INPUT OPTIMIZATION FOR SHORT DURATION RED GRAM [*Cajanus cajan* (L.) Millsp.]

by

ANJANA DEVARAJ G.
(2017-21-024)

THESIS

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COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM - 695 522

KERALA, INDIA

2021

DECLARATION

I, hereby declare that this thesis entitled "**Input optimization for short duration red gram [*Cajanus cajan* (L.) Millsp.]**" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Vellayani

Date: 13/09/2021

Anjana Devaraj G.

(2017-21-024)

CERTIFICATE

Certified that this thesis entitled **"Input optimization for short duration red gram [*Cajanus cajan* (L.) Millsp.]"** is a record of research work done independently by Ms. Anjana Devaraj G. (2017-21-024) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Vellayani

Date: 13.09.2021

Dr. Sheeba Rebecca Isaac
(Major Advisor, Advisory Committee)
Professor
Department of Agronomy
College of Agriculture, Vellayani
Thiruvananthapuram - 695 522

CERTIFICATE

We, the undersigned members of the advisory committee of Ms. Anjana Devaraj G. (2017-21-024), a candidate for the degree of **Doctor of Philosophy in Agriculture** with major in Agronomy, agree that the thesis entitled **"Input optimization for short duration red gram [*Cajanus cajan* (L.) Millsp.]"** may be submitted by Ms. Anjana Devaraj G. (2017-21-024), in partial fulfilment of the requirement for the degree.

13/9/21

Dr. Sheeba Rebecca Isaac
(Major Advisor, Advisory Committee)
Professor
Dept. of Agronomy
College of Agriculture, Vellayani
Thiruvananthapuram - 695 522

13/9/2021

Dr. Shalini Pillai P.
(Member, Advisory Committee)
Professor and Head
Dept. of Agronomy
College of Agriculture, Vellayani
Thiruvananthapuram - 695 522

13/9/21

Dr. Rajasree G.
(Member, Advisory Committee)
Professor (Agronomy)
RARS, Ambalavayal
Wayanad - 673 593

13.09.21

Dr. Naveen Leno
(Member, Advisory Committee)
Assistant Professor
Dept. of Soil Science and Agrl. Chemistry
College of Agriculture, Vellayani
Thiruvananthapuram - 695 522

13/9/21.

Dr. Chitra N.
(Member, Advisory Committee)
Assistant Professor
Dept. of Agricultural Microbiology
College of Agriculture, Vellayani
Thiruvananthapuram - 695 522

13/9/21

External Examiner:

Dr. S. Sunitha
Principal Scientist (Agronomy)
Division of Crop Production
ICAR - Central Tuber Crops Research Institute
Sreekariyam, Thiruvananthapuram - 695 017

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VII	Cost of inputs
VIII	Market price of produce
IX	Nutrient additions through red gram residues in the soil

LIST OF ABBREVIATIONS

Al	Aluminium
Al^{3+}	Aluminium cation (charge of +3)
ANOVA	Analysis of Variance
B:C ratio	Benefit cost ratio
C	Carbon
CD	Critical Difference
CGR	Crop Growth Rate
cm	centimetre
cm^3 $plant^{-1}$	cubic centimetre per plant
CO_2	Carbon dioxide
C:N ratio	Carbon to Nitrogen ratio
DAI	days after residue incorporation
DAP	Diammonium phosphate
DAS	days after sowing
DMP	Dry matter production
et al.	Co-workers/ Co-authors
Fe	Iron
Fig.	Figure
FYM	Farmyard manure
g	gram
g cm^{-3}	gram per cubic centimetre
g g^{-1} day^{-1}	gram per gram per day
g kg^{-1}	gram per kilogram
g kg $seed^{-1}$	gram per kilogram seed
g L^{-1}	gram per litre
g m^{-2} day^{-1}	gram per square metre per day
g $plant^{-1}$	gram per plant
g pod^{-1}	gram per pod
ha	hectare
ha^{-1}	per hectare
HI	Harvest Index
IAA	Indole Acetic Acid
INM	Integrated Nutrient Management
i.e.	that is
K	Potassium
K_2O	Potassium oxide
kg	kilogram
kg ha^{-1}	kilogram per hectare
kg kg^{-1}	kilogram per kilogram
KNO_3	Potassium nitrate
LC	Labile Carbon
LAI	Leaf Area Index
LAD	Leaf Area Duration
L^{-1}	per litre

Ltd.	Limited
log cfu g^{-1}	logarithm of colony forming unit per gram
m	metre
m^{-2}	square metre
MSL	Mean Sea Level
mg g^{-1}	milligram per gram
mg g^{-1} d^{-1}	milligram per gram per day
mg GAE 1 mg^{-1}	milligrams of gallic acid equivalents (GAE) per 1 milligram
µ TPF g^{-1} soil 24 hr^{-1}	microgram of triphenyl formazan (TPF) formed per gram of soil per 24 hours
mL	millilitre
mL L^{-1}	millilitre per litre
mm	millimetre
N	Nitrogen
NAA	Naphthalene Acetic Acid
P	Phosphorus
pH	potenz Hydrogen
PE	Physiological Efficiency
PFP	Partial Factor Productivity
PGPR	Plant Growth Promoting Rhizobacteria
PoP	Package of Practices
PPFM	Pink Pigmented Facultative Methylotrops
ppm	parts per million
PSB	Phosphorus Solubilizing Bacteria
P_2O_5	Phosphorus pentoxide
q ha^{-1}	quintal per hectare
RBD	Randomized Block Design
ROC	Recalcitrant Organic Carbon
RDF	Recommended Dose of Fertilizer
RGR	Relative Growth Rate
S	Sulphur
SOC	Soil Organic Carbon
₹ ha^{-1}	Rupees per ha
SEm±	Standard error of mean
t	tonnes
t ha^{-1}	tonnes per hectare
TOC	Total Organic Carbon
TNAU	Tamil Nadu Agricultural University
TTC	Triphenyl Tetrazolium Chloride
via	through
viz.,	Namely
$ZnSO_4$	Zinc sulphate

LIST OF SYMBOLS

@	at the rate of
° C	degree Celsius
/	or
º E	degrees East
º N	degrees North
%	per cent
=	equal to
>	greater than
±	plus-minus sign
₹	Rupees

Introduction

1. INTRODUCTION

The unprecedented events of climate change coupled with the exigency for food and nutritional security have entailed promotion of climate smart crops and sustainable practices in agriculture. Pulse crops have from ancient time been acknowledged for their role in healthy diets, contribution to soil health and livelihoods of farmers. The nitrogen (N) fixing potential, lower carbon (C) footprint and ability to adapt and thrive in marginal lands uphold the significance of pulses in diversifying the global cropping patterns and enhancing consumption to tackle the concerns of under nutrition, especially among the rural poor.

Pulses are essential integrants of a balanced diet being rich sources of proteins, minerals and vitamins and protective foods on account of the high dietary fibre, low fat, glycemic index and the antioxidant and anticarcinogenic constituents. In India, pulses accord only 7.74 per cent of the total food grain production of the country (DACFW, 2021), despite being a major consumer and has been dependent on imports for meeting the demands of the population. Transcending the nutritional importance, pulses are considered as crops for marginal lands. The multifaceted benefits of pulses have been undermined and its cultivation needs to be revitalised as one of the avenues for tackling the looming issues of malnutrition and climate change impacts.

Pulses are climate smart as they simultaneously adapt to climate change and contribute towards mitigating its effects. The crops complement cropping systems and add to production diversification as these exhibit differential responses to growing season rainfall and temperature patterns. The adaptive mechanisms have been enumerated as deep rooting system, high degree of dehydration tolerance, phenotypic plasticity, wider ranging sensitivity towards photo thermo periods and higher moisture retention capacity (Gull *et al*., 2020).

Red gram [*Cajanus cajan* (L.) Millsp.] also known as pigeon pea, arhar and tur, is the major *Kharif* pulse crop in India cultivated in an area of 4.78 million ha with a productivity averaging 751 kg ha^{-1} (DACFW, 2019). It continues to be the popular pulse crop amongst farmers because of its adaptability under dryland conditions and suitability for pure as well as mixed/intercropping systems including agroforestry systems. The drought tolerant ability is attributed to its deep rooting habit (Subbarao *et al.*, 2000).

The crop is an indeterminate perennial grain legume, belonging to the family Fabaceae. Red gram is a rich source of protein, carbohydrates, minerals and vitamins. It contains 20 - 22 per cent protein, 51.4 - 58.8 per cent carbohydrate, 1.2 - 8.1 per cent crude fibre and 0.6 - 3.8 per cent lipid (Faris and Singh, 1990). The seeds can be consumed either as decorticated splits or in the form of green seeds as vegetable. The considerable tolerance to drought, high N fixing ability and C sequestration potential confer red gram a potential crop for inclusion in climate mitigation strategies.

Red gram varieties cultivated in the country are mostly of medium duration (150 - 200 days). Recent breeding advances have led to the development of short and extra short duration varieties (120 - 150 and 90 -120 days, respectively) which fit well in the cropping systems favouring higher cropping intensities and diversities. Although the crop is widely cultivated in India, in the southernmost state, Kerala, red gram cultivation is confined to Palakkad district, the area being a meagre, 266 ha (GoK, 2020). Literature evince the cultivation in a larger area, 1186 ha during 2012 - 2013 (GoK, 2014), covering Palakkad, Idukki, Wayanad, Kannur and Kasaragod districts of the state, but with the passing of years, has declined by nearly 78 per cent. Nevertheless, the pulse is a regular component/ingredient in daily cuisines of the natives and promotion of its cultivation, especially short duration varieties, would complement the pulse production, sustain soil fertility and make it an efficient component in the existing cropping systems.

In this backdrop, the research project was envisaged to identify a short duration variety suitable for Kerala and standardise its agronomic management for recommendation and adoption. Agronomic management practices focus on planting geometry and nutrient management practices that are crucial for effective utilisation of growth resources and satisfactory economic yields. A lower or higher plant population leads to over or under exploitation of resources and poor economic yields. The nutrient dose is pivotal in deciding the nutrient availability and uptake for proper growth and development. Integration of nutrient sources improves the nutrient use efficiency and reduces the ill effects of chemical nutrition, fostering environmental friendly sustainable cultivation.

The residual and carryover effects of leguminous crops in improving soil fertility have been widely reviewed (Ghosh *et al*., 2007). Red gram being a leguminous crop is expected to have residual effects that can sustain N requirements of a succeeding crop grown in rotation. Incorporation and decomposition of the legume residues can enhance the soil productivity by improving soil physical environment, augmenting soil microbial activity and organic matter restoration. The scientific exploration of the residual effects of red gram in a cropping sequence will provide information for nutrient scheduling in red gram included cropping systems, minimising the use of costly fertilizer inputs.

The research work entitled "Input optimization for short duration red gram [*Cajanus cajan* (L.) Millsp.]" was carried out with the objectives:

- To assess the suitability of two short duration varieties of red gram
- To standardize the spacing and nutrient management practices for short duration red gram and
- To examine the legume effect on succeeding fodder maize crop

Review of Literature

2. REVIEW OF LITERATURE

Commercial cultivation of red gram necessitates selection of suitable varieties and adoption of agronomic management practices that ensure optimum utilisation of resources for economic yields. The available literature on red gram pertaining to varieties, management practices and residual effects are detailed in this chapter. Further, wherever there has been a paucity of research information in red gram, those relevant to other pulses have been included.

2.1 GROWTH CHARACTERS

2.1.1 Effect of Varieties

Varieties differ in their morphological characters and hence the growth attributes, and these are regarded as expressions of the intrinsic genetic characters. Varietal variations in red gram have been studied by several workers. Singh *et al.* (1985) assessed the performance of cultivars T 21 and AL 15, and recorded that T 21 produced taller plants, higher number of branches per plant and dry matter yield compared to cultivar AL 15, but later, the variety Bahar was reported to be taller than T 21 and with higher number of branches (Dwivedi and Patel, 1988). Chauhan (1990) observed that the red gram genotype ICPL 88039, a short duration and determinate type, produced lesser number of branches than the medium and late-maturing genotypes that were indeterminate in growth habit. Nagamani *et al.* (1995) observed that cultivar ICPL 8863 recorded significantly higher plant height but produced the lowest number of branches.

Singh *et al.* (1996) compared the performance of different extra short duration red gram genotypes (H 82-1, H 81-22, UPAS 120, Prabhat and Manak) and reported that among the varieties tested, H 81-22 recorded the tallest plants. Egbe *et al.* (2013) assessed the growth characters of different genotypes of red gram and concluded that early maturing and determinate genotypes recorded lesser number of branches than the medium to late maturing and indeterminate genotypes.

2.1.2 Effect of Spacing

Singh and Kalra (1989) observed significant increase in plant height in red gram with lowering of the plant to plant spacing from 30 cm to 10 cm. Sahu (1994) reportedthat the highest population (2,00,000 plants ha^{-1}) recorded significantly higher plant height, number of branches and nodule number per plant, compared to the other populations included. A closer spacing (22.5 cm x 10 cm) was found to record maximum plant height compared to the wider spacings of 30 cm x 10 cm and 45 cm x 10 cm (Mahajan *et al.,*1997). However, the number of branches per plant were higher at wider spacing of 45 cm x 10 cm (8.3 per plant) which decreased to 7.2 and 4.2 branches per plant in the closer spacings of 30 cm x 10 cm and 22.5 cm x 10 cm respectively. Similar reports of higher number of primary branches and secondary branches per plant in red gram at wider spacings were documented by Sharma *et al.* (2003) and Mula *et al.* (2010).

2.1.3 Effect of Nutrient Levels

Shivran and Ahlawat (2000) observed significant increases in the growth parameters *viz.*, plant height and number of branches per plant in red gram with the application of 75 per cent recommended dose of fertilizer (RDF). Singh (2007) reported that application of 50 per cent RDF + 5 t Farmyard manure (FYM) ha^{-1} in red gram significantly increased plant height (214.4 cm), number of branches (38.7) and dry matter per plant (167.5 g), which remained at par with 10 t FYM ha^{-1} and 100 per cent RDF. However, Patil and Padmani (2007 a) observed that the effect of 100 per cent RDF on plant height, branches per plant and number of nodules per plant was at par with 75 per cent RDF, but superior to 50 per cent RDF. Significant enhancement in nodule number per plant with higher doses of P_2O_5 (80 kg ha^{-1}) was reported by Kumar and Kushwaha (2006). Ray *et al.* (2015) documented that pooled analysis of the *Kharif* season data revealed maximum plant height and number of branches in red gram at 75 per cent RDF.

2.1.4 Effect of Biofertilizers

Biofertilizers transform the fixed and insoluble forms of nutrients into soluble forms and make them available to plants. They act as good supplements to chemical fertilizers in enhancing soil fertility, crop uptake and yields.

Singh *et al.* (1998) found that seed inoculation with *Rhizobium* significantly improved the growth of red gram. According to Singh and Yadav (2008), *Rhizobium* + phosphorus solubilising bacteria (PSB) produced significantly taller plants (198.7 cm), maximum number of branches (18.9) and dry matter (156.4 g per plant). Nevertheless, Reddy *et al.* (2011) reported that the application of 50 per cent RDF + seed treatment with *Rhizobium* @ 200 g kg^{-1} seeds recorded significantly higher number of branches per plant in red gram compared to *Rhizobium* + 100 per cent RDF + FYM @ 5 t ha^{-1}.

Rana *et al.* (1998) studied the effect of N fertilizer rates, *Rhizobium* inoculation and phosphorus (P) fertilizer rates and reported that nodulation increased with increasing N rate and *Rhizobium* inoculation. This was reinforced with the results of Gupta and Namdev (1999). Devanand *et al*. (2002) observed significant increases in nodule number and nodule dry weight in plants inoculated with *Rhizobium* sp. + *Azospirillum* sp. + *Pseudomonas striata*. Singh *et al.* (2005 a) also reported higher nodule number and nodule dry weight in red gram with *Rhizobium* inoculation.

2.2 YIELD ATTRIBUTES

2.2.1 Effect of Varieties

Yield attributes define the yield of crops. Varietal variations in red gram have been documented by several workers. Puste and Jana (1987) assessed the performance of four varieties, 20 (105), 5 (124), HY 3C and Bahar, and reported that the variety 20 (105) recorded higher number of seeds per pod and 1000 seed weight compared to other varieties whereas the number of pods per plant were higher in Bahar. Dwivedi and Patel (1988) also reported similar observation of the variety Bahar recording higher number of pods per plant, seeds per pod, grain weight per plant and 1000 grain weight. Among T 21, CO 5 and A 3-1, the variety T 21 registered the maximum values for yield attributes followed by CO 5 and A 3-1 (Prabhakaran and Ramasamy, 1989). However, when compared with Vamban 1, ICPL 871, ICPL 88027 and CORG 9301, CO 5 was superior (Natarajan *et al*., 1998).

Singh *et al.* (2010) observed VL Arhar-1 to be earlier in flowering compared to MANAK and UPAS 120. Mondal *et al.* (2012) indicated that genotype Asha recorded significantly the highest 100 seed weight (11.22 g), which was statistically at par with genotypes, Rajeevlochan (11.16 g), Laxmi (10.90 g) and RPS -2007-106 (11.09 g). The lowest 100 seed weight was recorded in the genotype RPS -2008-4.

2.2.2 Effect of Spacing

Wider spacing recorded higher number of pods, pod weight and seed yield per plant as compared to closer spacing in red gram (Mohammad, 1997). Antaravalli *et al.* (2002) reported higher number of pods per plant (124.50) in the spacing of 60 cm x 10 cm compared to 45 cm x 10 cm (115.41). Pramod *et al.* (2010) opined that wider spacing enhanced the individual plant performance. Similar results were documented by Jamadar *et al.* (2014) even with transplanting of seedlings. The inter row spacing of 150 cm recorded significantly higher number of pods (297.25), pod weight (336.17 g) and seed weight (226.17 g per plant) compared to 90 cm inter row spacing.

Subramani *et al*. (2020) explored the suitability of varieties and spacing of red gram in coconut gardens and documented the varieties ANP-12-02 and CO 6 and the wider spacing to record better growth and yield attributes.

2.2.3 Effect of Nutrient Levels

Singh and Pal (2003) observed that application of 100 per cent RDF in red gram was superior with respect to all the yield attributes ascertained, number of pods per branch, average pod length, pod weight, number of grains, weight of grains per pod and 1000 grain weight over 50 per cent RDF. Similar reports of improved yield parameters with 100 per cent RDF has been elucidated by Sharma *et al.* (2010) and they observed that the values declined with the decrease in the nutrient levels; 75 per cent RDF performing better than 50 per cent RDF compared to control. According to Aher *et al.* (2015), yield attributes in red gram did not differ markedly with the application of 100, 75 and 50 kg P_2O_5 ha^{-1}, but was significantly lower at 5 kg P_2O_5 ha^{-1}.

2.2.4 Effect of Biofertilizers

Singh *et al.* (1998) reported that yield attributes *viz.,* pods per plant, grains per pod and grain weight per plant in red gram improved significantly with increase in N level upto 30 kg ha^{-1} when applied along with *Rhizobium* inoculation. The better performance of pulse crops with PSB application was demonstrated in chickpea (Meena *et al.*, 2001) and black gram (Gupta *et al.*, 2006 a). Wagh *et al.* (2006) illustrated that 50 per cent RDF + 5 t pressmud ha^{-1} + inoculation with *Rhizobium* and

PSB significantly increased yield contributing characters *viz.,* 1000 seed weight and number of pods per plant in red gram. The positive effects of the dual inoculation was later confirmed by Patel *et al.* (2007) based on their investigation in chickpea and Ade *et al*. (2018) in red gram.

2.3 YIELD

2.3.1 Effect of Varieties on Seed Yield

Srivastava (1984) revealed that the red gram variety Bahar outyielded Laxmi and T 21 varieties and Reddy (1989) reported significantly higher yields in LRG 30 when evaluated with varieties, ST 1 and PDM 1. Selvaraj *et al.* (1989) assessed the grain yield of CORG 14 red gram variety in comparison with standard checks *viz.,* CO 2, Prabhat and T 21 and found CORG 14 to yield the highest (761 kg ha^{-1}). Varietal variations in yields have been documented by several authors (Sivasubramanian *et al.*, 1993; Nagamani *et al.*, 1995; Jehangir *et al.*, 1995). Rathnaswamy *et al.* (1996) compared the COH 1 red gram hybrid with ICPH 8, CO 5, ICPL 87 and Vamban 1 and reported that the hybrid COH 1 recorded a mean yield of 936 kg ha^{-1}, which was 49 per cent higher than the hybrid ICPH 8, and 34 to 41 per cent higher than the other varieties.

Muthiah *et al.* (2005) compared the yields in red gram varieties CO 7 and CO 5 and observed that CO 7 gave an average grain yield of 1021 kg ha^{-1} which was 24 per cent more than that in CO 5. The medium duration variety LRG 30 was found to yield better, nearly 70 per cent greater than the short duration variety ICPL 87 (Reddy *et al.*, 2006). Singh *et al.* (2010) observed that the short duration red gram variety VL Arhar 1 recorded the highest seed yield (1896 kg ha^{-1}) compared to the short duration varieties Manak and UPAS 120. Reddy *et al.* (2015) revealed that the seed yields in genotypes LRG 41 (933 kg ha^{-1}) and TRG 22 (1202 kg ha^{-1}) were significantly superior to ICPL 85063 (794 kg ha^{-1}).

On comparing the performance of short duration varieties, Jeyajothi and Pazhanivelan (2017) reported that the variety Co (Rg) 7 registered the significantly highest grain yield of 1650 kg ha^{-1}, while APK 1 and Vamban (Rg) 3 registered significantly lower grain yields of 1301 and 1076 kg ha^{-1} respectively.

2.3.2 Effect of Varieties on Haulm Yield

Varietal differences in haulm yield have been illustrated by several workers. Singh *et al.* (1975) compared the red gram varieties (T 21, AS 3, AS 5, and P 4785) and documented the highest haulm yield in AS 3. Ahuja (1984) reported that the haulm yield in red gram cultivar A -3 was significantly higher than that in Pant 1 and Prabhat. Singh and Prasad (1987) studied the response of red gram genotypes (T 21, UPAS 120, Pusa 33, and Pusa 78) and revealed that among the genotypes tested, Pusa 33 produced the significantly highest haulm yield. As per the reports of Panda *et al*. (2019), Laxmi (ICPL 85063) was the most suitable red gram genotype in terms of seed and haulm yield for the irrigated *Rabi* crop.

2.3.3 Effect of Spacing on Seed Yield

Higher seed yields with closer spacings have been elucidated by several workers. Dubey and Upadhyaya (1991) reported that in red gram, row spacings of 30 cm and 45 cm recorded significantly higher grain yields than that at 60 cm. Srinivasan *et al.* (1997) reported significantly higher grain yields with closer spacing of 30 cm x 10 cm (762 kg ha^{-1}) compared to the seed yield at wider spacing of 40 cm x 10 cm (704 kg ha^{-1}). Reports in corroboration with the above include those by Sekhon *et al.* (2000); Sharma *et al.* (2003); Parameswari *et al.* (2003); Telgote *et al.* (2004) in different red gram varieties. Sultana *et al.* (2018) revealed that the hybrid red gram (ICPH 3762) recorded the significantly highest seed yield at a spacing 180 cm x 20 cm, which was 13.1 per cent higher than the wider spacing of 180 cm x 40 cm. The increased yields under narrow spacing was attributed to the higher plant density. The experiments conducted by Mallikarjun *et al.* (2015) and Meena *et al.* (2015 a) also revealed higher seed yields at lower plant populations.

Contrary to the above, Meena *et al.* (2011) reported that the red gram hybrid ICPH 2671 planted at a spacing 90 cm x 45 cm yielded higher than that at the closer spacing of 60 cm x 30 cm. This was supported by the findings of Chandrakar *et al.* (2015) who recorded higher seed yields in a planting geometry 60 cm x 10 cm compared to 45 cm x 10 cm.

2.3.4 Effect of Spacing on Haulm Yield

Mohite *et al.* (1993) reported that the inter row spacing of 30 cm gave significantly higher haulm yields in red gram than 15 and 20 cm row spacing while Umesh *et al.* (2013), documented significantly higher haulm yields with closer spacings.

2.3.5 Effect of Nutrient Levels on Seed Yield

Nutrient management is crucial in designing crop yields and the levels of the nutrients adopted should ensure an adequate and balanced supply for optimum yields. Evidences on the responses of red gram to different levels of N, P and potassium (K) have been documented. According to Kene *et al.* (1990), application of 37.5 kg N in combination with 75 kg P and 20 kg K ha^{-1} resulted in the highest seed yield while the combination of 20 kg N, 17 kg P and 50 kg K ha^{-1} was reported as ideal by Mandal *et al.* (2000). Sarkar *et al.* (2004) observed that application of lime along with NPK could increase the yield significantly.

Meena *et al.* (2012) found that the soil test based application of fertilizers @ 60:60:40 kg NPK ha^{-1} in red gram could record a seed yield of 1.44 t ha^{-1} which was significantly higher than the yield in the unfertilized control (0.94 t ha^{-1}). Poonia *et al.* (2014) documented that application of 100 per cent RDF (25:50:00 kg NPK ha^{-1}) recorded significant improvement in the yield over control. Significantly higher seed yields were registered with the highest dose of 40 kg N and 80 kg P_2O_5 ha^{-1} (Karwasra and Kumar, 2007).

Phosphorus is regarded as the nutrient that is needed in larger amounts by crops capable of N fixation. In red gram, a dose of P_2O_5 @ 80 kg ha^{-1} was reported to record significantly higher yields in red gram (Chauhan and Singh, 1981; Avinash and Kushwaha, 2006). Singh and Singh (2012) found that maximum yields were realized with 75 kg P ha^{-1} and was significantly superior to 25 kg P_2O_5 ha^{-1} and control, but on par with 50 kg P_2O_5 ha^{-1}. Kailas (2017) who reported 60 kg P_2O_5 ha^{-1} to record the highest seed yield per plant (62.5 g) followed by 50 and 40 kg P_2O_5 ha^{-1}, the yields being 54.1 and 48.9 g per plant.

With respect to K, Tiwari *et al*. (2012) reported that increasing the K doses upto 60 kg K_2O ha^{-1} could significantly increase the seed yield in red gram.

2.3.6 Effect of Nutrient Levels on Haulm Yield

Haulm yields in red gram are reported to vary with the nutrient doses adopted. According to Sinha *et al.* (2005), application of NPK @ 20:30:20 kg ha^{-1} produced the highest haulm yield (93.2 q ha^{-1}). Singh *et al.* (2006) based on their experiment in red gram concluded that maximum haulm yield (47.85 q ha^{-1}) was realised at 100 per cent RDF (NPK @ 20:40:20 kg ha^{-1}). Kumar and Kushwaha (2006) observed that haulm yield of red gram was significantly higher at 80 kg P_2O_5 ha^{-1} than the lower doses of 20 and 40 kg ha^{-1}, but was at par with 60 kg P_2O_5 ha^{-1}. Comparing the performances under integrated nutrient management, Singh (2007) observed that haulm yield (98.4 q ha^{-1}) was maximum with 100 per cent RDF than the integration of 50 per cent RDF + 5 t ha^{-1} FYM. The superior yields with 100 per cent RDF was affirmed in the works of Patil and Padmani (2007 a). Sonawane *et al.* (2015) observed that haulm yield of red gram was significantly higher when the crop was supplied with 25 and 75 kg ha^{-1} of N and P respectively as compared to other treatments.

2.3.7 Effect of Biofertilizers on Seed Yield

The beneficial effects of biofertilizers on seed yield have been illustrated in lentil (Rathore *et al.,* 1992), red gram (Namdeo and Gupta, 1999), chickpea (Jain *et al.*, 1999; Sonboir and Sarawgi, 2001).

Application of P in the form of rock phosphate with PSB seed inoculation resulted in significantly higher seed yields compared to rock phosphate alone (Shankaralingappa *et al.,* 2002). Guggari and Kalaghatagi (2005) reported the superiority of integrated management of nutrients with N and P chemical fertilizer application along with biofertilizers (*Azospirillum* + PSB). Similarly Pandey and Kushwaha (2009) reported maximum seed yield in the combination, *Rhizobium* + PSB +100 per cent RDF followed by *Rhizobium* + PSB inoculation with 50 per cent RDF and as per the reports of Sahay *et al.* (2016), the combination, 100 per cent RDF + 5 t FYM ha^{-1} + *Rhizobium* + PSB was superior. Drip fertigation at 125 per cent RDF and water soluble fertilizers with Azophosmet and foliar spray of pink pigmented facultative methylotrophs (PPFM) recorded nearly 75 per cent higher yield in short duration red gram (Jeyajothi and Pazhanivelan, 2017).

2.3.8 Effect of Biofertilizers on Haulm Yield

Documented evidences throw light on the significant influence of biofertilizers on haulm yields in pulses. According to Sarawgi *et al.* (1999), haulm yield in chickpea increased with the inoculation of PSB as compared to application of fertilizer P alone. Inoculation of lentil seed with PSB also improved its haulm yield besides improving P use efficiency (Singh *et al.,* 2005 b). Tanwar *et al.* (2010) observed that application of P (25.8 kg ha^{-1}) along with FYM @ 5 t ha^{-1} and seed inoculation with PSB recorded the highest haulm yield (8.47 t ha^{-1}) in kabuli chickpea while Tomar *et al.* (2016) reported significant increase in haulm yield (21.8 and 22.6 q ha^{-1}) of black gram with the application of 100 per cent RDF + PSB during both the years of study.

In red gram, Singh and Yadav (2008) reported that among the biofertilizers tried, *Rhizobium* + PSB produced the significantly highest haulm yield (7560 kg ha^{-1}).

2.4 FOLIAR NUTRITION IN PULSES

Foliar nutrition is recognized as an important practice for improving crop productivity as it facilitates easy and rapid utilization of nutrients (Pandrangi *et al*., 1991). The application at appropriate stages of growth has been emphasised (Anandha *et al.,* 2004) for the utilization and better performance of the crop. Foliar nutrition in pulses includes application of nutrients, growth regulators and biofertilizers for higher economic production (Rajesh and Paulpandi, 2013). Among chemical fertilizers, urea is the most widely used foliar fertilizer, and is characterized by high leaf penetration rate and low cost. Most plants absorb urea rapidly and hydrolyse it in the cytosol (Witte *et al.,* 2002). Recent advances made in nutrient management strategies advocate the use multinutrient and high analysis water soluble fertilizers at recommended concentrations for increased nutrient use efficiencies in pulses.

2.4.1 Effect on Growth Characters

Reddy *et al.* (2004) studied the effect of potassium nitrate (KNO_3) and naphthalene acetic acid (NAA) on the growth and yield of red gram and reported that foliar application of NAA @ 20 ppm and KNO_3 @ 0.5 per cent could significantly increase the dry matter production (DMP).

Reddy *et al.* (2005) reported a significant increase in plant height with the application of 2 per cent urea spray at 30, 40 and 60 days after sowing (DAS) in black gram over absolute control (no spray). Verma *et al.* (2009) observed that foliar spraying of one per cent urea twice, at flowering stage and pod development stage, recorded the highest plant height, number of branches and DMP at harvest over control in chickpea. Deshmukh *et al.* (2008) demonstrated the efficacy of foliar nutrition with urea in rajma and the three time spray (pre flowering, 25 per cent pod initiation, pod development) was found to the most effective.

The application of urea at 2 per cent concentration during 60, 75 and 90 DAS in chickpea recorded higher number of branches per plant (5.9) which was on par with one or two sprays of urea over the control of no spray and water spray (Venkatesh and Basu, 2011). Gupta *et al.* (2011) observed that foliar application of 2 per cent urea at flowering and 10 days after flowering along with biofertilizers (*Rhizobium* + PSB + plant growth promoting rhizobacteria (PGPR)) resulted in maximum nodule number and nodule dry weight in chickpea. The positive effects of foliar nutrition with urea in green gram growth attributes have been elucidated (Mondal *et al.*, 2011; Khalilzadeh *et al.*, 2012; Naidu *et al.*, 2015).

In red gram, Kaur *et al.* (2015) detailed that application of 2 per cent urea at flowering stage registered 13 per cent increase in plant height and 58 per cent increase in number of branches compared to control (water) and, at pod formation the increases were 22 and 40 per cent respectively.

2.4.2 Effect on Yield and Yield Attributes

Significant improvements in yield attributes and hence yield with foliar nutrition in pulses have been documented by several workers. Dwivedi and Tiwari (1991) observed the highest number of pods in chickpea with the foliar application of 2 per cent urea compared to 2 per cent diammonium phosphate (DAP). Gomathi (1996) recorded that foliar spray of 1 per cent urea significantly increased the number of pods in green gram. A considerable increase in yield in red gram was observed with the foliar spray of 0.5 per cent zinc sulphate ($ZnSO_4$) at flower initiation stage (Ali and Mishra, 2001). Ganiger *et al.* (2003) reported that foliar application of urea (2 %) in cowpea at 35 DAS resulted in higher number of pods per plant, pod length, number of seeds per pod and 1000 seed weight. Better yield attributes with foliar application of urea fertilizer in chickpea (Palta *et al.,* 2005; Venkatesh and Basu*,* 2011), black gram (Sritharan *et al.*, 2005; Reddy *et al.*, 2005), green gram (Verma *et al.,* 2011) reveal the scope of advocating the practice in the nutrient management recommendations. Foliar application of NAA at 40 ppm recorded significantly highest pod length, seeds per pod and 100 seed weight in APK 1 red gram variety (Chinnathurai *et al.,* 2012). The effect of foliar application of mineral nutrients on growth attributes of two red gram varieties (PAU 881 and AL 201) was investigated by Kaur *et al.* (2015) and it was concluded that amongst the treatments, 2 per cent urea application resulted in the maximum increase in growth attributes *viz.*, plant height, number of branches, leaf area, leaf area index (LAI), crop growth rate (CGR) and relative growth rate (RGR).

The improvements in yield attributes were found reflected in the seed yields. Ganiger *et al.* (2003) reported that foliar application of urea (2 %) in cowpea at 35 DAS resulted in a significantly higher seed yield (1675 kg ha^{-1}). Rajavel and Vincent (2009) observed that foliar spray of 2 per cent urea recorded the highest yield of 955 kg ha^{-1} in black gram. Das and Jana (2015) found that foliar application of 2 per cent urea along with the basal dose of fertilizers (20:40:40 kg NPK ha^{-1}), could augment the seed yield in pulse crops (green gram - 14.2 %, black gram - 13.5 %, lathyrus - 26.9 %, lentil - 24.7 % and chickpea - 32.4 %). In red gram, maximum seed yield was reported with foliar application of NAA (25 ppm) and DAP (2 %) at 60 and 80 DAS (Nagamani *et al*., 2020).

2.5 PHYSIOLOGICAL PARAMETERS

2.5.1 Effect of Varieties

Variations in the dry matter yield of red gram varieties have been documented. Reddy (2001), screening different red gram genotypes, found LRG 30 (medium duration) variety to record the highest total DMP while it was the lowest in ICPL 87051 (medium duration). Sonawane *et al.* (2015) observed the genotype BSMR 736 (190 - 200 days) to accumulate significantly higher dry matter per plant at harvest, compared to Vipula (145 - 160 days) and ICPL 87 (120 - 125 days).

2.5.2 Effect of Spacing

Padmalatha and Rao (1993) reported that red gram at lower plant density produced the significantly highest dry matter yield and it decreased with the increase in plant density. Similar reports were given by Kachare *et al.* (2009) in green gram. Zote *et al*. (2010) observed that the dry matter accumulation was significantly higher in red gram plants at a row spacing of 90 cm than those at 120 cm and 60 cm. Saritha *et al.* (2012 a) based on the experiment evaluating the effect of planting geometry on red gram growth and yield concluded that among the different spacings tried, the wider spacing (150 cm x 60 cm) recorded the significantly highest per plant DMP and was on par with 150 cm x 90 cm. According to Kuri *et al*. (2018) significantly higher plant height, LAI, leaf area duration (LAD) and CGR were recorded under narrow row spacing.

2.5.3 Effect of Nutrient Levels

Chaudhary *et al.* (2008) noticed comparatively higher dry matter accumulation with FYM @ 2.5 t ha^{-1} + 50 per cent RDF application in chickpea. Shete *et al.* (2010) reported that application of 100 per cent RDF in green gram produced the highest dry matter accumulation compared to the lower doses. In red gram, application of FYM + 100 per cent NPK produced nearly 59 per cent higher CGR than the absolute control plots (Ghosh *et al.*, 2006).

2.5.4 Effect of Biofertilizers

Khoja *et al.* (2002) and later, Jat and Ahlawat (2004 b) reported that in chickpea, seed inoculation with *Rhizobium* + PSB significantly increased the dry matter accumulation per plant over uninoculated treatment. Significant increase in the dry matter accumulation with seed inoculation of biofertilizers (*Rhizobium* + *Pseudomonas striata)* in red gram was illustrated (Patil and Padmani, 2007 a). Mondal *et al.* (2013) reported the highest RGR in green gram (69.6 mg g^{-1} d^{-1}) with biofertilizer application. Maximum dry matter accumulation in red gram with the inclusion of biofertilizers in the nutrient management practice has been elucidated by Sonawane *et al*. (2015).

2.6 AGRONOMIC INDICES

2.6.1 Effect of Varieties

In comparison with cereals, pulses in general have a low harvest index (HI). Sinha and Khanna (1975) opined that improvement in yield potential of crops is largely due to improvement in HI. Nadarajan and Gupta (2010) observed that in short and medium duration cultivars, total biological yield is the limiting factor whereas in long duration varieties the lower HI adversely affects grain yield. Nagamani *et al.* (1995) and Reddy (2001) evaluating the performance of red gram varieties documented higher HI in LRG 30 compared to ICPL 332.

2.6.2 Effect of Spacing

Tripathi and Chauhan (1990) reported that the plant population of 111 x 103 plants ha^{-1} in red gram recorded higher HI (26.2 %) than 83 x 103 plants ha^{-1}. However, Rao *et al.* (2001) stated that planting at lower density (120 cm x 40 cm) recorded significantly higher HI compared to that at higher density (60 cm x 40 cm). In black gram, the spacing of 20 cm x 10 cm gave maximum HI (36 %) while it was the lowest HI (31 %) at 15 cm x 10 cm (Veeramani, 2019). Legha and Dhingra (1992) and later Saritha *et al.* (2012 a) also reported higher HI at wider spacing.

2.6.3 Effect of Nutrient Levels

The positive influence of nutrient application on the HI by virtue of the increase in seed yields have been reported. Significantly superior HI with the application of 100 per cent RDF + FYM was documented in cowpea (Subbarayappa *et al*., 2009), chickpea (Elamin and Madhavi, 2015), green gram (Patel *et al.*, 2016) and in the latter, was comparable with the application of 75 per cent RDF.

2.6.4 Effect of Biofertilizers

Patel *et al.* (2013) reported that application of biofertilizers (*Rhizobium* + PSB) in green gram resulted in the highest HI (27.51 %) than sole applications. Mondal *et al.* (2013) observed that the highest HI (35.13 %) was recorded in plants fertilized with biofertilizer and one-third recommended dose of urea.

2.6.5 Effect of Foliar Application of Urea

Sritharan *et al.* (2005) reported that in black gram, foliar application of 2 per cent urea at the three stages of crop growth *viz*., vegetative, flowering, and pod filling stage resulted in the highest HI (32 %). The positive effects of foliar application of urea on HI were documented in chickpea (Amany, 2007) and in cowpea (Chaudhary and Yadav, 2011).

2.7 CHLOROPHYLL CONTENT

Documented information on the effect of varieties and individual agronomic practices on chlorophyll content in red gram are meagre. Hence the available literature on other pulses are also compiled and presented.

Nagaraj *et al.* (2019) indicated that chlorophyll content in red gram leaves was maximum in plants treated at 100 per cent RDF and the lowest in 75 per cent RDF. The integrated nutrient management strategy in red gram involving 50 per cent RDF, 5 t pressmud ha^{-1} and *Rhizobium* + PSB inoculation contributed to the significant increase in leaf chlorophyll content (Wagh *et al.,* 2006). Biofertilizer application improved the chlorophyll content in different pulses (Mondal *et al*., 2013; Fernandes and Bhalerao, 2015; Amit and Satish, 2015; Venkatarao *et al.*, 2017).

Sritharan *et al.* (2015) found that 2 per cent urea foliar application in black gram recorded the highest total chlorophyll content (2.72 mg g^{-1}).

2.8 PROTEIN CONTENT IN PULSES

2.8.1 Effect of Varieties

Red gram is a rich source of protein and the content varies from 21 to 26 per cent with varieties (Singh, 2017). Kachare *et al.* (2019) observed that the red gram genotype PT-012-16 recorded the highest protein content (25.45 %) than other genotypes.

2.8.2 Effect of Spacing

Mansur *et al.* (2009) found that the planting density at 30 cm x 10 cm led to a higher protein content (23.8 %) in chickpea compared to higher and lower plant densities. According to Sathe and Patil (2012), the maximum protein yield of

350.25 kg ha^{-1} was realised in red gram at 60 cm x 15 cm spacing on par with the spacing of 45 cm x 30 cm (314.02 kg ha^{-1}). Amruta *et al.* (2016) reported that the wider spacing (60 cm x 10 cm) could impart higher seed protein content (23.08 %) in black gram compared to closer spacing 30 cm × 10 cm.

2.8.3 Effect of Nutrient Levels

Protein content was significantly influenced by nutrient doses. Patil and Padmani (2007 b) observed that 100 per cent RDF significantly increased the protein content (22.53 %) and protein yield (316.88 kg ha^{-1}) of red gram but was on par with 75 per cent RDF. Similarly in black gram, Patil *et al.* (2010) estimated the highest seed protein content in plants manured at 100 per cent RDF. Increased doses of P increased the protein content markedly in red gram (Aher *et al.,* 2015).

2.8.4 Effect of Biofertilizers

Singh *et al.* (1998) opined that integration of biofertilizers with chemical fertilizers increased the protein yields in red gram. Similar findings were reported by Patil and Padmani (2007 b) and Amruta *et al*. (2016). Sahay *et al.* (2016) observed a significant increase in protein content in red gram with fertility levels and maximum protein content was registered with 100 per cent RDF + 5 t FYM ha^{-1} + *Rhizobium* + PSB.

2.8.5 Effect of Foliar Nutrition

Amany (2007) reported that foliar application of urea (1 %) at pod filling in chickpea resulted in the highest seed protein content (25 %) whereas Venkatesh and Basu (2011) illustrated that foliar application of 2 per cent urea twice, 75 and 90 DAS significantly increased the protein content in chickpea. In green gram, foliar application of 2 per cent urea was found to be superior in terms of seed protein (Bhaskar *et al.*, 2018).

2.9 NUTRIENT CONTENT AND UPTAKE

Nutrient uptake is a function of the nutrient concentration in plants and the DMP.

2.9.1 Effect of Varieties

Nutrient uptake in pulse varieties was studied by Ahlawat and Saraf (1983), Puste and Jana (1987) and Chaudhary *et al.* (1988) and recorded the significant variations among the varieties.

2.9.2 Effect of Spacing

Dewangan *et al.* (1992) observed that wider row spacing (30 cm x 10 cm) in green gram recorded higher N and P content in seed and straw. Mansur *et al.* (2009) recorded significantly higher N uptake (68.20 kg ha^{-1}) under narrow spacing (15 cm x 10 cm) compared to wider spacing (45 cm x 10 cm) in chickpea. Singh *et al.* (2012 b) found the maximum nutrient uptake in red gram, 36.76, 63.56 and 49.7 kg N, P and K ha^{-1} respectively when spaced at 60 cm x 20 cm and was significantly superior to the other spacings (50 cm x 20 cm and 70 cm x 20 cm).

2.9.3 Effect of Nutrient Levels

Increased nutrient uptake was reported with increased P doses in red gram, upto 80 kg ha^{-1} (Hedge and Saraf, 1982). Goudalia *et al.* (1988) reported that the N uptake in grain, haulm and total plant, increased significantly with N application up to 30 kg ha^{-1}. Singh and Yadav (2008) reported that the application of 60 kg P_2O_5 ha^{-1} in red gram recorded higher N and P uptake over 45 kg P_2O_5 ha^{-1}. Singh (2007) observed that the application of 50 per cent RDF + 5 t FYM ha^{-1} in red gram resulted in the significantly highest uptake of N (150 kg ha^{-1}), P (31.9 kg ha^{-1}) and K (98.7 kg ha^{-1}) followed by 10 t FYM ha^{-1} and 100 per cent RDF. The total uptake of N, P and K were significantly higher with application of 100 per cent or 75 per cent RDF along with FYM in cowpea (Subbarayappa *et al.,* 2009). Reddy *et al.* (2011) observed that 100 per cent RDF recorded the highest NPK uptake in red gram followed by 75 and 50 per cent RDF. Based on their studies, Nagamani *et al*. (2020) concluded that seed yield, stalk yield, nutrient content and uptake in red gram were maximum with an NPK dose of 30:60:20 kg N, P_2O_5 and K_2O ha^{-1}.

2.9.4 Effect of Biofertilizers

Sarawgi *et al.* (1999) studied the effect of PSB on uptake of N and P in chickpea. It was observed that the N and P uptake increased with the application of PSB. Farmyard manure @ 5 t ha^{-1} + *Rhizobium* + PSB application in chickpea soil recorded higher N and P uptake (105.48 kg ha^{-1} and 19.10 kg ha^{-1}) as compared to rest of the treatments (Chaudhary *et al.,* 2008). Integration of inorganic fertilizers and biofertilizers resulted in better nutrient uptakes in black gram (Kumpawat, 2010) and green gram (Mandal *et al.,* 2014) as compared to sole application of inorganic fertilizers.

Singh and Yadav (2008) reported that among the biofertilizers, *Rhizobium* + PSB recorded significantly higher uptake of N (104.9 kg ha^{-1}) and P (16.9 kg ha^{-1}) in red gram. Sathe *et al.* (2011) recorded the highest P uptake in red gram with the application of 100 per cent fertilizer + PSB, and Sahay *et al.* (2016) illustrated improvement in N, P and K content in grain and haulm of red gram with 100 per cent RDF + 5 t FYM ha^{-1} + *Rhizobium* + PSB.

2.9.5 Effect of Foliar Nutrition

Foliar application is reported to ensure increased uptake of nutrients compared to soil application. Foliar nutrition with urea @ 2 per cent resulted in higher nutrient uptake in black gram (Devi and Pillai, 1997; Reddy *et al.*, 2005; Verma *et al.,* 2011), green gram (Upperi *et al.,* 2011) and chickpea (Venkatesh and Basu, 2011).

Krishna and Kaleeswari (2018) reported that application of 100 per cent RDF in soil and multinutrient (0.5 % KNO_3 + 2 % DAP + micronutrient) on foliage recorded the highest macro and micronutrient uptake in red gram.

2.10 SOIL PROPERTIES

2.10.1 Effect of Spacing

Soil available N, P and K were markedly influenced by planting geometry in crops. Higher available N, P and K (285.9, 14.3 and 292.1 kg ha^{-1} respectively) were recorded at the wider spacing of 40 cm × 30 cm in black gram compared to that in the spacing, 30 cm x 10 cm (Rajeshkumar *et al.,* 2017).

2.10.2 Effect of Nutrient Levels

Integrated application of chemical fertilizers with FYM recorded significantly higher available soil N (Babalad, 2000). Dekhane *et al*. (2011) observed that application of 100 per cent RDF in cowpea significantly increased the available N (196.32 kg ha^{-1}) and available P_2O_5 (45.36 kg ha^{-1}) status in the post harvest soil. Patel *et al.* (2016) reported that application of 100 per cent RDF in green gram recorded significantly higher amounts of available N, P and sulphur (S).

2.10.3 Effect of Biofertilizers

The solubilisation of fixed nutrients and increased availability are the important attributes that favour the inclusion of biofertilizers inclusion in nutrient management practices. Reports on the increased availability with biofertilizer application are many. Enhanced available P content in soils with PSB application have been documented (Alagawadi and Gaur, 1988; Sayed, 1998; Mir *et al.*, 2013). Combination of single species biofertilizers with organic manures (pressmud) and 50 per cent RDF significantly increased the available N, P and K in soil (Somnath *et al.*, 2006).

Shinde and Bangar (2003) reported the beneficial effects of combined inoculation of biofertilizers on soil microbial population. Rajput and Kushwah (2005) illustrated the augmentation of microbes in soil with reduced dose of recommended fertilizers (50 per cent RDF) and application of *Rhizobium* and PSB along with FYM.

2.10.4 Effect of Foliar Nutrition

Foliar nutrition during critical stages of crop growth supplements the nutrient demands of the crop reducing the amounts absorbed from the soil. This can result in a higher soil nutrient status due to the lower uptakes from soil.

Upperi *et al.* (2011) reported an increase in organic C content of soil from 0.32 to 0.65 per cent, with foliar application of 2 per cent urea in green gram. Improved post harvest soil nutrient status was documented with foliar application of urea @ 1 per cent concentration in green gram (Ezzat *et al.*, 2012).

2.11 ECONOMICS

2.11.1 Effect of Spacing

Kumar (2004) recorded the highest net return and benefit cost ratio (B: C ratio) of 2.71 under wider row spacing in cowpea. Patel *et al.* (2005) reported that sowing of green gram at wider row spacing gave the highest net returns (₹ 8,470 ha^{-1}) and B: C ratio (1.37) as compared to the closer row spacing. In red gram, Sathe and Patil (2012) computed the highest gross and net monetary returns under wider spacing (60 cm x 15 cm) which was at par with closer spacing (45 cm x 30 cm). The B: C ratio worked out was 3.11.

Nonetheless, economic analysis of different planting geometry in red gram (Kumar *et al.*, 2014) revealed a higher gross return (₹ 38,696 ha^{-1}), net return (₹ 20,914.91 ha^{-1}) and B:C ratio (2.18) at the closer spacing compared to wider spacing.

2.11.2 Effect of Nutrient Levels

Positive responses of red gram to the increased nutrient levels resulted in higher seed yields and hence gross returns. Singh and Yadav (2008) recorded maximum net returns (₹ 40,005) in red gram with 60 kg P_2O_5 ha^{-1} followed by 45 kg P_2O_5 ha^{-1} (₹ 38,920). Based on the site specificity and soil conditions the nutrient doses tried in the experiments varied and hence the net returns. Devendra and Kushwaha (2011) observed significant increase in the net returns with P application upto 80 kg P_2O_5 ha^{-1} while Ade *et al.* (2018) in their study observed maximum gross monetary returns with 60 kg P ha^{-1}, the highest dose included.

Studies have also demonstrated the economic superiority of chemical fertilizers in red gram cultivation (Patil and Padmani, 2007 b; Kumbhar *et al.*, 2015). A similar observation was documented in black gram by Singh *et al*. (2008).

2.11.3 Effect of Biofertilizers

Biofertilizers have proven to be economic in pulse cultivation. Tanwar *et al.* (2003) reported the highest gross and net returns and B:C ratio with the application of 60 kg P ha^{-1}, along with inoculation of *Rhizobium* and PSB in black gram.

Guggari and Kalaghatagi (2005) observed that application of 40 kg N, 30 kg P and biofertilizer in red gram recorded significantly higher net return (₹ 10,130 ha^{-1}) and B:C ratio (2.66). Tripathi and Vishwakarma (2008) reported that the application of 10 t FYM ha^{-1} + PSB + 100 per cent RDF recorded the significantly highest B: C ratio in red gram. Net returns was the highest in the combined inoculation of *Rhizobium* + PSB with 100 per cent RDF followed by *Rhizobium* + PSB inoculation with 50 per cent RDF (Pandey and Kushwaha, 2009; Sharma *et al.,* 2012). Similar observations were recorded in cowpea (Meena *et al.*, 2015 b; Khan *et al.*, 2015) and green gram (Patel *et al.*, 2016).

2.11.4 Effect of Foliar Nutrition

Foliar application of nutrients for increasing and exploiting genetic potential of the crop is considered an efficient and economic method of supplementing the nutrient requirement (Devaraju and Senthivel, 2018). Profitable cultivation in red gram with foliar nutrition was reported by Parasuraman (2001) with the combination of 100 per cent RDF + 2 per cent DAP spray twice and Ganiger *et al.* (2003), wherein spraying 2 per cent urea was superior to control. Deshmukh *et al.* (2008) observed that application of 1 per cent urea spray thrice, at pre-flowering, 25 per cent pod initiation and pod development in rajma during *Rabi* season was more economical (B:C ratio - 1.53). Similar observations were documented in chickpea by Gupta *et al.* (2011) and green gram (Baiwara *et al*., 2012).

2.12 RESIDUAL EFFECT OF LEGUMES

Incorporation of crop residues in agricultural soils is primarily a means to maintain soil organic matter which results in enhanced biological activity, physical properties and nutrient availability (Antil and Narwal, 2007). Organic inputs (crop residues) are valuable and inexpensive source of plant nutrients to maintain soil organic matter and reclaim degraded soils (Tejada *et al.,* 2008).

Crop residues, mainly leguminous residues, have greater N benefits (Svubure *et al.,* 2010) and its incorporation helps to reduce the need for mineral N fertilizer application for small holder farmers. This will subsequently increase the gross benefits in succeeding crop production. The legume crops access atmospheric N_2 through symbiosis with *Rhizobium* and contribute to succeeding non-legume crop through the decomposed legume top and roots (Singh *et al.,* 2005 a). Nonetheless, Negassa *et al.* (2007) reported that application of crop residue alone to sustain crop productivity is inadequate on account of its relatively lower nutrient content particularly, P and K, and slow release of nutrients.

2.12.1 Chemical Characters of Legume Residue

The main quality parameters of residues that determine mineralization include carbon to nitrogen ratio (C:N ratio), content of cellulose and lignin (Chaves *et al.,* 2004).

Mythili and Venkatachalam (2013) reported that red gram stalks contain 31.6 per cent cellulose, 19.4 per cent hemicellulose and 19.8 per cent lignin. According to Kirti *et al.* (2019), the red gram stalks contain 43 per cent cellulose, 18 per cent hemicellulose and 2 per cent lignin. Black gram residues contain 26.80 per cent cellulose, 32.48 per cent hemicellulose and 23.14 per cent lignin (Ilyas *et al.,* 2012). Maneechai *et al.* (2013) analysed of the phenolic contents in the different plant parts of red gram, and found that the ethanol extract from stems contained the maximum amount of phenols (4.408 mg GAE 1 mg^{-1} extract).

Legume residues generally have low C: N ratios (14 - 20 in roots and 18 - 24 in shoots). Carbon: N ratio in legume hay is 17:1 (USDA, 2011). Brunetto *et al.* (2011) stated that low C: N ratio is generally associated with higher mineralization rates and corroborates the findings of Abbasi *et al.* (2015).

2.12.2 Residual Effect of Legumes on Soil Properties

Crop residues are important for the redistribution of alkalinity within soils. A net increase in potenz hydrogen (pH) following residue addition to soil is typically observed (Butterly *et al.,* 2013). The application of residues to acid and moderately acid soils increased the pH of both topsoil and subsoils, which persisted over 26 months. Maximal increase of pH observed at three months was correlated with the concentration of excess cations in the residues.

Murungu *et al.* (2011) opined that incorporation of crop residues provides readily available C and N to soils depending upon the decomposition rates and synchrony of nutrient mineralization.

Kumar and Babalad (2018) assessed the soil dehydrogenase activity under different conservation tillage systems and reported that it was higher in the tillage systems with crop residue retention compared to the conventional tillage without crop residues.

2.12.3 Residual Effect of Legumes on Succeeding Crops

Gentry *et al.* (2001) reported that the fertilizer N requirements for optimum economic yields are less for maize succeeding soybean than for maize succeeding maize. Shuaibu *et al.* (2015) documented that incorporation of soybean and cowpea residues enhanced soil fertility and resulted in increased plant height of maize grown subsequently. Further, incorporation of cowpea residues resulted in the highest seed yield of maize and was comparable with fertilizer applied plots (Fataah and Addo, 2016). It was also evidenced that incorporation of cowpea residues resulted better yield parameters and yield of maize than surface mulching (Ndiso *et al.,* 2018). Ali *et al.* (2018) observed that incorporation of various N sources and green gram residues with mould board ploughing resulted in higher biological yield in maize. Kumar *et al.* (2019) also reported the beneficial effects of groundnut residue incorporation resulting in the highest N economy in wheat.

Literature pertaining to the various parameters of red gram and other pulses influenced by its varieties, spacing, nutrient management and the residual effects on succeeding crop have been reviewed in this chapter. Based on the above, the investigation was planned and conducted to assess the suitability of short duration red gram varieties under Kerala condition, to standardize its spacing and nutrient management and to evaluate its residual effect on succeeding fodder maize crop.

Materials and Methods

3. MATERIALS AND METHODS

The experiment entitled "Input optimization for short duration red gram [*Cajanus cajan* (L.) Millsp.]" was carried out at College of Agriculture, Vellayani during 2018 - 2020. The investigation was conducted as three separate experiments: (i) assessment of the suitability of two short duration varieties and standardization of spacing and nutrient levels (ii) assessment of legume effect on fodder maize and (iii) nutrient scheduling in red gram. The details of materials used and methods adopted are presented below.

3.1 GENERAL DETAILS

3.1.1 Location

The experiments were conducted in the Instructional Farm of College of Agriculture, Vellayani, located at 8.5 ^{o} N latitude, 76.9 ^{o} E longitude and at an altitude of 29 m above mean sea level (MSL).

3.1.2 Climate and Season

The experiment on the standardization of spacing and nutrient levels in red gram was conducted during *Rabi* season (November to March) in 2018 - 2019 and repeated for confirmation in 2019 - 2020. The study on the assessment of legume effect on fodder maize was done during *Kharif* (June to August 2019) and the nutrient scheduling experiment, during *Rabi*, 2019 - 2020.

The data on mean maximum and minimum temperatures, relative humidity and rainfall were collected from the Class B Agromet Observatory of Department of Agricultural Meteorology, College of Agriculture, Vellayani and are presented in Appendix I, II and III as standard week averages. The observations are graphically represented in Fig. 1 a, b and c.

3.1.3 Soil Characteristics

Soils of the experimental sites belonged to sandy clay loam textural class. The mechanical composition and physical properties of the soil are presented in Table 1 and soil chemical and biological characteristics of the sites of Experiment I and III are given in Table 2.

3.1.4 Cropping History of the Experimental Sites

The site of Experiment I and II (standardisation of spacing and nutrient management practices for short duration red gram and the residual study) was previously cultivated with baby corn (*Zea mays* L.) variety, G-5414 and the site of Experiment III (nutrient scheduling in red gram) was cropped with upland rice variety, Aiswarya (PTB 52) prior to the layout.

Table 1. Mechanical composition and physical properties of the soil

Parameters	Content	Method
A. Mechanical composition		
Sand (%)	47.44	Bouyoucos hydrometer method (Bouyoucos, 1962)
Silt (%)	23.85	
Clay (%)	27.81	
B. Physical properties		
Bulk density (g cm^{-3})	1.59	Core method (Gupta and Dakshinamoorthy, 1980)
Porosity (%)	41.05	
Water holding capacity (%)	19.03	

3.2 MATERIALS

3.2.1 Crops and Varieties

3.2.1.1 Red gram

Two short duration red gram varieties *viz.*, APK 1 and Vamban (Rg) 3 released from Tamil Nadu Agricultural University (TNAU) were used for the experiment. The seeds of APK 1 were procured from Regional Agricultural Research Station, Aruppukkottai, Tamil Nadu and seeds of Vamban (Rg) 3, from National Pulses Research Centre, Vamban, Tamil Nadu. The characteristics of the two varieties are detailed in Table 3.

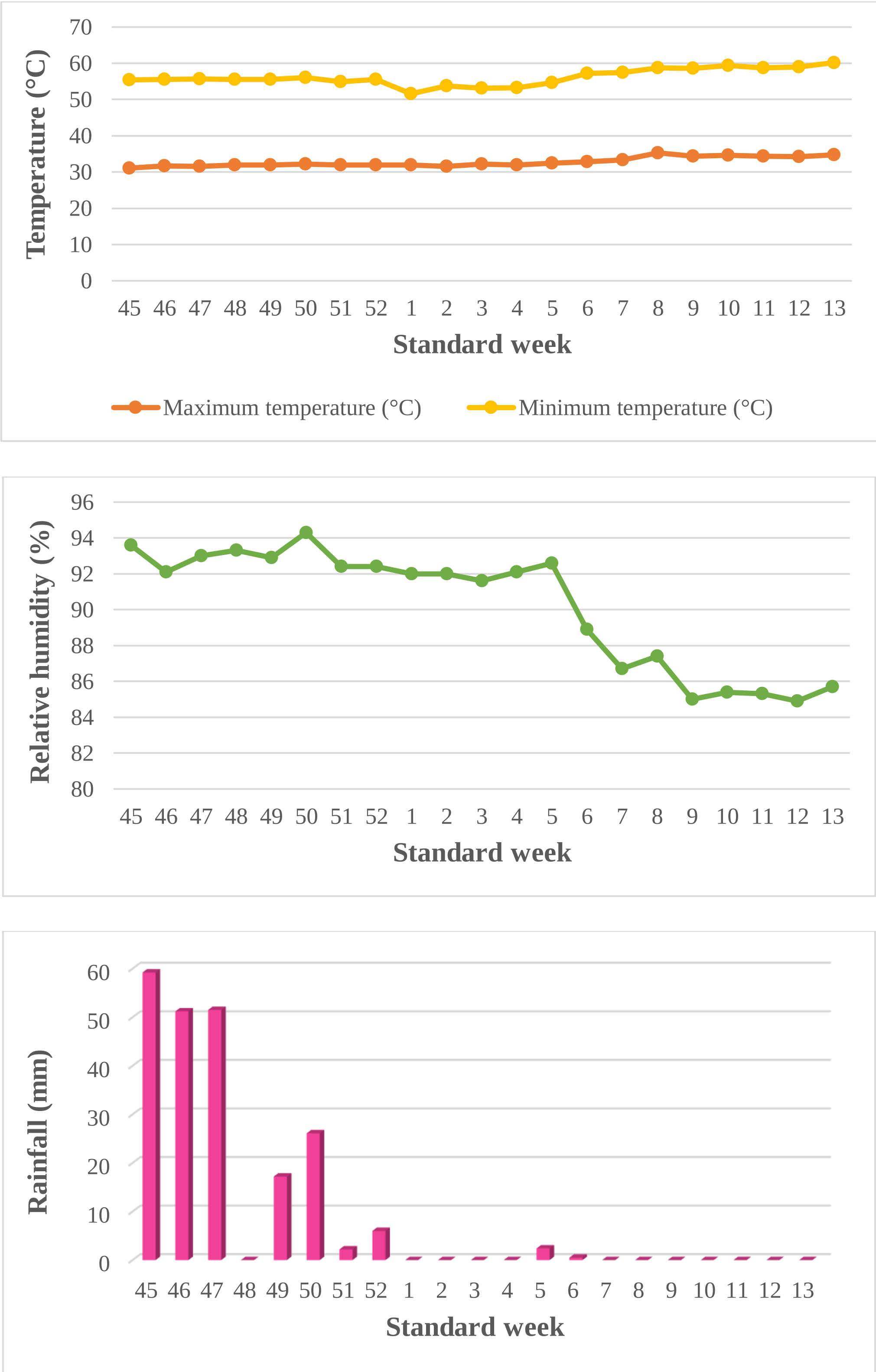


Fig. 1 a. Weather conditions during first year of Experiment I

(November 2018 - March 2019)

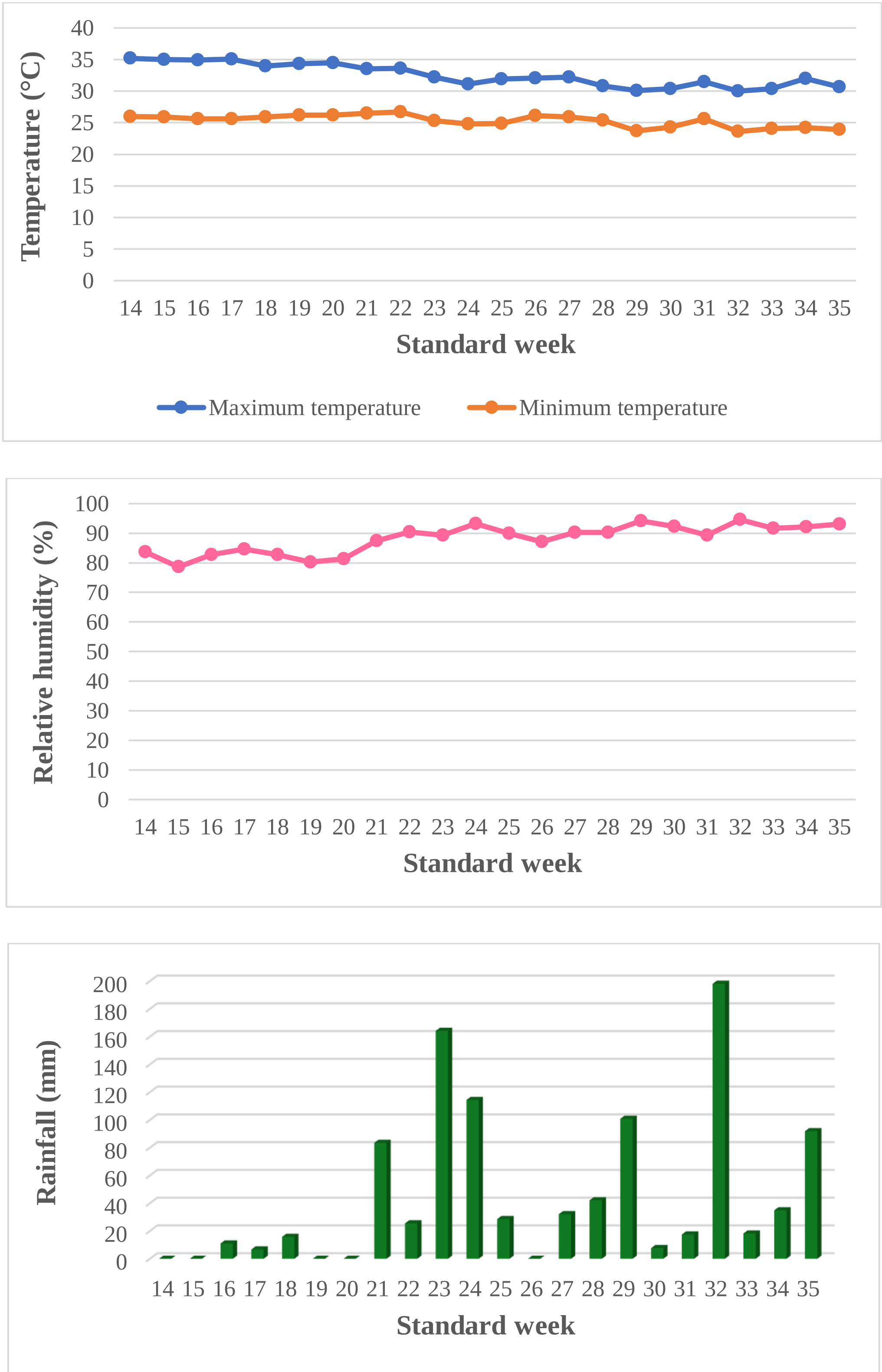
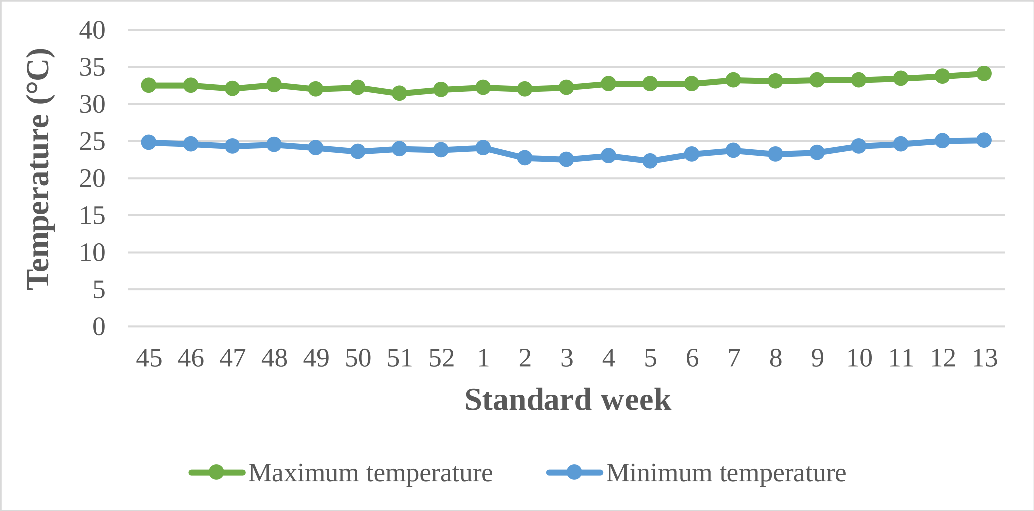
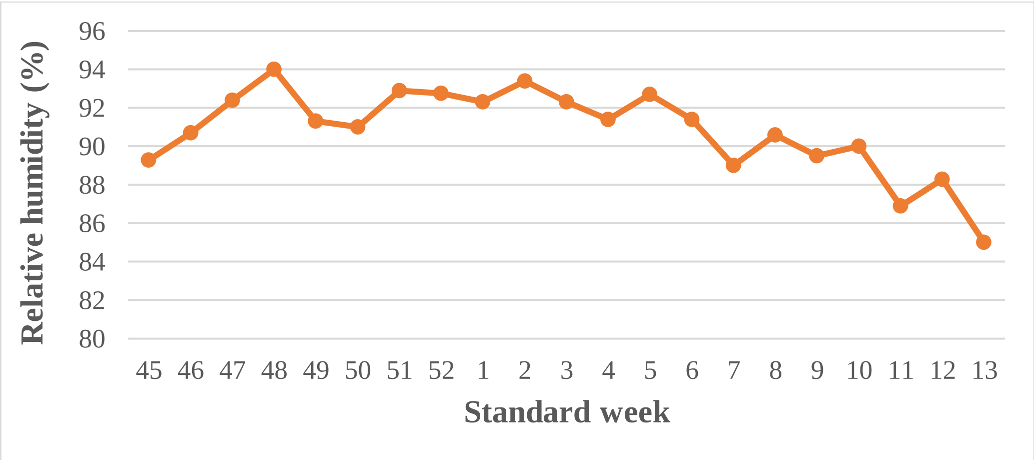


Fig. 1 b. Weather conditions during residue decomposition and cropping period of Experiment II (April 2019 - August 2019)





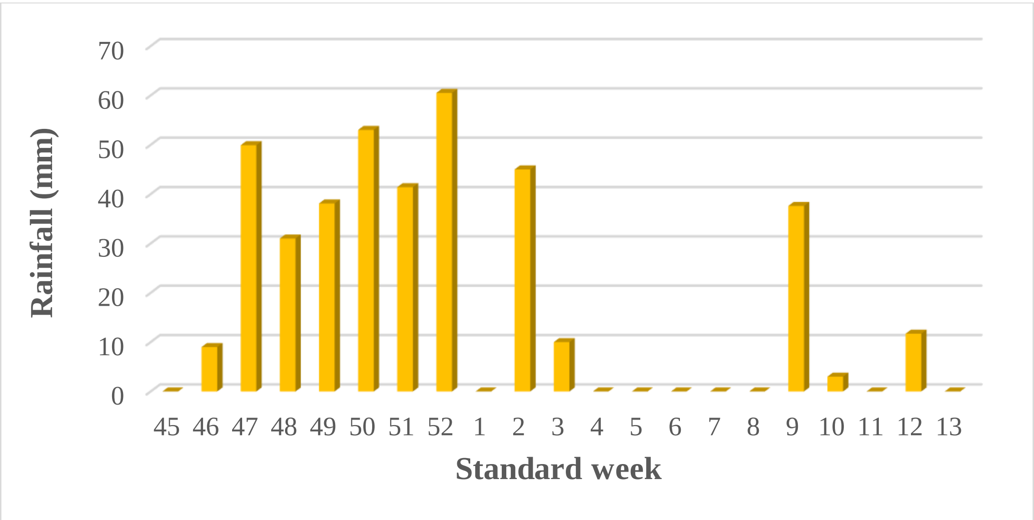


Fig. 1c. Weather conditions during Experiment III and second year of Experiment I (November 2019 - March 2020)

Table 2. Initial chemical and biological characteristics of soil of the experimental sites I and III

<table>
<tr><th rowspan="3" colspan="2">Particulars</th><th colspan="3">Content</th><th rowspan="3">Method</th></tr>
<tr><th colspan="2">Experiment I</th><th rowspan="2">Experiment III</th></tr>
<tr><th>First year</th><th>Second year</th></tr>
<tr><td colspan="6">A. Chemical properties</td></tr>
<tr><td colspan="2">pH</td><td>4.21 (Extremely acidic)</td><td>5.59 (Moderately acidic)</td><td>5.75 (Moderately acidic)</td><td>1:2.5 soil water suspension (Jackson, 1973)</td></tr>
<tr><td colspan="2">Organic C (%)</td><td>0.81 (Medium)</td><td>1.65 (High)</td><td>1.00 (High)</td><td>Walkley and Black rapid titration method (Jackson, 1973)</td></tr>
<tr><td colspan="2">Available N (kg ha^{-1})</td><td>100.35 (Low)</td><td>143.55 (Low)</td><td>111.02 (Low)</td><td>Alkaline permanganate method (Subbiah and Asija, 1956)</td></tr>
<tr><td colspan="2">Available P (kg ha^{-1})</td><td>47.14 (High)</td><td>104.30 (High)</td><td>67.14 (High)</td><td>Bray colorimetric method (Jackson, 1973)</td></tr>
<tr><td colspan="2">Available K (kg ha^{-1})</td><td>215.0 (Medium)</td><td>239.89 (Medium)</td><td>285.33 (High)</td><td>Neutral normal ammonium acetate extraction and flame photometry (Jackson, 1973)</td></tr>
<tr><td colspan="6">B. Biological properties</td></tr>
<tr><td rowspan="3">Total microbial count (log cfu g^{-1})</td><td>Bacteria</td><td>5.84</td><td>6.00</td><td>5.90</td><td rowspan="3">Serial dilution and plate count method (Johnson and Curl, 1972)</td></tr>
<tr><td>Fungi</td><td>3.30</td><td>3.47</td><td>3.74</td></tr>
<tr><td>Actinomycetes</td><td>2.00</td><td>2.14</td><td>2.15</td></tr>
</table>

3.2.1.2 Fodder Maize

The fodder maize variety ‘African tall’, released from TNAU was used as test crop to ascertain the legume effect of red gram and the seeds were procured from Dhoni Farm, Kerala Livestock Development Board Ltd., Palakkad. African tall is a tall annual with green and dry fodder yields ranging from 29.0 - 60.0 t ha^{-1} and 8.0 - 12.0 t ha^{-1}, respectively (Mishra, 2019).

Table 3. Characters of red gram varieties

Particulars	APK 1	Vamban (Rg) 3
Parentage	Pure line selection from ICPL 87101	Vamban 1 x Gulbarga
Year of release	1999	2005
Duration (days)	95 - 105	100 - 105
Colour of standard petal	Deep red in back of standard petal	Yellow
Colour of pod	Green with purple streaks	Green with purple streaks
Colour of grain	Reddish brown	Reddish brown
Pattern of growth	Determinate	Determinate

(TNAU, 2016)

3.2.2 Biofertilizers

The N biofertilizer, *Rhizobium* and P and K solubilisers (formulation of *Bacillus megaterium* and *Bacillus sporothermodurans* respectively) were used in the experiments. *Rhizobium* ideal for red gram was collected from TNAU for the Experiment I in the first year (2018 - 19) and for the experiments during 2019 - 20, *Rhizobium* isolated from the root nodules of red gram were used for seed inoculation. Phosphorus and K solubilisers were purchased from the Department of Agricultural Microbiology, College of Agriculture, Vellayani.

3.2.3 Manures and Fertilizers

Well decomposed FYM containing 0.5 per cent N, 0.2 per cent P_2O_5 and 0.5 per cent K_2O was used during the first year of Experiment I (2018 - 19). Urea (46 % N), Rajphos (20 % P_2O_5) and Muriate of Potash (60 % K_2O) were the fertilizers used for the experiments.

3.3 METHODS

3.3.1 Experiment I: Assessment of the Suitability of Two Short Duration Varieties and Standardization of Spacing and Nutrient Levels

3.3.1.1 Design and Layout

Design : Randomized Block Design (RBD)

Replications : 3

Treatments : 2 x 2 x 3

Treatment details:

Varieties (V) - 2

v_1 : APK 1

v_2 : Vamban (Rg) 3

Spacing (S) - 2

s_1 : 40 cm x 20 cm

s_2 : 60 cm x 30 cm

Nutrient levels (N) - 3

n_1 : 40:80:40 kg NPK ha^{-1}

n_2 : 30:60:30 kg NPK ha^{-1}

n_3 : 20:40:20 kg NPK ha^{-1}

Treatment combinations - 12

T_1	: $v_1s_1n_1$	T_2	: $v_1s_1n_2$	T_3	: $v_1s_1n_3$	T_4	: $v_1s_2n_1$
T_5	: $v_1s_2n_2$	T_6	: $v_1s_2n_3$	T_7	: $v_2s_1n_1$	T_8	: $v_2s_1n_2$
T_9	: $v_2s_1n_3$	T_{10}	: $v_2s_2n_1$	T_{11}	: $v_2s_2n_2$	T_{12}	: $v_2s_2n_3$

Plot size : 3.6 m x 2.4 m

Season : November 2018 - March 2019

November 2019 - March 2020

3.3.1.2 Field Preparation

The experimental area was cleared, ploughed thoroughly, levelled and converted into plots, each of 3.6 m length and 2.4 m width, separated by bunds as per the layout of the experiment (Fig. 2 a and b). Lime was applied @ 850 kg ha^{-1} during the first year and @ 250 kg ha^{-1} in the second year based on soil test results and package of practices (PoP) recommendations (KAU, 2016).

3.3.1.3 Seed Treatment and Sowing

Seeds were treated with *Rhizobium* (@ 50 g kg seed^{-1}) by mixing with rice gruel water of the previous day. The inoculated seeds were dried under shade for 30 minutes and then sown adopting a seed rate of 15 kg ha^{-1} at the spacings envisaged in the treatments.

3.3.1.4 Application of Manures and Fertilizers

Farmyard manure was applied uniformly in all plots @ 12.5 t ha^{-1} prior to sowing and incorporated well. Fertilizers were applied as per the recommendations fixed in the treatments and based on the soil test results and NPK ratings and recommendations (KAU, 2016). Entire dose of P was applied as basal, N and K, in two splits, as basal and at 30 DAS.

3.3.1.5 Thinning and Weeding

Thinning and gap filling were done 15 DAS and weedings, manually, at 15 and 30 DAS.

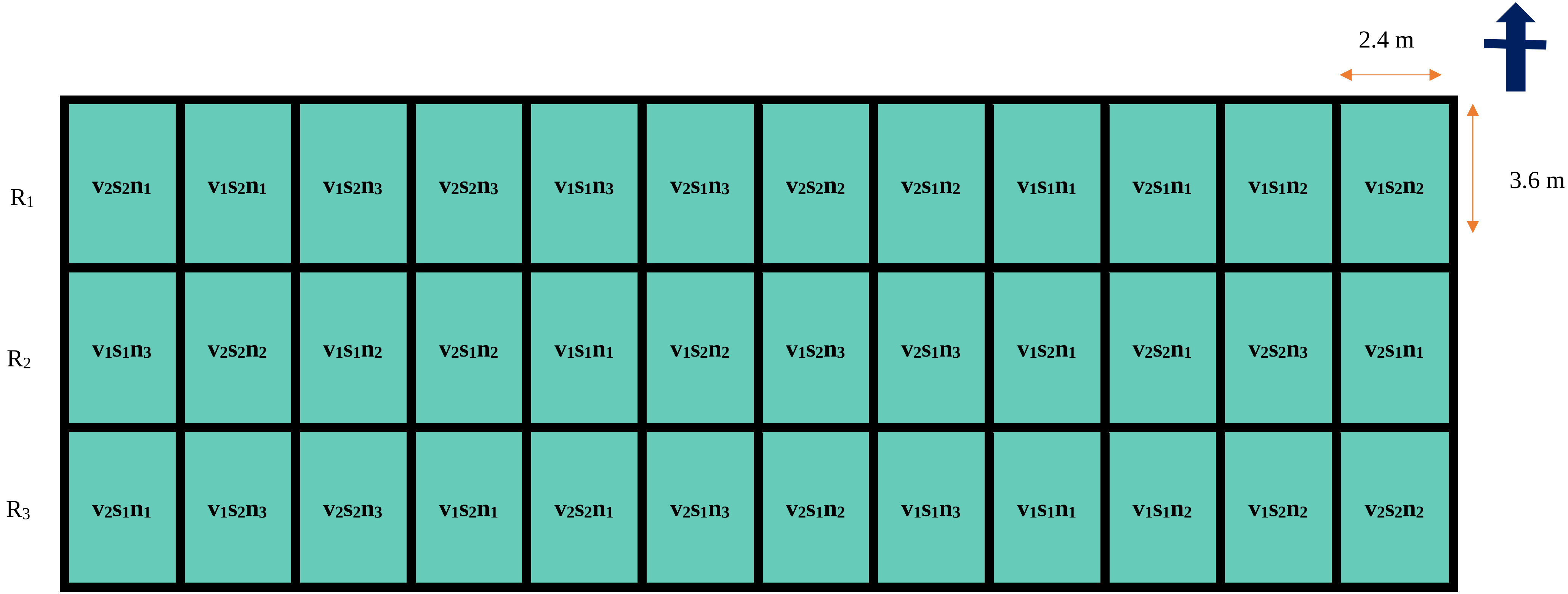


Fig. 2 a. Layout of Experiment I (first year)

v_1 -	APK 1	s_1 -	40 cm x 20 cm	n_1-	40:80:40 kg NPK ha^{-1}
v_2 -	Vamban (Rg) 3	s_2 -	60 cm x 30 cm	n_2 -	30:60:30 kg NPK ha^{-1}
				n_3 -	20:40:20 kg NPK ha^{-1}

Fig. 2 b. Layout of Experiment I (second year)

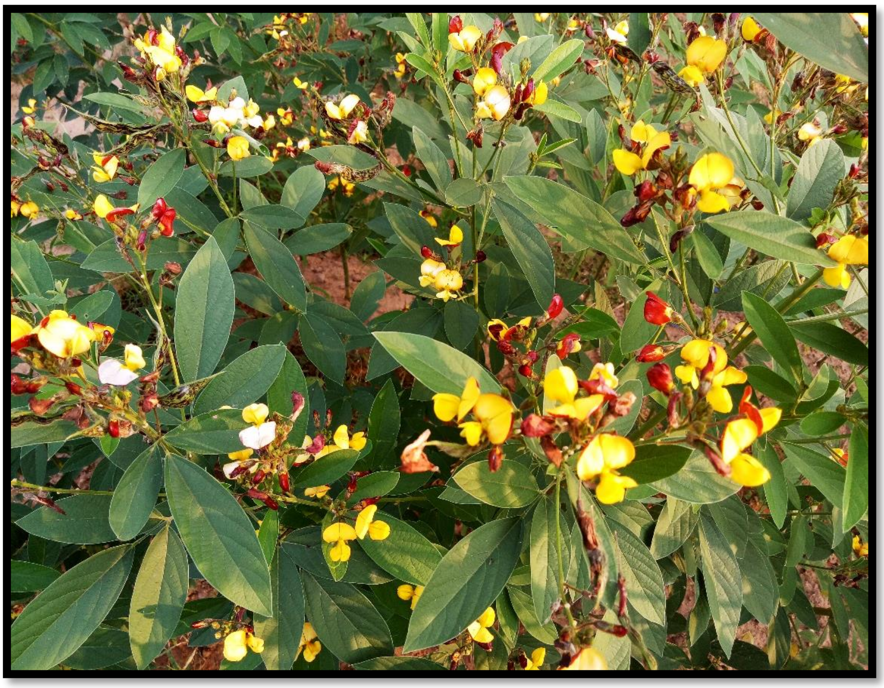
Plate 1. General view of experimental field I (first year)

Plate 2. General view of experimental field I (Second year)

Plate 3. Sowing of red gram seeds

Plate 4. Emergence of red gram seedlings

Plate 5. Flowering and pod development in red gram



APK 1

Vamban (Rg) 3

Plate 6. Short duration varieties of red gram

3.3.1.6 Plant Protection

A prophylactic drenching with chlorpyriphos (2 mL L^{-1}) was given to prevent termite attack. Plant protection measures were adopted at flowering and pod filling stages against insect pests. Flubendiamide (1 mL 10 L^{-1}) and chlorantraniliprole (3 mL 10 L^{-1}) were used in rotation to control pod borers when the infestation was noticed. Spraying of thiamethoxam at 2 g 10 L^{-1} was done against pod bug infestation.

3.3.1.7 Harvesting

The crop was harvested manually by picking the pods, when the leaves and pods turned reddish-brown and shedding became prominent. Border plants and the net plot area were harvested separately, threshed and winnowed to separate the seeds. The weight of seeds and haulm from individual plots were recorded.

3.3.2 Experiment II: Assessment of Legume Effect on Fodder Maize

3.3.2.1 Design and Layout

Crop	: Fodder maize
Variety	: African tall
Plot size	: 3.6 m x 2.4 m
Spacing	: 30 cm x 15 cm
Design	: RBD
Season	: June - August 2019

3.3.2.2 Details of Cultivation

The crop residues of red gram (root, shoot and fallen leaves) generated in each plot were incorporated in the respective plots after harvest and allowed to decompose for two months (April - May 2019). With the onset of monsoon in June 2019, seeds of fodder maize were sown at 30 cm x 15 cm spacing without any manure application in order to assess the legume effect on maize growth. Maize crop was harvested at milky stage for fodder by cutting the stem at 15 cm height from the base.

3.3.3 Experiment III: Nutrient Scheduling in Red gram

The variety, spacing and NPK dose adjudged superior in Experiment I were carried over for the experiment.

3.3.3.1 Design and Layout

Design : RBD

Plot size : 3.6 m x 2.4 m

Replications : 3

Treatments : 9

Season : November 2019 - March 2020

Treatment details:

T_1 : 100 % NPK as chemical fertilizers

T_2 : 100 % N + 50 % P + 100 % K + P solubiliser

T_3 : 100 % N + 100 % P + 50 % K + K solubiliser

T_4 : 100 % N + 50 % P + 50 % K + P solubiliser + K solubiliser

(T_1 to T_4 - N as soil application, basal and 30 DAS)

T_5 : 100 % NPK as chemical fertilizers

T_6 : 100 % N + 50 % P + 100 % K + P solubiliser

T_7 : 100 % N + 100 % P + 50 % K + K solubiliser

T_8 : 100 % N + 50 % P + 50 % K + P solubiliser + K solubiliser

(T_5 to T_8 - ½ N as soil application, basal and remaining as foliar spray (2 % urea))

T_9 : Absolute control (No fertilizers)

Plate 7. General view of experimental field after residue incorporation

Plate 8. General view of experimental field before sowing of fodder maize

Plate 9. General view of experimental field II

Plate 10. Emergence of fodder maize

Plate 11. Fodder maize at 20 DAS

Tasseling stage

Silking stage

Plate 12. Reproductive stages of fodder maize

Plate 13. Harvesting stage (milky stage) of fodder maize

3.3.3.2 Field Preparation

The experimental area was cleared of weeds and crop stubbles, ploughed and levelled thoroughly. After levelling, the experiment was laid out as per the design fixed (Fig. 3). The field was divided into 27 plots, each of 3.6 m length and 2.4 m width. Liming was done @ 250 kg ha^{-1} based on soil test results and PoP recommendations (KAU, 2016).

3.3.3.3 Sowing

Rhizobium inoculated seeds of red gram were sown in prepared plots @ 15 kg ha^{-1} at the spacing found superior in Experiment I.

3.3.3.4 Application of Manures and Fertilizers

Well rotten and dried FYM (0.48 per cent N, 0.19 per cent P_2O_5 and 0.46 per cent K_2O) @ 12.5 t ha^{-1} was applied uniformly prior to sowing and incorporated in each plot. The NPK dose adjudged superior in Experiment I was given using the different sources of chemical and biofertilizers as per the treatments fixed, based on the results of soil test and NPK ratings and recommendations (KAU, 2016).

3.3.3.5 Application of P and K Solubiliser

The P and K solubilisers were applied to substitute 50 per cent P and K recommendations in treatments T_2 to T_4 and T_6 to T_8. The solubilisers were applied @ 10 g mixture (dry cow dung and solubiliser mixed in the ratio, 50:1) per plant, one week after basal fertilizer application.

3.3.3.6 Foliar Application of Urea

Foliar spray of 2 per cent urea was given in treatments T_5 to T_8 twice, 30 and 45 DAS, to substitute 50 per cent of the N recommendation.

3.3.3.7 Thinning and Weeding

Thinning and weeding were done as described under 3.3.1.5.

3.3.3.8 Plant Protection

Plant protection measures were adopted as prophylactic measures against pod borers and bugs as described under 3.3.1.6. In addition, soil drench with the fungicide Saaf (Carbendazim 12 % + Mancozeb 63 %) at the rate of 3 g L^{-1} was done to manage wilt incidence noticed in the seedling stage.

3.3.3.9 Harvesting

Harvesting of red gram was done as described under 3.3.1.7

3.4 OBSERVATIONS

3.4.1 Experiment I : Assessment of the Suitability of Two Short Duration Varieties and Standardization of Spacing and Nutrient Levels

Experiment III : Nutrient Scheduling in Red gram

3.4.1.1 Biometric Observations

Five plants from the net plot area in each plot were labelled as observation plants.

3.4.1.1.1 Plant Height

The height of the five selected plants were measured from the ground level to the apical bud of the main stem and average was computed and expressed in centimetres (cm). The observation was recorded at monthly interval.

3.4.1.1.2 Number of Branches per Plant

The number of branches per plant were counted in the observation plants at monthly interval. The data were averaged to record the number of branches per plant.

3.4.1.1.3 Number of Nodules per Plant

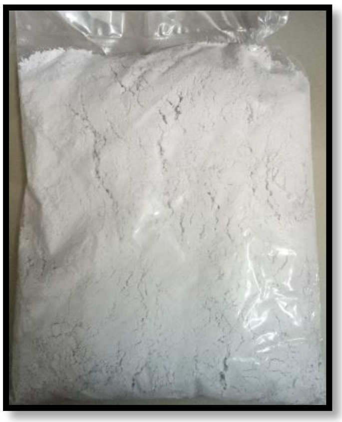
At flowering stage, three plants from the net plot area were uprooted with the roots intact and cleaned of soil by repeated washing with water. The nodules in each plant were carefully removed, counted and average was recorded.

Fig. 3. Layout of field Experiment III

Plate 14. General view of experimental field III

Plate 15. Harvesting stage of experimental field III

P solubiliser (*B. megaterium*)



K solubiliser (*B. sporothermodurans*)

Urea (2 %

Plate 16. Materials used in Experiment III

3.4.1.1.4 Weight of Nodules per Plant

The weight of nodules was recorded after taking the nodule count and expressed as fresh weight in grams (g) per plant.

3.4.1.1.5 Root Volume

Water displacement method was adopted to record root volume. After the harvest, sample plants were uprooted and roots separated. These were washed thoroughly to remove the adhering soil particles. The cleaned roots were immersed in a 500 mL beaker containing 300 mL water. The quantity of water displaced was taken as the measure of volume of roots and the average expressed in cm^3 per plant.

3.4.1.1.6 Root Dry Weight

Cleaned roots of the sample plants were oven dried to a constant weight at 70° C and weighed. The average dry weight was computed and recorded in g per plant.

3.4.1.1.7 Root - Shoot Ratio

Ratio of the weight of dried roots and shoots of sample plants were calculated and recorded as root : shoot ratio.

3.4.1.2 Yield and Yield Attributes

3.4.1.2.1 Days to 50 per cent Flowering

The number of days from the date of sowing to flowering in 50 per cent of the plants in each plot was taken as days to 50 per cent flowering.

3.4.1.2.2 Average Pod Length

Ten pods were selected randomly from pods harvested from the observation plants and lengths were measured. The average pod length was computed and expressed in cm.

3.4.1.2.3 Average Pod Weight

The pods selected for measuring the pod length were weighed individually and the weights were averaged to record the average pod weight in g per pod.

3.4.1.2.4 Number of Seeds per Pod

Ten pods were randomly taken from the selected plants in each plot and number of seeds in each pod was counted. The average was worked out to express the number of seeds per pod.

3.4.1.2.5 100 Seed Weight

After threshing the pods and sun drying, 100 bold seeds from the pods in each plot were weighed and recorded in g.

3.4.1.2.6 Seed - Pod Ratio

The ratio of the weight of seeds to the weight of pod in the sampled pods was recorded as seed-pod ratio.

3.4.1.2.7 Seed Yield

The pods harvested from the net plot area in each plot were sun dried, threshed, seeds separated and weighed to record the seed yield. Seed yield was expressed in t ha^{-1}.

3.4.1.2.8 Haulm Yield

After harvesting the pods, plants were uprooted, dried under sun, and weighed to record the haulm yield in t ha^{-1}.

3.4.1.3 Physiological Observations

3.4.1.3.1 Dry Matter Production (DMP)

Three plants from each plot were uprooted at 20 days interval. The plants were oven dried at 70° C and the weights were taken and expressed as g per plant.

3.4.1.3.2 Crop Growth Rate (CGR)

The CGR was computed adopting the formula proposed by Watson (1952) and expressed as g m^{-2} of land area per day.

$$CGR = \frac{(W_2 - W_1)}{(t_2 - t_1)} \times \frac{1}{A}$$

where,

W_1 : Dry weight of plant (g) at time t_1

W_2 : Dry weight of plant (g) at time t_2

A : Unit land area (m^2)

3.4.1.3.3 Relative Growth Rate (RGR)

Relative Growth Rate is the rate of increase in dry weight per unit dry matter present per unit time and was computed as per the equation given by Evans (1972) and expressed as g $g^{-1}day^{-1}$.

$$RGR = \frac{(\log_e w_2 - \log_e w_1)}{(t_2 - t_1)}$$

where, w_2 and w_1 represent total dry matter per plant at t_2 and t_1 times, respectively.

3.4.1.4 Agronomic Indices

The agronomic indices, Partial Factor Productivity (PFP) and Physiological Efficiency (PE) of nutrient use efficiency were calculated using the formulae given by Dobermann and Fairhurst (2000) as detailed in Table 4.

3.4.1.4.1 Harvest Index

Harvest index was computed using the formula proposed by Donald and Hamblin (1976).

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Biological yield}}$$

3.4.1.5 Pest and Disease Incidence

The plants were monitored for pests and disease incidence during the entire crop period.

Table 4. Agronomic indices

Agronomic Index	Formula
Partial Factor Productivity	PFP = (kg yield kg^{-1} nutrient applied) = Y / A
Physiological Efficiency	PE = (kg yield increase kg^{-1} fertilizer nutrient uptake) = $(Y - Y_0) / (U - U_0)$

Y : Yield from treated plot

Y_0 : Yield from control plot

U : Nutrient uptake in treated plot

U_0 : Nutrient uptake in control plot

A : Applied nutrient

3.4.1.6 Plant Analysis

3.4.1.6.1 Chlorophyll Content

Total chlorophyll content of leaves was estimated by the method of Arnon (1949) and expressed in mg g^{-1} of fresh weight of leaf.

$$\text{Total chlorophyll} = [8.02\ A_{663} + 20.20\ A_{645}] \times \frac{V}{1000 \times W}$$

where,

A : Absorbance at specific wavelengths

V : Final volume of chlorophyll extract in 80 per cent acetone

W : Fresh weight of tissue extracted in 80 per cent acetone

3.4.1.6.2 NPK Uptake

The seed, shoot, root and pod husk were analysed separately for N, P and K content and their total was calculated. Samples were collected at the time of harvest, dried and powdered. For P and K estimation, the samples were digested with diacid mixture and for N, with sulphuric acid and digestion mixture. The standard procedures adopted for the analysis of plant samples are detailed in Table 5. The uptake of nutrients was calculated based on the content of nutrient in plants and the dry matter produced. The values were expressed in kg ha^{-1}.

Table 5. Methods used for plant analysis

Particulars	Method	Reference
N	Micro-Kjeldahl digestion and distillation method	Jackson (1973)
P	Nitric-perchloric acid digestion (9:4) and spectrophotometry using vanadomolybdo phosphoric yellow colour method	
K	Nitric-perchloric acid digestion and flame photometry	

3.4.1.7 Quality Parameters

3.4.1.7.1 Seed Protein

The N content in seeds was estimated by micro-Kjeldahl digestion and distillation method (Table 5) and the seed protein content, by multiplying N content with a factor of 6.25 (Simpson *et al.*, 1965), and expressed in per cent.

3.4.1.8 Soil Analysis

Soil samples were analysed for the soil chemical and biological parameters before and after the experiments adopting the standard procedures for pH, organic C and available NPK and microbial counts as described in Table 2. Fresh soil samples were used for enumerating bacteria, fungi and actinomycete population.

3.4.1.9 Nutrient Balance Sheet

The nutrient balance sheet was worked out as follows:

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

where,

A : Initial nutrient status of the soil (soil contribution)

B : Nutrient added as per treatments

C : Nutrient taken by crop

- Apparent gain / loss (F) = E – D

where,

E : Actual nutrient balance *i.e.,* the available nutrient status of soil after harvest of the crop (Choudhary, 2007)

3.4.2 Experiment II: Assessment of Legume Effect on Fodder Maize

3.4.2.1 Decomposition of Crop Residues

3.4.2.1.1 Quantity of Crop Residues Added

After the harvest of red gram pods, quantity of crop residue (root + shoot + fallen leaves) in each plot were recorded separately and expressed as t ha^{-1}.

3.4.2.1.2 Biochemical Characters of Crop Residues

The cellulose, hemicellulose and lignin content of the red gram crop residues were estimated adopting the procedures given in Table 6.

3.4.2.1.3 C: N Ratio

Organic C content of red gram crop residues were assessed adopting the loss by ignition method (Jackson, 1973) and N, by the standard procedure given in Table 5. The ratio of organic C to N was calculated and presented as C: N ratio.

3.4.2.2 Soil Properties

The soil C fractions, pH, available N, P, K and dehydrogenase activity were estimated at 20 days interval during the residue decomposition period.

Table 6. Biochemical analysis of red gram residues

Parameters	Method	Reference
Cellulose	Acid - detergent fibre method	Sadasivam and Manickam (1992)
Lignin		
Hemicellulose	Neutral detergent fibre method	
Phenol	Folin - Ciocalteu colorimetric method	Waterhouse (2002)

3.4.2.2.1 Soil C Pool

The procedures adopted for the estimation of C pool in soil are given in Table 7.

Table 7. Soil C pool analysis

Parameters	Method	Reference
Total organic carbon (TOC)	Weight loss on ignition CHNS analyzer (Vario EI cube, Elementar, Germany)	Nelson and Sommers (1996)
Labile carbon (LC)	Potassium permanganate oxidation method	Blair *et al.* (1995)
Recalcitrant organic carbon (ROC)	Modified Walkley and Black titration method	Chan *et al.* (2001)

3.4.2.2.2 Soil pH and Available NPK

Soil samples were collected at 0 - 15 cm depth after the incorporation of red gram residues at 20 days interval from April to May 2019. Samples were analysed following procedures detailed in Table 2.

3.4.2.2.3 Dehydrogenase Activity

The dehydrogenase activity in soil was analysed in the fresh samples collected based on Triphenyl Tetrazolium Chloride (TTC) reduction technique suggested by Thalmann (1968).

3.4.2.3 Legume Effect on Fodder Maize Crop

3.4.2.3.1 Biometric and Yield Observations

3.4.2.3.1.1 Emergence per cent

In field, the germination count was recorded as the total number of seedlings emerged on the third day after sowing and expressed as emergence per cent.

$$\text{Emergence per cent} = \frac{\text{Number of emerged seedlings}}{\text{Total number of seeds sown}} \times 100$$

(Mitchell and Vogel, 2012)

3.4.2.3.1.2 Plant Height

Height of five randomly selected fodder maize plants labelled as observation plants were measured from the base of the plant to the tip of the growing point. The average was worked out and expressed in cm.

3.4.2.3.1.3 Days to Harvest

The number of days from sowing to the harvest of fodder maize was recorded as days to harvest.

3.4.2.3.1.4 Green Fodder Yield

After the harvest, green fodder of maize in the different plots were weighed separately and expressed in t ha^{-1}.

3.4.2.3.1.5 Dry Fodder Yield

Observation plants were sun dried after recording the fresh weights followed by oven drying at 70° C to compute the dry fodder yield. The yield was expressed in t ha^{-1}.

3.4.2.4 Plant Analysis

3.4.2.4.1 Crude Protein

Crude protein content of plant sample was calculated by multiplying the N content of whole plant estimated by the micro-Kjeldahl digestion and distillation method, by the factor 6.25 (Simpson *et al.*, 1965).

3.4.2.4.2 Carbohydrate Content

Carbohydrate content in fodder maize was estimated by Anthron method (Hedge and Hofreiter, 1962).

3.4.2.5 Soil Analysis

Soil samples were collected before sowing and after harvest of fodder maize and analysed for the chemical parameters as per the standard procedures detailed in Table 2.

3.5 ECONOMIC ANALYSIS

The cost of cultivation and gross returns were calculated based on prevailing market prices of various inputs and outputs, labour wages and expressed in rupees per ha. The total cost of cultivation of experiment I and III, market prices of red gram and various inputs are given in Appendices V, VI, VII and VIII.

The net income and B:C ratio were computed using the following formulae.

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

$$\text{B:C ratio} = \frac{\text{Gross income (₹ ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}}$$

3.6 STATISTICAL ANALYSIS

The data on various parameters were statistically analysed using analysis of variance technique (ANOVA) suggested by Panse and Sukhatme (1985) as applied to RBD. The significance was tested using f test (Snedecor and Cochran, 1967) and critical difference (CD) were calculated wherever treatments were found to be significant. Pooled analysis was done for seed yield, haulm yield, net return and B:C ratio in Experiment I based on the data of the two years. In Experiment III, the data in treatments T_1 to T_8 were statistically analysed while those in T_9 (absolute control) were used for computing agronomic indices.

Results

4. RESULTS

The investigation entitled "Input optimization for short duration red gram [*Cajanus cajan* (L.) Millsp.]'' was conducted in the Instructional Farm, College of Agriculture, Vellayani during 2018 - 2019 and 2019 - 2020. The observations recorded on various parameters have been tabulated, analyzed statistically and are presented in this chapter.

4.1 EXPERIMENT I

4.1.1 Biometric Observations

4.1.1.1 Plant Height

The effect of varieties, spacing and nutrient levels on plant height at monthly interval during the two years are presented in Tables 8 a, 8 b and 8 c.

During the first year of study, plant height did not vary significantly with either the variety, the spacing or the nutrient level at 30 DAS. At 60 DAS and at harvest, the variety Vamban (Rg) 3 (v_2) recorded significantly the highest plant height (106.55 and 121.26 cm respectively). Among the first order interactions, v_2s_2 (Vamban (Rg) 3 at 60 cm x 30 cm) and v_2n_3 (Vamban (Rg) 3 at 20:40:20 kg NPK ha^{-1}) recorded the tallest plants at 60 DAS (110.04 and 112.12 cm respectively) and at harvest (127.09 and 128.22 cm respectively). In S x N interaction, plants were tallest in s_2n_3 at harvest (113.43 cm). In V x S x N interaction, maximum plant heights (117.30 cm and 132.93 cm) were recorded in $v_2s_2n_3$ (Vamban (Rg) 3 at 60 cm x 30 cm and 20:40:20 kg NPK ha^{-1}) at 60 DAS and at harvest respectively. The values recorded in the combination $v_2s_2n_3$ were on par with $v_2s_2n_1$. The shortest plants were observed in $v_1s_2n_3$ (APK 1 at 60 cm x 30 cm and 20:40:20 kg NPK ha^{-1}) and $v_1s_1n_1$ (APK 1 at 40 cm x 20 cm and 40:80:40 kg NPK ha^{-1}) at 60 DAS and at harvest respectively.

In the second year, varieties and nutrient levels exerted significant influence on plant height at 30 DAS. The variety Vamban (Rg) 3 and the nutrient level 40:80:40 kg NPK ha^{-1} showed the maximum plant height at 30, 60 DAS and at harvest. The wider spacing (60 cm x 30 cm) resulted in the tallest plants at 60 DAS and at harvest. Among the first order interactions, plants were taller in v_2s_1, v_2n_1 and s_1n_1 at 30 DAS (53.92, 56.62 and 55.25 cm respectively) and the combinations, v_2s_1, v_1n_1 and s_2n_1 at 60 DAS

(99.60, 100.40, 102.50 cm respectively). At harvest, the interactions v_2s_2, v_2n_1 and s_2n_1 recorded the maximum plant heights. In V x S x N interaction, plants were significantly taller in $v_2s_1n_1$ (Vamban (Rg) 3 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}) $v_1s_2n_1$ (APK 1 + 60 cm x 30 cm + 40:80:40 kg NPK ha^{-1}) and $v_2s_2n_1$ (Vamban (Rg) 3 + 60 cm x 30 cm + 40:80:40 kg NPK ha^{-1}) at 30, 60 DAS and at harvest respectively.

4.1.1.2 Number of Branches per Plant

The data on number of branches per plant as influenced by the varieties, spacing and nutrient levels are presented in Tables 9 a, 9 b and 9 c.

At 30 DAS, the influences of variety, spacing and nutrient levels on number of branches per plant were not significant during the first year. However, at 60 DAS and at harvest, variety Vamban (Rg) 3 (v_2), spacing 60 cm x 30 cm (s_2) and nutrient level 20:40:20 kg NPK ha^{-1} (n_3) recorded significantly the highest number of branches per plant, the values being 7.1 and 9.1, 6.9 and 8.8, 6.9 and 8.8 respectively (Table 9 a). Among the first order interactions (Table 9 b), v_2s_2 and v_2n_3 (Vamban (Rg) 3 at 60 cm x 30 cm spacing and 20:40:20 kg ha^{-1}) and s_2n_1 (60 cm x 30 cm + 40:80:40 kg NPK ha^{-1}) recorded significantly higher number of branches per plant at 60 DAS and at harvest (7.9 and 10.4, 7.8 and 10.2, 8.1 and 9.7 respectively). In V x S x N interaction, $v_2s_2n_1$ (Vamban (Rg) 3 + 60 cm x 30 cm + 40:80:40 kg NPK ha^{-1}) recorded the highest number of branches per plant at 60 DAS and at harvest, which was on par with $v_2s_2n_3$ at both stages (Table 9 c).

During the second year, the variety Vamban (Rg) 3 and the nutrient level 40:80:40 kg NPK ha^{-1} recorded significantly the highest number of branches per plant at 30, 60 DAS and at harvest (Table 9 a), the values being 3.3, 6.7 and 10.0, 3.3, 6.3 and 8.9 respectively. The effect of spacing was significant only at harvest and the wider spacing, 60 cm x 30 cm, resulted in the maximum number of branches (8.9). In first order interactions, the maximum number of branches were observed in v_2s_2, v_2n_1 and s_2n_1 at 30, 60 DAS and at harvest (Table 9 b). Among second order interactions, $v_2s_2n_1$ (Vamban (Rg) 3 + 60 cm x 30 cm + 40:80:40 kg NPK ha^{-1}) registered significantly the highest number of branches per plant at 60 DAS and at harvest (Table 9 c).

Table 8 a. Effect of varieties, spacing and nutrient levels on plant height, cm

Treatments	Plant height					
	First year			Second year		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
Varieties (V)						
v_1: APK 1	50.06	93.99	96.09	49.13	93.53	105.04
v_2: Vamban (Rg) 3	47.80	106.55	121.26	52.41	98.63	117.00
SEm ±	1.34	2.02	2.39	0.05	0.60	0.60
CD (0.05)	-	5.912	7.021	0.142	1.751	1.751
Spacing (S)						
s_1: 40 cm x 20 cm	49.66	99.03	105.97	50.82	94.43	108.51
s_2: 60 cm x 30 cm	48.20	101.51	111.39	50.72	97.73	113.53
SEm ±	1.34	2.02	2.39	0.05	0.60	0.60
CD (0.05)	-	-	-	-	1.751	1.751
Nutrient levels (N) kg NPK ha^{-1}						
n_1: 40:80:40	48.43	97.57	105.02	54.96	100.28	114.43
n_2: 30:60:30	49.26	100.24	107.85	51.01	97.70	112.35
n_3: 20:40:20	49.10	103.01	113.17	46.34	90.26	106.28
SEm±	1.64	2.47	2.93	0.06	0.73	0.73
CD (0.05)	-	-	-	0.174	2.144	2.144

Table 8 b. Interaction effect of varieties, spacing and nutrient levels on plant height, cm

Treatments	Plant height					
	First year			Second year		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
V x S interaction						
v_1s_1	51.85	95.01	96.49	47.72	89.27	100.43
v_1s_2	48.27	92.98	95.69	50.54	97.78	109.64
v_2s_1	47.47	103.06	115.14	53.92	99.60	116.60
v_2s_2	48.14	110.04	127.09	50.90	97.67	117.41
SEm±	1.89	2.85	3.39	0.07	0.84	0.84
CD (0.05)	-	8.362	9.929	0.201	2.476	2.476
V x N interaction						
v_1n_1	50.94	92.77	94.95	53.29	100.40	111.40
v_1n_2	49.96	95.31	95.21	49.32	96.40	107.72
v_1n_3	49.27	93.91	98.13	44.78	83.78	95.99
v_2n_1	45.91	102.37	115.09	56.62	100.15	117.46
v_2n_2	48.56	105.17	120.48	52.70	99.00	116.99
v_2n_3	48.93	112.12	128.22	47.90	96.75	116.58
SEm ±	2.33	3.49	4.15	0.08	1.03	1.03
CD (0.05)	-	10.241	12.160	0.246	3.032	3.032
S x N interaction						
s_1n_1	48.47	94.43	98.69	55.25	98.05	110.61
s_1n_2	49.86	99.43	106.29	50.85	95.10	109.21
s_1n_3	50.63	103.24	112.92	46.37	90.15	105.73
s_2n_1	48.38	100.70	111.35	54.66	102.50	118.25
s_2n_2	48.66	101.05	109.40	51.17	100.30	115.49
s_2n_3	47.57	102.78	113.43	46.32	90.38	106.84
SEm ±	2.33	3.49	4.15	0.08	1.03	1.03
CD (0.05)	-	-	12.160	0.246	3.032	3.032

Table 8 c. Effect of V x S x N interaction on plant height, cm

Treatments	Plant height					
	First year			Second year		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
$v_1s_1n_1$	51.41	91.07	93.13	51.33	95.95	106.38
$v_1s_1n_2$	51.43	94.42	94.02	48.50	88.10	98.75
$v_1s_1n_3$	52.70	99.55	102.33	43.33	83.75	96.16
$v_1s_2n_1$	50.47	94.47	96.77	55.24	104.85	116.43
$v_1s_2n_2$	48.50	96.20	96.40	50.13	104.70	116.68
$v_1s_2n_3$	45.83	88.27	93.92	46.23	83.80	95.82
$v_2s_1n_1$	45.53	97.80	104.24	59.16	100.15	114.83
$v_2s_1n_2$	48.30	104.43	118.57	53.20	102.10	119.67
$v_2s_1n_3$	48.57	106.93	123.51	49.40	96.55	115.29
$v_2s_2n_1$	46.29	106.93	125.93	54.09	100.15	120.06
$v_2s_2n_2$	48.81	105.90	122.40	52.20	95.90	114.30
$v_2s_2n_3$	49.30	117.30	132.93	46.40	96.95	117.86
SEm ±	3.29	4.94	5.86	0.12	1.46	1.46
CD (0.05)	-	14.483	17.197	0.348	4.288	4.288

Table 9 a. Effect of varieties, spacing and nutrient levels on number of branches per plant

Treatments	Number of branches					
	First year			Second year		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
Varieties (V)						
v_1: APK 1	2.9	5.4	6.8	2.8	4.9	6.9
v_2: Vamban (Rg) 3	3.3	7.1	9.1	3.3	6.7	10.0
SEm ±	0.30	0.27	0.28	0.07	0.27	0.16
CD (0.05)	-	0.793	0.818	0.199	0.788	0.462
Spacing (S)						
s_1: 40 cm x 20 cm	3.0	5.7	7.0	3.1	5.7	8.1
s_2: 60 cm x 30 cm	3.3	6.9	8.8	3.0	5.8	8.9
SEm ±	0.30	0.27	0.28	0.07	0.27	0.16
CD (0.05)	-	0.793	0.818	-	-	0.462
Nutrient levels (N) kg NPK ha^{-1}						
n_1: 40:80:40	2.9	6.3	7.8	3.3	6.3	8.9
n_2: 30:60:30	3.1	5.6	7.2	3.2	5.3	7.8
n_3: 20:40:20	3.3	6.9	8.8	2.7	5.6	8.7
SEm±	0.37	0.33	0.34	0.08	0.33	0.19
CD (0.05)	-	0.972	1.002	0.243	0.965	0.566

Table 9 b. Interaction effect of varieties, spacing and nutrient levels on number of branches per plant

Treatments	Number of branches					
	First year			Second year		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
V x S interaction						
v_1s_1	3.2	5.0	6.3	2.9	4.8	6.5
v_1s_2	2.7	5.8	7.2	2.7	4.9	7.3
v_2s_1	2.8	6.3	7.8	3.2	6.5	9.7
v_2s_2	3.8	7.9	10.4	3.4	6.8	10.4
SEm±	0.43	0.38	0.39	0.10	0.38	0.22
CD (0.05)	-	1.122	1.157	0.281	1.114	0.654
V x N interaction						
v_1n_1	3.2	5.7	6.9	3.1	5.4	7.3
v_1n_2	2.6	4.7	5.9	2.8	4.5	6.3
v_1n_3	3.0	6.0	7.4	2.6	4.7	7.2
v_2n_1	2.7	6.9	8.8	3.5	7.3	10.6
v_2n_2	3.5	6.6	8.3	3.5	6.2	9.3
v_2n_3	3.6	7.8	10.2	2.8	6.5	10.1
SEm ±	0.52	0.47	0.48	0.12	0.47	0.27
CD (0.05)	-	1.374	1.417	0.344	1.364	0.800
S x N interaction						
s_1n_1	2.4	4.5	5.9	2.7	5.6	8.0
s_1n_2	3.2	5.8	7.2	3.6	5.3	7.8
s_1n_3	3.4	6.6	8.1	2.9	6.1	8.5
s_2n_1	3.5	8.1	9.7	3.9	6.9	9.9
s_2n_2	2.9	5.4	7.1	2.7	5.3	7.8
s_2n_3	3.3	7.2	9.6	2.4	5.2	8.8
SEm ±	0.52	0.47	0.48	0.12	0.47	0.27
CD (0.05)	-	1.374	1.417	0.344	1.364	0.800

Table 9 c. Effect of V x S x N interaction on number of branches per plant

Treatments	Number of branches					
	First year			Second year		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
$v_1s_1n_1$	3.1	4.5	5.9	2.6	4.9	6.4
$v_1s_1n_2$	3.0	4.8	5.9	3.3	4.5	6.1
$v_1s_1n_3$	3.5	5.9	7.0	3.0	5.2	7.1
$v_1s_2n_1$	3.4	6.9	7.8	3.7	5.8	8.3
$v_1s_2n_2$	2.3	4.5	6.1	2.3	4.4	6.5
$v_1s_2n_3$	2.5	6.1	7.9	2.1	4.3	7.3
$v_2s_1n_1$	1.8	4.6	5.9	2.8	6.4	9.6
$v_2s_1n_2$	3.4	6.9	8.5	3.9	6.2	9.4
$v_2s_1n_3$	3.2	7.4	9.1	2.9	7.0	9.9
$v_2s_2n_1$	3.7	9.3	11.7	4.3	8.2	11.6
$v_2s_2n_2$	3.7	6.3	8.2	3.2	6.3	9.2
$v_2s_2n_3$	4.1	8.2	11.3	2.8	6.0	10.3
SEm ±	0.74	0.66	0.68	0.17	0.66	0.39
CD (0.05)	-	1.943	2.004	-	1.930	1.132

4.1.1.3 Number of Nodules per Plant

The data on number of nodules per plant as influenced by varieties, spacing and nutrient levels at flowering stage are shown in Tables 10 a, 10 b and 10 c.

Perusal of the data in Table 10 a revealed that the number of nodules per plant did not differ markedly with either variety, spacing or nutrient levels during the first year. The interaction also failed to exert any significant variation.

During the second year, spacing exerted significant influence on the number of nodules per plant and it was the highest (6.2) at closer spacing 40 cm x 20 cm (s_1). Among the first order interactions, V x S and S x N effects were significant. The interactions v_2s_1 and s_1n_3 recorded significantly superior number of nodules per plant (6.6 and 6.7 respectively).

4.1.1.4 Weight of Nodules per Plant

Variations recorded in the weight of nodules per plant at the flowering stage of red gram with the treatments are presented in Tables 10 a, 10 b and 10 c. During the first year the variations due to the individual and combinations were non significant.

In second year, the spacing 40 cm x 20 cm and the nutrient level 40:80:40 kg NPK ha^{-1} recorded significantly the highest weight of nodules per plant (0.64 and 0.61 g respectively). Among the interactions, significantly the highest weight was observed in v_2s_1, v_1n_1, s_1n_2, s_1n_3 and $v_2s_1n_2$. The second order interaction $v_2s_1n_2$ was on par with $v_1s_2n_1$.

4.1.1.5 Root Volume

The variations in root volume at harvest due to varieties, spacing and nutrient levels are presented in Tables 11 a, 11 b and 11 c.

Varieties, spacing and nutrient levels significantly influenced the root volume during first and second year. The maximum root volume was recorded by the variety Vamban (Rg) 3, the spacing 60 cm x 30 cm and the nutrient level 40:80:40 kg NPK ha^{-1}. In first order interactions, v_2s_2, v_2n_1 and s_2n_1 showed significantly the highest root volume. In second order interaction, $v_2s_2n_1$ (Vamban (Rg) 3 + 60 cm x 30 cm + 40:80:40 kg NPK ha^{-1}) recorded significantly the highest root volume of 12.33 and 12.80 cm^3 $plant^{-1}$ during first and second year respectively.

Table 10 a. Effect of varieties, spacing and nutrient levels on number and weight of nodules per plant

Treatments	Number of nodules		Weight of nodules (g)	
	First year	Second year	First year	Second year
Varieties (V)				
v_1: APK 1	2.6	5.7	0.15	0.59
v_2: Vamban (Rg) 3	2.3	5.3	0.18	0.57
SEm ±	0.44	0.29	0.04	0.01
CD (0.05)	-	-	-	-
Spacing (S)				
s_1: 40 cm x 20 cm	2.9	6.2	0.19	0.64
s_2: 60 cm x 30 cm	1.9	4.8	0.14	0.53
SEm ±	0.44	0.29	0.04	0.01
CD (0.05)	-	0.842	-	0.022
Nutrient levels (N) kg NPK ha^{-1}				
n_1: 40:80:40	2.3	5.6	0.08	0.61
n_2: 30:60:30	2.5	5.6	0.16	0.59
n_3: 20:40:20	2.5	5.3	0.25	0.56
SEm±	0.54	0.35	0.05	0.01
CD (0.05)	-	-	-	0.027

Table 10 b. Interaction effect of varieties, spacing and nutrient levels on number and weight of nodules per plant

Treatments	Number of nodules		Weight of nodules (g)	
	First year	Second year	First year	Second year
V x S interaction				
v_1s_1	3.0	5.8	0.16	0.59
v_1s_2	2.1	5.6	0.14	0.60
v_2s_1	2.8	6.6	0.22	0.69
v_2s_2	1.8	4.0	0.13	0.46
SEm±	0.62	0.41	0.06	0.01
CD (0.05)	-	1.191	-	0.031
V x N interaction				
v_1n_1	3.0	6.5	0.12	0.67
v_1n_2	2.3	5.5	0.07	0.57
v_1n_3	2.3	5.0	0.27	0.55
v_2n_1	1.5	4.7	0.05	0.54
v_2n_2	2.7	5.7	0.25	0.61
v_2n_3	2.7	5.5	0.23	0.57
SEm ±	0.76	0.50	0.07	0.01
CD (0.05)	-	-	-	0.038
S x N interaction				
s_1n_1	2.3	5.5	0.05	0.58
s_1n_2	3.3	6.3	0.25	0.67
s_1n_3	3.0	6.7	0.27	0.67
s_2n_1	2.2	5.7	0.12	0.64
s_2n_2	1.7	4.8	0.07	0.51
s_2n_3	2.0	3.8	0.23	0.45
SEm ±	0.76	0.50	0.07	0.01
CD (0.05)	-	1.458	-	0.038

Table 10 c. Effect of V x S x N interaction on number and weight of nodules per plant

Treatments	Number of nodules		Weight of nodules (g)	
	First year	Second year	First year	Second year
$v_1s_1n_1$	3.0	5.7	0.07	0.57
$v_1s_1n_2$	2.7	5.3	0.07	0.54
$v_1s_1n_3$	3.3	6.3	0.33	0.65
$v_1s_2n_1$	3.0	7.3	0.17	0.77
$v_1s_2n_2$	2.0	5.7	0.07	0.59
$v_1s_2n_3$	1.3	3.7	0.20	0.44
$v_2s_1n_1$	1.7	5.3	0.03	0.58
$v_2s_1n_2$	4.0	7.3	0.43	0.79
$v_2s_1n_3$	2.7	7.0	0.20	0.68
$v_2s_2n_1$	1.3	4.0	0.07	0.50
$v_2s_2n_2$	1.3	4.0	0.07	0.42
$v_2s_2n_3$	2.7	4.0	0.27	0.45
SEm ±	1.07	0.70	0.11	0.02
CD (0.05)	-	-	-	0.054

4.1.1.6 Root Weight

The significant influence of varieties, spacing and nutrient levels on root dry weight at harvest is evident from Tables 11 a, 11 b and 11 c.

Root weights were significantly the highest in Vamban (Rg) 3, wider spacing (60 cm x 30 cm) and the nutrient level (40:80:40 kg NPK ha^{-1}) in both the years. Among the first order interactions, superior root weights were recorded in v_2s_2, v_2n_1 and s_2n_1 during the first year, whereas the effects were non significant in the second year. In V x S x N interaction, $v_2s_2n_1$ (Vamban (Rg) 3 + 60 cm x 30 cm + 40:80:40 kg NPK ha^{-1}) recorded the highest root weight of 5.95 and 6.71 g $plant^{-1}$ during the first and second year respectively.

4.1.1.7 Root - Shoot Ratio

Data on root-shoot ratio is presented in Tables 11 a, 11 b and 11 c. During the first year, there were no marked differences due to spacing and nutrient levels. Among the varieties, Vamban (Rg) 3 recorded significantly the highest root - shoot ratio (0.25). No significant variation in root - shoot ratio was observed in first and second order interactions.

In second year, the variety Vamban (Rg) 3 and the nutrient levels 30:60:30 and 20:40:20 kg NPK ha^{-1} registered significantly the highest root - shoot ratio. Among interactions, V x S alone was significant and v_2s_2 resulted in the maximum root - shoot ratio (0.28).

4.1.2 Yield Attributes

4.1.2.1 Days to 50 Per cent Flowering

Tables 12 a, 12 b and 12 c depict the effect of varieties, spacing and nutrient levels on days to 50 per cent flowering.

Significant differences were observed in the number of days taken for 50 per cent flowering in both years. Flowering was earlier in APK 1 (58.22 and 61.67 days during first and second years respectively) compared to the variety Vamban (Rg) 3 (69.33 and 70.06 days respectively). However, the individual effects were not carried over to the combinations and hence interaction effects remained non significant.

Table 11 a. Effect of varieties, spacing and nutrient levels on root volume, weight and root-shoot ratio at harvest

Treatments	Root volume (cm^3 $plant^{-1}$)		Root dry weight (g $plant^{-1}$)		Root - shoot ratio	
	First year	Second year	First year	Second year	First year	Second year
Varieties (V)						
v_1: APK 1	11.43	11.70	4.33	5.61	0.19	0.24
v_2: Vamban (Rg) 3	11.69	11.99	5.33	6.31	0.25	0.27
SEm ±	0.07	0.07	0.05	0.03	0.01	0.004
CD (0.05)	0.194	0.201	0.165	0.078	0.021	0.013
Spacing (S)						
s_1: 40 cm x 20 cm	11.43	11.72	4.45	5.72	0.21	0.25
s_2: 60 cm x 30 cm	11.69	11.97	5.20	6.20	0.23	0.26
SEm ±	0.07	0.07	0.05	0.03	0.01	0.004
CD (0.05)	0.194	0.201	0.165	0.078	-	-
Nutrient levels (N) kg NPK ha^{-1}						
n_1: 40:80:40	12.00	12.47	5.06	6.22	0.21	0.24
n_2: 30:60:30	11.54	11.85	4.85	5.98	0.23	0.26
n_3: 20:40:20	11.14	11.22	4.58	5.68	0.22	0.26
SEm±	0.08	0.08	0.07	0.03	0.01	0.01
CD (0.05)	0.238	0.247	0.193	0.096	-	0.016

Table 11 b. Interaction effect of varieties, spacing and nutrient levels on root volume, weight and root-shoot ratio at harvest

Treatments	Root volume (cm^3 plant^{-1})		Root dry weight (g plant^{-1})		Root - shoot ratio	
	First year	Second year	First year	Second year	First year	Second year
V x S interaction						
v_1s_1	11.28	11.56	4.08	5.37	0.19	0.24
v_1s_2	11.58	11.85	4.57	5.85	0.20	0.24
v_2s_1	11.58	11.87	4.82	6.06	0.23	0.25
v_2s_2	11.81	12.10	5.84	6.56	0.27	0.28
SEm±	0.09	0.10	0.08	0.04	0.01	0.01
CD (0.05)	0.275	0.285	0.222	-	-	0.018
V x N interaction						
v_1n_1	11.84	12.29	4.59	5.89	0.19	0.22
v_1n_2	11.39	11.69	4.30	5.59	0.20	0.25
v_1n_3	11.07	11.13	4.09	5.33	0.19	0.25
v_2n_1	12.17	12.66	5.53	6.54	0.24	0.25
v_2n_2	11.69	11.99	5.39	6.37	0.26	0.28
v_2n_3	11.21	11.31	5.07	6.03	0.25	0.27
SEm ±	0.12	0.12	0.09	0.05	0.01	0.01
CD (0.05)	0.337	0.349	0.281	-	-	-
S x N interaction						
s_1n_1	11.84	12.34	4.62	5.93	0.21	0.24
s_1n_2	11.35	11.65	4.53	5.78	0.21	0.25
s_1n_3	11.09	11.15	4.20	5.44	0.21	0.25
s_2n_1	12.17	12.60	5.50	6.50	0.22	0.24
s_2n_2	11.74	12.04	5.16	6.19	0.23	0.27
s_2n_3	11.18	11.29	4.95	5.91	0.22	0.27
SEm ±	0.12	0.12	0.09	0.05	0.01	0.01
CD (0.05)	0.337	0.349	0.281	-	-	-

Table 11 c. Effect of V x S x N interaction on root volume, weight and root-shoot ratio at harvest

Treatments	Root volume (cm^3 $plant^{-1}$)		Root dry weight (g $plant^{-1}$)		Root - shoot ratio	
	First year	Second year	First year	Second year	First year	Second year
$v_1s_1n_1$	11.67	12.17	4.13	5.50	0.18	0.22
$v_1s_1n_2$	11.17	11.47	4.09	5.36	0.19	0.24
$v_1s_1n_3$	11.00	11.03	4.01	5.24	0.19	0.26
$v_1s_2n_1$	12.00	12.40	5.05	6.30	0.20	0.22
$v_1s_2n_2$	11.61	11.92	4.51	5.83	0.21	0.25
$v_1s_2n_3$	11.13	11.22	4.16	5.41	0.19	0.24
$v_2s_1n_1$	12.02	12.52	5.10	6.36	0.23	0.25
$v_2s_1n_2$	11.53	11.84	4.97	6.19	0.23	0.26
$v_2s_1n_3$	11.18	11.27	4.39	5.64	0.22	0.24
$v_2s_2n_1$	12.33	12.80	5.95	6.71	0.24	0.25
$v_2s_2n_2$	11.86	12.16	5.81	6.56	0.28	0.29
$v_2s_2n_3$	11.23	11.35	5.75	6.41	0.28	0.30
SEm ±	0.16	0.17	0.13	0.07	0.02	0.01
CD (0.05)	0.476	0.493	0.392	0.191	-	-

4.1.2.2 Average Pod Length

The average pod length did not show any variations due to the individual and interaction effects of varieties, spacing, nutrient levels during both the years (Tables 12 a, 12 b and 12 c).

4.1.2.3 Average Pod Weight

Perusal of the data on the effect of varieties, spacing and nutrient levels on average pod weight (Tables 12 a, 12 b and 12 c) reveal that the average pod weight was significantly different for the varieties in the first and second year. APK 1 was superior (0.40 g pod^{-1}), but the influence of spacing and nutrient levels was non significant. In first order interaction, variations were significant and v_1s_1 (0.40 g pod^{-1}) and v_1n_1 (0.42 g pod^{-1}) recorded the maximum average pod weight. In V x S x N interaction, $v_1s_1n_1$ recorded significantly the highest average pod weight (0.43 g pod^{-1}) and the lowest was in $v_2s_2n_3$ (0.32 g pod^{-1}).

In the second year the variations observed were significant. The pod weight was maximum in the variety APK 1, the spacing 40 cm x 20 cm and the nutrient level 40:80:40 kg NPK ha^{-1}. The combinations involving v_1, s_1 and n_1 resulted in superior values for average pod weight. The significantly highest average pod weight was observed in $v_2s_1n_1$ (0.57 g pod^{-1}) on par with $v_1s_1n_1$ (0.54 g pod^{-1}) and, the lowest in $v_2s_2n_3$ (0.39 g pod^{-1}).

4.1.2.4 Number of Seeds per Pod

The treatments, individually and in combinations did not exert any significant influence on number of seeds per pod (Tables 12 a, 12 b and 12 c) during both years.

4.1.2.5 100 Seed Weight

The effect of varieties, spacing and nutrient levels on 100 seed weight are given in Tables 12 a, 12 b and 12 c.

The 100 seed weight was significantly higher in APK 1 in both years (9.04 and 9.15 g respectively) while it did not vary significantly with nutrient levels and spacing. Interaction effects were significant in the first year alone. The interaction, v_1s_2 and v_1n_3 resulted in significantly the highest 100 seed weight (9.22 and 9.27 g respectively). In V x S x N interaction, $v_1s_2n_1$ recorded significantly the highest 100 seed weight (9.63 g).

4.1.2.6 Seed - Pod Ratio

The variations in seed - pod ratio as influenced by the varieties, spacing and nutrient levels are presented in Tables 12 a, 12 b and 12 c.

During both the years, the influence on seed - pod ratio was significant due to nutrient level alone. The nutrient level n_2 (30:60:30 kg NPK ha^{-1}) resulted in the maximum seed - pod ratio (0.78), which was on par with n_1 (0.76) but significantly greater than n_3 (0.72) and in the second year n_1 was superior.

During the second year, the first order interactions, v_2s_2 and s_2n_1 recorded the highest values (0.76 and 0.78 respectively). In V x S x N interaction, $v_2s_2n_2$ (0.79) and $v_2s_1n_2$ (0.64) resulted in the highest and the lowest seed - pod ratio respectively.

4.1.3 Yield

4.1.3.1 Seed Yield

Variations in seed yield due to varieties, spacing and nutrient levels are given in Tables 13 a, 13 b and 13 c. It is evident that the individual and interaction effects on seed yields were significant in both years. The maximum seed yield was recorded in APK 1 (0.99 and 1.07 t ha^{-1}), 40 cm x 20 cm spacing (1.19 and 1.28 t ha^{-1}) and 40:80:40 kg NPK ha^{-1} (1.06 and 1.11 t ha^{-1}). The trend remained same for the interactions also. In first order interaction, significantly higher seed yield was observed in v_1s_1, v_1n_1 and s_1n_1 during both years. In V x S x N interaction, $v_1s_1n_1$ (APK 1 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}) registered significantly the highest seed yield of 1.36 t ha^{-1} and 1.39 t ha^{-1} during the first and second year respectively on par with $v_2s_1n_1$ and $v_1s_1n_2$. Seed yield was the lowest in $v_2s_2n_3$ (Vamban (Rg) 3 + 60 cm x 30 cm + 20:40:20 kg NPK ha^{-1}). The results of pooled analysis also revealed similar trends with maximum seed yield of 1.38 t ha^{-1} in $v_1s_1n_1$ interaction on par with $v_2s_1n_1$ (1.33 t ha^{-1}).

Table 12 a. Effect of varieties, spacing and nutrient levels on yield attributes

Treatments	Days to 50 % flowering		Average pod length (cm)		Average pod weight (g pod^{-1})		Number of seeds per pod		100 seed weight (g)		Seed - pod ratio	
	First year	Second year	First year	Second year	First year	Second year	First year	Second year	First year	Second year	First year	Second year
Varieties (V)												
v_1: APK 1	58.22	61.67	5.58	5.66	0.40	0.48	4.5	4.6	9.04	9.15	0.74	0.73
v_2: Vamban (Rg)3	69.33	70.06	5.35	5.68	0.34	0.46	4.4	4.6	8.08	8.73	0.76	0.74
SEm ±	0.25	0.25	0.12	0.03	0.01	0.01	0.07	0.07	0.17	0.08	0.01	0.004
CD (0.05)	0.726	0.741	-	-	0.021	0.022	-	-	0.486	0.242	-	-
Spacing (S)												
s_1: 40 cm x 20 cm	63.61	66.11	5.60	5.65	0.38	0.51	4.4	4.6	8.46	8.92	0.76	0.73
s_2: 60 cm x 30 cm	63.94	65.61	5.33	5.69	0.37	0.43	4.5	4.5	8.66	8.96	0.74	0.74
SEm ±	0.25	0.25	0.12	0.03	0.01	0.01	0.07	0.07	0.17	0.08	0.01	0.004
CD (0.05)	-	-	-	-	-	0.022	-	-	-	-	-	-
Nutrient levels (N) kg NPK ha^{-1}												
n_1: 40:80:40	64.25	65.83	5.45	5.71	0.38	0.50	4.5	4.7	8.68	9.10	0.76	0.78
n_2: 30:60:30	63.42	66.17	5.58	5.67	0.37	0.45	4.5	4.5	8.37	8.83	0.78	0.70
n_3: 20:40:20	63.67	65.58	5.37	5.61	0.37	0.44	4.4	4.6	8.63	8.88	0.72	0.74
SEm±	0.30	0.31	0.15	0.03	0.01	0.01	0.08	0.08	0.20	0.10	0.01	0.005
CD (0.05)	-	-	-	-	-	0.028	-	-	-	-	0.038	0.015

Table 12 b. Interaction effect of varieties, spacing and nutrient levels on yield attributes

Treatments	Days to 50 % flowering		Pod length (cm)		Pod weight (g pod^{-1})		Number of seeds per pod		100 seed weight (g)		Seed - pod ratio	
	First year	Second year	First year	Second year	First year	Second year	First year	Second year	First year	Second year	First year	Second year
V x S interaction												
v_1s_1	58.22	61.67	5.71	5.70	0.40	0.52	4.5	4.7	8.86	9.01	0.75	0.73
v_1s_2	58.22	61.67	5.46	5.62	0.39	0.44	4.5	4.5	9.22	9.29	0.72	0.73
v_2s_1	69.00	70.56	5.49	5.60	0.35	0.50	4.4	4.6	8.07	8.83	0.76	0.73
v_2s_2	69.67	69.56	5.21	5.76	0.34	0.41	4.4	4.5	8.10	8.63	0.77	0.76
SEm±	0.35	0.36	0.17	0.04	0.01	0.01	0.10	0.10	0.23	0.12	0.02	0.006
CD (0.05)	-	-	-	-	0.030	0.032	-	-	0.688	-	-	0.017
V x N interaction												
v_1n_1	58.17	61.17	5.53	5.73	0.42	0.51	4.5	4.7	9.24	9.28	0.74	0.77
v_1n_2	58.33	62.33	5.80	5.66	0.38	0.47	4.6	4.5	8.62	9.08	0.76	0.69
v_1n_3	58.17	61.50	5.43	5.60	0.40	0.47	4.4	4.5	9.27	9.08	0.71	0.73
v_2n_1	70.33	70.50	5.38	5.70	0.34	0.50	4.5	4.7	8.13	8.92	0.77	0.78
v_2n_2	68.50	70.00	5.36	5.70	0.35	0.44	4.3	4.5	8.13	8.58	0.79	0.71
v_2n_3	69.17	69.67	5.32	5.63	0.34	0.42	4.4	4.6	7.99	8.70	0.73	0.74
SEm ±	0.43	0.44	0.21	0.05	0.01	0.01	0.12	0.12	0.29	0.14	0.02	0.007
CD (0.05)	-	-	-	-	0.037	0.039	-	-	0.842	-	-	-
S x N interaction												
s_1n_1	64.17	66.17	5.65	5.68	0.38	0.56	4.5	4.7	8.37	8.98	0.77	0.77
s_1n_2	63.50	66.50	5.74	5.63	0.36	0.49	4.4	4.6	8.28	8.88	0.78	0.67
s_1n_3	63.17	65.67	5.41	5.63	0.39	0.49	4.4	4.6	8.74	8.89	0.73	0.75
s_2n_1	64.33	65.50	5.25	5.74	0.38	0.45	4.5	4.6	8.99	9.22	0.75	0.78
s_2n_2	63.33	65.83	5.42	5.73	0.38	0.42	4.6	4.5	8.47	8.78	0.77	0.74
s_2n_3	64.17	65.50	5.33	5.59	0.36	0.41	4.4	4.5	8.52	8.88	0.71	0.72
SEm ±	0.43	0.44	0.21	0.05	0.01	0.01	0.12	0.12	0.29	0.14	0.02	0.007
CD (0.05)	-	-	-	-	-	0.039	-	-	-	-	-	0.021

Table 12 c. Effect of V x S x N interaction on yield attributes

Treatments	Days to 50 % flowering		Pod length (cm)		Pod weight (g pod^{-1})		Number of seeds per pod		100 seed weight (g)		Seed - pod ratio	
	First year	Second year	First year	Second year	First year	Second year	First year	Second year	First year	Second year	First year	Second year
$v_1s_1n_1$	58.00	61.00	5.73	5.80	0.43	0.54	4.5	4.7	8.85	9.07	0.74	0.78
$v_1s_1n_2$	58.33	62.33	5.92	5.67	0.37	0.51	4.6	4.7	8.42	8.97	0.77	0.70
$v_1s_1n_3$	58.33	61.67	5.48	5.63	0.42	0.52	4.3	4.6	9.32	8.98	0.75	0.73
$v_1s_2n_1$	58.33	61.33	5.32	5.65	0.41	0.47	4.5	4.6	9.63	9.50	0.75	0.77
$v_1s_2n_2$	58.33	62.33	5.68	5.65	0.39	0.43	4.7	4.4	8.82	9.20	0.74	0.69
$v_1s_2n_3$	58.00	61.33	5.37	5.55	0.39	0.42	4.4	4.5	9.21	9.17	0.68	0.74
$v_2s_1n_1$	70.33	71.33	5.57	5.57	0.33	0.57	4.6	4.7	7.90	8.90	0.79	0.77
$v_2s_1n_2$	68.67	70.67	5.57	5.60	0.35	0.47	4.2	4.5	8.14	8.80	0.79	0.64
$v_2s_1n_3$	68.00	69.67	5.33	5.63	0.36	0.45	4.4	4.7	8.15	8.80	0.71	0.78
$v_2s_2n_1$	70.33	69.67	5.18	5.83	0.34	0.43	4.4	4.6	8.36	8.93	0.76	0.78
$v_2s_2n_2$	68.33	69.33	5.15	5.80	0.36	0.41	4.4	4.5	8.11	8.37	0.79	0.79
$v_2s_2n_3$	70.33	69.67	5.30	5.63	0.32	0.39	4.5	4.5	7.83	8.60	0.75	0.70
SEm ±	0.61	0.62	0.29	0.06	0.02	0.02	0.16	0.16	0.41	0.20	0.03	0.01
CD (0.05)	-	-	-	-	0.052	0.055	-	-	1.191	-	-	0.030

4.1.3.2 Haulm Yield

The variations in haulm yield due to varieties, spacing and nutrient levels are given in Tables 13 a, 13 b and 13 c.

During the first and second year, the variety APK 1, spacing, 40 cm x 20 cm and nutrient level, 40:80:40 kg NPK ha^{-1} recorded significantly the highest haulm yield. Among the first order interactions, v_2s_1, v_1n_1 and s_1n_1 were superior and among the second order interactions, $v_1s_1n_1$ and $v_2s_1n_1$ were the higher and on par during both the years. Pooled analysis revealed the significantly highest haulm yield in the combination $v_2s_1n_1$ (4.82 t ha^{-1}).

4.1.4 Physiological Parameters

4.1.4.1 Dry Matter Production (DMP)

The DMP per plant recorded at 20 days interval are given in Tables 14 a, 14 b and 14 c. Dry matter accumulation in the plant increased with advancement in crop age and reached the maximum at harvest.

During the first year, the significantly highest DMP was recorded in the variety APK1 during 20, 40, 60 and 80 DAS. At 100 DAS the varietal effect was non significant. The wider spacing and the highest nutrient level recorded the maximum DMP and was significantly higher than closer spacing and lower nutrient levels during all the periods. Among the first order interactions, v_1s_2, v_1n_1 and s_2n_1 resulted in significantly the highest DMP. In V x S x N interaction, maximum DMP was recorded in $v_1s_2n_1$ (APK 1 + 60 cm x 30 cm + 40:80:40 kg NPK ha^{-1}).

During the second year, DMP was superior in Vamban (Rg) 3 at 40 DAS. The spacing, 60 cm x 30 cm and the nutrient level, 40:80:40 kg NPK ha^{-1} registered the maximum dry matter accumulation at 40, 60, 80 and 100 DAS. Among the first order interactions, DMP was maximum in v_2n_2, v_2s_2 and v_1s_2 at 20, 40 and 60 DAS respectively while at 40 and 60 DAS, v_2n_1 resulted in significantly the highest DMP. At 80 and 100 DAS, it was maximum in v_1s_2 and v_1n_1 and s_2n_1, at 40, 60, 80 and 100 DAS. In V x S x N interaction, $v_2s_2n_2$ and $v_2s_2n_1$ resulted in the maximum DMP at 20 and 40 DAS and $v_1s_2n_1$ at 60, 80 and 100 DAS.

Table 13 a. Effect of varieties, spacing and nutrient levels on seed and haulm yield, t ha^{-1}

Treatments	Seed yield			Haulm yield		
	First year	Second year	Pooled mean	First year	Second year	Pooled mean
Varieties (V)						
v_1: APK 1	0.99	1.07	1.04	3.57	3.83	3.70
v_2: Vamban (Rg) 3	0.92	0.97	0.94	3.44	3.66	3.55
SEm ±	0.03	0.01	0.01	0.02	0.02	0.01
CD (0.05)	0.069	0.014	0.036	0.053	0.059	0.041
Spacing (S)						
s_1: 40 cm x 20 cm	1.19	1.28	1.24	4.48	4.70	4.59
s_2: 60 cm x 30 cm	0.72	0.76	0.74	2.53	2.78	2.66
SEm ±	0.03	0.01	0.01	0.02	0.02	0.01
CD (0.05)	0.069	0.014	0.036	0.053	0.059	0.041
Nutrient levels (N) kg NPK ha^{-1}						
n_1: 40:80:40	1.06	1.11	1.08	3.75	4.03	3.89
n_2: 30:60:30	0.94	1.00	0.97	3.46	3.69	3.57
n_3: 20:40:20	0.88	0.96	0.91	3.31	3.52	3.42
SEm±	0.03	0.01	0.02	0.02	0.03	0.02
CD (0.05)	0.090	0.017	0.045	0.065	0.072	0.050

Table 13 b. Interaction effect of varieties, spacing and nutrient levels on seed and haulm yield, t ha^{-1}

Treatments	Seed yield			Haulm yield		
	First year	Second year	Pooled mean	First year	Second year	Pooled mean
V x S interaction						
v_1s_1	1.22	1.31	1.27	4.46	4.68	4.57
v_1s_2	0.78	0.83	0.81	2.68	2.98	2.83
v_2s_1	1.17	1.25	1.21	4.49	4.73	4.61
v_2s_2	0.66	0.69	0.68	2.38	2.59	2.49
SEm±	0.04	0.01	0.02	0.03	0.03	0.02
CD (0.05)	0.104	0.020	0.051	0.075	0.083	0.058
V x N interaction						
v_1n_1	1.07	1.14	1.11	3.75	4.09	3.92
v_1n_2	1.02	1.06	1.04	3.53	3.78	3.65
v_1n_3	0.90	1.01	0.96	3.44	3.62	3.53
v_2n_1	1.04	1.07	1.06	3.74	3.97	3.86
v_2n_2	0.86	0.94	0.90	3.39	3.60	3.50
v_2n_3	0.85	0.90	0.87	3.19	3.41	3.30
SEm ±	0.04	0.01	0.02	0.03	0.04	0.02
CD (0.05)	0.127	0.025	0.063	0.092	0.102	0.071
S x N interaction						
s_1n_1	1.34	1.36	1.35	4.64	4.96	4.80
s_1n_2	1.18	1.26	1.22	4.49	4.66	4.58
s_1n_3	1.07	1.22	1.14	4.30	4.48	4.39
s_2n_1	0.78	0.85	0.82	2.85	3.09	2.97
s_2n_2	0.69	0.74	0.72	2.43	2.71	2.57
s_2n_3	0.68	0.69	0.69	2.33	2.55	2.44
SEm ±	0.04	0.01	0.02	0.03	0.04	0.02
CD (0.05)	0.127	0.025	0.063	0.092	0.102	0.071

Table 13 c. Effect of V x S x N interaction on seed and haulm yield, t ha^{-1}

Treatments	Seed yield			Haulm yield		
	First year	Second year	Pooled mean	First year	Second year	Pooled mean
$v_1s_1n_1$	1.36	1.39	1.38	4.60	4.97	4.79
$v_1s_1n_2$	1.25	1.30	1.28	4.45	4.62	4.53
$v_1s_1n_3$	1.05	1.24	1.14	4.33	4.44	4.38
$v_1s_2n_1$	0.79	0.90	0.84	2.90	3.20	3.05
$v_1s_2n_2$	0.78	0.82	0.80	2.60	2.94	2.77
$v_1s_2n_3$	0.76	0.78	0.77	2.55	2.80	2.68
$v_2s_1n_1$	1.31	1.34	1.33	4.68	4.95	4.82
$v_2s_1n_2$	1.12	1.22	1.17	4.53	4.70	4.62
$v_2s_1n_3$	1.09	1.19	1.14	4.27	4.53	4.40
$v_2s_2n_1$	0.77	0.80	0.79	2.80	2.99	2.89
$v_2s_2n_2$	0.61	0.66	0.63	2.25	2.49	2.37
$v_2s_2n_3$	0.60	0.61	0.61	2.10	2.29	2.20
SEm ±	0.06	0.01	0.03	0.04	0.05	0.03
CD (0.05)	0.180	0.035	0.089	0.130	0.144	0.101

Table 14 a. Effect of varieties, spacing and nutrient levels on dry matter production, g plant^{-1}

Treatments	Dry matter production									
	First year					Second year				
	20 DAS	40 DAS	60 DAS	80 DAS	100 DAS	20 DAS	40 DAS	60 DAS	80 DAS	100 DAS
Varieties (V)										
v_1: APK 1	0.52	5.82	18.24	28.25	32.52	0.51	5.37	18.97	28.19	32.92
v_2: Vamban (Rg) 3	0.51	5.74	17.48	27.51	31.87	0.55	5.78	18.31	28.71	32.74
SEm ±	0.003	0.02	0.23	0.20	0.23	0.02	0.11	0.31	0.25	0.12
CD (0.05)	0.008	0.069	0.680	0.587	-	-	0.322	-	-	-
Spacing (S)										
s_1: 40 cm x 20 cm	0.48	5.27	16.32	25.11	29.17	0.52	4.79	17.40	26.43	30.40
s_2: 60 cm x 30 cm	0.55	6.30	19.40	30.65	35.22	0.54	6.36	19.88	30.47	35.25
SEm ±	0.003	0.02	0.23	0.20	0.23	0.02	0.11	0.31	0.25	0.12
CD (0.05)	0.008	0.069	0.680	0.587	0.669	-	0.322	0.895	0.729	0.354
Nutrient levels (N) kg NPK ha^{-1}										
n_1: 40:80:40	0.56	5.96	20.34	30.81	35.39	0.54	5.99	19.96	30.75	35.51
n_2: 30:60:30	0.50	5.75	18.12	28.13	32.43	0.55	5.70	18.46	28.11	32.62
n_3: 20:40:20	0.48	5.64	15.13	24.71	28.77	0.50	5.05	17.50	26.50	30.36
SEm±	0.003	0.03	0.28	0.25	0.28	0.02	0.13	0.37	0.30	0.15
CD (0.05)	0.009	0.085	0.832	0.719	0.819	-	0.394	1.096	0.893	0.433

Table 14 b. Interaction effect of varieties, spacing and nutrient levels on dry matter production, g plant^{-1}

Treatments	Dry matter production									
	First year					Second year				
	20 DAS	40 DAS	60 DAS	80 DAS	100 DAS	20 DAS	40 DAS	60 DAS	80 DAS	100 DAS
V x S interaction										
v_1s_1	0.48	5.29	16.55	25.39	29.47	0.51	4.53	17.80	25.50	30.08
v_1s_2	0.56	6.35	19.93	31.11	35.58	0.51	6.21	20.14	30.89	35.75
v_2s_1	0.48	5.24	16.08	24.83	28.87	0.54	5.05	17.00	27.37	30.73
v_2s_2	0.53	6.24	18.88	30.19	34.86	0.56	6.51	19.62	30.06	34.75
SEm±	0.004	0.03	0.33	0.28	0.32	0.02	0.16	0.43	0.35	0.17
CD (0.05)	0.011	0.098	0.961	0.830	0.945	-	0.455	1.265	1.031	0.500
V x N interaction										
v_1n_1	0.56	6.01	21.02	31.58	36.17	0.53	5.67	20.53	31.00	36.16
v_1n_2	0.52	5.78	18.56	28.50	32.66	0.54	5.59	18.69	27.75	32.66
v_1n_3	0.49	5.67	15.15	24.67	28.75	0.45	4.85	17.69	25.83	29.93
v_2n_1	0.55	5.90	19.65	30.04	34.61	0.55	6.30	19.38	30.50	34.85
v_2n_2	0.49	5.71	17.67	27.75	32.21	0.56	5.80	18.24	28.47	32.58
v_2n_3	0.48	5.61	15.11	24.75	28.79	0.55	5.24	17.32	27.17	30.80
SEm ±	0.01	0.04	0.40	0.35	0.40	0.03	0.19	0.53	0.43	0.21
CD (0.05)	0.013	0.120	1.177	1.017	1.158	0.081	0.557	1.550	1.263	0.613
S x N interaction										
s_1n_1	0.53	5.46	18.27	27.50	31.62	0.54	4.99	18.42	28.00	32.48
s_1n_2	0.49	5.23	16.63	25.50	29.56	0.53	5.04	17.40	26.55	30.78
s_1n_3	0.43	5.11	14.05	22.33	26.33	0.49	4.34	16.38	24.75	27.96
s_2n_1	0.59	6.45	22.40	34.13	39.16	0.54	6.99	21.49	33.50	38.53
s_2n_2	0.51	6.27	19.60	30.75	35.30	0.57	6.35	19.52	29.67	34.46
s_2n_3	0.54	6.17	16.21	27.08	31.20	0.51	5.75	18.63	28.25	32.76
SEm ±	0.01	0.04	0.40	0.35	0.40	0.03	0.19	0.53	0.43	0.21
CD (0.05)	0.013	0.120	1.177	1.017	1.158	-	0.557	1.550	1.263	0.613

Table 14 c. Effect of V x S x N interaction on dry matter production, g plant^{-1}

Treatments	Dry matter production									
	First year					Second year				
	20 DAS	40 DAS	60 DAS	80 DAS	100 DAS	20 DAS	40 DAS	60 DAS	80 DAS	100 DAS
$v_1s_1n_1$	0.53	5.51	18.55	28.00	32.12	0.58	4.54	19.04	27.50	32.62
$v_1s_1n_2$	0.50	5.23	17.11	26.00	30.08	0.53	5.04	17.60	25.50	30.42
$v_1s_1n_3$	0.41	5.12	14.00	22.17	26.20	0.41	4.00	16.76	23.50	27.20
$v_1s_2n_1$	0.59	6.51	23.50	35.17	40.21	0.49	6.80	22.02	34.50	39.70
$v_1s_2n_2$	0.53	6.33	20.00	31.00	35.23	0.56	6.14	19.78	30.00	34.90
$v_1s_2n_3$	0.56	6.22	16.29	27.17	31.29	0.49	5.70	18.62	28.16	32.65
$v_2s_1n_1$	0.52	5.40	18.00	27.00	31.11	0.51	5.44	17.80	28.50	32.33
$v_2s_1n_2$	0.48	5.22	16.15	25.00	29.05	0.53	5.04	17.21	27.60	31.13
$v_2s_1n_3$	0.44	5.10	14.09	22.50	26.47	0.57	4.67	15.99	25.99	28.73
$v_2s_2n_1$	0.58	6.40	21.30	33.08	38.11	0.58	7.17	20.96	32.50	37.37
$v_2s_2n_2$	0.49	6.20	19.20	30.50	35.36	0.59	6.57	19.26	29.34	34.03
$v_2s_2n_3$	0.53	6.11	16.13	27.00	31.11	0.52	5.80	18.64	28.33	32.87
SEm ±	0.01	0.06	0.57	0.49	0.56	0.04	0.27	0.75	0.61	0.30
CD (0.05)	0.019	0.170	1.665	1.438	1.638	0.115	0.788	2.192	1.786	0.885

4.1.4.2 Crop Growth Rate (CGR)

Crop growth rates computed at 20 days interval between 20 - 40, 40 - 60, 60 - 80 and 80 - 100 DAS are presented in Tables 15 a, 15 b and 15 c. The trend indicated that the CGR increased up to 40 - 60 DAS and thereafter, declined.

During the first year, CGR did not differ markedly with the varieties tried. However, it was greater with a closer spacing. With respect to the nutrient levels, 40:80:40 kg NPK ha^{-1} recorded significantly the highest CGR during 20 - 40 and 40 - 60 DAS, the values being 2.36 g m^{-2} day^{-1} and 6.22 g m^{-2} day^{-1} respectively. Amongst the first order interactions, v_1s_1 and s_1n_1, recorded significantly the highest CGR at 20 days interval. In V x N interaction, v_1n_1 recorded significantly the highest CGR during 40 - 60 DAS. In V x S x N interaction, the significantly superior CGR was recorded in $v_1s_1n_1$ (APK 1 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}) during all periods.

The varieties, spacing and nutrient levels significantly influenced the CGR during the second year. Maximum values were registered in APK 1 during 40 - 60 and 80 - 100 days interval. The spacing, 40 cm x 20 cm and the nutrient level, 40:80:40 kg NPK ha^{-1} showed superior CGR during all the periods. The interactions, v_2s_1, v_2n_1 and $v_2s_1n_1$ resulted in the highest CGR during 20 - 40 and 60 - 80 day period and at 40 - 60 and 80 - 100 day interval CGR values were significantly superior in the combinations, v_1s_1, v_1n_1 and $v_1s_1n_1$. In S x N interaction, the highest CGR at 20 - 40 days period in s_1n_2 on par with s_1n_1 and the latter showed significantly the highest CGR during 40 - 60, 60 - 80 and 80 - 100 day interval.

4.1.4.3 Relative Growth Rate (RGR)

Tables 16 a, 16 b and 16 c illustrate the influence of varieties, spacing and nutrient levels on RGR computed at 20 days interval.

RGR was maximum during 20 - 40 DAS in both years. During the first year, RGR did not record any marked variations in the two varieties while spacing registered significant effects and the highest RGR at 20 - 40 DAS was with the wider spacing. The nutrient levels effected significant variations and 40:80:40 kg NPK ha^{-1} recorded significantly the highest RGR at 40 - 60 DAS and 20:40:20 kg NPK ha^{-1} at 20 - 40 and 60 - 80 DAS. Among the interactions, at 20 - 40 DAS, v_2s_2, v_1n_3, s_2n_2 and $v_2s_2n_2$

recorded significantly the highest RGR. At 40 - 60 DAS, v_1n_1, s_2n_1 and $v_1s_2n_1$ and at 60 - 80 DAS v_2n_3, s_2n_3 and $v_2s_2n_3$ led to the significantly highest RGR.

During the second year, the variety APK 1 and Vamban (Rg) 3 recorded significantly the highest RGR during 40 - 60 and 60 - 80 DAS respectively. Among the spacings, RGR was superior at 60 cm x 30 cm during 20 - 40 DAS and 40 cm x 20 cm, at 40 - 60 DAS. In first order interactions, v_1s_2, v_2n_1 and s_2n_1 resulted in significantly the highest RGR at 20 - 40 DAS, v_1s_1, v_1n_1 and s_1n_3 showed the significantly highest RGR during 40 - 60 DAS, v_2s_1 and v_2n_1 at 60 - 80 DAS and v_1s_1 at 80 - 100 DAS. In V x S x N interaction, the effects varied widely during the periods of observation. $v_1s_2n_1$, $v_1s_1n_1$, $v_2s_1n_3$ and $v_1s_1n_2$ resulted in significantly the highest RGR during 20 - 40, 40 - 60, 60 - 80 and 80 - 100 DAS respectively.

4.1.5 Agronomic Indices

4.1.5.1 Harvest Index (HI)

The varieties, spacing, nutrient levels and their interactions did not exert any significant influence on HI during both years (Tables 17 a, 17 b and 17 c). The HI ranged from 0.20 - 0.23 and 0.21 - 0.22 during the first and second year respectively.

4.1.5.2 Partial Factor Productivity (PFP)

The data on the effect of varieties, spacing and nutrient levels on PFP are presented in Table 18 a, 18 b and 18 c.

Partial factor productivity for N, P and K during the both years were significantly higher in APK 1 and the spacing, 40 cm x 20 cm. The nutrient level n_1 (40:80:40 kg NPK ha^{-1}) resulted in the highest PFP for K during the first year, while the effect was non significant for N and P. During second year, n_1 resulted in significantly highest values of PFP for N, P and K. Among the interactions, v_1s_1, s_1n_1 and $v_1s_1n_1$ resulted in the significantly highest values of PFP for N, P and K during the both years. In V x N interaction, v_1n_1 recorded highest PFP for N and K during the first year and for N, P, K during the second year. v_1n_2 recorded highest value of PFP for P during the first year.

Table 15 a. Effect of varieties, spacing and nutrient levels on crop growth rate, g m^{-2} day^{-1}

Treatments	Crop Growth Rate							
	First year				Second year			
	20 - 40 DAS	40 - 60 DAS	60 - 80 DAS	80 - 100 DAS	20 - 40 DAS	40 - 60 DAS	60 - 80 DAS	80 - 100 DAS
Varieties (V)								
v_1: APK 1	2.31	5.41	4.31	1.90	2.05	6.08	3.90	1.99
v_2: Vamban (Rg)3	2.28	5.14	4.30	1.91	2.24	5.56	4.69	1.70
SEm ±	0.01	0.12	0.15	0.10	0.06	0.12	0.11	0.12
CD (0.05)	-	-	-	-	0.165	0.363	0.334	0.360
Spacing (S)								
s_1: 40 cm x 20 cm	2.99	6.91	5.50	2.54	2.67	7.88	5.65	2.38
s_2: 60 cm x 30 cm	1.60	3.64	3.12	1.27	1.62	3.76	2.94	1.33
SEm ±	0.01	0.11	0.15	0.10	0.06	0.12	0.11	0.12
CD (0.05)	0.034	0.338	0.425	0.305	0.165	0.363	0.334	0.360
Nutrient levels (N) kg NPK ha^{-1}								
n_1: 40:80:40	2.36	6.22	4.51	1.99	2.29	6.21	4.66	2.03
n_2: 30:60:30	2.28	5.42	4.32	1.90	2.21	5.70	4.27	1.93
n_3: 20:40:20	2.25	4.19	4.10	1.82	1.93	5.55	3.95	1.59
SEm±	0.01	0.14	0.18	0.13	0.07	0.15	0.14	0.15
CD (0.05)	0.042	0.414	-	-	0.202	0.444	0.409	0.440

Table 15 b. Interaction effect of varieties, spacing and nutrient levels on crop growth rate, g m^{-2} day^{-1}

Treatments	Crop Growth Rate							
	First year				Second year			
	20 - 40 DAS	40 - 60 DAS	60 - 80 DAS	80 - 100 DAS	20 - 40 DAS	40 - 60 DAS	60 - 80 DAS	80 - 100 DAS
V x S interaction								
v_1s_1	3.01	7.04	5.52	2.55	2.51	8.30	4.82	2.65
v_1s_2	1.61	3.77	3.11	1.24	1.59	3.87	2.99	1.35
v_2s_1	2.98	6.77	5.47	2.53	2.82	7.47	6.48	2.10
v_2s_2	1.59	3.51	3.14	1.30	1.65	3.64	2.90	1.30
SEm±	0.02	0.16	0.21	0.15	0.08	0.18	0.16	0.17
CD (0.05)	0.048	0.478	0.601	0.432	0.234	0.513	0.473	0.509
V x N interaction								
v_1n_1	2.38	6.44	4.57	1.99	2.12	6.65	4.38	2.19
v_1n_2	2.28	5.61	4.31	1.86	2.19	5.82	3.89	2.11
v_1n_3	2.26	4.17	4.06	1.83	1.85	5.78	3.43	1.69
v_2n_1	2.34	6.01	4.45	1.98	2.46	5.78	4.95	1.88
v_2n_2	2.28	5.22	4.34	1.94	2.24	5.57	4.65	1.76
v_2n_3	2.24	4.20	4.14	1.81	2.02	5.32	4.47	1.48
SEm ±	0.02	0.20	0.25	0.18	0.10	0.21	0.20	0.21
CD (0.05)	-	0.586	-	-	0.286	0.628	0.579	0.623
S x N interaction								
s_1n_1	3.09	8.01	5.77	2.57	2.78	8.40	5.99	2.67
s_1n_2	2.96	7.13	5.55	2.54	2.82	7.73	5.72	2.54
s_1n_3	2.93	5.59	5.18	2.50	2.41	7.52	5.23	1.92
s_2n_1	1.63	4.43	3.26	1.40	1.79	4.03	3.34	1.40
s_2n_2	1.60	3.71	3.10	1.27	1.61	3.66	2.82	1.33
s_2n_3	1.57	2.79	3.02	1.14	1.46	3.58	2.67	1.25
SEm ±	0.02	0.20	0.25	0.18	0.10	0.21	0.20	0.21
CD (0.05)	0.059	0.586	0.737	0.529	0.286	0.628	0.579	0.623

Table 15 c. Effect of V x S x N interaction on crop growth rate, g m^{-2} day^{-1}

Treatments	Crop Growth Rate							
	First year				Second year			
	20 - 40 DAS	40 - 60 DAS	60 - 80 DAS	80 - 100 DAS	20 - 40 DAS	40 - 60 DAS	60 - 80 DAS	80 - 100 DAS
$v_1s_1n_1$	3.12	8.15	5.91	2.58	2.48	9.06	5.29	2.94
$v_1s_1n_2$	2.95	7.43	5.56	2.55	2.82	7.85	4.94	2.86
$v_1s_1n_3$	2.95	5.55	5.11	2.52	2.25	7.97	4.21	2.13
$v_1s_2n_1$	1.64	4.72	3.24	1.40	1.75	4.23	3.47	1.44
$v_1s_2n_2$	1.61	3.80	3.06	1.18	1.55	3.79	2.84	1.36
$v_1s_2n_3$	1.58	2.80	3.02	1.15	1.45	3.59	2.65	1.25
$v_2s_1n_1$	3.05	7.87	5.63	2.57	3.08	7.73	6.68	2.40
$v_2s_1n_2$	2.96	6.83	5.54	2.53	2.82	7.61	6.49	2.21
$v_2s_1n_3$	2.92	5.62	5.26	2.48	2.56	7.07	6.25	1.71
$v_2s_2n_1$	1.62	4.14	3.27	1.40	1.83	3.83	3.21	1.35
$v_2s_2n_2$	1.59	3.61	3.14	1.35	1.66	3.53	2.80	1.30
$v_2s_2n_3$	1.55	2.78	3.02	1.14	1.47	3.57	2.69	1.26
SEm ±	0.03	0.28	0.36	0.26	0.14	0.30	0.28	0.30
CD (0.05)	0.084	0.828	1.042	0.748	0.405	0.888	0.819	0.881

Table 16 a. Effect of varieties, spacing and nutrient levels on relative growth rate, g g^{-1} day^{-1} x 10^{-2}

Treatments	Relative Growth Rate							
	First year				Second year			
	20 - 40 DAS	40 - 60 DAS	60 - 80 DAS	80 - 100 DAS	20 - 40 DAS	40 - 60 DAS	60 - 80 DAS	80 - 100 DAS
Varieties (V)								
v_1: APK 1	12.09	5.66	2.21	0.71	11.73	6.39	1.97	0.78
v_2: Vamban (Rg) 3	12.14	5.54	2.28	0.74	11.77	5.80	2.26	0.66
SEm ±	0.04	0.08	0.07	0.04	0.18	0.12	0.07	0.05
CD (0.05)	-	-	-	-	-	0.345	0.215	-
Spacing (S)								
s_1: 40 cm x 20 cm	11.99	5.62	2.17	0.75	11.13	6.49	2.09	0.69
s_2: 60 cm x 30 cm	12.23	5.58	2.31	0.70	12.37	5.70	2.14	0.73
SEm ±	0.04	0.08	0.07	0.04	0.18	0.12	0.07	0.05
CD (0.05)	0.113	-	-	-	0.523	0.345	-	-
Nutrient levels (N) kg NPK ha^{-1}								
n_1: 40:80:40	11.86	6.12	2.08	0.69	12.00	6.10	2.16	0.72
n_2: 30:60:30	12.19	5.74	2.20	0.72	11.69	5.91	2.10	0.75
n_3: 20:40:20	12.30	4.94	2.45	0.77	11.56	6.27	2.08	0.68
SEm±	0.05	0.09	0.09	0.05	0.22	0.14	0.09	0.06
CD (0.05)	0.139	0.272	0.248	-	-	-	-	-

Table 16 b. Interaction effect of varieties, spacing and nutrient levels on relative growth rate, g g^{-1} day^{-1} x 10^{-2}

Treatments	Relative Growth Rate							
	First year				Second year			
	20 - 40 DAS	40 - 60 DAS	60 - 80 DAS	80 - 100 DAS	20 - 40 DAS	40 - 60 DAS	60 - 80 DAS	80 - 100 DAS
V x S interaction								
v_1s_1	12.03	5.67	2.16	0.75	10.96	6.90	1.80	0.82
v_1s_2	12.15	5.66	2.26	0.67	12.50	5.87	2.14	0.73
v_2s_1	11.97	5.57	2.19	0.76	11.31	6.07	2.39	0.58
v_2s_2	12.32	5.50	2.37	0.72	12.24	5.53	2.13	0.73
SEm±	0.06	0.11	0.10	0.06	0.25	0.17	0.10	0.07
CD (0.05)	0.160	-	-	-	0.739	0.487	0.305	0.200
V x N interaction								
v_1n_1	11.86	6.24	2.04	0.68	11.71	6.55	2.05	0.78
v_1n_2	12.07	5.84	2.15	0.69	11.66	6.06	1.97	0.82
v_1n_3	12.33	4.91	2.43	0.77	11.81	6.56	1.89	0.74
v_2n_1	11.86	6.01	2.12	0.71	12.29	5.65	2.28	0.66
v_2n_2	12.31	5.64	2.25	0.75	11.71	5.76	2.23	0.67
v_2n_3	12.26	4.96	2.46	0.76	11.31	5.98	2.27	0.63
SEm ±	0.07	0.13	0.12	0.07	0.31	0.20	0.13	0.08
CD (0.05)	0.196	0.384	0.351	-	0.905	0.597	0.373	-
S x N interaction								
s_1n_1	11.71	6.03	2.05	0.70	11.15	6.58	2.09	0.74
s_1n_2	11.84	5.78	2.14	0.74	11.30	6.20	2.11	0.74
s_1n_3	12.44	5.05	2.32	0.83	10.95	6.68	2.07	0.62
s_2n_1	12.00	6.21	2.11	0.69	12.86	5.62	2.23	0.69
s_2n_2	12.55	5.70	2.26	0.69	12.07	5.62	2.09	0.75
s_2n_3	12.15	4.83	2.57	0.71	12.17	5.87	2.09	0.75
SEm ±	0.07	0.13	0.12	0.07	0.31	0.20	0.13	0.08
CD (0.05)	0.196	0.384	0.351	-	0.905	0.597	-	-

Table 16 c. Effect of V x S x N interaction on relative growth rate, g g^{-1} day^{-1} x 10^{-2}

Treatments	Relative Growth Rate							
	First year				Second year			
	20 - 40 DAS	40 - 60 DAS	60 - 80 DAS	80 - 100 DAS	20 - 40 DAS	40 - 60 DAS	60 - 80 DAS	80 - 100 DAS
$v_1s_1n_1$	11.71	6.05	2.07	0.69	10.27	7.23	1.84	0.85
$v_1s_1n_2$	11.74	5.92	2.10	0.73	11.27	6.26	1.86	0.88
$v_1s_1n_3$	12.63	5.02	2.30	0.84	11.32	7.22	1.70	0.73
$v_1s_2n_1$	12.00	6.42	2.02	0.67	13.15	5.86	2.26	0.70
$v_1s_2n_2$	12.40	5.75	2.20	0.64	12.05	5.85	2.08	0.76
$v_1s_2n_3$	12.04	4.80	2.56	0.71	12.29	5.91	2.08	0.74
$v_2s_1n_1$	11.71	6.01	2.03	0.71	12.03	5.93	2.35	0.63
$v_2s_1n_2$	11.94	5.64	2.19	0.75	11.32	6.14	2.36	0.60
$v_2s_1n_3$	12.26	5.07	2.34	0.81	10.57	6.14	2.44	0.50
$v_2s_2n_1$	12.01	6.01	2.21	0.71	12.56	5.37	2.20	0.70
$v_2s_2n_2$	12.69	5.65	2.31	0.74	12.09	5.38	2.10	0.74
$v_2s_2n_3$	12.26	4.85	2.58	0.71	12.05	5.82	2.09	0.76
SEm ±	0.10	0.19	0.17	0.11	0.44	0.29	0.18	0.12
CD (0.05)	0.277	0.543	0.496	-	1.280	0.844	0.528	0.347

Table 17 a. Effect of varieties, spacing and nutrient levels on harvest index

Treatments	Harvest index	
	First year	Second year
Varieties (V)		
v_1: APK 1	0.22	0.22
v_2: Vamban (Rg) 3	0.21	0.21
SEm ±	0.003	0.001
CD (0.05)	-	-
Spacing (S)		
s_1: 40 cm x 20 cm	0.21	0.21
s_2: 60 cm x 30 cm	0.22	0.22
SEm ±	0.003	0.001
CD (0.05)	-	-
Nutrient levels (N) kg NPK ha^{-1}		
n_1: 40:80:40	0.22	0.22
n_2: 30:60:30	0.22	0.21
n_3: 20:40:20	0.21	0.21
SEm±	0.004	0.001
CD (0.05)	-	-

Table 17 b. Interaction effect of varieties, spacing and nutrient levels on harvest index

Treatments	Harvest index	
	First year	Second year
V x S interaction		
v_1s_1	0.21	0.22
v_1s_2	0.22	0.22
v_2s_1	0.21	0.21
v_2s_2	0.22	0.21
SEm±	0.01	0.002
CD (0.05)	-	-
V x N interaction		
v_1n_1	0.22	0.22
v_1n_2	0.23	0.22
v_1n_3	0.21	0.22
v_2n_1	0.22	0.21
v_2n_2	0.21	0.21
v_2n_3	0.21	0.21
SEm ±	0.01	0.002
CD (0.05)	-	-
S x N interaction		
s_1n_1	0.22	0.22
s_1n_2	0.21	0.21
s_1n_3	0.20	0.21
s_2n_1	0.22	0.22
s_2n_2	0.22	0.22
s_2n_3	0.22	0.22
SEm ±	0.01	0.002
CD (0.05)	-	-

Table 17 c. Effect of V x S x N interaction on harvest index

Treatments	Harvest index	
	First year	Second year
$v_1s_1n_1$	0.23	0.22
$v_1s_1n_2$	0.22	0.22
$v_1s_1n_3$	0.20	0.22
$v_1s_2n_1$	0.21	0.22
$v_1s_2n_2$	0.23	0.22
$v_1s_2n_3$	0.23	0.22
$v_2s_1n_1$	0.22	0.21
$v_2s_1n_2$	0.20	0.21
$v_2s_1n_3$	0.20	0.21
$v_2s_2n_1$	0.22	0.21
$v_2s_2n_2$	0.21	0.21
$v_2s_2n_3$	0.22	0.21
SEm ±	0.01	0.003
CD (0.05)	-	-

Table 18 a. Effect of varieties, spacing and nutrient levels on partial factor productivity, kg kg^{-1}

Treatments	Partial Factor Productivity					
	First year			Second year		
	N	P	K	N	P	K
Varieties (V)						
v_1: APK 1	5.24	11.44	3.34	4.76	7.48	3.39
v_2: Vamban (Rg) 3	4.80	10.48	3.06	4.31	6.78	3.08
SEm ±	0.13	0.29	0.09	0.02	0.03	0.02
CD (0.05)	0.394	0.863	0.248	0.063	0.100	0.045
Spacing (S)						
s_1: 40 cm x 20 cm	6.28	13.69	3.99	5.69	7.48	4.06
s_2: 60 cm x 30 cm	3.77	8.23	2.40	3.38	6.78	2.41
SEm ±	0.13	0.29	0.09	0.02	0.03	0.02
CD (0.05)	0.394	0.863	0.248	0.063	0.100	0.045
Nutrient levels (N) kg NPK ha^{-1}						
n_1: 40:80:40	5.30	11.46	3.45	4.78	7.48	3.45
n_2: 30:60:30	4.94	10.77	3.14	4.45	6.99	3.17
n_3: 20:40:20	4.83	10.65	2.99	4.38	6.91	3.08
SEm±	0.16	0.36	0.10	0.03	0.04	0.02
CD (0.05)	-	-	0.304	0.078	0.122	0.055

Table 18 b. Interaction effect of varieties, spacing and nutrient levels on partial factor productivity, kg kg^{-1}

Treatments	Partial Factor Productivity					
	First year			Second year		
	N	P	K	N	P	K
V x S interaction						
v_1s_1	6.40	13.96	4.08	5.82	9.15	4.15
v_1s_2	4.08	8.91	2.60	3.70	5.82	2.64
v_2s_1	6.15	13.42	3.91	5.56	8.74	3.97
v_2s_2	3.46	7.54	2.20	3.06	4.82	2.19
SEm±	0.19	0.42	0.12	0.03	0.05	0.02
CD (0.05)	0.557	1.221	0.351	0.090	0.141	0.064
V x N interaction						
v_1n_1	5.39	11.65	3.51	4.93	7.72	3.56
v_1n_2	5.35	11.67	3.40	4.72	7.42	3.37
v_1n_3	4.99	10.99	3.10	4.63	7.30	3.26
v_2n_1	5.21	11.27	3.39	4.62	7.24	3.34
v_2n_2	4.52	9.87	2.88	4.18	6.58	2.98
v_2n_3	4.68	10.31	2.90	4.13	6.52	2.91
SEm ±	0.23	0.51	0.15	0.04	0.06	0.03
CD (0.05)	0.682	1.495	0.429	0.110	0.173	0.078
S x N interaction						
s_1n_1	6.70	14.49	4.36	5.88	9.21	4.24
s_1n_2	6.22	13.58	3.96	5.61	8.82	4.00
s_1n_3	5.90	13.01	3.66	5.58	8.80	3.93
s_2n_1	3.90	8.43	2.54	3.67	5.75	2.65
s_2n_2	3.64	7.96	2.32	3.29	5.18	2.35
s_2n_3	3.77	8.29	2.34	3.18	5.02	2.24
SEm ±	0.23	0.51	0.15	0.04	0.06	0.03
CD (0.05)	0.682	1.495	0.429	0.110	0.173	0.078

Table 18 c. Effect of V x S x N interaction on partial factor productivity, kg kg^{-1}

Treatments	Partial Factor Productivity					
	First year			Second year		
	N	P	K	N	P	K
$v_1s_1n_1$	6.83	14.76	4.45	5.98	9.37	4.32
$v_1s_1n_2$	6.57	14.35	4.18	5.78	9.09	4.12
$v_1s_1n_3$	5.80	12.78	3.60	5.70	8.98	4.01
$v_1s_2n_1$	3.95	8.54	2.57	3.88	6.08	2.80
$v_1s_2n_2$	4.12	8.99	2.62	3.66	5.76	2.61
$v_1s_2n_3$	4.18	9.21	2.59	3.57	5.63	2.51
$v_2s_1n_1$	6.58	14.22	4.28	5.78	9.06	4.17
$v_2s_1n_2$	5.87	12.82	3.74	5.44	8.55	3.88
$v_2s_1n_3$	6.00	13.23	3.73	5.47	8.62	3.85
$v_2s_2n_1$	3.85	8.32	2.51	3.46	5.43	2.50
$v_2s_2n_2$	3.17	6.92	2.02	2.93	4.60	2.09
$v_2s_2n_3$	3.35	7.39	2.08	2.80	4.42	1.97
SEm ±	0.33	0.72	0.21	0.05	0.08	0.04
CD (0.05)	0.965	2.114	0.607	0.155	0.244	0.111

4.1.6 Pest and Disease Incidence

The incidence of pests and diseases were found to be very less in the present study. Even though diseases were completely absent, pod borers and pod bugs were observed and the timely control measures taken could manage them without affecting the seed yield.

4.1.7 Plant Analysis

4.1.7.1 Chlorophyll Content

During the first year, total chlorophyll content was significantly influenced by spacing and nutrient levels (Table 19 a). The wider spacing, 60 cm x 30 cm and the nutrient levels, n_1 and n_2 resulted in higher chlorophyll content. Among the first order interactions, highest chlorophyll content was observed in v_1s_2, v_2n_2 and s_2n_2. In V x S x N interaction, $v_2s_2n_2$ resulted in the significantly highest total chlorophyll content of 1.15 mg g^{-1} (Table 19 c).

During the second year, the total chlorophyll content varied with spacing alone. The wider spacing, 60 cm x 30 cm recorded the maximum chlorophyll content (1.23 mg g^{-1}) and among the interactions, v_1s_2, v_1n_1 and s_2n_2 resulted in the highest chlorophyll content. In V x S x N interaction, $v_1s_2n_1$ resulted in the highest total chlorophyll content (1.28 mg g^{-1}), which was on par with $v_2s_2n_2$ (1.26 mg g^{-1}).

4.1.7.2 Uptake of NPK

The data on the effect of varieties, spacing and nutrient levels on total NPK uptake are given in Tables 20 a, 20 b and 20 c.

During both years, the significantly highest total N, P and K uptake were observed in the narrow spacing, 40 cm x 20 cm and in the higher nutrient level 40:80:40 kg NPK ha^{-1}. Varietal effects revealed the highest P uptake during first year and highest total N, P and K uptake in APK 1 during the second year. Among the first order interactions, v_2n_1 and s_1n_1 recorded significantly higher values for total N and K uptake. In V x S interaction, v_1s_1 and v_2s_1 resulted in the highest values for total N and K uptake respectively. During the second year, superior N and K uptake were computed in v_1s_1, v_1n_1 and s_1n_1. Among the first order interactions, v_1n_1 and s_1n_1 recorded significantly the highest total P uptake during both the years and v_1s_1, during the first year. In V x S x N interaction, $v_2s_1n_1$ (Vamban (Rg) 3 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}) and $v_1s_1n_1$ recorded significantly the highest total N and K uptake during the first and second year respectively. The significantly highest P uptake during both years were observed in the interaction, $v_1s_1n_1$ (APK 1 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}).

4.1.8 Quality Parameter

4.1.8.1 Seed Protein

Significant influence of the treatments on seed protein content during both the years is evident (Table 21 a). The variety APK 1, the spacing 60 cm x 30 cm and the nutrient level 40:80:40 kg NPK ha^{-1} resulted in significantly the highest seed protein content. Among the first order interactions, v_2s_2 and v_1s_2 resulted in higher seed protein content during first and second year respectively while v_1n_1 and s_2n_1 brought about the highest seed protein content during both years. In second order interaction, $v_1s_2n_1$ (APK 1 + 60 cm x 30 cm + 40:80:40 kg NPK ha^{-1}) recorded the maximum seed protein content of 19.38 and 21.99 per cent during first and second year respectively.

4.1.9 Soil Chemical and Biological Properties

4.1.9.1 Soil pH

During both years, the results on the soil pH after the experiment (Tables 22 a, 22 b and 22 c) showed that varieties, spacing, nutrient levels and their interaction had no significant effect on soil pH. However, there was an increase in soil pH from the initial value.

4.1.9.2 Organic Carbon

The effect of varieties, spacing and nutrient levels on organic C status of the soil after the experiment is presented in Tables 22 a, 22 b and 22 c.

No significant difference was observed in organic C status of the soil with the varieties, spacing, nutrient levels and their interactions during the first and second year. The values in post harvest soil of red gram were higher than the initial status.

Table 19 a. Effect of varieties, spacing and nutrient levels on chlorophyll content, mg g^{-1}

Treatments	Chlorophyll content	
	First year	Second year
Varieties (V)		
v_1: APK 1	1.08	1.20
v_2: Vamban (Rg) 3	1.08	1.17
SEm ±	0.01	0.01
CD (0.05)	-	-
Spacing (S)		
s_1: 40 cm x 20 cm	1.04	1.14
s_2: 60 cm x 30 cm	1.12	1.23
SEm ±	0.01	0.01
CD (0.05)	0.013	0.038
Nutrient levels (N) kg NPK ha^{-1}		
n_1: 40:80:40	1.09	1.20
n_2: 30:60:30	1.09	1.20
n_3: 20:40:20	1.05	1.16
SEm±	0.01	0.02
CD (0.05)	0.016	-

Table 19 b. Interaction effect of varieties, spacing and nutrient levels on chlorophyll content, mg g^{-1}

Treatments	Chlorophyll content	
	First year	Second year
V x S interaction		
v_1s_1	1.03	1.14
v_1s_2	1.13	1.26
v_2s_1	1.05	1.15
v_2s_2	1.10	1.20
SEm±	0.01	0.02
CD (0.05)	0.019	0.053
V x N interaction		
v_1n_1	1.11	1.23
v_1n_2	1.07	1.18
v_1n_3	1.06	1.18
v_2n_1	1.08	1.16
v_2n_2	1.12	1.22
v_2n_3	1.04	1.14
SEm ±	0.01	0.02
CD (0.05)	0.023	0.065
S x N interaction		
s_1n_1	1.05	1.14
s_1n_2	1.04	1.15
s_1n_3	1.04	1.14
s_2n_1	1.14	1.25
s_2n_2	1.15	1.26
s_2n_3	1.06	1.17
SEm ±	0.01	0.02
CD (0.05)	0.023	0.065

Table 19 c. Effect of V x S x N interaction on chlorophyll content, mg g^{-1}

Treatments	Chlorophyll content	
	First year	Second year
$v_1s_1n_1$	1.07	1.18
$v_1s_1n_2$	1.00	1.11
$v_1s_1n_3$	1.01	1.12
$v_1s_2n_1$	1.14	1.28
$v_1s_2n_2$	1.14	1.25
$v_1s_2n_3$	1.11	1.23
$v_2s_1n_1$	1.02	1.10
$v_2s_1n_2$	1.08	1.19
$v_2s_1n_3$	1.06	1.16
$v_2s_2n_1$	1.13	1.22
$v_2s_2n_2$	1.15	1.26
$v_2s_2n_3$	1.02	1.11
SEm ±	0.01	0.03
CD (0.05)	0.033	0.092

Table 20 a. Effect of varieties, spacing and nutrient levels on NPK uptake, kg ha^{-1}

Treatments	Total nutrient uptake					
	First year			Second year		
	N	P	K	N	P	K
Varieties (V)						
v_1: APK 1	71.99	11.67	35.13	71.73	13.18	31.51
v_2: Vamban (Rg) 3	72.26	9.19	34.47	66.95	12.04	28.84
SEm ±	0.76	0.20	0.59	0.14	0.07	0.14
CD (0.05)	-	0.577	-	0.411	0.209	0.422
Spacing (S)						
s_1: 40 cm x 20 cm	95.41	13.59	43.92	90.29	17.20	36.16
s_2: 60 cm x 30 cm	48.84	7.26	25.68	48.39	8.02	24.18
SEm ±	0.76	0.20	0.59	0.14	0.07	0.14
CD (0.05)	2.22	0.577	1.741	0.411	0.209	0.422
Nutrient levels (N) kg NPK ha^{-1}						
n_1: 40:80:40	76.33	12.07	37.62	85.92	13.34	37.21
n_2: 30:60:30	73.14	10.43	34.54	62.47	12.31	28.99
n_3: 20:40:20	66.92	8.79	32.24	59.63	12.18	24.31
SEm±	0.93	0.24	0.73	0.17	0.09	0.18
CD (0.05)	2.71	0.706	2.133	0.503	0.256	0.517

Table 20 b. Interaction effect of varieties, spacing and nutrient levels on NPK uptake, kg ha^{-1}

Treatments	Total nutrient uptake					
	First year			Second year		
	N	P	K	N	P	K
V x S interaction						
v_1s_1	95.44	15.18	43.63	94.44	17.70	37.26
v_1s_2	48.54	8.15	26.63	49.03	8.66	25.75
v_2s_1	95.39	11.99	44.21	86.15	16.70	35.06
v_2s_2	49.14	6.38	24.73	47.76	7.38	22.61
SEm±	1.07	0.28	0.84	0.20	0.10	0.20
CD (0.05)	3.13	0.815	2.462	0.581	-	0.597
V x N interaction						
v_1n_1	75.73	13.26	37.18	87.74	14.26	39.74
v_1n_2	73.57	11.74	34.83	63.99	12.85	31.01
v_1n_3	66.67	10.00	33.39	63.48	12.43	23.78
v_2n_1	76.92	10.88	38.06	84.11	12.42	34.69
v_2n_2	72.70	9.11	34.26	60.96	11.77	26.98
v_2n_3	67.17	7.57	31.09	55.80	11.93	24.84
SEm ±	1.31	0.34	1.03	0.24	0.12	0.25
CD (0.05)	3.84	0.999	3.016	0.712	0.362	0.731
S x N interaction						
s_1n_1	101.96	15.58	48.20	109.11	18.13	45.65
s_1n_2	97.64	13.45	43.36	79.49	16.67	34.93
s_1n_3	86.63	11.75	40.20	82.28	16.81	27.92
s_2n_1	50.69	8.57	27.04	62.73	8.55	28.78
s_2n_2	48.63	7.40	25.73	45.46	7.95	23.06
s_2n_3	47.20	5.82	24.28	36.99	7.56	20.70
SEm ±	1.31	0.34	1.03	0.24	0.12	0.25
CD (0.05)	3.84	0.999	3.016	0.712	0.362	0.731

Table 20 c. Effect of V x S x N interaction on NPK uptake, kg ha^{-1}

Treatments	Total nutrient uptake					
	First year			Second year		
	N	P	K	N	P	K
$v_1s_1n_1$	100.89	16.77	46.18	111.01	19.13	49.37
$v_1s_1n_2$	99.66	15.06	43.02	83.63	17.25	36.93
$v_1s_1n_3$	85.76	13.72	41.69	88.68	16.73	25.49
$v_1s_2n_1$	50.57	9.75	28.17	64.46	9.39	30.11
$v_1s_2n_2$	47.49	8.42	26.63	44.35	8.45	25.08
$v_1s_2n_3$	47.57	6.28	25.09	38.27	8.14	22.06
$v_2s_1n_1$	103.03	14.39	50.22	107.21	17.13	41.93
$v_2s_1n_2$	95.62	11.83	43.69	75.34	16.08	32.92
$v_2s_1n_3$	87.51	9.77	38.72	75.88	16.89	30.34
$v_2s_2n_1$	50.82	7.39	25.90	61.00	7.71	27.45
$v_2s_2n_2$	49.77	6.38	24.82	46.57	7.45	21.04
$v_2s_2n_3$	46.83	5.36	23.46	35.71	6.97	19.34
SEm ±	1.85	0.48	1.45	0.34	0.17	0.35
CD (0.05)	5.43	1.412	4.265	1.007	0.512	1.033

Table 21 a. Effect of varieties, spacing and nutrient levels on seed protein content, %

Treatments	Protein content	
	First year	Second year
Varieties (V)		
v_1: APK 1	18.65	20.53
v_2: Vamban (Rg) 3	18.55	19.98
SEm ±	0.002	0.01
CD (0.05)	0.006	0.027
Spacing (S)		
s_1: 40 cm x 20 cm	18.42	20.04
s_2: 60 cm x 30 cm	18.78	20.47
SEm ±	0.002	0.01
CD (0.05)	0.006	0.027
Nutrient levels (N) kg NPK ha^{-1}		
n_1: 40:80:40	18.89	21.45
n_2: 30:60:30	18.77	19.48
n_3: 20:40:20	18.14	19.84
SEm±	0.003	0.01
CD (0.05)	0.008	0.033

Table 21 b. Interaction effect of varieties, spacing and nutrient levels on seed protein content, %

Treatments	Protein content	
	First year	Second year
V x S interaction		
v_1s_1	18.52	20.14
v_1s_2	18.77	20.92
v_2s_1	18.31	19.94
v_2s_2	18.79	20.03
SEm±	0.003	0.01
CD (0.05)	0.009	0.038
V x N interaction		
v_1n_1	18.96	21.54
v_1n_2	18.82	19.92
v_1n_3	18.16	20.14
v_2n_1	18.82	21.36
v_2n_2	18.72	19.04
v_2n_3	18.12	19.55
SEm ±	0.004	0.02
CD (0.05)	0.011	0.047
S x N interaction		
s_1n_1	18.54	21.05
s_1n_2	18.54	18.46
s_1n_3	18.17	20.62
s_2n_1	19.23	21.85
s_2n_2	19.00	20.51
s_2n_3	18.11	19.07
SEm ±	0.004	0.02
CD (0.05)	0.011	0.047

Table 21 c. Effect of V x S x N interaction on seed protein content, %

Treatments	Protein content	
	First year	Second year
$v_1s_1n_1$	18.53	21.08
$v_1s_1n_2$	18.89	18.41
$v_1s_1n_3$	18.13	20.93
$v_1s_2n_1$	19.38	21.99
$v_1s_2n_2$	18.75	21.43
$v_1s_2n_3$	18.19	19.34
$v_2s_1n_1$	18.55	21.01
$v_2s_1n_2$	18.19	18.50
$v_2s_1n_3$	18.20	20.30
$v_2s_2n_1$	19.08	21.70
$v_2s_2n_2$	19.25	19.58
$v_2s_2n_3$	18.03	18.80
SEm ±	0.01	0.02
CD (0.05)	0.016	0.066

Table 22 a. Effect of varieties, spacing and nutrient levels on soil pH and organic C

Treatments	First year		Second year	
	Soil pH	Organic C (%)	Soil pH	Organic C (%)
Varieties (V)				
v_1: APK 1	4.82	1.08	5.71	1.72
v_2: Vamban (Rg) 3	4.83	1.03	5.69	1.69
SEm ±	0.04	0.03	0.008	0.01
CD (0.05)	-	-	-	-
Spacing (S)				
s_1: 40 cm x 20 cm	4.85	1.06	5.71	1.72
s_2: 60 cm x 30 cm	4.80	1.05	5.69	1.70
SEm ±	0.04	0.03	0.008	0.01
CD (0.05)	-	-	-	-
Nutrient levels (N) kg NPK ha^{-1}				
n_1: 40:80:40	4.88	1.10	5.74	1.70
n_2: 30:60:30	4.84	1.05	5.70	1.71
n_3: 20:40:20	4.75	1.03	5.67	1.73
SEm±	0.04	0.04	0.01	0.02
CD (0.05)	-	-	-	-

Table 22 b. Interaction effect of varieties, spacing and nutrient levels on soil pH and organic C

Treatments	First year		Second year	
	Soil pH	Organic C (%)	Soil pH	Organic C (%)
V x S interaction				
v_1s_1	4.85	1.11	5.72	1.74
v_1s_2	4.79	1.06	5.70	1.71
v_2s_1	4.85	1.01	5.70	1.70
v_2s_2	4.81	1.05	5.68	1.69
SEm±	0.05	0.05	0.01	0.02
CD (0.05)	-	-	-	-
V x N interaction				
v_1n_1	4.90	1.12	5.76	1.70
v_1n_2	4.79	1.12	5.70	1.72
v_1n_3	4.78	1.03	5.68	1.76
v_2n_1	4.86	1.07	5.72	1.70
v_2n_2	4.90	0.98	5.69	1.69
v_2n_3	4.73	1.03	5.67	1.71
SEm ±	0.06	0.06	0.01	0.02
CD (0.05)	-	-	-	-
S x N interaction				
s_1n_1	4.92	1.08	5.74	1.68
s_1n_2	4.83	1.09	5.71	1.73
s_1n_3	4.79	1.01	5.69	1.75
s_2n_1	4.84	1.11	5.74	1.71
s_2n_2	4.85	1.01	5.68	1.69
s_2n_3	4.71	1.05	5.66	1.72
SEm ±	0.06	0.06	0.01	0.02
CD (0.05)	-	-	-	-

Table 22 c. Effect of V x S x N interaction on soil pH and organic C

Treatments	First year		Second year	
	Soil pH	Organic C (%)	Soil pH	Organic C (%)
$v_1s_1n_1$	4.91	1.14	5.74	1.69
$v_1s_1n_2$	4.80	1.16	5.72	1.76
$v_1s_1n_3$	4.83	1.04	5.69	1.77
$v_1s_2n_1$	4.88	1.11	5.77	1.70
$v_1s_2n_2$	4.78	1.07	5.68	1.69
$v_1s_2n_3$	4.73	1.01	5.66	1.74
$v_2s_1n_1$	4.93	1.03	5.72	1.68
$v_2s_1n_2$	4.86	1.02	5.70	1.70
$v_2s_1n_3$	4.75	0.98	5.68	1.73
$v_2s_2n_1$	4.80	1.12	5.71	1.72
$v_2s_2n_2$	4.93	0.94	5.68	1.68
$v_2s_2n_3$	4.70	1.08	5.66	1.69
SEm ±	0.09	0.08	0.02	0.03
CD (0.05)	-	-	-	-

4.1.9.3 Available NPK

An increase in soil nutrient status was observed after the harvest of the crop during both years and the variations with the treatments are presented in Tables 23 a, 23 b and 23 c.

During both years, the wider spacing, 60 cm x 30 cm and the higher nutrient level, 40:80:40 kg NPK ha^{-1} registered significantly the highest soil available NPK. Among the varieties, the highest available N was registered in APK 1 grown soil, while P and K was in Vamban (Rg) 3. Available N status in soil remained significantly high for the combinations involving v_1, s_2 and n_1 in first order interaction in both years of experimentation. In second order interaction, $v_1s_2n_1$ and $v_2s_2n_1$ registered the significantly highest values during the first and second year respectively. Maximum available P status was observed in interactions involving v_2, s_2 and n_1 in first and second order interactions during both years. During the first year, the significantly highest available K was observed in interactions s_2n_1, v_1n_1, v_2s_2 and $v_1s_2n_1$, while it was maximum in the interactions s_2n_1, v_2n_1, v_2s_2 and $v_2s_2n_1$ in the second year.

4.1.9.4 Microbial Count

The variations in soil microbial count due to varieties, spacing and nutrient levels are given in Tables 24 a, 24 b and 24 c. An increase in soil microbial count was observed after the harvest of red gram.

During the first year, the significantly highest bacterial count in soil was recorded in variety APK 1, at the spacing 40 cm x 20 cm, and at the highest nutrient level, 40:80:40 kg NPK ha^{-1}, and among the interactions in s_1n_1 and $v_1s_1n_1$. The effect was not prominent for the variety while in the second year, the count enumerated was maximum with closer spacing and the highest nutrient level, 40:80:40 kg NPK ha^{-1}. The interactions v_1s_1, v_1n_1, s_1n_1 and $v_1s_1n_1$ also revealed maximum bacterial count.

Fungal populations were superior in 40 cm x 20 cm spacing and the highest nutrient level, 40:80:40 kg NPK ha^{-1} during both years. No marked variation was observed due to varieties in the first year, nevertheless it was significant in the second year, maximum being in the variety APK 1. The interactions, v_2s_1, v_1n_1 and s_1n_1 in the first year and v_1s_1 and $v_1s_1n_1$ in the second year resulted in superior fungal counts.

During both years, the actinomycete counts varied significantly with the treatments and variety APK 1, spacing 40 cm x 20 cm, nutrient level 40:80:40 kg NPK ha^{-1}, the interaction v_1n_1 recorded the maximum counts. Among the S x N interactions, s_2n_1 and s_1n_1 resulted in significantly higher counts during the first and second year respectively. In second order interaction, $v_1s_2n_1$ and $v_1s_1n_1$ recorded maximum counts during first and second year respectively.

4.1.10 Nutrient Balance Sheet

4.1.10.1 Nitrogen

The data on balance sheet of N computed after the harvest of red gram in each year of Experiment I are presented in Tables 25 a and b respectively. The N balance in soil was positive for all the treatments during both years. The highest positive balance was observed in the treatments $v_2s_1n_1$ (73.17 kg ha^{-1}) and $v_1s_1n_1$ (107.13 kg ha^{-1}) during the first and second year respectively.

4.1.10.2 Phosphorus

The balance sheet of soil P after first and second year field crops of Experiment I are depicted in Tables 26 a and b respectively. The balance sheet for P was positive for all the treatment combinations involving s_2 during the first year. During the second year, all treatments showed positive balance for P except $v_1s_1n_1$, $v_1s_1n_2$, $v_1s_2n_2$ and $v_2s_2n_3$.

4.1.10.3 Potassium

Perusal of the balance sheet of K in Tables 27 a and b reveal positive balance for K during the first year in the treatments $v_1s_1n_1$, $v_1s_2n_1$ and $v_2s_1n_1$ and the highest positive balance was recorded in $v_2s_1n_1$ (8.95 kg ha^{-1}). All other treatments showed negative balance for K.

Computation of K balance in the second year showed the treatments $v_1s_1n_1$, $v_1s_2n_1$ and $v_2s_1n_1$ and $v_2s_2n_1$ to manifest a positive balance with the highest positive balance in $v_1s_1n_1$ (15.43 kg ha^{-1}), while the maximum loss was recorded in $v_1s_1n_3$.

Table 23 a. Effect of varieties, spacing and nutrient levels on soil available NPK after harvest, kg ha^{-1}

Treatments	First year			Second year		
	Available N	Available P	Available K	Available N	Available P	Available K
Varieties (V)						
v_1: APK 1	176.91	72.27	253.96	228.97	129.97	270.60
v_2: Vamban (Rg) 3	174.82	78.12	257.48	223.17	139.44	275.36
SEm ±	0.07	0.004	0.12	0.13	0.02	0.15
CD (0.05)	0.199	0.011	0.340	0.374	0.051	0.430
Spacing (S)						
s_1: 40 cm x 20 cm	161.25	62.38	253.88	219.53	130.38	266.04
s_2: 60 cm x 30 cm	190.48	88.01	257.56	232.61	139.03	279.92
SEm ±	0.07	0.004	0.12	0.13	0.02	0.15
CD (0.05)	0.199	0.011	0.340	0.374	0.051	0.430
Nutrient levels (N) kg NPK ha^{-1}						
n_1: 40:80:40	183.03	80.39	269.02	231.78	142.78	290.15
n_2: 30:60:30	174.47	74.26	253.84	227.35	133.02	273.34
n_3: 20:40:20	170.10	70.92	244.29	219.09	128.32	255.44
SEm±	0.08	0.01	0.14	0.16	0.02	0.18
CD (0.05)	0.244	0.014	0.417	0.458	0.062	0.527

Table 23 b. Interaction effect of varieties, spacing and nutrient levels on soil available NPK after harvest, kg ha^{-1}

Treatments	First year			Second year		
	Available N	Available P	Available K	Available N	Available P	Available K
V x S interaction						
v_1s_1	161.70	60.74	253.91	222.25	124.05	263.73
v_1s_2	192.12	83.78	254.01	235.69	135.89	277.46
v_2s_1	160.80	64.01	253.85	216.81	136.71	268.34
v_2s_2	188.85	92.23	261.10	229.54	142.17	282.38
SEm±	0.10	0.01	0.16	0.18	0.02	0.21
CD (0.05)	0.282	0.016	0.481	0.529	0.072	0.608
V x N interaction						
v_1n_1	183.85	74.72	269.80	233.04	137.09	289.59
v_1n_2	174.67	70.55	248.28	230.71	124.82	269.90
v_1n_3	172.20	71.53	243.79	223.17	128.02	252.31
v_2n_1	182.20	86.06	268.24	230.53	148.47	290.71
v_2n_2	174.27	77.98	259.39	223.99	141.22	276.79
v_2n_3	168.00	70.32	244.79	215.00	128.63	258.57
SEm ±	0.12	0.01	0.20	0.22	0.03	0.25
CD (0.05)	0.345	0.019	0.590	0.647	0.088	0.745
S x N interaction						
s_1n_1	169.64	68.83	262.36	224.26	134.68	285.80
s_1n_2	158.41	58.79	252.36	221.80	124.92	263.83
s_1n_3	155.70	59.52	246.92	212.54	131.55	248.47
s_2n_1	196.41	91.95	275.68	239.31	150.88	294.50
s_2n_2	190.54	89.74	255.32	232.90	141.12	282.86
s_2n_3	184.50	82.33	241.66	225.63	125.10	262.41
SEm ±	0.12	0.01	0.20	0.22	0.03	0.25
CD (0.05)	0.345	0.019	0.590	0.647	0.088	0.745

Table 23 c. Effect of V x S x N interaction on soil available NPK after harvest, kg ha^{-1}

Treatments	First year			Second year		
	Available N	Available P	Available K	Available N	Available P	Available K
$v_1s_1n_1$	169.90	65.33	260.05	228.07	128.58	287.45
$v_1s_1n_2$	157.81	53.19	252.18	225.62	118.25	263.16
$v_1s_1n_3$	157.41	63.72	249.49	213.07	125.33	240.59
$v_1s_2n_1$	197.81	84.11	279.55	238.00	145.60	291.73
$v_1s_2n_2$	191.54	87.91	244.39	235.80	131.38	276.63
$v_1s_2n_3$	187.00	79.33	238.09	233.27	130.70	264.03
$v_2s_1n_1$	169.39	72.33	264.67	220.44	140.78	284.15
$v_2s_1n_2$	159.00	64.39	252.54	217.98	131.58	264.50
$v_2s_1n_3$	154.00	55.31	244.34	212.00	137.76	256.36
$v_2s_2n_1$	195.00	99.79	271.82	240.62	156.16	297.26
$v_2s_2n_2$	189.54	91.56	266.25	230.00	150.86	289.08
$v_2s_2n_3$	182.00	85.33	245.23	218.00	119.50	260.79
SEm ±	0.17	0.01	0.28	0.31	0.04	0.36
CD (0.05)	0.488	0.027	0.834	0.915	0.124	1.053

Table 24 a. Effect of varieties, spacing and nutrient levels on soil microbial count after harvest, log cfu g^{-1}

Treatments	Microbial count					
	First year			Second year		
	Bacteria	Fungi	Actinomycetes	Bacteria	Fungi	Actinomycetes
Varieties (V)						
v_1: APK 1	6.55	3.46	2.36	6.44	3.79	2.22
v_2: Vamban (Rg) 3	6.53	3.50	2.31	6.44	3.67	2.20
SEm ±	0.004	0.02	0.01	0.01	0.02	0.01
CD (0.05)	0.012	-	0.022	-	0.048	0.021
Spacing (S)						
s_1: 40 cm x 20 cm	6.55	3.59	2.35	6.49	3.77	2.24
s_2: 60 cm x 30 cm	6.54	3.37	2.32	6.40	3.69	2.17
SEm ±	0.004	0.02	0.01	0.01	0.02	0.01
CD (0.05)	0.012	0.055	0.022	0.022	0.048	0.021
Nutrient levels (N) kg NPK ha^{-1}						
n_1: 40:80:40	6.60	3.74	2.48	6.56	3.85	2.29
n_2: 30:60:30	6.54	3.49	2.27	6.44	3.68	2.12
n_3: 20:40:20	6.49	3.21	2.26	6.33	3.65	2.21
SEm±	0.01	0.02	0.01	0.01	0.02	0.01
CD (0.05)	0.015	0.068	0.027	0.027	0.058	0.026

Table 24 b. Interaction effect of varieties, spacing and nutrient levels on soil microbial count after harvest, log cfu g^{-1}

Treatments	Microbial count					
	First year			Second year		
	Bacteria	Fungi	Actinomycetes	Bacteria	Fungi	Actinomycetes
V x S interaction						
v_1s_1	6.55	3.51	2.37	6.55	3.88	2.25
v_1s_2	6.55	3.41	2.34	6.34	3.70	2.19
v_2s_1	6.55	3.67	2.32	6.43	3.66	2.23
v_2s_2	6.52	3.32	2.30	6.46	3.67	2.16
SEm±	0.01	0.03	0.01	0.01	0.02	0.01
CD (0.05)	-	0.078	-	0.031	0.067	-
V x N interaction						
v_1n_1	6.61	3.82	2.52	6.60	3.91	2.32
v_1n_2	6.55	3.46	2.24	6.44	3.72	2.07
v_1n_3	6.49	3.11	2.31	6.29	3.73	2.26
v_2n_1	6.59	3.66	2.44	6.51	3.78	2.25
v_2n_2	6.53	3.52	2.30	6.44	3.64	2.17
v_2n_3	6.49	3.31	2.20	6.38	3.58	2.16
SEm ±	0.01	0.03	0.01	0.01	0.03	0.01
CD (0.05)	-	0.096	0.039	0.038	-	0.037
S x N interaction						
s_1n_1	6.61	3.87	2.47	6.59	3.85	2.33
s_1n_2	6.53	3.55	2.34	6.54	3.72	2.12
s_1n_3	6.50	3.37	2.23	6.33	3.73	2.27
s_2n_1	6.59	3.61	2.49	6.52	3.84	2.24
s_2n_2	6.55	3.44	2.20	6.33	3.64	2.12
s_2n_3	6.48	3.05	2.28	6.33	3.58	2.16
SEm ±	0.01	0.03	0.01	0.01	0.03	0.01
CD (0.05)	0.022	0.096	0.039	0.038	-	0.037

Table 24 c. Effect of V x S x N interaction on soil microbial count after harvest, log cfu g^{-1}

Treatments	Microbial count					
	First year			Second year		
	Bacteria	Fungi	Actinomycetes	Bacteria	Fungi	Actinomycetes
$v_1s_1n_1$	6.62	3.92	2.48	6.63	3.93	2.34
$v_1s_1n_2$	6.55	3.45	2.35	6.60	3.90	2.09
$v_1s_1n_3$	6.49	3.17	2.29	6.43	3.81	2.31
$v_1s_2n_1$	6.60	3.71	2.57	6.58	3.90	2.30
$v_1s_2n_2$	6.56	3.47	2.13	6.28	3.54	2.05
$v_1s_2n_3$	6.50	3.05	2.33	6.15	3.65	2.22
$v_2s_1n_1$	6.60	3.81	2.46	6.56	3.78	2.32
$v_2s_1n_2$	6.52	3.64	2.33	6.49	3.54	2.15
$v_2s_1n_3$	6.52	3.56	2.17	6.24	3.65	2.23
$v_2s_2n_1$	6.58	3.51	2.41	6.46	3.78	2.18
$v_2s_2n_2$	6.54	3.40	2.27	6.39	3.74	2.19
$v_2s_2n_3$	6.46	3.05	2.23	6.51	3.50	2.10
SEm ±	0.01	0.05	0.02	0.02	0.04	0.02
CD (0.05)	0.030	-	0.055	0.054	0.117	0.052

Table 25 a. Balance sheet for nitrogen during the first year of Experiment I, kg ha^{-1}

Treatments	Nitrogen added				Crop uptake	Balance		
	Soil contribution	FYM	Fertilizer	Total N		Expected balance	Actual balance	Apparent gain/ loss
$T_1 : v_1s_1n_1$	100.35	62.50	36.40	199.25	100.89	98.36	169.90	71.54
$T_2 : v_1s_1n_2$	100.35	62.50	27.30	190.15	99.66	90.49	157.81	67.32
$T_3 : v_1s_1n_3$	100.35	62.50	18.20	181.05	85.76	95.29	157.41	62.12
$T_4 : v_1s_2n_1$	100.35	62.50	36.40	199.25	50.57	148.68	197.81	49.13
$T_5 : v_1s_2n_2$	100.35	62.50	27.30	190.15	47.49	142.66	191.54	48.88
$T_6 : v_1s_2n_3$	100.35	62.50	18.20	181.05	47.57	133.48	187.00	53.52
$T_7 : v_2s_1n_1$	100.35	62.50	36.40	199.25	103.03	96.22	169.39	73.17
$T_8 : v_2s_1n_2$	100.35	62.50	27.30	190.15	95.62	94.53	159.00	64.47
$T_9 : v_2s_1n_3$	100.35	62.50	18.20	181.05	87.51	93.54	154.00	60.46
$T_{10} : v_2s_2n_1$	100.35	62.50	36.40	199.25	50.82	148.43	195.00	46.57
$T_{11} : v_2s_2n_2$	100.35	62.50	27.30	190.15	49.77	140.38	189.54	49.16
$T_{12} : v_2s_2n_3$	100.35	62.50	18.20	181.05	46.83	134.22	182.00	47.78

Table 25 b. Balance sheet for nitrogen during the second year of Experiment I, kg ha^{-1}

Treatments	Nitrogen added				Crop uptake	Balance		
	Soil contribution	FYM	Fertilizer	Total N		Expected balance	Actual balance	Apparent gain/ loss
T_1 : $v_1s_1n_1$	143.55	60.00	28.40	231.95	111.01	120.94	228.07	107.13
T_2 : $v_1s_1n_2$	143.55	60.00	21.30	224.85	83.63	141.22	225.62	84.40
T_3 : $v_1s_1n_3$	143.55	60.00	14.20	217.75	88.68	129.07	213.07	84.00
T_4 : $v_1s_2n_1$	143.55	60.00	28.40	231.95	64.46	167.49	238.00	70.51
T_5 : $v_1s_2n_2$	143.55	60.00	21.30	224.85	44.35	180.50	235.80	55.30
T_6 : $v_1s_2n_3$	143.55	60.00	14.20	217.75	38.27	179.48	233.27	53.79
T_7 : $v_2s_1n_1$	143.55	60.00	28.40	231.95	107.21	124.74	220.44	95.70
T_8 : $v_2s_1n_2$	143.55	60.00	21.30	224.85	75.34	149.51	217.98	68.47
T_9 : $v_2s_1n_3$	143.55	60.00	14.20	217.75	75.88	141.87	212.00	70.13
T_{10} : $v_2s_2n_1$	143.55	60.00	28.40	231.95	61.00	170.95	240.62	69.67
T_{11} : $v_2s_2n_2$	143.55	60.00	21.30	224.85	46.57	178.28	230.00	51.72
T_{12} : $v_2s_2n_3$	143.55	60.00	14.20	217.75	35.71	182.04	218.00	35.96

Table 26 a. Balance sheet for phosphorus during the first year of Experiment I, kg ha^{-1}

Treatments	Phosphorus added				Crop uptake	Balance		
	Soil contribution	FYM	Fertilizer	Total P		Expected balance	Actual balance	Apparent gain/ loss
T_1 : $v_1s_1n_1$	47.14	25.00	20.00	92.14	16.77	75.37	65.33	-10.04
T_2 : $v_1s_1n_2$	47.14	25.00	15.00	87.14	15.06	72.08	53.19	-18.89
T_3 : $v_1s_1n_3$	47.14	25.00	10.00	82.14	13.72	68.42	63.72	-4.70
T_4 : $v_1s_2n_1$	47.14	25.00	20.00	92.14	9.75	82.39	84.11	1.72
T_5 : $v_1s_2n_2$	47.14	25.00	15.00	87.14	8.42	78.72	87.91	9.19
T_6 : $v_1s_2n_3$	47.14	25.00	10.00	82.14	6.28	75.86	79.33	3.47
T_7 : $v_2s_1n_1$	47.14	25.00	20.00	92.14	14.39	77.75	72.33	-5.42
T_8 : $v_2s_1n_2$	47.14	25.00	15.00	87.14	11.83	75.31	64.39	-10.92
T_9 : $v_2s_1n_3$	47.14	25.00	10.00	82.14	9.77	72.37	55.31	-17.06
T_{10} : $v_2s_2n_1$	47.14	25.00	20.00	92.14	7.39	84.75	99.79	15.04
T_{11} : $v_2s_2n_2$	47.14	25.00	15.00	87.14	6.38	80.76	91.56	10.80
T_{12} : $v_2s_2n_3$	47.14	25.00	10.00	82.14	5.36	76.78	85.33	8.55

Table 26 b. Balance sheet for phosphorus during the second year of Experiment I, kg ha^{-1}

Treatments	Phosphorus added				Crop uptake	Balance		
	Soil contribution	FYM	Fertilizer	Total P		Expected balance	Actual balance	Apparent gain/ loss
$T_1 : v_1s_1n_1$	104.30	23.75	20.00	148.05	19.13	128.92	128.58	-0.34
$T_2 : v_1s_1n_2$	104.30	23.75	15.00	143.05	17.25	125.80	118.25	-7.55
$T_3 : v_1s_1n_3$	104.30	23.75	10.00	138.05	16.73	121.32	125.33	4.01
$T_4 : v_1s_2n_1$	104.30	23.75	20.00	148.05	9.39	138.66	145.60	6.94
$T_5 : v_1s_2n_2$	104.30	23.75	15.00	143.05	8.45	134.60	131.38	-3.22
$T_6 : v_1s_2n_3$	104.30	23.75	10.00	138.05	8.14	129.91	130.70	0.79
$T_7 : v_2s_1n_1$	104.30	23.75	20.00	148.05	17.13	130.92	140.78	9.86
$T_8 : v_2s_1n_2$	104.30	23.75	15.00	143.05	16.08	126.97	131.58	4.61
$T_9 : v_2s_1n_3$	104.30	23.75	10.00	138.05	16.89	121.16	137.76	16.60
$T_{10} : v_2s_2n_1$	104.30	23.75	20.00	148.05	7.71	140.34	156.16	15.82
$T_{11} : v_2s_2n_2$	104.30	23.75	15.00	143.05	7.45	135.60	150.86	15.26
$T_{12} : v_2s_2n_3$	104.30	23.75	10.00	138.05	6.97	131.08	119.50	-11.58

Table 27 a. Balance sheet for potassium during the first year of Experiment I, kg ha^{-1}

Treatments	Potassium added				Crop uptake	Balance		
	Soil contribution	FYM	Fertilizer	Total K		Expected balance	Actual balance	Apparent gain/ loss
$T_1 : v_1s_1n_1$	215.04	62.50	28.40	305.94	46.18	259.76	260.05	0.29
$T_2 : v_1s_1n_2$	215.04	62.50	21.30	298.84	43.02	255.82	252.18	-3.64
$T_3 : v_1s_1n_3$	215.04	62.50	14.20	291.74	41.69	250.05	249.49	-0.56
$T_4 : v_1s_2n_1$	215.04	62.50	28.40	305.94	28.17	277.77	279.55	1.78
$T_5 : v_1s_2n_2$	215.04	62.50	21.30	298.84	26.63	272.21	244.39	-27.82
$T_6 : v_1s_2n_3$	215.04	62.50	14.20	291.74	25.09	266.65	238.09	-28.56
$T_7 : v_2s_1n_1$	215.04	62.50	28.40	305.94	50.22	255.72	264.67	8.95
$T_8 : v_2s_1n_2$	215.04	62.50	21.30	298.84	43.69	255.15	252.54	-2.61
$T_9 : v_2s_1n_3$	215.04	62.50	14.20	291.74	38.72	253.02	244.34	-8.68
$T_{10} : v_2s_2n_1$	215.04	62.50	28.40	305.94	25.90	280.04	271.82	-8.22
$T_{11} : v_2s_2n_2$	215.04	62.50	21.30	298.84	24.82	274.02	266.25	-7.77
$T_{12} : v_2s_2n_3$	215.04	62.50	14.20	291.74	23.46	268.28	245.23	-23.05

Table 27 b. Balance sheet for potassium during the second year of Experiment I, kg ha^{-1}

Treatments	Potassium added				Crop uptake	Balance		
	Soil contribution	FYM	Fertilizer	Total K		Expected balance	Actual balance	Apparent gain/ loss
$T_1 : v_1s_1n_1$	239.89	57.50	24.00	321.39	49.37	272.02	287.45	15.43
$T_2 : v_1s_1n_2$	239.89	57.50	18.00	315.39	36.93	278.46	263.16	-15.30
$T_3 : v_1s_1n_3$	239.89	57.50	12.00	309.39	25.49	283.9	240.59	-43.31
$T_4 : v_1s_2n_1$	239.89	57.50	24.00	321.39	30.11	291.28	291.73	0.45
$T_5 : v_1s_2n_2$	239.89	57.50	18.00	315.39	25.08	290.31	276.63	-13.68
$T_6 : v_1s_2n_3$	239.89	57.50	12.00	309.39	22.06	287.33	264.03	-23.30
$T_7 : v_2s_1n_1$	239.89	57.50	24.00	321.39	41.93	279.46	284.15	4.69
$T_8 : v_2s_1n_2$	239.89	57.50	18.00	315.39	32.92	282.47	264.5	-17.97
$T_9 : v_2s_1n_3$	239.89	57.50	12.00	309.39	30.34	279.05	256.36	-22.69
$T_{10} : v_2s_2n_1$	239.89	57.50	24.00	321.39	27.45	293.94	297.26	3.32
$T_{11} : v_2s_2n_2$	239.89	57.50	18.00	315.39	21.04	294.35	289.08	-5.27
$T_{12} : v_2s_2n_3$	239.89	57.50	12.00	309.39	19.34	290.05	260.79	-29.26

4.1.11 Economic Analysis

The economics of red gram cultivation computed based on the costs involved and market price of produce are detailed in Table 28. Among the various treatments tried, the treatment T_1 ($v_1s_1n_1$) recorded the highest net return and B:C ratio during first and second year of cultivation, followed by the treatment T_7 ($v_2s_1n_1$). The lowest net return and B:C ratio was recorded in the treatment T_{12} ($v_2s_2n_3$) during both years. Based on the pooled mean values computed for the two years, T_1 was adjudged most economic as it fetched the highest net return (₹ 88621 ha^{-1}) and B: C ratio (2.03), followed by the treatment T_7 (₹ 82546 ha^{-1}).

4.2 EXPERIMENT II

4.2.1 Decomposition of Crop Residues

4.2.1.1 Quantity of Crop Residues Added

The quantity of crop residues (shoot + root + fallen leaves) available for incorporation in red gram as influenced by the treatments is presented in Table 29. The significantly highest quantity of residues (4.83 t ha^{-1}) was generated in treatment T_7 ($v_2s_1n_1$, Vamban (Rg) 3 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}), which was at par with that in treatment T_1 ($v_1s_1n_1$, APK 1 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}). The lowest quantity (2.25 t ha^{-1}) was added in the treatment T_{12} ($v_2s_2n_3$, Vamban (Rg) 3 + 60 cm x 30 cm + 20:40:20 kg NPK ha^{-1}).

4.2.1.2 Biochemical Characters of Crop Residues

The variations in biochemical characters of red gram residues in response to the treatments imposed are presented in Table 29. The data revealed that there was no significant variation in biochemical characters studied *viz*., cellulose, hemicellulose, lignin and phenol content of red gram residues. The biochemical constituents, cellulose content ranged from 12.28 - 12.72 per cent, hemicellulose, 19.10 - 19.14 per cent, lignin, 6.76 - 6.89 per cent and phenol, 5.80 - 5.93 mg g^{-1}. The C: N ratio of the residues varied significantly with the treatments imposed in red gram crops. The narrowest values were recorded in the treatments T_1 (18.2:1) and T_7 (18.9:1), APK 1 and Vamban (Rg) 3 respectively raised with 40 :80 :40 kg NPK ha^{-1} at 40 cm x 20 cm spacing. The wider C:N ratio (21.8:1) was recorded in the crop residues from the treatment T_5.

Table 28. Effect of treatments on economics of cultivation of red gram during Experiment I

Treatments	First year		Second year		Pooled mean	
	Net return (₹ ha^{-1})	B:C ratio	Net return (₹ ha^{-1})	B:C ratio	Net return (₹ ha^{-1})	B:C ratio
$T_1 : v_1s_1n_1$	84746	1.92	92496	2.14	88621	2.03
$T_2 : v_1s_1n_2$	71222	1.78	82022	2.02	76622	1.90
$T_3 : v_1s_1n_3$	45998	1.51	75298	1.94	60648	1.73
$T_4 : v_1s_2n_1$	10646	1.12	31246	1.38	20946	1.25
$T_5 : v_1s_2n_2$	10122	1.11	22022	1.27	16072	1.19
$T_6 : v_1s_2n_3$	8298	1.09	17798	1.22	13048	1.16
$T_7 : v_2s_1n_1$	78546	1.86	86546	2.07	82546	1.96
$T_8 : v_2s_1n_2$	54622	1.60	72322	1.90	63472	1.75
$T_9 : v_2s_1n_3$	51498	1.57	69348	1.87	60423	1.72
$T_{10} : v_2s_2n_1$	8346	1.09	19046	1.24	13696	1.16
$T_{11} : v_2s_2n_2$	-11678	0.87	2322	1.03	-4678	0.95
$T_{12} : v_2s_2n_3$	-12202	0.86	-3152	0.96	-7677	0.91

Table 29. Quantum of residues and biochemical characters as influenced by V x S x N interactions

Treatments	Quantity of crop residues (t ha^{-1})	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Phenol (mg g^{-1})	C:N ratio
T_1 : $v_1s_1n_1$	4.75	12.32	19.13	6.77	5.93	18.2
T_2 : $v_1s_1n_2$	4.60	12.60	19.11	6.89	5.92	19.3
T_3 : $v_1s_1n_3$	4.48	12.68	19.12	6.77	5.92	20.8
T_4 : $v_1s_2n_1$	3.05	12.60	19.10	6.83	5.88	20.9
T_5 : $v_1s_2n_2$	2.75	12.72	19.12	6.79	5.93	21.8
T_6 : $v_1s_2n_3$	2.70	12.28	19.14	6.78	5.91	21.4
T_7 : $v_2s_1n_1$	4.83	12.51	19.11	6.78	5.87	18.9
T_8 : $v_2s_1n_2$	4.68	12.54	19.14	6.81	5.89	19.4
T_9 : $v_2s_1n_3$	4.42	12.41	19.11	6.76	5.80	19.4
T_{10} : $v_2s_2n_1$	3.05	12.35	19.12	6.79	5.92	20.4
T_{11} : $v_2s_2n_2$	2.65	12.54	19.13	6.78	5.89	20.9
T_{12} : $v_2s_2n_3$	2.25	12.43	19.14	6.77	5.90	21.7
SEm±	0.04	0.15	0.02	0.05	0.05	0.12
CD (0.05)	0.130	-	-	-	-	0.352

4.2.1.3 Soil Properties

4.2.1.3.1 Soil pH

The changes in soil pH with red gram residue incorporation recorded at 20 days interval are presented in Table 30. An increase in soil pH was observed due to residue incorporation. There was no significant variation in soil pH due to different treatments at 20 and 40 days after residue incorporation (DAI). After 60 days, the treatment T_7 ($v_2s_1n_1$) recorded significantly the highest pH (5.49) which was on par with the treatments T_1, T_{10}, T_4, T_9, T_{11} and T_3. The lowest soil pH of 5.28 was recorded in T_{12} ($v_2s_2n_3$).

4.2.1.3.2 Soil C Pool

The significant effect of residue incorporation on soil C pool is presented in Table 31. Perusal of the data revealed the significant influence of residue incorporation on TOC. Maximum TOC was assessed in treatment T_1 ($v_1s_1n_1$- APK 1 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}) at 20 and 40 DAI. The treatment T_7 ($v_2s_1n_1$, Vamban (Rg) 3 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}) registered significantly the highest TOC (1.74 %) after 60 DAI on par with T_1 ($v_1s_1n_1$).

The LC varied significantly with the residues added (Table 31). In general, there was an increase in LC with residue incorporation upto 60 DAI. The treatment T_7 ($v_2s_1n_1$) recorded significantly the highest LC of 819.87, 867.34 and 915.75 mg kg^{-1} at 20, 40 and 60 DAI respectively. The treatment T_6 resulted in the lowest LC after 40 days of incorporation and T_{12}, the lowest LC after 20 and 60 days of incorporation.

Significant variations in ROC were observed with red gram residue incorporation (Table 31). After 20 days of incorporation, the treatment T_7 ($v_2s_1n_1$) resulted in significantly the highest ROC (1.26 %) and the treatment T_1 ($v_1s_1n_1$), the significantly superior values for ROC, 1.32 and 1.39 per cent, after 40 and 60 days of residue incorporation respectively, but at 60 DAI, T_1 and T_7 were on par.

Table 30. Effect of crop residue incorporation on soil pH at 20 days interval

Treatments	Soil pH		
	20 *DAI	40 DAI	60 DAI
$T_1 : v_1s_1n_1$	5.07	5.34	5.47
$T_2 : v_1s_1n_2$	5.02	5.20	5.32
$T_3 : v_1s_1n_3$	4.90	5.09	5.37
$T_4 : v_1s_2n_1$	5.04	5.35	5.43
$T_5 : v_1s_2n_2$	4.82	5.18	5.34
$T_6 : v_1s_2n_3$	5.04	5.16	5.20
$T_7 : v_2s_1n_1$	4.96	5.18	5.49
$T_8 : v_2s_1n_2$	5.02	5.22	5.29
$T_9 : v_2s_1n_3$	5.00	5.24	5.41
$T_{10} : v_2s_2n_1$	4.82	5.42	5.46
$T_{11} : v_2s_2n_2$	4.99	5.23	5.38
$T_{12} : v_2s_2n_3$	4.89	5.30	5.28
SEm±	0.10	0.07	0.04
CD (0.05)	-	-	0.129

*DAI- Days after residue incorporation

Table 31. Effect of residue incorporation on soil C pool at 20 days interval

Treatments	Total organic carbon (%)			Labile carbon (mg kg^{-1})			Recalcitrant organic carbon (%)		
	20 *DAI	40 DAI	60 DAI	20 DAI	40 DAI	60 DAI	20 DAI	40 DAI	60 DAI
T_1 : $v_1s_1n_1$	1.55	1.60	1.73	802.87	824.50	881.37	1.17	1.32	1.38
T_2 : $v_1s_1n_2$	1.41	1.57	1.69	739.25	805.50	823.50	1.07	1.20	1.31
T_3 : $v_1s_1n_3$	1.22	1.45	1.64	620.25	682.60	711.00	0.95	1.13	1.22
T_4 : $v_1s_2n_1$	1.44	1.50	1.71	643.50	710.25	776.25	0.99	1.15	1.21
T_5 : $v_1s_2n_2$	1.37	1.43	1.69	570.13	626.67	684.00	0.94	1.11	1.18
T_6 : $v_1s_2n_3$	1.18	1.42	1.57	529.75	574.89	668.25	0.85	1.09	1.14
T_7 : $v_2s_1n_1$	1.52	1.58	1.74	819.87	867.34	915.75	1.26	1.31	1.33
T_8 : $v_2s_1n_2$	1.37	1.49	1.64	762.50	769.50	843.75	1.03	1.23	1.30
T_9 : $v_2s_1n_3$	1.31	1.52	1.61	590.50	663.75	708.75	0.94	1.02	1.25
T_{10} : $v_2s_2n_1$	1.31	1.53	1.68	618.75	725.87	748.80	1.02	1.12	1.22
T_{11} : $v_2s_2n_2$	1.23	1.48	1.65	609.75	663.20	720.00	0.89	1.01	1.20
T_{12} : $v_2s_2n_3$	1.22	1.47	1.58	515.53	591.75	636.75	0.74	0.92	1.13
SEm±	0.03	0.07	0.01	0.20	0.37	4.54	0.03	0.03	0.006
CD (0.05)	0.077	0.022	0.005	0.597	1.101	13.40	0.090	0.091	0.017

*DAI- Days after residue incorporation

4.2.1.3.3 Available NPK

The available NPK status in soil was found to increase with the incorporation of red gram residues over the period of analysis (Table 32). The available N recorded significant variations. The treatments T_4 ($v_1s_2n_1$, APK 1 + 60 cm x 20 cm + 40:80:40 kg NPK ha^{-1}) and T_{10} ($v_2s_2n_1$, Vamban (Rg) 3 + 60 cm x 30 cm + 40:80:40 kg NPK ha^{-1}) registered significantly the highest soil available N at 20, 40 DAI respectively and T_1 ($v_1s_1n_1$, APK 1+ 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}) at 60 DAI.

Perusal of the data on the changes in soil available P status in Table 32 showed an increase in P status with incorporation and decomposition. After 20 and 40 days, the maximum values were seen in the treatment T_4 ($v_1s_2n_1$, APK 1 + 60 cm x 30 cm + 40:80:40 kg NPK ha^{-1}) while at the end of 60 days, it was the highest in T_1 ($v_1s_1n_1$, APK 1 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}) on par with T_4 and T_7.

On comparing the available K status, the treatment T_1 ($v_1s_1n_1$, APK 1 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}) recorded the significantly highest soil available K after 20 days whereas at 40 and 60 days, T_7 ($v_2s_1n_1$, Vamban (Rg) 3 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}) resulted in the significantly highest K. The soil K status was lowest in T_6 ($v_1s_2n_3$) after 20 and 40 days and after 60 days in the T_8 ($v_2s_1n_2$).

4.2.1.3.4 Dehydrogenase Activity

An increase in dehydrogenase activity was observed due to the incorporation of red gram residues as decomposition proceeded (Table 33). The values were maximum at 60 DAI. The treatment T_1 ($v_1s_1n_1$) resulted in significantly the highest dehydrogenase activity at 20, 40 and 60 DAI, the value being 30.13 µ TPF g^{-1} soil 24 hr^{-1}, on par with the treatment T_7 ($v_2s_1n_1$) at 60 DAI. The lowest was recorded in treatment T_6 ($v_1s_2n_3$).

4.2.2 Legume Effect on Fodder Maize

4.2.2.1 Biometric and Yield Observations

4.2.2.1.1 Emergence Per cent

The percentage emergence of maize seedlings did not show any significant variation (Table 34) and the emergence ranged from 76.6 to 87.7 per cent.

Table 32. Effect of residue incorporation on soil available NPK at 20 days interval, kg ha^{-1}

Treatments	Available N			Available P			Available K		
	20 *DAI	40 DAI	60 DAI	20 DAI	40 DAI	60 DAI	20 DAI	40 DAI	60 DAI
T_1 : $v_1s_1n_1$	172.87	197.63	219.51	77.00	102.44	120.19	288.40	299.39	303.83
T_2 : $v_1s_1n_2$	170.99	202.72	213.54	70.04	96.98	112.83	279.99	300.44	306.13
T_3 : $v_1s_1n_3$	166.81	183.91	190.23	78.28	91.42	107.65	277.50	291.61	295.04
T_4 : $v_1s_2n_1$	203.08	210.18	215.32	104.37	116.70	119.66	281.70	287.84	291.64
T_5 : $v_1s_2n_2$	196.81	208.09	212.23	101.42	111.50	116.23	286.70	296.09	301.22
T_6 : $v_1s_2n_3$	190.26	200.45	207.97	90.44	109.35	113.54	262.13	263.09	272.39
T_7 : $v_2s_1n_1$	171.24	198.99	217.50	68.42	108.39	119.64	285.79	311.56	317.73
T_8 : $v_2s_1n_2$	160.54	186.44	191.96	79.26	93.59	118.54	266.57	268.32	270.65
T_9 : $v_2s_1n_3$	156.54	180.18	206.59	68.27	89.29	108.89	274.51	291.48	295.59
T_{10} : $v_2s_2n_1$	197.00	212.72	216.86	100.56	110.56	115.46	278.77	307.60	314.07
T_{11} : $v_2s_2n_2$	194.26	200.18	208.17	92.46	108.71	113.62	279.95	305.50	310.81
T_{12} : $v_2s_2n_3$	189.72	199.33	203.23	83.95	99.42	110.78	268.55	276.81	280.44
SEm±	0.43	0.06	0.08	0.03	1.41	0.43	0.40	0.09	0.21
CD (0.05)	1.262	0.172	0.234	0.087	4.158	1.269	1.157	0.262	0.622

*DAI- Days after residue incorporation

Table 33. Effect of residue incorporation on dehydrogenase activity at 20 days interval

Treatments	Dehydrogenase activity (µ TPF g^{-1} soil 24 hr^{-1})		
	20 *DAI	40 DAI	60 DAI
T_1 : $v_1s_1n_1$	22.84	26.10	30.13
T_2 : $v_1s_1n_2$	22.41	24.38	29.17
T_3 : $v_1s_1n_3$	20.92	23.80	28.79
T_4 : $v_1s_2n_1$	20.35	22.65	29.75
T_5 : $v_1s_2n_2$	20.33	22.07	27.06
T_6 : $v_1s_2n_3$	19.60	20.73	26.68
T_7 : $v_2s_1n_1$	21.69	25.91	30.12
T_8 : $v_2s_1n_2$	21.11	24.95	28.79
T_9 : $v_2s_1n_3$	19.96	24.76	27.83
T_{10} : $v_2s_2n_1$	19.19	22.46	29.37
T_{11} : $v_2s_2n_2$	19.00	21.50	28.41
T_{12} : $v_2s_2n_3$	18.43	21.11	27.64
SEm±	0.21	0.01	0.01
CD (0.05)	0.627	0.016	0.017

*DAI- Days after incorporation

4.2.2.1.2 Plant Height

The effect of residue incorporation on plant height of fodder maize at harvest in Table 34 evince the significant variations. Plants were significantly the tallest (183.78 cm) in T_7 ($v_2s_1n_1$). The treatment T_{11} ($v_2s_2n_2$) recorded the shortest plants (168.75 cm) on par with T_8, T_4, T_1, T_3 and T_2.

4.2.2.1.3 Days to Harvest

There was no significant difference in the number of days taken for harvesting fodder maize due to the residual effects of treatments imposed in red gram. The crop was harvested at 60 DAS (milky stage) in all the plots.

4.2.2.1.4 Green Fodder Yield

The effect of treatments on green fodder yield is presented in Table 34. Among the different treatments, the T_7 ($v_2s_1n_1$, Vamban (Rg) 3 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}) resulted in superior green fodder yield (33.61 t ha^{-1}), and was on par with the treatment T_1 ($v_1s_1n_1$, APK 1 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}). The lowest green fodder yield of 28.81 t ha^{-1} was recorded in treatment T_5 ($v_1s_2n_2$).

4.2.2.1.5 Dry Fodder Yield

The dry fodder yield was significantly influenced by the treatments given in the preceding red gram crop (Table 34) and was the highest yield (11.37 t ha^{-1}) was obtained in T_7 ($v_2s_1n_1$) which was on par with T_1 ($v_1s_1n_1$), 11.08 t ha^{-1}. Fodder yield (9.82 t ha^{-1}) was lowest in T_6 ($v_1s_2n_3$).

4.2.2.2 Soil Chemical Properties

4.2.2.2.1 Organic Carbon

Comparison of the soil data prior to maize cultivation and harvest revealed the increase in soil organic C status with maize cultivation (Table 35). The incorporation of the residues in T_1 recorded significantly the highest organic C before sowing (1.58 %). With cultivation the organic C status was maximum in T_7 (1.64 %), on par with the T_1 (1.63 %).

Table 34. Residual effect of red gram on growth and yield in fodder maize

Treatments	Emergence per cent	Plant height at harvest (cm)	Green fodder yield (t ha^{-1})	Dry fodder yield (t ha^{-1})
T_1 : $v_1s_1n_1$	83.8	181.92	32.85	11.08
T_2 : $v_1s_1n_2$	80.1	179.50	32.40	10.95
T_3 : $v_1s_1n_3$	82.4	179.17	32.21	10.71
T_4 : $v_1s_2n_1$	81.4	180.83	30.21	10.87
T_5 : $v_1s_2n_2$	79.6	173.25	28.81	9.92
T_6 : $v_1s_2n_3$	84.1	170.00	28.86	9.82
T_7 : $v_2s_1n_1$	85.9	183.78	33.61	11.37
T_8 : $v_2s_1n_2$	86.4	181.55	32.11	10.52
T_9 : $v_2s_1n_3$	80.6	173.22	31.66	10.74
T_{10} : $v_2s_2n_1$	87.2	174.08	31.15	10.68
T_{11} : $v_2s_2n_2$	87.7	168.75	31.08	10.59
T_{12} : $v_2s_2n_3$	76.6	175.46	29.39	9.91
SEm±	2.48	2.26	0.37	0.10
CD (0.05)	-	6.680	1.086	0.295

4.2.2.2.2 Available NPK

The soil available NPK was found to decline from the status before fodder maize cultivation (Table 35). Comparing the available NPK status after cropping, maximum content was recorded in treatment T_{10} (168.67, 114.92 and 275.48 kg N, P and K ha^{-1} respectively). The values were the lowest in the treatments T_6, T_9 and T_3 for available N, P and K respectively.

4.2.2.3 Plant Analysis

4.2.2.3.1 Protein Content

The data pertaining to the effect of different treatments on protein content in fodder maize are given in Table 36. Maize grown on the residues of T_7 ($v_2s_1n_1$) had the significantly highest protein content (8.75 %), but was on par with the treatment T_1 (8.60 %). The lowest protein content of 7.22 per cent was observed in the treatment T_{12} ($v_2s_2n_3$).

4.2.2.3.2 Carbohydrate Content

The carbohydrate content in fodder maize grown on the residues of red gram is presented in Table 36. The variations were significant and the maximum content (77.50 %) was in the shoots in T_{12} ($v_2s_2n_3$), on par with T_6 (77.33 %). The lowest carbohydrate content were in T_1 (68.72 %) and T_7 (69.07 %).

Table 35. Variations in soil organic carbon and available NPK status with fodder maize cultivation

Treatments	Organic carbon (%)		Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})	
	Initial	After harvest	Initial	After harvest	Initial	After harvest	Initial	After harvest
T_1 : $v_1s_1n_1$	1.58	1.63	225.26	152.94	133.85	113.08	333.45	243.33
T_2 : $v_1s_1n_2$	1.53	1.60	223.40	153.13	127.14	111.16	325.48	241.74
T_3 : $v_1s_1n_3$	1.50	1.50	218.99	144.50	125.02	108.92	312.99	235.40
T_4 : $v_1s_2n_1$	1.47	1.52	219.86	158.68	129.95	113.88	319.36	252.14
T_5 : $v_1s_2n_2$	1.45	1.49	215.48	149.85	130.85	112.09	311.45	246.76
T_6 : $v_1s_2n_3$	1.41	1.44	211.69	140.33	130.15	107.22	309.34	239.67
T_7 : $v_2s_1n_1$	1.57	1.64	223.57	166.30	134.76	111.42	338.24	248.86
T_8 : $v_2s_1n_2$	1.54	1.62	219.00	148.05	132.82	108.37	305.23	245.17
T_9 : $v_2s_1n_3$	1.51	1.60	218.99	162.08	122.54	100.92	314.78	239.69
T_{10} : $v_2s_2n_1$	1.50	1.54	220.63	168.67	125.55	114.92	335.49	275.48
T_{11} : $v_2s_2n_2$	1.46	1.50	212.72	153.08	127.36	113.20	328.01	251.52
T_{12} : $v_2s_2n_3$	1.41	1.47	209.40	147.63	127.79	102.82	311.49	249.15
SEm±	0.003	0.004	0.08	0.05	0.41	0.41	0.09	0.47
CD (0.05)	0.009	0.013	0.248	0.147	1.198	1.210	0.279	1.378

Table 36. Residual effect of red gram on protein and carbohydrate content in fodder maize, %

Treatments	Protein	Carbohydrate
T_1 : $v_1s_1n_1$	8.60	68.72
T_2 : $v_1s_1n_2$	7.38	71.53
T_3 : $v_1s_1n_3$	7.31	74.67
T_4 : $v_1s_2n_1$	7.65	70.01
T_5 : $v_1s_2n_2$	7.25	73.18
T_6 : $v_1s_2n_3$	7.23	77.33
T_7 : $v_2s_1n_1$	8.75	69.07
T_8 : $v_2s_1n_2$	8.10	72.20
T_9 : $v_2s_1n_3$	7.63	76.69
T_{10} : $v_2s_2n_1$	7.86	71.65
T_{11} : $v_2s_2n_2$	7.60	74.61
T_{12} : $v_2s_2n_3$	7.22	77.50
SEm±	0.17	0.24
CD (0.05)	0.503	0.718

4.3 EXPERIMENT III

The results of Experiment I revealed that of the two varieties, APK 1 was superior and hence was identified as the variety for Experiment III. The spacing of 40 cm x 20 cm and NPK dose of 40 :80: 40 kg NPK ha^{-1} recorded significantly higher yields and were adopted as management practices for APK 1 in the nutrient management experiment. The nine treatments included an absolute control (no nutrient application) and this was inferior in growth and yield and hence the data were used for computation of per cent increase/ decrease and agronomic indices.

4.3.1 Biometric Observations

4.3.1.1 Plant Height

The effect of integrated nutrient management (INM) practices on plant height of red gram at monthly interval are depicted in Table 37. Plant height varied significantly with the different treatments at harvest alone. The treatment T_4 (100 % N + 50 % P +50 % K + P solubiliser + K solubiliser (N soil)) recorded the tallest plants (109.70 cm), which was on par with the treatments involving 100 per cent chemical fertilizers in soil (T_1) and with P solubiliser (T_2 and T_6). Plants were the shortest (103.50 cm) in T_7 (100 % N + 100 % P +50 % K + K solubiliser (50 % N foliar)) but 15 per cent taller than those in the absolute control (no fertilizers).

4.3.1.2 Number of Branches per Plant

Perusal of the data on number of branches per plant (Table 38) revealed that there was no significant difference in number of branches with the treatments at 30 and 60 DAS. However, at harvest, significantly higher number of branches was recorded in the treatment T_4 (6.5) on par with T_2 (6.4). The lowest was in treatment T_7 (5.7) and in the absolute control (no fertilizers), the number of branches at harvest was 5.3.

4.3.1.3 Number of Nodules per Plant

The effect of treatments on number of nodules per plant is presented in Table 39. There was no marked differences in the of number of nodules per plant due to various INM practices.

Table 37. Effect of INM practices on plant height, cm

Treatments	Plant height		
	30 DAS	60 DAS	At harvest
T_1: 100 % NPK as chemical fertilizers	52.20	106.67	107.17
T_2: 100 % N + 50 % P +100 % K + P solubiliser	52.45	106.40	108.60
T_3: 100 % N + 100 % P +50 % K + K solubiliser	50.32	104.67	106.00
T_4: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	52.00	107.15	109.70
(T_1 to T_4 – N as soil application, basal and 30 DAS)			
T_5: 100 % NPK as chemical fertilizers	52.60	103.00	106.33
T_6: 100 % N + 50 % P +100 % K + P solubiliser	52.75	104.25	107.63
T_7: 100 % N + 100 % P +50 % K + K solubiliser	49.98	101.00	103.50
T_8: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	52.90	102.83	104.75
(T_5 to T_8 – ½ N in soil and remaining as foliar spray)			
SEm±	2.07	1.44	1.08
CD (0.05)	-	-	3.301
T_9: Absolute control: No fertilizers	45.55	87.33	90.00

Table 38. Effect of INM practices on number of branches per plant

Treatments	Number of branches		
	30 DAS	60 DAS	At harvest
T_1: 100 % NPK as chemical fertilizers	3.3	5.3	6.3
T_2: 100 % N + 50 % P +100 % K + P solubiliser	3.1	5.7	6.4
T_3: 100 % N + 100 % P +50 % K + K solubiliser	2.9	5.4	6.0
T_4: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	2.8	5.6	6.5
(T_1 to T_4 – N as soil application, basal and 30 DAS)			
T_5: 100 % NPK as chemical fertilizers	3.3	4.9	6.0
T_6: 100 % N + 50 % P +100 % K + P solubiliser	2.9	5.2	6.2
T_7: 100 % N + 100 % P +50 % K + K solubiliser	3.1	4.8	5.7
T_8: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	2.7	5.0	6.3
(T_5 to T_8 – ½ N in soil and remaining as foliar spray)			
SEm±	0.44	0.54	0.03
CD (0.05)	-	-	0.084
T_9: Absolute control: No fertilizers	2.6	4.1	5.3

4.3.1.4 Weight of Nodules per Plant

Weight of nodules per plant varied significantly with the treatments (Table 39). The treatment T_8, which included P and K solubilisers and 50 per cent N dose as foliar application, resulted in the highest weight of nodules (0.59 g $plant^{-1}$). Among the treatments, the lowest weight of nodules (0.41 g $plant^{-1}$) was observed in the treatment of 100 per cent NPK as chemical fertilizers (N soil). The absolute control treatment (T_9 - without fertilizer) recorded 0.22 g nodule weight per plant.

4.3.1.5 Root Volume

The data pertaining to the mean root volume at harvest (Table 40) revealed the treatment T_8 (100 % N + 50 % P +50 % K + P solubiliser + K solubiliser (50 % N foliar)) to be significantly superior (12.20 cm^3 $plant^{-1}$), 100 per cent more than that in absolute control. The treatment T_3 (100 % N + 100 % P +50 % K + K solubiliser (N soil)) resulted in the lowest root volume (10.00 cm^3 $plant^{-1}$). The absolute control (T_9) recorded a root volume of 5.70 cm^3 $plant^{-1}$.

4.3.1.6 Root Weight

Perusal of data in Table 40, revealed that treatment T_8 had the significantly highest root dry weight at harvest (5.80 g $plant^{-1}$), which was on par with T_4 (5.65 g $plant^{-1}$). The lowest root dry weight of 4.10 g $plant^{-1}$ was observed in treatment T_3. The root dry weight in the absolute control was 2.20 g $plant^{-1}$.

4.3.1.7 Root - Shoot Ratio

The data on root - shoot ratio at harvest is presented in Table 40. It is evident that the ratio was significantly the highest (0.25) in T_4 and T_8. The lowest root - shoot ratio was observed in treatment T_3 (0.21) while the absolute control (T_9) recorded a root - shoot ratio of 0.19.

Table 39. Effect of INM practices on number and weight of nodules per plant

Treatments	Number of nodules	Weight of nodules (g)
T_1: 100 % NPK as chemical fertilizers	5.0	0.41
T_2: 100 % N + 50 % P +100 % K + P solubiliser	5.2	0.46
T_3: 100 % N + 100 % P +50 % K + K solubiliser	4.7	0.45
T_4: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	5.5	0.53
(T_1 to T_4 – N as soil application, basal and 30 DAS)		
T_5: 100 % NPK as chemical fertilizers	5.3	0.57
T_6: 100 % N + 50 % P +100 % K + P solubiliser	4.9	0.54
T_7: 100 % N + 100 % P +50 % K + K solubiliser	4.3	0.48
T_8: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	5.0	0.59
(T_5 to T_8 – ½ N in soil and remaining as foliar spray)		
SEm±	0.52	0.007
CD (0.05)	-	0.020
T_9: Absolute control: No fertilizers	2.0	0.22

Table 40. Effect of INM practices on root volume, root weight and root – shoot ratio at harvest

Treatments	Root volume (cm^3 $plant^{-1}$)	Root weight (g $plant^{-1}$)	Root - shoot ratio
T_1: 100 % NPK as chemical fertilizers	10.30	4.70	0.24
T_2: 100 % N + 50 % P +100 % K + P solubiliser	11.83	5.50	0.24
T_3: 100 % N + 100 % P +50 % K + K solubiliser	10.00	4.10	0.21
T_4: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	11.97	5.65	0.25
(T_1 to T_4 – N as soil application, basal and 30 DAS)			
T_5: 100 % NPK as chemical fertilizers	10.03	4.50	0.23
T_6: 100 % N + 50 % P +100 % K + P solubiliser	11.30	5.30	0.23
T_7: 100 % N + 100 % P +50 % K + K solubiliser	10.13	4.47	0.23
T_8: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	12.20	5.80	0.25
(T_5 to T_8 – ½ N in soil and remaining as foliar spray)			
SEm±	0.07	0.05	0.003
CD (0.05)	0.227	0.163	0.009
T_9: Absolute control: No fertilizers	5.70	2.20	0.19

4.3.2 Yield Attributes

The mean data on yield attributes are presented in Table 41. The time taken for 50 per cent flowering did not vary with the treatments. Perusal of data revealed that there were no marked variations in pod length, number of seeds per pod, 100 seed weight and seed - pod ratio in APK 1 variety with the INM practices adopted.

Average pod weight alone varied significantly with the different treatments. The weights varied from 0.62 to 0.51 g and was maximum (0.62 g) in T_4 (100 % N + 50 % P +50 % K + P solubiliser + K solubiliser (N soil)), which was on par with T_2 and T_8. The lowest weight was registered in T_1, 100 per cent chemical nutrition in soil (0.51 g) and in absolute control, the pod weight was 0.40 g.

4.3.3 Yield

Influence of the INM practices on the seed and haulm yield of red gram are given in Table 42. Significant variations were recorded for seed yield and among the different treatments, the maximum seed yield was in treatment T_4 (1.48 t ha^{-1}), which was on par with $T_{8,}$ the same management practice with 50 per cent N as foliar and T_2, P solubiliser alone and soil application of N. The seed yield was significantly the lowest in the treatments T_5 and T_7. Integration of P and K solubilisers in the RDF yielded 50 per cent greater than the absolute control.

The trend remained similar for haulm yields but the effects were non significant. The absolute control (T_9) resulted in 0.98 t ha^{-1} and 3.97 t ha^{-1} seed and haulm yield respectively.

4.3.4 Physiological Parameters

4.3.4.1 Dry Matter Production (DMP)

The variations in dry matter production due to INM practices are presented in Table 43. The treatments T_6, T_1 and T_4 recorded superior values for DMP at 20, 40 and 100 DAS respectively. At 60 and 80 DAS, the treatment T_8 resulted in significantly the highest DMP of 20.38 and 29.40 g per plant respectively. The treatment T_1 resulted in the lowest DMP at 100 DAS.

Table 41. Effect of INM practices on yield attributes

Treatments	Days to 50 per cent flowering	Average pod length (cm)	Average pod weight (g pod^{-1})	Number of seeds per pod	100 seed weight (g)	Seed - pod ratio
T_1: 100 % NPK as chemical fertilizers	64.00	5.45	0.51	4.7	8.80	0.77
T_2: 100 % N + 50 % P +100 % K + P solubiliser	65.33	5.53	0.60	4.8	8.83	0.75
T_3: 100 % N + 100 % P +50 % K + K solubiliser	64.33	5.46	0.54	4.7	8.70	0.77
T_4: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	65.00	5.67	0.62	4.8	8.95	0.79
(T_1 to T_4 – N as soil application, basal and 30 DAS)						
T_5: 100 % NPK as chemical fertilizers	65.33	5.43	0.53	4.8	8.77	0.73
T_6: 100 % N + 50 % P +100 % K + P solubiliser	65.00	5.50	0.58	4.7	8.86	0.76
T_7: 100 % N + 100 % P +50 % K + K solubiliser	65.00	5.57	0.52	4.8	8.63	0.75
T_8: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	64.67	5.60	0.60	4.8	8.93	0.78
(T_5 to T_8 – ½ N in soil and remaining as foliar spray)						
SEm±	0.41	0.11	0.01	0.03	0.23	0.02
CD (0.05)	-	-	0.023	-	-	-
T_9: Absolute control: No fertilizers	66.00	5.43	0.40	4.5	8.18	0.70

Table 42. Effect of INM practices on seed and haulm yield, t ha^{-1}

Treatments	Seed yield	Haulm yield
T_1: 100 % NPK as chemical fertilizers	1.35	4.58
T_2: 100 % N + 50 % P +100 % K + P solubiliser	1.40	5.01
T_3: 100 % N + 100 % P +50 % K + K solubiliser	1.37	4.73
T_4: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	1.48	5.07
(T_1 to T_4 – N as soil application, basal and 30 DAS)		
T_5: 100 % NPK as chemical fertilizers	1.32	4.47
T_6: 100 % N + 50 % P +100 % K + P solubiliser	1.39	5.00
T_7: 100 % N + 100 % P +50 % K + K solubiliser	1.32	4.71
T_8: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	1.46	5.00
(T_5 to T_8 – ½ N in soil and remaining as foliar spray)		
SEm±	0.03	0.16
CD (0.05)	0.088	-
T_9: Absolute control: No fertilizers	0.98	3.97

Table 43. Effect of INM practices on dry matter production, g plant^{-1}

Treatments	Dry matter production				
	20 DAS	40 DAS	60 DAS	80 DAS	100 DAS
T_1: 100 % NPK as chemical fertilizers	0.62	5.61	17.48	27.50	30.90
T_2: 100 % N + 50 % P +100 % K + P solubiliser	0.66	5.37	17.80	28.00	33.49
T_3: 100 % N + 100 % P +50 % K + K solubiliser	0.59	5.45	18.45	28.00	32.50
T_4: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	0.67	5.13	19.34	28.67	34.18
(T_1 to T_4 – N as soil application, basal and 30 DAS)					
T_5: 100 % NPK as chemical fertilizers	0.61	5.59	17.09	28.10	31.10
T_6: 100 % N + 50 % P +100 % K + P solubiliser	0.69	4.53	20.16	29.20	32.29
T_7: 100 % N + 100 % P +50 % K + K solubiliser	0.57	4.33	16.85	27.50	31.30
T_8: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	0.61	4.63	20.38	29.40	32.85
(T_5 to T_8 – ½ N in soil and remaining as foliar spray)					
SEm±	0.02	0.002	0.01	0.01	0.02
CD (0.05)	0.060	0.007	0.015	0.024	0.070
T_9: Absolute control: No fertilizers	0.51	3.71	12.54	21.00	23.20

4.3.4.2 Crop Growth Rate (CGR)

Perusal of the data in Table 44 revealed that the treatments, T_1, T_8, T_5 and T_4 resulted in the highest CGR of 3.12, 9.84, 6.88 and 3.44 g m^{-2} day^{-1} respectively during 20 - 40, 40 - 60, 60 - 80 and 80 - 100 DAS respectively. At 80 - 100 DAS, the treatment T_4 was at par with T_2. The highest CGR was recorded at 40 - 60 days period. The lowest CGR was observed in the treatment T_5 (1.88 g m^{-2} day^{-1}) at 80 - 100 DAS. The absolute control recorded CGR values of 2.00, 5.52, 5.29 and 1.38 g m^{-2} day^{-1} during 20 - 40, 40 - 60, 60 - 80 and 80 - 100 DAS respectively. Comparatively lower during all periods of computation.

4.3.4.3 Relative Growth Rate (RGR)

Relative growth rate was the highest during the early stage of growth (20 - 40 DAS) and thereafter declined (Table 45). The treatments T_3, T_6, T_5 and T_2 recorded superior RGR during 20 - 40, 40 - 60, 60 - 80 and 80 - 100 DAS respectively.

4.3.5 Agronomic Indices

4.3.5.1 Harvest Index (HI)

The mean data on harvest index as influenced by the nutrient management practices are given in Table 46. No significant variations were observed for HI due to the treatments. The absolute control resulted in a HI of 0.20.

4.3.5.2 Physiological Efficiency (PE)

Physiological efficiency of K alone varied significantly with the INM treatments as evident from the data depicted in Table 47. Physiological efficiency for N (9.65 kg kg^{-1}) and P (35.38 kg kg^{-1}) were comparatively higher in T_4, and significantly the highest for K (20.77 kg kg^{-1}), at par with the treatments T_8 and T_2. The treatment T_7 resulted in the lowest PE for K.

4.3.6 Pest and Disease Incidence

The incidence of pests and diseases were found to be very less as protection measures were taken at flowering itself to keep the pod borers and bugs at bay.

Table 44. Effect of INM practices on crop growth rate, g m^{-2} day^{-1}

Treatments	Crop Growth Rate			
	20-40 DAS	40-60 DAS	60-80 DAS	80-100 DAS
T_1: 100 % NPK as chemical fertilizers	3.12	7.42	6.26	2.13
T_2: 100 % N + 50 % P +100 % K + P solubiliser	2.94	7.77	6.37	3.43
T_3: 100 % N + 100 % P +50 % K + K solubiliser	3.04	8.13	5.97	2.81
T_4: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	2.79	8.88	5.83	3.44
(T_1 to T_4 – N as soil application, basal and 30 DAS)				
T_5: 100 % NPK as chemical fertilizers	3.11	7.19	6.88	1.88
T_6: 100 % N + 50 % P +100 % K + P solubiliser	2.40	9.77	5.65	1.94
T_7: 100 % N + 100 % P +50 % K + K solubiliser	2.35	7.83	6.66	2.38
T_8: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	2.51	9.84	5.64	2.16
(T_5 to T_8 – ½ N in soil and remaining as foliar spray)				
SEm±	0.002	0.001	0.002	0.02
CD (0.05)	0.006	0.003	0.006	0.045
T_9: Absolute control: No fertilizers	2.00	5.52	5.29	1.38

Table 45. Effect of INM practices on relative growth rate, g g^{-1} day^{-1} x 10^{-2}

Treatments	Relative Growth Rate			
	20-40 DAS	40-60 DAS	60-80 DAS	80-100 DAS
T_1: 100 % NPK as chemical fertilizers	11.06	5.68	2.27	0.583
T_2: 100 % N + 50 % P +100 % K + P solubiliser	10.51	5.99	2.26	0.895
T_3: 100 % N + 100 % P +50 % K + K solubiliser	11.16	6.10	2.08	0.745
T_4: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	10.20	6.64	1.97	0.879
(T_1 to T_4 – N as soil application, basal and 30 DAS)				
T_5: 100 % NPK as chemical fertilizers	11.08	5.59	2.49	0.508
T_6: 100 % N + 50 % P +100 % K + P solubiliser	9.45	7.46	1.85	0.504
T_7: 100 % N + 100 % P +50 % K + K solubiliser	10.14	6.79	2.45	0.648
T_8: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	10.16	7.40	1.83	0.555
(T_5 to T_8 – ½ N in soil and remaining as foliar spray)				
SEm±	0.01	0.002	0.001	0.004
CD (0.05)	0.029	0.008	0.003	0.011
T_9: Absolute control: No fertilizers	9.95	6.09	2.58	0.498

Table 46. Effect of INM practices on harvest index

Treatments	Harvest Index
T_1: 100 % NPK as chemical fertilizers	0.23
T_2: 100 % N + 50 % P +100 % K + P solubiliser	0.22
T_3: 100 % N + 100 % P +50 % K + K solubiliser	0.22
T_4: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	0.23
(T_1 to T_4 – N as soil application, basal and 30 DAS)	
T_5: 100 % NPK as chemical fertilizers	0.23
T_6: 100 % N + 50 % P +100 % K + P solubiliser	0.22
T_7: 100 % N + 100 % P +50 % K + K solubiliser	0.22
T_8: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	0.23
(T_5 to T_8 – ½ N in soil and remaining as foliar spray)	
SEm±	0.01
CD (0.05)	-
T_9: Absolute control: No fertilizers	0.20

Table 47. Effect of INM practices on physiological efficiency, kg kg^{-1}

Treatments	Physiological efficiency		
	N	P	K
T_1: 100 % NPK as chemical fertilizers	9.26	33.55	16.17
T_2: 100 % N + 50 % P +100 % K + P solubiliser	8.20	26.70	17.50
T_3: 100 % N + 100 % P +50 % K + K solubiliser	9.54	33.01	15.66
T_4: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	9.65	35.38	20.77
(T_1 to T_4 – N as soil application, basal and 30 DAS)			
T_5: 100 % NPK as chemical fertilizers	8.32	30.92	14.10
T_6: 100 % N + 50 % P +100 % K + P solubiliser	8.48	30.98	16.88
T_7: 100 % N + 100 % P +50 % K + K solubiliser	9.52	28.41	13.76
T_8: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	9.64	30.33	20.29
(T_5 to T_8 – ½ N in soil and remaining as foliar spray)			
SEm±	0.68	2.27	1.18
CD (0.05)	-	-	3.615
T_9: Absolute control: No fertilizers	-	-	-

4.3.7 Plant Analysis

4.3.7.1 Chlorophyll

The chlorophyll content estimated are presented in Table 48. The results of statistical analysis indicated that there was no significant difference in total chlorophyll content due to the different treatments.

4.3.7.2 NPK Uptake

Table 49 illustrates the effect of INM practices on total NPK uptake. The treatments T_4 and T_8 resulted in significantly the highest N (129.77 kg ha^{-1}) and P (30.59 kg ha^{-1}) uptake respectively. With respect to P uptake, the treatment T_8 was on par with T_2. The treatments T_1 and T_5 recorded the lowest N and P uptake respectively. Potassium uptake did not record any significant variation. The absolute control (T_9) recorded 77.54, 14.63 and 24.66 kg ha^{-1} uptake of NPK respectively which were nearly 31, 42 and 48 per cent lower than the treatments with nutrient inputs.

4.3.8 Quality Parameter

4.3.8.1 Seed Protein

Seed protein content ranged from 17.30 to 21.59 per cent (Table 50) and the significantly superior value was observed in the treatment T_4 (21.59 %), which was on par with T_8 (21.33 %). The lowest seed protein content was observed in the treatment T_5 (18.32 %) but it was comparatively higher than that in the absolute control (17.30 %).

4.3.9 Soil Chemical and Biological Properties

The changes in soil properties with the nutrient management practices are presented in Table 51.

4.3.9.1 Soil pH

Soil pH was significantly influenced by the different treatments. A decrease in soil pH was observed in P and K solubiliser applied plots after the harvest of crop compared to the initial status. It was highest in T_5, followed by T_1, the treatments with 100 per cent chemical fertilizer nutrition which were on par. The lowest soil pH was observed in treatment T_8 (5.43).

Table 48. Effect of INM practices on chlorophyll content, mg g^{-1}

Treatments	Total chlorophyll content
T_1: 100 % NPK as chemical fertilizers	1.41
T_2: 100 % N + 50 % P +100 % K + P solubiliser	1.45
T_3: 100 % N + 100 % P +50 % K + K solubiliser	1.46
T_4: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	1.49
(T_1 to T_4 – N as soil application, basal and 30 DAS)	
T_5: 100 % NPK as chemical fertilizers	1.44
T_6: 100 % N + 50 % P +100 % K + P solubiliser	1.47
T_7: 100 % N + 100 % P +50 % K + K solubiliser	1.48
T_8: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	1.47
(T_5 to T_8 – ½ N in soil and remaining as foliar spray)	
SEm±	0.05
CD (0.05)	-
T_9: Absolute control: No fertilizers	1.27

Table 49. Effect of INM practices on total NPK uptake, kg ha^{-1}

Treatments	Total nutrient uptake		
	N	P	K
T_1: 100 % NPK as chemical fertilizers	117.93	25.78	47.79
T_2: 100 % N + 50 % P +100 % K + P solubiliser	128.42	29.93	48.50
T_3: 100 % N + 100 % P +50 % K + K solubiliser	118.51	26.46	49.61
T_4: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	129.77	28.88	48.92
(T_1 to T_4 – N as soil application, basal and 30 DAS)			
T_5: 100 % NPK as chemical fertilizers	118.09	25.54	48.58
T_6: 100 % N + 50 % P +100 % K + P solubiliser	125.57	27.78	48.78
T_7: 100 % N + 100 % P +50 % K + K solubiliser	113.69	26.74	49.66
T_8: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	127.76	30.59	48.51
(T_5 to T_8 – ½ N in soil and remaining as foliar spray)			
SEm±	0.10	0.32	0.89
CD (0.05)	0.317	0.966	-
T_9: Absolute control: No fertilizers	77.54	14.63	24.66

Table 50. Effect of INM practices on seed protein content, %

Treatments	Protein
T_1: 100 % NPK as chemical fertilizers	18.78
T_2: 100 % N + 50 % P +100 % K + P solubiliser	20.77
T_3: 100 % N + 100 % P +50 % K + K solubiliser	19.37
T_4: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	21.59
(T_1 to T_4 – N as soil application, basal and 30 DAS)	
T_5: 100 % NPK as chemical fertilizers	18.32
T_6: 100 % N + 50 % P +100 % K + P solubiliser	20.52
T_7: 100 % N + 100 % P +50 % K + K solubiliser	18.55
T_8: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	21.33
(T_5 to T_8 – ½ N in soil and remaining as foliar spray)	
SEm±	0.11
CD (0.05)	0.324
T_9: Absolute control: No fertilizers	17.30

4.3.9.2 Organic Carbon

Organic carbon content in soil was significantly influenced by the different treatments. Compared to initial status an increase in organic C was observed in all plots. The treatment T_4 resulted in significantly superior organic C content (1.46 %) followed by T_8 (1.44 %).

4.3.9.3 Available NPK

The data pertaining to available NPK status of post harvest soil is presented in Table 51. Available NPK varied significantly among the treatments. Significantly higher available N (225.79 kg ha^{-1}) and P (107.07 kg ha^{-1}) status were observed in treatment T_4. The treatment T_7 resulted in the highest soil available K (327.33 kg ha^{-1}), which was on par with T_8 (326.00 kg ha^{-1}) and T_3 (325.55 kg ha^{-1}). The lowest soil available nutrient status was recorded in treatments T_3 (N) and T_5 (P and K).

4.3.9.4 Microbial Count

The variations in microbial counts are depicted in Table 52. Perusal of the data revealed that the INM practices exerted significant influence on the soil bacterial population alone. The highest bacterial count was recorded in the treatment T_4 (6.82 log cfu g^{-1}) and the lowest was in T_5 (6.66 log cfu g^{-1}). No significant variation was observed for fungal and actinomycete counts. Microbial counts were the lowest in the absolute control.

4.3.10 Nutrient Balance Sheet

The nutrient balance sheets computed for soil N, P and K are presented in Tables 53 to 55.

4.3.10.1 Nitrogen

The data on balance sheet of N is presented in Table 53. The N balance of soil was positive for all the treatments indicative of N accretions in soil. The N balance was the highest for the treatment T_8 (158.40 kg ha^{-1}) followed by T_4 (148.14 kg ha^{-1}). The lowest balance was observed in absolute control (94.68 kg ha^{-1}).

Table 51. Effect of INM practices on soil pH, organic carbon and available NPK

Treatments	Soil pH	Organic carbon (%)	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
T_1: 100 % NPK as chemical fertilizers	5.91	1.37	203.42	99.24	310.59
T_2: 100 % N + 50 % P +100 % K + P solubiliser	5.63	1.42	213.25	104.27	309.94
T_3: 100 % N + 100 % P +50 % K + K solubiliser	5.50	1.39	200.70	100.20	325.55
T_4: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	5.45	1.46	225.79	107.07	320.67
(T_1 to T_4 – N as soil application, basal and 30 DAS)					
T_5: 100 % NPK as chemical fertilizers	5.92	1.40	205.79	98.66	308.00
T_6: 100 % N + 50 % P +100 % K + P solubiliser	5.58	1.38	210.44	102.49	318.71
T_7: 100 % N + 100 % P +50 % K + K solubiliser	5.58	1.43	209.89	99.57	327.33
T_8: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	5.43	1.44	219.86	102.98	326.00
(T_5 to T_8 – ½ N in soil and remaining as foliar spray)					
SEm±	0.05	0.001	0.32	0.02	1.29
CD (0.05)	0.150	0.002	0.967	0.056	3.956
T_9: Absolute control: No fertilizers	5.87	1.12	188.16	22.81	290.00

Table 52. Effect of INM practices on soil microbial count, log cfu g^{-1}

Treatments	Bacteria	Fungi	Actinomycetes
T_1: 100 % NPK as chemical fertilizers	6.69	3.90	2.78
T_2: 100 % N + 50 % P +100 % K + P solubiliser	6.74	3.97	2.82
T_3: 100 % N + 100 % P +50 % K + K solubiliser	6.72	3.94	2.77
T_4: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	6.82	3.88	2.85
(T_1 to T_4 – N as soil application, basal and 30 DAS)			
T_5: 100 % NPK as chemical fertilizers	6.66	3.90	2.84
T_6: 100 % N + 50 % P +100 % K + P solubiliser	6.72	3.92	2.74
T_7: 100 % N + 100 % P +50 % K + K solubiliser	6.74	3.98	2.78
T_8: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	6.79	3.87	2.66
(T_5 to T_8 – ½ N in soil and remaining as foliar spray)			
SEm±	0.01	0.04	0.05
CD (0.05)	0.042	-	-
T_9: Absolute control: No fertilizers	6.34	3.81	2.54

4.3.10.2 Phosphorus

The INM practices evaluated in the experiment resulted in positive balance for P (Table 54) with the comparatively higher balance in T_4 (35.06 kg ha^{-1}) followed by T_2 (33.31 kg ha^{-1}). Nevertheless, the absolute control showed a negative balance (-53.45 kg ha^{-1}) for P.

4.3.10.3 Potassium

The K balance in soil was positive in the treatments T_3, T_4, T_6, T_7 and T_8 (Table 55) with the higher K balance in treatments involving K solubiliser application. The highest positive balance for K was observed in treatment T_7 (24.56 kg ha^{-1}) followed by treatment T_3 (22.73 kg ha^{-1}) whereas it was negative in treatments T_1, T_2, T_5 and the absolute control. The highest negative balance was observed in absolute control (-28.17 kg ha^{-1}).

4.3.11 Economic Analysis

The net returns and B: C ratio in experiment III are presented in Table 56. The returns and B: C ratio were maximum (₹ 94722 ha^{-1} and 2.05 respectively) in T_4 (100 % N + 50 % P +50 % K + P solubiliser + K solubiliser (N soil)) followed by the treatment $T_{8,}$ the same combination with 50 per cent N as foliar application. The absolute control treatment T_9 recorded the lowest net return (₹ 48150 ha^{-1}) and B:C ratio (1.65).

Table 53. Balance sheet for nitrogen, kg ha^{-1}

Treatments	Nitrogen added				Crop uptake	Balance		
	Soil contribution	FYM	Fertilizer	Total N		Expected balance	Actual balance	Apparent gain / loss
T_1: 100 % NPK as chemical fertilizers	111.02	60.00	36.40	207.42	117.93	89.49	203.42	113.93
T_2: 100 % N + 50 % P +100 % K + P solubiliser	111.02	60.00	36.40	207.42	128.42	79.00	213.25	134.25
T_3: 100 % N + 100 % P +50 % K + K solubiliser	111.02	60.00	36.40	207.42	118.51	88.91	200.70	111.79
T_4: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	111.02	60.00	36.40	207.42	129.77	77.65	225.79	148.14
T_5: 100 % NPK as chemical fertilizers	111.02	60.00	18.20	189.22	118.09	71.13	205.79	134.66
T_6: 100 % N + 50 % P +100 % K + P solubiliser	111.02	60.00	18.20	189.22	125.57	63.65	210.44	146.79
T_7: 100 % N + 100 % P +50 % K + K solubiliser	111.02	60.00	18.20	189.22	113.69	75.53	209.89	134.36
T_8: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	111.02	60.00	18.20	189.22	127.76	61.46	219.86	158.40
T_9: Absolute control: No fertilizers	111.02	60.00	0.00	171.02	77.54	93.48	188.16	94.68

T_1 to T_4 - N as soil application, basal and 30 DAS; T_5 to T_8 - ½ N in soil and remaining as foliar spray

Table 54. Balance sheet for phosphorus, kg ha^{-1}

Treatments	Phosphorus added				Crop uptake	Balance		
	Soil contribution	FYM	Fertilizer	Total P		Expected balance	Actual balance	Apparent gain / loss
T_1: 100 % NPK as chemical fertilizers	67.14	23.75	20.00	110.89	25.78	85.11	99.24	14.13
T_2: 100 % N + 50 % P +100 % K + P solubiliser	67.14	23.75	10.00	100.89	29.93	70.96	104.27	33.31
T_3: 100 % N + 100 % P +50 % K + K solubiliser	67.14	23.75	20.00	110.89	26.46	84.43	100.20	15.77
T_4: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	67.14	23.75	10.00	100.89	28.88	72.01	107.07	35.06
T_5: 100 % NPK as chemical fertilizers	67.14	23.75	20.00	110.89	25.54	85.35	98.66	13.31
T_6: 100 % N + 50 % P +100 % K + P solubiliser	67.14	23.75	10.00	100.89	27.78	73.11	102.49	29.38
T_7: 100 % N + 100 % P +50 % K + K solubiliser	67.14	23.75	20.00	110.89	26.74	84.15	99.57	15.42
T_8: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	67.14	23.75	10.00	100.89	30.59	70.30	102.98	32.68
T_9: Absolute control: No fertilizers	67.14	23.75	0.00	90.89	14.63	76.26	22.81	-53.45

T_1 to T_4 - N as soil application, basal and 30 DAS; T_5 to T_8 - ½ N in soil and remaining as foliar spray

Table 55. Balance sheet for potassium, kg ha^{-1}

Treatments	Potassium added				Crop uptake	Balance		
	Soil contribution	FYM	Fertilizer	Total K		Expected balance	Actual balance	Apparent gain / loss
T_1: 100 % NPK as chemical fertilizers	285.33	57.50	19.20	362.03	47.79	314.24	310.59	-3.65
T_2: 100 % N + 50 % P +100 % K + P solubiliser	285.33	57.50	19.20	362.03	48.5	313.53	309.94	-3.59
T_3: 100 % N + 100 % P +50 % K + K solubiliser	285.33	57.50	9.60	352.43	49.61	302.82	325.55	22.73
T_4: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	285.33	57.50	9.60	352.43	48.92	303.51	320.67	17.16
T_5: 100 % NPK as chemical fertilizers	285.33	57.50	19.20	362.03	48.58	313.45	308	-5.45
T_6: 100 % N + 50 % P +100 % K + P solubiliser	285.33	57.50	19.20	362.03	48.78	313.25	318.71	5.46
T_7: 100 % N + 100 % P +50 % K + K solubiliser	285.33	57.50	9.60	352.43	49.66	302.77	327.33	24.56
T_8: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	285.33	57.50	9.60	352.43	48.51	303.92	326.00	22.08
T_9: Absolute control: No fertilizers	285.33	57.50	0.00	342.83	24.66	318.17	290.00	-28.17

T_1 to T_4 - N as soil application, basal and 30 DAS; T_5 to T_8 - ½ N in soil and remaining as foliar spray

Table 56. Effect of INM practices on economics of cultivation of red gram

Treatments	Net return (₹ ha^{-1})	B:C ratio
T_1: 100 % NPK as chemical fertilizers	84312	1.99
T_2: 100 % N + 50 % P +100 % K + P solubiliser	87878	2.00
T_3: 100 % N + 100 % P +50 % K + K solubiliser	84256	1.97
T_4: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	94722	2.05
T_5: 100 % NPK as chemical fertilizers	79962	1.94
T_6: 100 % N + 50 % P +100 % K + P solubiliser	85428	1.97
T_7: 100 % N + 100 % P +50 % K + K solubiliser	76806	1.87
T_8: 100 % N + 50 % P +50 % K + P solubiliser + K solubiliser	91622	2.01
T_9: Absolute control: No fertilizers	48150	1.65

T_1 to T_4 - N as soil application, basal and 30 DAS; T_5 to T_8 - ½ N in soil and remaining as foliar spray

Discussion

5. DISCUSSION

The study entitled "Input optimization for short duration red gram [*Cajanus cajan* (L.) Millsp.]" was undertaken with the objectives to identify a suitable variety of red gram for cultivation in Kerala, to evolve suitable management practices for improved productivity and to examine the legume effect on succeeding fodder maize crop during 2018 - 2020. The results of the experiment presented in the previous chapter are discussed herewith available documented literature to justify, support and substantiate the findings of the study.

5.1 EXPERIMENT I

5.1.1 Growth Characters

The growth characters in red gram were significantly influenced by the treatments *viz*., varieties, spacing and nutrient levels. The variety Vamban (Rg) 3 (v_2) recorded significantly taller plants compared to APK1 variety. The effects of spacing and nutrient levels were non significant during the first year, and in the second year, the wider spacing (60 cm x 30 cm) and the highest NPK dose (40:80:40 kg ha^{-1}) were superior. The first and second order interactions involving v_2 (Vamban (Rg) 3), s_2 (60 cm x 30 cm) and n_3 (20:40:20 kg NPK ha^{-1}) recorded significantly taller plants compared to the other combinations during the first year, and was at par with $v_2s_2n_1$. It also resulted in the maximum plant height at harvest in the second year. With respect to the influence on the branching nature, variety Vamban (Rg) 3, spacing 60 cm x 30 cm, nutrient level 20:40:20 kg NPK ha^{-1} and the combination, $v_2s_2n_1$ (Vamban (Rg) 3 + 60 cm x 30 cm + 40:80:40 kg NPK ha^{-1}) recorded significantly higher number of branches per plant during the both the years of study.

APK 1, the variety released from Regional Agricultural Research Station, Aruppukkottai, Tamil Nadu was found to be shorter in stature and of less branching nature compared to Vamban (Rg) 3 in accordance with the characters assigned to the varieties by their parental institutes. The differences in plant characters of the two varieties are attributed to the genetic factors (Poehlman, 1991).

The variations in plant height in red gram due to spacing and nutrient doses were non significant in the first year, nevertheless in the second year, the effects were significant. Plant height and number of branches were significantly greater under wider spacing. It is reasoned that the wider spacing assured an adequate supply and optimum utilization of growth resources in individual plants due to the lower plant density, 5 plants m^{-2} in 60 cm x 30 cm compared to 12 plants m^{-2} in 40 cm x 20 cm spacing. Red gram plants have an architecture with the branches of almost erect orientation and hence it is assumed that the shading and elongation that would have otherwise occurred did not happen in the closely spaced plants, 40 cm x 20 cm. Lawn (1981) had documented that canopy development in red gram was very slow and light interception was less than 10 per cent up to 30 days, and even up to 60 days, hardly 50 per cent light intercepted was utilized by the plant canopy. Further, according to Anuradha *et al*. (2020), high density planting can be adopted in early maturing types of red gram. The results obtained corroborate the findings of Prasad and Shrivastava (2011); Dhandayuthapani *et al.* (2015); Nagar *et al.* (2015). The highest number of branches per plant observed under wider spacing are in accordance with the reports of Nagamani *et al.* (1995); Mahajan *et al.* (1997); Srinivasan *et al.* (1997); Mula *et al.* (2010); Mula *et al.* (2011).

The significance of nutrient management in red gram is well documented (Tiwari *et al.,* 2011) and balanced application of nutrients assumes prime importance (Nath *et al.,* 2009; Patil *et al.,* 2012; Singh *et al.,* 2015). The nutrient dose, 40:80:40 kg NPK ha^{-1} produced significantly higher values for growth attributes. It is inferred that the application of N, P and K at higher levels enhanced tissue differentiation and expansion that resulted in taller plants and production of higher number of branches per plant. The results are in conformity with the findings of Shivran *et al*. (2000); Kantwa *et al*. (2005); Esakkiammal *et al*. (2015).

The variations in the number and weight of nodules per plant were not significant during the first year but were markedly influenced by spacing, nutrient levels and their combinations in the second year. The nodule number and weight remained similar in the two varieties, APK 1 and Vamban (Rg) 3. The closer spacing (40 cm x 20 cm) and the highest nutrient dose (40:80:40 kg NPK ha^{-1}) were superior.

Nodulation was comparatively lower and partial in the first year, the numbers ranging from 1.3 to 4.0 (Table 10 c) whereas it ranged from 3.7 to 7.3 per plant in the second year. The *Rhizobium* that was used for inoculation in the first year was collected from TNAU. It is presumed that the species did not establish well in the soil due to the inherent soil properties especially the soil pH. However, in the second year, *Rhizobium* isolated from red gram roots were used for the inoculation and hence better nodulation was observed. This brings to light the significance of specific strains and soil properties influencing the multiplication and nodulation in pulses.

At wider spacing, number of nodules and weight of nodules per plant were lower but on par with closer spacing in the first year. Under closer spacing, the root density was higher and hence the rhizospheric effects including the microbial activities were more dominant, facilitating root infection and nodulation. The competition between plants under wider spacing was less as there was enough space between rows, and available nutrients could be easily taken up by the plant roots. The increased per plant nutrient availability, especially N would have limited infection of *Rhizobium* on roots under the wider spacing. This might cause them to fail to bear nodules and hence the number of nodule could be lowered (Merga, 2020).

Nodule weight per plant was the higher with the NPK doses, 30 :60 :30 (n_2) and 40:80:40 kg (n_1) NPK ha^{-1} compared to 20:40:20 kg NPK ha^{-1} (n_3) reflecting the need for an optimum nutrient availability for nodulation and N fixation. In the second year, although the nodule number remained similar (5.6 per plant), nodule weight was slightly higher in n_1. Better plant growth including that of the roots were observed with the highest nutrient dose in this study (Tables 8, 9 and 11). The short duration red gram varieties responded to the balanced application of the major nutrients and the increased shoot and root growth of plants would also have contributed to the larger sized nodules through better photosynthesis and assimilate partitioning. The results corroborate the findings of Zaltae and Padmani (2009) and Vala *et al.* (2017). Addition of P in red gram has beneficial effect on root growth, which provides more root surface for bacterial infection and since P serves as energy source for the rhizobia, enhances root nodulation (Rathore *et al.* (1992); Thenua *et al*. (2010); Singh *et al*. (2011)).

The variety Vamban (Rg) 3, spacing 60 cm x 30 cm, nutrient level 40:80:40 kg NPK ha^{-1} individually and in combinations as first order interactions, v_2s_2, v_2n_1 and s_2n_1 and second order interaction $v_2s_2n_1$ (Vamban (Rg) 3 + 60 cm x 30 cm + 40:80:40 kg NPK ha^{-1}) registered the highest root volume and weight in the experiments during both the years. Interactions involving v_2 and s_2 resulted in the highest root - shoot ratio (0.28) during the second year. Wider spacing ensured better root ramification and hence higher root weights (Rajeshkumar *et al.,* 2017). The application of higher level of nutrients (40:80:40 kg NPK ha^{-1}) contributed to the proliferous root growth. This might be due to efficient utilization of nutrients by the crop (Bandopadhyay *et al.,* 2003). Higher level of P is also associated with proliferous root growth (Shambhavi *et al.,* 2017).

5.1.2 Yield Attributes

The red gram varieties varied significantly in the number of days taken for 50 per cent flowering during both years of experimentation and the variety APK 1 showed earliness in flowering (58.22 and 61.67 days respectively). Gardner *et al.* (1988) reported that floral induction occurs in response to a specific number of favourable photo induction cycles, and it varies with plant species and varieties. The difference observed in days to 50 per cent flowering between two varieties attributed to their inherent characteristics. Similar observations were documented by Gangaiah and Ahlawat (2008) and Rao (2011) in chickpea and red gram respectively.

The pod length did not record any marked differences with the treatments in the both the years. Maximum pod weight (0.43 g pod^{-1} during first year) was recorded in the combinations involving APK 1, 40 cm x 20 cm spacing and nutrient level of 40:80:40 kg NPK ha^{-1}. During the second year, $v_2s_1n_1$ resulted in significantly highest pod weight of 0.57 g pod^{-1}, which was at par with $v_1s_1n_1$ (0.54 g pod^{-1}). Pod weight is a varietal character and among the combinations, narrow spacing and the highest nutrient level were superior consequent to the increased photosynthetic activity and greater translocation of photosynthates from leaves *via* stem to sink site *i.e.* pods as explained by Singh and Yadav (2008). It is also interpreted that the better availability and utilization of the available resources under wider spacing would have encouraged better growth and more pod production per plant which would have brought the differences in individual pod weights.

There were no marked variations in the number of seeds per pod due to varieties, spacing and nutrient levels during both years of experimentation. Similar reports of the non significant influence of different spacing and nutrient levels on number of seeds per pod were outlined by Saig *et al.* (1993); Sharma *et al.* (2003); Telgote *et al.* (2004); Saritha *et al.* (2012 b).

The variety APK 1 recorded the highest 100 seed weight (9.04 and 9.15 g) during both the years. The 100 seed weight are mostly regulated by the genetic makeup of the varieties and hence, the management practices of spacing and nutrient levels did not significantly influence these characters.

The seed - pod ratio varied significantly with different nutrient levels tried in both years. The NPK dose of 30:60:30 kg ha^{-1} resulted in the highest seed - pod ratio during first year and was on par with 40:80:40 kg NPK ha^{-1} (n_1), which recorded superior values in the second year. The increased seed - pod ratio registered with the application of higher levels of nutrients (n_1 and n_2) could be traced to the comparatively higher test weights recorded in these treatments. Similar findings were reported by Kantwa *et al.* (2006); Meena *et al.* (2011).

Variations in yield attributing characters between APK 1 and Vamban (Rg) 3 observed were in response to the genetic constitution of the varieties. The results are in accordance with the findings of Singh *et al.* (2009). Positive response of yield attributes to inorganic fertilizers have been reported by Patel *et al*. (2010); Patil *et al.* (2011); Reddy *et al.* (2011); Tiwari *et al.* (2012). Appropriate and balanced application of fertilizers are of great significance in crop growth and productivity. Application of the major nutrients (NPK) based on soil test results might have improved the fertility status of the soil ensuring an efficient and balanced nutrient supply system in soil during the growth stages, leading to better plant growth, dry matter production thereby positively influencing the yield attributes (Rajesh *et al.,* 2017). Singh and Yadav (2008) opined that application of higher NPK doses enhanced tissue differentiation from somatic to reproductive, meristematic activity and development of floral primordia causing greater production of flowers and hence pods.

5.1.3 Yield

Yield is dependent upon the sum total of crop growth and development and is the cumulative expression of different yield attributes (Kaur *et al.,* 2015).

During both years, individual effects of variety APK 1, spacing 40 cm x 20 cm and nutrient level 40:80:40 kg NPK ha^{-1} resulted in the significantly highest per hectare seed and haulm yields. Among the interactions, the second order interaction, $v_1s_1n_1$ (APK 1 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}) recorded the highest seed yield while haulm yield was maximum in $v_2s_1n_1$ (Vamban (Rg) 3 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}), but were on par. Pooled analysis results clearly indicated the superiority of the varieties at the closer spacing and the highest nutrient dose (Fig. 4).

The higher seed yield realized in APK 1 compared to Vamban (Rg) 3 is the consequence of the higher yield attributes, pod length, pod weight and 100 seed weight recorded in APK 1. The variations in seed yield due to varieties was expected. Prashanthi *et al.* (2001) reported significant differences in the seed yield of various genotypes of red gram.

The higher seed and haulm yields per hectare at narrow spacing (40 cm x 20 cm) compared to wider spacing (60 cm x 30 cm), despite the per plant performances being superior can be ascribed to the higher plant density in the former. The results are in conformity with the findings of Kumar *et al*. (2014) and Goud *et al.* (2016). The higher number of plants per unit area and number of pods harvested resulted in the maximum seed yields, it being 68 per cent higher than that realized with the wider spacing.

The maximum seed and haulm yields recorded with the highest level of nutrients (40:80:40 kg NPK ha^{-1}) reveal the response of the short duration red gram varieties to the increased doses. Seed yields were 11 and 19 per cent greater than that with 75 and 50 per cent lower NPK doses respectively. The superior yields would be due to the higher nutrient demands of the N fixing crop that could have been met with the 40:80:40 kg ha^{-1} dose of NPK. The significant role of N, P and K in pulse production has been reviewed by Thiyagarajan *et al.* (2003). According to Tandon (1995), a crop of red gram producing 1.20 t ha^{-1} of economic yield removes 85 kg N, 8 kg P, 16.0 kg K and 9.0 kg S ha^{-1}. This brings to focus the relevance of NPK nutrition in red gram. It is interpreted that the application of the chemical fertilizers increased the availability of nutrients (N, P and K) in soil solution and their utilization by the crop. Soil test based application could ensure the availability eliminating the possibilities of excesses and antagonistic interactions especially that with micronutrients. The greater absorption of nutrients influences photosynthetic rate and translocation to sink, ensuing better expression of yield attributes (Umesh *et al.,* 2013).

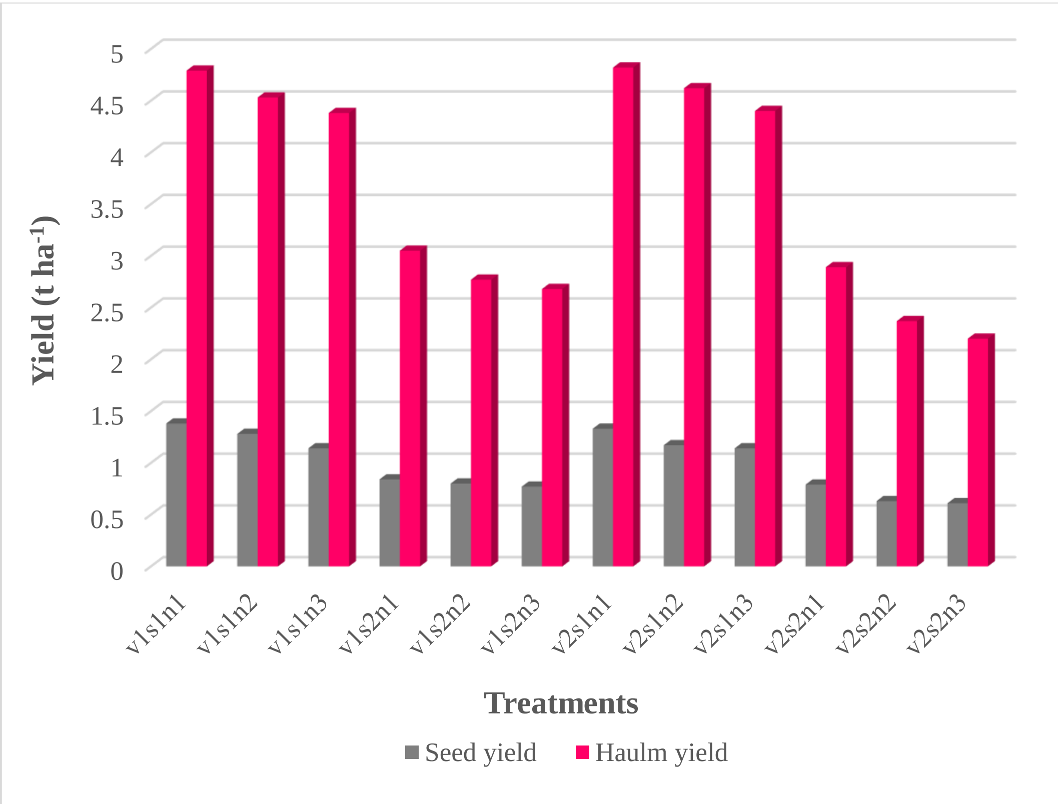
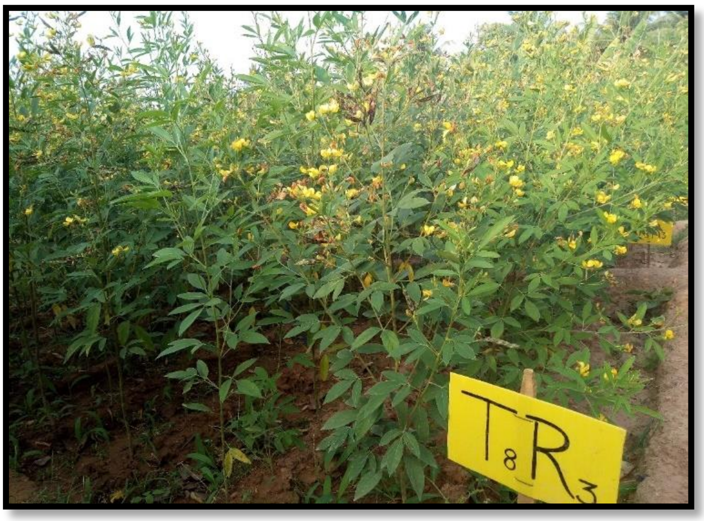


Fig. 4. Effect of V x S x N interaction on seed and haulm yield (pooled mean)



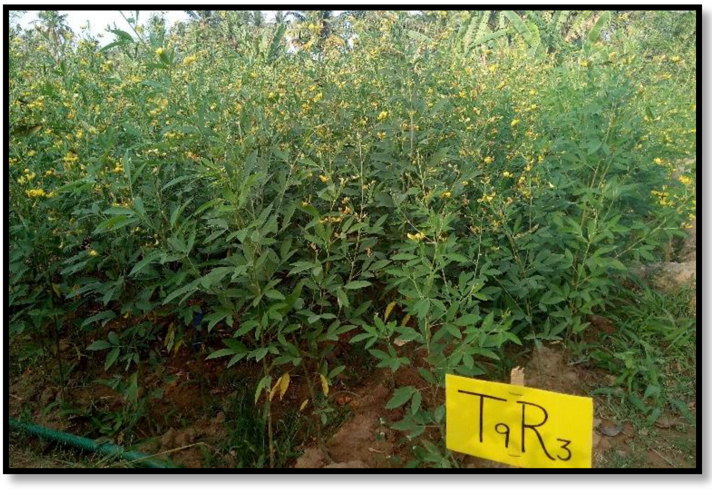


Plate 17. Pod formation stage in treatments T_7 ($v_2s_1n_1$), T_8 ($v_2s_1n_2$) and T_9 ($v_2s_1n_3$) during Experiment I

Plate 18. Pod development stage in treatments T_1 ($v_1s_1n_1$) and T_4 ($v_1s_2n_1$) during Experiment I

Plate 19. Individual pods in treatments T_1 ($v_1s_1n_1$), T_4 ($v_1s_2n_1$), T_7 ($v_2s_1n_1$) and T_{10} ($v_2s_2n_1$) during Experiment I

5.1.4 Physiological Parameters

Dry matter production in the plant computed at 20 days interval increased with advancement in crop age and was maximum at harvest (Table 14). Maximum DMP per plant was computed in the variety APK 1, at all stages except at 40 DAS during the second year. The spacing 60 cm x 30 cm, the nutrient level 40:80:40 kg NPK ha^{-1} and the interaction involving v_1 / v_2, s_2 and n_1 recorded the highest DMP at all stages of observation.

APK 1 was found to be shorter and lesser branching compared to Vamban (Rg) 3. However, it is interpreted that the higher pod yields (15 - 20 g plant^{-1}) contributed to the higher DMP per plant in this variety. The better growth and yield attributes recorded under wider spacing contributed to the higher per plant DMP in the treatments involving 60 cm x 30 cm (Meena, 2010). Maximum DMP per plant was registered by the NPK dose of 40:80:40 kg ha^{-1} and it was the lowest in 20:40:20 kg NPK ha^{-1} level. Plant dry weight increased markedly with increasing levels of nutrients. The balanced and adequate use of NPK at the highest rate promoted plant growth parameters that resulted in increased DMP (Kumar *et al.,* 2013). The higher DMP at harvest in the combination involving APK 1, 60 cm x 30 cm and 40:80:40 kg NPK ha^{-1} might be due to combined effect of these factors on plant growth and yield attributes.

Crop growth rate is the rate of dry matter accumulation per unit land area per unit time in crop stands. It is considered as a useful growth parameter for estimating the production efficiency of the crops. In the present study, the CGR was found to increase up to 40 - 60 DAS, the stage of flowering to pod development and thereafter it declined (Fig. 5 a and b) as the crop matured.

The lower CGR values assessed in the initial growth stage (20 - 40 DAS) is on account of the crop being in the seedling and early development stages during this period. The values were found to decline at the terminal stages of crop growth owing to the maturity and senescence that set in towards the harvest stage. Further red gram is characterized by a leaf shedding nature and it was noticed in the in the standing crop from the pod development stage onwards. The trend for CGR remained similar in both years.

Although the DMP per plant was higher under wider spacing, CGR computed were maximum under closer spacing as these were computed on land area basis and spacing and plant density were critical in its computation. The higher CGR computed is thus due to the higher biomass per unit area due to the higher plant density. According to Cirilo *et al*. (2009) CGR depends upon its radiation use efficiency, which is the amount of intercepted photosynthetic active radiation, and the efficiency of the crop to convert intercepted photosynthetic active radiation to above ground biomass. The intercepted photosynthetic active radiation is related to canopy size, canopy architecture, and incident photosynthetic active radiation (Maddonni *et al.,* 2001). A lower plant density led to decreased interception of the photosynthetically active radiation than warranted, and hence photosynthetic efficiency. It is explicated that the better photosynthesis and carbohydrate accumulation is due to the larger leaf area during the grand growth phase 40 - 60 DAS.

The effect of the higher nutrient dose is the consequence of the adequate nutrient supply and growth promotion that followed. The combined influence of the better growth elicited by APK 1, closer spacing and nutrient level of 40:80:40 kg NPK ha^{-1} resulted in the highest CGR at 80 - 100 DAS (Fig. 5 a and b).

Relative growth rate determines the dry weight increase in plant over a time interval in relation to initial dry weight (Tajul *et al.,* 2013). Varietal differences in RGR was not marked while the wider spacing resulted in the highest RGR in the vegetative stages and this would be on account of the better availability of the resources enhancing growth and dry matter production. However, as growth advanced, RGR values were not significantly different from that under closer spacing. With respect to the nutrient levels, fluctuations were noticed in the first year as the lower doses could record higher RGR values and the variations are assumed to be due to the computation with respect to the initial dry weights. In the interaction effects also RGR computed during the different growth intervals varied widely.

Irrespective of the treatments, RGR was greater at the early stage (20 to 40 days interval) and showed a decreasing trend with the advancement of plant age (Fig. 6 a and b). The decrease in RGR was probably due to the increase of metabolically active tissues than meristematic tissues at further stages of crop, which contributed less to the plant growth (Ahmad *et al.* (2002); Hussain *et al.* (2011)). This has been explained by Benincasa (2003) that as plant organs develop and the plant approaches the physiological maturity, organ demands for photo assimilates for their own maintenance increases, reducing the photo assimilate availability for extra growth.

5.1.5 Agronomic Indices

Harvest index is a measure of physiological productivity potential of a crop variety and is interpreted as the ability to convert the dry matter into economic yield. It is computed as the ratio of economic yield to biological yield and varieties that have more seed yield and less biological yield would have higher HI values (Abdalla *et al.,* 2015). Higher the HI value, more will be the production efficiency and *vice versa.* Perusal of the data (Table 17) revealed that the varieties, spacing, nutrient levels and their combinations had no significant influence on HI during both years. The HI ranged from 0.20 - 0.23 and 0.21- 0.22 during the first and second year respectively, within the values reported for red gram, 0.20 - 0.24 (Singh *et al.,* 2016). Excessive vegetative growth in pulses, dry matter accumulation in vegetative parts as compared to reproductive parts would be the reason for low HI.

The partial factor productivity is a useful measure of nutrient use efficiency because it provides an integrative index that quantifies total economic output related to utilization of all nutrient resources added to the system (Cassman *et al.,* 1996). The production efficiency, PFP is computed as the ratio of yield to the total nutrients received including both applied as well as indigenous (Panwar *et al.,* 2019). The variety APK 1, the spacing 40 cm x 20 cm and the highest nutrient level resulted in the maximum PFP for N, P and K. In V x S x N, the highest PFP for N, P and K were realized in $v_1s_1n_1$ interaction.

The higher values of PFP recorded corresponds to the higher yields recorded with APK 1 variety, closer spacing and higher nutrient levels. Yadav (2003) attributed the increase in PFP to the better crop management practices, and increased nutrient conversion ratio in plant systems. In the present study also, the balanced fertilization and crop management practices would have led to the efficient conversion of solar energy to economic yields which increased the partial factor productivity. The results are in accordance with reports of Jat *et al.* (2011).

5.1.6 Plant Analysis

During both the years, total chlorophyll content was significantly the highest for the wider spacing 60 cm x 30 cm and for the combination $v_2s_2n_2$. The higher levels of nutrients, n_1 and n_2 resulted in a superior value (1.09 mg g^{-1}) during the first year alone. Chlorophyll is cardinal for photosynthesis and are present in the chloroplasts. The higher chlorophyll contents recorded can be related to the increased uptake of N by the plants under wider spacing (0.879 and 0.871 g N per plant during first and second year respectively) and higher nutrient levels. Kulsum *et al.* (2007) observed that with the increasing N levels in black gram, leaf chlorophyll and N content increased linearly. The presence of N in excess promotes development of the above ground organs with abundant dark green (high chlorophyll) tissues of soft consistency and its contribution in increasing the grain yield (Saeid and Maryam, 2011).

Nutrient uptake is computed as the product of nutrient content and DMP. The variety APK 1, narrow spacing 40 cm x 20 cm and the higher nutrient level 40:80:40 kg NPK ha^{-1} recorded the highest total N, P and K uptake during both years (Fig. 7 a and b).

Significantly higher uptake of NPK recorded under narrow spacing (40 cm x 20 cm) and higher nutrient level 40:80:40 kg NPK ha^{-1} might be due to increased per unit area DMP under narrow spacing (3646 and 3800 kg ha^{-1} during first and second year respectively) and at higher nutrient dose. Higher nutrient uptake with closer spacing have been illustrated in green gram by Tekale *et al*. (2011) and at higher nutrient levels in red gram by Shivran and Ahlawat (2000).

5.1.7 Quality Parameters

Pulses are rich sources of protein and supplement the daily requirements of the human diet and its content is estimated based on the assumption that protein contains 16 per cent N, and the N to protein conversion factor is taken as 6.25 (Simpson *et al.,* 1965). The seed protein content in red gram was found to vary significantly with varieties, spacing and nutrient levels during both years. Higher content in APK1 is a varietal attribute, while the effects of spacing and nutrient dose were due to the higher N uptake and content in seeds. The interaction $v_1s_2n_1$ (APK 1 + 60 cm x 30 cm + 40:80:40 kg NPK ha^{-1}) also eventuated in the significantly highest

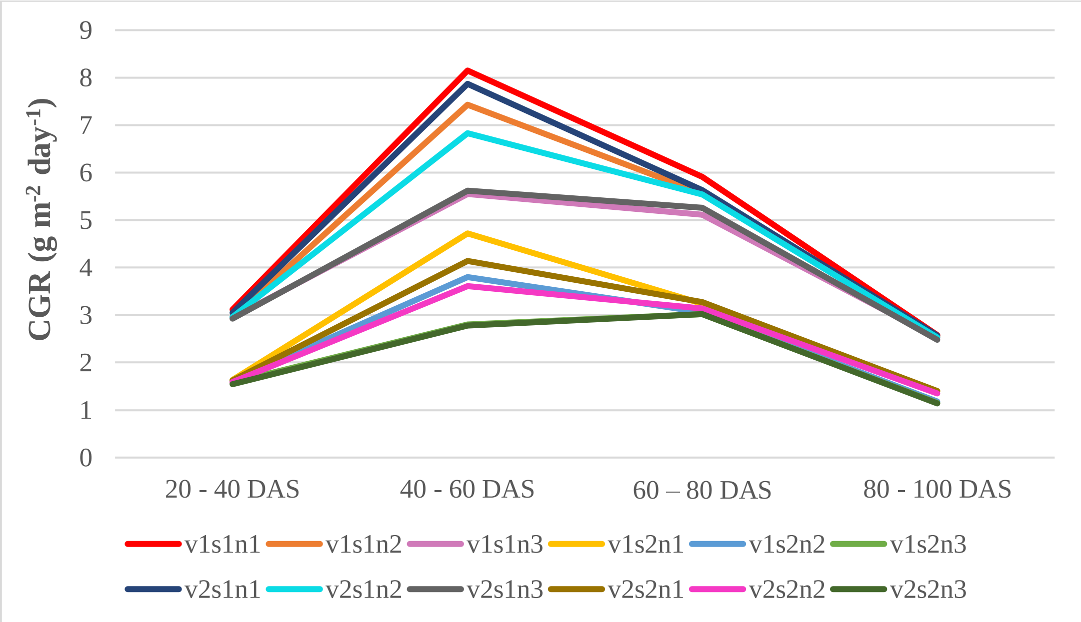


Fig. 5 a. Effect of V x S x N interaction on CGR during the first year (Experiment I)

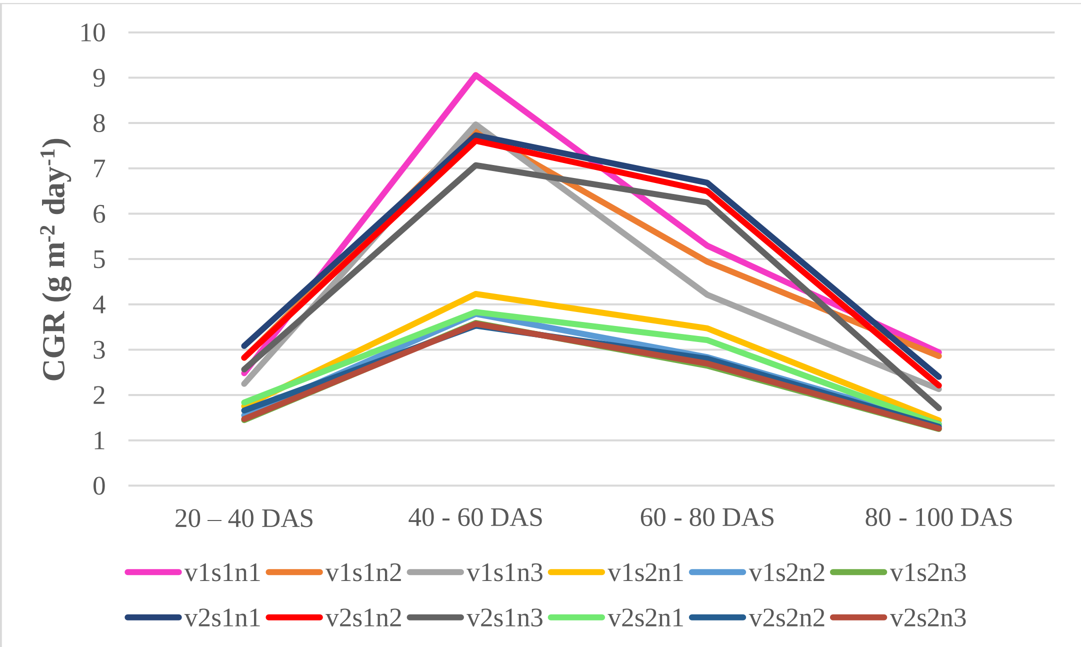


Fig. 5 b. Effect of V x S x N interaction on CGR during the second year (Experiment I)

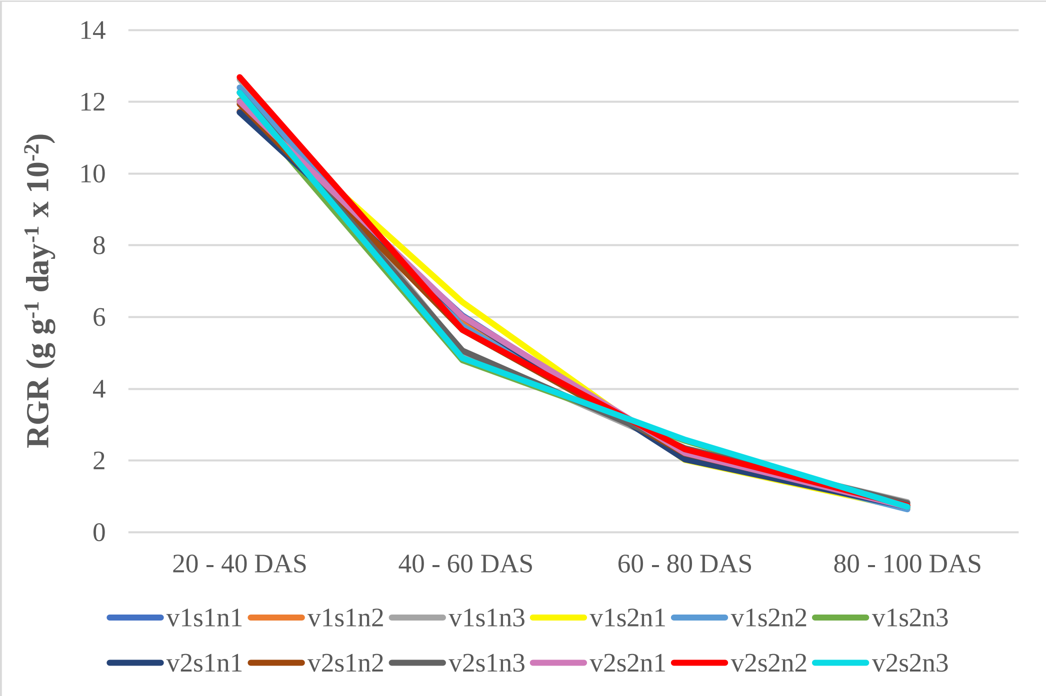


Fig. 6 a. Effect of V x S x N interaction on RGR during the first year (Experiment I)

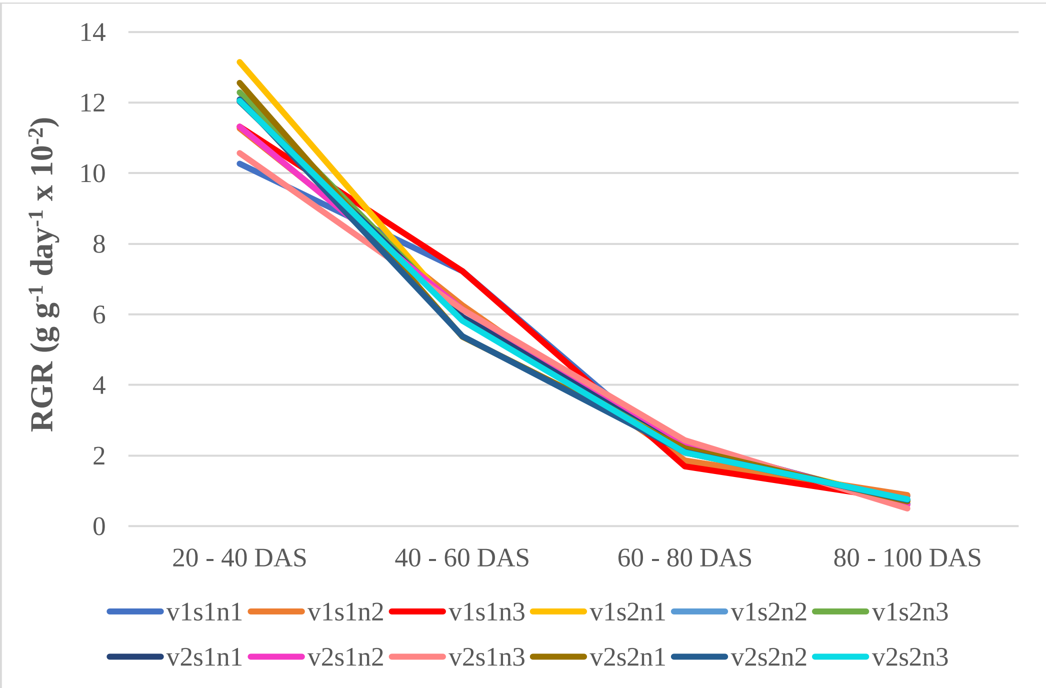


Fig. 6 b. Effect of V x S x N interaction on RGR during the second year (Experiment I)

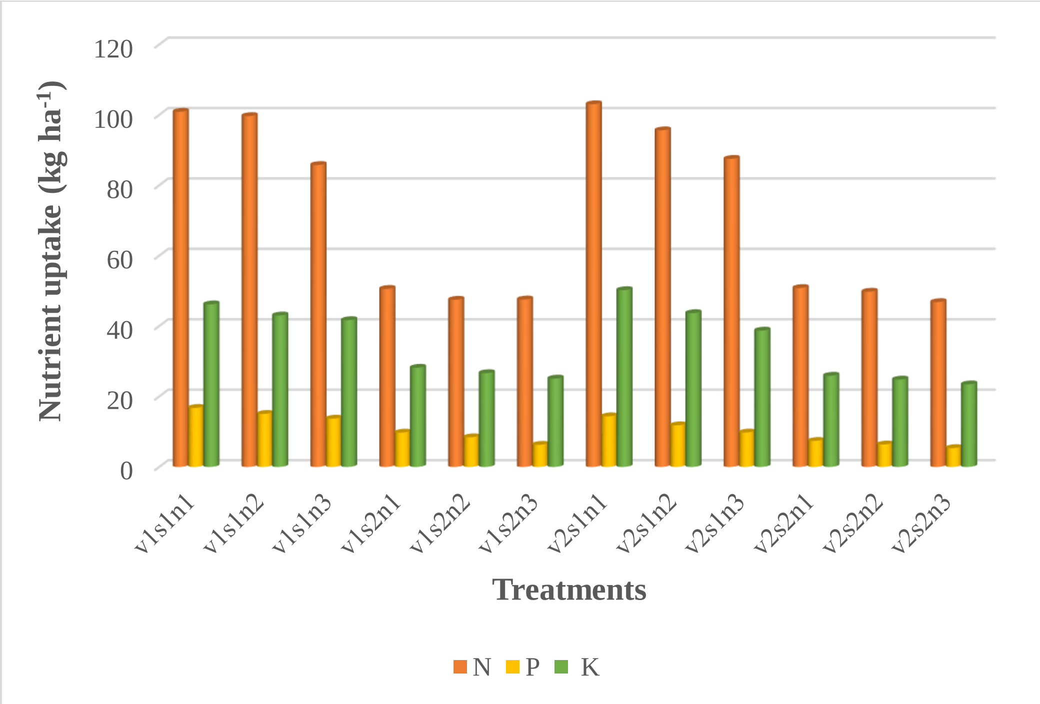


Fig. 7 a. Effect of V x S x N interaction on nutrient uptake during the first year (Experiment I)

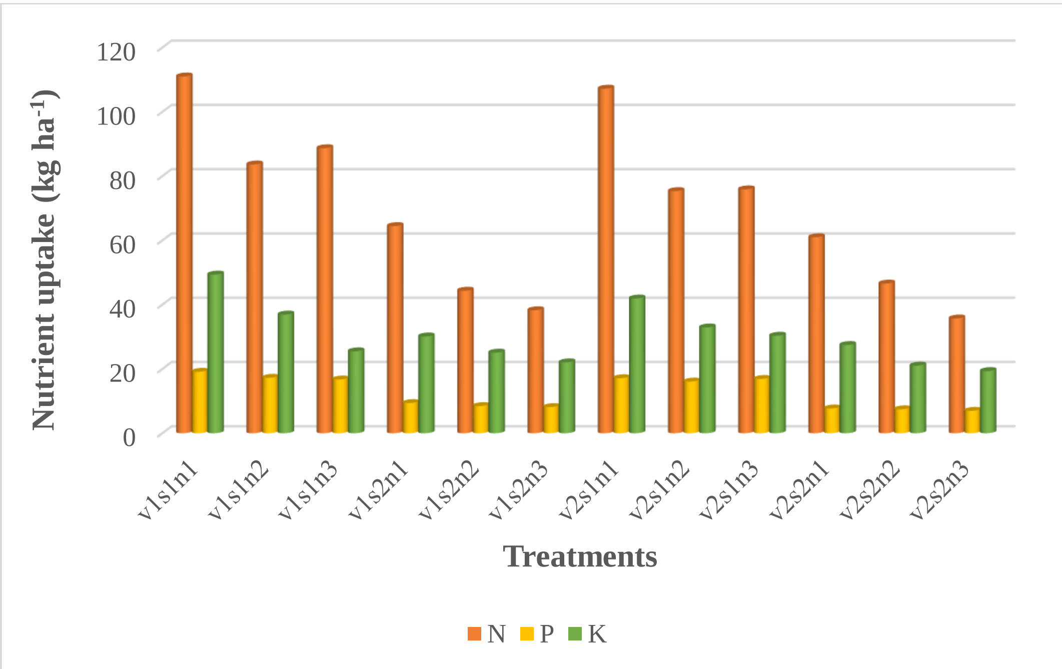


Fig. 7 b. Effect of V x S x N interaction on nutrient uptake during the second year (Experiment I) seed protein content, 19.38 and 21.99 per cent during the first and second year respectively (Fig. 8).

The wider spacing (60 cm x 30 cm) resulted in increased per plant N uptake of 0.879 and 0.871 g N during first and second year respectively (Table 20 a), owing to the increased N content in seeds (3.00 and 3.28 per cent during first and second year respectively). The highest N content under wider spacing resulted in highest seed protein content (18.78 and 20.47 per cent during the first and second year respectively).

The significantly highest seed protein content was observed in the highest nutrient level (40:80:40 kg NPK ha^{-1}). The N content in seed (3.02 and 3.43 per cent during first and second year respectively) were the highest and N being fundamental for protein synthesis, it would have ensured the enhanced protein content in seeds. The results are in agreement with the findings of Bhalu *et al.* (1995).

5.1.8 Soil Chemical and Biological Properties

The varieties, spacing, nutrient levels and their interaction did not exert any significant influence on soil pH during both the years. Nevertheless, increases in the soil pH status from initial values (4.21 and 5.59 during the first and second year respectively) were recorded with cultivation of red gram under different management practices in both the years.

Plant roots have the ability to induce pH changes either by releasing protons (H^+) or hydroxyl ions (OH^-) to maintain ion balance (Hinsinger *et al.,* 2003), depending on the nutritional status of the plants. Legume roots are generally known to exude organic acids that can lower the soil pH. However, the relationship between organic acid exudation and rhizosphere acidification is not that simple as the extrusion of H^+ would depend on the amounts of anions absorbed by roots relative to cations (Haynes, 1990; Jones and Darrah, 1994). Plant uptake of anions in excess of cations often causes the roots to secrete HCO_3^- in order to maintain electrical neutrality, a process that leads to increased rhizosphere pH. Further the liming done based on soil test data would have contributed to the increase in soil pH. Available evidence also suggested that legumes can lower soil acidity (Sakala *et al*., 2003; Anjaly, 2018).

No significant difference was observed in organic C status of the soil with the varieties, spacing, nutrient levels and their interaction during the both years. However, organic C (0.94 -1.16 and 1.68 -1.77 % during first and second year respectively) were observed to have increased from the initial status (0.81 and 1.65 %) after the harvest of red gram. The probable reason would be the leaf shedding noticed during crop growth. Quantification of the leaf fall during maturity stages revealed the additions to range from 115 to 150 kg ha^{-1} in the different combinations. According to Adjei-Nsiah (2012), leaf litters of upto about 2 t ha^{-1} are added by red gram during a single growing season, which can add to the organic C pool in soil.

An increase in soil nutrient status was registered from initial value after the harvest of the crop. The potential of red gram in improving soil fertility has been elucidated by Adjei-Nsiah (2012). Among the varieties, APK 1 resulted in the significantly highest soil available N, while P and K were assessed the highest in Vamban (Rg) 3. The wider spacing 60 cm x 30 cm and the higher nutrient level 40:80:40 kg NPK ha^{-1} recorded the maximum available NPK content in soil during both years.

The significantly highest post harvest available N estimated in APK 1 grown soil might be due to comparatively higher root nodulation, which is expected to have contributed to the N in soil. The higher uptake of P and K by APK 1 (11.67 and 13.18 kg ha^{-1} P and 35.13 and 31.51 kg ha^{-1} K during the first and second year respectively) would have caused reduction in available P and K status in post harvest soil compared to Vamban (Rg) 3. The higher available NPK under wider spacing might be due to lower uptake of nutrients, computed on area basis DMP, which was nearly 49 and 46 (N), 47 and 53 (P) and 42 and 33 (K) per cent less during the first and second year respectively compared to that in narrow spacing. Plant population was lower under wider spacing leading to a higher status in soil indicating the lower utilization of the nutrients. The higher nutrient dose added more NPK in soil compared to the lower doses. In addition, the N fixing property of red gram, the free N fixers in soil and the solubilization effect of root exudates and microbial activity on insoluble and fixed reserves of P and K in soil would have added to the availability of P and K (Ghosh *et al*., 2007). The authors have elucidated the exudation of significant amounts of malonic and oxalic acids along with piscidic acid from red gram roots which can specifically chelate from iron (Fe) ligands and solubilize P.

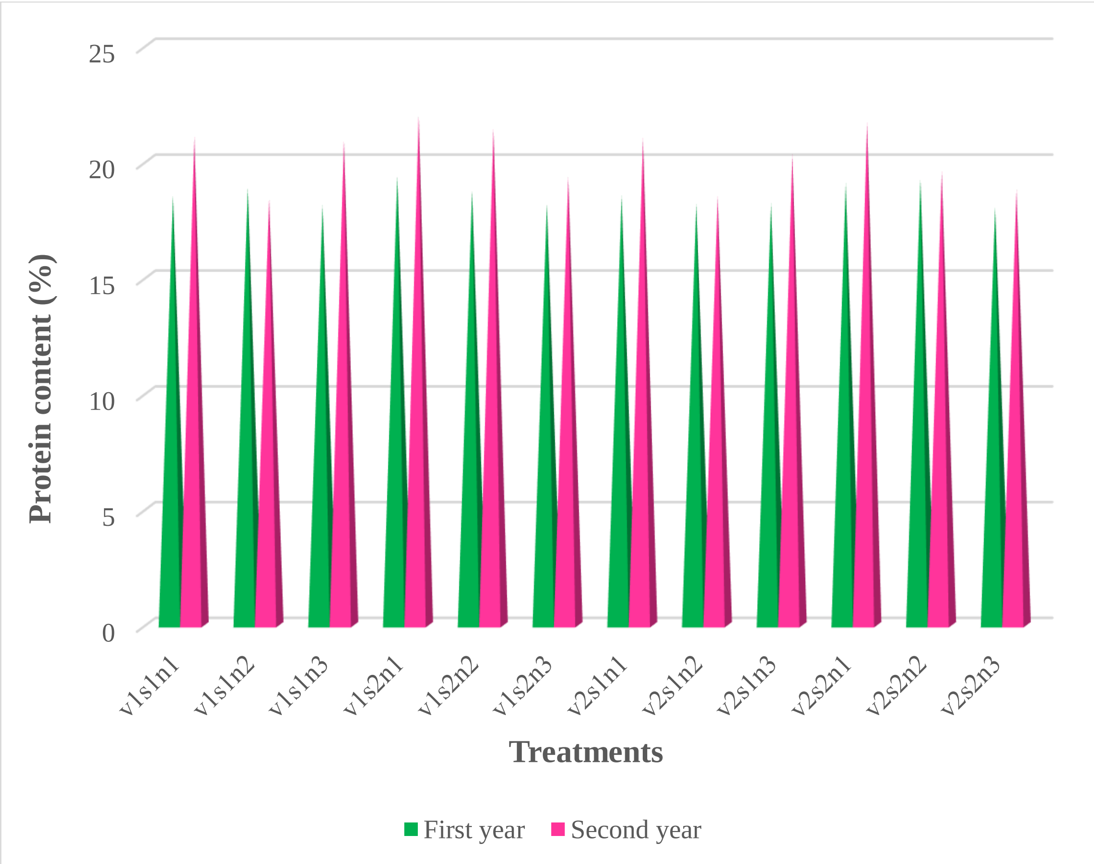


Fig. 8. Effect of V x S x N interaction on seed protein content

An increase in soil microbial counts were observed after the harvest of red gram. Microbes control the soil enzymatic activities that catalyze biochemical reactions and nutrient cycling in soils (Burns, 1982) and the changes in soil chemical properties are consequent to microbial activities. Among the microbial communities enumerated, the domination followed the order bacteria > fungi > actinomycetes. The increased microbial count represents the mineralization rates of organic matter (Frankenberger and Dick, 1983).

Superior microbial counts in APK 1 combination with 40 cm x 20 cm spacing and NPK dose of 40:80:40 kg ha^{-1} can be attributed to the better growth, biomass production with the higher nutrient levels and closer spacing. In addition the root nodulation, fallen leaves and higher root density and hence increased rhizospheric exudation ensure a congenial environment for microbial multiplication, especially the plant growth promoting microorganisms (Nagar *et al.,* 2016). The favourable niche created thus enhanced the microbial counts.

5.1.9 Nutrient Balance Sheet

Nutrient balance sheet is an assessment of nutrient additions, removals and balances in the agricultural production system, which generates useful and practical information on whether the nutrient status of a soil (or area) is being maintained, built up, or depleted with cultivation and management practices adopted (Singh *et al.,* 2017).

The N balance in soil was positive and whereas the balance sheet for P was positive for all the treatment combinations involving s_2 during the first year. During the second year, all treatments showed positive balance for P except $v_1s_1n_1$, $v_1s_1n_2$, $v_1s_2n_2$ and $v_2s_2n_3$. The treatments with the exception of $v_1s_1n_1$, $v_1s_2n_1$ and $v_2s_1n_1$ during both years and $v_2s_2n_1$ during the second year showed negative balance for K (Fig. 9 to 11).

The actual N balance in soil was comparatively higher than the expected balance. It is deduced that apart from the nutrient inputs added through external sources (FYM, N biofertilizer and chemical fertilizer) and soil contribution, there was an apparent gain attributed to the legume effect enunciated in pulses (Ghosh *et al.,* 2007). Legumes have the capacity to fix atmospheric N which contributes to N status in soil. The results are supported by the findings of Zahran (1999). Red gram is reported to shed senescent leaves during maturity phase (Singh *et al.,* 1994) and the decomposition of fallen leaves would have augmented the soil N status. After accounting for the N uptake, the status remained positive indicating the increase in the net N balance of soil. The results are in conformity with the reports of Katayama *et al.* (1999) in red gram. The magnitude of apparent N was highest in the treatments involving 40 kg N ha^{-1}, the highest dose and the narrow spacing 40 cm x 20 cm due to increased legume effect.

The high initial P status and additions of P, resulted in positive P apparent balance during both years in treatments involving s_2, a lower plant density and hence a lower crop uptake. Negative balances recorded in the combinations involving s_1 might be due to the higher P uptake and the P dynamics that normally ensue in acidic soils. Yan *et al.* (2020) documented the possibility of leaching risks in P as continuous P application in acidic red soils changed the composition of P fractions and the bioavailability as well as the leaching risks were found to have increased.

The negative balance of K in treatment combinations involving n_2 and n_3 might be due to the leaching losses due to the total precipitation experienced during the first (216.2 mm) and second year (390.2 mm) of cropping. Immobilization of K in soil also contributed to the negative balance of K (Vipitha, 2016). Although the same phenomenon occurs in the entire field irrespective of the treatments, combinations involving the highest dose of K, n_1 (40 kg ha^{-1}) recorded positive balances during both the years indicating retention in soil after losses. The negative balance was found maximum in the lowest dose (n_3) treatment.

5.1.10 Economic Analysis

Among the various treatments tried, the treatment T_1 ($v_1s_1n_1$), the combination of APK 1 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1} recorded the highest net return and B:C ratio during the both years, followed by the treatment T_7 ($v_2s_1n_1$) Vamban (Rg) 3 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}. The above could be ascribed to the higher seed yields realized in the treatment being the cumulative effects of the variety, higher plant density and adequate and balanced nutrition. Net returns and B : C ratio were the lowest in the combination of Vamban (Rg) 3 + 60 cm x 30 cm + 20:40:20 kg NPK ha^{-1} (T_{12}) due to the lower yields. Pooled mean of net return and B: C ratio were also the highest for the APK 1 raised at 40 cm x 20 cm with 40:80:40 kg NPK ha^{-1}, followed by the treatment Vamban (Rg) 3 cultivated with the same management practice.

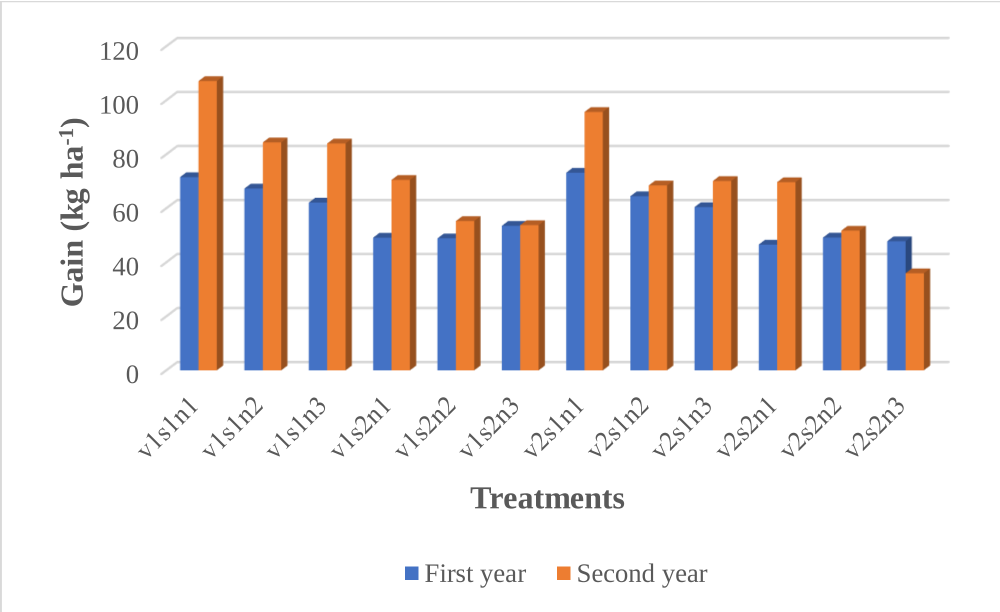


Fig. 9. Nitrogen balance during the first and second year (Experiment I)

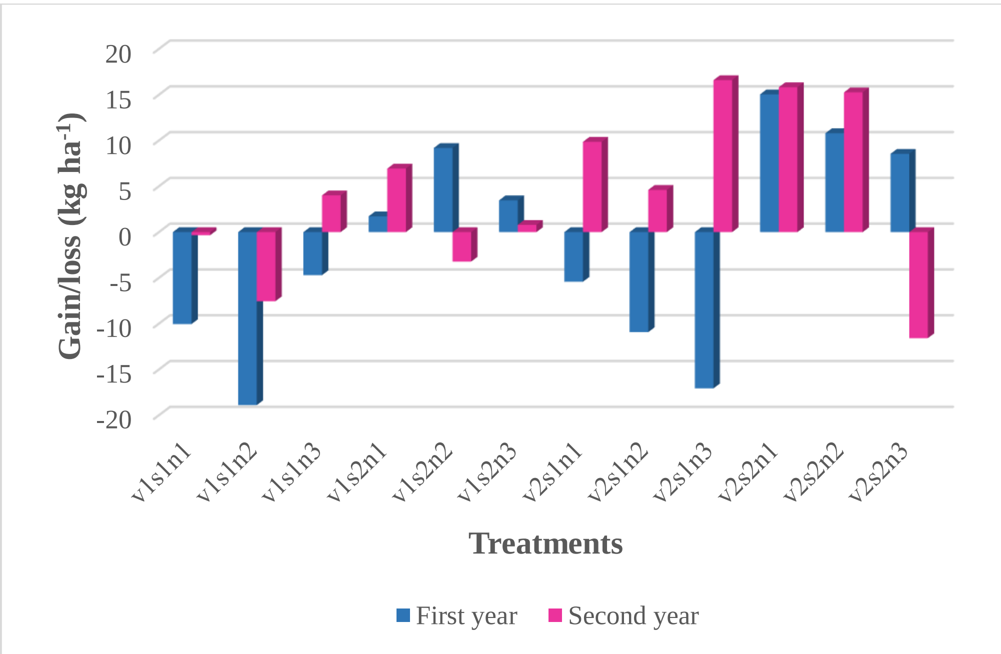


Fig. 10. Phosphorus balance during the first and second year (Experiment I)

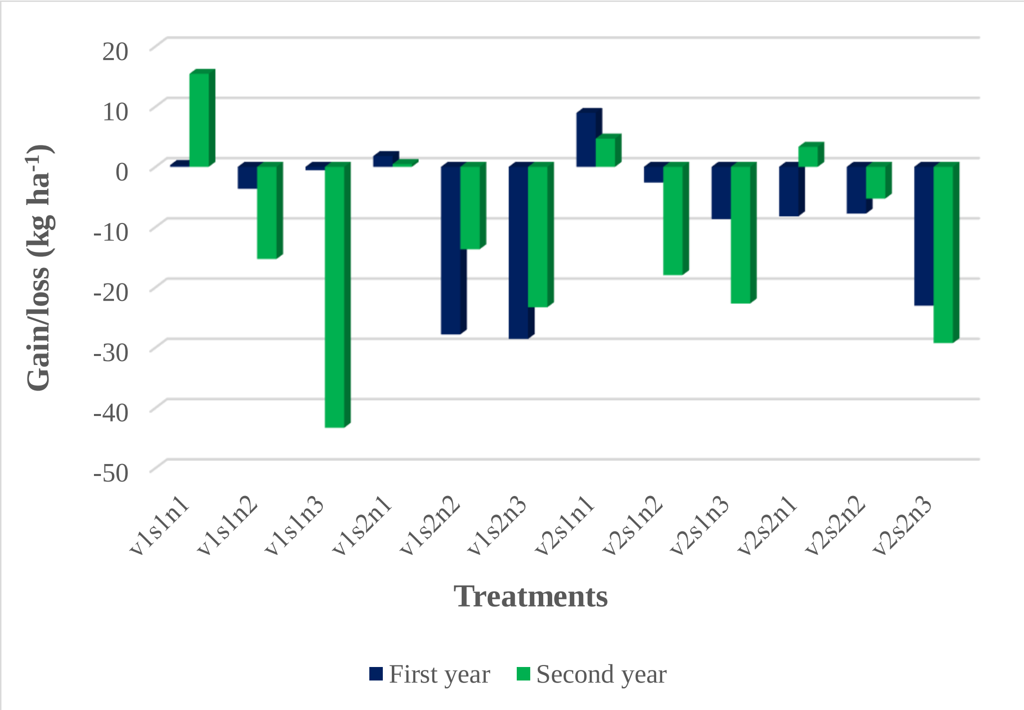


Fig. 11. Potassium balance during the first and second year (Experiment I)

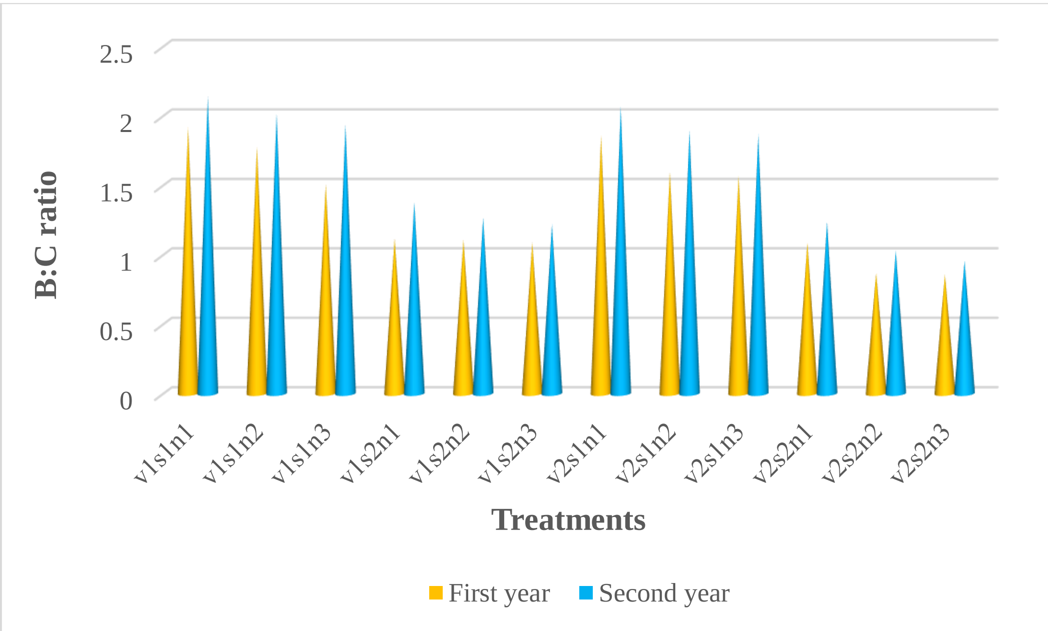


Fig. 12. Effect of V x S x N interaction on B:C ratio during the first and second year (Experiment I)

The experiment on the identification of a suitable short duration variety in red gram, and standardization of its spacing and nutrient levels conducted for two consecutive years has proven that APK 1 and Vamban (Rg) 3 are suitable for cultivation at a spacing of 40 cm x 20 cm with an NPK dose of 40:80:40 kg ha^{-1} given based on soil test results and nutrient rating recommendations. Considering the economics, APK 1 combination with 40 cm x 20 cm and NPK dose of 40:80:40 kg ha^{-1} was found to be more profitable.

5.2 EXPERIMENT II

5.2.1 Decomposition of Crop Residues

Crop residues are efficacious resources with multifaced uses and its recycling is considered a viable management strategy in agriculture for sustaining soil fertility and productivity. Amongst the various factors that control decomposition rates, the quality, soil decomposer organisms and environment are imperative. In the present study, the climatic conditions being similar, the residue quality and soil decomposers assumed prime importance.

Pulses are attractive propositions in cropping systems on account of the unique N fixing ability and carryover traits, organic matter build up, solubilization of P, improvement in soil physical conditions and soil microbial activity (Ghosh *et al.,* 2007), collectively called legume effect. Incorporation of legume residues in soil adds to the indigenous soil N status and compared to cereal crop residues, legume residues are of better quality (Tiemann *et al.,* 2015). Jakhar *et al.* (2020) evaluated the N mineralization rates in various legume residues and sequenced them in the order: red gram > green gram > black gram > soybean > cowpea.

The quantum and quality of residues are critical in deciding the nutrient turnover in soil. Residues in red gram accounted in the study for incorporation included shoots, roots and fallen leaves and the major contribution to the total residue was from the above ground plant parts. The quantity of residues generated varied with the agronomic management practices (2.25 to 4.83 t ha^{-1}) and irrespective of the variety, maximum quantity was produced in the treatments that involved the narrow spacing and higher nutrient dose (Fig.13). This was in accordance with the yields documented in these treatments. It is evident that the higher plant density under narrow spacing

(40 cm x 20 cm) and higher nutrient dose (40:80:40 kg NPK ha^{-1}) contributed to higher haulm yields and hence the larger amount of crop residues in these treatments. Maximum crop residue generation was recorded in Vamban Rg (3) + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1} (T_7), 4.83 t ha^{-1}, on par with APK 1 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1} (T_1), 4.75 t ha^{-1}.

The quality of residues is decided by its biochemical characters and these play a significant role in deciding the decomposition rates. Perusal of the variations in the biochemical characters, cellulose, hemicellulose, lignin and phenol content of red gram residues revealed that there were no marked differences with the treatments. The values were in the range, 12.28 - 12.72 per cent cellulose, 19.10 - 19.14 per cent hemicellulose, 6.76 - 6.89 per cent lignin and 5.80 - 5.93 mg g^{-1} phenol. According to Chen *et al.* (2011), the hierarchy of decay of residue constituents follows the order, sugars > hemicellulose >cellulose = chitin > lignin.

A C:N ratio less than 20:1 favours mineralization (Hadas *et al.,* 2004), and ensures recycling of nutrients, while the ratio of more than 20:1 is reported to favour immobilization (Moritsuka *et al.,* 2004). In the present study, the C:N ratio of the red gram residues, 18.2:1 to 21.8:1 (Fig. 14) fall close to the 20:1 range specified, ensuring higher decomposition rates. Nevertheless, the variations due to the treatments were significant. The residues from the treatment T_1 (APK 1 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}) recorded the narrowest C:N ratio (18.2:1). The widest C:N ratio was recorded in the crop residues from the treatment T_5, APK 1 + 60 cm x 30 cm + 30:60:30 kg NPK ha^{-1} (21.8:1). The higher N content (3.06 %) in red gram residues in T_1 would have contributed to the lower C:N ratio.

Residues with high N, low lignin and phenol concentrations and low C:N ratio are high quality residues and inscribes higher nutrient mineralization rates. With the lower lignin and phenol contents recorded, coupled with the higher N contents it is assumed that decomposition would be most rapid especially in the residues of T_1 with the narrowest C:N ratio.

Decomposition of the organic materials is expected to alter the soil properties. Monitoring the changes in soil pH over the 60 day period of decomposition, an increase with the residue decomposition was observed. The variations in soil pH were significant only at 60 and 80 DAI.

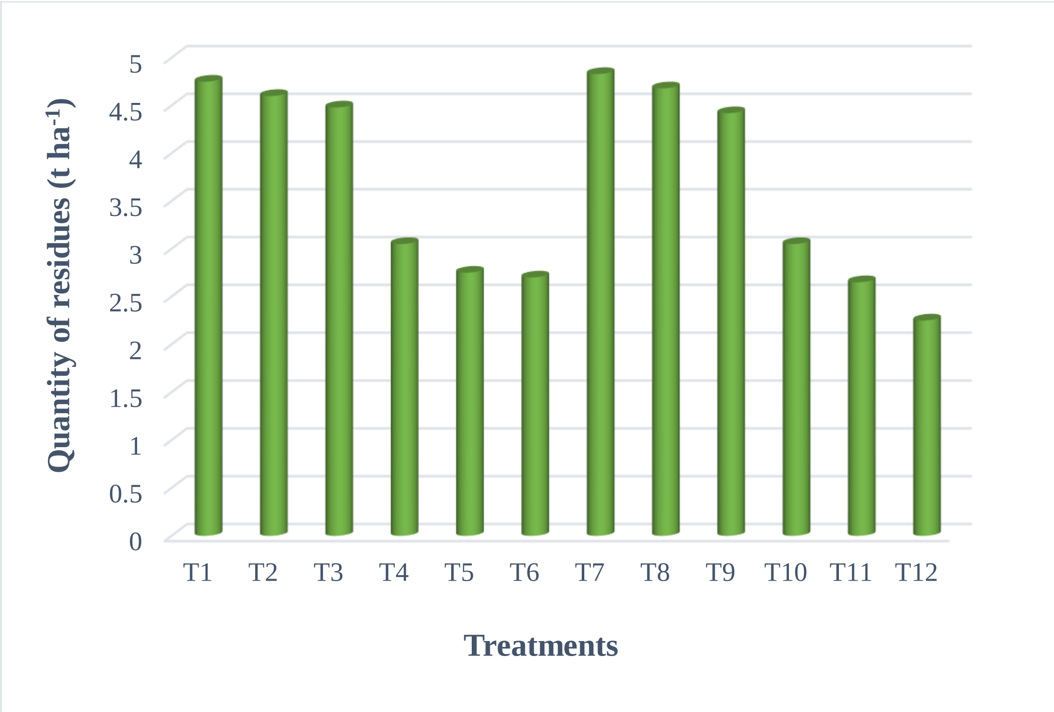


Fig. 13. Quantity of crop residues generated in red gram

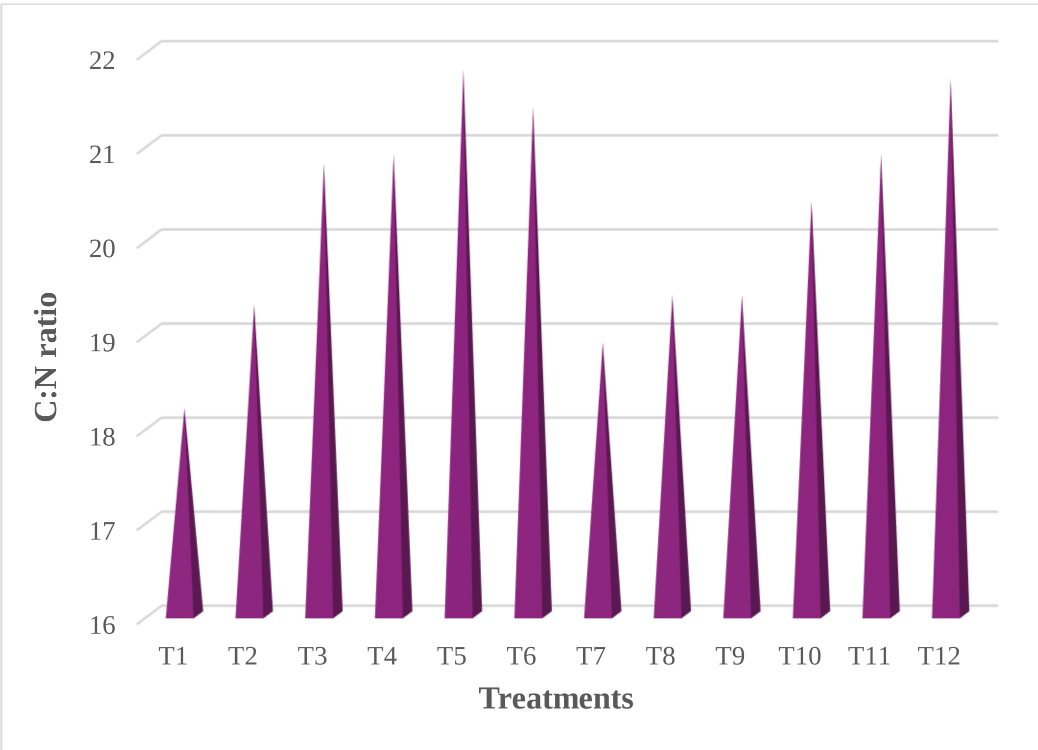


Fig. 14. C:N ratio of crop residues under different treatments

It is interpreted that the applied residues are subjected to microbial decomposition resulting in the release of organic acids that would have caused the changes in the soil pH (Malhi *et al.,* 2011). Yan *et al.* (1996) explained that addition of legume residue can cause an increase in soil pH due to biological decarboxylation of organic anions. The incorporation results in the formation of organic aluminium (Al) complexes in soil solution with the release of low molecular weight organic acids such as malates and oxalates. The organic-Al complex lowers the concentration of phytotoxic Al^{3+} in solution therefore precluding Al^{3+} from the hydrolysis reaction that increase soil pH (Haynes and Mokolobate, 2001). Available evidence also suggested that green manure legumes may lower soil acidity (Sakala *et al*., 2004). Kiiya *et al.* (2010) based on their investigation concluded that the reduction in soil acidity with lupine incorporation was greater than that with garden pea on account of its higher biomass production. Further differences in accumulation of organic anions between plant species could also occur. Legumes accumulated higher amounts of organic anions than grasses (Mengel and Steffens, 1982). Reduction in soil acidity and increase in pH to the near neutral range has its benefits on subsequent crops due to the positive effects on nutrient availability. The observations of the study indicate that addition of red gram residues could induce an increase in pH to the maximum of 0.6 units with its decomposition in 60 days.

Soil plays a major role in maintaining balance between global C cycle through sequestration of atmospheric C as soil organic carbon (SOC). Lal (2004), ascertained that the soil stores about three times the C as in terrestrial vegetation. SOC is the epicenter of physical, chemical and biological health of the soil and is the major source of energy for the soil biota.

Total organic carbon is a measure of the C contained within soil organic matter. Management practices that ensure greater amounts of C return to the soil are expected to cause a net build-up of the TOC stock (Singh and Benbi, 2020), amongst which crop residue incorporation is the most widely accepted approach (Lian *et al.,* 2016). The two fractions that constitute the TOC include labile and recalcitrant C. Labile soil carbon pool is smaller with rapid turnover and provides most of the energy for microorganisms. It mainly consists of soil microbial biomass C, dissolved organic matter, and easily oxidative organic matter, whereas the ROC usually refers to the fraction that is resistant to microbial decomposition or protected by mineral soil particles (Fang *et al*., 2005; Lutzow *et al.,* 2007). Recalcitrant organic C accounts for the long term C storage (Yang *et al.*, 2011).

The incorporation of red gram residues in soil could result in the accumulation of TOC; a resultant increase in LC and ROC during the 60 day period of assessment, owing to the organic matter addition and mineralization (Fig. 15, 16 and 17). The contents were significantly higher in treatments T_1 and T_7 consequent to the larger amounts of red gram residue added. Residue generated and hence incorporated in T_1 were more than 100 per cent higher than the lowest quantity in T_{12} (2.25 t ha^{-1}). According to Jiao *et al.* (2011), residue incorporation enhances the microbial population, provides energy and creates a conducive environment for accumulation of soil enzymes leading to organic matter decomposition. The rate of C mineralization was inversely proportional to the C:N ratio and the residues having lower C:N ratio had higher C mineralization (Jakhar *et al.,* 2020). The results of the study accord with the above finding. The higher dehydrogenase activity recorded is suggestive of the higher microbial activity and coupled with the lower C: N ratio of residues in treatments T_1 and T_7, it is interpreted that the decomposition would have been rapid, adding organic matter to different soil C pool.

Decomposition of organic materials is also the pathway for the release of nutrients entrapped in them enriching the soil nutrient pool. The variations in soil available NPK status are mainly due to differences in the quantum of residues and hence nutrients added *via* decomposition of residues in the different treatments. High soil moisture and temperature accelerate the decomposition of crop residues (Devevre and Horwath, 2000). During the decay period (60 days) 129.7 mm total rainfall was received. The soil moisture maintained by precipitation and high soil temperature during the month of April - June would have caused rapid decomposition of residues.

Considering the nutrient contents in the residues, the nutrient accretions estimated with the incorporation of residues in the different treatments followed the order $T_7 > T_1 > T_2 > T_8 > T_3 > T_9 > T_{11} > T_4 > T_{10} > T_6 > T_5 > T_{12}$ (Appendix IX). The rapid rate of decay and mineralization from the residues assured maximum addition in treatments T_1 and T_7, which substantiates the highest soil available NPK status in these

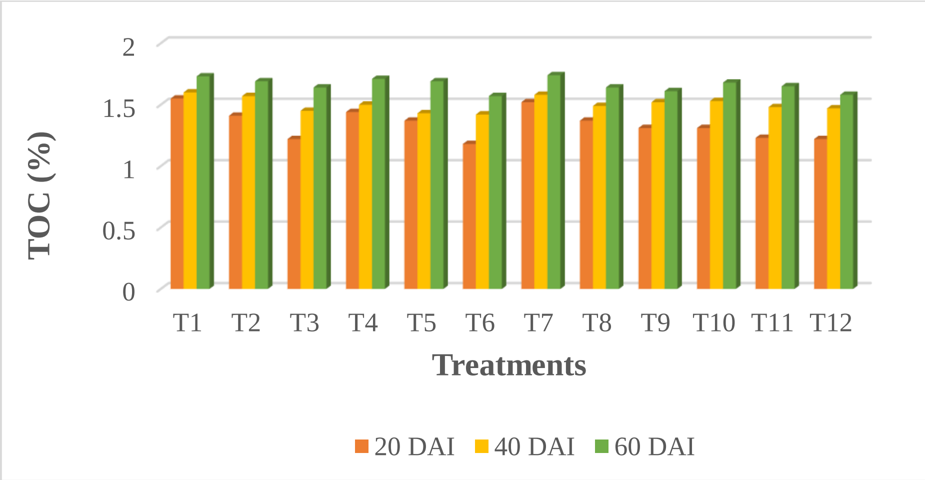


Fig. 15. Effect of residue incorporation on TOC at 20 days interval

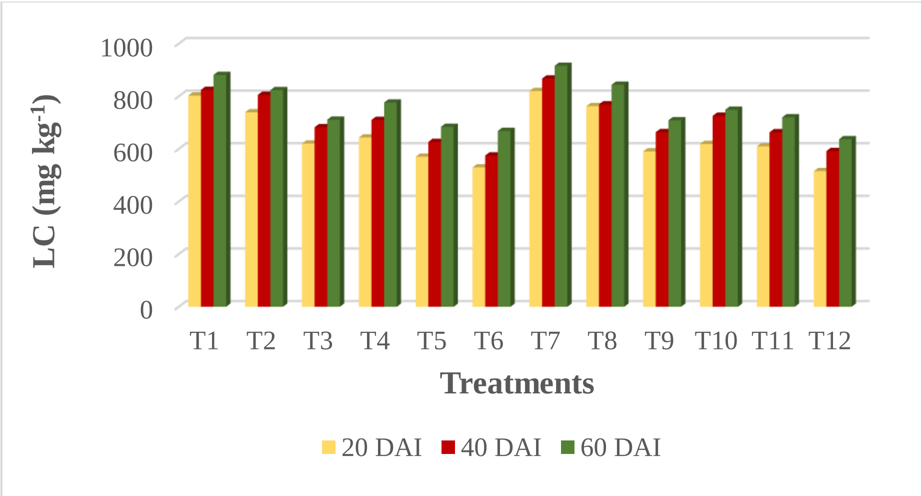


Fig. 16. Effect of residue incorporation on LC at 20 days interval

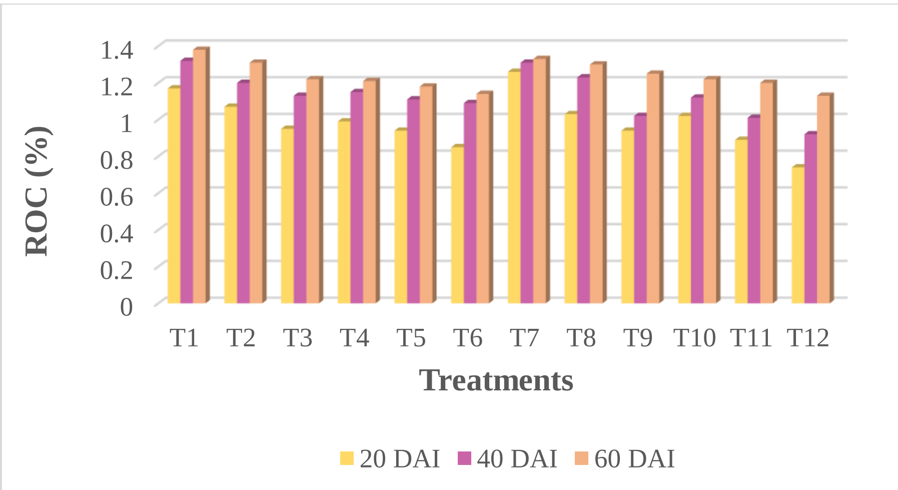


Fig. 17. Effect of residue incorporation on ROC at 20 days interval

treatments (Fig. 18). The higher apparent gain of N (Table 25 a) during the growth period of red gram in treatments T_1 (71.54 kg ha^{-1}) and T_7 (73.17 kg ha^{-1}) would also have added to the N status in the respective treatments. Bakht *et al.* (2009) also reported a significant increase in N content of soil due to green gram residue incorporation in green gram - wheat cropping system.

Ghosh *et al.* (2007) opined that nearly 40 per cent of C and 80 per cent of total N present in Sesbania were released on incorporation in about two weeks. Based on the P and K uptake values in red gram (Table 20) it is speculated that the increased available P and K status in T_1 and T_7 with decay are due to the comparatively higher P and K contents in red gram and their mineralization during decomposition. This is in accordance with the findings of Singh *et al.* (2012 a). According to their reports, organic P in crop residues could provide a relatively labile form of P to succeeding crops, thus, providing a larger pool of mineralizable soil organic P to supplement soluble inorganic P in soil (Singh *et al.,* 2012 a).

Dehydrogenase enzymes are indicators of overall soil microbial activity (Gu *et al.,* 2009; Salazar *et al.,* 2011). The enzymes play a significant role in the biological oxidation of soil organic matter by transferring hydrogen from organic substrates to inorganic acceptors (Zhang *et al.*, 2010). Several authors have reported the positive correlation between dehydrogenase activity and organic matter content (Zhao *et al.,* 2010; Yuan and Yue, 2012). The dehydrogenase activity and nutrient dynamics are directly related (Manjaiah and Singh, 2001). An increase in dehydrogenase activity was observed with incorporation of red gram residues and is indicative of higher microbial oxidative activities in soil. The highest values were obtained at 60 DAI and were the maximum in T_1 and T_7 corresponding to the larger quantum of quality residues in these treatments. The higher organic matter content could provide enough substrate to support the higher microbial biomass and hence the higher enzyme activity in these treatments at 60 DAI.

5.2.2 Legume Effect on Fodder Maize

5.2.2.1 Growth and Yield

The legume effect realized with incorporation of red gram residues generated with the different treatments did not bring about any marked variations in the emergence percentage of fodder maize and days to harvest, the latter being uniform, 60 DAS (milky stage). As no additional input was given, the growth was in response to the residual nutrient status. Vegetative growth in terms of plant height was maximum in T_7 (Vamban (Rg) 3 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}) and it is assumed that the highest nutrient status in soil ensured adequate supply of nutrients enhancing growth in maize. Fodder yield being the cumulative effect of the vegetative growth, recorded a similar trend (Fig. 19).

The green fodder yields realized in maize raised on the residual effect of red gram ranged from 28.81 to 33.61 t ha^{-1} which was nearly 77 to 90 per cent the potential yield of the crop under package of practice recommendations, wherein the external nutrient inputs had taken care of the nutrient demands of the crop. Satisfactory yields realized in fodder maize is indicative of residual effect of red gram. Singh and Verma (1985) had earlier reported that in a grain legume- wheat cropping system, red gram grown in the rainy season benefited the succeeding wheat and economized N by 12 kg N ha^{-1} over pearl millet. In this study it was observed that fodder maize grew on the nutrients added to the soil *via* the residues including the leaf fall and the net gain from red gram cropping. The direct and residual effect of fertilizers applied to legume crops benefiting the succeeding crops are documented (Ghosh *et al.,* 2007, Anjaly, 2018). The ease in availability was governed by the mineralization and activity of soil microorganisms. The variation in the performance among treatments involving residue incorporation may be ascribed to the quantum of residues generated in red gram and N fixed due to the treatment imposed during its cultivation and the subsequent decomposition. The highest dehydrogenase activities registered in T_7 and T_1 support the better availability of nutrients and growth.

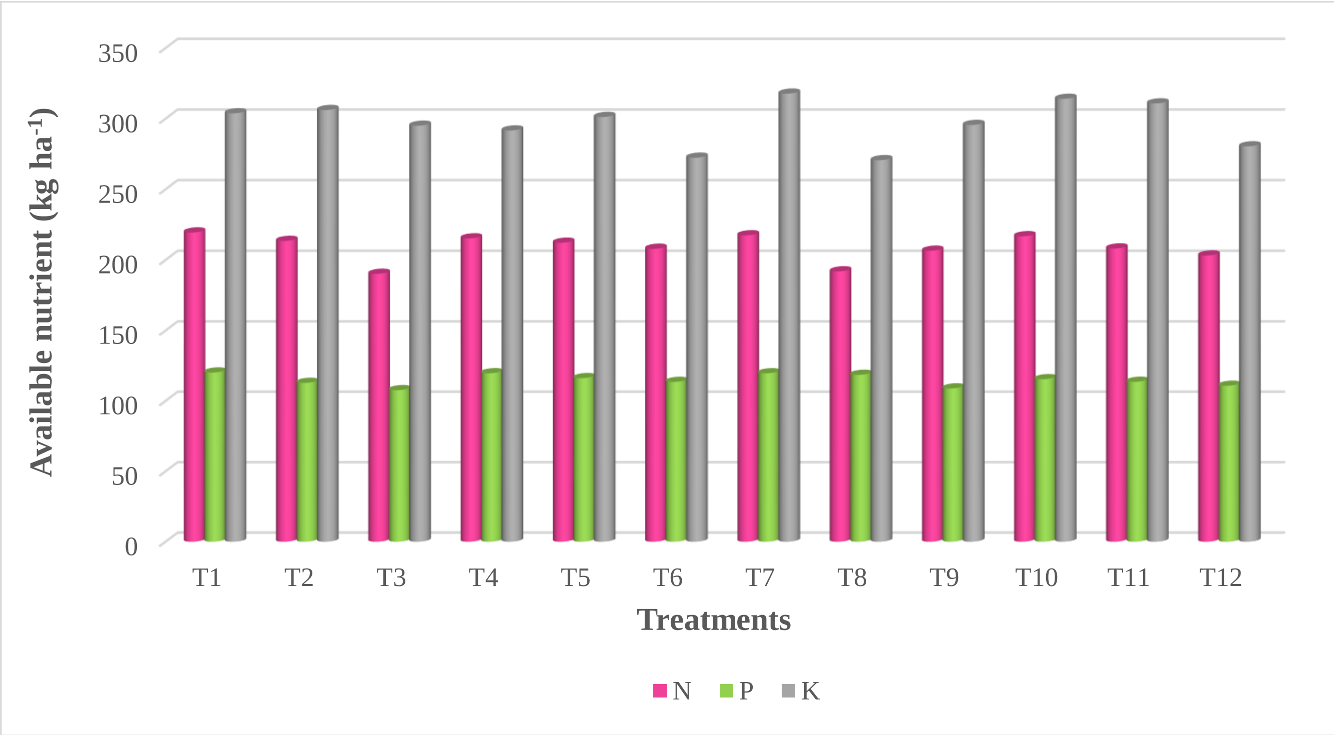


Fig. 18. Effect of residue incorporation on soil available NPK at 60 days after incorporation

Fig. 19. Residual effect of red gram on green and dry fodder yield

Plate 20. Fodder maize in treatments T_7 and T_1 (Experiment II)

5.2.2.2 Protein and Carbohydrate Content in Fodder Maize

An adequate supply and absorption of nutrients is fundamental for improved quality of fodder (Khan *et al.,* 2014 a). Legume effect and carryover effects from red gram influenced the protein content of fodder maize. Nitrogen plays a key role in plant metabolism as a constituent of amino acids and is involved in protein synthesis. Increased availability of N in soil enhances the leaf N content and hence the fodder quality by improving its protein content (Vinayraj, 2013). The available N contents in soil before cropping were high in the treatments T_7 (223.57 kg ha^{-1}) and T_1 (225.26 kg ha^{-1}) and it is presumed that there was an increased absorption of the nutrient as evident from their content in foliage (1.38 and 1.40 %). This resulted in higher protein content of 8.75 and 8.60 per cent (Fig. 20). The lowest protein content of 7.22 per cent was observed in the treatment T_{12} and it was noted that the soil available N status in the soil was also the lowest.

Carbohydrate is the main product of plant photosynthesis and plays an important role in the metabolic processes of plants. The difference in the amount of carbohydrates in the fodder was due to differences in N availability (Khan *et al.,* 2014 b). A negative relation for total carbohydrates has been reported with increase in N levels (Araya *et al.,* 2010).

According to Patel (2014) increase in N causes conversion of carbohydrates into fats due to increased meristematic activity and rapid respiration process. The higher amount of soil available N in the treatment T_1 and T_7 would have enhanced N uptake and hence a higher N content in fodder maize which would have led to lower amount of carbohydrates. The lowest N content (1.16 %) in T_{12} contributed to the significantly highest carbohydrate accumulation (Fig. 20).

5.2.2.3 Soil Properties

Decomposition and the subsequent mineralization of the residues has led to an increased fertility of the soils prior to raising the maize crop. Instead of a decline with cropping, the SOC was found to have improved with fodder maize cultivation. Kaur *et al.* (2008) reported that fodder maize is capable of sequestering atmospheric CO_2 into the plants and later returned the organic C into the soil. The crop is a soil exhausting crop with high biomass production potential, attributes that favour sequestration. Badri and Vivanco (2009) reported that plants contain about 20 - 40 per cent of their photosynthetically fixed C in root exudates. Carvalhais *et al.* (2010) also described the rhizodeposition effect in maize. Through rhizodeposition, plants add organic C to the soil. This C input, increased SOC status (Dijkstra *et al.,* 2020). According to Sundaram *et al.* (2012), the amount of C sequestered in the soil by fodder maize was 1.09 per cent. In addition, the residue incorporation contributed to the C storage in soil.

On the contrary the soil available NPK was observed to decline considerably after the harvest of fodder maize and is undoubtedly due to the utilization by the crop for its growth and metabolic activities. Maize crop requires an adequate supply of nutrients particularly N, P and K for its optimum growth and yield (Agba and Long, 2005). Being a soil exhaustive crop, fodder maize can exploit the inherent fertility of the soil to meet its demands and this would have depleted the nutrient status. However, the fertility status in soil with residue incorporation could support the maize crop for satisfactory yields.

The residual effect of the red gram legume and fertilizer treatments in fodder maize was apparent from the results of the study. The direct effect of the legume coupled with the decomposition dynamics of the incorporated residues could raise the fertility status of the soil resulting in fodder yields, nearly 80 - 90 per cent that realized under the package of practice recommendation. The study highlights the scope of reducing the external nutrient inputs in the succeeding crops of red gram cultivation, in a cropping sequence.

5.3 EXPERIMENT III

5.3.1 Growth Attributes

Growth attributes in terms of plant height and number of branches per plant in APK 1 were significantly higher in the nutrient management practice involving soil application of P and K solubilisers along with 100 per cent N, 50 per cent P and K through chemical fertilizers, T_4 (Fig. 21). The influence of the treatments is clearly evident from low values recorded in the treatment with no nutrient input application (absolute control). Plants were shorter with poor branching habit when no external

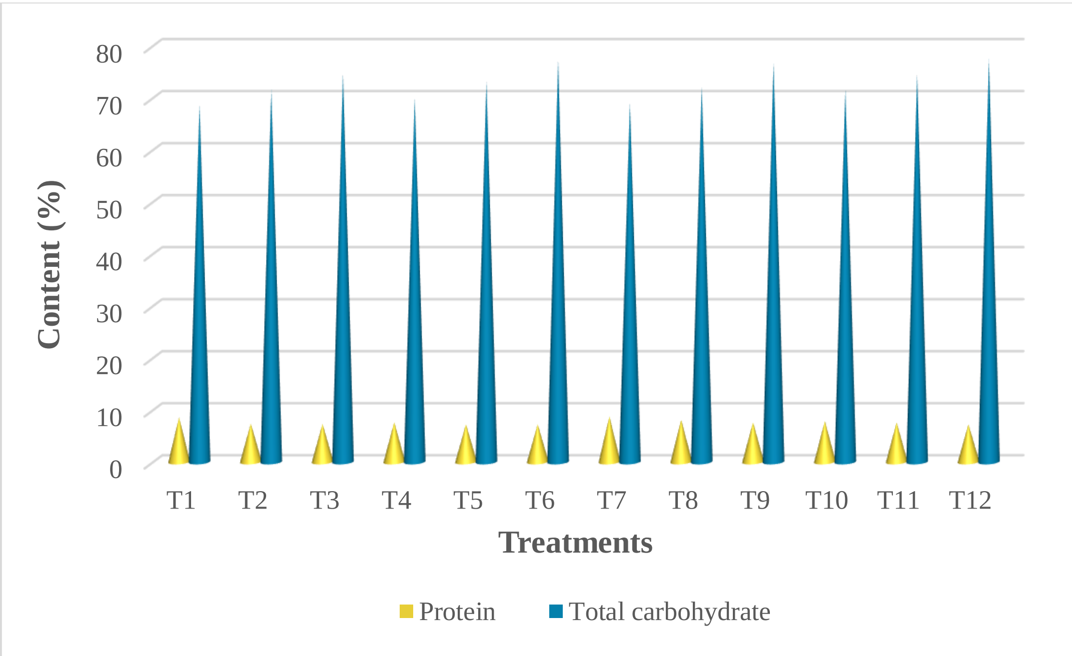


Fig. 20. Residual effect of red gram on protein and carbohydrate content in fodder maize

nutrient input was added as they had to survive on the native soil fertility. The better growth in red gram realized in T_4 is ascribed to the INM strategy adopted. Nitrogen fixation and the chemical fertilizer, urea ensured N requirement of the crop. The inclusion of P and K solubilisers, *Bacillus megaterium* and *Bacillus sporothermodurans* respectively along with P and K fertilizers increased the availability of these nutrients for uptake by red gram. Similar findings of increased availability and uptake resulting in profused growth and production of higher number of primary branches per plant have been reported (Singh, 2007). Further, *Bacillus* has the ability to produce growth hormones, especially indole acetic acid (IAA) (Sheng and Huang, 2001), and siderophores (Hu and Boyer, 1996) which would also have contributed to the enhanced growth. The higher nodulation observed is also supportive of the increased N supply. Enhancement of growth in red gram with microbial consortium over chemical fertilizer application has been reported by Gupta *et al.* (2015).

There were no marked variations in the nodule number, but the nodule weights were maximum in the treatments with foliar N application. Soil N application reduced the nodule weights although the numbers were comparable. It has been reported that the development of root nodules and N fixation activity are repressed when the nodulated roots are exposed to high concentrations of combined form of N, especially nitrate (Gibson and Harper, 1985; Streeter, 1988; Ohyama *et al.,* 2012). Yamashita *et al.* (2019) have documented repression of nodule growth and N fixation activity with ammonium and urea application in soybean. The inhibitory effect is caused directly by the accumulation of N compounds in nodules or *via* changes in photo assimilate partitioning in nodules. Among the foliar applied treatments (T_5 - T_8), the maximum nodulation was seen in 100 per cent N and 50 per cent P and K + biofertilizer application (T_8).

The role of P in root growth and proliferation has been well elucidated (Yin *et al.,* 2018). In the present experiment, root parameters were comparatively higher in the treatments involving P solubilisers (Table 40). Raja *et al.* (2006) based on their experiment opined that the improved growth and grain yield of rice with microbial consortium can be related to higher nutrient uptake by plant roots due to the induced morphological changes like increased root number, hair, length and thickness with inoculation of phosphate solubilizing *Bacillus sp.* The initial available P status in soil was 67.14 kg ha^{-1} and after harvest of red gram, there was more than 50 per cent increase in available P status in treatments T_4 and T_8. This might be due to the ability of *B. megaterium* to solubilize the fixed form of P in the rhizosphere, making it available to the growing plants which in turn ensured better root growth and development.

Strategizing P nutrition in red gram as 50 per cent in the form of chemical fertilizer and the remaining 50 per cent through the P solubiliser was found to yield better root growth. The results corroborate the findings of Sharma *et al.* (1995); Jain and Singh (2003).

5.3.2 Yield Attributes and Yield

The seed yield (1.48 t ha^{-1}) in red gram was superior with the soil application of 100 per cent recommended dose of N and 50 per cent recommended doses of P and K along with the biofertilizers (T_4), the results are depicted in Fig. 22. Perusal of data on yield attributes; pod length, number of seeds per pod, 100 seed weight, seed - pod ratio and average pod weight revealed that although there were no marked variations in these parameters except in pod weight, higher values were recorded in the same treatment, T_4. Thus, the highest yield obtained in the treatment can be deduced as due to the accruing effects of the higher values in the yield attributes. The second highest seed yield (1.46 t ha^{-1}) was recorded in the same combination in which 50 per cent N was applied as foliar spray. It was also noted that the yield attributes *viz.,* average pod length, number of seeds per pod and the 100 seed weight remained similar in the absolute control demonstrating the intrinsic varietal characters and hence the variations in the yield may be attributed to the differences in the number of pods harvested per plant.

The enhancement in yield attributing characters in treatment T_4 might be due to positive effects of the biofertilizers in solubilizing nutrients and promoting microbial activity in the rhizosphere. This is evident from the 10 per cent increase in yield in T_4 and T_8 compared to 100 per cent chemical fertilizer applied treatments. A higher uptake of these nutrients (Table 49) and the ensuing photosynthetic efficiency and source sink relations led to the improvement in yield attributes and yield in red gram. It is in consistence with the findings of Jat and Ahlawat (2004 a); Sikka *et al.* (2016); Nagar *et al.* (2016). The significant role of nutrients in regulating the source to sink translocation is well elucidated by Zhao *et al.* (2019).

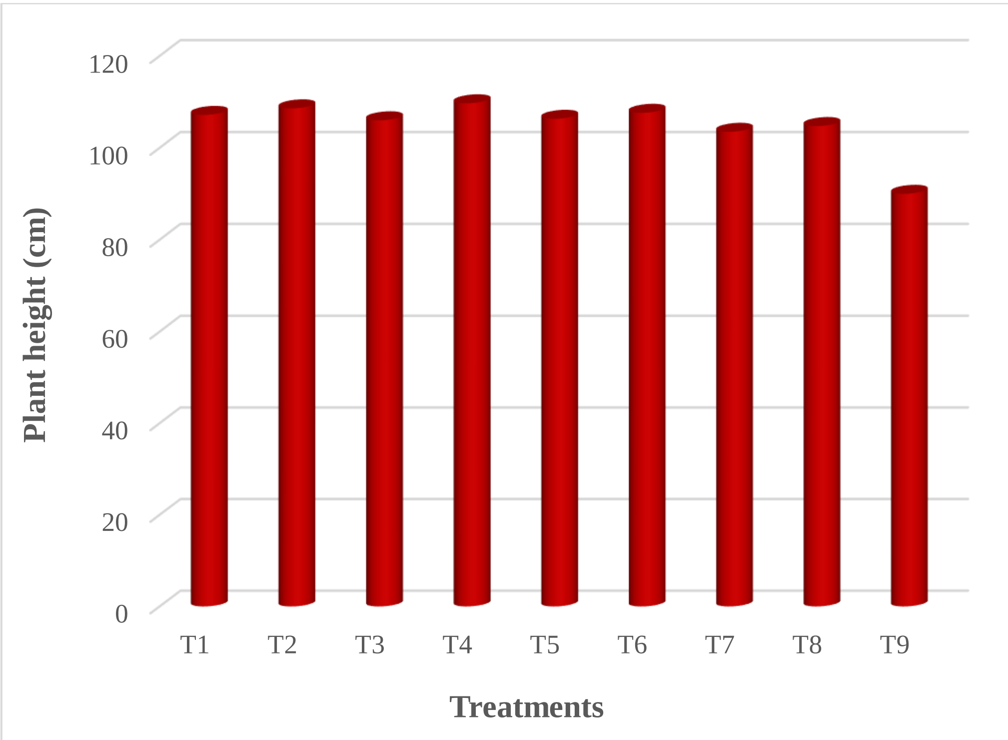


Fig. 21. Effect of INM practices on plant height at harvest

Rhizospheric microorganisms contribute directly and indirectly to the physical, chemical and biological properties of soil through their beneficial activities (Meena *et al.,* 2014). The bacteria help in soil processes such as storage and release of nutrients, mobilization and mineralization of nutrients, soil organic matter decomposition and solubilization of K (Zeng *et al.,* 2012; Parmar and Sindhu, 2013; Archana *et al.,* 2013), phosphate solubilization, N fixation, nitrification, denitrification and sulfur reduction (Khan *et al.,* 2007). Tiwari *et al.* (2016) explored the soil properties in bulk and rhizosphere soils of red gram and reported higher bacterial counts, IAA and siderophores in the latter. The exudates from plant roots provide the C source and supports microbial growth which is dependent on the growth and vigour of plants. Microbial activities were augmented with the biofertilizer inoculations. Despite the rhizospheric effects plausible in red gram as evinced by Rajendran *et al.* (2008), the control treatment could not realize the beneficial effects as in the INM practice because in the latter, the direct effect of the nutrient inputs and / biofertilizer and the indirect effect of the rhizospheric processes resulted in the enhanced growth and yields. The same could also explain the better yields in INM over chemical fertilizer alone.

The seed yield realized in T_4 was 51 per cent higher than that in the absolute control clearly indicating the relevance of nutrient management for higher yields in red gram. Haulm yield (5.07 t ha^{-1}) was also maximum corresponding to the better growth and yields in T_4.

5.3.3 Physiological Parameters

The crop DMP depends on growth parameters and yield attributes. As growth advanced, CGR increased and reached the maximum at 40 - 60 DAS and later declined. Maximum DMP was recorded at 60 DAS and it was 200 per cent more than that at 40 DAS. The trend remained same as in experiment I wherein CGR computed was the highest at 40 - 60 DAS. Crop Growth Rate was the highest when 50 per cent P and K were applied with their corresponding solubilisers and on par with 100 per cent K + P solubiliser (Fig. 23). Inspite of the lower plant height and number of branches, higher DMP were registered in T_8 and T_6 and this would be due the higher leaf biomass at 60 DAS. The crop at this stage is in the flower initiation period and would have attained maximum vegetative growth. The favorable soil environment for better plant growth with the inclusion of biofertilizers would have contributed to the higher CGR values in these treatments. Gupta *et al.* (2015) reported maximum abundance of nifH genes and transcripts at the flowering stage in red gram and according to Burgmann *et al.* (2005), this could be due to the maximum rhizodeposition occurring at this stage thereby harboring most of the beneficial microbes in its rhizosphere.

Relative Growth Rate is the rate of accumulation of new dry mass per unit of existing dry mass and was maximum at 20 - 40 DAS and declined thereafter. Among the treatments, RGR values were maximum in INM but in the initial stages were on par with chemical fertilizer application (Fig. 24). The decrease in RGR with the increase in amount of dry matter of the plant is due to the aging of the leaves. Towards maturity, the plant respiration rate is more than the amount of photosynthesis, which caused reduction in RGR (Razavian, 2017; Shariatmadari, 2018).

5.3.4 Agronomic Indices

No significant difference was observed for harvest index due to various INM practices. It ranged from 0.22 - 0.23, confirming the low HI recorded in pulses.

Physiological efficiency mirrors the ability of the crop to convert the nutrient acquired from the given source into economic yield. Physiological efficiency for N (9.65 kg kg^{-1}), P (35.38 kg kg^{-1}) and K (20.77 kg kg^{-1}) were comparatively the highest in treatment T_4. It is interpreted that the significantly highest seed yield, N, P and K uptake registered in the combined application of P and K solubilisers at 50 per cent P and K fertilizer contributed to the higher PE. The results are in accordance with the findings of Singh *et al.* (2021).

5.3.5 Chlorophyll Content and Nutrient Uptake

The total chlorophyll content in red gram ranged from 1.41 to 1.49 mg g^{-1} and did not vary markedly with various INM practices.

The N and P uptake were significantly the highest in treatments T_4 and T_8 respectively. No significant difference was observed for K uptake. The significantly higher DMP and higher N content in T_4 would have resulted in the significantly highest N uptake. Similarly, the comparatively higher DMP and higher P content in treatment

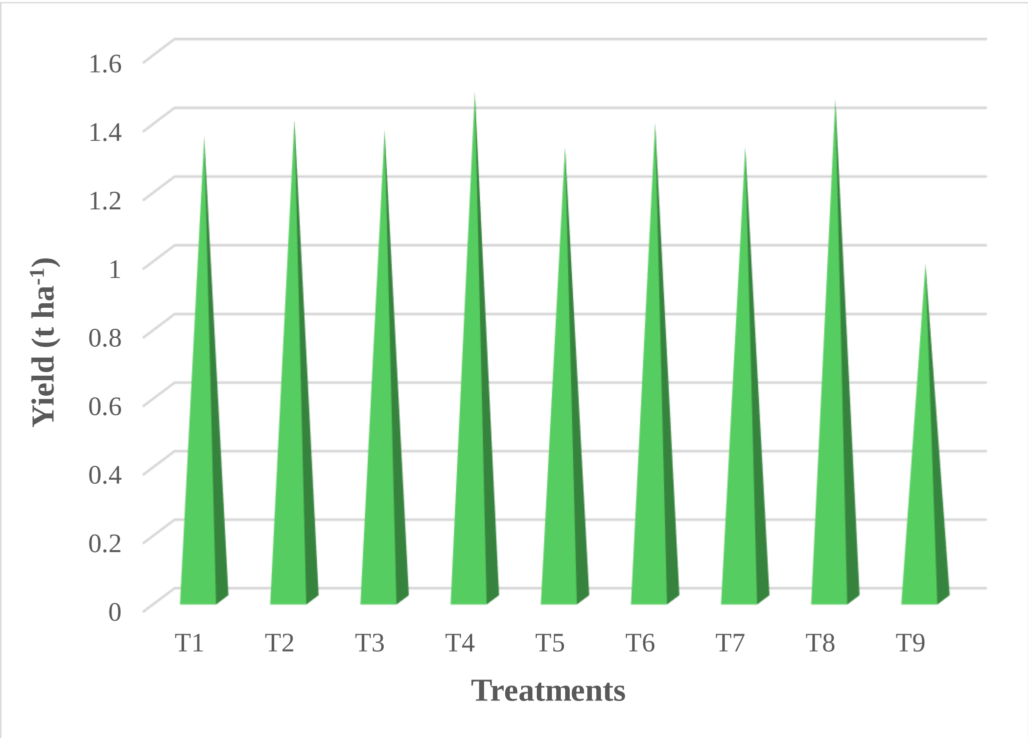


Fig. 22. Effect of INM practices on seed yield

Plate 21. Pods at harvesting stage in treatments T_4 and T_8 (Experiment III)

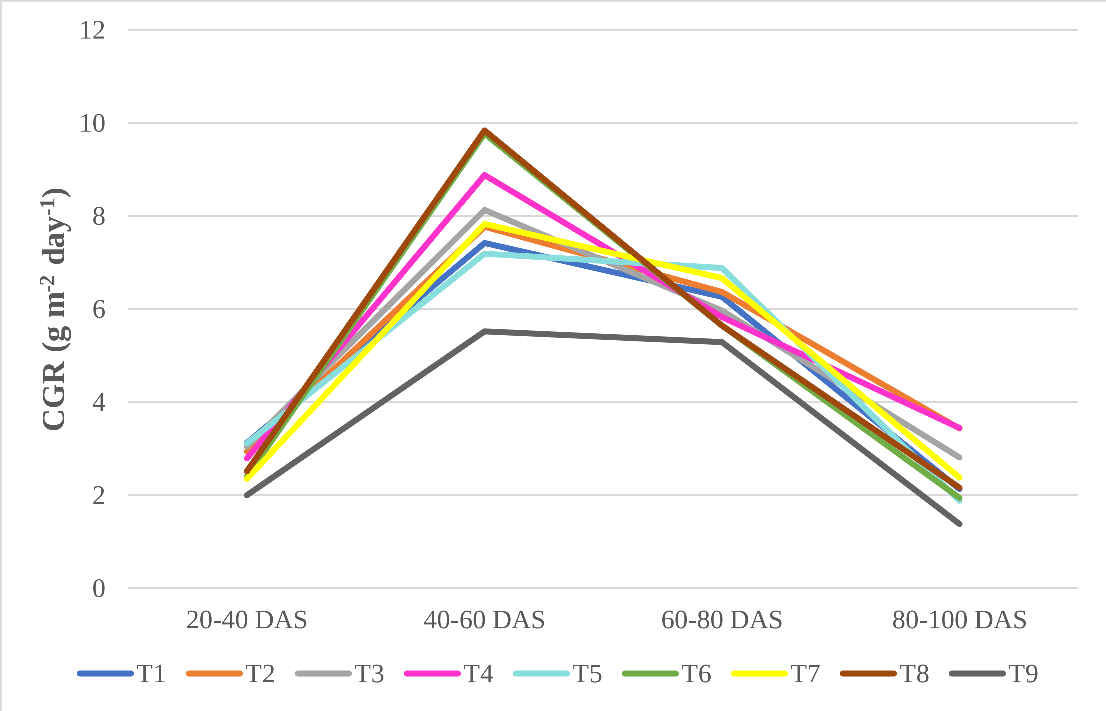


Fig. 23. Effect of INM practices on crop growth rate

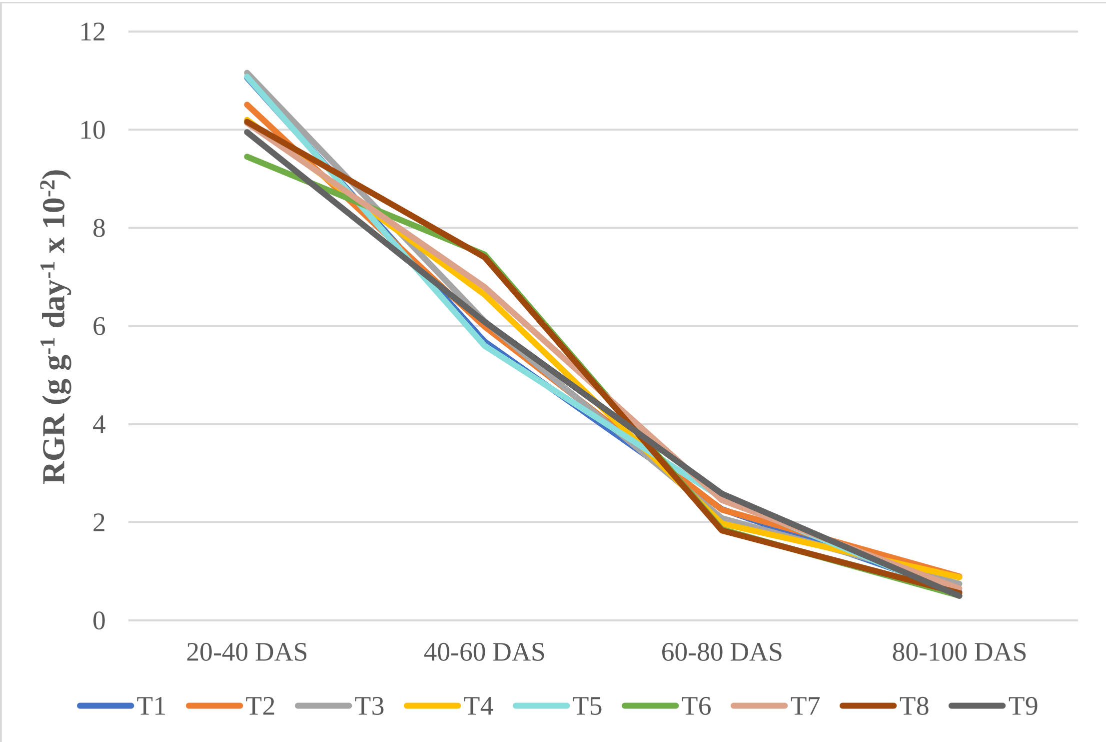


Fig. 24. Effect of INM practices on relative growth rate

T_8 recorded the significantly highest P uptake. Being a leguminous crop, the N and P requirements are higher.

5.3.6 Seed Protein

Seed protein content is dependent on seed N content and in the present study INM with P and K solubilisers recorded the highest protein content (Fig. 25) on account of the higher N content in seeds (3.45 %). Nitrogen is an integral part of protein and is a structural element of certain co-enzymes involved in protein synthesis. Therefore the increased N concentration in seeds resulted in the higher protein content (21.59 %). The results are in agreement with Tammanagowda (2002); Maheshbabu *et al*. (2006). Negrila *et al.* (1995) have described the role of the major nutrients N, P and K in protein synthesis. It is inferred that balanced and adequate supply of nutrients with INM including biofertilizers ensured efficient photosynthesis in the plants and the carbohydrates synthesized are diverted to seeds to form more of proteins (Choudhary *et al.,* 2001). This is supported by the inferior protein status of seeds in plants in absolute control, which was devoid of nutrient addition.

5.3.7 Soil Properties

Significant improvement in the soil chemical and biological properties were observed with the nutrient management practices adopted. The pH of soil is important as it governs the availability of nutrients to crop plants and biological activities in soil. The soil pH was found to have lowered from the initial values in the biofertilizer applied treatments and is ascribed to the release of organic acids by solubilizing bacteria to solubilize the insoluble nutrients fixed in soil layers (Chen *et al.,* 2006) and the rhizospheric effects as legume roots release protons acidifying the soil. The principal mechanism for solubilization of soil P and K is lowering of soil pH by microbial production of organic acids or through release of protons (Kumar *et al.,* 2018; Meena *et al.*, 2014). However, in the fully chemical fertilizer applied treatments, a slight increase in pH from the initial values was noticed.

Compared to initial soil C status (1.00 %), an increase in organic C was observed in all plots. The treatment T_4 resulted in the significantly highest organic C content. The increase in organic C content might be due to the addition of organic matter through leaf fall at maturity and decomposition (Srinivasulu *et al.,* 2000). Red gram is characterized by substantial amounts of litter fall during its growth (Adjei-Nsiah, 2012). The higher microbial population (bacteria and actinomycetes), recorded bear testimony to the mineralization of fallen leaves that would have occurred. Better plant growth is associated with increased root exudation of organic substances which is also deduced to have added to the C status in soil.

The changes in the available NPK were significant depending upon the nutrient input used in the treatments (Fig. 26). The available N status was maximum in the integration of P and K biofertilizers with 100 per cent N, 50 per cent P and K as chemical fertilizers and the plausible reason would be the increased symbiotic activities of *Rhizobium*, indirect effects of microbial inoculation on augmenting N fixers in the rhizosphere (Gupta *et al.,* 2006 b), which added more N to soil. The results are in accordance with the findings of Rout and Kohire (1991) and Pal (1997). The solubilizing effects of the microbes contributed to the increased status of the corresponding nutrients and this was more in the treatments in which solubilisers were included. These results corroborate the reports of Gaind and Gaur (1990) and Meena *et al.* (2014).

Soil microbial population play an influential role in the biological management of soil fertility and productivity. An increase in microbial counts from the initial status was observed after the harvest of red gram. The soil bacterial population showed significant variations due to various INM practices and was significantly the highest in treatment T_4 which was on par with the treatment T_8. No significant differences were observed for fungi and actinomycete count. The increases in bacterial counts may be attributed to inoculation with the bacterial solubilisers (Shinde and Bangar, 2003) and also to the microbial proliferation with the leaf litter addition favouring decomposition (Musokwa and Mafongoya, 2021).

5.3.8 Nutrient Balance Sheet

The N balance of soil was positive for all the treatments (Fig. 27) whereas for P, all the treatments except absolute control resulted in positive balance. The K solubiliser applied treatments recorded maximum K apparent gain (17.16 to 24.56 kg ha^{-1}) and the

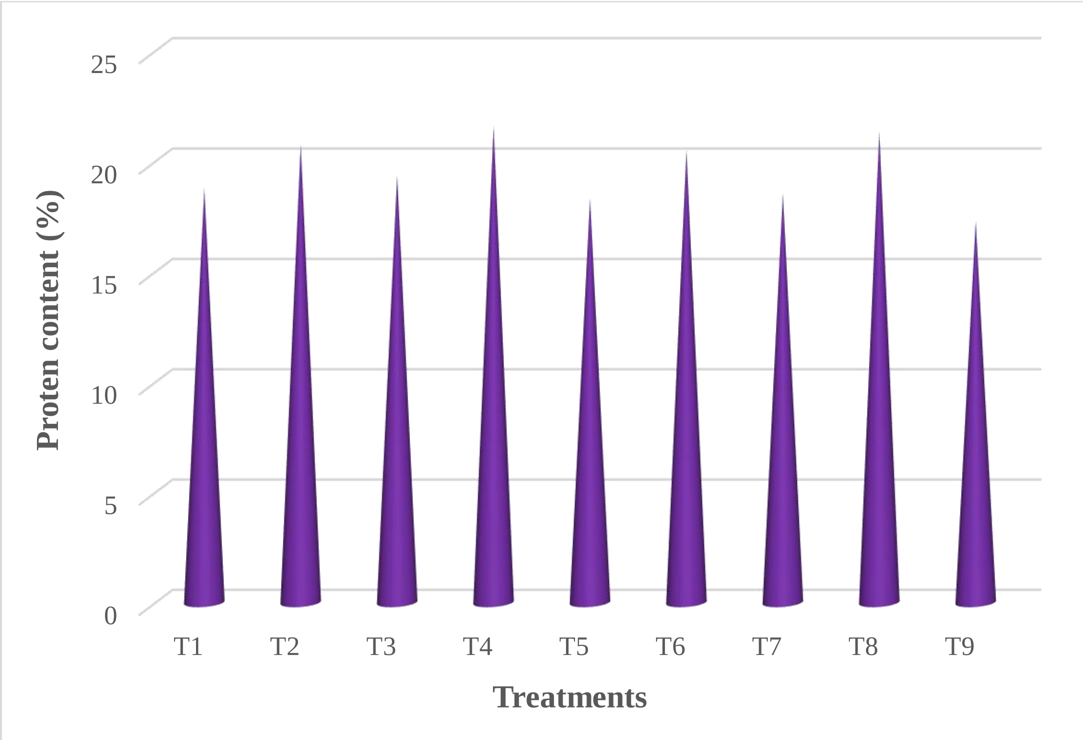


Fig. 25. Effect of INM practices on seed protein content

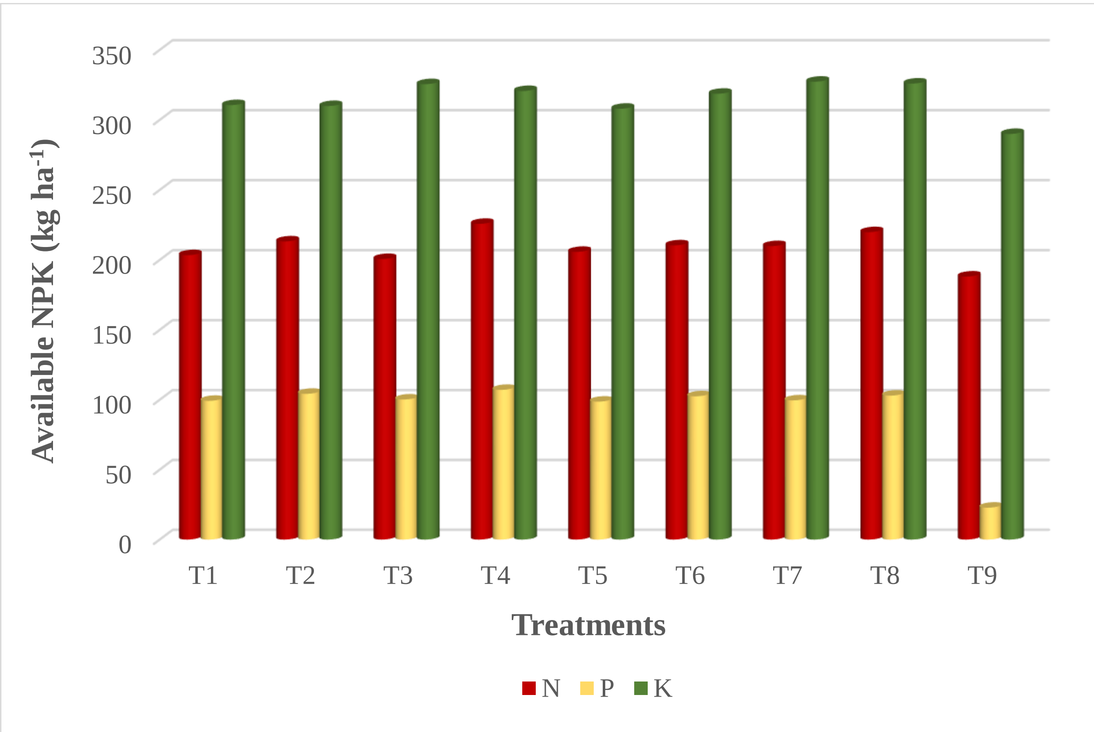


Fig. 26. Effect of INM practices on soil available NPK after harvest

treatment T_6 showed a small positive balance (5.46 kg ha^{-1}). The N, P and K balance were lowest in the absolute control.

The actual balance in N was nearly thrice than the expected balance indicating the significant additions from the red gram crop. Nitrogen fixation, nodule sloughing, leaf shedding and mineralization from organic sources would have added to the soil status. With respect to P, apparent gain was comparatively the highest in P solubilser applied treatments. Inclusion of P biofertilizers could raise the balance to an apparent gain reflecting the P solubilising effect of *B. megaterium*. Positive balance for P with P solubiliser has been reported by Jain and Dahama (2006). A similar effect with K solubiliser was also observed. Madar *et al*. (2020) have recorded the effect of K solubiliser and the resulted positive balances in soil. *B. sporothermodurans* activity would have been responsible for the positive K balances recorded. The possibility of leaching loss in K has been reported by Mendes *et al*. (2016). The precipitation received and the irrigation given during the non-rainy periods would have promoted the leaching losses of K, even so, solubilisation with *Bacillus* could sustain the positive balance. In the absolute control red gram relied on the native soil fertility status and hence a decline, as expected higher than that in the manured plots was observed. The FYM application, N fixing character and nutrients released through decomposition of the fallen leaves would have sustained the crop.

5.3.9 Economic Analysis

The cost of cultivation and gross returns of red gram varied markedly with the INM practices and these influenced the overall net returns and B: C ratio (Fig. 28). The treatment T_4 resulted in the highest net return of ₹ 94722 ha^{-1} and B: C ratio of 2.05, followed by the treatment T_8. (2.01) Inclusion of P and K biofertilizers and reduction in P and K to 50 per cent RDF in the nutrient management practice paved way for the increased yields and hence the highest economic gains in these treatments. The higher seed yields could compensate for the additional cost of biofertilizers, while the absolute control treatment (no fertilizers) recorded the lowest net return (₹ 48150 ha^{-1}) and B:C ratio (1.65) on account of the poor yields, despite the lowest cost involved in the cultivation.

Based on the results of the experiment a nutrient management strategy involving the application of the 40:40:20 kg ha^{-1} NPK dose based on the soil test results, with urea, rajphos and MOP and soil application of *B. megaterium* (P solubiliser) and *B. sporothermodurans* (K solubiliser) was found to be economic in the cultivation of red gram variety APK 1.

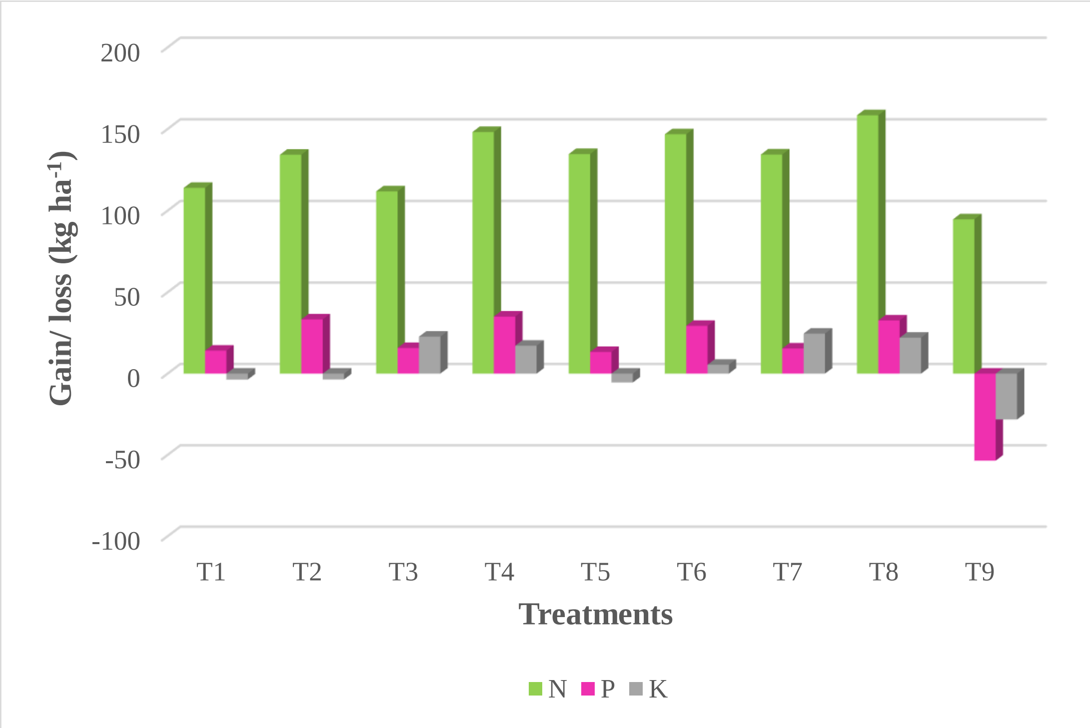


Fig. 27. Effect of INM practices on nutrient balances in soil

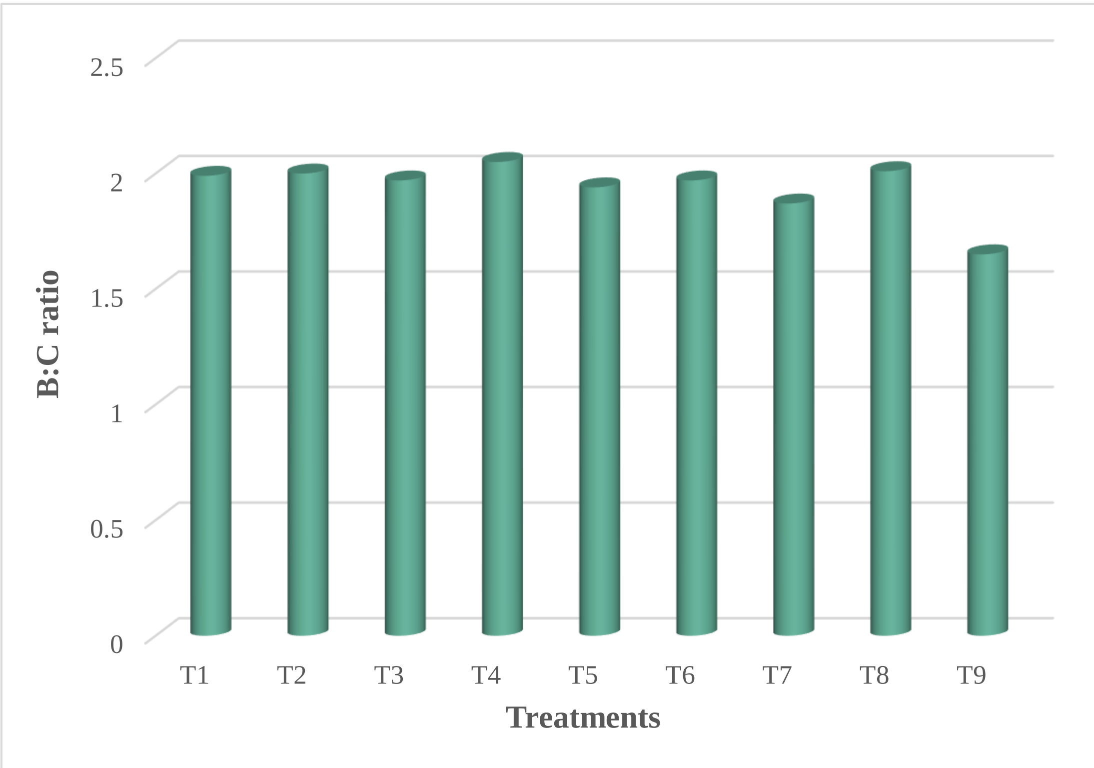


Fig. 28. Effect of INM practices on B:C ratio

Summary

6. SUMMARY

The research experiment on “Input optimization for short duration red gram [*Cajanus cajan* (L.) Millsp.]” was conducted in the College of Agriculture, Vellayani during 2018 - 2020. The experiment aimed to assess the suitability of two short duration varieties of red gram, standardize the spacing and nutrient management practices for short duration red gram and to examine the legume effect on succeeding fodder maize crop. The research work was carried out as three separate experiments (i) assessment of the suitability of two short duration varieties and standardization of spacing and nutrient levels (ii) assessment of legume effect on fodder maize and (iii) nutrient scheduling in red gram.

6.1 EXPERIMENT I : ASSESSMENT OF THE SUITABILITY OF TWO SHORT DURATION VARIETIES AND STANDARDIZATION OF SPACING AND NUTRIENT LEVELS

The field experiment was conducted in the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram from November 2018 to March 2019 and November 2019 to March 2020, laid out in factorial RBD (2 x 2 x 3) with three replications. The treatments comprised of three factors - two varieties (v_1: APK 1 and v_2: Vamban (Rg) 3), two levels of spacing (s_1: 40 cm x 20 cm and s_2: 60 cm x 30 cm) and three nutrient levels (n_1: 40:80:40 kg NPK ha^{-1}, n_2: 30:60:30 kg NPK ha^{-1} and n_3: 20:40:20 kg NPK ha^{-1}). The results of the experiment I are summarised below.

Varieties, spacing, nutrient levels and their interactions had significant influence on plant growth parameters. Among the varieties, Vamban (Rg) 3 resulted in significantly taller plants with higher number of branches and root parameters during both years, while APK 1 resulted in comparatively highest number of nodules and weight of nodules (second year) per plant. The wider spacing (60 cm x 30 cm) and the highest nutrient level (40:80:40 kg NPK ha^{-1}) also recorded taller plants, higher number of branches per plant and increased root parameters, while nodulation was higher in plants at narrow spacing (40 cm x 20 cm) and the higher nutrient level application. The effects were seen reflected in first order interaction. At harvest, plants were taller in the combination $v_2s_2n_3$ (Vamban (Rg) 3 + 60 cm x 30 cm + 20:40:20 kg NPK ha^{-1}) during the first year, but was at par with $v_2s_2n_1$ (Vamban (Rg) 3 + 60 cm x 30 cm +

40:80:40 kg NPK ha^{-1}). The combination $v_2s_2n_1$ resulted in taller plants at harvest during the second year, highest number of branches, root volume and root dry weight during both years. The superior weight of nodules per plant observed in the interaction, $v_2s_1n_2$ (Vamban (Rg) 3 + 40 cm x 20 cm + 30:60:30 kg NPK ha^{-1}), which was at par with $v_1s_2n_1$ (APK 1 + 60 cm x 30 cm + 40:80:40 kg NPK ha^{-1}) during the second year.

Analysing the effect on the yield attributes, APK 1 recorded earliness in flowering, maximum pod weight and 100 seed weight during both years. The narrow spacing and the highest nutrient level recorded the highest average pod weight (second year), and the latter, superior values for seed - pod ratio. The first order interactions also recorded significant variations in average pod weight, 100 seed weight and seed - pod ratio. Amongst the second order interactions, the combinations $v_1s_1n_1$ (APK 1 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}) and $v_2s_1n_1$ (Vamban (Rg) 3 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}) recorded the significantly highest average pod weight during first and second year respectively. The interaction $v_2s_1n_1$ was at par with $v_1s_1n_1$. The combination, $v_1s_2n_1$ (APK 1 + 60 cm x 30 cm + 40:80:40 kg NPK ha^{-1}) resulted in the highest 100 seed weight during the first year, which was at par with $v_1s_1n_1$. $v_2s_2n_2$ (Vamban (Rg) 3 + 60 cm x 30 cm + 30:60:30 kg NPK ha^{-1}) recorded the maximum seed - pod ratio during the second year, but was on par with $v_1s_1n_1$.

The variety APK 1 (v_1), narrow spacing s_1 (40 cm x 20 cm) and the highest nutrient level n_1 (40:80:40 kg NPK ha^{-1}) registered superior seed and haulm yields. First order interactions also resulted in significant variations. The second order interaction $v_1s_1n_1$ (APK 1 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}) recorded significantly superior seed yields during both years and the pooled analysis also showed a similar trend with maximum seed yield (1.38 t ha^{-1}) in $v_1s_1n_1$. The haulm yield was significantly the highest in the combinations $v_2s_1n_1$ and $v_1s_1n_1$ during the first and second year respectively. On pooled analysis, $v_2s_1n_1$ recorded a higher haulm yield of 4.82 t ha^{-1}.

During the first year, dry matter production per plant was significantly the highest in APK 1 at 20, 40, 60 and 80 DAS whereas in the second year, variety Vamban (Rg) 3 recorded the highest DMP at 40 DAS. No significant variations were observed at 100 DAS, but comparatively highest DMP was registered in APK 1 during both years. During the second year, the significantly highest CGR was observed in Vamban (Rg) 3 at 20 - 40 and 60 - 80 DAS, and in APK 1 at 40 - 60 and 80 - 100 DAS. Among the spacings tried, the wider spacing (60 cm x 30 cm) resulted in the significantly highest DMP and narrow spacing (40 cm x 20 cm), the highest CGR. Dry matter production and CGR were superior in the highest nutrient level (40:80:40 kg NPK ha^{-1}). First order interactions also resulted in significant variations. The significantly highest DMP was recorded in the combination $v_1s_2n_1$ during both years but CGR was maximum in $v_1s_1n_1$ at 80 - 100 DAS during both years. Relative Growth Rate was significantly the highest in the variety APK 1 at 40 - 60 DAS, and in Vamban (Rg) 3 at 60 - 80 DAS during the second year. The wider spacing resulted in the highest RGR at 20 - 40 DAS during both years, and in narrow spacing at 40 - 60 DAS during the second year. Nutrient levels and first order interactions also resulted in significant variations for RGR. In second order interaction, the combination $v_1s_1n_2$ resulted in the highest RGR during the second year at 80 - 100 DAS, but was at par with all other combinations except $v_2s_1n_3$.

No significant variations were observed for harvest index due to varieties, spacing, nutrient levels and their interactions. Partial factor productivity for NPK was significantly the highest in APK 1 and in the spacing 40 cm x 20 cm. The effects of nutrient levels were comparable for N and P in the first year while the highest nutrient level 40:80:40 kg NPK ha^{-1} resulted in significantly the highest PFP for K during the first year and for N, P and K during the second year. Individual effects were seen reflected in first and second order interactions.

The plants grown under wider spacing recorded significantly the highest chlorophyll content during both years. The higher nutrient levels registered significantly superior values for chlorophyll content during the first year. First order interactions also recorded significant variations. In second order interaction, $v_2s_2n_2$ and $v_1s_2n_1$ resulted in the highest chlorophyll content during the first and second year respectively, but were on par.

Individual effects on NPK uptake was significantly the highest in APK 1, 40 cm x 20 cm spacing and nutrient level 40:80:40 kg NPK ha^{-1}. First order interactions also recorded significant variations. The uptakes remained maximum in APK 1/ Vamban (Rg) 3 combinations with spacing 40 cm x 20 cm and nutrient level 40:80:40 kg NPK ha^{-1} in both years and were on par with each other.

Highest seed protein content was recorded in APK 1, spacing 60 cm x 30 cm and nutrient level 40:80:40 kg NPK ha^{-1}. First and second order interactions also showed significant variations. The second order interaction, $v_1s_2n_1$ resulted in significantly highest protein content during both years.

No significant variations were observed in soil pH and organic C due to varieties, spacing, nutrient levels and their interactions. An increase in soil available nutrient status was observed after the harvest of red gram. The variety APK 1 resulted in the significantly highest soil available N, while Vamban (Rg) 3 resulted in highest available P and K. The wider spacing and highest nutrient level resulted in significantly superior values for available NPK. Significant variations were registered in the interactions also. During the first year, the combination, $v_1s_2n_1$ resulted in the significantly highest available N and K, while $v_2s_2n_1$ resulted in available P. The interaction $v_2s_2n_1$ resulted in the significantly highest available NPK during the second year.

Microbial counts, bacteria, fungi and actinomycetes in soil increased with red gram cultivation and the treatments. During the first year, the significantly highest bacterial and actinomycete count were observed in APK 1 and fungal count during the second year. The population enumerated were superior under narrow spacing and the highest nutrient level during both years. First order interactions also recorded significant variations. During the first year, the combinations, $v_1s_1n_1$ and $v_1s_2n_1$ resulted in superior values for bacteria and actinomycetes respectively. The interaction, $v_1s_1n_1$ recorded significantly the highest count for bacteria, fungi and actinomycetes during the second year.

The N balance of soil was positive for all the treatments in both years. The highest positive balance was observed in the treatments $v_2s_1n_1$ (73.17 kg ha^{-1}) and $v_1s_1n_1$ (107.13 kg ha^{-1}) during the first and second year respectively. The balance sheet for P was positive for all the treatment combinations involving s_2 during the first year. During the second year, all treatments showed positive balance for P except $v_1s_1n_1$, $v_1s_1n_2$, $v_1s_2n_2$ and $v_2s_2n_3$. The treatments $v_1s_1n_1$, $v_1s_2n_1$ and $v_2s_1n_1$ showed positive balance for K during both years and also $v_2s_2n_1$ during the second year. The treatments

$v_2s_1n_1$ (8.95 kg ha^{-1}) and $v_1s_1n_1$ (15.43 kg ha^{-1}) resulted in highest positive balance for K during the first and second year respectively.

The treatment T_1 ($v_1s_1n_1$) recorded the highest net return and B:C ratio during first and second year of cultivation, followed by the treatment T_7 ($v_2s_1n_1$). On pooled analysis, a similar trend was observed, the treatment T_1 produced the highest net return (₹ 88621 ha^{-1}) and B: C ratio (2.03), followed by the treatment T_7, net return (₹ 82546 ha^{-1}) and B:C ratio (1.96).

6.2 EXPERIMENT II : ASSESSMENT OF LEGUME EFFECT ON FODDER MAIZE

The study on the legume effect of red gram on fodder maize was undertaken during *Kharif* season, June to August 2019, in which the crop residues (root + shoot + fallen leaves) generated in red gram in response to the treatments imposed were incorporated in the respective plots and allowed to decompose for two months. Seeds of fodder maize, variety, African tall were sown in the plots at a spacing of 30 cm x 15 cm and were allowed to establish on the residual fertility in soil. The results of Experiment II are briefed in the following section.

The quantity of crop residues generated ranged from 2.25 to 4.83 t ha^{-1}. The significantly highest crop residues were realized in the treatment $T_{7,}$ Vamban (Rg) 3 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1} (4.83 t ha^{-1}) followed by T_1, APK 1 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1} (4.75 tha^{-1}). The residue biochemical characters ascertained, cellulose, hemicellulose, lignin and phenol were non significant, while C: N ratio varied significantly. Residue in the treatment T_1 resulted in the narrowest C:N ratio (18.2: 1) followed by T_7 (18.9:1). The widest C:N ratio was recorded in treatment T_5, APK 1 + 60 cm x 30 cm + 30:60:30 kg NPK ha^{-1} (21.8:1). Exploring the changes in soil properties, soil pH, organic C pools and available NPK were found to improve with residue decomposition. Dehydrogenase activity estimated were higher compared to the initial status and values remained the highest in T_7/T_1 at the different stages.

The emergence percentage in fodder maize and days to harvest were not markedly influenced by the residues added. The crop was harvested at milky stage (60 DAS) in all treatments. Irrespective of the variety, the residues produced under wider spacing and higher nutrient levels (T_7 and T_1) showed better plant growth and fodder yields in maize. Plant height (183.78 cm), green (33.61 t ha^{-1}) and dry (11.37 t ha^{-1}) fodder yield were significantly higher in Vamban (Rg) 3 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1} on par with APK 1 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}.

The soil organic C status recorded was higher after the harvest of fodder maize and the maximum (1.64 %) was in the treatment T_7. A decline in soil available NPK status from the initial was observed after fodder maize cultivation. The quality of fodder maize was also influenced by red gram residue incorporation. The treatment T_7 recorded significantly the highest protein content (8.75 %), which was at par with T_1. The total carbohydrate content was significantly the highest in treatment T_{12} (77.50 %), which was at par with T_6.

6.3 EXPERIMENT III : NUTRIENT SCHEDULING IN RED GRAM

The experiment was laid out during *Rabi* season in 2019 - 2020 in RBD with 9 treatments and replicated thrice. The variety APK 1, spacing 40 cm x 20 cm and nutrient level 40:80:40 kg NPK ha^{-1} found superior in Experiment I comprised the variety and management practices for the study. The plot size adopted was 3.6 m x 2.4 m. The treatments on nutrient management practices included were T_1 and T_5: 100 % NPK as chemical fertilizers, T_2 and T_6: 100 % N + 50 % P + 100 % K + P solubiliser, T_3 and T_7: 100 % N + 100 % P + 50 % K + K solubiliser, T_4 and T_8: 100 % N + 50 % P + 50 % K + P solubiliser + K solubiliser and an absolute control (without fertilizers) as T_9 for comparison and computation of PE. The entire dose of N was given in soil in treatments T_1 to T_4, whereas in T_5 to T_8, 50 per cent N was given in soil and remaining 50 per cent as foliar spray (2 % urea). The salient findings of the study are briefed below.

Plant growth parameters, height and number of branches per plant at 30 and 60 DAS did not differ markedly with the INM practices but at harvest were significantly taller (109.70 cm) with higher number of branches (6.5) in the treatment T_4 [100 % N + 50 % P + 50 % K + P solubiliser + K solubiliser (N soil)]. Foliar nutrition registered superior values for weight of nodules per plant in treatment T_8 [100 % N + 50 % P + 50 % K + P solubiliser + K solubiliser (50 % N foliar)]. No significant difference was observed for number of nodules per plant. Root parameters (root volume and root dry weight) were also significantly the highest in treatment T_8, and root dry weight in T_8

was at par with T_4. The treatments T_4 and T_8 recorded superior values for root - shoot ratio.

Variations in yield attributes, *viz.*, days to 50 per cent flowering, average pod length, number of seeds per pod, 100 seed weight and seed - pod ratio with the nutrient management practices remained non significant. The average pod weight (0.62 g) was significantly the highest in treatment T_4 in which 100 per cent N and 50 per cent P and K was given through chemical fertilizers along with P and K solubilisers, and was at par with treatments T_2 and T_8. The significantly highest seed yield (1.48 t ha^{-1}) was observed in the nutrient management practice of integration of chemical fertilizers along with P and K solubilisers, T_4, which was 50 per cent higher than the seed yield recorded in absolute control (0.98 t ha^{-1}). The treatment T_4 was at par with T_8 and T_2. No significant differences were observed for haulm yield, which ranged from 4.58 to 5.07 t ha^{-1} in INM practices.

Dry matter production varied significantly with the stages of observation. It was higher in the treatments, T_6 (20 DAS), T_1 (40 DAS), T_8 (60 and 80 DAS) and T_4 (100 DAS). The CGR and RGR were superior in the treatments T_4 (3.44 g m^{-2} day^{-1}) and T_2 (0.895 g g^{-1} day^{-1} x 10^{-2}) respectively at 80 - 100 DAS.

Harvest index did not vary significantly with the INM practices included. Physiological efficiency for K was significantly the highest in treatment T_4, which was at par with T_8 and T_2. No significant difference was observed for N and P.

The various INM practices revealed non significant influence on total chlorophyll content, the values ranged from 1.41 to 1.49 mg g^{-1}. Nitrogen and P uptake were significantly the highest for the treatments T_4 and T_8 respectively, while no significant difference was observed for K. Seed protein content (21.59 %) in T_4 was superior and remained on par with treatment T_8.

Soil properties were favourably influenced by INM practices with improvements in organic C, available NPK and microbial count over the initial status. Maximum organic C, available N and P status and bacterial count were recorded in T_4, while T_7 resulted in the highest available K. A decrease in soil pH was observed in the P and K solubiliser applied treatments. However, in the absolute control an increase in soil pH, organic carbon, available N and K and microbial count were observed, while soil available P decreased. No significant difference was observed for fungi and actinomycete count due to various INM practices.

The N balance of soil was positive for all the treatments. The N balance was the highest (158.40 kg ha^{-1}) for the treatment T_8 followed by T_4 (148.14 kg ha^{-1}). All the INM practices recorded positive balance for P and the highest positive balance (35.06 kg ha^{-1}) was in T_4. The balance sheet for K remained positive in the treatments involving K solubiliser application and in treatment T_6. The highest positive balance for K was observed in treatment T_7 (24.56 kg ha^{-1}) followed by treatment T_3 (22.73 kg ha^{-1}).

The INM practice was found to be profitable, with the treatment T_4 [100 % N + 50 % P + 50 % K + P solubiliser + K solubiliser (N soil)] recording maximum net returns (₹ 94722 ha^{-1}) and B:C ratio (2.05), followed by $T_{8,}$ the values being ₹ 91622 ha^{-1} and 2.01 respectively.

From the results of the experiments it could be concluded that

- The short duration varieties of red gram APK 1 and Vamban (Rg) 3 are suitable for cultivation in Kerala.
- Among the two varieties tested, APK 1 at a spacing 40 cm x 20 cm and an NPK dose of 40:80:40 kg ha^{-1} applied based on the soil test results was found to be superior .
- The integrated nutrient management practice for higher productivity and profitability in red gram included the application of chemical fertilizers at 40:40:20 kg NPK ha^{-1} along with P and K solubilisers @ 10 g mixture per plant (dry cow dung and solubiliser mixed in the ratio, 50:1).
- Irrespective of the varieties tested, the residual effect of red gram planted at 40 cm x 20 cm and supplied with 40:80:40 kg NPK ha^{-1}, was superior in terms of yield of succeeding crop of fodder maize.

Future line of work

- Suitability of short duration red gram varieties as inter crops in coconut garden and tuber crops
- Identification of the most suitable season for cultivation
- Agronomic and physiological studies for improving source - sink relations and harvest index
- Rhizosphere microbiome and legume effects of red gram in intercropping systems

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Appendices

APPENDIX - I

Weather parameters during first year of Experiment I (November 2018 - March 2019)

Standard week	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Rainfall (mm)
45	31.1	24.3	93.6	59.2
46	31.7	23.8	92.1	51.2
47	31.6	24.1	93	51.5
48	31.9	23.7	93.3	0.0
49	31.9	23.7	92.9	17.2
50	32.2	23.8	94.3	26.1
51	32.0	22.9	92.4	2.2
52	32.0	23.5	92.4	6.0
1	32.0	19.6	92.0	0.0
2	31.6	22.1	92.0	0.0
3	32.2	20.9	91.6	0.0
4	32.0	21.2	92.1	0.0
5	32.5	22.1	92.6	2.4
6	32.9	24.3	88.9	0.5
7	33.3	24.1	86.7	0.0
8	35.3	23.4	87.4	0.0
9	34.4	24.2	85.0	0.0
10	34.6	24.8	85.4	0.0
11	34.4	24.4	85.3	0.0
12	34.2	24.8	84.9	0.0
13	34.8	25.4	85.7	0.0

Total rainfall - 216.30 mm

APPENDIX - II

Weather parameters during residue decomposition and cropping period of Experiment II (April 2019 - August 2019)

Standard week	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Rainfall (mm)
14	35.2	26.0	83.7	0.0
15	35.0	25.9	78.6	0.0
16	34.9	25.6	82.8	11.0
17	35.1	25.6	84.6	6.7
18	34.0	25.9	82.7	15.8
19	34.3	26.2	80.3	0.0
20	34.5	26.2	81.3	0.0
21	33.5	26.5	87.4	83.5
22	33.6	26.7	90.4	25.5
23	32.2	25.3	89.3	164.2
24	31.1	24.8	93.3	114.4
25	31.9	24.9	90.0	28.6
26	32.1	26.1	87.1	0.0
27	32.2	25.9	90.3	32.1
28	30.8	25.4	90.3	42.1
29	30.1	23.7	94.1	100.8
30	30.4	24.3	92.3	7.7
31	31.5	25.6	89.3	17.5
32	30.0	23.6	94.6	198.1
33	30.4	24.1	91.6	18.2
34	32.0	24.2	92.1	34.9
35	30.7	23.9	93.1	91.9

Total rainfall - 993.00 mm

APPENDIX - III

Weather parameters during Experiment III and second year of Experiment I (November 2019 - March 2020)

Standard week	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Rainfall (mm)
45	32.5	24.8	89.3	0.0
46	32.5	24.6	90.7	9.0
47	32.1	24.3	92.4	49.9
48	32.6	24.5	94.0	31.0
49	32.0	24.1	91.3	38.1
50	32.2	23.6	91.0	53.0
51	31.4	23.9	92.9	41.4
52	31.9	23.8	92.8	60.5
1	32.2	24.1	92.3	0.0
2	32.0	22.7	93.4	45.0
3	32.2	22.5	92.3	10.0
4	32.7	23.0	91.4	0.0
5	32.7	22.3	92.7	0.0
6	32.7	23.2	91.4	0.0
7	33.2	23.7	89.0	0.0
8	33.1	23.2	90.6	0.0
9	33.2	23.4	89.5	37.6
10	33.2	24.3	90.0	3.0
11	33.4	24.6	86.9	0.0
12	33.7	25.0	88.3	11.7
13	34.1	25.1	85.0	0.0

Total rainfall - 390.20 mm

APPENDIX - IV

Composition of media used for the isolation of microorganisms

1. Bacteria - Nutrient Agar Medium

Beef extract	- 3 g
Peptone	- 5 g
Agar	- 20 g
Distilled water	- 1000 mL

2. Fungi - Martin's Rose Bengal Agar Medium

Dextrose	- 10 g
Peptone	- 5 g
KH_2PO_4	- 1 g
$MgSO_4.2H_20$	- 0.5 g
Agar	- 15 g
Rose Bengal	- 35 mg
Streptomycin	- 30 mg
Distilled water	- 1000 mL

3. Actinomycetes - Kenknight's Medium

Glucose	- 1 g
KH_2PO_4	- 0.1 g
$NaNO_3$	- 0.1 g
KCl	- 0.1 g
$MgSO_4.7H_2O$	- 0.1 g
Agar	- 15 g
Distilled water	- 1000 mL

APPENDIX - V

Cost of cultivation of red gram, Experiment I, ₹ ha^{-1}

Treatments	Cost excluding treatments		Treatment cost	Total cost of cultivation	
	First year	Second year		First year	Second year
T_1 : $v_1s_1n_1$	87150	76350	4904	92054	81254
T_2 : $v_1s_1n_2$	87150	76350	4128	91278	80478
T_3 : $v_1s_1n_3$	87150	76350	3352	90502	79702
T_4 : $v_1s_2n_1$	87150	76350	4904	92054	81254
T_5 : $v_1s_2n_2$	87150	76350	4128	91278	80478
T_6 : $v_1s_2n_3$	87150	76350	3352	90502	79702
T_7 : $v_2s_1n_1$	87150	76350	4604	91754	80954
T_8 : $v_2s_1n_2$	87150	76350	3828	90978	80178
T_9 : $v_2s_1n_3$	87150	76350	3052	90202	79402
T_{10} : $v_2s_2n_1$	87150	76350	4604	91754	80954
T_{11} : $v_2s_2n_2$	87150	76350	3828	90978	80178
T_{12} : $v_2s_2n_3$	87150	76350	3052	90202	79402

APPENDIX - VI

Cost of cultivation of red gram, Experiment III, ₹ ha^{-1}

Treatments	Cost excluding treatments	Treatment cost	Total cost of cultivation
T_1	80994	2844	83838
T_2	83236	3886	87122
T_3	83172	3822	86994
T_4	85414	4864	90278
T_5	82194	2844	85038
T_6	84436	3886	88322
T_7	84372	3822	88194
T_8	86614	4864	91478
T_9	74350	0	74350

APPENDIX - VII

Cost of inputs

Inputs	Cost (₹)
Red gram seeds • APK 1 • Vamban (Rg) 3	 120 kg^{-1} 100 kg^{-1}
FYM	900 t^{-1}
Lime	18 kg^{-1}
Fertilizers • Urea • Rajphos • MoP	 8 kg^{-1} 15 kg^{-1} 17 kg^{-1}
Biofertilizers • Rhizobium • P solubiliser • K solubiliser	 50 kg^{-1} 75 kg^{-1} 50 kg^{-1}
Plant protection chemicals	1000

APPENDIX - VIII

Market price of produce

Produce	Market price (₹)
Red gram seeds	125 kg^{-1}

APPENDIX - IX

Nutrient additions through red gram residues in the soil

Treatments	Quantity of residues ($t\ ha^{-1}$)	Nutrient content (%)			Nutrients added ($kg\ ha^{-1}$)		
		N	P	K	N	P	K
T_1	4.75	2.02	0.34	0.61	95.71	16.34	28.79
T_2	4.60	2.02	0.30	0.60	92.92	13.80	27.60
T_3	4.48	1.90	0.27	0.60	85.12	12.28	26.92
T_4	3.05	1.85	0.39	0.62	56.43	11.89	18.85
T_5	2.75	1.68	0.29	0.61	46.20	8.19	16.72
T_6	2.70	2.07	0.18	0.71	55.89	4.97	19.25
T_7	4.83	2.09	0.32	0.73	101.19	15.36	35.16
T_8	4.68	1.99	0.25	0.63	92.89	11.61	29.48
T_9	4.42	2.00	0.20	0.58	88.40	8.84	25.72
T_{10}	3.05	1.74	0.33	0.66	53.07	10.00	20.01
T_{11}	2.65	2.29	0.35	0.77	60.69	9.17	20.46
T_{12}	2.25	2.07	0.20	0.74	46.58	4.50	16.74

INPUT OPTIMIZATION FOR SHORT DURATION RED GRAM [*Cajanus cajan* (L.) Millsp.]

by

ANJANA DEVARAJ G.
(2017-21-024)

ABSTRACT

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Faculty of Agriculture
Kerala Agricultural University, Thrissur

DEPARTMENT OF AGRONOMY
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM - 695 522
KERALA, INDIA

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ABSTRACT

The study entitled "Input optimization for short duration red gram [*Cajanus cajan* (L.) Millsp.]" was conducted at College of Agriculture, Vellayani during 2017 - 2020 with the objectives, to assess the suitability of two short duration varieties of red gram, standardize the spacing and nutrient management practices for short duration red gram and to examine the legume effect on succeeding fodder maize crop.

The investigation was done as three experiments (i) assessment of the suitability of two short duration varieties and standardization of spacing and nutrient levels (ii) assessment of legume effect on fodder maize and (iii) nutrient scheduling in red gram. The experiment I was laid out in randomized block design (RBD) with three replications during *Rabi* season (November to March) in 2018 - 2019 and the confirmatory experiment, during 2019 - 2020. The treatments included combinations of varieties [v_1: APK 1; v_2: Vamban (Rg) 3], spacings [s_1: 40 cm x 20 cm; s_2: 60 cm x 30 cm] and nutrient levels [n_1: 40:80:40, n_2: 30:60:30; n_3: 20:40:20 kg NPK ha^{-1}]. Half nitrogen (N), potassium (K) and full phosphorus (P) were given basally, remaining as top dressing, 30 days after sowing (DAS). Farmyard manure (FYM) was applied uniformly @ 12. 5 t ha^{-1}.

The varieties, spacings and nutrient levels had significant influence on the growth characters of red gram at the different stages of observation. Variety Vamban (Rg) 3 (v_2) recorded significantly taller plants, higher number of branches and root parameters compared to APK1 (v_1) during both the years of experimentation. The wider spacing, s_2 (60 cm x 30 cm), the highest nutrient level, n_1 (40:80:40 kg NPK ha^{-1}) and the combination, $v_2s_2n_1$ resulted in superior values for plant height, number of branches per plant, root volume and root dry weight, while narrow spacing (40 cm x 20 cm) recorded the highest number and weight of nodules per plant. The interactions also exerted significant influence on growth parameters with the interactions involving v_2, s_2 and n_1 recording higher values.

The variety APK 1 showed earliness in flowering with significantly higher average pod weight, 100 seed weight, seed yield (1.04 t ha^{-1}) and haulm yield (3.70 t ha^{-1}). Narrow spacing and the highest nutrient level recorded superior values for average pod weight, seed and haulm yields. The interactions also resulted in

significant variations in yield attributes and yield. Pooled analysis of yield data of the two years registered the highest seed yield (1.38 t ha^{-1}) in $v_1s_1n_1$ (APK 1 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}).

Maximum dry matter production (DMP), crop growth rate (CGR) and seed protein content were recorded in APK 1 and at the highest nutrient level. Among the spacings tried, wider spacing resulted in the highest DMP and seed protein, while CGR was higher in the narrow spacing. The partial factor productivity (PFP) for N, P and K were superior in the combination $v_1s_1n_1$ in both years. Individual effects of the variety APK 1, narrow spacing and the highest nutrient level recorded maximum nutrient uptake and in the combinations of APK 1 or Vamban (Rg) 3 with 40 cm x 20 cm and 40:80:40 kg NPK ha^{-1}.

Available soil N and microbial counts assessed after the experiment were the highest after APK 1. Wider spacing and the highest NPK level recorded maximum soil available nutrient status, while microbial counts, at narrow spacing. Soil nutrient balance sheet computed for N was positive during both years. The balance sheet for P was positive for all the treatment combinations involving wider spacing during the first year. During the second year, all treatments showed positive balance for P except $v_1s_1n_1$, $v_1s_1n_2$, $v_1s_2n_2$ and $v_2s_2n_3$. Nutrient balance for K was positive in treatments $v_1s_1n_1$, $v_1s_2n_1$ and $v_2s_1n_1$ during the both years.

Pooled mean of the economics of cultivation during the two years revealed maximum net returns per hectare (₹ 88621/-) and B:C ratio (2.03) in $v_1s_1n_1$ (APK 1 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1}).

The legume effect of red gram on fodder maize was assessed during *Kharif* season, June to August 2019. Crop residues (root + shoot + fallen leaves) of red gram were incorporated *in situ* and allowed to decompose for two months. The maximum quantity of residues (4.83 tha^{-1}) was generated in the treatment combination T_7, Vamban (Rg) 3 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1} imposed in red gram, which was on par with T_1, the combination, APK 1 + 40 cm x 20 cm + 40:80:40 kg NPK ha^{-1} (4.75 tha^{-1}). There were no marked variations in the biochemical characters of residues, while C: N ratio was significantly narrower in T_1 (18.2: 1) and T_7 (18.9:1). Residue incorporation improved the soil chemical properties and at 60 days after residue incorporation (DAI), maximum soil pH and C pool (total organic carbon and labile carbon) were estimated in treatment T_7, and recalcitrant organic carbon, in T_1. Soil available N, P status and dehydrogenase activity were higher in T_1, and available K, in T_7 at 60 DAI.

Fodder maize seeds (variety, African tall) were sown during the third week of June in the residue incorporated plots. Green and dry fodder yields (33.61 and 11.37 t ha^{-1} respectively) were the highest in the treatment T_7 which was on par with T_1 (32.85 and 11.08 t ha^{-1} respectively). Soil available NPK status were found to decline from the initial status with fodder maize cultivation.

The nutrient scheduling experiment was conducted during *Rabi* season, 2019 - 2020, in RBD with nine treatments and three replications. The variety APK 1, spacing 40 cm x 20 cm and nutrient level 40:80:40 kg NPK ha^{-1} found superior in Experiment I were adopted. The integrated nutrient management (INM) practices evaluated were T_1: 100 % NPK as chemical fertilizers, T_2: 100 % N + 50 % P + 100 % K + P solubiliser, T_3: 100 % N + 100 % P + 50 % K + K solubiliser, T_4: 100 % N + 50 % P + 50 % K + P solubiliser + K solubiliser, T_5: T_1 (50 % N foliar), T_6: T_2 (50 % N foliar), T_7 : T_3 (50 % N foliar), T_8 : T_4 (50 % N foliar) and T_9 : Absolute control: No fertilizers. The entire dose of N was given as soil application in T_1 to T_4 and foliar spray of 50 per cent N in T_5 to T_8 with urea (2 %) at 30 and 45 DAS. Phosphorus and K solubilisers (*Bacillus megaterium* and *Bacillus sporothermodurans* respectively) were mixed with powdered FYM in the ratio 1: 50 separately, and 10 g of each mixture was added in soil one week after basal fertilizer application.

The INM practice of 100 per cent N + 50 per cent P + 50 per cent K along with P and K solubilisers (T_4) recorded significantly taller plants (109.70 cm), maximum number of branches (6.5) at harvest, whereas weight of nodules per plant at flowering (0.59 g) and root parameters were significantly the highest in treatment T_8. Average pod weight (0.62 g) and seed yield (1.48 t ha^{-1}) were superior in T_4 and on par with the combination involving foliar nutrition, T_8 (1.46 t ha^{-1}). Integration of P and K solubilisers with chemical fertilizers (100 % N and 50 % P and K), registered 50 per cent higher yield than the absolute control.

Among the agronomic indices, DMP at 100 DAS (34.18 g plant^{-1}), CGR at 80 - 100 DAS (3.44 g m^{-2} day^{-1}) were the highest in T_4, and RGR, in T_2 followed by T_4. Substitution of 50 per cent P and K with biofertilizers recorded maximum uptake of N, P and K and physiological efficiencies for the nutrients.

Computation of nutrient balances with the INM practices adopted revealed the highest positive balance for N in T_8, P in T_4 and for K in T_7. Economic analysis showed the treatment T to record the highest net return per hectare (₹ 94722 /-) and B: C ratio (2.05).

Based on the results it could be concluded that the short duration red gram varieties, APK 1 and Vamban (Rg) 3 are suitable for cultivation in the southern laterites of Kerala. The variety APK 1 was superior in terms of yield and profit and can be recommended for planting at a spacing of 40 cm x 20 cm and an NPK dose of 40:80:40 kg ha^{-1} based on the soil test results. Evaluation of the legume effect of red gram revealed significant increases in soil fertility status with residue incorporation. Among the treatments imposed in red gram, irrespective of the variety, the residual effect realized with red gram planted at 40 cm x 20 cm spacing and fertilized with 40:80:40 kg NPK ha^{-1} was found to be superior in terms of fodder yield in the succeeding crop of maize. The integrated nutrient management practice that proved profitable in APK 1 involved application of 40:40:20 kg NPK ha^{-1} as chemical fertilizers along with P and K solubilisers, the entire dose in soil.

സംഗ്രഹം

"ഹ്രസ്വകാല തുവര പയറിന്റെ വിഭവ ഉത്തമീകരണം" എന്ന വിഷയത്തെ ആസ്പദമാക്കി 2017 - 2020 കാലയളവിൽ വെള്ളായണി കാർഷിക കോളേജിൽ വച്ച് ഒരു ഗവേഷണ പഠനം നടത്തുകയുണ്ടായി. കേരളത്തിൽ തുവരയിലെ ഹ്രസ്വകാല ഇനങ്ങളുടെ അനുയോജ്യത വിലയിരുത്തുക, കാർഷികമുറകളിൽ നടീൽ അകലവും വളപ്രയോഗവും ക്രമീകരിക്കുക, പയർവിളയുടെ അവശിഷ്ട പ്രഭാവം തുടർന്നുള്ള തീറ്റധാന്യ ചോളവിളയിൽ പരിശോധിക്കുക എന്നിവയായിരുന്നു പ്രധാന പഠനലക്ഷ്യങ്ങൾ.

മൂന്ന് വ്യത്യസ്ത പരീക്ഷണങ്ങളായാണ് ഗവേഷണം നടത്തിയത്. രണ്ട് ഹ്രസ്വകാല ഇനങ്ങളുടെ അനുയോജ്യത വിലയിരുത്തൽ, അവയുടെ നടീൽ അകലവും പോഷക അളവും ക്രമീകരിക്കൽ എന്നിവ ഉൾപ്പെടുന്ന പരീക്ഷണം 2018 - 2019 നവംബർ മുതൽ മാർച്ച് വരെയും സ്ഥിരീകരണ പരീക്ഷണം 2019 - 2020 കാലയളവിലും നടത്തി. എ പി കെ 1, വമ്പൻ (ആർ ജി) 3 ഹ്രസ്വകാല ഇനങ്ങൾ 40 സെ. മീ. x 20 സെ. മീ., 60 സെ. മീ. x 30 സെ. മീ. എന്നീ അകലങ്ങളിൽ ഹെക്ടറിന് 40:80:40, 30:60:30, 20:40:20 കിലോഗ്രാം പോഷക നിരക്കിൽ പാക്യജനകം (N), ഭാവഹം (P), പൊട്ടാസിയം (K) എന്നിവയുമാണ് പരീക്ഷണത്തിൽ ഉൾപ്പെടുത്തിയത്. മണ്ണ് പരിശോധനയുടെ അടിസ്ഥാനത്തിൽ പോഷക അളവ് തിട്ടപ്പെടുത്തിയതിന് ശേഷമാണ് രാസവളപ്രയോഗം നടത്തിയത്.

കാലിത്തീറ്റ ചോള വിളയിൽ പയർവർഗ്ഗ വിള അവശിഷ്ടങ്ങളുടെ സ്വാധീനം പഠിക്കുന്നതിനായ് (2019 ജൂൺ മുതൽ ആഗസ്റ്റ് വരെ) വിളവെടുത്ത പയറിന്റെ അവശിഷ്ടങ്ങൾ (വേര് + തണ്ട് + കൊഴിഞ്ഞ ഇലകൾ) അതാത് പ്ലോട്ടിലെ മണ്ണിൽ സംയോജിപ്പിച്ച് ഏപ്രിൽ മുതൽ ജൂൺ 2019 വരെ അഴുകുവാൻ അനുവദിച്ചു. അതിനുശേഷം ചോളത്തിന്റെ തീറ്റധാന്യ വിളയിനമായ "ആഫ്രിക്കൻ ടോൾ" വിത്തുകൾ പാകി മറ്റ് വളങ്ങൾ ഒന്നും തന്നെ ചേർക്കാതെ കൃഷി ചെയ്തു.

തുവര പയറിലെ വളപ്രയോഗ ക്രമീകരണം എന്ന പരീക്ഷണം 2019 - 2020 നവംബർ മുതൽ മാർച്ച് വരെ നടത്തി. N, P, K എന്നിവയുടെ രാസവളങ്ങളുടെ കൂടെ P, K മൂലകങ്ങളെ ലയിപ്പിക്കുന്ന സൂക്ഷ്മാണു ഉത്പ്പന്നങ്ങൾ ഉൾപ്പെടുത്തി വ്യത്യസ്തമായ 9 രീതികൾ പ്രയോഗിച്ചു. ഇതിൽ 1 മുതൽ 4 വരെയുള്ള രീതിയിൽ, മുഴുവൻ N മണ്ണിൽ രണ്ട് തവണയായ് ഇട്ടുകൊടുക്കുകയും 5 മുതൽ 8 വരെയുള്ളവയിൽ പകുതി N മണ്ണിലും ബാക്കി പകുതി ഇലകളിൽ പർണ്ണപോഷണം വഴിയായും നൽകി. ഇവയുടെ പ്രഭാവം താരതമ്യം ചെയ്യുവാൻ വളമിടാത്ത രീതിയും പരീക്ഷണത്തിൽ ഉൾപ്പെടുത്തി.

ഗവേഷണ പഠനത്തിലൂടെ എ പി കെ 1, വമ്പൻ (ആർ ജി) 3 എന്നീ രണ്ട് ഹ്രസ്വകാല ഇനങ്ങളും കേരളത്തിൽ കൃഷി ചെയ്യാൻ അനുയോജ്യമാണെന്നു കണ്ടെത്തി. ഇവയിൽ എ പി കെ 1 ഇനം 40 സെ. മീ. x 20 സെ. മീ. അകലത്തിൽ നടുന്നതും NPK ഹെക്റ്ററിന് 40:80:40 കിലോഗ്രാം അടിസ്ഥാനത്തിൽ രാസവളം നൽകുന്നതും നല്ല വിളവിനും ലാഭത്തിനും ഉതകുന്നു എന്ന് തെളിഞ്ഞു. തുവര പയറിന്റെ വിള അവശിഷ്ട സംയോജനത്തിലൂടെ മണ്ണിന്റെ ഫലഭൂയിഷ്ഠതയിൽ ഗണ്യമായ വർദ്ധനവ് കണ്ടെത്താൻ കഴിഞ്ഞു. തുവര 40 സെ. മീ. x 20 സെ. മീ. അകലത്തിൽ നട്ടതും ഹെക്റ്ററിന് 40:80:40 കിലോഗ്രാം എന്ന നിരക്കിൽ NPK നൽകിയ പ്ലോട്ടിൽ നിന്നുമുള്ള അവശിഷ്ടങ്ങളുടെ സംയോജനം വഴി തീറ്റധാന്യ ചോളവിളയിൽ മറ്റ് വളങ്ങളൊന്നും നൽകാതെ തന്നെ മികച്ച വിളവ് ലഭിക്കുന്നതായി കണ്ടു. തുവര എ പി കെ 1 ഇനം പയറിലെ സംയോജിത പോഷക പരിപാലന പരീക്ഷണത്തിൽ ഹെക്റ്ററിന് 40:40:20 കിലോഗ്രാം N, P, K രാസവളമായും കൂടെ ഭാവഹം, പൊട്ടാസിയം എന്നിവയെ ലയിപ്പിക്കുന്ന സൂക്ഷമാണു ഉത്പ്പന്നങ്ങൾ ഉപയോഗിക്കുന്നത് ചെടിയുടെ വളർച്ചയ്ക്കും വിളവിനും അധിക വരുമാനത്തിനും ഉത്തമമാണെന്ന് പഠനത്തിലൂടെ കണ്ടെത്താൻ കഴിഞ്ഞു.