. These findings are in accordance with those reported by Sutagundi (2000).

The pooled data also showed similar trend in both the net returns and B:C ratio. The interaction m_3f_1 produced the highest net returns and B:C ratio of Rs. 3,17,358.00 ha^{-1} and 2.26 respectively with an increase of 21.35 per cent net returns and 10.78 per cent B:C ratio compared to that of the next best treatment of m_3f_4 (Fig. 20). The net returns and B:C ratio depend on the quantity and price of the produce and the cost of cultivation, which in turn depends on the quantity and cost of inputs including labour. The higher net returns and B:C ratio of these two treatments could be attributed to their higher system yield. Inclusion of legume like cowpea in the cropping system also might have a positive impact on maintaining soil fertility leading to high system yield and economic returns. Sharma *et al*. (2004) were also of the opinion that addition of third crop as legume in the sequence resulted in higher yield and profitability.

5.4.4. Nutrient Balance Sheet

Since the balance sheet of the direct as well as residual effect of the nutrients applied to each treatment was calculated the available nutrient balance after each crop in the sequence was found.

5.4.4.1. Balance Sheet of Available Nitrogen

During 2013-14, the nitrogen balance sheet of rice was influenced by the methods of planting, weed control measures and nutrient management practices (Fig. 21). The gain in the available nitrogen was observed in the direct and residual effect of the treatments m_1f_1, m_1f_3, m_2f_5 and m_3f_3 compared to the initial status of soil. All the other treatments had a negative balance of nitrogen. In the second year, a negative balance of available nitrogen was observed in all the combinations in rice. High mobility of nitrogen and its rapid loss through leaching, volatilization and denitrification might be responsible for the unaccountability of nitrogen in the balance sheet, which showed a negative balance (Pillai *et al.*, 2007).

The balance sheet of available nitrogen for cassava in the first year showed a negative balance in most of the combinations, while in the second year, the direct and residual effect of the treatment combinations was found positively balanced compared to that of the initial available soil nitrogen. The combinations of m_1f_1, m_1f_4, m_2f_3, m_2f_5 and m_3f_4 showed a slow rate of depletion of available nitrogen (Fig. 22). Cassava is said to be a nutrient depleting crop but the nitrogen balance sheet results of rice – cassava + groundnut – cowpea system showed a more positive balance after second year. This might be due to the influence of intercrop groundnut in fixing nitrogen and also may be more nitrogen was made available by the incorporation of groundnut haulm. The available nitrogen in soil after groundnut was higher compared to initial status of the soil (Rana and Rana, 2011). Another reason could be due to the reduced uptake of nitrogen in the second year, compared to the first year, resulting in high soil N balance.

The actual gain or loss of available nitrogen after the third crop of cowpea in the sequence was positively balanced by the influence of direct and residual effect of methods of planting, weed control measures and fertilizer application methods in the first year except three combinations (m_2f_1, m_2f_4 and m_3f_2), which were negatively balanced (Fig. 19). Legumes make less demand on the soil resources and at the same time they have the capacity to fix atmospheric nitrogen in their root nodules. The results support the findings of Singh *et al.* (1996). During 2014-15, a depletion of available nitrogen was observed in the balance sheet of cowpea for most of the treatments. It was reported that small quantities of mineral N available during early growth can promote nodulation and N fixation in cowpea and if the mineral N is supplied in abundance in soil through fertilizers, it can completely suppress the symbiosis (Subasinghe *et al*., 2001) leading to low N fixation. The rate of depletion was less in those treatments where complex foliar fertilizers were applied compared to soil application. The direct and residual effect of complex foliar fertilizer application might have led to very limited nitrogen losses since they are less affected by other external factors compared with that of soil application of fertilizers. In foliar nutrition, the dependence of crop on soil nutrients is low resulting in more N balance.

5.4.4.2. Balance Sheet of Available Phosphorus

In the first year, a gain in phosphorus was observed in most of the treatment combinations of rice while during second year, a slight depletion of available phosphorus was found, but the rate of depletion was less in the complex foliar fertilizer combinations compared to the combinations of soil application of fertilizers (Fig. 20). Shafiee *et al*. (2013) had reported that the plants easily get sufficient P

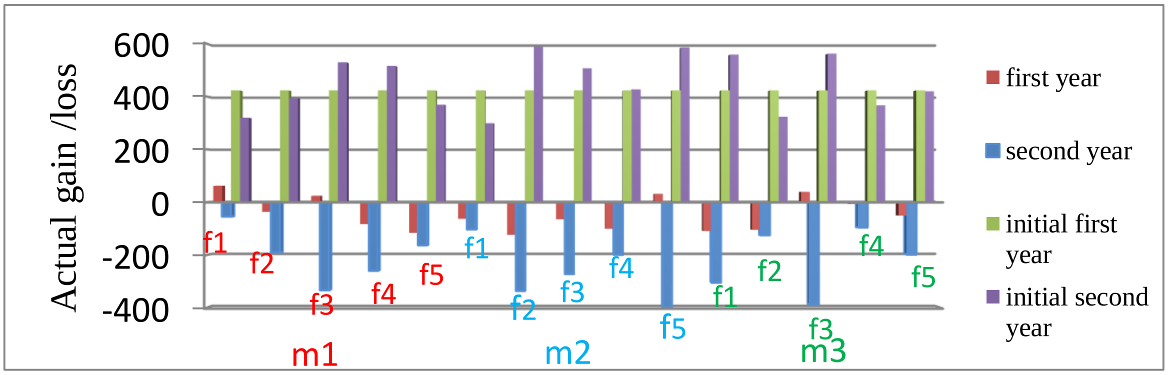


Fig 21. Direct and residual effect of treatments on nitrogen balance sheet of rice (kg ha^{-1})

Fig 21. Direct and residual effect of treatments on nitrogen balance sheet of rice (kg ha^{-1})

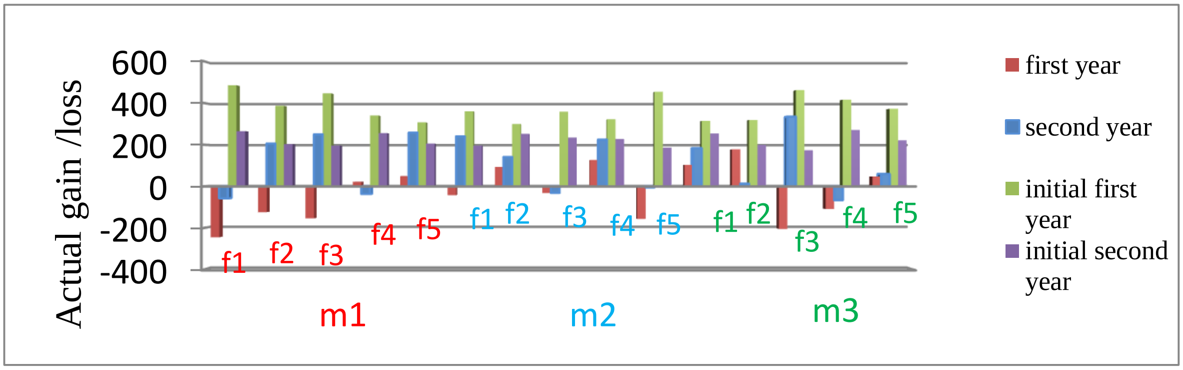


Fig 22. Direct and residual effect of treatments on nitrogen balance sheet of cassava (kg ha^{-1})

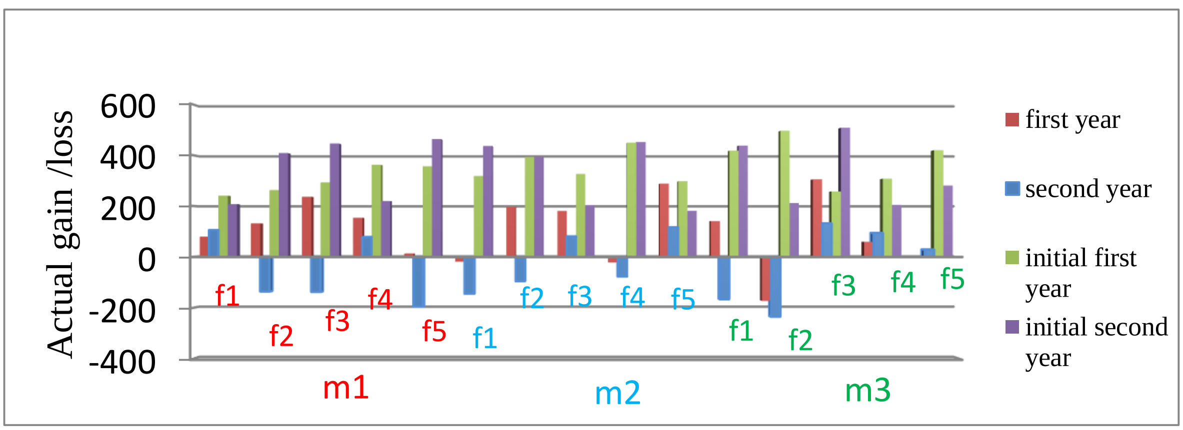


Fig 23. Direct and residual effect of treatments on nitrogen balance sheet of cowpea (kg ha^{-1})

from foliar fertilizers and therefore extraction of phosphorus from soil will be minimum.

For cassava in the first year, a negative balance of phosphorus was observed for all the treatment combinations while in the second year, a gain in available phosphorus was observed in most of the combinations, except some treatments where the rate of depletion was less compared to initial year (Fig. 21). This could be attributed to the P supply through soil applied fertilizers, residue incorporation of groundnut and cowpea and supplemental P nutrition through foliar fertilizers. The nutrient uptake was also observed to be less in the second year.

The direct and residual effect of the treatment combinations was found to affect the phosphorus balance sheet of cowpea during 2013-14 and 2014-15. During 2013-14, all the combinations were observed to have a build up of available phosphorus in the soil, which shows the sustainability of the cropping system. While in the second year, some of the combinations of fertilizers applied through soil has a slight loss in available phosphorus compared to those treatments where complex fertilizers were applied (Fig 22). Comparatively lower P uptake from soil in foliar treatments might have enhanced P balance in those treatments and also soil application might have fixed some amount of available P. Phosphorus stimulates root and plant growth, initiates nodule formation as well as influences the general efficiency of the rhizobium legume symbiosis (Luyindula *et al.*, 1994) thereby optimizes the biological nitrogen fixation (BNF) system of cowpea (Norman *et al.*, 1995).

5.4.4.3. Balance Sheet of Available Potassium

For rice crop in the first year, a rapid depletion of available potassium was observed in most of the combinations, while in the second year, the actual loss was

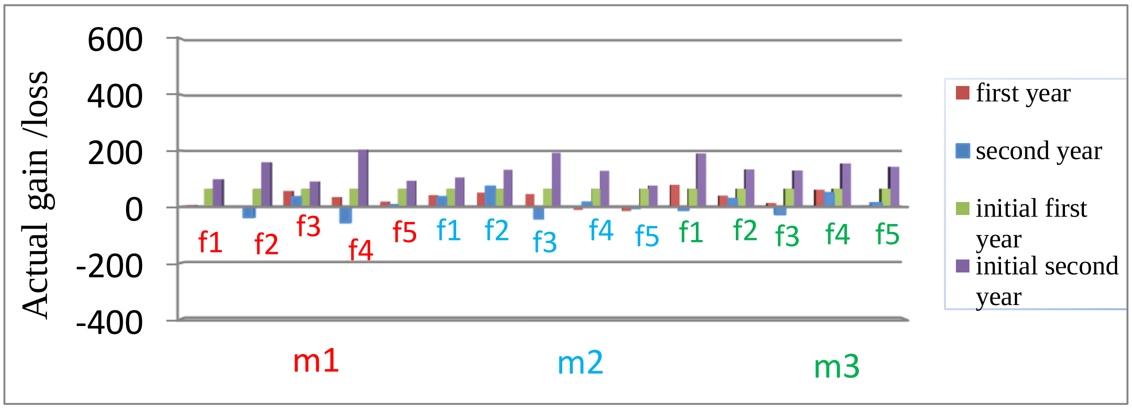


Fig 24. Direct and residual effect of treatments on phosphorus balance sheet of rice (kg ha^{-1})

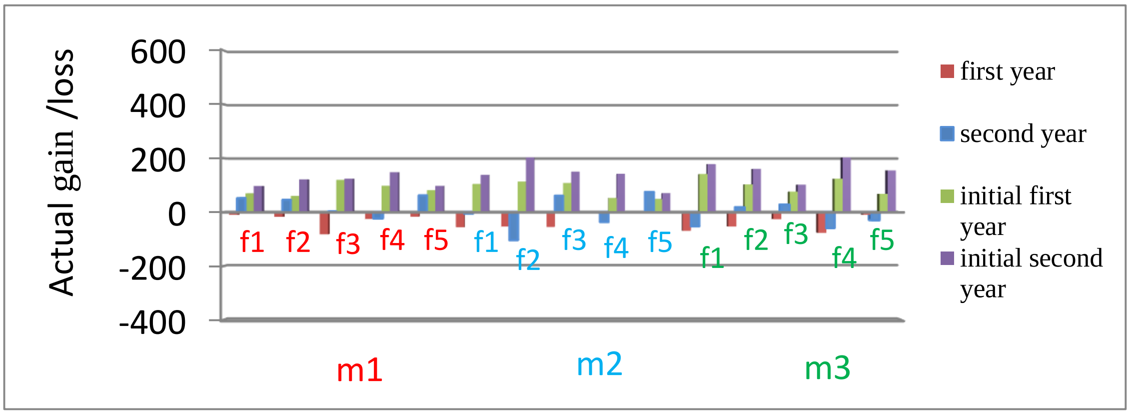


Fig 25. Direct and residual effect of treatments on phosphorus balance sheet of cassava (kg ha^{-1})

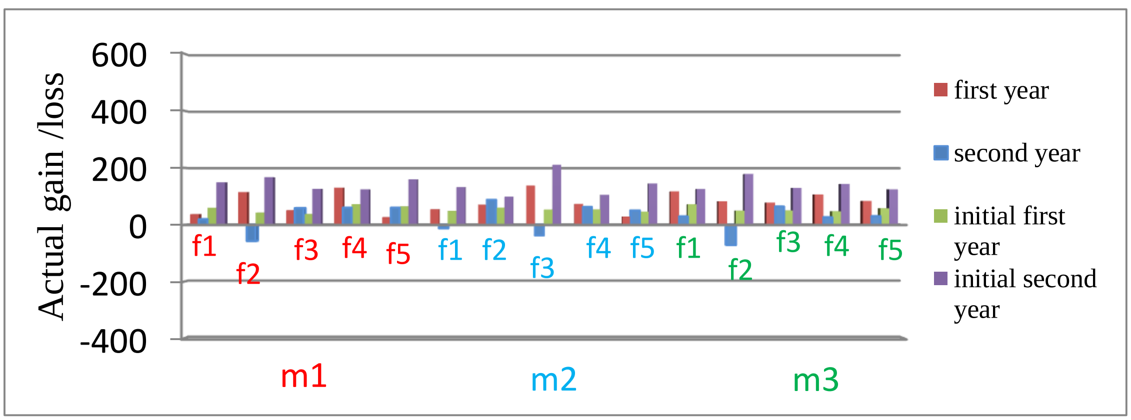


Fig 26. Direct and residual effect of treatments on phosphorus balance sheet of cowpea (kg ha^{-1})

only in the combination where stubble mulching was adopted for weed control (Fig 23). The straw mulch might have immobilized the available potassium in the soil compared to the initial status, which ultimately led to the negative balance.

The potassium balance sheet results of cassava also showed similar trend as that of rice, where depletion was observed after first year cassava and a build up of available K was found in the second year (Fig. 24). Since cassava is a high potassium requiring crop, intercropping in both the years enhanced the potassium availability in cassava by addition of groundnut crop residues as reported by Rana and Rana (2011).

The same trend cannot be observed in the case of third crop of cowpea. In the initial period of study after the cultivation of cowpea in the system, there was a build up of available K content in the soil. The biological nitrogen fixing ability of leguminous crops not only supplied additional nitrogen but also helped the plant to provide more macro and micronutrients (Azam *et al.*, 2008). In the second year, the cultivation of cowpea could not positively influence the K balance in the soil (Fig 25). Potassium was highly depleted compared to N and P, but the rate of depletion was less in those combinations where complex foliar fertilizers was applied compared to the soil application of nutrients. Sharma and Sharma (2002) also reported a similar trend *i.e.* N and P balance was found positive in rice-wheat-greengram and rice-potato-greengram cropping systems, whereas K balance was negative in these cropping systems. These results thus showed that K was the most depleted nutrient by the crops, which results in mining of soil K and thus calls for adequate K fertilization for all the component crops in a system.

From the perusal of data on different aspects it can be concluded that dibbling of sprouted seeds using drum seeder + power weeding along with either band

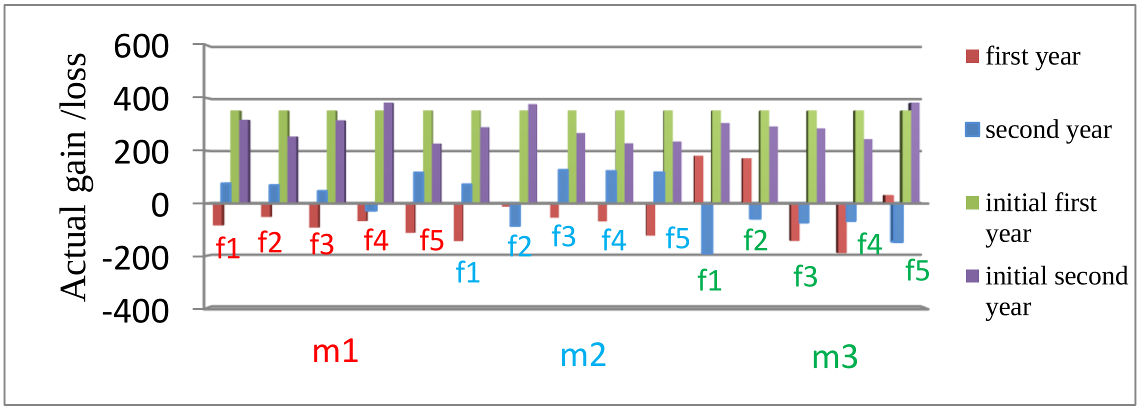


Fig 27. Direct and residual effect of treatments on potassium balance sheet of rice (kg ha^{-1})

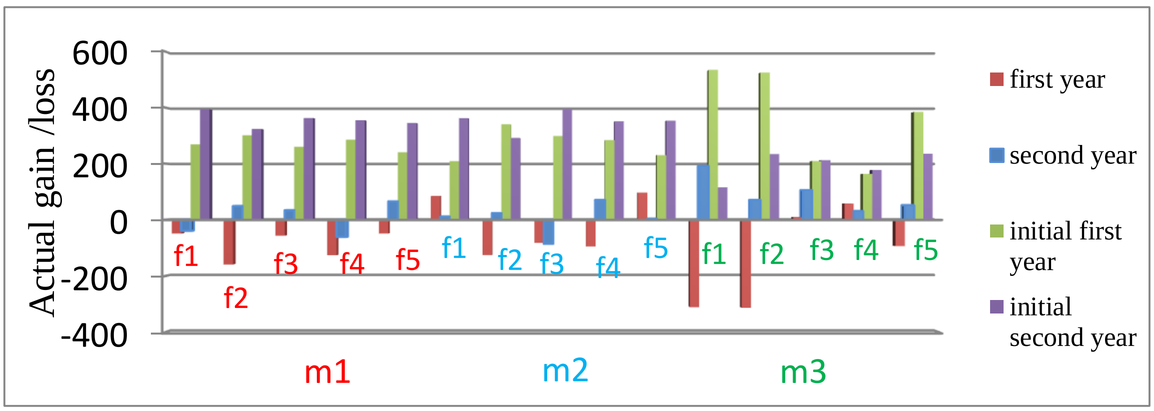


Fig 28. Direct and residual effect of treatments on potassium balance sheet of cassava (kg ha^{-1})

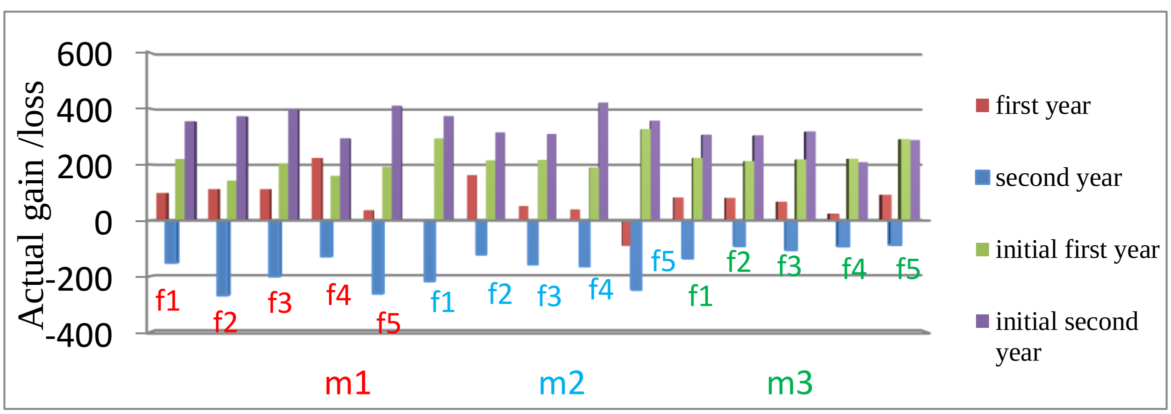


Fig 29. Direct and residual effect of treatments on potassium balance sheet of cowpea (kg ha^{-1})

placement of 60:30:30 kg NPK ha^{-1} or foliar spray of water soluble complex fertilizer 19:19:19 @ 0.5 per cent concentrate (at tillering, panicle initiation and flowering stage) was the most productive, profitable and energy efficient agronomic intervention for rice in upland condition. Direct and residual effect of stubble mulching along with either broadcasting of 60:30:30 kg NPK ha^{-1} or foliar spray of DAP and SOP each @ 2 per cent concentrate (at tillering, panicle initiation and flowering stage) was the most productive with a system yield of 29.71 t ha^{-1}, profitable, energy efficient and sustainable agronomic intervention for rice-cassava + groundnut-cowpea system in upland condition.

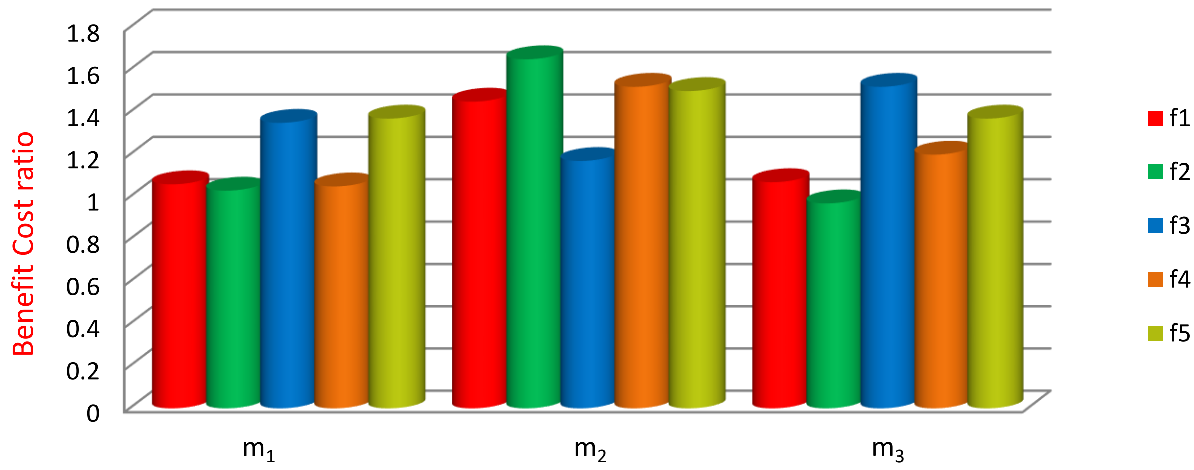


Fig 7. Effect of treatments on benefit cost ratio of rice in rice- cassava + groundnut – cowpea cropping system (2013-14)

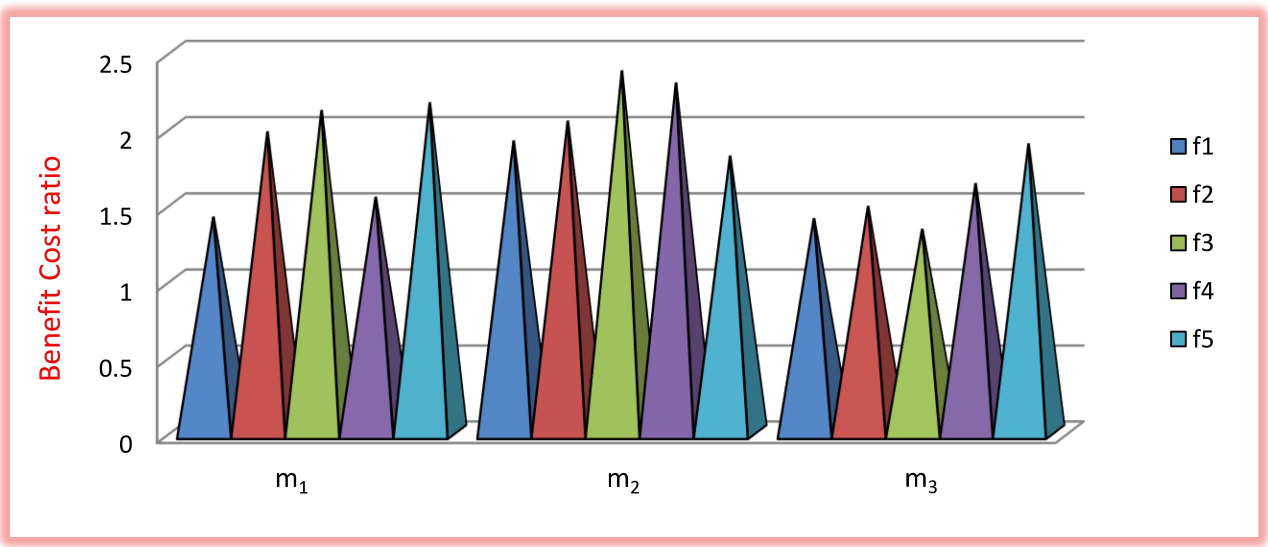


Fig 8. Effect of treatments on benefit cost ratio of rice in rice- cassava + groundnut – cowpea cropping system (2014-15)

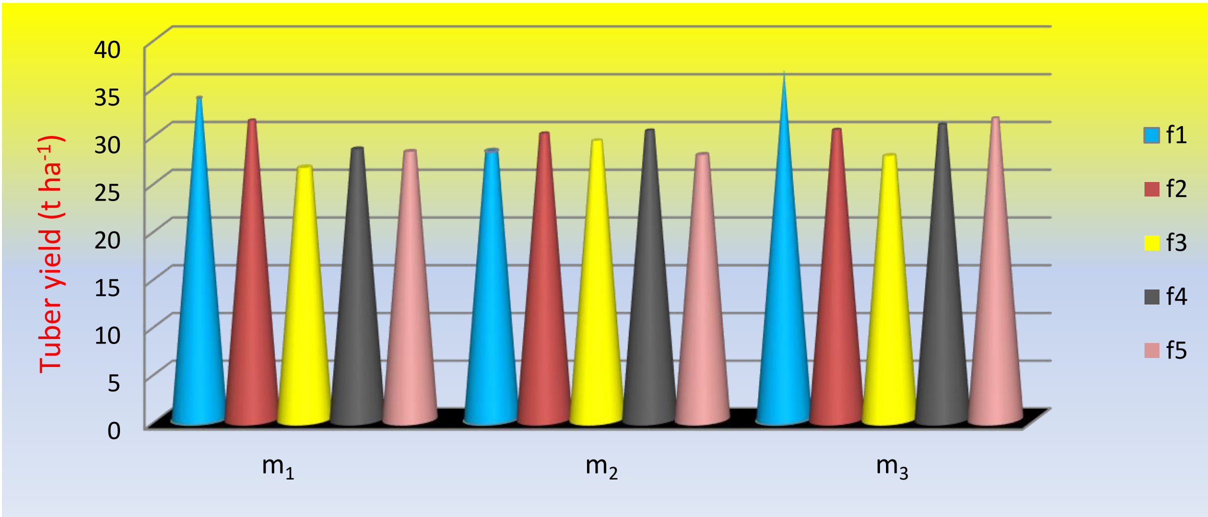


Fig 9. Residual effect of treatments of rice on tuber yield of cassava in rice- cassava + groundnut – cowpea cropping system (2013-14)

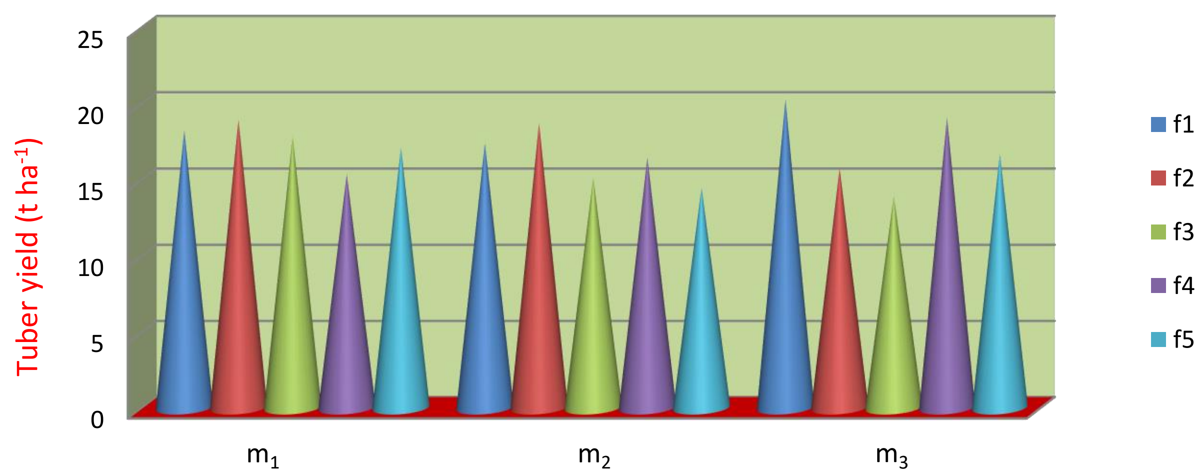


Fig 10. Residual effect of treatments of rice on tuber yield of cassava in rice- cassava + groundnut – cowpea cropping system (2014-15)

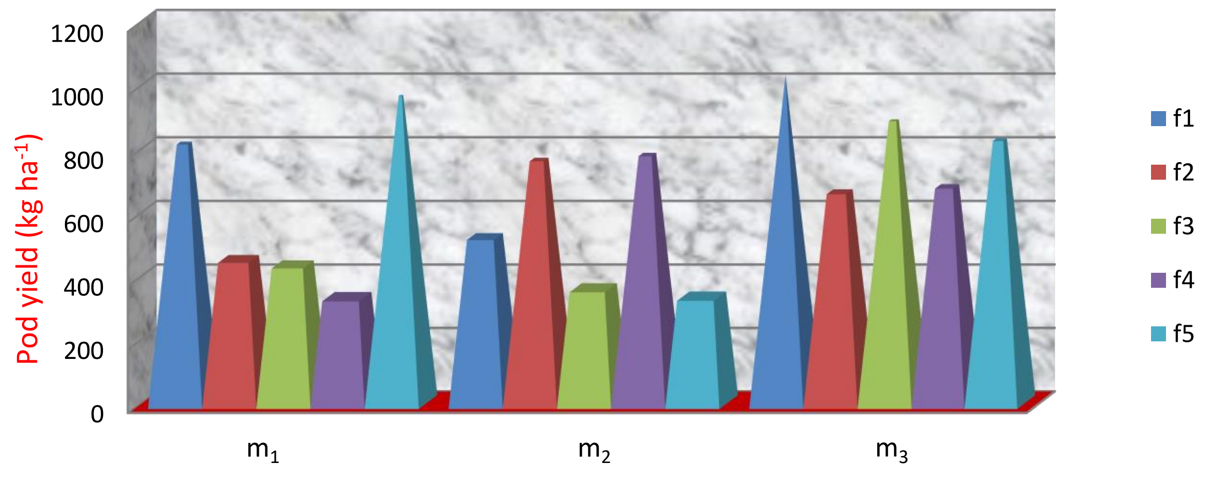


Fig 13. Residual effect of treatments of rice on pod yield of groundnut in rice-cassava + groundnut – cowpea cropping system (2013-14)

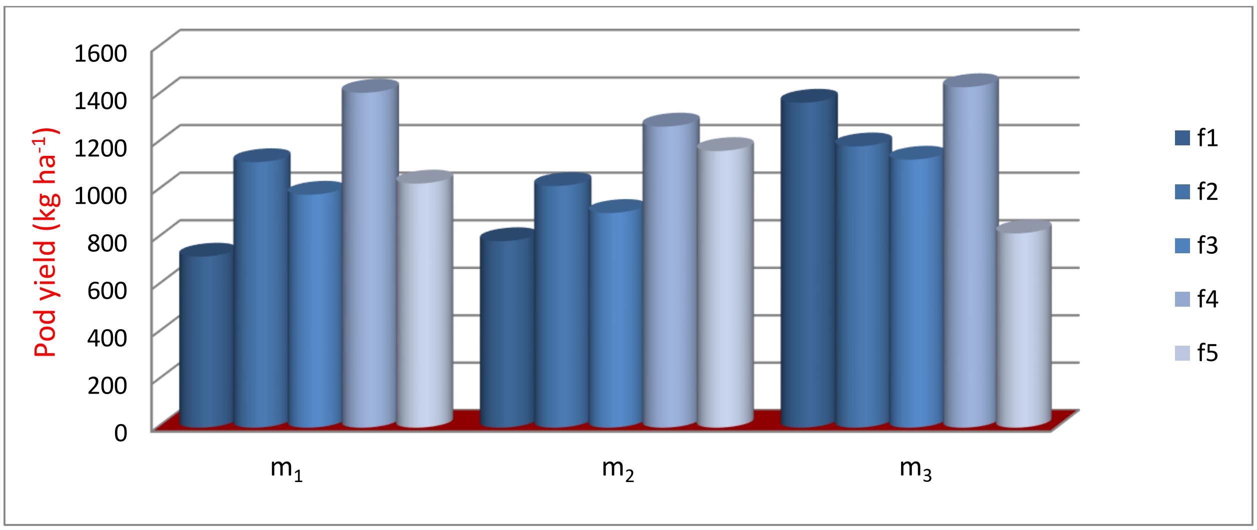


Fig 14. Residual effect of treatments of rice on pod yield of groundnut in rice-cassava + groundnut – cowpea cropping system (2014-15)

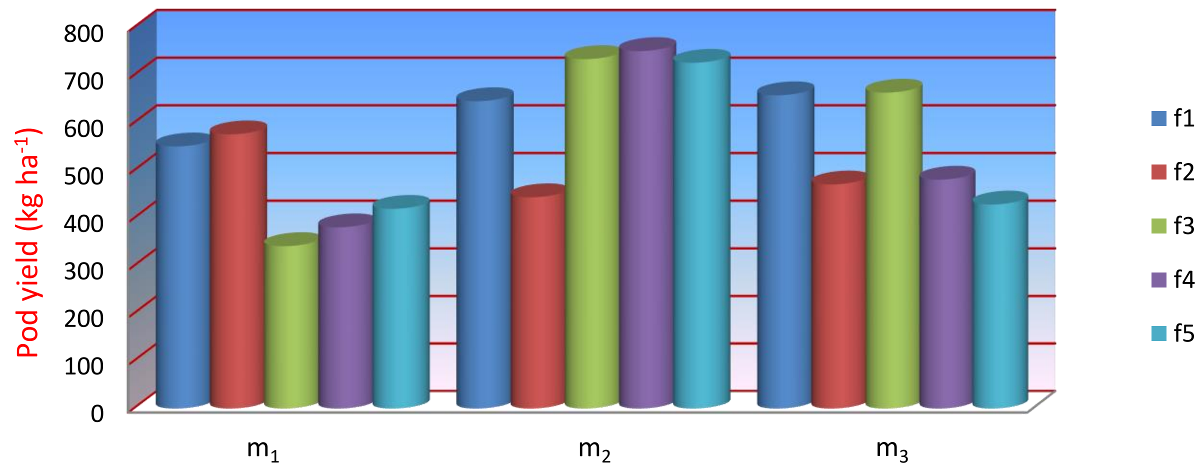


Fig 15. Residual effect of treatments of rice on pod yield of cowpea in rice- cassava + groundnut – cowpea cropping system (2013-14)

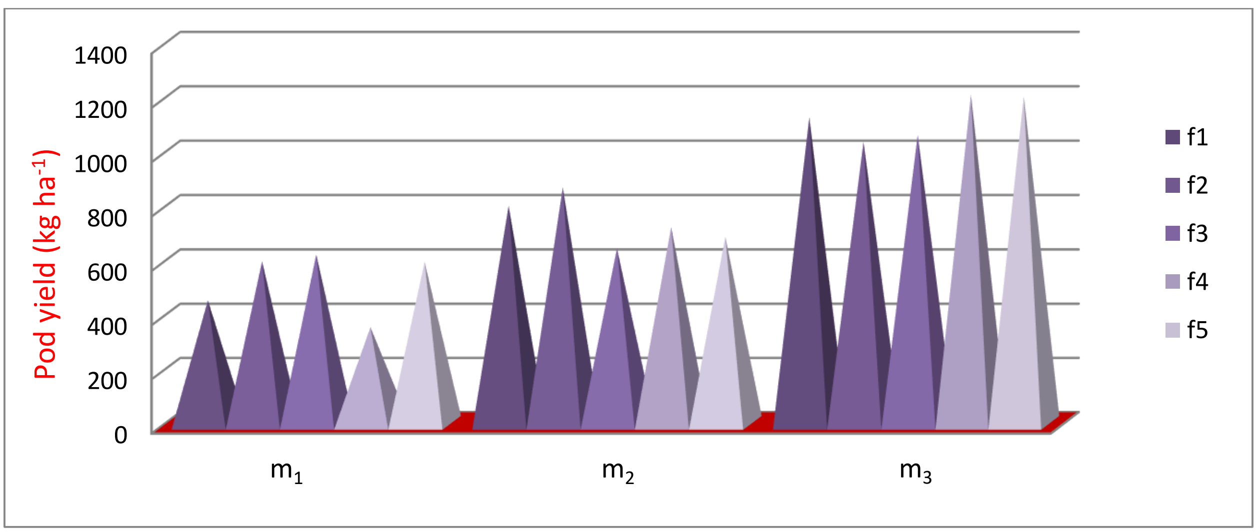


Fig 16. Residual effect of treatments of rice on pod yield of cowpea in rice- cassava + groundnut – cowpea cropping system (2014-15)

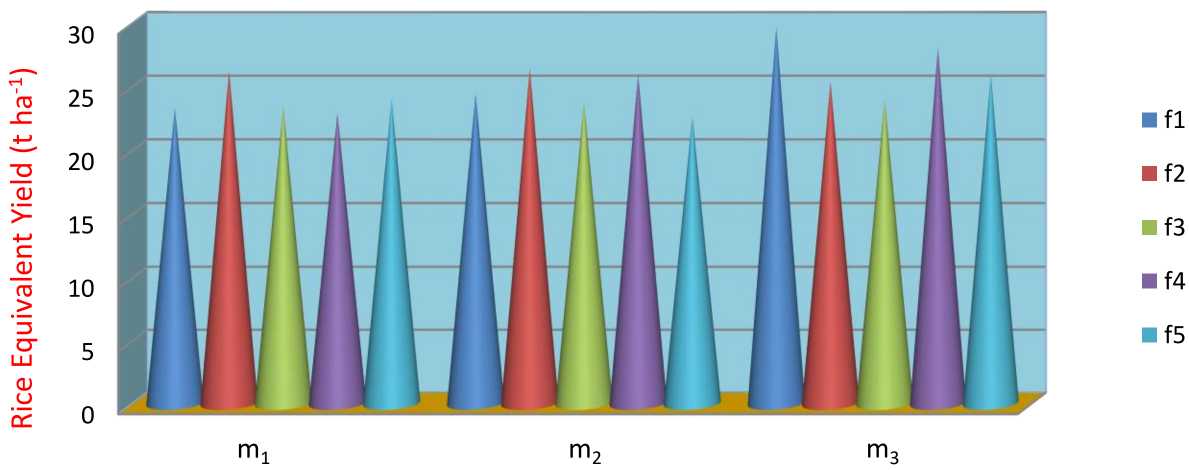


Fig 19. Direct and residual effect of treatments of rice on rice equivalent yield of rice-cassava + groundnut – cowpea cropping system (pooled data)

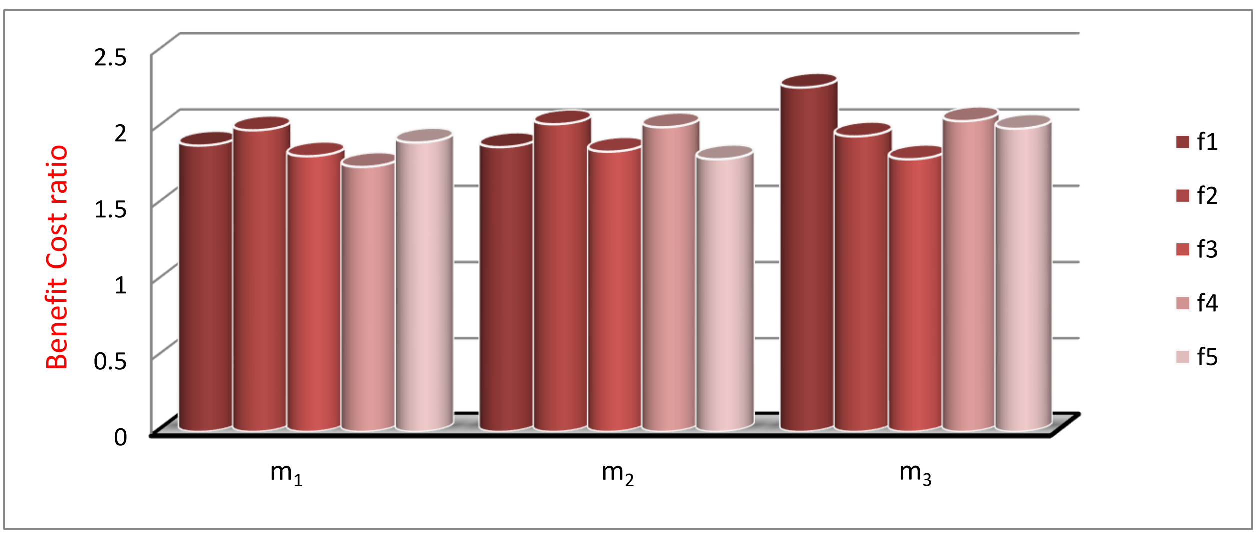


Fig 20. Direct and residual effect of treatments of rice on benefit cost ratio of rice-cassava + groundnut – cowpea cropping system (pooled data)

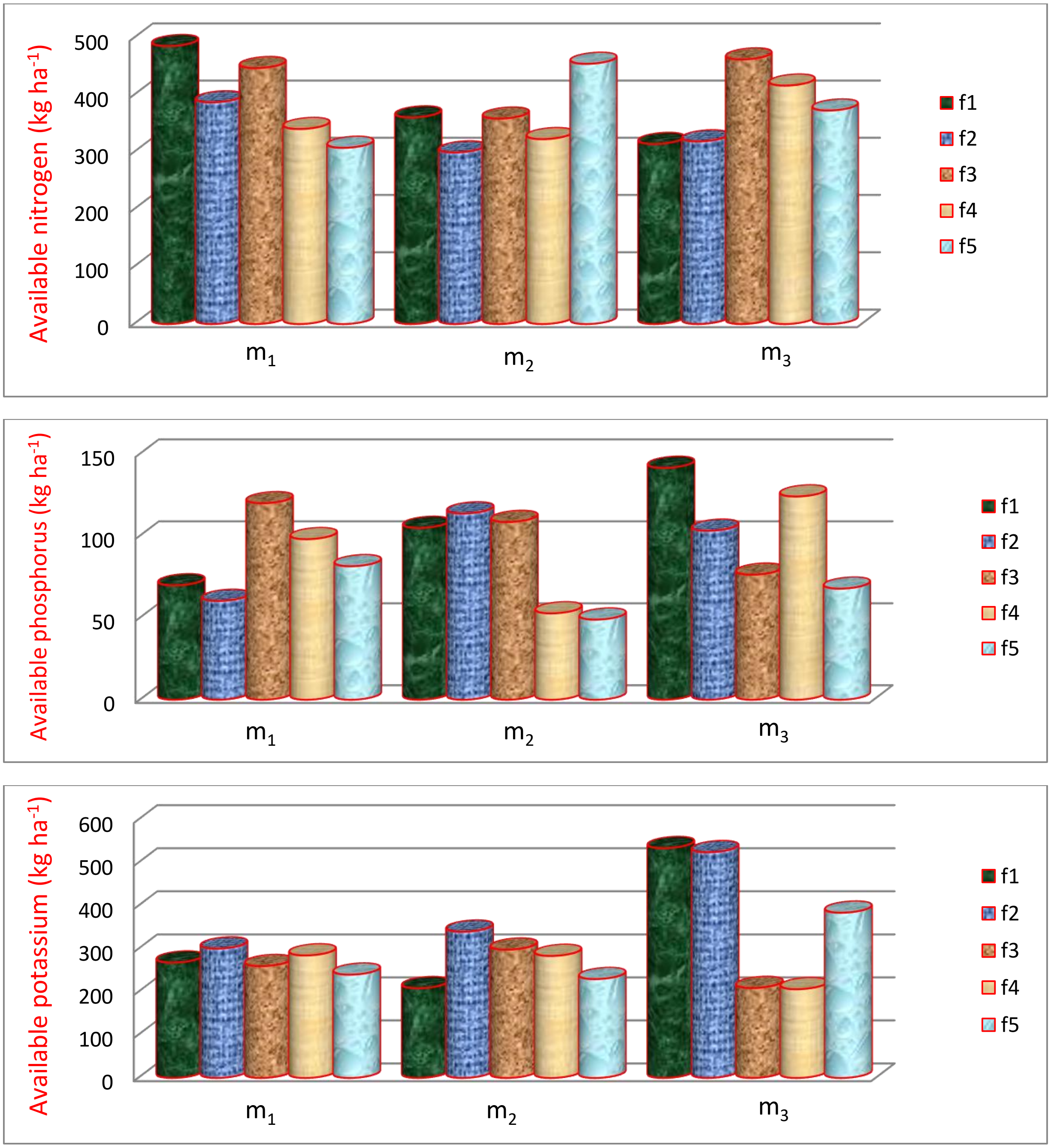


Fig 11. Effect of treatments on available nitrogen, phosphorus and potassium content in soil after first year rice

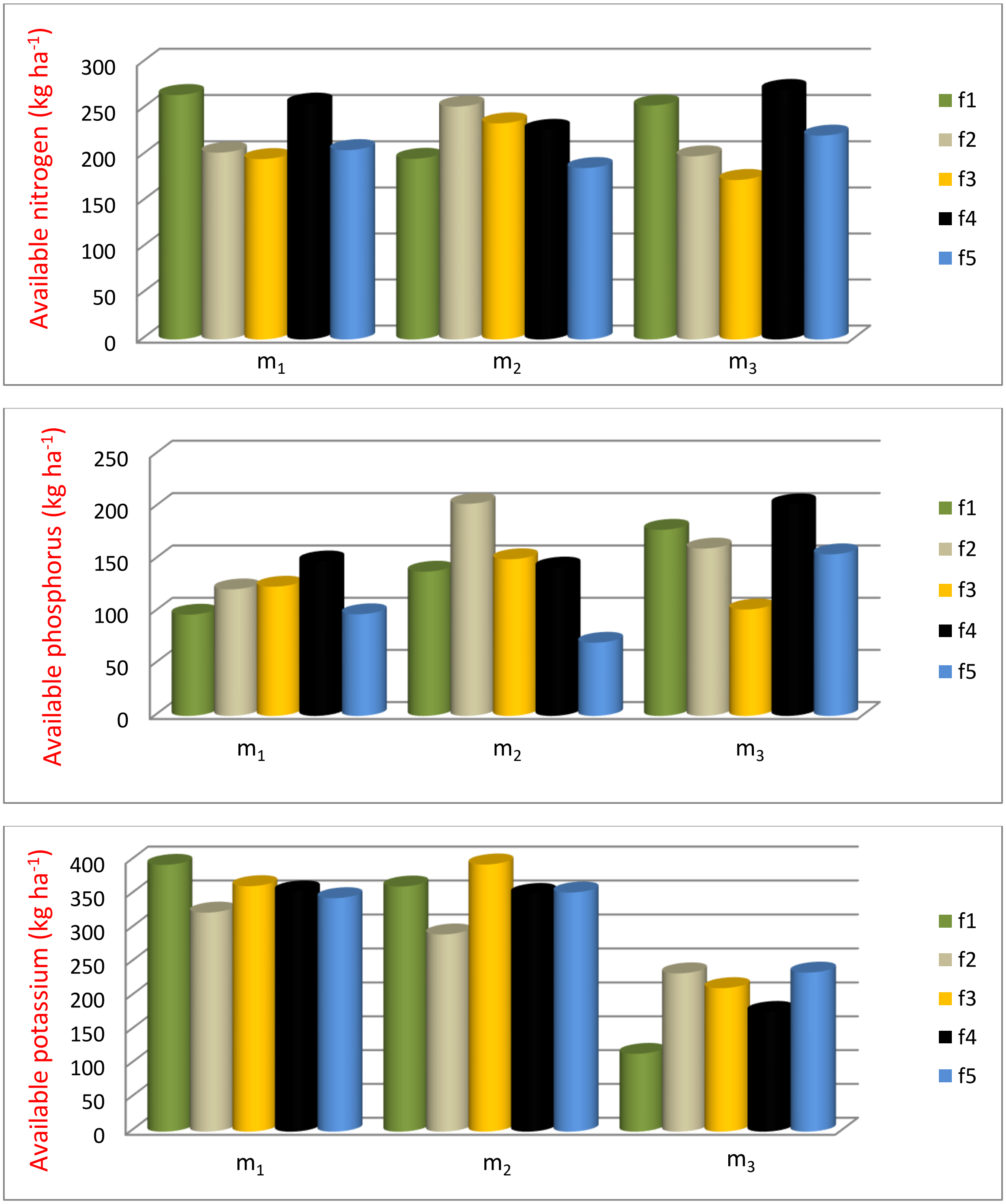


Fig 12. Effect of treatments on available nitrogen, phosphorus and potassium content in soil after second year rice

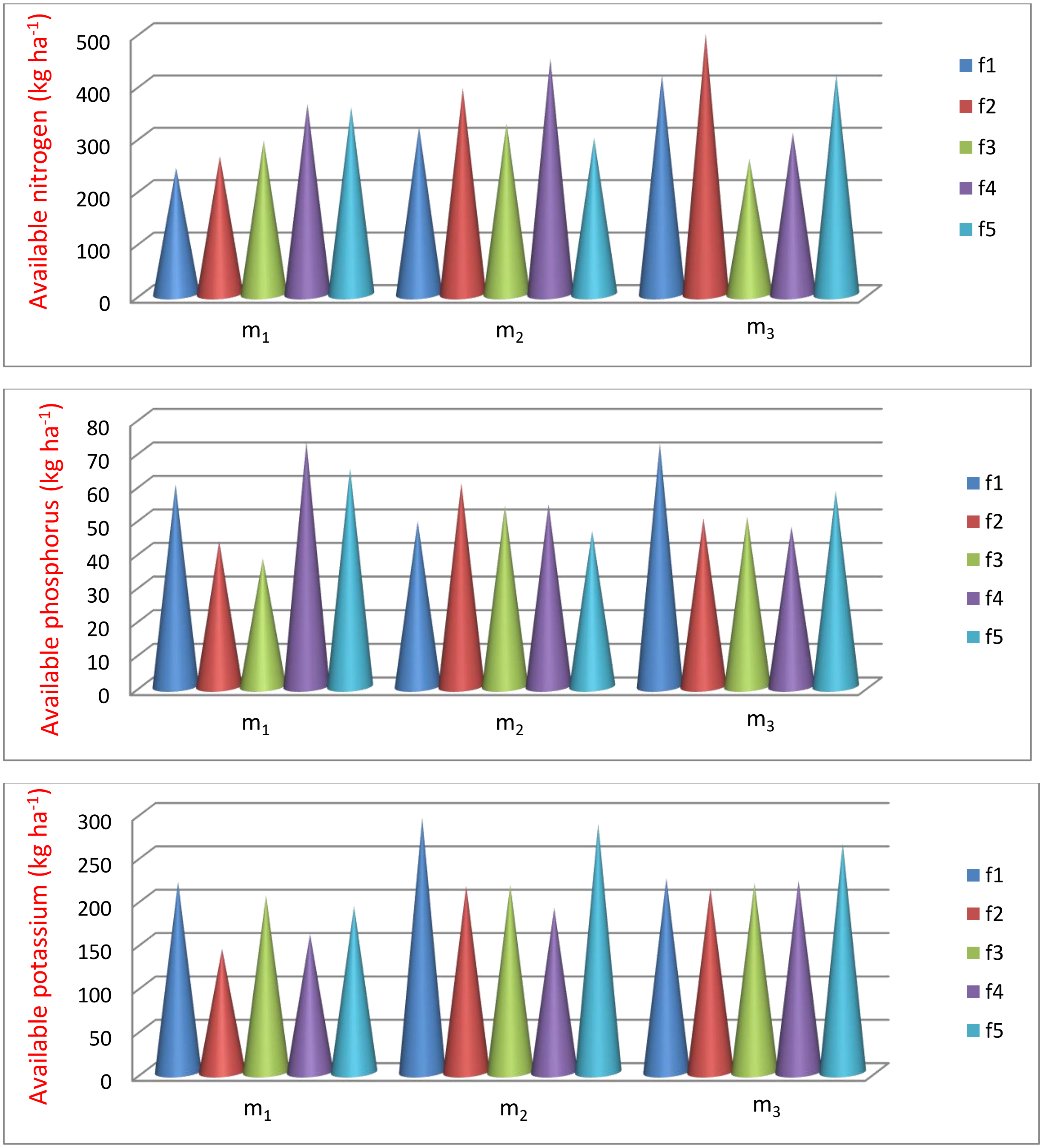


Fig 17. Residual effect of treatments on available nitrogen, phosphorus and potassium content in soil after first year cassava

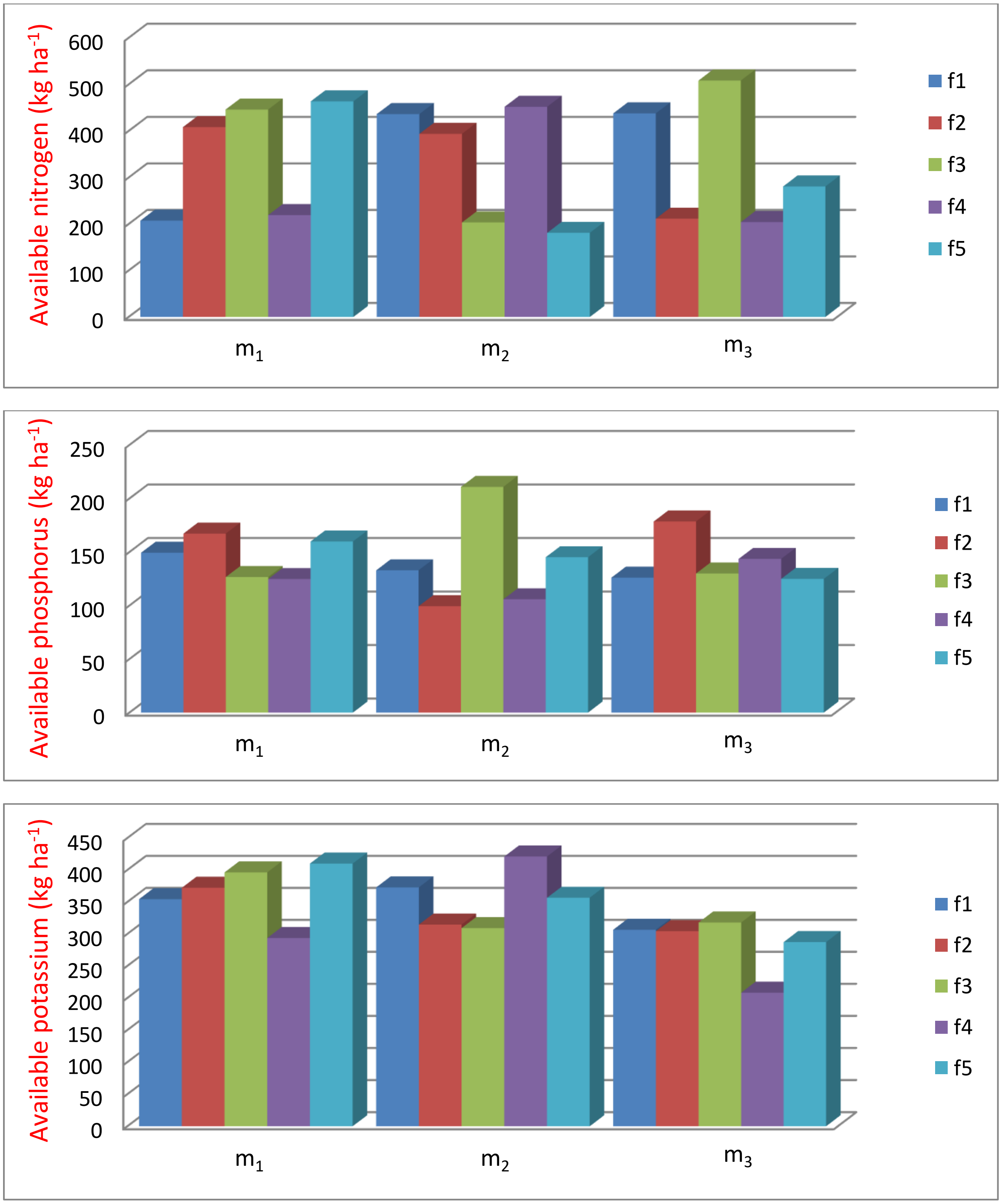


Fig 18. Residual effect of treatments on available nitrogen, phosphorus and potassium content in soil after second year cassava

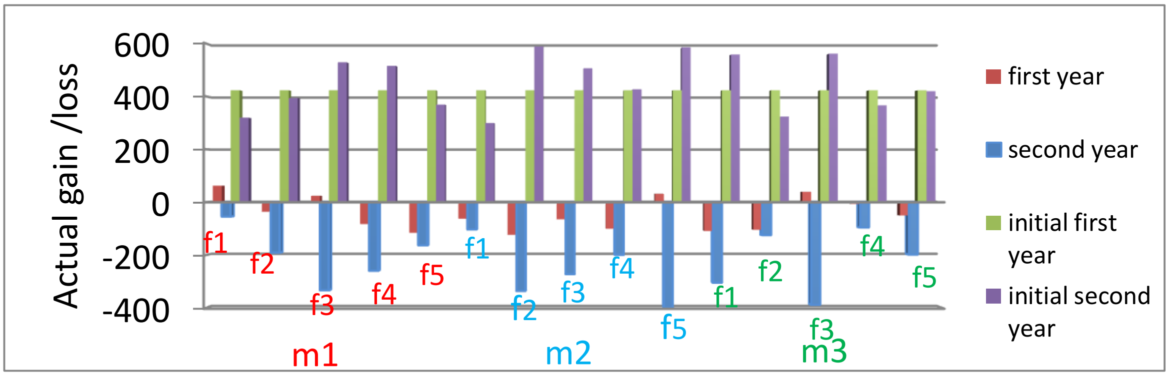


Fig 21. Direct and residual effect of treatments on nitrogen balance sheet of rice (kg ha^{-1})

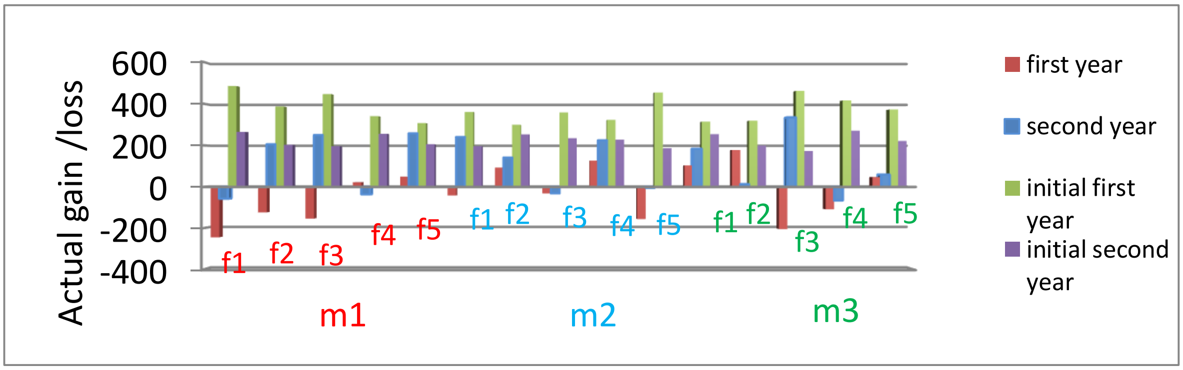


Fig 22. Direct and residual effect of treatments on nitrogen balance sheet of cassava (kg ha^{-1})

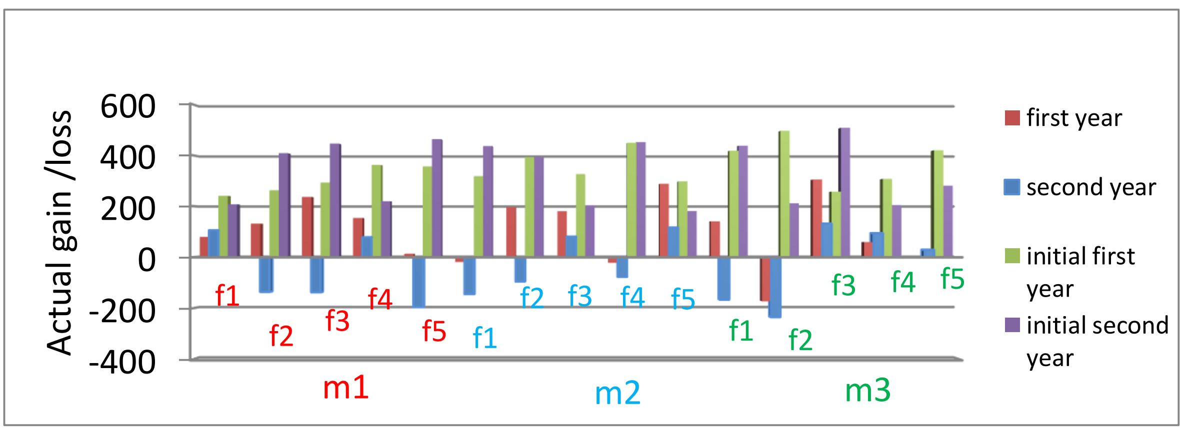


Fig 23. Direct and residual effect of treatments on nitrogen balance sheet of cowpea (kg ha^{-1})

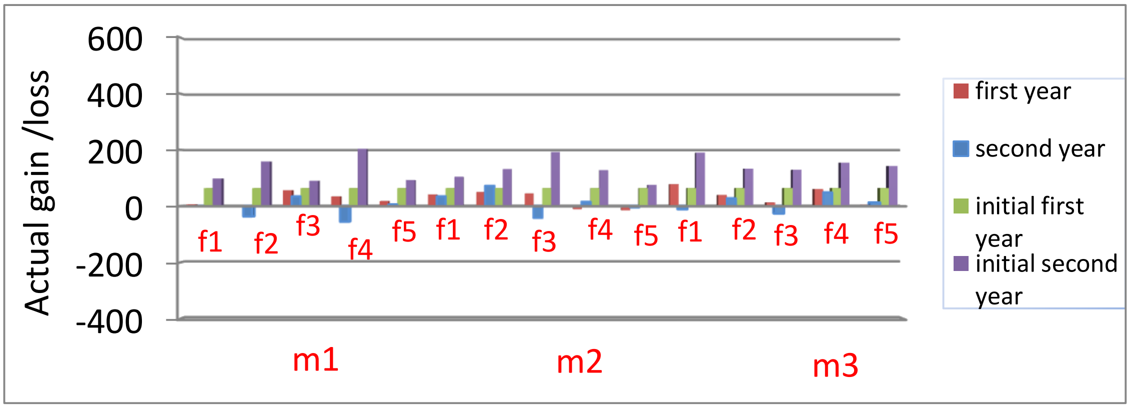


Fig 24. Direct and residual effect of treatments on phosphorus balance sheet of rice (kg ha^{-1})

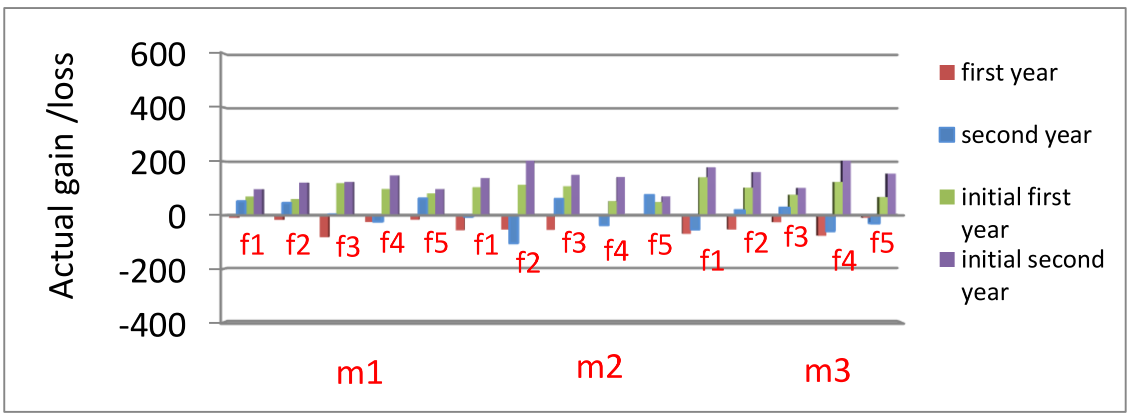


Fig 25. Direct and residual effect of treatments on phosphorus balance sheet of cassava (kg ha^{-1})

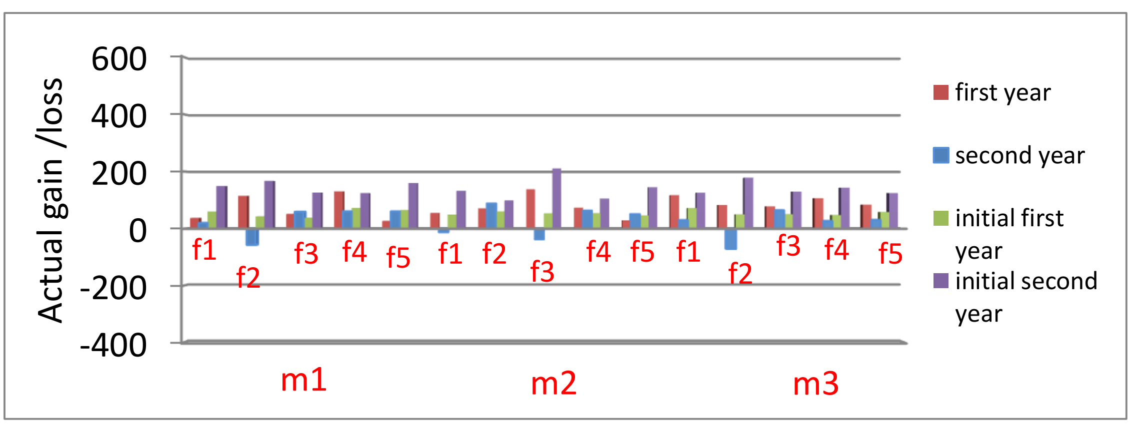


Fig 26. Direct and residual effect of treatments on phosphorus balance sheet of cowpea (kg ha^{-1})

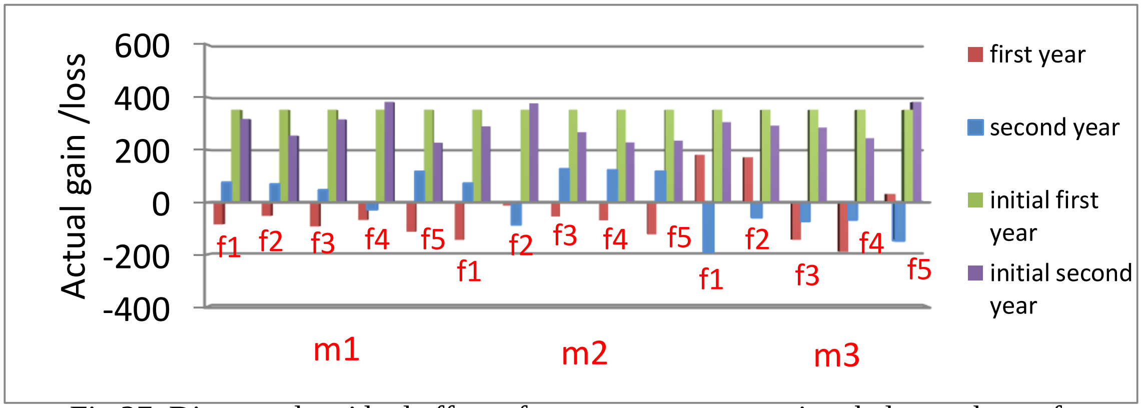


Fig 27. Direct and residual effect of treatments on potassium balance sheet of rice (kg ha^{-1})

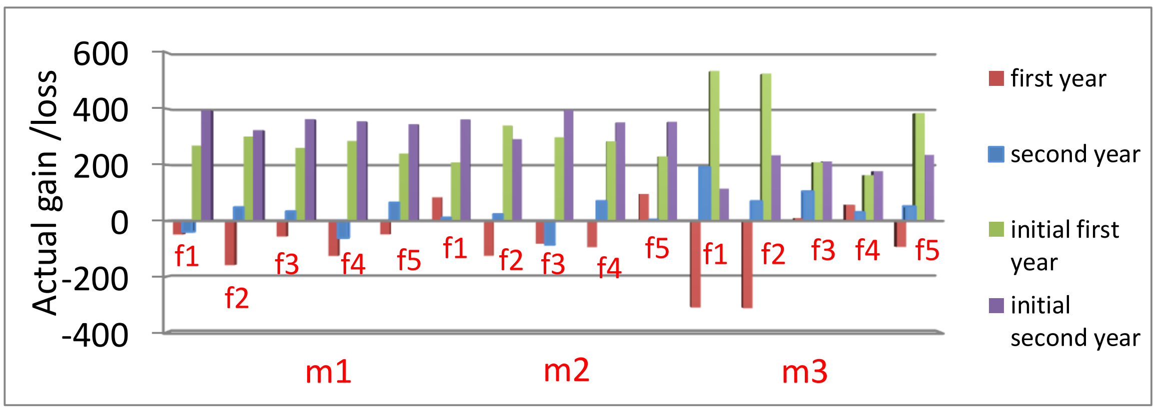


Fig 28. Direct and residual effect of treatments on potassium balance sheet of cassava (kg ha^{-1})

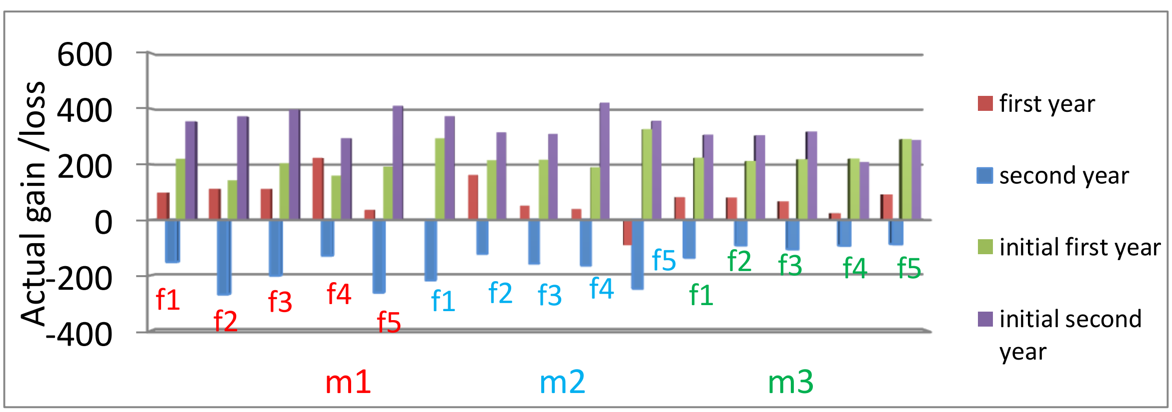


Fig 29. Direct and residual effect of treatments on potassium balance sheet of cowpea (kg ha^{-1})

Summary

6. SUMMARY

The experiment entitled “Agronomic interventions for a sustainable rice based cropping system in paddy fields” was undertaken for two years at the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, during 2013-14 and 2014-15. The experiment consisted of rice based cropping system comprised of rice followed by cassava (intercropped with groundnut) and cowpea in upland condition. The main objectives of the study were to assess the impact of agronomic interventions on growth, productivity, sustainability, nutrient balance, energetics and economics of the cropping system.

The experiment comprised of three main plot treatments, which included methods of planting in combination with weed control measures [M_1 - broadcasting of sprouted seeds, M_2 - dibbling (sprouted seeds with drum seeder along with weeding by power weeder) and M_3 - dibbling (sprouted seeds with drum seeder along with stubble mulching)] and five methods of fertilizer application as sub plot treatments [F_1 - broadcasting (60:30:30 kg NPK ha^{-1}), F_2 - band placement (60:30:30 kg NPK ha^{-1}), F_3 - foliar spray of water soluble complex foliar fertilizer 19:19:19 @ 0.5 per cent, F_4 - foliar spray of diammonium phosphate (DAP) and sulphate of potash (SOP) each @ 2 per cent, F_5 - control] for upland rice. For cassava intercropped with groundnut, the recommended dose of fertilizer (FYM @ 12.5 t ha^{-1} and 110:120:120 kg NPK ha^{-1}) along with 0.5 per cent foliar spray of 19:19:19 at 30 days (up to three weeks before harvest in both cassava and groundnut) interval was applied uniformly to all plots. For cowpea, the recommended dose of fertilizer (FYM @ 20 t ha^{-1} and 20:30:10 kg NPK ha^{-1}) along with 0.5 per cent foliar spray of 19:19:19 at 14 days interval (up to one week before first harvest) was applied uniformly to all plots. The residual effect of the

treatments imposed to rice was assessed in the succeeding crops such as cassava intercropped groundnut and cowpea during both the years of study. The investigation was laid out in split plot design with five replications.

Summary of results of component crops in the cropping system are as follows.

The methods of planting and weed control measures had significant effect on most of the growth and yield attributes of rice. The highest grain yield (2085.42 kg ha^{-1}) as well as straw yield was produced in M_2 (dibbling of seeds using drum seeder + power weeding), which was on par with M_3 (dibbling of seeds using drum seeder + stubble mulching), during the first year of experimentation. In the second year, the methods of planting and weed control measures did not have any significant effect on the grain yield, straw yield and HI of rice. Even though the yield attributes such as, number of productive tillers m^{-2} and panicle length were significant and the highest for treatments M_2 and M_3, all other attributes were not significant.

During 2013-14, the effect of methods of fertilizer application on the grain yield and straw yield of rice was not significant. During 2014-15, the grain yield, straw yield and HI were significantly influenced by the treatments and the yield was comparatively higher compared to the first year. This was due to the higher yield attributes and lower sterility percentage produced in the second year. The highest grain yield was produced in F_3 (foliar spray of 19:19:19 @ 0.5 per cent) and was on par with F_2 and F_4. The highest straw yield was resulted in F_2, which was significantly higher than all the other treatments.

The treatment combination of m_2f_2 (dibbling of seeds using drum seeder + power weeding along with band placement of 60:30:30 kg NPK ha^{-1}) produced the highest grain yield (2927.97 kg ha^{-1}), straw yield (4652.50 kg ha^{-1}) and HI (0.39) during the first year. The highest straw yield was recorded in m_1f_3 and HI in m_1f_4 which were on par with m_2f_2. During 2014-15, the highest grain yield (3109.33 kg ha^{-1}), straw yield (4982.96 kg ha^{-1}) and HI (0.38) were recorded in m_2f_3 (dibbling of seeds using drum seeder + power weeding along with foliar spray of 19:19:19 @ 0.5 per cent).

The treatment combination, m_2f_2 (dibbling of seeds using drum seeder + power weeding along with band placement of 60:30:30 kg NPK ha^{-1}) resulted in the highest B:C ratio of 1.65 in the first year. During the second year, the highest B:C ratio of 2.38 was observed in dibbling of seeds using drum seeder + power weeding along with foliar spray of 19:19:19 @ 0.5 per cent (m_2f_3).

Residual effect of the treatments applied to first crop rice was observed in the growth and yield of succeeding cassava intercropped with groundnut in both the years. Among the main plot treatments, the highest tuber yield, marketable tuber yield and top yield were produced in residual effect of stubble mulching (M_3) during the first year. In the second year, the tuber yield was found not significant.

During 2013-14, higher tuber yield of 31.90 and 31.68 t ha^{-1} was observed in the residual effect of soil application of 60:30:30 kg NPK ha^{-1} through broadcasting (F_1) as well as band placement (F_2) respectively. In the second year, the residual effect of application of 60:30:30 kg NPK ha^{-1} as broadcasting (F_1) and foliar spray of DAP and SOP each @ 2 per cent (F_4) produced the higher tuber yield of 18.63 and 17.78 t ha^{-1} respectively.

The residual effect of stubble mulching along with broadcast application of 60:30:30 kg NPK ha^{-1} (m_3f_1) significantly enhanced tuber yield in both the years and it was on par with m_3f_4 (residual effect of stubble mulching along with foliar spray of DAP and SOP each @ 2 per cent) during the second year.

The yield and yield attributes of groundnut were significantly influenced by the carry over effect of treatments of rice. Residual effect of stubble mulching using rice straw resulted in the highest haulm yield, kernel yield, pod yield, biomass yield and HI of groundnut in both the years.

Among the methods of fertilizer application, the haulm yield, kernel yield, pod yield, biomass yield and HI of groundnut were significantly improved in the residual effect of broadcast application of 60:30:30 kg NPK ha^{-1} in the rice during the first year. During 2014-15, the highest pod yield was observed in the residual effect of DAP and SOP each @ 2 per cent foliar spray.

Comparing the treatment combinations, the pod yield of groundnut was the highest in the residual effect of stubble mulching along with broadcasting of 60:30:30 kg NPK ha^{-1} and was on par with m_1f_5 and m_3f_3 in the first year. During 2014-15, the significantly highest pod yield of 1433.60 kg ha^{-1} was observed in the residual application of stubble mulching along with foliar spray of DAP and SOP each @ 2 per cent and it was due to the cumulative effect of the highest kernel yield and HI.

The residual effect of treatments of rice had significant influence on the growth and yield attributes of cowpea during both the years. In the first year, the residual effect of various weed control measures did not have any significant influence on the DMP, number of pods $plant^{-1}$ and pod yield. In the second year, the residual effect of stubble mulching (M_3) showed significant effect on the DMP, number of pods $plant^{-1}$ and pod yield of cowpea.

Comparing the various methods of fertilizer application, the DMP, number of pods $plant^{-1}$ and pod yield was higher in the residual effect of soil application of nutrients in rice (F_1) during the first year. While in the second year, the residual effect of treatment F_2 (band placement of 60:30:30 kg NPK ha^{-1} applied to rice) resulted in the highest DMP and pod yield (833.54 kg ha^{-1}) and the number of pods $plant^{-1}$ was found not significant.

Among the combination of weed management and fertilizer application, residual effect of mechanical weeding along with foliar spray of DAP and SOP each @ 2 per cent resulted in the highest number of pods $plant^{-1}$ and pod yield in the first year. During 2014-15, the DMP, number of pods $plant^{-1}$ and pod yield of 1209.33 kg ha^{-1} was higher in the residual effect of stubble mulching along with foliar spray of DAP and SOP each @ 2 per cent.

Summary of results of the cropping system are given below.

The three methods of planting and weed controlpractices exhibited significant variation in rice equivalent yield (REY) during both the years of experimentation in rice – cassava+groundnut - cowpea system. Direct and residual effect of dibbling of seeds using drum seeder + stubble mulching (M_3) produced significantly higher REY during both the years.

The REY varied significantly among the direct and residual effect of different fertilizer application methods. In the first year, the direct as well as residual effect of soil application of fertilizers (broadcast (F_1) and band placement (F_2)) in rice produced the higher REY. While in the second year, the direct and residual effect of soil (band placement of 60:30:30 kg NPK ha^{-1} (F_2)) as well as foliar application of fertilizer (foliar spray of DAP and SOP each @ 2 per cent) resulted in the higher REY of 21.78 t ha^{-1} and 21.45 t ha^{-1} respectively.

The pooled data of treatment combinations on REY over years showed that, the direct and residual effect of treatment combination of m_3f_1 (dibbling of seeds + stubble mulching along with broadcasting of 60:30:30 kg NPK ha^{-1}) produced the highest system yield of 29.71 t ha^{-1}, which was superior to all the other combinations, except m_3f_4 (dibbling of seeds + stubble mulching along with foliar spray of water soluble complex fertilizer DAP and SOP each @ 2 per cent) which was on par.

Energetics of the cropping system includes various parameters such as energy efficiency, energy productivity, specific energy and energy intensity. The different methods of planting, weed control as well as nutrient management practices significantly affected each parameters of the energetics in both the years. The highest energy efficiency, energy productivity and energy intensity was observed in the direct and residual effect of dibbling of seeds using drum seeder + power weeding (M_2) during both the years of experimentation.

Among the direct and residual effect of four methods of fertilizer application, the highest energy efficiency and energy productivity were registered in foliar application of fertilizers 19:19:19 @ 0.5 per cent (F_3) and DAP and SOP each @ 2 per cent (F_4) in the two years respectively. Even though the specific energy was found not significant in the first year, the direct and residual effect of foliar spray of both the fertilizers influenced the specific energy of the cropping system. All the energy parameters performed better in the combination of direct and residual effect of dibbling of seeds using drum seeder + power weeding along with foliar spray of DAP and SOP each @ 2 per cent during both the years.

Nutrient balance sheet results indicated that after the first year, a buildup of available nitrogen, phosphorus and potassium was observed in all the treatments.

During second year, a depletion of available nutrients was observed, but the rate of depletion was less in complex foliar fertilizers compared to soil application.

During the first year of experimentation (2013-14), the highest net returns and B:C ratio were observed in the direct and residual effect of dibbling of seeds using drum seeder + stubble mulching along with soil application of 60:30:30 kg NPK ha^{-1} as broadcasting in rice (m_3f_1). In the second year also, the combination of m_3f_1 resulted in the highest net returns and B:C ratio, which was followed by the direct and residual effect of m_3 along with foliar spray of DAP and SOP each @ 2 per cent (f_4) with a net returns of Rs 2,11,122.00 ha^{-1}. The B:C ratio of 1.85 was observed in both the combinations of m_3f_1 and m_3f_4. The pooled data also showed similar trend.

Based on the results of the present investigation, it can be concluded that, dibbling of sprouted seeds using drum seeder + power weeding along with either band placement of 60:30:30 kg NPK ha^{-1} or foliar spray of water soluble complex fertilizer 19:19:19 @ 0.5 per cent concentrate (at tillering, panicle initiation and flowering stage) was the most productive, profitable and energy efficient agronomic intervention for rice in upland condition. Residual effect of stubble mulching along with either broadcasting of 60:30:30 kg NPK ha^{-1} or foliar spray of DAP and SOP each @ 2 per cent concentrate (at tillering, panicle initiation and flowering stage) was the most productive with a system yield of 29.71 t ha^{-1}, profitable, energy efficient and sustainable agronomic intervention for rice - cassava + groundnut - cowpea system in upland condition.

Future Line of Work

- Study on the efficiency of various components of integrated nutrient management and its residual effect on different cropping systems.
- Research on alternate fertilizer management practices like foliar along with adjuvants in individual crops as well as cropping system.
- A basic study to understand the effect of foliar nutrition on the physiological and metabolic functions of crops.
- Effect of foliar nutrition on quality of produce need to be assessed especially on the hydrocyanic (HCN) content of cassava.
- Study on farm mechanization for labour saving.
- Explore the possibility of different weeding machines and mulches on crop performance of rice based cropping system.

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Appendices

APPENDIX I

Weather data during the first year (2013-14) of experimentation

Month	Temperature (^0C)		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
August	29.9	24.3	88.5	9.4
September	29.4	24.0	94.4	216.2
October	31.1	23.4	91.4	166.0
November	30.6	23.2	97.4	292.7
December	30.6	22.4	97.3	84.2
January	30.9	21.5	93.3	28.5
February	31.6	22.4	92.0	21.0
March	32.4	22.8	91.2	31.5
April	32.8	24.2	91.3	115.0
May	31.9	24.5	91.7	280.4
June	30.9	25.4	92.5	88.0

July	29.9	24.2	93.5	105.0
August	28.9	23.1	94.6	80.2

APPENDIX II

Weather data during the second year (2014-15) of experimentation

Month	Temperature (^{0}C)		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
August	29.8	24.0	88.4	456.3
September	30.1	24.0	90.3	219.4
October	30.7	23.7	80.2	230.2
November	29.8	23.4	94.0	137.3
December	29.9	23.2	90.9	133.5
January	30.9	21.9	94.9	8.0
February	32.0	22.5	90.4	0.0
March	32.6	24.0	89.5	56.1
April	32.7	24.7	91.1	182.6
May	32.7	25.5	88.2	406.0
June	30.9	24.1	91.2	346.9
July	31.2	24.7	89.3	53.5
August	31.6	24.5	87.9	6.7

APPENDIX III

Details of economics of rice based cropping system during the first (2013-14) and second (2014-15) year of experimentation

Sl. No	Particulars	Units (ha^{-1})	Labour		Unit cost (Rs)	Total cost (Rs ha^{-1})
			Male (612 day^{-1})	Female (306 day^{-1})		
I	**Cost of inputs and labour - rice**					
1.	Preparatory cultivation					
a)	Ploughing and land leveling using power tiller		2			1224
	i. Diesel	18 L			54 L^{-1}	972
b)	Taking broad bed and furrow		6			3672
c)	Lay out of the field		5			3060
2.	Seeds and sowing					

a)	Cost of Seeds	100 kg			27 kg^{-1}	2700
b)	Sowing		4	3		3366
3.	Manure					
a)	FYM	5 t			400 t^{-1}	2000
b)	FYM loading and application		3	2		2448
4.	Irrigation		1	3		1530
a)	Diesel	40 hr			54 L^{-1}	3240
5.	Thinning and gap filling		2	1		1530
6.	Plant protection					
a)	Cost of malathion	1 L			400 L^{-1}	400
b)	Application charges	3 times		3		918
7.	Harvesting		4	2		3060
8.	Threshing and cleaning		2	2		1836
9.	Drying			3		918
II	**Cost of treatments (ha^{-1})**					
1.	Fertilizers and other inputs					
a)	Urea	125 kg			7 kg^{-1}	875
b)	Rock phosphate	137.5 kg			10 kg^{-1}	1375
c)	Muriate of potash	45.83 kg			18 kg^{-1}	825
d)	19:19:19	3.6 kg			175 kg^{-1}	630
e)	DAP	13.8 kg			35 kg^{-1}	483
f)	SOP	13.8 kg			75 kg^{-1}	1035
g)	Stanowet	2.1 L			710 L^{-1}	1491
h)	Straw	2.5 t			3 kg^{-1}	7500
i)	Chemical fertilizer weighing, mixing and application		3	2		2448
Sl. No	Particulars	Units (ha^{-1})	Labour		Unit cost (Rs)	Total cost (Rs ha^{-1})
			Male (612 day^{-1})	Female (306 day^{-1})		
j)	Foliar fertilizer spraying	3 times	1	3		1530
2.	Weeding and mulching					
a)	Hand weeding		3	3		2754
b)	Power weeding		2			1224
	i. Petrol	10 hr			68 L^{-1}	680
c)	Straw mulching		3	2		2448
III	**Cost of inputs and labour - cassava**					
1.	Nursery preparation					

a)	Filling of potting mixture and planting the stem cuttings in protrays		9	7		7650
2.	Preparatory cultivation					0
a)	Ploughing and removal of weeds		9	12		9180
b)	Taking mounds		14			8568
3.	Planting					
a)	Cost of planting material	1250 stems			3 stem^{-1}	3750
b)	Planting of minisetts to main field		9	11		8874
4.	Manures and fertilizers					
a)	FYM	12.5 t			400 t^{-1}	5000
b)	Urea	217 kg			7 kg^{-1}	1519
c)	Rock phosphate	500 kg			10 kg^{-1}	5000
d)	Muriate of potash	167 kg			18 kg^{-1}	3006
e)	19:19:19	12.5 kg			175 kg^{-1}	2187
f)	Stanowet	2.5 L			710 L^{-1}	1775
g)	Chemical fertilizer weighing, mixing and application		8	7		7038
h)	FYM loading and application		10	8		8568
i)	Foliar fertilizer spraying	5 times	7	8		6732
5.	Irrigation		7	6		6120
a)	Diesel	10 hr			54 L^{-1}	810
6.	Gap filling		5	5		4590
7.	Weeding and earthing up	2 times	20	20		18360
8.	Harvesting, loading and cleaning of tubers		25	22		22032
9.	Weighing of sample plants and tubers		16	17		14994
Sl. No	Particulars	Units (ha^{-1})	Labour		Unit cost (Rs)	Total cost (Rs ha^{-1})
			Male (612 day^{-1})	Female (306 day^{-1})		
IV	**Cost of inputs and labour - groundnut**					
1.	Seeds and sowing					
a)	Cost of seeds	40 kg			70 kg^{-1}	2800
b)	Sowing			5		1530

2.	Manures and fertilizers					
a)	Urea	22 kg			7 kg^{-1}	154
b)	Rock phosphate	100 kg			10 kg^{-1}	1000
c)	Muriate of potash	33 kg			18 kg^{-1}	594
d)	Lime	1 t			7.8 kg^{-1}	7800
e)	Chemical fertilizer weighing, mixing and application		2	3		2142
3.	Thinning and gap filling		2	2		1836
4.	Weeding, lime application and earthing up		3	4		3060
5.	Harvesting					
a)	Pulling out the plants and loading		5	5		4590
b)	Separating the pods, cleaning and drying		3	3		2754
V	**Cost of inputs and labour - cowpea**					
1.	Preparatory cultivation					
a)	Land leveling and bed preparation		2			1224
b)	Taking ridges and furrows		2			1224
2.	Seeds and sowing					
a)	Cost of seeds	20 kg			600 kg^{-1}	12000
b)	Sowing			3		918
3.	Manures and fertilizers					
a)	FYM	20 t			400 t^{-1}	8000
b)	Urea	44 kg			7 kg^{-1}	308
c)	Rock phosphate	150 kg			10 kg^{-1}	1500
d)	Muriate of potash	17 kg			18 kg^{-1}	306
e)	19:19:19	2.5 kg			175 kg^{-1}	437
f)	Stanowet	500 mL			710 L^{-1}	355
g)	Chemical fertilizer weighing, mixing and application			3		918
h)	FYM loading and application			2		612
i)	Foliar fertilizer spraying	3 times		3		918
4.	Irrigation			3		918
Sl. No	Particulars	Units (ha^{-1})	Labour		Unit cost (Rs)	Total cost (Rs ha^{-1})
			Male (612 day^{-1})	Female (306 day^{-1})		

a)	Diesel	11.5 hr			54 L^{-1}	930
5.	Thinning and gap filling			2		612
6.	Weeding and terminal bud removing			3		918
7.	Plant protection					
a)	Cost of malathion	1 L			400 L^{-1}	400
b)	Application charges	2 times		2		612
8.	Harvesting and weighing	3 times	1	2		1224
VI	**Cost of outputs**					
1.	Rice grain					18 kg^{-1}
2.	Rice straw					4 kg^{-1}
3.	Cassava tuber					15 kg^{-1}
4.	Groundnut pod					40 kg^{-1}
5.	Cowpea pod					40 kg^{-1}

Appendix IV. Energy equivalents per unit of input or output (MJ unit^{-1})

	Particulars	Unit	Energy equivalents (MJ)	Reference
A.	**INPUT**			
1.	Labour			
a)	Men	Hr	1.96	Mohammadi *et al.* (2008)
b)	Women	Hr	1.57	Mohammadi *et al.* (2008)
2.	Machinery			
a)	Power tiller	Hr	62.70	Singh and Mittal (1992)
3.	Fuel			
a)	Diesel	L	56.31	Mohammadi *et al.* (2008)
4.	Planting material			
a)	Rice seed	Kg	14.7	Heidari and Omid (2011)

b)	Cassava stem	Kg	5.6	Singh and Mittal (1992)
c)	Groundnut seed	Kg	26	Singh and Mittal (1992)
d)	Cowpea seed	Kg	1.9	Devasenapathy *et al.* (2009)
5.	Manures and fertilizers			
a)	FYM	Kg	0.3	Ozkan *et al*. (2007)
b)	Nitrogen (N)	Kg	66.14	Mohammadi and Omid, (2010)
c)	Phosphorus(P_2O_5)	Kg	12.44	Mohammadi and Omid, (2010)
d)	Potassium (K_2O)	Kg	11.15	Mohammadi and Omid, (2010)
e)	Sulphur	Kg	5.00	Mohammadi and Omid, (2010)
6.	Lime	Kg	1.320	Pimentel (1980)
7.	Water for irrigation	m^3	1.02	Mohammadi *et al*. (2008)
8.	PP chemicals			
a)	Insecticides	L	199	Gundogmus (2006)

B.	**OUTPUT**			
1.	Rice grain	Kg	14.7	Khan and Hossain (2007)
2.	Rice straw	Kg	15.59	Khan and Hossain (2007)
3.	Cassava tuber	Kg	5.6	Singh and Mittal (1992)
4.	Groundnut pod	Kg	25	Singh and Mittal (1992)
5.	Groundnut haulm	Kg	18	Devasenapathy *et al.* (2009)
6.	Cowpea pod	Kg	3.89	Devasenapathy *et al.* (2009)
7.	Cowpea haulm	Kg	12.5	Devasenapathy *et al.* (2009)

AGRONOMIC INTERVENTIONS FOR A SUSTAINABLE RICE BASED CROPPING SYSTEM IN PADDY FIELDS

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Abstract of the
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ABSTRACT

The experiment entitled “Agronomic interventions for a sustainable rice based cropping system in paddy fields” was conducted at the Instructional farm, College of Agriculture, Vellayani, Kerala during the period from 2013-14 (first year) to 2014-15 (second year) in reclaimed paddy field. The main objectives were to evaluate the impact of agronomic interventions on growth, productivity and sustainability of a rice

based cropping system and to study the nutrient balance, energetics and economics of the cropping system.

The sequential cropping system consisted of rice (first crop) succeeded by cassava intercropped with groundnut (second crop) and cowpea (third crop). The experiment was laid out in split plot design with five replications. The treatment comprising three main plots were assigned with methods of planting in combination with weed control measures *viz*: M_1- broadcasting of sprouted seeds, M_2- dibbling (sprouted seeds with drum seeder along with weeding by power weeder) and M_3- dibbling (sprouted seeds with drum seeder along with stubble mulching). Five methods of fertilizer application constituted the sub plot treatments [F_1- broadcasting (60:30:30 kg NPK ha^{-1} at 10 DAS, tillering and panicle initiation stage), F_2- band placement (60:30:30 kg NPK ha^{-1} at 10 DAS, tillering and panicle initiation stage), F_3- foliar spray of water soluble complex fertilizer 19:19:19 @ 0.5 per cent (at tillering, panicle initiation and flowering stage), F_4- foliar spray of diammonium phosphate (DAP) and sulphate of potash (SOP) each @ 2 per cent (at tillering, panicle initiation and flowering stage), F_5- control] for upland rice. Farmyard manure @ 5 t ha^{-1} was applied uniformly to all the treatments except control. For cassava intercropped with groundnut and cowpea, recommended dose of fertilizers (FYM @ 12.5 t ha^{-1}, 110:120:120 kg NPK ha^{-1} for cassava+groundnut and FYM @ 20 t ha^{-1}, 20:30:10 kg NPK ha^{-1} for cowpea) along with 0.5 per cent foliar spray of water soluble complex fertilizer 19:19:19 was applied at 30 (up to three weeks before harvest in both cassava and groundnut) and 14 days (up to one week before first harvest in cowpea) interval. The varieties used for the study were Aiswarya (rice), Vellayani Hraswa (cassava), TMV-2 (groundnut) and Bhagyalakshmi (cowpea). The same experiment was repeated in the second year for confirmatory results.

The results indicated that methods of planting and weed control measures along with methods of fertilizer application had significant effect on the yield attributes and yield of first crop, rice. During first year among the main plot treatments, the highest grain yield was produced in M_2 (dibbling of sprouted seeds +power weeding) and it was on par with M_3 (dibbling of sprouted seeds + stubble mulching). The subplot treatments were not significant. The treatment m_2f_2 (dibbling of sprouted seeds + power weeding along with band placement of 60:30:30 kg NPK ha^{-1}) produced the highest number of productive tillers m^{-2}, number of grains $panicle^{-1}$,thousand grain weight, grain yield (2927.97 kg ha^{-1}), straw yield and B:C ratio (1.65). During second year, the main plot treatments were not significant and among the methods of fertilizer application, F_3 (foliar spray of 19:19:19 @ 0.5 %) resulted in the highest grain yield and was on par with F_2 and F_4. Comparing the interaction, the higher yield attributes and grain yield (3109.33 kg ha^{-1}) were produced in m_2 (dibbling of sprouted seeds +power weeding) along with f_3 (foliar spray of 19:19:19 @ 0.5 %) with a B:C ratio of 2.38. It was on par with m_1 (broadcasting of seeds) along with f_2 (band placement of 60:30:30 kg NPK ha^{-1}) and f_3 and m_2 along with f_2 and f_4 (foliar spray of DAP and SOP each @ 2 %).

For cassava intercropped with groundnut, the residual effect of stubble mulching of rice along with broadcasting of 60:30:30 kg NPK ha^{-1} (m_3f_1) produced the highest tuber yield and utilization index of cassava and the highest pod yield and kernel yield of groundnut in the first year. The treatment combination of m_3f_1 was on par with m_1f_1 [residual effect of broadcasting of seeds (m_1) along with broadcasting of 60:30:30 kg NPK ha^{-1} (f_1)] (tuber yield) in cassava and it was on par with m_1 along with f_5 (control) and m_3 along with f_3 (residual effect of foliar spray of 19:19:19 @ 0.5 %) (pod yield and kernel yield) in groundnut. During second year, m_3f_1 produced the highest yield and yield attributes and it was on par with m_3f_4 (residual effect of stubble mulching of the first crop rice along with foliar spray of DAP and SOP each @ 2 %) in cassava. The combination of m_3f_4 produced the highest yield and yield attributes in groundnut which was on par with m_1f_4.

During first year, m_2f_4 (the residual effect of power weeding along with foliar spray of DAP and SOP each @ 2 %) significantly produced the highest number of pods plant^{-1} and pod yield of cowpea which was on par with m_2 along with f_3 (residual effect of foliar spray of 19:19:19 @ 0.5 %) and f_5 (control). During second year, m_3f_4 (residual effect of stubble mulching of the first crop rice (m_3) along with foliar spray of DAP and SOP each @ 2 %) resulted in the highest number of pods plant^{-1} and pod yield of cowpea and was significantly different from all other combinations except m_3 along with f_1 (residual effect of broadcasting of 60:30:30 kg NPK ha^{-1}) and f_5 (control).

Nutrient balance sheet results after first year indicated a buildup of available nitrogen, phosphorous and potassium in all the treatments. However after second year, a depletion of available nutrients was observed but the rate of depletion was less in those treatments where complex foliar fertilizers were applied compared to soil application. Combination of dibbling + power weeding along with complex foliar fertilizers were more energy efficient compared to the soil application of nutrients.

Economic analysis of the system indicated that the direct and residual effect of stubble mulching along with broadcasting of 60:30:30 kg NPK ha^{-1} (m_3f_1) resulted in the highest net returns and B:C ratio.

Based on the results of the present investigation it can be concluded that, dibbling of sprouted seeds using drum seeder + power weeding along with either band placement of 60:30:30 kg NPK ha^{-1} (at 10 DAS, tillering and panicle initiation stage) or foliar spray of water soluble complex fertilizer 19:19:19 @ 0.5 per cent (at tillering, panicle initiation and flowering stage) was the most productive, profitable and energy efficient agronomic interventions for upland rice. Direct and residual effect of stubble mulching with either broadcasting of 60:30:30 kg NPK ha^{-1} (at 10 DAS, tillering and panicle initiation stage) or foliar spray of DAP and SOP each @ 2 per cent (at tillering, panicle initiation and flowering stage) was the most productive (system yield of 29.71 t ha^{-1}), profitable, energy efficient and sustainable agronomic interventions for rice-cassava + groundnut- cowpea system in upland condition.

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