PERFORMANCE OF RED GRAM (*Cajanus cajan* (L.) Millsp.) INTERCROPPING SYSTEMS IN LOWLANDS

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"PERFORMANCE OF RED GRAM (*Cajanus cajan* (L.) Millsp.) INTERCROPPING SYSTEMS IN LOWLANDS"** is bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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LIST OF ABBREVIATIONS

Abbreviation/Symbol	**Expansion**
ANOVA	Analysis of variance
A	Aggressivity
BCR	Benefit cost ratio
CD	Critical difference
Cm	Centimetre
cm^2	Centimetre square
DAS	Days after sowing
$dS\ m^{-1}$	Deci siemens per metre
EC	Electrical conductivity
et al.	Co-workers
Fig.	Figure
FYM	Farmyard manure
$g\ m^{-2}$	Gram per metre square
$g\ L^{-1}$	Gram per litre
IFSRS	Integrated Farming System Research Station
K/K_2O	Potassium
KAU	Kerala Agricultural University
$kg\ ha^{-1}$	Kilogram per hectare
LAI	Leaf area index
LER	Land equivalent ratio
MAI	Monetary advantage index
M	Metre
Mm	Millimetre
$ml\ L^{-1}$	Millilitre per litre

Abbreviation/Symbol	**Expansion**
N	Nitrogen
nos.	Numbers
NS	Not significant
OC	Organic carbon
P/P_2O_5	Phosphorus
pH	Potential of hydrogen
RARS	Regional Agricultural Research Station
RCC	Relative crowding coefficient
REY	Red gram equivalent yield
RH	Relative humidity
SE m	Standard error of mean
t ha^{-1}	Tonnes per hectare
USDA	United States Department of Agriculture
WSE	Weed smothering efficiency
viz.	Namely
%	Per cent
°C	Degree celsius
₹ ha^{-1}	Rupees per hectare

INTRODUCTION

1. INTRODUCTION

In Kerala, regardless of the significance of rice in every realm of the agrarian economy, the performance of the crop in recent years is grim. During the past, numerous farmers have been opting for crops of their choice and are converting paddy fields for other crops.

Rice-rice-fallow is the major rice based cropping system followed in Kerala. (John *et al*., 2014). A practical way to increase output, in terms of produce and income, is diversification, which is intended to give a wider choice of enterprises (Varughese *et al.*, 2007). Intercropping as an example of sustainable agricultural system follow objectives such as ecological balance, more utilization of resources, increasing the quantity and quality and reduce yield damage due to pests, diseases and weeds. Restoring on-farm biodiversity through diversified farming systems that mimic nature is considered to be a key strategy for sustainable agriculture. On-farm biodiversity, if correctly assembled in time and space, can lead to agro-ecosystems capable of maintaining their own soil fertility, regulating natural protection against pests, and sustaining productivity (Nandhini and Somasundaram, 2020).

Red gram (*Cajanus Cajan* (L.) Millsp.) is one of the important grain legume of tropical and subtropical regions. According to FAO statistics, red gram is cultivated worldwide in an area of 60.96 lakh hectares with a production of 50.12 lakh tonnes and productivity of 822.2 kg ha^{-1} (FAO STAT, 2020). India produces 4.32 MT of red gram from an area of roughly 4.80 m ha (ICAR-IIPR, 2022). In Kerala, it covers an area of about 0.002 lakh hectare with production and productivity accounting to 0.003 lakh tonnes and 1647 kg ha^{-1} respectively (DPD-GOI, 2022).

Red gram being an integral component of various cropping systems can be grown either as a sole crop or as an intercrop. Apart from providing biological insurance, it ensures higher total yield advantage of component crops than their sole cropping (Andrews, 1972). It can be intercropped with many compatible crops. Cowpea and green gram are considered suitable in intercropping system due to its short duration, less competitiveness, ability to fix nitrogen and is nutritional rich in protein and minerals. Finger millet is another choice for intercropping as it can yield well even under limiting soil moisture conditions.

Red gram has been successfully demonstrated in summer fallows in rice cropping system of lowland areas in Kerala (Adarsh, 2019). However, owing to the wide spacing adopted, weed infestation is a major problem thereby necessitating labour intensive intercultural operations. Introducing intercrops is a practical means of reducing weed infestation and also increasing total income from unit area.

In this context, the present investigation entitled "Performance of red gram (*Cajanus cajan* (L.) Millsp.) intercropping systems in lowlands" was undertaken with following objectives

i. To find the suitability of different red gram based intercropping systems in the summer fallow of double cropped lowland rice field

ii. To assess the biological efficiency and weed dynamics of the different red gram based intercropping systems

iii. To determine the effect of intercropping on economics of the system

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Developing countries around the world are promoting sustainable development through sustainable agricultural practices which will help them in addressing socio-economic as well as environmental issues simultaneously. Hence, a system involving pulses assumes paramount importance for climate resilience, food security and contribution of considerable share to the economy. In terms of area and production, red gram is the second most important tropical pulse crop in India after chickpea. India produces 4.32 MT of red gram from an area of roughly 4.80 M ha (ICAR-IIPR, 2022). In Kerala, it covers an area of about 0.002 lakh hectare with production and productivity of 0.003 lakh tonnes and 1647 kg ha^{-1} respectively (DPD-GOI, 2022). Hence, it plays a crucial part of many cropping systems and is planted either as a sole or as an intercrop.

In Kerala, rice-rice-fallow is the major rice-based cropping system followed (John *et al*., 2014). Farmers have begun to experiment with intercropping owing to the limited per capita land availability and risk associated with sole cropping. Intercropping not only improves cropping intensity but also aids in resource optimization and serves as a biological insurance against risk.

In the present study, an attempt was made to assess the productivity and biological efficiency of red gram based intercropping systems in summer fallow of double cropped lowland. The research work done in this area is reviewed.

2.1. EFFECT OF INTERCROPPING ON COMPONENT CROPS

2.1.1. Effect of Intercropping on Growth and Growth Parameters

Tiwari *et al.* (2011) recorded higher number of trifoliate leaves per plant under red gram + black gram (227.93) intercropping system compared to red gram + maize (146.57) and sole red gram (203.97).

Sreechandan and Mangaraj (2015) reported that intercrops black gram and groundnut contributed to better initial growth (1.64 to 1.77 g/day/plant during 30 to 60 DAS) as well as production of effective branches (30.7 to 31.7) in red gram crop. On the other hand, sesamum and finger millet had depressing effect on red gram crop.

According to Pal *et al.* (2016) in red gram + black gram intercropping system, red gram recorded significantly taller plants (231.22 cm plant $^{-1}$), number of branches (18.20 plant $^{-1}$) and plant dry matter (213.25 g plant $^{-1}$), than red gram + sorghum intercropping system.

Sekhon and Singh (2019) observed lowest plant height of red gram in intercropping system during all the growth stages when fodder crops were grown but was not significantly affected during the maturity stage. It was attributed to the higher demand of nutrients for growth and development of intercrops during early growth stage of red gram which declined after the harvest of fodder crops.

According to Kumar *et al.* (2022), red gram when intercropped with millets did not adversely affect plant height and number of branches per plant. They suggested that it was due to efficient utilization of resources and ability of red gram to contribute to increased nitrogen availability.

2.1.2 Effect of Intercropping on Nutrient Uptake by the Crops

Aravinth *et al.* (2011) observed that the nutrient uptake of baby corn was not influenced by the intercrops *viz.,* black gram and cowpea since the intercrops were harvested before 45 DAS and not much of nutrients were depleted.

According to Kumawat *et al.* (2012), N, P and K uptake by the red gram + black gram (1:1) system was 121.61, 16.80 and 95.90 kg ha^{-1} respectively, which was significantly higher over sole red gram (103.84, 14.95 and 76.94 kg ha^{-1} respectively).

Pandey *et al.* (2013) recorded higher nitrogen uptake (159 kg ha^{-1}) in red gram + black gram intercropping system and higher potassium uptake (57 kg ha^{-1}) in red gram + maize intercropping system when compared to sole red gram (102 kg ha^{-1} N and 25 kg ha^{-1} K).

Red gram when raised as pure crop recorded highest nitrogen uptake (139.5 kg ha^{-1}) which was followed by red gram + groundnut (4:5) intercropping system (93.9 kg ha^{-1}). Similarly, the highest phosphorus uptake (7.2 kg ha^{-1}) was observed in sole red gram followed by red gram + black gram (4.8 kg ha^{-1}) (Vijayaprabhakar *et al.*, 2018).

An experiment conducted by Emmanuel (2019), revealed that N, P and K uptake by baby corn was highest in paired row of baby corn + cowpea (239.94 kg ha^{-1}, 24.44 kg ha^{-1} and 335.27 kg ha^{-1} respectively). Among the intercropping treatments, cowpea in baby corn + cowpea (skip row) recorded the highest N (155.52 kg ha^{-1}), P (7.94 kg ha^{-1}) and K (30.26 kg ha^{-1}) uptake.

2.1.3 Effect of Intercropping on Yield Attributes of Red Gram

According to Giri *et al.* (1980) intercropping red gram with green gram (2:1), soybean (1:1 and 2:1) and with groundnut (1:1 and 2:1) did not have significant effect on red gram yield in comparison to sole red gram. However, red gram + pearl millet (1:1, 2:1 and 2:2) reduced red gram grain yield. It may be attributed to the quick growing characteristics of pearl millet which had shading effect on the red gram crop.

Katayama *et al*. (1995) observed that yield obtained in red gram and cowpea intercropping system was significantly lower (1405 kg ha^{-1}) as compared to sole red gram (1777 kg ha^{-1}) due to the competition between the crops for light.

Keshava and Ramachandrappa (2000) reported that in red gram + cowpea intercropping system, red gram yield was slightly reduced in 1:2 proportion as compared to 1:3 proportion.

According to Maitra *et al.* (2001), finger millet provided a higher yield when planted as intercrop with red gram than when cultivated as a sole crop.

Padhi *et al.* (2010) revealed that raising finger millet and red gram in 4:2 ratio under rainfed condition proved most productive and economically viable with significantly higher red gram seed equivalent yield (1.32 t/ha) than their sole planting.

Number of pods per plant and grain yield of red gram was significantly higher when intercropped with finger millet (Murali *et al.*, 2014).

Barod *et al.* (2017) inferred that the synergistic effect of component crop contributed to the higher grain yield of red gram (1684 kg ha^{-1}) in red gram + green gram (1:2) systems and was found to be at par with red gram + green (1:1) intercropping system.

Kumar *et al.* (2019) recorded that red gram + cowpea intercropping system produced more red gram yield equivalent (15.76 q/ha) which was nearly 64 per cent more than sole red gram.

Anandkumar *et al.* (2020) concluded that sole red gram recorded higher seed yield (2,126 kg ha^{-1}) followed by red gram + black gram (1:3) (1,986 kg ha^{-1}) and red gram + green gram (1:3) (1898 kg ha^{-1}). This was attributed to the higher competition for resources between main and intercrop which resulted in lower yield attributes.

Deolankar *et al.* (2016) revealed that higher grain (19.34q ha^{-1}) and straw (34.58 q ha) yield of red gram was obtained in red gram + French bean (1:3) system.

2.1.4 Effect of Intercropping on Yield Attributes of Intercrops

There was significant effect of intercropping on finger millet with respect to the yield attributes. Ramamoorthy *et al*. (2004) recorded higher grain yield of finger millet (2212 kg ha^{-1}) when intercropped with red gram. Das and Sudhishri (2010) reported that when finger millet was intercropped with red gram in the ratio 3:2 the number of fingers per ear was reduced.

Intercropping of finger millet with black gram or moth bean in 8:2 or 4:1 row proportion resulted in maximum grain and straw yield (Nigade *et al.*, 2012). The maximum number of fingers (3.51), finger length (5.75 cm) and 1000 grain weight (6.37g) were observed in sole finger millet, which was superior and at par with red gram + finger millet (1:4) intercropping system while lowest in finger millet + niger cropping system (Pradhan *et al.*, 2014).

Ray *et al.* (2016) reported that in red gram based cropping system, highest intercrop yield (475 kg ha^{-1}) was obtained in red gram + cowpea (1:2) system. It might be due to relatively higher crop stand (92.1%) in the system.

Sole crop of green gram recorded maximum grain, straw and biological yield as compared to intercropping system. However, when compared to red gram and green gram 1:2 and 1:1 intercropping system higher yield of green gram was recorded in 1:2 system (6510 kg ha^{-1}). It was because of increased number of rows of green gram and reduced competition between and within crop plants (Barod *et al*., 2017).

2.2 EFFECT OF INTERCROPPING ON SOIL PROPERTIES

2.2.1. Effect of Intercropping on Soil Chemical Properties

Crop residues added through growing of food crops assures substantial benefits in terms of soil organic carbon and conservation of resources and these in turn contribute to sustainable agricultural systems and crop productivity (Venkatesh *et al.*, 2013).

Wilhelm *et al.*, (2004) opined that in pulses like red gram, more nutrients are added through their substantial biomass which contains low C: N ratio resulting in long term improvement in soil quality.

Intercropping of red gram + black gram improved the level of N (216.45 kg ha^{-1}), P (19.40 kg ha^{-1}), K (214.33 ka ha^{-1}) and organic carbon (0.89%) which was on par with sole red gram (210.56 N, 18.03 P, 206.96 K kg ha-1 and 0.85% OC). In contrast, red gram + maize had a deteriorating effect on the fertility status of N (198 kg ha^{-1}) , P (15.40 kg ha^{-1}), K (190.76 kg ha^{-1}) and organic carbon (0.81%) in soil (Tiwari *et al.*, 2011).

Kumawat *et al.* (2012) concluded that higher available N, P, K was recorded in sole red gram (209.72 kg ha^{-1}) when compared to red gram + black gram (205.79 kg ha^{-1}) intercropping system. It was ascribed to lower plant population in sole cropping than intercropping system.

According to Nagar *et al.* (2016), soil pH and electrical conductivity (EC) was not significantly influenced by different cropping systems. However, lowest soil pH (7.97) and EC (0.15 dS/m) were found in red gram + black gram followed by red gram + green gram and highest in sole red gram, whereas higher level of organic carbon (5.56 g/kg), available nitrogen (182.8 g/kg), phosphorus (22.5 g/ kg) and potassium (431.8 g/kg) were analysed in red gram + black gram and red gram + green gram intercropping system and lowest was recorded in sole red gram.

Barod *et al.* (2017) reported that available nitrogen in soil after harvest increased under treatments involving sole and intercropping of grain legumes *viz.*, green gram and red gram but contrasting values were observed in the case of sole pearl millet. However, such effects were not apparent in respect to phosphorus and potassium.

2.2.2. Effect of Intercropping on Dehydrogenase Activity

Legume-inclusive diversification of cereal-cereal rotations had notable influence on soil enzymatic activities. According to Gosh *et al.* (2002), dehydrogenase activity in soybean + sorghum (80.3µg TPF g^{-1} 24 h^{-1}) intercropping system was higher compared to sole crops of soybean (69µg TPF g^{-1} 24 h^{-1}) and sorghum (77µg TPF g^{-1} 24 h^{-1}) .

Ahamad *et al.* (2016) concluded that maximum dehydrogenase activity (DHA) was observed in red gram + black gram i.e. 15.97µg TPF g^{-1} h^{-1} when compared to 14.94µg TPF g^{-1} h^{-1} of sole red gram crop.

An experiment conducted by Choudhary *et al.* (2018) revealed that intercropping system including guinea grass and forage legume improved dehydrogenase activity by 32 per cent when compared to grass alone system.

Nayawade *et al.* (2019) reported that soil dehydrogenase activity increased by 15-38 per cent in intercropping system including legumes compared to the sole cropping of potato.

2.3 EFFECT OF INTERCROPPING ON WEED PARAMETERS

2.3.2 Effect of Intercropping on Weed Dry Weight

Intercropping has been reported to reduce weed growth by creating a good crop cover. Research undertaken at the Indian Institute of Pulses Research, Kanpur revealed that intercropping red gram with cowpea, urd bean, and mung bean reduced the weed flora by 30 to 40%. (IIPR, 2009).

Tewari *et al.* (1989) reported that inclusion of intercrops viz., black gram, green gram, groundnut and cowpea between the rows of red gram resulted in 17.57, 16.09, 31.78 and 39.86 per cent weed suppression respectively.

Ali (1988) reported that the lowest weed dry matter was recorded in red gram + cowpea system (1:1) with weight being 45.1 g m^{-2} as against 80.2 g m^{-2} under sole red gram.

According to Kiroriwal and Yadav (2013), pearl millet intercropped with cluster bean and moth bean significantly lowered weed density and dry matter production of different weeds *viz.*, *Tribulus terrestris*, *Cenchrus biflorus* and *Corchorus tridense* probably due to the higher crop canopy than sole pearl millet.

Sidar and Thakur (2017) reported that finger millet + red gram had more weed density at 45 and 60 DAS which was attributed to the slow growth of red gram which did not cover the ground area thereby promoting weed growth.

Red gram + cowpea (1:1) intercropping system had the lowest density of monocot and dicot weeds as well as dry matter production of weeds at 60 and 90 DAS. This was attributed to the cowpea's lush foliage which had a smothering effect in the interspace between red gram thereby preventing radiation from reaching the rhizosphere and reducing the infestation of weed flora by impeding germination, emergence, and establishment (Singh and Abraham, 2017).

Intercropping had significant effect on total weed density and weed dry weight. Choudhary *et al*. (2021) observed maximum weed density as well as weed dry weight under sole red gram while minimum weed density was recorded under sole black gram which was on par with red gram + black gram (1:1) and red gram + black gram (1:2).

2.3.3 Effect of Intercropping on Weed Flora

Rai *et al.* (2016) reported that red gram sole as well as intercropped system faced acute problems of weed infestation. Monocot weeds like *Echinochloa* sp., *Cynodon dactylon*, *Cyperus rotundus* and *Sorghum helpense* and dicot weeds *viz., Convolvulus arvensis*, *Commelina benghalensis*, *Launea splenifolia*, *Amaranthus virdis* and *Digara arvensis* dominated the system.

Red gram based intercropping system, as noted by Nambi (2017), recorded nine species of broad-leaved weeds, four species of grasses, and one species of sedge. In terms of broad-leaved weeds, *Trianthema portulascatrum*, *Phyllanthus niruri*, *Phyllanthus madraspatensis,* and *Amaranthus viridis* were more prevalent than the grass species *Cynodon dactylon, Panicum repens,* and *Panicum flavidum. Cyperus rotundus* was the only sedge present.

2.3.4. Nutrient Removal by Weeds

As observed by Choudhary *et al.* (2014) maize intercropped with legume in the ratio 1:5 recorded lowest N, P and K removal by weeds followed by 1:2 and 1:1 when compared with sole crop of maize. The amount of nutrients removed by weeds was smallest in maize + cowpea (29%), followed by maize + black gram (25%) and maize + french bean (24%). Less removal of nutrients in intercropping system involving pulses might be due to low weed density and weed biomass.

According to Jiwan *et al.* (2021), the maximum nutrient uptake by weeds was observed in sole crop of mustard (6166.9 kg ha-1) when compared to the intercrops *viz.*, Wheat + Mustard (4568.2 kg ha-1), Wheat + Linseed (3792.5 kg ha-1), Gram + Mustard (4706.9 kg ha-1) and Pea + Mustard (3274.5 kg ha-1). But the highest total nutrient uptake by weeds was in the fallow land (8083.2 kg ha-1).

2.3.5. Weed Smothering Efficiency

Rathika *et al*. (2013) reported that baby corn + fodder cowpea had the maximum weed smothering efficiency (WSE) over baby corn + fenugreek system at 45 DAS. This was attributed to better vegetative growth of baby corn and intercrops which caused severe competition resulting in reduced weed population and increased WSE.

Pearl millet + black gram (1:1) recorded highest weed smothering efficiency of 52 per cent and was closely followed by pearl millet + green gram (1:1) system with 39.3 per cent over sole cropping (Mathukia *et al.*, 2015).

Reddy *et al.* (2020) observed that in intercropping experiment of finger millet with pulses resulted in higher WSE of 42.92 per cent in finger millet (without AMF) + cowpea followed by finger millet (with AMF) + cowpea (40.35%).

2.4 EFFECT OF INTERCROPPING ON CROP COMPETITION INDICES

2.4.1. Leaf Area Index

Subramanian and Venkateswarlu (1989) observed that leaf area index (LAI) of sole red gram (1.84) was higher when compared with red gram + sorghum (0.58) and red gram + black gram (1.12) intercropping system.

Among different intercropping system, transplanted red gram + green gram (1:2) recorded higher LAI of 4.03 (120 DAT) and the lowest was observed in direct sown red gram + soybean (2.03 – 120 DAS) (Sujatha and Babalad, 2018).

According to Rajashree *et al.* (2022) different fodder intercropping systems in red gram had significant influence on LAI of red gram at all growth stages. Sole crop of red gram had maximum LAI of 1.09 (at harvest) while lowest was recorded in red gram + fodder maize (0.74 – at harvest) intercropping system. It was inferred that the inter and intra row competitions among plants might have influenced the LAI of red gram.

2.4.2. Land Equivalent Ratio

Land Equivalent Ratio (LER) indicates the biological efficiency and yield per unit area of land as compared to the monocropping system.

Sarkar and Shit (1993) concluded that land equivalent ratio increased to about 27 to 65 per cent in intercropping system over sole cropping. Higher LER was achieved in red gram + groundnut (1.63) followed by red gram + black gram (1.43) and red gram + maize (1.42).

Deolankar *et al.* (2016) reported that red gram + French bean (1:3) obtained highest LER (1.52) and was at par with red gram + soyabean (1.48) intercropping system.

Intercropping of red gram + foxtail millet (1:2 ratio) recorded significantly higher LER (1.16 and 1.06) for the year 2017 and 2018 respectively compared to sole crop (Biradar *et al.*, 2020).

2.4.3. Relative Crowding Coefficient

Relative crowding coefficient (RCC) is used to assess the competitive interactions of species in the intercropping system. It provides a measure whether the crop has produced more or less than expected.

An experiment conducted by Ghosh (2004), revealed that the RCC value was significantly higher (26.0) in groundnut + fodder maize (3:1) intercropping system and the lowest (8.7) was recorded in groundnut + fodder pearl millet (3:1) system.

Verma *et al*. (2005) reported that intercropping systems red gram (75cm row spacing) + fodder sorghum in the ratio 1:1 and 1:2 row ratio had higher RCC values (15.07 and 9.19) respectively.

Reddy (2020) reported that the highest RCC value was recorded under finger millet (without AMF) + cowpea (16.01) and finger millet (with AMF) + cowpea (12.67) indicating their yield advantage which was followed by finger millet + green gram and finger millet + black gram intercropping systems.

2.4.4. Red gram Equivalent Yield

Crop equivalent yield provides the overall production potential of intercropping systems.

According to Garud *et al.* (2019) red gram equivalent yield (REY) was significantly superior in red gram + green gram intercropping system i.e., 1832 kg ha^{-1} when compared with REY of black gram (1664 kg ha^{-1}), soybean (1663 kg ha^{-1}) and cowpea (1505 kg ha^{-1}).

Deshmukh *et al.* (2020) reported that red gram + soyabean (1:2) gave significantly higher red gram equivalent yield (1222 kg ha^{-1}) and was found at par with red gram + green gram (1:2) (1150 kg ha^{-1}) and lowest REY was obtained from sole red gram (1077 kg ha^{-1}).

Higher red gram equivalent yield was obtained when red gram was intercropped with French bean (2932 Kg ha^{-1}) and groundnut (2406 Kg ha^{-1}) in the ratio 1:2 and the lowest REY was obtained in the case of sole red gram (1543 kg ha^{-1}) (Rathod *et al.*, 2002).

2.4.5. Aggressivity

According to Chaudhari *et al*. (2017), positive aggressivity values were recorded for intercrops and negative value for the main crop groundnut. Among the intercrops, value of aggressvity was highest in groundnut + soybean (± 0.77) followed by groundnut + black gram (± 0.65) while the lowest value was observed in groundnut + cotton (± 0.30) which was followed by groundnut + red gram (± 0.48) and groundnut + castor (± 0.49) intercropping system.

The intercropping system of palisade grass (60×40 cm) with fodder rice bean registered highest aggressivity index of 1.43 while lowest was recorded in palisade grass (60 40cm) + fodder cowpea (0.723). Higher aggressivity of fodder cowpea (0.896) when compared to rice bean (-1.43) indicates that in low input system, palisade grass + fodder cowpea intercropping can be introduced as an alternative to sole palisade grass (Nasreen, 2018).

Panda *et al.* (2022) reported that the aggressivity of red gram was found to have negative value (-0.46 and -0.12 respectively) when intercropped with french bean and cowpea. Conversely, aggressivity was positive when intercropped with french bean (0.46) and cowpea (0.12) thereby proving their dominance over red gram. Nevertheless, red gram was found equally competitive with yam bean when sown in 1:1 proportion, having aggressivity value zero and dominant over yam bean when sown in 2:2 proportion with positive aggressivity value (0.16).

2.4.7. Monetary Advantage Index (MAI)

Monetary Advantage Index (MAI) value of 4926 indicated that red gram (75 cm) + green gram (l :2) intercropping system was more remunerative than planting single row of green gram irrespective of row spacing in red gram (Kumar *et al.*, 2005)

Kumawat *et al.* (2013) concluded that with additional yield procured from black gram, MAI in red gram + black gram (1:1) was found to be at par with red gram + black gram (1:2) and significantly superior to sole red gram cropping system.

Bhadu *et al.* (2021) noted that red gram + groundnut intercropping system recorded significantly higher MAI (13,650) which was followed by red gram + cowpea system (12,941) whereas lowest MAI value was obtained from red gram and sesame intercropping system (2582).

Tripathi *et al.* (2021) reported that maize + cowpea followed by wheat at 100 per cent recommended dose of fertilizer recorded maximum MAI (47,570) which was on par with (maize + cowpea) – wheat (75% RDF) (45,376) and minimum MAI was observed under (maize + cluster bean) – wheat (100% RDF) (7326).

2.5 EFFECT OF INTERCROPPING ON ECONOMICS OF CULTIVATION

According to Dass and Sudhishri (2010), the highest net returns (Rs. 9,665/Ha) and benefit: cost ratio (1.00) was obtained with finger millet + red gram (6:2 ratio) intercropping system.

Sharma *et al.*, (2010) recorded significantly higher gross return (Rs. 31273 ha-1), net returns (Rs. 22546 ha-1) and B:C ratio (3.59) in red gram + green gram (1:2) intercropping system compared to red gram + pearl millet (1:2) intercropping system.

Singh *et al.*, (2013) on evaluating the performance of intercropping system with phosphorus fertilization and bio-fertilizer application recorded that red gram + green gram intercropping system had significantly higher B:C ratio (2.40 and 2.81) followed by sole red gram (2.13 and 2.55) and green gram (1.16 and 1.15) in the year 2005 and 2006 respectively.

Murali *et al.*, (2014) deduced that intercropping of finger millet with transplanted red gram gave maximum net returns with benefit :cost ratio of 2.49.

Ray *et al*. (2016) concluded that maximum net return was recorded in red gram + black gram (1:1 at Rs.84115 ha^{-1}) followed by red gram + green gram (1:1 at Rs.82554 ha^{-1}) while the minimum net return was recorded in sole cropping of red gram (Rs. 48527 ha^{-1}).

Kujur *et al.* (2018) reported that red gram + short duration finger millet in 1:1 row proportion produced maximum net returns of Rs. 15090.5 ha^{-1} and benefit : cost ratio of 2:31 which was on par with red gram + medium duration finger millet (1:1), red gram + long duration finger millet (1:1) and red gram + short duration finger millet (1:2) but was significantly superior to sole cropping.

Literature search revealed that red gram being a long duration crop was seldom raised as a sole crop and has been highly appreciated for its climate resilient and nutrient recycling properties. From the above review it can be summarised that the red gram intercropping systems can enrich soil with nutrients and organic matter, improve land use efficiency and provides additional yield and monetary advantage. The significant influence of intercropping has been studied by several authors. However, studies based on intercropping systems in double cropped lowland rice fields has not been undertaken so far.

Therefore, the present study is indispensable to realise the objectives of evaluation of the suitability of different red gram based intercropping systems in summer fallow of double cropped lowland rice field in terms of weed dynamics, biological efficiency and economics.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The field experiment entitled “Performance of red gram [*Cajanus cajan* (L.) Millsp.] intercropping systems in lowlands” was carried out at College of Agriculture, Vellayani and Integrated Farming System Research Station (IFSRS), Karamana during 2020-2022. The experiment was undertaken with the objective of evaluating different red gram based intercropping systems in the summer fallow of double cropped lowland rice field in terms of weed dynamics, biological efficiency and economics. The details of the material used and the methods adopted during the course of experiment are presented in this chapter.

3.1 EXPERIMENTAL SITE

The study was conducted as part of the ongoing All India Co-ordinated Research Project on Integrated Farming system being implemented in the Integrated Farming System Research Station (IFSRS) of Kerala Agricultural University located at Karamana, Thiruvananthapuram, Kerala. The experimental site is double cropped lowland rice field located at 8° 28' 25'' N latitude and 76^0 57' 32'' E longitude and at an altitude of 5 m above mean sea level.

3.1.1 Climate

A warm humid tropical climate prevails over the experimental site. The data on various weather parameters (mean maximum and minimum temperature, relative humidity (RH) and rainfall) during the cropping period were collected from the Agromet observatory, IFSRS, Karamana. The details of weather parameters are given in Appendix 1 and graphical illustration of weekly weather data are represented in Fig 1. The maximum and minimum temperature during the period from 27 January 2022 to 6 June 2022 ranged from 23.06℃ - 25.94℃ and 29.37℃ - 32.87℃ while maximum relative humidity ranged between 80.58- 91.90 per cent and minimum relative humidity ranged between 59.99-78.87 per cent . A total rainfall of 600.20 mm was recorded during the cropping period.

3.1.2 Cropping Season

The experiment was conducted during summer season of 2022 (January – June) including crops *viz.*, red gram, bush cowpea, fodder cowpea, green gram and finger millet.

3.1.3 Soil

The experiment comprised treatments including pulses and millet in an intercropping system. Hence, composite soil samples were collected from 15 cm depth from the site before and after the experiment and were analysed for its mechanical and chemical properties. The mechanical and chemical properties of soil are presented in Table 1 and 2. The soil properties were rated as per Package of Practices Recommendations of Kerala Agricultural University (KAU, 2016).

The soil of the experimental site was sandy clay loam in texture, moderately acidic pH, medium in available nitrogen and potassium and high in phosphorus.

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

Fractions	Content in soil (%)	Method adopted
Coarse sand	47.69	Bouyoucos Hydrometer method (Bouyoucos,1962)
Fine sand	10.61	
Silt	8.53	
Clay	32.69	
Textural Class: Sandy clay loam (USDA textural triangle, (USDA, 1999))		

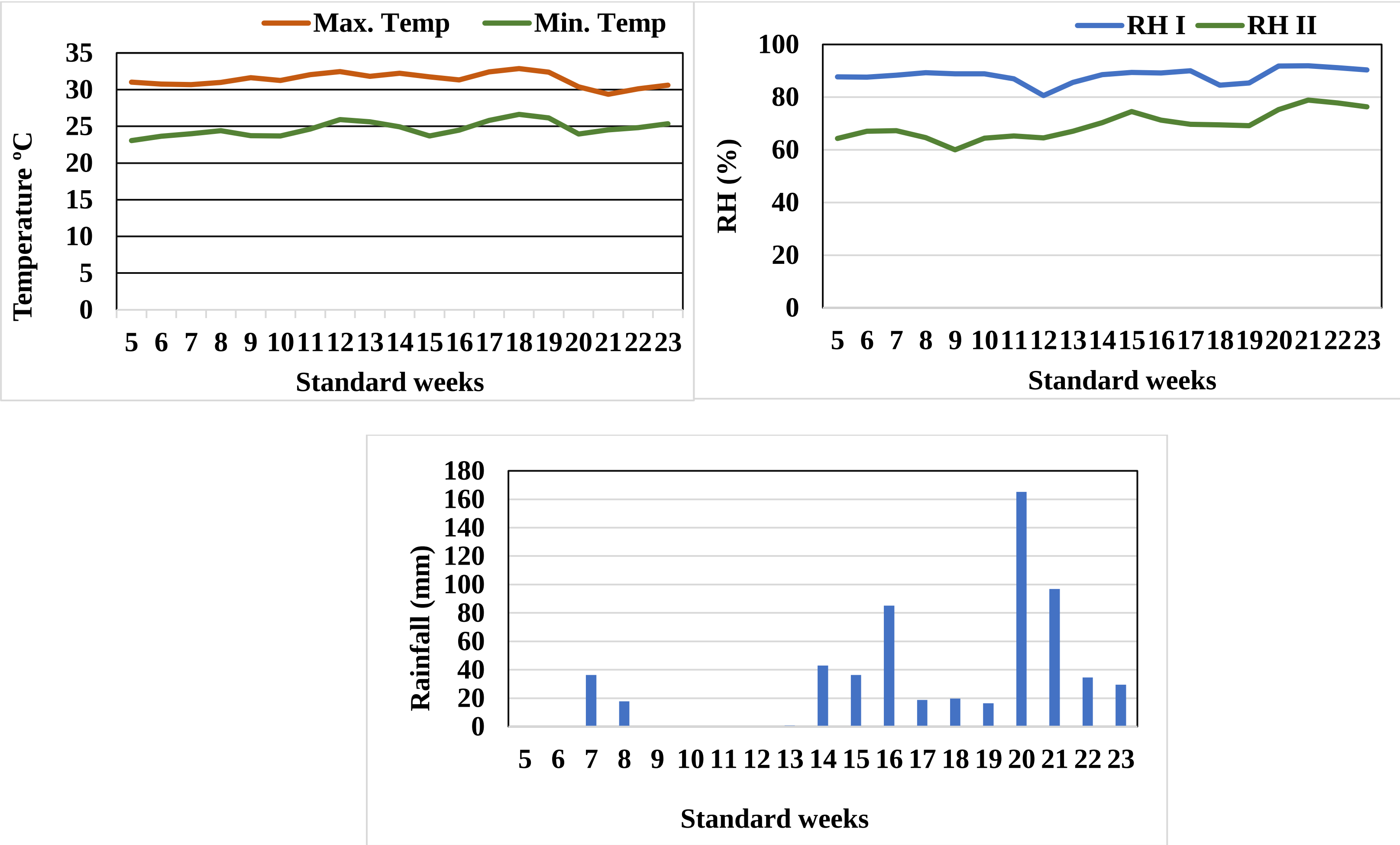


Fig 1. Weather parameters during the cropping period (27/01/2022 to 06/06/2022)

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

SI. No.	Parameters	Content	Rating	Method adopted
1.	Soil reaction (pH)	5.73	Moderately acidic	1:2.5 soil solution ratio using pH meter (Jackson, 1973)
2.	Electrical conductivity (dS m^{-1})	0.19	Normal	Using electrical conductivity meter (Jackson, 1973)
3.	Organic carbon (%)	1.42	Medium	Walkley and Black's rapid titration (Walkley and Black, 1934)
4.	Available N (kg ha^{-1})	332.58	Medium	Alkaline permanganate method (Subbiah and Asija, 1956)
5.	Available P_2O_5 (kg ha^{-1})	45.53	High	Bray colorimetric method (Jackson, 1973)
6.	Available K_2O (kg ha^{-1})	136.06	Medium	Ammonium acetate method (Jackson, 1973)
7.	Dehydrogenase activity (µg TPF g^{-1}soil d^{-1})	58.24		Casida *et al*. (1964)

3.1.4 Cropping History of the Field

The experiment was conducted in the lowland rice field of IFSRS, Karamana, where the cropping sequence followed was rice-rice-fallow.

3.2 MATERIALS

3.2.1 Crop and Variety

3.2.1.1. Red gram

The red gram (*Cajanus cajan (L.*) Millsp.) variety used was Ujwala (PRG 176) released from the Regional Agricultural Research Station (RARS), Palem, Telangana. It is of long duration (130-135 days), resistant to terminal drought and is suitable for light red soils with low water retention capacity. The seeds of the variety were obtained from RARS, Palem.

3.2.1.2 Bush cowpea

The bush cowpea (*Vigna unguiculata*) variety Pant Lobia-3 (PGCP-6) released by G.B. Pant University of Agriculture and Technology in the year 2015 was selected for the study. It is of 60-75 days duration and is resistant to yellow mosaic virus (YMV) and bacterial blight. The seeds of the variety were obtained from RARS, Pattambi.

3.2.1.3 Fodder Cowpea

The fodder cowpea (*Vigna unguiculata* (L.) Walp.) variety Aiswarya, released by Kerala Agricultural University in the year 2013 was used for the study. The single cut fodder variety tolerant to mosaic and moderately resistant to leaf spot and leaf hoppers, is recommended for uplands and homesteads in southern districts of Kerala. The seeds of the variety were obtained from AICRP on fodder and forage crops COA, Vellayani.

3.2.1.4 Green gram

The green gram (*Vigna radiata* L.) variety CO-6 released by TNAU, Coimbatore in the year 1999 was used for the study. It is resistant to yellow mosaic virus and has a duration of 62-67 days. The seeds were procured from RARS, Pattambi.

3.2.1.5 Finger millet

The finger millet (*Eleusine coracana* (L.) Gaertn.) variety VR 847 (Srichaitanya) was used for the study which was developed by Acharya N.G. Ranga Agricultural University (ANGRAU), Vizianagaram in the year 2009. It has a duration of 110-115 days and is moderately resistant to blast. The seeds of the variety were obtained from Professor Jayashankar Telangana State Agricultural University (PJTSAU), Hyderabad.

3.2.2 Manures and Fertilizers

Well decomposed farmyard manure containing 0.5 per cent N, 0.2 per cent P_2O_5 and 0.4 per cent K_2O was applied as source of organic manure. Urea (46% N), Rajphos (20% P_2O_5) and Muriate of Potash (60% K_2O) were used as inorganic source of N, P and K respectively.

3.3 METHODS

3.3.1 Design and layout

Design : Randomized Block Design

Treatments : 10

Replication : 3

Plot size : 4.8m × 4.4m

Spacing : 60 cm × 20 cm (Red gram)

30 cm × 15 cm (Bush cowpea, Fodder cowpea)

25 cm × 15 cm (Green gram, Finger millet)

3.3.2 Treatment details

Treatment combinations

T_1 : Red gram + bush cowpea (1:2)

T_2 : Red gram + green gram (1:2)

T_3 : Red gram + fodder cowpea (1:2)

T_4 : Red gram + finger millet (1:2)

T_5 : Sole crop of red gram

T_6 : Sole crop of bush cowpea

T_7 : Sole crop of green gram

T_8 : Sole crop of fodder cowpea

T_9 : Sole crop of finger millet

T_{10} : Fallow

Note- Red gram was raised as per recommendations of Regional Agricultural Research Station, Palem, Telengana and the intercrops as per the Package of Practices Recommendations of Kerala Agricultural University (KAU, 2016).

3.3.3 Crop Management

3.3.3.1 Land Preparation

After the harvest of preceding crop, weeds were removed and the field was modified into raised bed of dimensions 4.8m × 4.4m × 30cm wherein intercrops were raised. Drainage and irrigation channels were constructed on all the four sides of the field. A distance of 30cm was maintained between the beds. FYM was applied during the final land preparation. The beds were perfectly levelled and brought to fine tilth.

3.3.3.2 Application of Manures and Fertilizers

Manures and fertilizers were applied as per Package of Practices Recommendations of Kerala Agricultural University (KAU, 2016) for all crops except red gram for which nutrients were given according to the recommendations of RARS, Palem, Telengana. Application of manures and fertilizers were done separately for the main crop and intercrops. Well decomposed farm yard manure was applied to all the plots, except T_{10} (fallow) at the time of land preparation. The fertilizer recommendation adopted are detailed in Table 3.

Table 3. Details of manures and nutrients applied

SI. No.	Crops	FYM (t ha^{-1})	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
1	Red gram	3	20	50	0
2	Bush cowpea	20	20	30	10
3	Green gram	20	20	30	30
4	Fodder cowpea	10	25	60	30
5	Finger millet	5	22.5	22.5	22.5

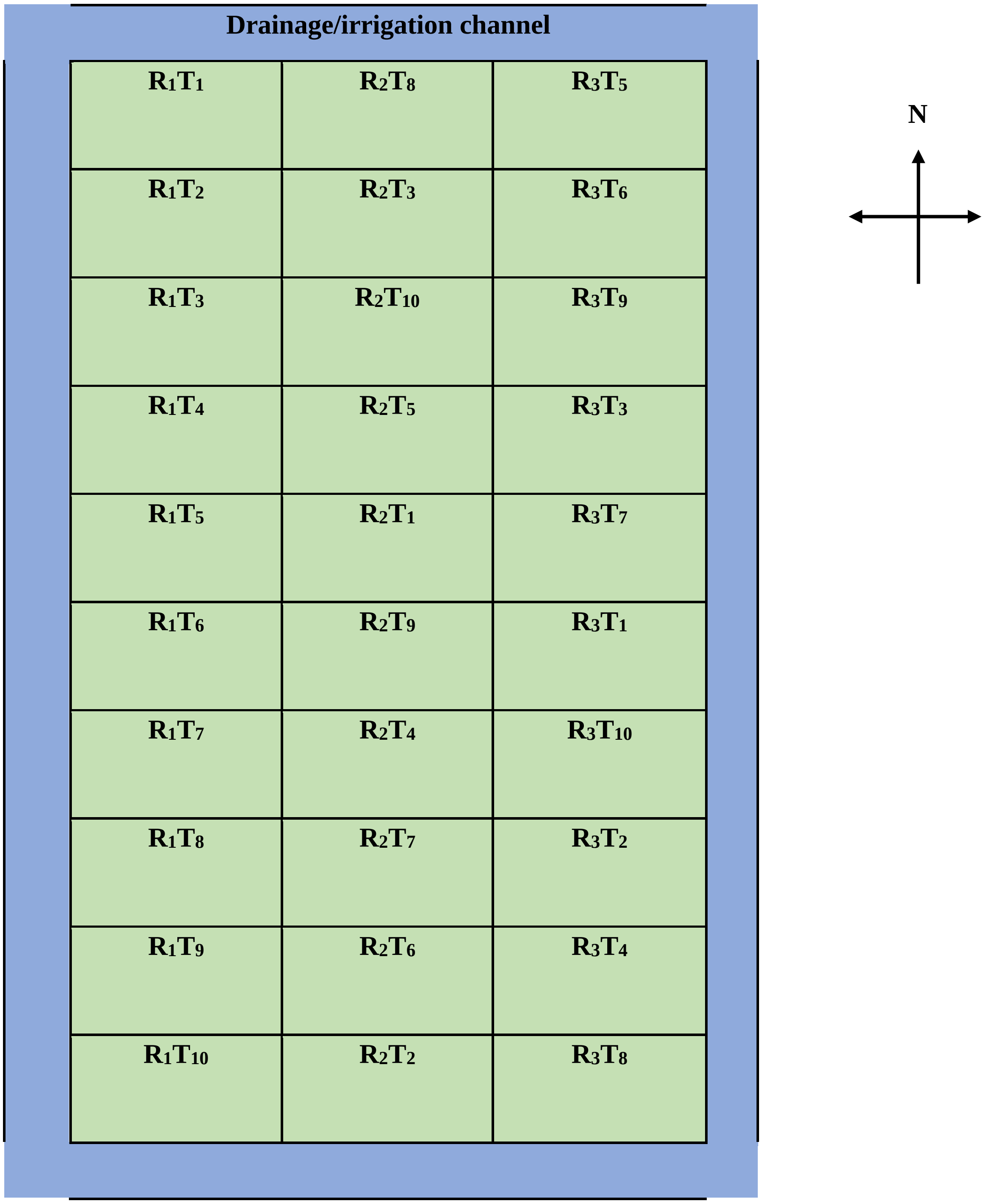
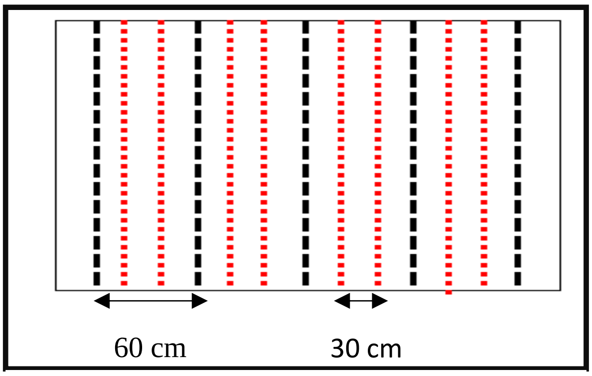
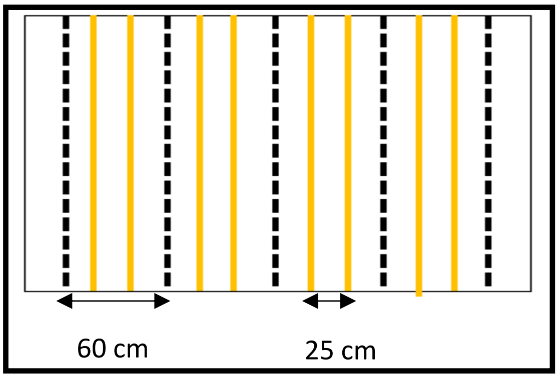


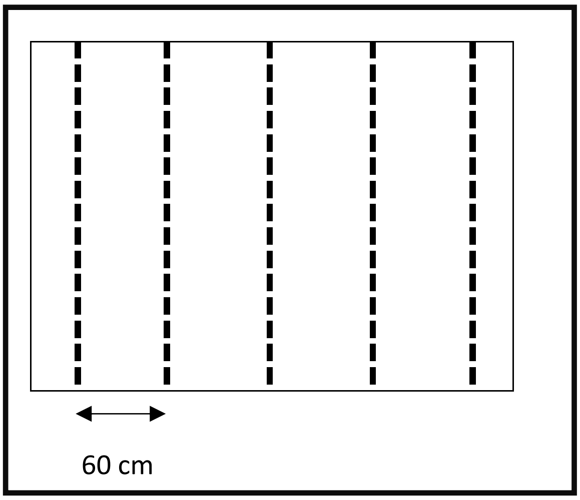
Fig 2. Layout of the experimental plot



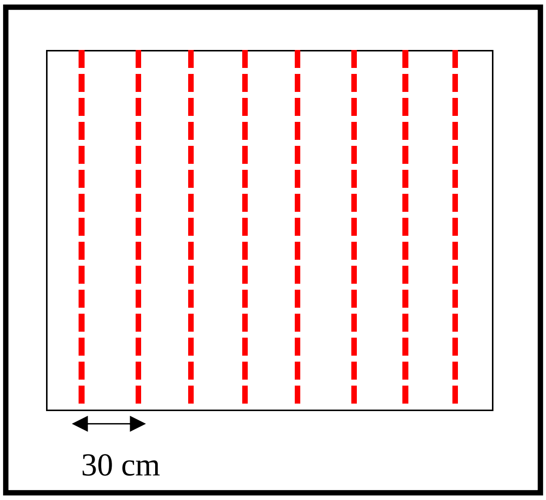
T_1: Red gram + bush cowpea (1:2) and
T_3: Red gram + fodder cowpea (1:2)



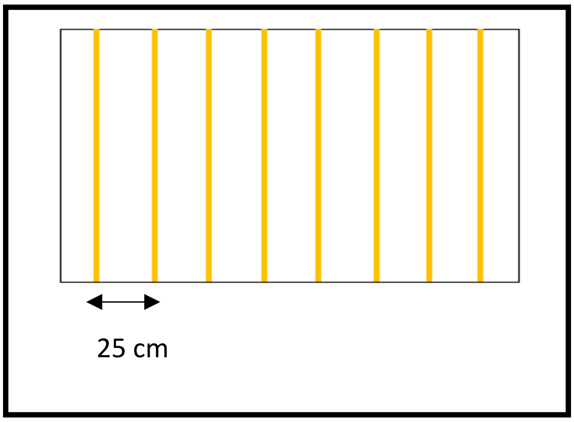
T_2: Red gram + green gram (1:2) and
T_4: Red gram + finger millet (1:2)



T_5: Sole crop of red gram



T_6: Sole crop of bush cowpea and
T_8: Sole crop of fodder cowpea



T_7: Sole crop of green gram
T_9: Sole crop of finger millet

Fig 3. Schematic representation of intercropping treatments

3.3.3.3 Sowing

The details of seed rate and spacing is given in Table 4.

The crops *viz.*, red gram, bush cowpea, green gram and fodder cowpea were dibbled and the sowing was done on 27th January 2022. On the other hand, the finger millet was raised in nursery and transplanted to the main field after four weeks. The transplanting was done on 14th February 2022. The treatment wise plant population is indicated in Appendix III.

Table 4. Seed rate and spacing of the crops

SI. No.	Crops	Seed rate (kg ha^{-1})	Spacing
1.	Red gram	10	60 cm × 20cm
2	Bush cowpea	50	30 cm × 15 cm
3	Green gram	20	25 cm × 15 cm
4	Fodder cowpea	30	30 cm × 15 cm
5	Finger millet	5	25 cm × 15 cm

3.3.3.4 Irrigation

Need based irrigation was given to all the crops.

3.3.3.5 Gap Filling and Thinning

Germination was uniform, however some plots needed to have gaps filled, which was done at 10 DAS. At 15 DAS, the crop stand was thinned to maintain the ideal plant population.

3.3.3.6 Weeding

Weeding was done at monthly intervals in all the plots uniformly by leaving an area of 1 m^2 per plot for taking weed observations.

3.3.3.7 Plant Protection

Plant protection measures were adopted as prophylactic measures against leaf webber (*Maruca vitrata*) using Chlorantraniliprole (Coragen) at the rate of 3ml $10L^{-1}$. In addition, soil drench with fungicide Indofil M-45 (Mancozeb 75%) at the rate of 3g L^{-1} was done to manage Southern blight (*Sclerotium rolfsii)* incidence.

3.3.3.8 Harvesting

Pulses and millets were harvested when the grains attained maturity. Red gram was harvested at 130 DAS (6th June 2022), bush cowpea at 60 DAS (28th March 2022), green gram at 60 DAS (28th March 2022) and finger millet at 115 DAS (23rd May 2022).

Fodder crop was harvested when it attained 50 per cent flowering i.e., at 45 DAS (13th March 2022). The crop was cut at base and bundled, weighed and values were recorded.

3.4 OBSERVATION ON CROPS

3.4.1 Growth Attributes

Five observational plants were selected randomly from the net plot area and tagged as observational plants. Growth attributes were recorded at monthly interval from the selected observational plants

3.4.1.1 Red gram, green gram, bush cowpea and fodder cowpea

3.4.1.1.1 Plant Height

The height of the observational plants was taken at monthly intervals from the ground level to the tip of the growing bud and mean expressed in cm.

3.4.1.1.2 Number of Branches per Plant

Number of primary and secondary branches arising from the stem were counted at monthly intervals from tagged plants.

3.4.1.1.3 Leaf Area per Plant

At monthly intervals, the leaf area was measured from the observational plants and expressed in cm^2 .

3.4.1.1.4. Leaf Area Index

Leaf area was calculated by multiplying the length and maximum width of all the leaves. The length and breadth of the fully opened and physiologically active leaves were measured in five plants per plot. LAI was recorded at 30 DAS for fodder cowpea. For crops *viz.,* bush cowpea and green gram at 30, 60 DAS and harvest and for red gram at 30, 60, 90, 120 DAS.

$$\text{LAI} = \frac{L \times B \times N \times K}{\text{Spacing (cm)}}$$

L- length of leaf

B- Breadth of leaf

N- Number of leaves per plant

K- constant

Red gram- 0.748 (Sharma *et al.,* 1987)

Bush cowpea- 0.75 (Olal, 2015)

Green gram- 0.6306 (Puttasamy *et al.,* 1976)

Fodder cowpea- 0.75

3.4.1.2 Finger millet

3.4.1.2.1 Plant Height

At monthly intervals, the height of the observational plants was taken from the base of the plant to the tip of the longest leaf. It is expressed in cm.

3.4.1.2.2 Number of tillers m^{-2}

Total number of tillers from a m^2 area were counted at 30, 60, 90 DAS and at harvest and the mean was expressed as number of tillers per m^2.

3.4.1.2.3 Number of productive tillers m^{-2}

The number of tillers bearing ear heads were counted using quadrate of size $0.25m^2$.

3.4.1.2.4 Leaf Area per Plant

The leaf area was measured from the observational plants at monthly intervals and expressed in cm^2.

3.4.1.2.4 Leaf Area Index

Leaf area index (LAI) was recorded at 30, 60 DAS and harvest. The mean leaf area was multiplied by the constant, 0.71 (Pandusastry, 1977). LAI was calculated as the ratio between leaf area and land area occupied by the crop (Watson, 1952).

3.4.2 Yield and Yield Attributes

3.4.2.1 Red gram, bush cowpea and green gram

3.4.2.1.1 Number of Pods per Plant

Pods of the sample plants were counted and the mean expressed as number of pods per plant.

3.4.2.1.2 Grain Yield

The harvested produce of each net plot was threshed, cleaned and dried separately, weighed and expressed in kg ha^{-1}.

3.4.2.1.3 Haulm Yield

The crop residue left over after the removal of seeds was sun dried and weighed and expressed in kg ha^{-1}.

3.4.2.2 Fodder cowpea

3.4.2.2.1 Leaf Stem Ratio

The leaves and the main stem were separated from the observational plants which were uprooted without damage. They were shade dried followed by oven drying at 60° ± 5°C till the constant weight is attained. The dry weight of leaves and stem of each plant was estimated and the ratio of leaves to stem was calculated.

3.4.2.2.2 Green Fodder Yield

The plants in the net plot area were cut from the base and made into bundles. The weight of green fodder was recorded and expressed in kg ha^{-1}.

3.4.2.2.3 Dry Fodder Yield

The observational plants were cut from the base, separately packed and labelled. These were first shade dried and then oven dried at 60 ± 5°C till the constant weight was achieved. The weight of the dried samples was taken and total dry fodder yield was calculated and expressed in kg ha^{-1}.

3.4.2.3 Finger millet

3.4.2.3.1 Number of Productive Tiller Plant^{-1}

Number of tillers bearing ear heads were counted from the sample plants and the mean was expressed as number of productive tillers per plant.

3.4.2.3.2 Grain Yield

Net plot area was harvested and the grains were sun dried and the weight was expressed in t ha^{-1}.

3.4.2.3.3 Stover Yield

The straw of the crop harvested from the net plot area was sun dried to constant weight and expressed in t ha^{-1}.

3.5 OBSERVATION ON WEEDS

The observation on weeds was taken at 30 and 60 DAS using the quadrat of size 50cm × 50cm which was placed randomly in each plot. The weeds which were present in quadrat were used to make the following information.

3.5.1 Weed Composition

The weed flora from the sampled area were identified and grouped into grasses, sedges and broadleaved weeds.

3.5.2 Weed Count

Weed count was recorded by counting the number of weeds under each group viz., grasses, sedges and broadleaved weeds.

3.5.3 Dry Matter Production

Weeds in the quadrat area were pulled out along with roots, washed, shade dried and later oven dried at 60° ± 5°C till constant weight is attained. The dry weight of the weeds was recorded and expressed as g m^{-2}.

3.5.4. Weed Smothering Efficiency (WSE)

Weed smothering efficiency (WSE) was computed using the given formula and was expressed in per cent (%).

$$WSE = \frac{W_1 - W_2}{W_1} \times 100$$

where,

W_1: Weed dry weight in sole crop (g m^{-2})

W_2: Weed dry weight in intercrop (g m^{-2})

3.6 CHEMICAL ANALYSIS

3.6.1 Plant Analysis

Observational plants from each plot at the time of harvest and weed samples at 30 and 60 DAS were collected and analyzed for N, P and K content. The samples were shade dried and oven dried at 60° ± 5°C until constant weight was attained and then powdered. Nutrients were extracted using single acid and analyzed.

$$\text{Nutrient Uptake by Crop or Nutrient Removal by Weed} = \frac{\text{Nutrient content (\%)} \times \text{Dry matter (kg ha}^{-1})}{100}$$

Table 5. Methods of plant nutrient analysis

Parameter	Method used	Reference
Nitrogen (%)	Modified micro kjeldahl method	Jackson (1973)
Phosphorus (%)	Nitric- perchloric acid digestion (9:4) and Vanado- molybdo phosphoric yellow colour method using spectrophotometer	Jackson (1973)
Potassium (%)	Nitric- perchloric acid digestion (9:4) and flame photometry method	Jackson (1973)

3.6.2 Soil Analysis

Composite samples were collected from each plot separately before and after the experiment and analyzed for available N, P, K and organic carbon status. The samples were analysed for the following chemical properties.

3.6.2.1. pH

The pH of the soil sample was found out by diluting with water in the ratio 1:2.5 and analysed using pH meter (Jackson, 1973).

3.6.2.2. Electrical conductivity (EC)

The EC of the soil samples were estimated by using conductivity meter and expressed in dSm^{-1} (Jackson, 1973).

3.6.2.3. Available N

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

3.6.2.2 Available P

Available phosphorus was determined by Bray I (0.03 N ammonium fluoride in 0.025 N hydrochloric acid) method as described by Jackson (1973) and estimated using spectrophotometer and expressed in kg ha^{-1}.

3.6.2.3 Available K

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

3.6.2.4. Dehydrogenase Activity

The dehydrogenase activity in soil was analyzed in the fresh samples collected based on Triphenyl Tetrazolium Chloride (TTC) reduction technique suggested by Casida *et al*., (1964).

3.7 COMPETITION INDICES

3.7.1 Land Equivalent Ratio (LER)

The land equivalent ratio (LER) denotes the relative land area under sole crop required to give the same yield as obtained under a mixed or an intercropping system at the same level of management. The LER was calculated by the formula given by Willey (1979).

$$LER = \frac{Y_{ri}}{Y_{rr}} + \frac{Y_{ir}}{Y_{ii}} = LER_r + LER_i$$

Where,

- Y_{rr} and Y_{ii} were the yields of red gram and component crops as sole crops
- Y_{ri} and Y_{ir} were the yields of red gram and component crops as intercrops, respectively.

3.7.2 Relative Crowding Coefficient (RCC)

The relative crowding coefficient (RCC) is a measure of the relative dominance of one species over the other in an intercropping system. The RCC was calculated by the formula given by De Wit (1960).

$K = Kr \times Ki$

K = RCC of the intercropping system

Kr = RCC of red gram

Ki = RCC of component crops

where, $$K_b = \frac{Y_{ri} \times Z_{ir}}{[(Y_{rr} - Y_{ri}) \times Z_{ri}]}$$

$$Ki = \frac{Y_{ir} \quad Z_{ri}}{[(Y_{ii} - Y_{ir}) \times Z_{ir}]}$$

Where,

- Y_{rr} and Y_{ii} were the yields of red gram and component crops as sole crops and Y_{ri} and Y_{ir} were the yields of red gram and component crops as intercrops, respectively.
- The Z_{ri} and Z_{ir} were the proportions of red gram and component crops in the mixture.

3.7.3 Aggressivity (A)

Aggressivity (A) is a measure of competitive ability of component crops which indicates how much the relative yield increase in component 'a' is greater than that of component 'b'. the aggressivity of intercropping systems (A_{ri} and A_{ir}) were calculated by the formula suggested by Mc Gilchrist (1965).

1) $A_{ri} = (Y_{ri} / Y_{rr} \times Z_{ri}) - (Y_{ir} / Y_{ii} \times Z_{ir})$
2) $A_{ir} = (Y_{ir} / Y_{ii} \times Z_{ir}) - (Y_{ri} / Y_{rr} \times Z_{ri})$

$$Ari = \frac{Y_{ri}}{Y_{rr} \times Z_{ri}} - \frac{Y_{ir}}{Y_{ii} \times Z_{ir}}$$

$$A_{ir} = \frac{Y_{ir}}{Y_{ii} \times Z_{ir}} - \frac{Y_{ri}}{Y_{rr} \times Z_{ri}}$$

Where,

- A_{ri} and A_{ir} were the aggressivity of red gram with respect to component crops and aggressivity of component crops with respect to red gram, respectively.
- Y_{ri} and Y_{ir} were the yields of red gram and component crops respectively under intercropping.
- Y_{rr} and Y_{ii} were the yields of red gram and component crops respectively as sole crops.
- Z_{ri} and Z_{ir} were the proportions of red gram and component crops respectively in the mixture.

3.8. ECONOMIC ANALYSIS

3.8.1. Monetary Advantage Index (MAI)

The monetary advantage index (MAI) quantifies the monetary advantage of intercropping system over sole cropping. The MAI was calculated by the formula suggested by Willey (1979)

$$\text{MAI} = (\text{Value of combined intercrop yield}) \times \frac{(\text{LER - 1})}{\text{LER}}$$

3.8.2. Red gram Equivalent Yield (REY)

The yields of intercrops bush cowpea, fodder cowpea, green gram and finger millet were converted into equivalent yield of red gram based on the price of the produce and the red gram equivalent yield of the intercropping system was calculated by the following formula

$$\text{REY} = \text{Red gram yield} + \frac{(\text{Intercrop yield} \times \text{price})}{\text{Price of red gram}}$$

3.8.3. Net Income

Net income was calculated using the following formula and was expressed as ₹ ha^{-1}.

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

3.8.4. Benefit : Cost Ratio

The benefit : cost ratio was calculated as the ratio of gross income to cost of cultivation.

$$BCR = \frac{\text{Gross income (₹ ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}}$$

3.9 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 randomized block design (RBD). Treatment comparison was statistically analysed using GRAPES software developed by the Department of Agricultural Statistics, College of Agriculture, Vellayani. The significance was tested using F- test (Snedecor and Cochran, 1967) and critical differences were calculated for comparison, wherever treatments were found to be significant. Student T test was carried out to compare sole and intercrop treatments of component crops (Gomez and Gomez, 1984).

RESULTS

4. RESULTS

The study entitled “Performance of red gram (*Cajanus cajan* (L.) Millsp.) intercropping systems in lowlands” was carried out at IFSRS, Karamana, Thiruvananthapuram, Kerala, during the period from January 2022 to June 2022. The aim of the study was to assess the feasibility of intercropping bush cowpea, green gram, fodder cowpea and finger millet in red gram and to work put the biological efficiency and economics of the intercropping systems. The results of this study are presented in this chapter.

4.1. EFFECT OF INTERCROPPING ON RED GRAM

4.1.1. Growth and Growth Attributes

4.1.1.1. Plant Height

The result of the effect of intercropping on plant height of red gram are presented in Table 6.

The effect of intercropping on plant height of red gram exhibited significance at 30 DAS and 60 DAS. The plants were taller in sole crop of red gram (T_5) with the mean height of 37.24 cm and 104 cm at 30 and 60 DAS, respectively. However, it was on par with red gram + green gram (T_2). While shorter plants were observed in red gram + finger millet (T_4) and red gram + bush cowpea (T_1) at 30 DAS and red gram + fodder cowpea (T_3) at 60 DAS.

4.1.1.2. Number of Branches per Plant

The results of intercropping red gram with regards to the number of primary branches per plant are presented in Table 7.

The number of primary branches per plant varied significantly at 60 and 90 DAS. At 60 DAS, highest number of primary branches (9.55) were recorded in sole crop of red gram (T_5) which was found to be on par with red gram + green gram (T_2) (8.55) system.

At 90 DAS, sole crop of red gram (T_5) recorded more number of primary branches (11.77) which was on par with red gram + finger millet (T_4) (11.21). Lower number of branches were observed in red gram + bush cowpea (T_1) (9.77) intercropping system.

4.1.1.3. Leaf Area per Plant

The effect of intercropping on leaf area per plant is furnished in Table 8.

Intercropping red gram had significant influence on leaf area per plant at 30, 60 and 120 DAS. The higher leaf area (142.79 cm^2 , 1454.17 cm^2 and 5164.31 cm^2) was recorded in T_5 (sole crop of red gram) at all the stages of crop growth. At 30 DAS, it was on par with T_2 (red gram + green gram) and T_4 (red gram + finger millet) and at 120 DAS, it was on par with T_2 (red gram + green gram) and T_3 (red gram + fodder cowpea).

4.1.1.4. Leaf Area Index

The data on the response of red gram to intercropping with respect to leaf area index (LAI) are presented in Table 9.

The LAI of red gram was significantly influenced by the treatments. Sole crop of red gram (T_5) recorded the highest value of 0.12, 1.21 and 4.30 at 30, 60 and 120 DAS, respectively compared to the intercropping treatments.

Among the intercropping systems, higher LAI (0.10 and 0.11) were recorded in red gram + green gram (T_2) and red gram + finger millet (T_4) systems at 30 DAS. At 60 DAS, red gram + fodder cowpea (T_3) was observed to be superior (0.84) which was comparable to red gram + green gram (T_2) and red gram + bush cowpea (T_1). At 120 DAS, T_5 (sole crop of red gram) was on par with T_2 (red gram + green gram), T_3 (red gram + fodder cowpea) and T_4 (red gram + finger millet).

4.1.2. Yield and Yield Attributes

4.1.2.1. Number of Pods per Plant

The data pertaining to number of pods per plant are presented in Table 10.

Table 6. Effect of intercropping on plant height of red gram, cm

Treatments	Plant height				
	30 DAS	60 DAS	90 DAS	120 DAS	At harvest
T_1: Red gram + bush cowpea	27.48	90.85	128.81	152.67	159.59
T_2: Red gram + green gram	34.62	92.80	128.35	152.09	156.02
T_3: Red gram + fodder cowpea	30.65	78.25	117.20	145.22	151.47
T_4: Red gram + finger millet	29.16	88.45	127.56	136.22	147.86
T_5: Sole red gram	37.24	104.55	117.35	152.56	160.52
SEm (±)	1.50	3.82	3.26	4.40	4.22
CD (0.05)	4.905	12.479	NS	NS	NS

NS – Not significant

Table 7. Effect of intercropping on number of branches of red gram, nos.

Treatments	Number of branches per plant				
	30 DAS	60 DAS	90 DAS	120 DAS	At harvest
T_1: Red gram + bush cowpea	4.76	7.44	9.77	10.88	11.55
T_2: Red gram + green gram	5.22	8.55	10.33	11.88	12.33
T_3: Red gram + fodder cowpea	4.83	8.22	10.44	11.66	11.88
T_4: Red gram + finger millet	4.77	7.77	11.21	11.99	12.21
T_5: Sole red gram	4.99	9.55	11.77	12.22	12.55
SEm (±)	0.19	0.36	0.37	0.32	0.27
CD (0.05)	NS	1.193	1.210	NS	NS

NS- Not significant

Table 8. Effect of intercropping on leaf area per plant of red gram, cm^2

Treatments	Leaf area per plant				
	30 DAS	60 DAS	90 DAS	120 DAS	At harvest
T_1: Red gram + bush cowpea	95.31	904.59	970	3730.97	1539.42
T_2: Red gram + green gram	132.33	942.01	1440.05	4642.26	2145.28
T_3: Red gram + fodder cowpea	82.19	1017.38	1531.60	5016.18	2139.98
T_4: Red gram + finger millet	124.79	624.16	1459.02	4076.51	1822.46
T_5: Sole red gram	143.79	1454.17	1567.48	5164.31	2530.19
SEm (±)	12.76	118.05	242.22	265.59	221.20
CD (0.05)	41.632	384.981	NS	866.162	NS

NS- Not significant

Table 9. Effect of intercropping on leaf area index of red gram

Treatments	LAI				
	30 DAS	60 DAS	90 DAS	120 DAS	At harvest
T_1: Red gram + bush cowpea	0.07	0.75	1.21	3.10	1.28
T_2: Red gram + green gram	0.11	0.78	1.20	3.86	1.78
T_3: Red gram + fodder cowpea	0.06	0.84	1.27	4.18	1.78
T_4: Red gram + finger millet	0.10	0.52	1.21	3.39	1.51
T_5: Sole red gram	0.12	1.21	1.30	4.30	2.10
SEm (±)	0.01	0.09	0.21	0.22	0.18
CD (0.05)	0.035	0.321	NS	0.722	NS

NS- Not- significant

The number of pods per plant was significantly different among the treatments. Sole crop of red gram (T_5) recorded higher number of pods (110.43) and it was on par with T_2 (red gram + green gram) (103.10) and T_4 (red gram + finger millet) (101.32). However, significant reduction was observed in number of pods per plant when red gram was intercropped with cowpea in T_1 (86.66).

4.1.2.2. Grain yield

Grain yield recorded by red gram in response to intercropping is presented in Table 10.

Grain yield was significantly higher (1429.61 kg ha^{-1}) when red gram was raised as sole crop (T_5) which was followed by red gram + green gram (T_2) intercropping system (1237.87 kg ha^{-1}). Grain yield was lower in intercropping treatments *viz.*, T_1 (red gram + bush cowpea), T_3 (red gram + fodder cowpea) and T_4 (red gram + finger millet).

4.1.2.3. Haulm yield

Results on haulm yield per hectare of red gram as influenced by intercropping are presented in Table 10.

Sole crop of red gram (T_5) recorded more haulm yield (6095 kg ha^{-1}) and was comparable with T_2 (red gram + green gram – 5639 kg ha^{-1}). Lower haulm yield was recorded in red gram + bush cowpea (T_1) (4419 kg ha^{-1}) which was statistically similar to red gram + fodder cowpea (T_3) (4621 kg ha^{-1}).

4.2. EFFECT OF INTERCROPPING ON DIFFERENT INTERCROPS

4.2.1. Growth and Growth Attributes

4.2.1.1. Bush cowpea

4.2.1.1.1. Plant Height

The results on the effect of intercropping on plant height of bush cowpea are presented in Table 11.

Table 10. Effect of intercropping on number of pods per plant, grain yield per hectare and haulm yield per hectare of red gram

Treatments	Number of pods $plant^{-1}$ (nos.)	Grain yield (kg ha^{-1})	Haulm yield (kg ha^{-1})
T_1: Red gram + bush cowpea	86.66	905	4419
T_2: Red gram + green gram	103.10	1238	5639
T_3: Red gram + fodder cowpea	90.43	947	4621
T_4: Red gram + Finger millet	101.32	1029	5026
T_5: Sole red gram	110.43	1430	6095
SEm (±)	3.87	43.85	205.59
CD (0.05)	12.632	143.019	670.489

The plant height exhibited significant variation between intercrop and sole crop of bush cowpea at 30 and 60 DAS and at harvest. Taller plants (125.85cm and 127.16 cm) were recorded in treatment, T_1 (red gram + bush cowpea).

4.2.1.1.2. Number of Branches per Plant

The effect of intercropping on bush cowpea with regard to primary branches per plant are furnished in Table 11.

The number of primary branches per plant did not exhibit any significant variation between intercrop and sole crop of bush cowpea.

4.2.1.1.3. Leaf Area per Plant

The results on leaf area of bush cowpea in response to intercropping with red gram are presented in Table 13.

Sole crop of bush cowpea (T_6) recorded significantly superior leaf area of 1449.93 and 911.92 cm^2 at 60 DAS and at harvest, respectively. It showed no significant difference at 30 DAS.

4.2.1.1.4. Leaf Area Index

The results on leaf area index (LAI) of bush cowpea when intercropped with red gram are presented in Table 13.

Leaf area index of bush cowpea did not differ significantly at 30 DAS. Significantly higher LAI of 2.62 and 3.22 was recorded at 60 DAS and harvest respectively, for T_6 (sole crop of bush cowpea).

4.2.1.2.Green gram

4.2.1.2.1. Plant Height

The results on the effect of intercropping on plant height of green gram are presented in Table 12.

Plant height at 30 DAS did not vary significantly for green gram whereas taller plants were observed at 60 DAS (94.80 cm) and at harvest (97.15 cm) in sole crop of green gram (T_7).

Table 11. Effect of intercropping on plant height and number of branches of bush cowpea

Treatments	Plant height (cm)			Number of branches per plant (nos)		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
T_1: red gram + bush cowpea	53.62	125.85	127.16	6.33	10.16	10.77
T_6: sole crop of bush cowpea	44.53	95.25	97.78	5.66	11.22	11.77
T value	4.61	4.40	4.67	1.51	-1.81	-2.06
P value	0.00	0.00	0.00	NS	NS	NS

Table 12. Effect of intercropping on plant height and number of branches of green gram

Treatments	Plant height (cm)			Number of branches per plant (nos)		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
T_2: red gram + green gram	39.71	61.75	65.84	4.33	9.10	9.55
T_7: sole crop of green gram	44.00	94.80	97.15	4.55	10.22	11.21
T value	-1.87	-25.99	-54.36	-0.77	-4.64	-11.86
P value	NS	0.00	0.00	NS	0.00	0.00

Table 13. Effect of intercropping on leaf area and leaf area index of bush cowpea

Treatments	Leaf area per plant (cm^2)			LAI		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
T_1: red gram + bush cowpea	922.23	1178.90	651.35	2.06	2.62	1.44
T_6: sole crop of bush cowpea	954.05	1449.93	911.92	2.12	3.22	2.02
T value	-0.82	-4.21	-4.30	-0.14	-2.33	-4.30
P value	NS	0.00	0.00	NS	0.03	0.00

Table 14. Effect of intercropping on leaf area and leaf area index of green gram

Treatments	Leaf area per plant (cm^2)			LAI		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
T_2: red gram + green gram	471.89	1317.54	839.73	1.25	3.51	2.23
T_7: sole crop of green gram	688.42	1646.91	1088.53	1.83	4.39	2.90
T value	-3.54	-2.14	-2.61	-3.54	-2.14	-2.61
P value	0.00	0.04	0.01	0.00	0.04	0.01

4.2.1.2.2. Number of Branches per Plant

The effect of intercropping on green gram with regards to primary branches per plant are furnished in Table 12.

Green gram did not exhibit significant difference on number of branches per plant at 30 DAS. However, at 60 DAS and harvest, green gram was observed to elicit significant response to intercropping. The highest number of branches were observed in T_7 (sole crop of green gram).

4.2.1.2.3. Leaf Area per Plant

The results on leaf area of green gram in response to intercropping with red gram are presented in Table 14.

Leaf area was significantly more (688.42 cm^2, 1646.91 cm^2,and 1088.53 cm^2) in sole crop of green gram at 30, 60 DAS and harvest.

4.2.1.2.4. Leaf Area Index

The results on leaf area index (LAI) of green gram when intercropped with red gram are presented in Table 14.

In the case of green gram, LAI was significantly superior (1.83, 4.39 and 2.90) in sole crop of green gram (T_7) at 30, 60 DAS and harvest, respectively.

4.2.1.3. Fodder cowpea

4.2.1.3.1. Plant Height

The data on plant height of fodder cowpea is presented in Table 15.

The plant height of fodder cowpea was significantly influenced by the treatments. The sole crop (T_8) registered taller plants of 46.35 cm at 30 DAS whereas, it exhibited no significant variation at harvest.

4.2.1.3.2. Number of Branches per Plant

The data on the effect of intercropping on number of branches of fodder cowpea are presented in the Table 15.

The treatments could not exert any marked influence on number of branches per plant at harvest. Significantly higher (5.66) number of branches were recorded for T_8 (sole crop of fodder cowpea) at 30 DAS.

4.2.1.3.3. Leaf Area per Plant

The effect of intercropping of red gram with fodder cowpea on leaf area per plant is furnished in Table 16.

The leaf area of fodder cowpea was significantly higher (602.29 cm^2) when raised as sole crop (T_8) at 30 DAS. However, the treatments could not produce any significant effect at the time of harvest.

4.2.1.3.4. Leaf Area Index

Leaf area index recorded by fodder cowpea in response to intercropping is presented in Table 16.

Sole cropping of fodder cowpea (T_8) produced significantly higher LAI (1.33) compared to the intercropped system at 30 DAS. While, LAI was observed to be not significant at the time of harvest .

4.2.1.4. Finger millet

4.2.1.4.1. Plant Height

The results on the effect of intercropping finger millet on the plant height is given in Table 17.

Plant height of finger millet were the tallest (106.15 cm and 118.02 cm) in T_4 (red gram + finger millet) when compared to the sole crop of finger millet (T_9) (78.96 cm and 91.94 cm) at 60 DAS and harvest.

4.2.1.4.2. Leaf Area per Plant

Response of finger millet to intercropping with red gram with respect to leaf area per plant is presented in Table 18.

There was no significant difference in the leaf area per plant either with sole or intercropping at 30 DAS and at harvest.

Sole crop of finger millet (T_9) registered significantly higher leaf area (989.16 cm^2) than in intercropped treatment, T_4 (red gram + finger millet).

4.2.1.4.3. Leaf Area Index

The results on the effect of intercropping of finger millet with red gram on leaf area index are presented in Table 18.

Both sole and intercropping had no significant effect on the LAI of finger millet at 30 DAS and at harvest. Results showed significantly higher values of 2.63 at 60 DAS for treatment T_8 (sole crop of finger millet).

4.2.1.4.4. Tillers per meter square

The data on the number of tillers as influenced by intercropping are presented in Table 19.

The results indicated that number of tillers varied significantly with treatments during all stages of crop growth. More number of tillers were observed in sole cropping of finger millet (T_9) (47.27, 66.06 and 52.33) at 30, 60 DAS and at harvest, respectively when compared to its intercropping treatment.

4.2.1.4.5. Number of Productive Tillers per meter square

The result on the effect of intercropping on the productive tillers are presented in Table 19.

Sole cropping of finger millet (T_9) registered significantly higher (45.88) number of productive tillers at the time of harvest while red gram + finger millet (T_4) recorded lower number of productive tillers (35.33).

Table 15. Effect of intercropping on plant height and number of branches of fodder cowpea

Treatments	Plant height		Number of branches per plant	
	30 DAS	At harvest	30 DAS	At harvest
T_3: red gram + fodder cowpea	32.68	73.13	4.44	8.10
T_8: sole crop of fodder cowpea	46.35	71.58	5.66	7.88
T value	-8.88	0.34	-2.87	0.88
P value	0.00	NS	0.01	NS

Table 16. Effect of intercropping on leaf area and leaf area index of fodder cowpea

Treatments	Leaf area per plant (cm^2)		LAI	
	30 DAS	At harvest	30 DAS	At harvest
T_3: red gram + fodder cowpea	449.37	2546.34	0.99	5.65
T_8: sole crop of fodder cowpea	602.29	2612.51	1.33	5.80
T value	-3.17	-0.48	-3.17	-0.48
P value	0.00	NS	0.00	NS

Table 17. Effect of intercropping on plant height of finger millet, cm

Treatments	Plant height		
	30 DAS	60 DAS	At harvest
T_4: red gram + finger millet	24.90	106.15	118.02
T_9: sole crop of finger millet	30.50	78.96	91.94
T value	-5.08	4.49	17.28
P value	0.00	0.00	0.00

Table 18. Effect of intercropping on leaf area and leaf area index of finger millet

Treatments	Leaf area per plant (cm^2)			LAI		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
T_4: red gram + finger millet	355.87	847.47	639.57	0.94	2.36	1.70
T_9: sole crop of finger millet	417.36	989.16	676.95	1.11	2.63	1.80
T value	-1.73	-2.14	-1.42	-1.73	-2.14	-1.42
P value	NS	0.04	NS	NS	0.04	NS

Table 19. Effect of intercropping on number of tillers and productive tillers per m^2

Treatments	Number of tillers per m^2 (nos)			Number of productive tillers per m^2 (nos)
	30 DAS	60 DAS	At harvest	At harvest
T_4: red gram + finger millet	29.74	55.49	42.83	35.33
T_9: sole crop of finger millet	47.27	66.06	52.33	45.88
T value	-21.19	-9.14	-16.26	-12.61
P value	0.00	0.00	0.00	0.00

4.2.2. Yield and Yield Attributes

4.2.2.1. Bush cowpea and green gram

4.2.2.1.1. Number of Pods per Plant

The results on the number of pods per plant, produced by the intercropped pulses are presented in Table 20 and Table 21.

The number of pods per plant produced by bush cowpea were found to be higher in T_6 (sole crop of bush cowpea) (13.33) compared to intercropping treatment.

Sole crop of green gram (T_7) recorded significantly higher number of pods (30.10) than T_2 (red gram + green gram) (27.77) intercropping system.

4.2.2.1.2. Grain Yield

The data on the effect of intercropping of bush cowpea and green gram on its grain yield are presented in Table 20 and Table 21.

Grain yield was significantly higher (2322 kg ha^{-1}) when cowpea raised as a sole crop (T_6) which was followed by T_1 (red gram + bush cowpea – 1394 kg ha^{-1}).

Sole cropping of green gram (T_7) recorded significantly superior (1271 kg ha^{-1}) grain yield and it was found to be reduced when intercropped (675 kg ha^{-1}) with red gram (T_2).

4.2.2.1.3. Haulm Yield

Table 20 and Table 21. expounds the effect of intercropping on the haulm yield of pulses *viz.*, bush cowpea and green gram.

The higher haulm yield per ha was recorded in sole crop of bush cowpea (T_6 - 4615 kg ha^{-1}) which was significantly superior to the intercropping treatment.

As in the case of grain yield, haulm yield of green gram was also observed to be significantly higher (3560 kg ha^{-1}) in sole crop (T_7). Intercropping green gram in red gram (T_2) resulted in substantially reduced haulm yield (1883 kg ha^{-1}) than sole crop.

4.2.2.2. Fodder cowpea

4.2.2.2.1. Leaf Stem Ratio

The results on leaf stem ratio of fodder cowpea as influenced by intercropping are presented in Table 22.

At harvest, leaf to stem ratio was recorded to be significantly higher (0.83) in treatment, T_8 (sole crop of fodder cowpea).

4.2.2.2.2. Green Fodder Yield

The result of the effect of intercropping on green fodder yield of fodder cowpea is detailed in Table 22.

Green fodder yield of fodder cowpea was influenced by the treatments. The treatment T_8 (sole crop of fodder cowpea) produced higher green fodder yield (13179 kg ha^{-1}) which was significantly higher than T_3 (red gram + fodder cowpea – 7970 kg ha^{-1}).

4.2.2.2.3. Dry Fodder Yield

The result of the effect of intercropping on dry fodder yield of fodder cowpea is given in Table 22.

Dry fodder yield was significantly higher (2919 kg ha^{-1}) when fodder cowpea was raised as sole crop.

4.2.2.3. Finger millet

4.2.2.3.1. Number of Productive Tillers per Plant

The results on the effect of intercropping on the number of productive tillers per plant are presented in Table 23.

Sole cropping and intercropping had significant effect on the number of productive tillers per plant of finger millet. Higher productive tillers were recorded in the treatment T_6 (sole crop of finger millet).

Table 20. Effect of intercropping on number of pods per plant, grain yield and haulm yield of bush cowpea

Treatments	Number of pods plant^{-1} (nos)	Grain yield (kg ha^{-1})	Haulm yield (kg ha^{-1})
T_1: red gram + bush cowpea	12.22	1394	2590
T_6: sole crop of bush cowpea	13.33	2322	4615
T value	-11.28	-155.04	-29.19
P value	0.00	0.00	0.00

Table 21. Effect of intercropping on number of pods per plant, grain yield and haulm yield of green gram

Treatments	Number of pods plant^{-1} (nos)	Grain yield (kg ha^{-1})	Haulm yield (kg ha^{-1})
T_2: red gram + green gram	27.77	675	1883
T_7: sole crop of green gram	30.10	1271	3560
T value	-14.14	-34.11	-19.40
P value	0.00	0.00	0.00

4.2.2.3.2. Grain Yield

Grain yield recorded by finger millet in response to intercropping with red gram is presented in Table 23.

Sole cropping of finger millet (T_9) produced significantly higher grain yield per hectare (2201 kg ha^{-1}) whereas red gram + finger millet (T_4) recorded reduced grain yield (1289 kg ha^{-1}).

4.2.2.3.3. Stover Yield

Stover yield per hectare as influenced by intercropping with red gram is detailed in Table 23.

Sole crop of finger millet (T_9) produced considerably higher stover yield (4288 kg ha^{-1}) than the intercropped treatment T_4 (red gram + finger millet).

4.3. OBSERVATION ON WEEDS

4.3.1. Weed Count at 30 DAS

Effect of intercropping on weed count at 30 DAS if furnished in Table 24.

In 30 DAS, among the weeds present, grasses dominated in majority of the treatments. The weed count of grasses was significantly lower in T_8 (sole crop of fodder cowpea) which was on par with treatments, T_2 (red gram + green gram), T_3 (red gram + fodder cowpea) and T_7 (sole crop of green gram).

The weed count of broad leaved weeds was significantly low in T_3 (red gram + fodder cowpea) which was on par with other treatments, T_6 (sole crop of bush cowpea), T_7 (sole crop of green gram) and T_8 (sole crop of fodder cowpea).

The weed count of sedges was significantly low in T_3 (red gram + fodder cowpea) which was on par with other treatments T_1 (red gram + bush cowpea), T_2 (red gram + green gram), and T_7 (sole crop of green gram).

The total weed count was significantly less in T_8 (sole crop of fodder cowpea) which was on par with T_7 (sole crop of green gram).

Table 22. Effect of intercropping on leaf stem ratio, green fodder yield, dry fodder yield of fodder cowpea

Treatments	Leaf : stem ratio	Green fodder yield (kg ha^{-1})	Dry fodder yield (kg ha^{-1})
T_3: red gram + fodder cowpea	0.70	7970	1854
T_8: sole crop of fodder cowpea	0.83	13179	2919
T value	4.30	-13.92	-3.62
P value	0.00	0.00	0.00

Table 23. Effect of intercropping on number of productive tillers per plant, grain yield and stover yield of finger millet

Treatments	Number of productive tillers $plant^{-1}$ (nos)	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})
T_4: red gram + finger millet	2.66	1289	2858
T_9: sole crop of finger millet	2.99	2201	4288
T value	-2.72	-13.00	-8.73
P value	0.01	0.00	0.00

4.3.2. Weed Count at 60 DAS

Effect of intercropping on weed count at 60 DAS is given in Table 25.

In 60 DAS, among the weeds present, grasses dominated which was followed by sedges and broad leaved weeds.

The weed count of grasses was significantly less in T_5 (sole crop of red gram) which was comparable of T_1 (red gram + bush cowpea) and T_6 (sole crop of bush cowpea).

The weed count of broad leaved weeds were significantly less in T_1 (red gram + bush cowpea) and was comparable to T_4 (red gram + finger millet) and T_9 (sole crop of finger millet).

The weed count of sedges was significantly less in T_2 (red gram + green gram) and T_5 (sole crop of red gram).

The total weed count was significantly less in T_1 (red gram + bush cowpea) and significantly highest value was obtained in T_{10} (fallow).

4.3.2. Weed Composition

The different weed species found in the experimental field during the study were collected, identified and classified into grasses, sedges and broad leaved weeds in Table 26.

Among grasses, *Echinochloa colona, Digitaria ciliaris, Cynodon dactylon, Eleusine indica, Setaria barbata and Isachne miliacea* were the major weed species observed.

Among sedges, *Cyperus iria and Fimbristylis miliacea* were the major weed species observed.

Among broad leaved weeds, *Cleome rutidospermum, Euphorbia hirta, Oldenlandia umbellata, Ludwigia perennis, Alternanthera sessilis, Kyllinga monocephala, Phyllanthus niruri and Commelina benghalensis* were the major weed species observed.

4.3.3. Dry Matter Production of Weeds

The data on dry matter production of weeds in different intercropping systems are presented in Table 27.

In general, very high weed dry weight was obtained in 30 and 60 DAS in T_{10} (fallow).

The dry matter production differed significantly among treatments at 30 and 60 DAS. Among the treatments, except T_{10} (fallow), significantly higher dry matter (63.00 g m^{-2}) was recorded in sole crop of finger millet (T_9) which was followed by T_5 (sole crop of red gram) (48.43 g m^{-2}).

Weed dry matter production was notably lower in T_1 (red gram + bush cowpea) (27.20 g m^{-2}). It was on par with T_3 (red gram + fodder cowpea) (30.80 g m^{-2}) and T_7 (sole crop of bush cowpea) (38.00 g m^{-2}).

4.3.4. Nutrient Removal by Weeds

The results pertaining to the effect of intercropping red gram are presented in Table 28.

Nutrient removal by weeds varied significantly among the treatments at 30 and 60 DAS. At 30 DAS, the highest nitrogen removal by weeds was in fallow (T_{10}) (19.28 kg ha^{-1}) which was followed by T_5 (sole crop of red gram) and T_4 (red gram + finger millet). The lowest values were obtained in T_1 (red gram + bush cowpea) which was on par with T_2 (red gram + green gram) , T_3 (red gram + fodder cowpea) and T_6 (sole crop of bush cowpea). At 60 DAS, N removal of weeds were highest in fallow T_{10} (87.92 kg ha^{-1}) which was followed by T_9 (sole crop of finger millet) and the lowest values were recorded in T_1 (red gram + bush cowpea) which was statistically similar to T_2 (red gram + green gram) and T_6 (sole crop of bush cowpea).

The P removal by weeds at 30 DAS, was significantly higher in fallow (T_{10}) (2.02 kg ha^{-1}) which was followed by T_5 (sole crop of red gram) (1.50 kg ha^{-1}) and was on par with T_8 (sole crop of fodder cowpea) (1.28 kg ha^{-1}) and T_6 (sole crop of bush cowpea) (1.21 kg ha^{-1}). However, the lowest values were recorded in T_2 (red gram + green gram) (0.66 kg ha^{-1}) and it was on par with T_1 (red gram + bush cowpea) (0.80

kg ha^{-1}) and T_7 (sole crop of green gram) (0.94 kg ha^{-1}). At 60 DAS, P removal by weeds was the highest in T_{10} (fallow) (7.94 kg ha^{-1}) followed by T_5 (sole crop of red gram) (5.63 kg ha^{-1}) while the lowest values were recorded in T_1 (red gram + bush cowpea) (2.05 kg ha^{-1}) and it was statistically similar to T_2 (red gram + green gram) (2.11 kg ha^{-1}).

At 30 DAS, K removal by weeds was significantly higher in T_{10} (fallow) (9.86 kg ha^{-1}) followed by T_9 (sole crop of finger millet) (5.16 kg ha^{-1}). The lowest value was obtained from T_1 (red gram + bush cowpea) (0.94 kg ha^{-1}) which was on par with T_2 (red gram + green gram) (1.26 kg ha^{-1}), T_3 (red gram + fodder cowpea) (1.44 kg ha^{-1}) and T_6 (sole crop of bush cowpea) (1.79 kg ha^{-1}). At 60 DAS, K removal by weeds was higher in T_{10} (fallow) (29.12 kg ha^{-1}) which was followed by T_5 (sole crop of red gram) (16.31 kg ha^{-1}). The K removal were lowest in T_1 (red gram + bush cowpea) (1.55 kg ha^{-1}) which was followed by T_2 (red gram + green gram) (2.99 kg ha^{-1}).

4.3.5. Weed Smothering Efficiency

The results on the effect of intercropping on weed smothering efficiency (WSE) is presented in Table 27.

In general, intercropping system exhibited more WSE than sole cropping. Weed smothering efficiency (WSE) was higher in T_1 (red gram + bush cowpea) with a value of 40.86 per cent and 58.93 per cent at 30 and 60 DAS, respectively which was followed by the treatment T_3 (red gram + fodder cowpea) at 30 DAS and T_2 (red gram + green gram) at 60 DAS.

Table 24. Effect of intercropping on weed count at 30 DAS

Treatments	Grasses	Broad leaved weeds	Sedges	Total
T_1: Red gram + bush cowpea	30.66	27.00	5.66	63.33
T_2: Red gram + green gram	27.33	26.33	6.66	60.33
T_3: Red gram + fodder cowpea	25.66	13.66	3.66	43.00
T_4: Red gram + Finger millet	42.33	40.33	13.33	96.00
T_5: Sole red gram	30.00	47.66	14.33	92.00
T_6: Sole bush cowpea	32.00	19.66	8.33	60.00
T_7: Sole green gram	22.33	18.66	6.66	47.66
T_8: Sole fodder cowpea	19.33	18.66	4.00	42.00
T_9: Sole finger millet	42.00	38.66	13.00	93.66
T_{10}: Fallow	77.00	61.33	27.66	166.00
SEm (±)	2.72	3.35	1.95	4.80
CD (0.05)	8.106	9.955	3.549	14.275

Table 25. Effect of intercropping on weed count at 60 DAS

Treatments	Grasses	Broad leaved weeds	Sedges	Total
T_1: Red gram + bush cowpea	50.33	31.33	27.66	109.33
T_2: Red gram + green gram	71.33	51.33	17.33	140.00
T_3: Red gram + fodder cowpea	-	-	-	-
T_4: Red gram + Finger millet	77.33	34.33	31.00	142.66
T_5: Sole red gram	45.33	69.00	17.33	131.66
T_6: Sole bush cowpea	56.66	50.33	27.33	134.33
T_7: Sole green gram	74.66	61.66	24.33	160.66
T_8: Sole fodder cowpea	-	-	-	-
T_9: Sole finger millet	102.00	40.00	35.00	177.00
T_{10}: Fallow	237.33	63.66	236.33	537.33
SEm (±)	4.29	3.88	1.51	6.86
CD (0.05)	13.012	11.78	4.608	20.82

Table 26. Effect of intercropping on weed composition

Grasses	Broad leaved weeds	Sedges
Echinochloa colona	*Cleome rutidospermum*	*Cyperus rotundus*
Digitaria ciliaris	*Euphorbia hirta*	*Fimbristylis miliacea*
Cynodon dactylon	*Oldenlandia umbellata*	
Eleusine indica	*Ludwigia perennis*	
Setaria barbata	*Alternanthera sessilis*	
Isachne miliacea	*Kyllinga monocephala*	
	Phyllanthus niruri	
	Commelina benghalensis	

Table 27. Effect of intercropping on weed dry matter production and weed smothering efficiency

Treatments	Weed dry matter production ($g\ m^{-2}$)		Weed smothering efficiency (%)	
	30 DAS	60 DAS	30 DAS	60 DAS
T_1: Red gram + bush cowpea	27.20	71.20	40.86	58.93
T_2: Red gram + green gram	41.20	75.50	10.43	56.45
T_3: Red gram + fodder cowpea	30.80	-	33.04	-
T_4: Red gram + Finger millet	45.66	144.60	5.71	16.60
T_5: Sole red gram	48.43	173.40	-	-
T_6: Sole bush cowpea	38.60	121.60	-	-
T_7: Sole green gram	44.00	127.80	-	-
T_8: Sole fodder cowpea	38.00	-	-	-
T_9: Sole finger millet	63.00	212.40	-	-
T_{10}: Fallow	83.86	299.60	-	-
SEm (±)	3.65	6.40	-	-
CD (0.05)	13.742	19.434	-	-

Table 28. Effect of intercropping on nutrient removal by weeds, kg ha^{-1}

Treatments	N		P		K	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
T_1: Red gram + bush cowpea	1.36	5.24	0.80	2.05	0.94	1.55
T_2: Red gram + green gram	2.46	6.29	0.66	2.11	1.26	2.99
T_3: Red gram + fodder cowpea	1.93	-	1.08	-	1.44	-
T_4: Red gram + Finger millet	7.82	17.05	1.14	3.57	2.19	8.01
T_5: Sole red gram	6.93	14.97	1.50	5.63	4.01	16.31
T_6: Sole bush cowpea	2.64	7.34	1.21	3.65	1.79	4.28
T_7: Sole green gram	3.04	13.36	0.94	2.93	1.97	6.54
T_8: Sole fodder cowpea	3.68	-	1.28	-	2.53	-
T_9: Sole finger millet	5.02	44.68	1.35	3.98	5.16	12.72
T_{10}: Fallow	19.28	87.92	2.02	7.94	9.86	29.12
SEm (±)	0.49	1.02	0.10	0.16	0.25	0.32
CD (0.05)	1.482	3.121	0.307	0.510	0.752	0.992

4.4. PLANT ANALYSIS

4.4.1 Nutrient uptake

4.4.1.1. Red gram

The results on the effect of intercropping red gram with bush cowpea, green gram, fodder cowpea and finger millet on NPK uptake of red gram are presented in Table 29.

Sole crop of red gram (T_5) resulted in significantly higher nitrogen uptake (69.98 kg ha-1) followed by T_2 (red gram + green gram- 57.25 kg ha^{-1}). T_2 (red gram + green gram) was statistically similar to T_4 (red gram + finger millet). The lowest value was obtained from T_3 (red gram + fodder cowpea- 38.34 kg ha^{-1}).

The P uptake was higher (16.76 kg ha^{-1}) in T_5 (sole crop of red gram) which was followed by T_4 (red gram + finger millet) (12.15 kg ha^{-1}). Treatment, T_4 (red gram + finger millet) was statistically similar to T_2 (red gram + green gram) and T_3 (red gram + fodder cowpea).

Red gram raised as sole crop (T_5) resulted in the highest potassium uptake (53.28 kg ha^{-1}). The uptake value was lower in T_1 (red gram + bush cowpea) (27.57 kg ha^{-1}) and was at on par with all other treatments.

4.4.1.2. Bush cowpea

Tables 30. presents the variation in NPK uptake by bush cowpea.

Sole cropping of bush cowpea (T_6) recorded highest N (69.74 kg ha^{-1}), P (11.37 kg ha^{-1}) and K (36.80 kg ha^{-1}) uptake than red gram + bush cowpea intercropping system.

4.4.1.3. Green gram

Nutrient uptake of green gram as influenced by intercropping in red gram is detailed in Tables 31.

Highest value of N (56.23 kg ha^{-1}), P (11.71 kg ha^{-1}) and K (32.18 kg ha^{-1}) uptake by green gram was recorded in its sole cropping (T_7) when compared to intercropping system.

4.4.1.4. Fodder cowpea

Nutrient uptake by fodder cowpea is presented in Table 32.

Sole crop of fodder cowpea (T_8) recorded significantly highest value of N (45.95 kg ha^{-1}), P (10.60 kg ha^{-1}) and K (22.13 kg ha^{-1}) uptake than its intercropping system.

4.4.1.5. Finger millet

The results on nutrient uptake of finger millet as influenced by intercropping is presented in Table 33.

Finger millet when raised as sole crop (T_9) recorded significantly higher values of N (43.18 kg ha^{-1}), P (10.72 kg ha^{-1}) and K (33.67 kg ha^{-1}) uptake compared to its intercropping system.

4.5. SOIL ANALYSIS

4.5.1. Soil pH

The result of the effect of intercropping with red gram on soil pH after the experiment is presented in the Table 34.

Intercropping bush cowpea, green gram, fodder cowpea and finger millet did not have any significant effect on soil pH after the experiment.

4.5.2. Electrical Conductivity

The result of the intercropping on electrical conductivity of soil after the experiment is presented in the Table 34.

The treatments could not significantly affect the electrical conductivity of soil after the experiment.

Table 29. Effect of intercropping on NPK uptake by red gram, kg ha^{-1}

Treatments	N uptake	P uptake	K uptake
T_1: red gram + bush cowpea	45.19	9.43	27.57
T_2: red gram + green gram	57.25	10.78	32.77
T_3: red gram + fodder cowpea	38.34	10.68	36.85
T_4: red gram + finger millet	53.49	12.15	32.61
T_5: sole red gram	69.98	16.76	53.28
SEm (±)	3.63	0.75	3.08
CD (0.05)	11.868	2.460	10.044

Table 30. Effect of intercropping on NPK uptake by bush cowpea, kg ha^{-1}

Treatments	N uptake	P uptake	K uptake
T_1: red gram + bush cowpea	34.45	5.13	21.57
T_6: sole crop of bush cowpea	69.74	11.37	36.80
T value	-15.44	-19.05	-9.84
P value	0.00	0.00	0.00

Table 31. Effect of intercropping on NPK uptake by green gram gram, kg ha^{-1}

Treatments	N uptake	P uptake	K uptake
T_2: red gram + green gram	25.22	3.75	12.84
T_7: sole crop of green gram	56.23	11.71	32.18
T value	-22.94	-21.44	-20.20
P value	0.00	0.00	0.00

Table 32. Effect of intercropping on NPK uptake by fodder cowpea, kg ha^{-1}

Treatments	N uptake	P uptake	K uptake
T_3: red gram + fodder cowpea	27.03	4.77	12.80
T_8: sole crop of fodder cowpea	45.95	10.60	22.13
T value	-4.06	-4.73	-4.22
P value	0.00	0.00	0.00

Table 33. Effect of intercropping on NPK uptake by finger millet, kg ha^{-1}

Treatments	N uptake	P uptake	K uptake
T_4: red gram + finger millet	30.82	5.03	19.12
T_9: sole crop of finger millet	43.18	10.72	33.67
T value	-13.24	-11.10	-9.17
P value	0.00	0.00	0.00

4.5.3. Organic Carbon

The result of effect of intercropping in red gram on organic carbon content of the soil after the experiment is given in Table 34.

None of the intercropping treatments could significantly influence the organic carbon content of the soil after the experiment.

4.5.4. Dehydrogenase activity of soil after the experiment

Table 35. expounds the effect of intercropping on the dehydrogenase activity of soil after the experiment.

The dehydrogenase activity of soil after the experiment was comparable in T_1 (red gram + bush cowpea) (356 µg TPF g^{-1} soil d^{-1}) and T_6 (sole crop of bush cowpea) (342.75 µg TPF g^{-1} soil d^{-1}) which was followed by T_2 (red gram + green gram) (295.85 µg TPF g^{-1} soil d^{-1}). The lowest value was obtained in T_{10} (fallow) which was statistically similar to T_9 (sole crop of finger millet).

4.5.5. Available nutrient status of soil after the experiment

4.5.5.1. Available N

Table 36. presents the data on the effect of intercropping red gram with bush cowpea, green gram, fodder cowpea and finger millet on the available nitrogen status of soil after the experiment.

The treatments did not have significant effect on available N content of soil after the experiment.

4.5.5.2. Available P

The results on the effect of intercropping on the available phosphorus status of the soil are presented in the Table 36.

Available phosphorus status was significantly higher in sole crop of fodder cowpea (T_8) (76.03 kg ha^{-1}) and it was on par with T_1 (red gram + bush cowpea) (53.33 kg ha^{-1}), T_3 (red gram + fodder cowpea) (57.66 kg ha^{-1}), T_6 (sole crop of bush cowpea) (57.12 kg ha-1) and T_7 (sole crop of green gram) (57.66 kg ha-1).

Table 34. Effect of intercropping on soil pH, EC and organic carbon

Treatments	pH	EC (dS m^{-1})	OC (%)
T_1: Red gram + bush cowpea	5.70	0.178	1.49
T_2: Red gram + green gram	5.66	0.187	1.46
T_3: Red gram + fodder cowpea	5.65	0.172	1.46
T_4: Red gram + Finger millet	5.66	0.172	1.44
T_5: Sole red gram	5.57	0.171	1.46
T_6: Sole bush cowpea	5.66	0.181	1.48
T_7: Sole green gram	5.53	0.168	1.46
T_8: Sole fodder cowpea	5.55	0.171	1.43
T_9: Sole finger millet	5.55	0.168	1.42
T_{10}: Fallow	5.66	0.190	1.40
SEm (±)	0.04	0.005	0.12
CD (0.05)	NS	NS	NS

NS- Not significant

Table 35. Effect of intercropping on dehydrogenase activity

Treatments	Dehydrogenase activity (μg TPF g^{-1} soil d^{-1})
T_1: Red gram + bush cowpea	356.37
T_2: Red gram + green gram	295.85
T_3: Red gram + fodder cowpea	184.30
T_4: Red gram + Finger millet	161.54
T_5: Sole red gram	190.51
T_6: Sole bush cowpea	342.75
T_7: Sole green gram	190.85
T_8: Sole fodder cowpea	141.37
T_9: Sole finger millet	75.17
T_{10}: Fallow	56.03
SEm (±)	12.71
CD (0.05)	37.785

NS- Not significant

Table 36. Effect of intercropping on available nutrients in soil after the experiment

Treatments	Available nutrients		
	N	P	K
T_1: Red gram + bush cowpea	351.23	53.33	98.41
T_2: Red gram + green gram	338.68	44.89	122.06
T_3: Red gram + fodder cowpea	301.05	57.66	150.00
T_4: Red gram + Finger millet	338.68	33.95	121.47
T_5: Sole red gram	321.96	49.54	140.83
T_6: Sole bush cowpea	313.60	57.12	112.56
T_7: Sole green gram	313.60	57.66	97.68
T_8: Sole fodder cowpea	301.05	76.03	106.70
T_9: Sole finger millet	288.51	27.08	105.82
T_{10}: Fallow	288.51	26.13	76.30
SEm (±)	14.94	8.77	7.24
CD (0.05)	NS	26.059	21.536

4.5.5.3. Available K

The data pertaining to available potassium status of soil as influenced by intercropping are presented in Table 36.

The available K status after the experiment was higher in T_3 (red gram + fodder cowpea- 150.00 kg ha^{-1}) which was on par with treatment, T_5 (sole crop of red gram- 140.83 kg ha^{-1}). The lowest value was recorded in T_{10} (Fallow – 76.30 kg ha^{-1})

4.6 COMPETITION INDICES

Different competition indices like land equivalent ratio (LER), relative crowding coefficient (RCC), monetary advantage index (MAI), aggressivity and red gram equivalent yield (REY) were computed in the present study and were not statistically analysed.

4.6.1. Land Equivalent Ratio (LER)

Result of the effect of intercropping systems on LER is presented in Table 37.

The LER of all intercropping systems recorded values higher than one which indicated yield advantage over sole cropping of red gram and other intercrops. Intercropping of red gram with bush cowpea (T_1) showed higher LER of 1.68 followed by red gram + green (T_2) with the value of 1.39. Next higher value of LER was recorded with T_4 (red gram + finger millet) and T_3 (red gram + fodder cowpea) with LER 1.30 and 1.29, respectively.

4.6.2. Relative Crowding Coefficient (RCC)

Result of the effect of intercropping systems on relative crowding coefficient (RCC) are given in Table 37.

The RCC value of red gram was found to be higher than that of other intercrops which indicated that red gram was a dominant crop in all intercropping treatments. Red gram expressed the highest RCC in red gram + green gram (T_2 – 12.91) followed by red gram + finger millet (T_4 – 5.14). The RCC of the system was the highest (7.22) with T_2 (red gram + green gram) followed by T_4 (red gram + finger millet- 3.59), T_3 (red gram + fodder cowpea- 3.40) and T1 (red gram + bush cowpea- 2.58), respectively.

4.6.3. Aggressivity

Results of the effect of intercropping bush cowpea, green gram, fodder cowpea and finger millet in red gram on aggressivity of component crops are shown in Table 37.

The aggressivity values indicate the competitive ability of component crops in an intercropping system. Aggressivity value of red gram in all intercropping system was positive which indicated the dominant nature of red gram over the component crops. The aggressivity of red gram was more pronounced in red gram + green gram (T_2) with a value of 0.60.

4.6.4. Monetary Advantage Index (MAI)

Results on the effect of intercropping on monetary advantage index (MAI) of the intercropping systems are presented in Table 38.

The MAI was the highest (₹ 83470 ha^{-1}) with red gram + bush cowpea (T_1) indicating the monetary advantage of the system and was followed by T_2 (red gram + green gram), T_4 (red gram + finger millet) and T_3 (red gram + bush cowpea) with MAI values ₹ 56839 ha^{-1}, ₹ 40402 ha^{-1} and ₹ 26404 ha^{-1}, respectively.

4.6.5. Red gram Equivalent Yield

Results on the effect of intercropping on red gram equivalent yield (REY) is presented in Table 38.

The sole crop of bush cowpea recorded the highest equivalent yield (2243 kg ha^{-1}). Among the intercropping systems, red gram + bush cowpea (T_1) recorded the highest equivalent yield (1719 kg ha^{-1}) followed by red gram + green gram (T_2- 1688).

4.7. ECONOMIC ANALYSIS

4.7.1. Net Income

The result of the effect of intercropping systems on net returns of cultivation is presented in Table 38.

Economic analysis indicated that red gram + bush cowpea (T_1) recorded the highest net income (₹ 138611 ha^{-1}) and was followed by red gram + green gram (T_2- ₹ 137892 ha^{-1}). The lowest net returns among intercropping systems was recorded in treatment T_3 (red gram + fodder cowpea - ₹ 61568 ha^{-1}). All sole crops except red gram recorded lower net income compared to the intercropping treatments.

4.7.2 Benefit : Cost Ratio (BCR)

The result of the effect of red gram intercropping systems on benefit : cost ratio (BCR) is presented in Table 38.

Intercropping bush cowpea, green gram , fodder cowpea and finger millet in red gram expressed BCR greater than one. Red gram + green gram (T_2) recorded the highest BCR of 3.13 followed by red gram + bush cowpea (T_1- 3.05). The BCR was the lowest in case of sole cropping compared to intercropping except in the case of sole crop of red gram (T_5).

Table 37. Effect of intercropping on land equivalent ratio (LER), relative crowding coefficient (K) and aggressivity (A)

Treatments	LER	Relative crowding coefficient			Aggressivity	
		K_{ri}	K_{ir}	K	A_{ri}	A_{ir}
T_1: red gram + bush cowpea	1.68	3.45	0.75	2.58	0.33	-0.33
T_2: red gram + green gram	1.39	12.91	0.56	7.22	0.60	-0.60
T_3: red gram + fodder cowpea	1.29	3.91	0.87	3.40	0.35	-0.35
T_4: red gram + finger millet	1.30	5.14	0.70	3.59	0.43	-0.43

Kri, Ari- relative crowding coefficient and aggressivity of red gram in combination with different intercrops respectively

Kir, Air- - relative crowding coefficient and aggressivity of intercrops in combination with red gram respectively

Table 38. Effect of intercropping on red gram equivalent yield, net returns, benefit cost ratio and monetary advantage index

Treatments	REY (kg ha^{-1})	Net income (₹ ha^{-1})	BCR	MAI (₹ ha^{-1})
T_1: red gram + bush cowpea	1719	138611	3.05	83470
T_2: red gram + green gram	1688	137892	3.13	56839
T_3: red gram + fodder cowpea	1055	61568	1.94	26404
T_4: red gram + finger millet	1459	116263	2.97	40402
T_5: red gram as sole crop	1430	113534	2.95	-
T_6: bush cowpea as sole crop	2243	64866	1.34	-
T_7: green gram as sole crop	1880	-45987	0.75	-
T_8: fodder cowpea as sole crop	1600	-87667	0.18	-
T_9: finger millet as sole crop	2163	25555	1.40	-
T_{10}: fallow	-	-	-	-

DISCUSSION

5. DISCUSSION

The study entitled "Performance of red gram (*Cajanus cajan* (L.) Millsp.) intercropping systems in lowlands" was carried out to investigate the feasibility of intercropping bush cowpea, green gram, fodder cowpea and finger millet in red gram and to find out the effect on growth, yield, productivity and economics of the intercropping systems. The results of the study are discussed concisely in this chapter.

5.1. GROWTH AND GROWTH ATTRIBUTES

5.1.1. Main crop – red gram

In general, the different intercropping treatments showed significant influence on the growth characters of red gram.

The results revealed that the sole crop of red gram surpassed its associated intercropping systems in plant height (Fig. 4), number of branches, leaf area (Fig. 5) and leaf area index (LAI) (Fig. 6) at all the growth stages. Similar trend was reported by Shivaran and Ahlawat (2000) and Vijayaprabhakar *et al.,* (2018) in red gram + black gram intercropping system. It might be due to the absence of inter and intra specific competition between the plants in a sole cropping situation. Hence, uptake of nutrients by the crop increased thereby contributing to improved overall growth attributes of the system.

In all treatments, LAI of red gram showed a definite pattern at various growth stages. The sole crop of red gram recorded higher LAI at all the growth stages when compared to its associated intercropping treatments. It increased progressively in all treatments up to 120 DAS and thereafter declined. It is evident from the results that higher LAI was recorded due to good vegetative growth and favorable soil conditions. Among intercropping systems, higher LAI was noticed when red gram was intercropped with green gram. It might be due to the temporal and spatial complementarities between the respective crops. The results were in conformity with Pramod *et al.,* (2012) and Barod *et al.,* (2017).

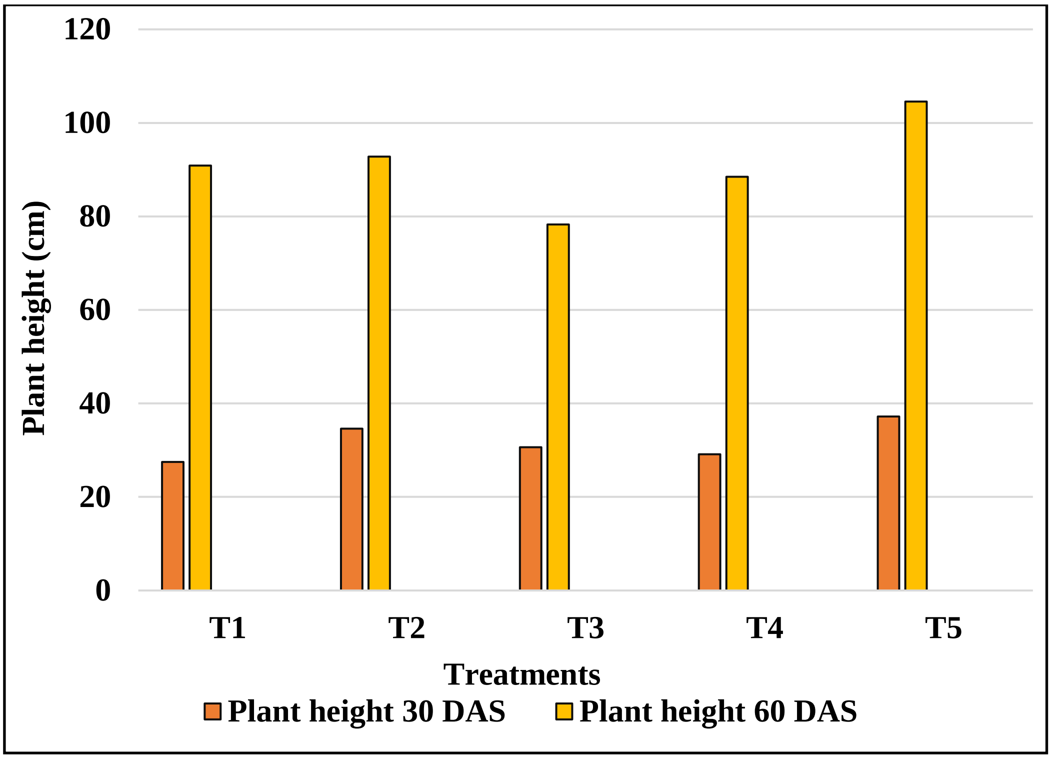


Fig 4. Effect of intercropping on plant height of red gram, cm

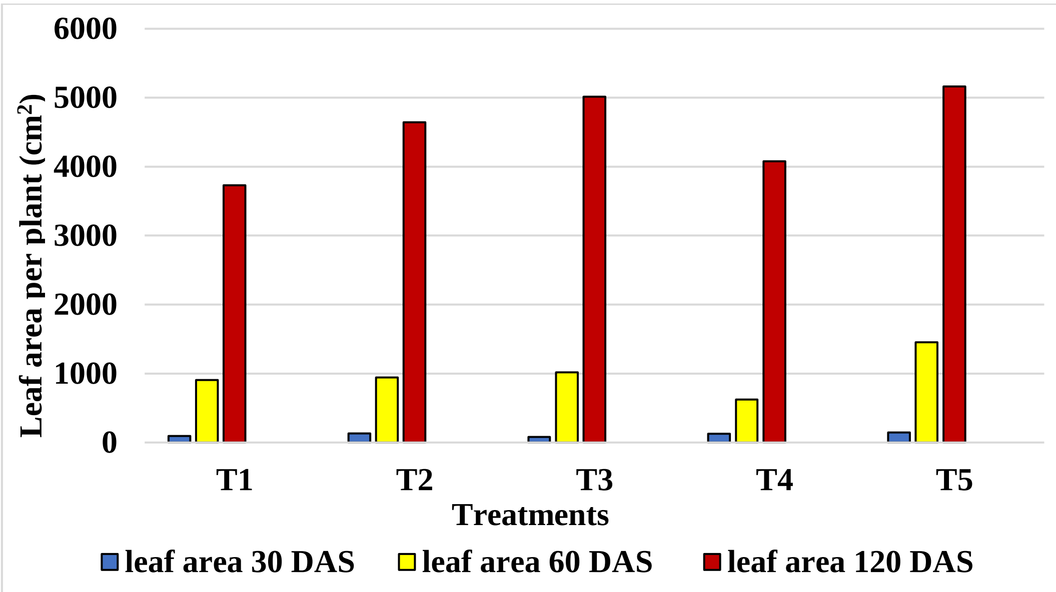


Fig 5. Effect of intercropping on leaf area per plant of red gram, cm^2

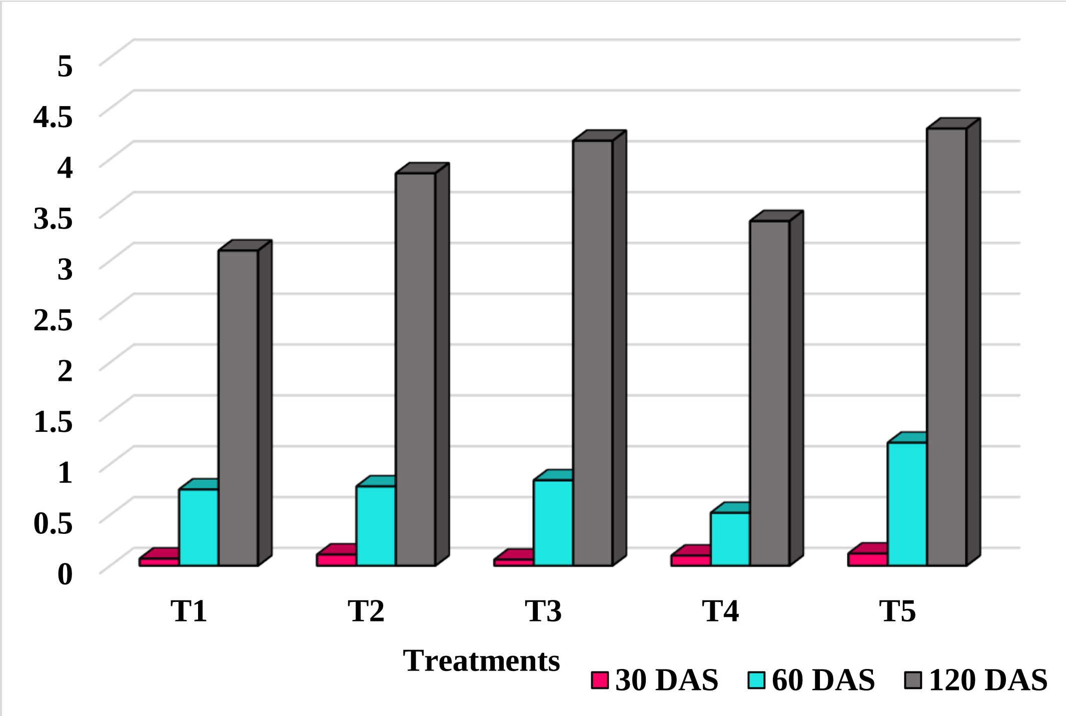


Fig 6. Effect of intercropping on leaf area index of red gram

Growth attributes of red gram was reduced when intercropped with cowpea. It clearly indicated the dominance and aggressive nature of the cowpea which might have depressed the growth of associated red gram where the growth rate was slower in the initial growth stages. Similar results have been reported by Vijayaprabhakar and Jayanthi (2018).

5.1.2. Intercrops

The growth parameters of the crops were measured in terms of plant height, number of branches, leaf area and LAI at different growth stages. The plant height and number of branches had increasing trend with the advancement of plant growth and it reached maximum at harvest. However, leaf area and LAI increased upto 60 DAS and thereafter declined.

Component crops including bush cowpea, green gram, fodder cowpea and finger millet when grown as sole crops recorded highest plant height, number of branches, leaf area and LAI compared to its associated intercropping treatments. Better performance in sole crop could be attributed to the above and below ground interactions which responded well to the applied nutrients and thereby contributing to better growth attributes.

Nutrient availability and uptake in the intercropping system is affected by the interspecific interaction between the species in the rhizosphere (Li *et al.,* 2010). Therefore, when intercropped a competition might have emerged among the main crop and the intercrops for light, space, nutrients and water hereby affecting the growth of individual plants in an intercropping system.

5.2 YIELD AND YIELD ATTRIBUTES

5.2.1. Main crop – red gram

Significantly the highest number of pods, grain yield and haulm yield were recorded in sole crop of red gram (Table. 10) which was found to be on par with the treatment involving red gram + green gram intercropping system. The increase in the yield of red gram in sole cropping may be due to more availability of nitrogen, phosphorus and potassium nutrients at the time of its critical stage of growth *viz.,* pod formation. The legume effect would have harnessed its effective utilization which resulted in an increase in sink capacity and nutrient uptake by the crop. This is in conformity with the findings of Telkar *et al*., (2017) in maize + soyabean intercropping system.

Yield is also a function of growth and yield attributes such as number of branches per plant, leaf area, LAI and number of pods per plant. This might have contributed to the highest grain yield in sole crop of red gram. Similar results were obtained by Mahto *et al.,* (2007) and Biradar *et al.,* (2020).

The magnitude of yield reduction for various intercropping systems were in the order 13.42 per cent, 28.04 per cent, 33.77 per cent and 36.71 per cent for the treatments red gram + green gram, red gram + finger millet, red gram + fodder cowpea and red gram + bush cowpea, respectively in comparison to sole red gram (Fig. 13). The maximum yield advantage was obtained with the red gram + green gram intercropping system due to their distinct growth habits, rooting pattern and maturity periods. The results are in agreement with Kumawat *et al.,* (2013) and Bhadu *et al.,* (2021). Competition for space, nutrients, moisture and solar radiation would have contributed to the reduced grain yield of red gram in red gram + bush cowpea intercropping system. Similar results were reported by Ahamad *et al.,* (2016).

5.2.2. Intercrops

Following the trend in growth and growth attributes, there was significant reduction in the yield and yield attributes of bush cowpea and green gram under intercropping situation. Sole crop of bush cowpea and green gram registered significantly higher number of pods per plant, grain yield and haulm yield when compared to their respective intercropping systems (Table. 20 and Table. 21). The difference in the population proportion among the treatments might have contributed in producing higher yield. Maintaining optimum population of bush cowpea and green gram under sole cropping which was higher than the population that was maintained in the intercropping system increased their dry matter production. Better light interception might have further increased higher assimilation of photosynthates and its translocation to the economic part. Similar results were reported by Sharma *et al.*(2010) and Barod *et al.*(2017).

Similarly, leaf to stem ratio, green fodder yield and dry fodder yield were higher in sole cropping of fodder cowpea than its associated intercropping system (Table. 22).

As in the case of bush cowpea and green gram, number of tillers, number of productive tillers, grain yield and stover yield were superior for sole crop of finger millet compared to that of its intercropping system (Table. 23).

The percentage reduction in grain yield for various intercropping systems were 39.96 per cent (red gram + bush cowpea), 46.89 per cent (red gram + green gram), 41.43 per cent (red gram + finger millet) in comparison to their respective sole crops. Similarly, percentage reduction in dry fodder yield of fodder cowpea was 36.48 per cent in intercropping system when compared to its sole crop.

5.3. OBSERVATIONS ON WEEDS

5.3.1. Weed count

There was no particular trend in weed population with respect to different treatments. The analysis of weed count at 30 DAS revealed the dominance of grasses followed by broad leaved weeds and sedges as indicated in Table. 24. The highest weed count was recorded in fallow and the lowest value in sole crop of fodder cowpea.

At 60 DAS, grasses dominated the system which was followed by sedges and broadleaved weeds. The lowest weed population was recorded in red gram + bush cowpea intercropping system however, the highest weed density was observed in fallow plot (Table. 25).

5.3.2. Weed composition

The weeds comprised of grasses, sedges and broadleaved weeds (Table. 26).

Among the grasses, *Echinochloacolona, Digitariaciliaris, Cynodondactylon, Eleusine indica*, *Setariabarbata* and*Isachnemiliacea*were the major weeds observed.

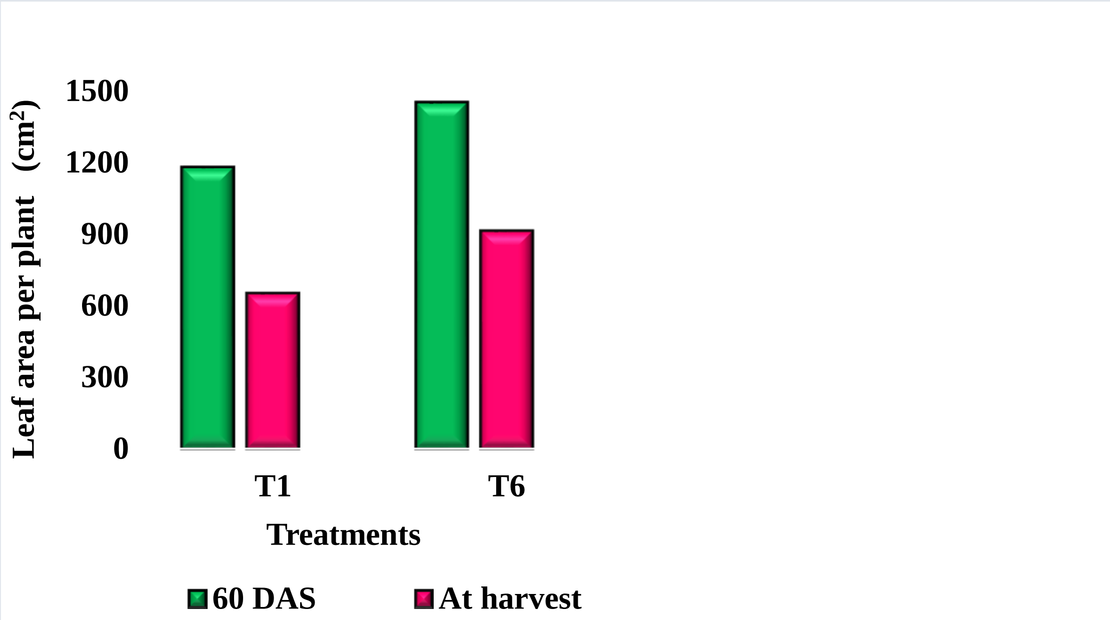


Fig 7. Effect of intercropping on leaf area of bush cowpea

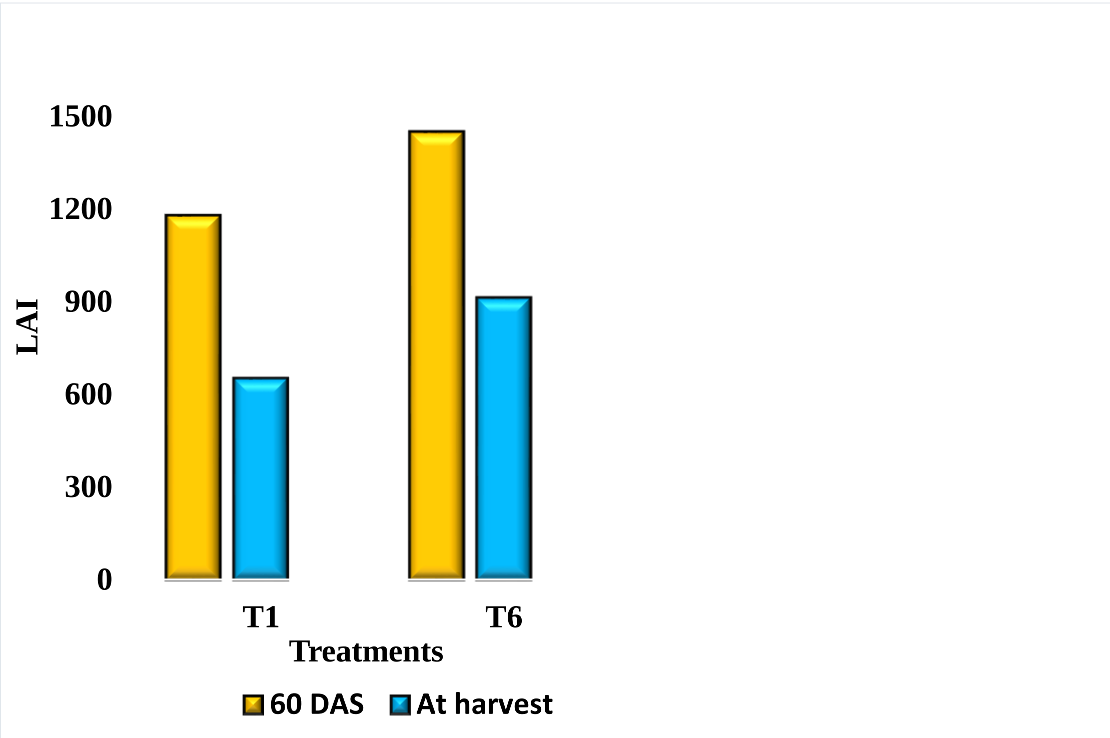


Fig 8. Effect of intercropping on leaf area index of bush cowpea

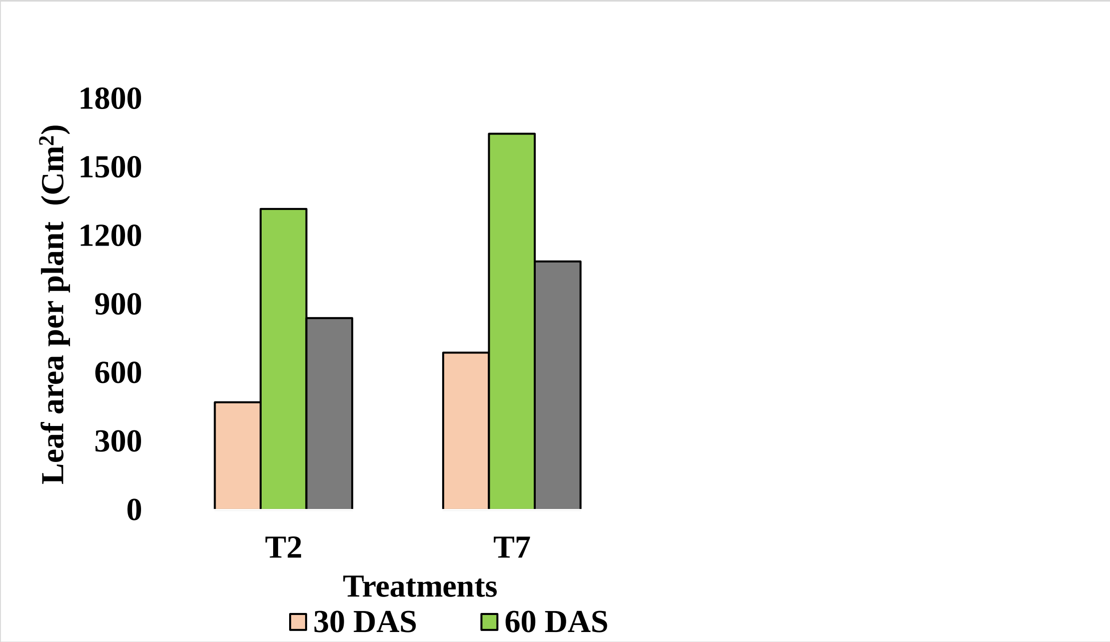


Fig 9. Effect of intercropping on leaf area of green gram

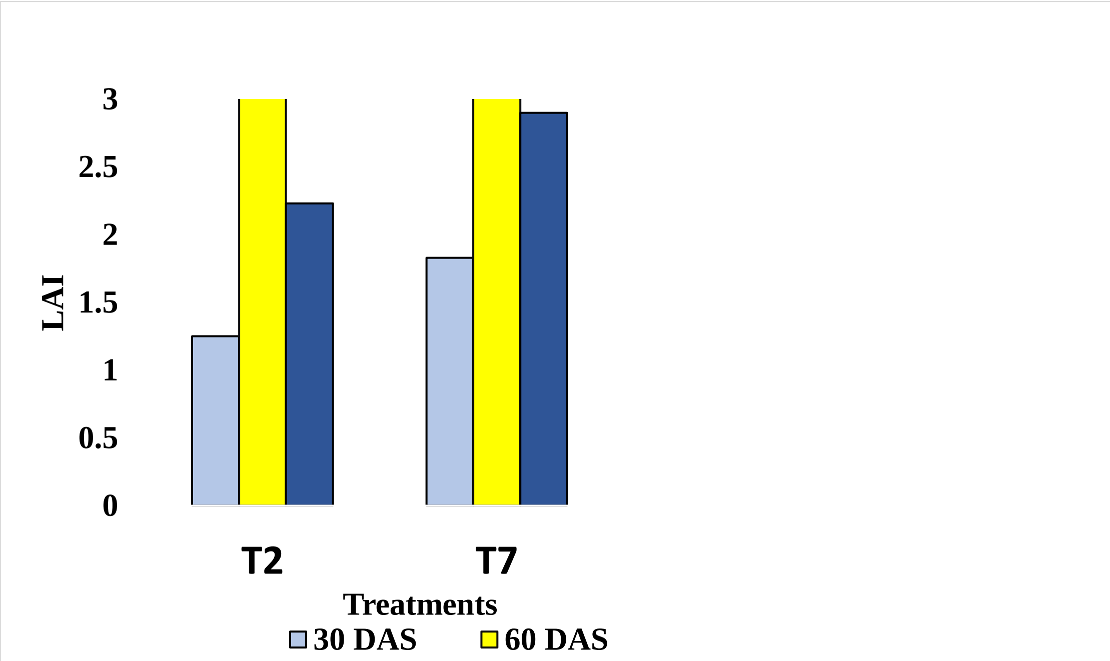


Fig 10. Effect of intercropping on leaf area index of green gram

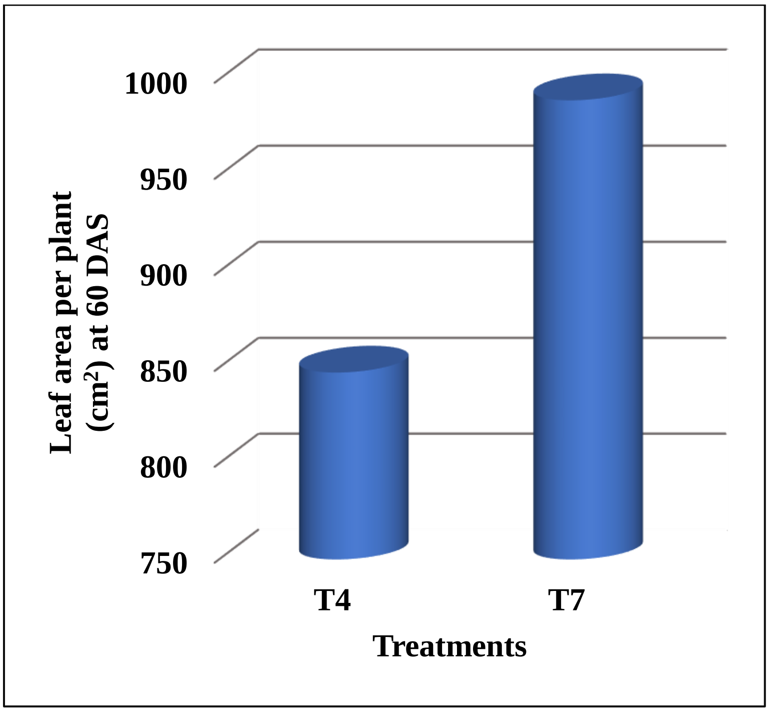


Fig 11. Effect of intercropping on leaf area of finger millet

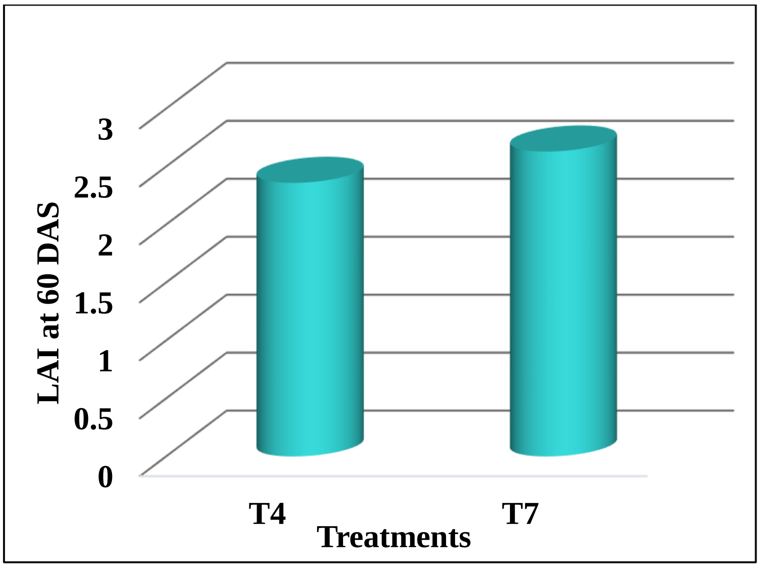


Fig 12. Effect of intercropping on leaf area index of finger millet

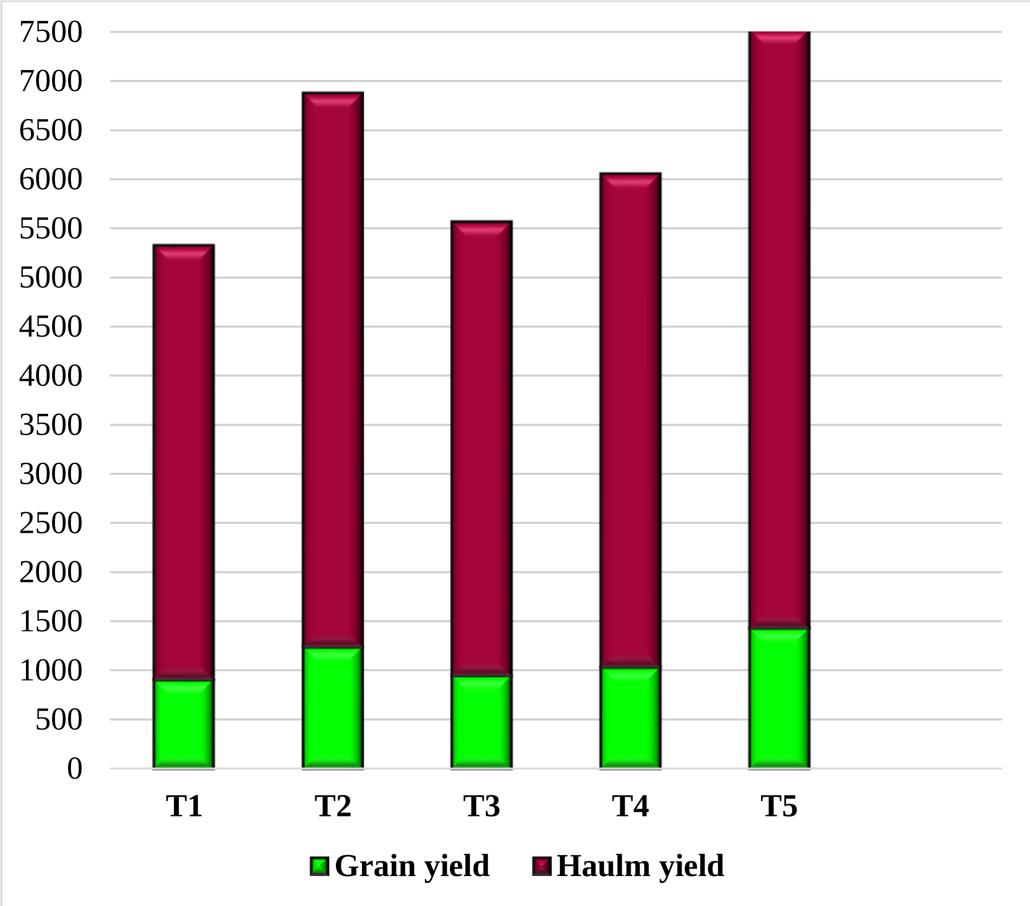


Fig 13. Effect of intercropping on grain yield and haulm yield of red gram

Broadleaved weeds comprised *Cleome rutidospermum, Euphorbia hirta, Oldenlandia umbellata, Ludwigia perennis, Alternanthera sessilis, Kyllinga monocephala , Phyllanthus niruri* and *Commelina benghalensis.*

Among the sedges, *Cyperus rotundus* and *Fimbristylis miliacea* dominated the system.

5.3.3. Weed dry matter production

In general, total weed dry matter production was higher in fallow plot. Sole crop of finger millet registered considerably higher dry matter production of weeds which was followed by sole crop of red gram (Fig. 14). On the contrary, intercropping system involving red gram and bush cowpea recorded 67.56 per cent and 76.73 per cent reduction in dry matter production of weeds than fallow plot at 30 and 60 DAS, respectively. The erect growth habit of finger millet which allowed more penetration of solar radiation might have benefitted the weeds in the sole crop (Reddy, 2020). Also, red gram when grown as sole crop did not provide a fast and adequate ground cover which thereby provided suitable environment for the development of weeds. Similar report was stated by Ferreira *et al.*,(2018).

As reported by Yih (1982), intercropping systems involving pulses suppresses weed growth both by producing higher crop yield and through their allelopathic effects. Intercrops also have the capability of providing yield advantages by utilising the resources that are not used by weeds and transforming them into economically valuable dry matter (Liebman and Elizabeth, 1993). The increased population per unit area in red gram and bush cowpea intercropping system might have resulted in lowest dry matter production. Being a crop of vigorous growth habit, cowpea might have offered an effective competition with the weeds at initial stages and formed a dense soil cover along with red gram. Greater reduction in weed dry weight in intercropping was also reported by Rajesh *et al.*, (2014).

5.3.4. Weed Smothering Efficiency

Weed smothering efficiency (WSE) was higher when red gram was intercropped than sole cropping of red gram. At 30 DAS, highest WSE was noted with red gram + bush cowpea intercropping system (40.86 %) which was followed by red gram + fodder cowpea intercropping system (33.04 %). The least value was recorded with red gram + finger millet intercropping system (5.71 %). At 60 DAS, the highest value was again observed in red gram + bush cowpea intercropping system (58.93 %) closely followed by red gram + green gram intercropping system (56.45 %) (Fig.15). The higher weed smothering efficiency by the intercropping system may be attributed to the greater foliage producing capacity of intercrops. In addition, better utilization of light, water and nutrients by the main crop and the intercrop might have posed greater competition to the weeds thereby restricting its germination (Altieri and Liebman, 1986).

5.3.5. Nutrient removal by weeds

Nutrient removal by weeds varied significantly among the treatments (Table 28). The highest N, P and K removal by weeds was registered in fallow plot at 30 and 60 DAS which was followed by sole crop of finger millet and sole crop of red gram. The least nutrient removal by weeds were obtained in intercropping systems involving bush cowpea and green gram.

The higher nutrient removal by weeds was proportional to the dry matter production by weeds. Therefore, lower nutrient removal in the intercropping systems could be attributed to growing of intercrop in widely spaced red gram crop which while utilizing the space efficiently reduced the intensity and dry matter production leading to lower NPK removal by weeds (Kaur *et al.*, 2014).

5.4. COMPETITION INDICES

5.4.1. Land Equivalent Ratio

Land equivalent ratio (LER) is the relative land area under sole crops that is required to produce the yield that is achieved in intercropping. LER value greater than unity denotes yield advantage and less than unity denotes disadvantage (Palaniappan and Sivaraman, 1996).

In all the intercropping systems, LER excelled one indicating greater biological efficiency of intercropping over sole cropping (Fig. 17). The mean LER for the intercropping systems ranged from 1.29 to 1.68 implying 29 to 68 per cent land use efficiency over sole cropping. Red gram when intercropped with bush cowpea recorded

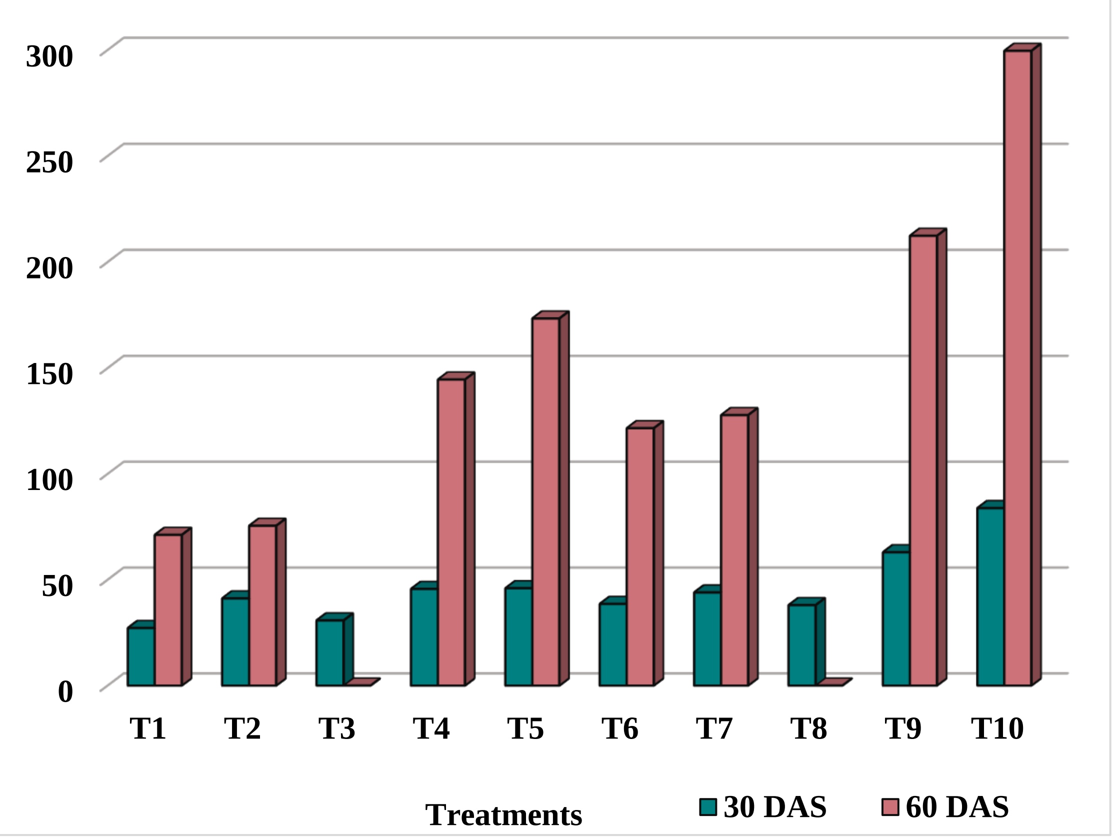


Fig 14. Effect of intercropping on weed dry matter production g m^{-2}

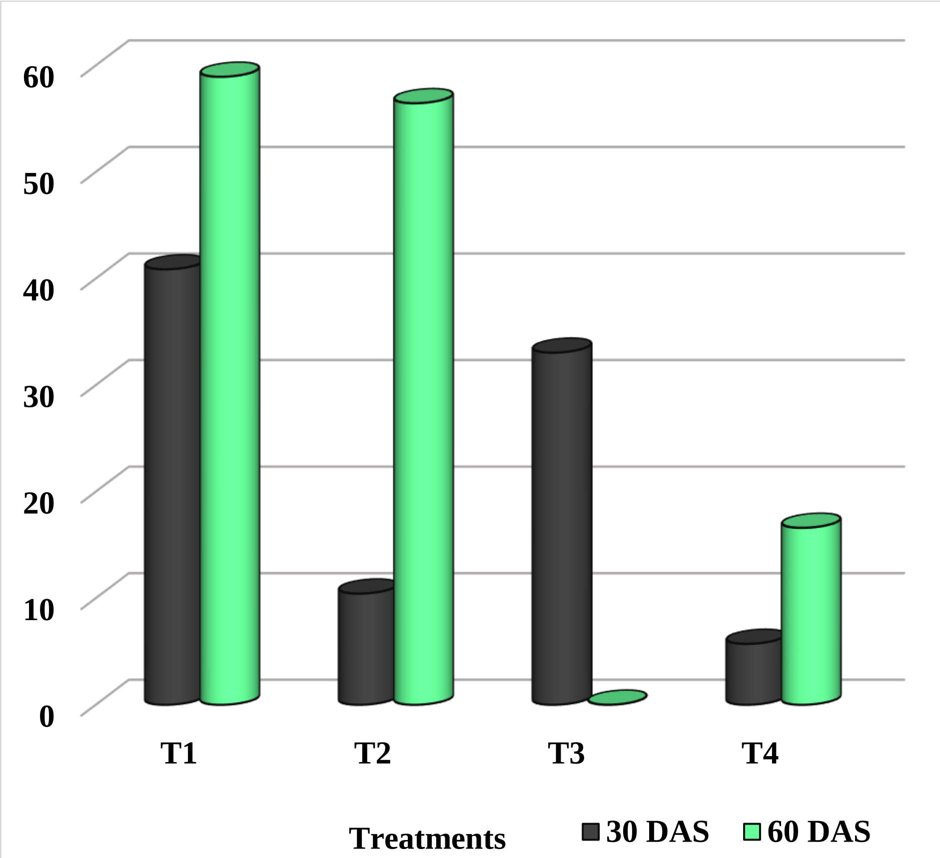


Fig 15. Effect of intercropping on weed smothering efficiency (%)

higher LER (1.68) followed by red gram and green gram intercropping system. The results clearly showed that growing bush cowpea as intercrop with red gram has the potential of giving maximum yields per unit area and time.

5.4.2. Relative crowding coefficient

Relative crowding coefficient determines the competition effects and advantages of intercropping. The products of RCC (K) of main crop (K_{ri}) and intercrops (K_{ir}) were more than one in all the intercropping system (2.58 to 7.22) indicating a definite yield advantage due to intercropping (Fig.17). In the intercropping system, RCC value of the main crop (K_{ri}) showed higher values (3.45 to 12.91) than the intercrops (K_{ir}) (0.56 to 0.87) indicating that the main crop had highly dominated over all the intercrops. It can be attributed to the efficient utilization of resources by the main crop than all other intercrops in the intercropping systems.

Among the intercropping systems, higher value was recorded in red gram + green gram followed by red gram + finger millet. It could be inferred that the maximum yield advantage was obtained by these cropping systems due to their niche complementarities due to spatial and temporal differences between both the component crops. It might be also due to the distant difference in rooting pattern, growth habit and maturity periods of the component crops. The results were in accordance with the findings of Chaudhari *et al.*(2017) and Gitari *et al.*(2020).

5.4.3. Aggressivity

Aggressivity is the competition function used to assess the competition between component crops in intercropping system. It gives a measure of how much the relative yield increase in species ‘a’ is greater than that of species ‘b’. Values with positive sign denotes the dominant species and negative sign denotes the dominated species.

Aggressivity value of red gram was positive in all the intercropping system which denotes the dominant nature of red gram over other component crops (Fig. 17). The competitive ability of red gram on component crops was more pronounced when red gram was intercropped with green gram. These results corroborate with the findings of Pandey *et al.* (2013), when red gram was intercropped with black gram.

5.4.4. Red gram equivalent yield

Intercropping systems involves more than one species therefore, it is difficult to compare the produce of different crops with different nature and hence efforts have been made to convert the yield of component crops into equivalent yield of the main crop. Crop equivalent yield has been recognized as the most efficient indices capable of assessing the overall production potential of intercropping systems. Here the total productivity was given in terms of red gram equivalent after converting intercrop yield into red gram based on market prices.

The highest equivalent yield was recorded in sole crop of bush cowpea. Among the intercropping systems, red gram intercropped with bush cowpea registered higher equivalent yield than sole crop of red gram which was followed by red gram + green gram intercropping system (Table 37). These treatments showed 20.20 per cent and 13.56 per cent increase in REY than sole red gram yield. This clearly indicated the superiority of intercropping over sole cropping. Here, it may be pointed out that the higher REY might be mainly due to an additional yield of intercrops viz., bush cowpea in the intercropping system. The results are in close conformity with Bindhu (1999) in sesamum and pulses intercropping system. Inclusion of bush cowpea and red gram attributed to less exhaustion of soil fertility, reduced early stage of crop weed competition compared to other treatments, thereby increased the red gram equivalent yield.

5.4.5. Monetary advantage index

Monetary advantage index is an indicator of the economic feasibility of intercropping system. The maximum monetary advantage of ₹ 83470 ha^{-1}was obtained when red gram was intercropped with bush cowpea which was followed by red gram and green gram (₹ 56839 ha^{-1}). The elevated MAI might be due to higher value of the produce of combined intercrops. The results are in agreement with the findings of Kumar *et al.*, (2013).

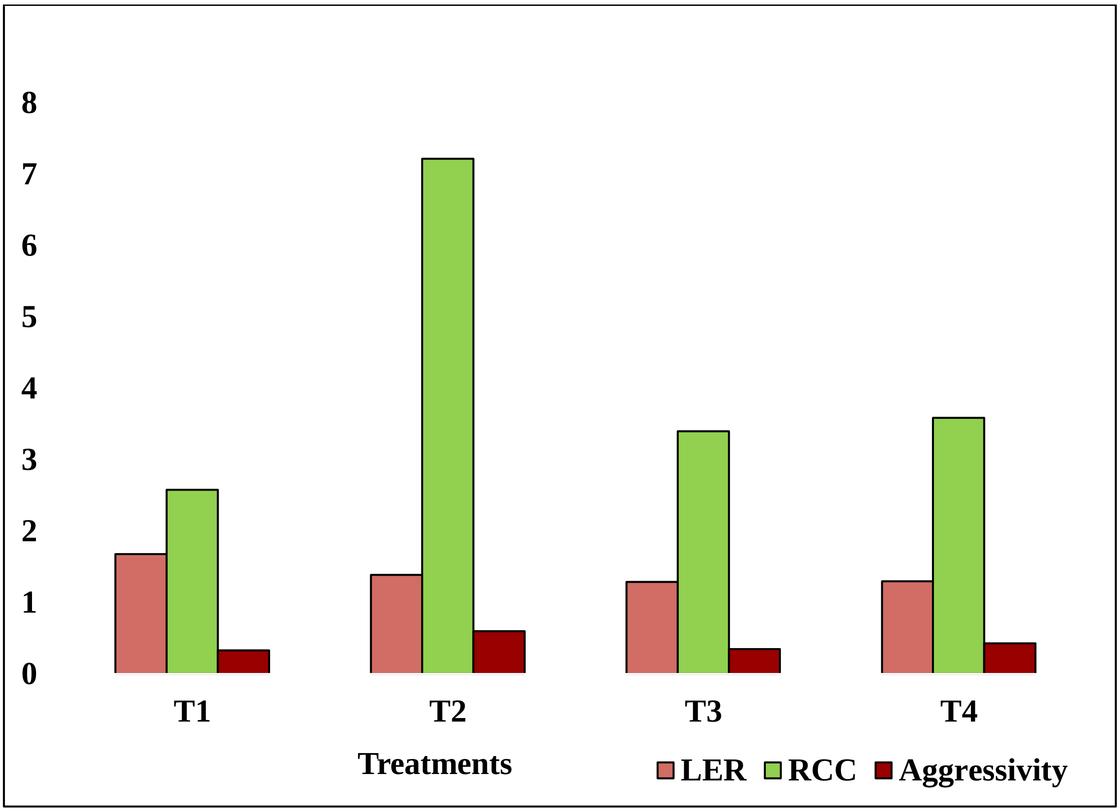


Fig 16. Effect of intercropping on LER, RCC and aggressivity

5.5.SOIL PROPERTIES

The soil of the experimental site were analysed for pH, EC, organic carbon and nutrients N, P and K before and after the experiment. Soil analysis after the experiment failed to exhibit significant variation in pH, EC, organic carbon (Table 34) and available nitrogen (Table 36). Compared to the initial status of the soil (Table 2), pH and EC were found to decrease in all the treatments after the experiment. Organic carbon content and available nitrogen content was observed to increase after the experiment when compared to its initial values. The increase in the acidity of the soil after the experiment may be due to the proton release from the roots of the legume crop. As a consequence, plants may accumulate organic anions which if returned and decomposed in the soil has the ability to neutralise the soil acids (Yan *et al.*, 1996). Higher nitrogen values were reported for red gram + bush cowpea intercropping system which was followed by the sole crop of bush cowpea. According to Hauggaard – Nielsen *et al.*(2003), crop diversification is associated with nutrient cycling and in addition limits the nutrient leaching losses. The biological nitrogen fixation by bush cowpea alone ranges from 36 – 75 kg ha^{-1} (Vasconcelos *et al*., 2020). It is estimated that the total nitrogen fixation in the world is about 1.75×10^{11} kg of which 8×10^{10}kg is fixed through symbiotic nitrogen fixation in legumes (Shah *et al.*, 2021).

The results revealed that the available phosphorus and potassium status were significantly superior after the experiment (Table 36). Sole crop of fodder cowpea recorded the highest P availability while the highest available K was registered in red gram + fodder cowpea intercropping system. It might be due to the ability of legume crop to solubilize and recover phosphorus from unavailable forms. It was reported that there was increase in P availability in rhizosphere in intercropping system than in sole cropping. Legume roots releases organic acid which reduces pH of the soil surrounding the roots thereby solubilizing and releasing the unavailable phosphorus (Stagnari *et al*., 2017).

Intercropping red gram with bush cowpea reported significantly higher dehydrogenase enzyme activity in soil (356.37 μg TPF g^{-1} soil d^{-1}) which was followed by sole crop of bush cowpea (342.75 μg TPF g^{-1} soil d^{-1}) and red gram + green gram

(295.85 μg TPF g^{-1} soil d^{-1}) intercropping system (Table 35).This was possibly due to decomposing root nodules and root tissues which provided carbon and energy to the soil microbes resulting in increased dehydrogenase activity. Similar results were also reported by Ahamad *et al.* (2016) and Singh *et al.* (2012). Increase in the organic matter content improved organic carbon content of the soil which might have corresponded to the higher enzyme activity (Mandal *et al.,* 2007). It has also been reported by Manjaiah and Singh (2001) that the increase in dehydrogenase activity is proportional to the addition of number and amount of nutrients.

5.6 NUTRIENT UPTAKE

N, P and K uptake by red gram significantly varied with the treatments and the highest value was obtained in sole crop of red gram (Fig. 16). Red gram being a deep rooted crop can exploit nutrients from the deeper layers of the soil. Moreover, red gram root exudates are also reported to have ability to solubilize Al- P and Fe – P forms (Ishikawa *et al*., 2002).

In case of intercrops, N, P and K uptakes were higher in sole crops of bush cowpea, green gram, fodder cowpea and finger millet compared to their intercropping system. The optimum population maintained in the sole cropping resulted in higher dry matter accumulation and consequently, in higher nutrient uptake. Since nutrient uptake is also a function of total dry matter and nutrient content in plant, this might have contributed in higher uptake by the sole cropping. According to Salvi *et al.,* (2014), there is a linear relationship between dry matter production and nutrient uptake.

5.7 ECONOMICS

In general, intercropping resulted in the higher net income and benefit cost ratio than the sole crops of red gram, bush cowpea, green gram, fodder cowpea and finger millet. Economic analysis of the intercropping system revealed that the treatment red gram + bush cowpea resulted in higher net income which was followed by red gram + green gram intercropping system (Table 38). Benefit: cost ratio was found to be the highest in red gram + green gram intercropping system which was followed by red gram + bush cowpea intercropping system in additive series (Fig. 18). Thus, indicating the

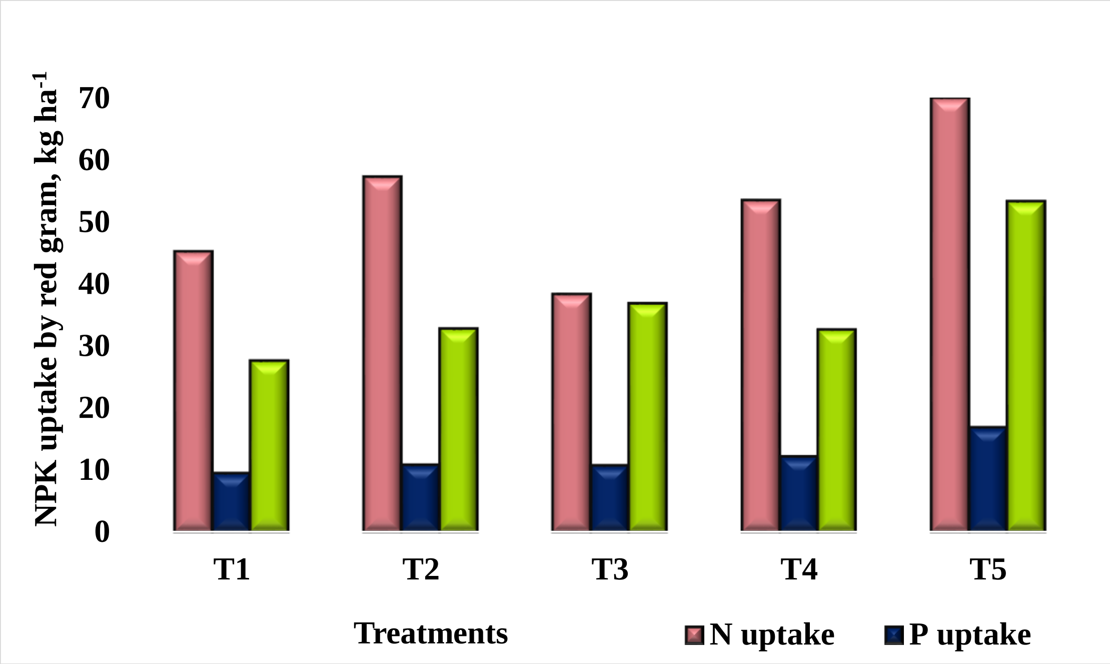


Fig 17. Effect of intercropping on nutrient uptake by red gram

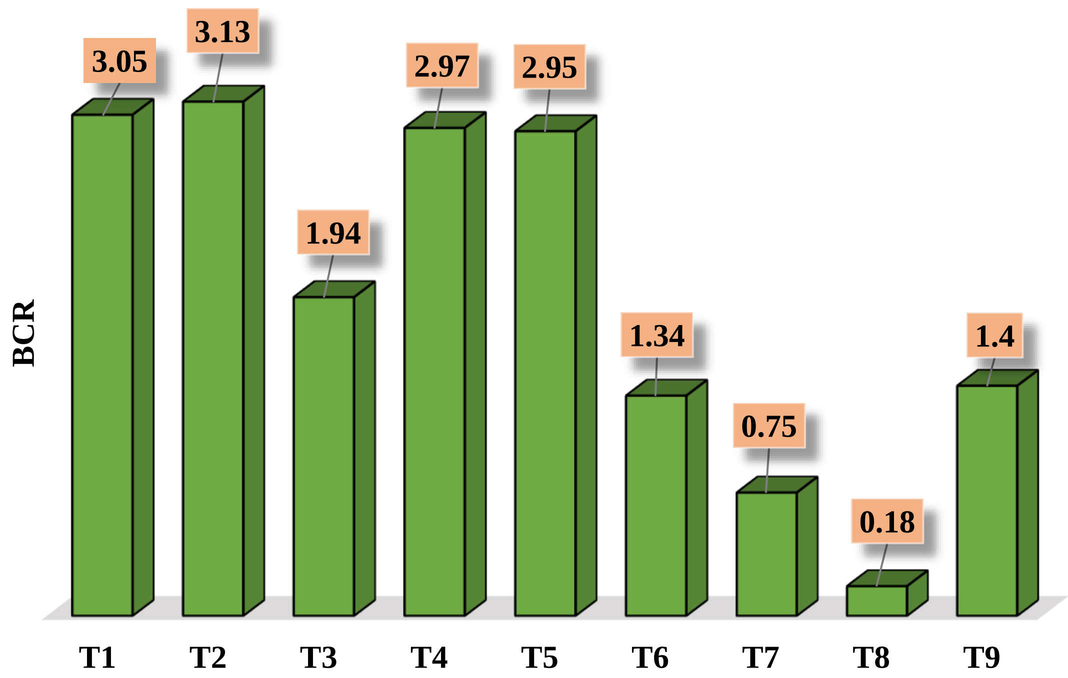


Fig 18. Effect of intercropping on benefit cost ratio

suitability of bush cowpea and green gram as an intercrop in red gram compared to fodder cowpea and finger millet.

From the present study it could be concluded that the systems involving bush cowpea and green gram in additive series (1:2) were more suitable for intercropping with red gram in the summer fallow of double cropped lowland rice field. It was identified as the best intercropping system considering the weed smothering efficiency, red gram equivalent yield, land equivalent ratio, monetary advantage index, net income and benefit: cost ratio.

SUMMARY

6. SUMMARY

The study entitled "Performance of red gram (*Cajanus cajan* (L.) Millsp.) intercropping systems in lowlands" was undertaken at College of Agriculture, Vellayani, Thiruvananthapuram during 2020-2022. The main objective was to evaluate different red gram based intercropping systems in the summer fallow of double cropped lowland rice field in terms of weed dynamics, biological efficiency and economics.

The field experiment was carried out at Integrated Farming System Research Station (IFSRS), Karamana from January to June 2022 in Randomized Block Design with 10 treatments and three replications. The treatments comprised of T_1: red gram + bush cowpea (1:2), T_2: red gram + green gram (1:2), T_3: red gram + fodder cowpea (1:2), T_4: red gram + finger millet (1:2), T_5: sole crop of red gram, T_6: sole crop of bush cowpea, T_7: sole crop of green gram, T_8: sole crop of fodder cowpea, T_9: sole crop of finger millet and T_{10}: fallow. Red gram (var. PRG 176) was raised as the main crop and bush cowpea (var. PGCP-6), green gram (CO-6), fodder cowpea (var. Aiswarya) and finger millet (var. VR 847) were raised as intercrops. Red gram was raised as per the recommendation of Regional Agricultural Research Station, Palem, Telengana and the intercrops as per KAU Package of Practice Recommendations Crops (KAU, 2016). The salient results of the experiment are summarized below.

The results of the study revealed that the intercropping treatments had significant influence on the growth and growth attributes of red gram. The effect of intercropping on plant height had significant influence only on 30 and 60 days after sowing (DAS). The treatment T_5 (sole crop of red gram) registered tallest plants of 37.24 cm and 104.55 cm at 30 and 60 DAS, respectively which was on par with T_2 (red gram + green gram) intercropping system. The number of branches per plant were substantially more (9.55 and 11.77) in sole crop of red gram at 60 and 90 DAS while reduced value was observed in treatment T_1 (red gram + bush cowpea) intercropping system. The sole crop of red gram recorded highest leaf area of 143.79 cm^2, 1454.17 cm^2 and 5164.31 cm^2 at 30, 60 and 120 DAS, respectively. Leaf area index (LAI) of red gram was significantly higher in sole crop of red gram (T_5) at 30, 60 and 120 DAS. However, the intercropping system T_3 (red gram + fodder cowpea) with LAI 0.06 at 30

DAS and treatment T_1 (red gram + bush cowpea) with LAI 0.75 and 3.10 at 60 and 120 DAS, respectively recorded the lowest values.

Yield attributes of red gram revealed significant variation in response to intercropping. Number of pods per plant (110.43), grain yield (1430 kg ha^{-1}) and haulm yield (6095 kg ha^{-1}) were noted to be significantly higher for sole crop of red gram (T_5). When intercropping treatments were compared, it was observed that intercropping red gram + green gram (T_2) resulted in higher number of pods (103.10), grain yield (1238 kg ha^{-1}) and haulm yield (5639 kg ha^{-1}). The lowest value of number of pods (86.66), grain yield (905 kg ha^{-1}) and haulm yield (4419 kg ha^{-1}) was registered in the treatment T_1 (red gram + bush cowpea).

The results of the growth parameters of intercrop bush cowpea revealed that red gram + bush cowpea (T_1) intercropping system produced taller plants with the highest plant height (127.16 cm) at harvest. Sole crop of bush cowpea (T_6) had the highest leaf area per plant 911.92 cm^2 which was superior to its intercropping system. The LAI of bush cowpea was significantly influenced by the intercropping and sole cropping. The T_6 (sole crop of bush cowpea) produced the highest LAI of 3.22 and 2.02 at 60 DAS and at harvest, respectively.

The sole crop of bush cowpea (T_6) recorded the highest number of pods per plant (13.33), grain yield (2322 kg ha^{-1}) and haulm yield (4615 kg ha^{-1}) when compared to its respective intercropping system.

The sole crop of green gram (T_7) recorded the highest plant height (94.80 cm and 97.15 cm) at 60 DAS and at harvest wherein a significant reduction in plant height was recorded in red gram + green gram intercropping system. Number of branches per plant at 60 DAS and at harvest was reduced in intercropping treatment compared to sole crop of green gram (10.22 and 11.21), respectively. The sole crop of green gram (T_7) registered the highest leaf area per plant and LAI at all the growth stages.

Significantly higher number of pods (30.10), grain yield (1271 kg ha^{-1}) and haulm yield (3560 kg ha^{-1}) were recorded in sole crop of green gram compared to its intercropping treatment.

Growth and growth attributes of fodder cowpea varied significantly when intercropped with red gram. Significantly taller plants (46.35 cm) were observed in sole crop of fodder cowpea (T_8) at 30 DAS. The sole crop of fodder cowpea (T_8) had considerably more number of branches at 30 DAS (5.66) compared to its intercropping system. The leaf area per plant and LAI was observed to be superior in sole crop at 30 DAS.

Analysis of yield attributes of fodder cowpea revealed that there was significant increase in the leaf :stem ratio (0.83), dry fodder yield (2919 kg ha^{-1}) and green fodder yield (13179 kg ha^{-1}) in sole cropping (T8) than intercropping treatment.

In finger millet, the growth characters like plant height, number of tillers, leaf area per plant and LAI were significantly influenced by the intercropping treatments. the sole crop of finger millet (T_9) recorded the highest value throughout the growth period.

Number of productive tillers per plant (2.99), grain yield (2201 kg ha^{-1}) and stover yield (4288 kg ha^{-1}) was recorded to be significantly higher in sole crop of finger millet (T_9) when compared to its intercropping system.

The lowest weed count was recorded for the treatment, T_8 (sole crop of fodder cowpea) (42.00 no. m^{-2}) and T_1 (red gram + bush cowpea) (109.33 no. m^{-2}) at 30 and 60 DAS, respectively. Dry matter production of weeds differed significantly at 30 and 60 DAS and T_1 (red gram + bush cowpea) recorded 67.56 per cent and 76.73 per cent reduction in dry matter production than T_{10} (fallow) at 30 and 60 DAS, respectively. Red gram intercropped with bush cowpea (T_1) recorded lower nitrogen removal by weeds (1.36 kg ha^{-1} and 5.24 kg ha^{-1}) at 30 and 60 DAS, respectively. Treatments T_2 (red gram + green gram) and T_1 (red gram + bush cowpea) registered lowest phosphorus removal by weeds (0.66 kg ha^{-1} and 2.05 kg ha^{-1}) at 30 and 60 DAS, respectively while the lowest K removal by weeds at 30 and 60 DAS was recorded in T_1 (red gram + bush cowpea) (0.94 kg ha^{-1} and 1.55 kg ha^{-1}), respectively. In general, intercropping system exhibited more weed smothering efficiency than sole cropping. Higher values were obtained for T_1 (red gram + bush cowpea) (40.86% and 58.93%) at 30 and 60 DAS, respectively.

Analysis of nutrient uptake of main crop red gram at harvest showed highest nitrogen uptake in sole crop of red gram (T_5) whereas, among the intercrops, sole crop of bush cowpea (T_6) resulted in significantly superior nitrogen uptake. Highest phosphorus uptake (16.76 kg ha^{-1}) was observed for sole crop of red gram (T_5). Among the different intercrops raised, bush cowpea had significantly higher phosphorus uptake (11.37 kg ha^{-1}). Uptake of potassium by red gram showed similar results as nitrogen and phosphorus.

The treatments did not show any significant effect on the soil reaction, electrical conductivity, organic carbon and available nitrogen of the soil after the experiment. Sole crop of fodder cowpea (T_8) showed higher value (76.03 kg ha^{-1}) of available phosphorus and was comparable with T_1 (red gram + bush cowpea), T_3 (red gram + fodder cowpea), T_6 (sole crop of bush cowpea) and T_7 (sole crop of green gram). The treatment T_3 (red gram + fodder cowpea) registered higher available potassium (150 kg ha^{-1}) in the soil after the experiment. The dehydrogenase enzyme activity in soil was significantly influenced by the intercropping systems. The highest value was observed in T_1 (red gram + bush cowpea) which was on par with T_6 (sole crop of bush cowpea).

Different competitive indices computed in the study were land equivalent ratio (LER), relative crowding coefficient (RCC), Aggressivity, red gram equivalent yield (REY) and monetary advantage index (MAI). In all the intercropping systems, LER excelled one indicating greater biological efficiency of intercropping over sole cropping. LER was observed to be highest (1.68) for red gram + bush cowpea (T_1) intercropping system. RCC value of red gram was found to be higher than other intercrops which indicated red gram as a dominant crop and its highest value was recorded in T_2 (red gram + green gram) (12.91). Aggressivity value of red gram in all intercropping systems were positive and the highest value was recorded in treatment, T_2 (red gram + green gram) (0.60). The MAI was the highest (₹ 83470) in T_1 (red gram + bush cowpea) indicating monetary advantage of the system. The highest red gram equivalent yield (1719 kg ha^{-1}) was recorded in T_1 (red gram + bush cowpea).

Economic analysis indicated that red gram + bush cowpea intercropping system recorded the highest net income (₹ 138611) while the lowest value was recorded in sole crop of fodder cowpea (-₹ 87667). All the intercropping systems recorded BCR greater than one. Intercropping system involving red gram + green gram registered highest BCR of 3.13.

The results of the study indicated that red gram + bush cowpea and red gram + green gram are more suitable intercropping systems in summer fallows. Higher productivity, red gram equivalent yield, monetary advantage index and economics of cultivation was recorded when bush cowpea and green gram were intercropped with red gram.

FUTURE LINE OF WORK

- Suitability of intercropping with different millets in red gram may be studied.
- The effect of intercropping on the quality and nutritional parameters may be tested.
- The effect of intercropping on light interception by crop canopies may be investigated
- The feasibility of red gram based intercropping in different crop geometries may be explored
- The root characters of component crops in an intercropping system may be analysed

Plate 1. Land preparation

Plate 2. General view of the experimental plot

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PERFORMANCE OF RED GRAM (*Cajanus cajan* (L.) Millsp.) INTERCROPPING SYSTEMS IN LOWLANDS

by

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ABSTRACT

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ABSTRACT

The study entitled "Performance of red gram (*Cajanus cajan* (L.) Millsp.) intercropping systems in lowlands" was undertaken at College of Agriculture, Vellayani during 2020-2022. The main objective was to evaluate different red gram based intercropping systems in the summer fallow of double cropped lowland rice field in terms of weed dynamics, biological efficiency and economics.

The field experiment was carried out at Integrated Farming System Research Station (IFSRS), Karamana from January to June 2022 in Randomized Block Design with 10 treatments and three replications. The treatments comprised of T_1: red gram + bush cowpea (1:2), T_2: red gram + green gram (1:2), T_3: red gram + fodder cowpea (1:2), T_4: red gram + finger millet (1:2), T_5: sole crop of red gram, T_6: sole crop of bush cowpea, T_7: sole crop of green gram, T_8: sole crop of fodder cowpea, T_9: sole crop of finger millet and T_{10}: fallow. Red gram (var. PRG 176) was raised as the main crop and bush cowpea (var. PGCP-6), green gram (CO-6), fodder cowpea (var. Aiswarya) and finger millet (var. VR 847) were raised as intercrops. Red gram was raised as per the recommendation of Regional Agricultural Research Station, Palem, Telengana and the intercrops as per KAU Package of Practice Recommendations (KAU, 2016).

The results indicated that intercropping in red gram had significant influence on the growth and yield of both main crop and intercrops. Growth attributes of red gram, *viz.,* plant height, number of branches per plant, leaf area per plant and leaf area index (LAI) showed significant variation with the intercropping systems. The treatment T_5 resulted in taller plants at 30 and 60 Days after sowing (DAS), highest number of branches at 60 and 90 DAS and highest leaf area and LAI at 30, 60 and 120 DAS. Number of pods per plant (110.43), grain yield (1430 kg ha^{-1}), haulm yield (5639 kg ha^{-1}), of red gram were also found to be highest in T_5.

Growth and yield attributes of intercrops were significantly reduced under intercropping systems. Sole crops of bush cowpea (T_6) and green gram (T_7) produced highest leaf area, LAI, number of pods, grain yield and haulm yield compared to its intercropping system. The highest plant height, number of branches, leaf area, LAI, L:S ratio, green fodder yield and dry fodder yield were recorded in the treatment T_8 (sole

crop of fodder cowpea). Similarly, finger millet when raised as sole crop (T_9) registered highest number of tillers m^{-2}, productive tillers m^{-2}, grain yield and stover yield.

Intercropping with red gram profoundly reduced the weed count, dry matter production (DMP), and NPK removal by weeds. The treatment T_8 (sole crop of fodder cowpea) and T_1 (red gram + bush cowpea) recorded the lowest weed count at 30 and 60 DAS, respectively. Higher DMP was recorded in T_{10} (fallow) and lowest in T_1 (red gram + bush cowpea). The lowest N removal by weeds was observed in T_1 at 30 DAS (1.36 kg ha^{-1}) and 60 DAS (5.24 kg ha^{-1}), respectively. The treatments T_2 at 30 DAS (0.66 kg ha^{-1}) and T_1 at 60 DAS (2.05 kg ha^{-1}) resulted in the lowest P removal by weeds. The treatment T_1 recorded the lowest K removal at 30 DAS (0.94 kg ha^{-1}) and 60 DAS (1.55 kg ha^{-1}), respectively. In general, intercropping system exhibited more weed smothering efficiency than sole cropping. Higher values were obtained for T_1 at 30 DAS (40.86 %) and 60 DAS (58.93 %), respectively.

All crops were analyzed for N, P and K uptake and highest value was recorded in sole crop of both main crop and intercrops.

Analysis of soil sample after harvest recorded that all parameters except available P and K were not significantly influenced by different treatments. The highest P and K content were observed in T_8 (76.03 kg ha^{-1}) and T_3 (150 kg ha^{-1}) respectively. The dehydrogenase enzyme activity was recorded highest in treatment T_1 (red gram + bush cowpea) with the value of 356.37 μg TPF g^{-1} soil d^{-1}.

Analysis of competitive indices of intercropping system revealed that the land equivalent ratio (LER), monetary advantage index (MAI) and red gram equivalent yield (REY) were the highest in T_1. The highest relative crowding coefficient (Kri) and positive aggressivity value of red gram indicated the dominance and competitive nature of red gram over intercrops. Treatment T_1 (red gram + bush cowpea) produced highest net income (₹ 138611 ha^{-1}) and the highest B:C ratio (3.13) was recorded in T_2 (red gram + green gram) intercropping system.

From the present study it can be concluded that the systems involving bush cowpea and green gram in additive series (1:2) were more suitable for intercropping with red gram in the summer fallow of double cropped lowland rice field. It was identified as the best intercropping system considering the weed smothering efficiency, red gram equivalent yield, land equivalent ratio, monetary advantage index, net income and benefit: cost ratio.

സംഗ്രഹം

തുവര താഴ്ന്ന പ്രദേശങ്ങൾ ഇടവിളയായി കൃഷിചെയ്യുന്നതിന്റെ കാര്യക്ഷമതയെപ്പറ്റി പഠനം, 2020-2022 കാലയളവിൽ നടത്തുക ഉണ്ടായി. രണ്ടുതവണ വിളയിടുന്ന താഴന്ന പ്രദേശങ്ങളിലെ നെൽപ്പാടങ്ങളിൽ , വിവിധ തുവര അധിഷ്ഠിത ഇടവിള സമ്പ്രദായങ്ങൾ കളകൾ വളരുന്നതിന്റെയും, വിളവിന്റെയും , സാമ്പത്തിക ലാഭത്തിന്റെയും അടിസ്ഥാനത്തിൽ വിലയിരുത്തുക എന്നതായിരുന്നു പഠനത്തിന്റെ പ്രധാന ലക്ഷ്യം.

തിരുവനന്തപുരം, കരമനയിൽ സ്ഥിതി ചെയ്യുന്ന സംയോജിത കൃഷിസമ്പ്രദായ ഗവേഷണ കേന്ദ്രത്തിൽ, 2022 ജനുവരി മുതൽ ജൂൺ വരെയായിരുന്നു പഠനം. പഠനത്തിന് ഉപയോഗിച്ചിരുന്ന ട്രീറ്റമെന്റുകൾ: ടി1-തുവര+ കുറ്റി പയർ (1 :2), ടി2 - തുവര+ ചെറു പയർ (1 :2), ടി3 - തുവര+ തീറ്റ പയർ , ടി4 തുവര + കൂവരക് , ടി5 - തുവര തനി വിള, ടി6 - കുറ്റി പയർ- തനി വിള , ടി7 - ചെറു പയർ തനി വിള, ടി8 - തീറ്റ പയർ തനിവിള , ടി9 കൂവരക് തനി വിള, ടി10 തരിശു ഭൂമി. കൃഷിക്ക് ഉപയോഗിച്ച ഇനങ്ങൾ : തുവര - പി ആർ ജി 176 , കുറ്റി പയർ - പി ജി സി പി -6 , ചെറു പയർ- സി ഓ -6 , തീറ്റ പയർ- ഐശ്വര്യ, കൂവരക് - വി ആർ 847 .

പ്രധാന വിളകളുടെയും ഇടവിളകളുടെയും വളർച്ചയിലും വിളവിലും തുവര ഇടവിള കൃഷിക്ക് സ്വാധിനമുള്ളതായി ഫലങ്ങൾ സൂചിപ്പിക്കുന്നു. തുവരയുടെ വളർച്ച ഗുണങ്ങൾ, അതായത്, ഉയരം, ഓരോ ചെടിയുടെയും ശാഖകളുടെ എണ്ണം, ചെടിയുടെയും ഇലയുടെയും വിസ്തീർണ്ണം, ഇലകളുടെ വിസ്തീർണ്ണ സൂചിക എന്നിവയ്ക്കും കാര്യമായ വ്യത്യാസങ്ങൾ ഇടവിള കൃഷിയിൽ കാണപ്പെട്ടു. വിതച്ചതിനു 30 -60 ദിവസത്തിനു ശേഷം ഉയരം കൂടിയ

ചെടികളും, 60 - 90 ദിവസത്തിന് ശേഷം അധികം ശിഖരങ്ങളുടെ എണ്ണവും, 30 , 60 , 120 ദിവസത്തിനു ശേഷം ഇലകളുടെ വിസ്തീർണ്ണ സൂചിക കൂടുതലുമായി ടി5 ൽ കണ്ടു. ഓരോ ചെടിയുടെയും കായ്കളുടെ എണ്ണം (110.43), ധാന്യ വിളവ് (1430 കി.ഗ്രാം ഹെക്ടറൊന്നിനു) എന്നിവയും ഏറ്റവും ഉയർന്നതായി കണ്ടെത്തിയത് ടി5 ൽ ആണ്. ഇടവിള സമ്പ്രദായത്തിൽ, മറ്റു ഇടവിളകളുടെ വളർച്ചയും വിളവ് ഗുണങ്ങളും ഗണ്യമായി കുറഞ്ഞു. തുവര ഉയോഗിച്ചുള്ള ഇടവിള കൃഷി കളകളുടെ വളർച്ചയും, എണ്ണവും, കളകൾ വളങ്ങൾ വലിച്ചെടുക്കുന്നതും കുറയ്ക്കുന്നതായി കണ്ടു. ടി8 , ടി1 ട്രീട്മെന്റുകളിലാണ് കളകളുടെ എണ്ണം ഏറ്റവും കുറഞ്ഞ രേഖപ്പെടുത്തിയത് .വളം വലിച്ചെടുക്കുന്നതിനുള്ള മൂല്യം ഏറ്റവും കൂടുതൽ രേഖപ്പെടുത്തിയത് പ്രധാന വിളയുടെയും ഇടവിളകളുടെയും തനി വിളകൾക്കാണ്. ഇടവിള സമ്പ്രദായത്തിന്റെ മത്സര സൂചികകളുടെ വിശകലനത്തിൽ, ഭൂമി തുല്യ അനുപാതം,പണ നേട്ട സൂചിക, തുവരയുടെ തുല്യ അളവ് എന്നിവ ടി1ൽ മികച്ചതായി കാണപ്പെട്ടു. ടി1 ൽ തന്നെ ഏറ്റവും ഉയർന്ന അറ്റാദായവും ഉണ്ടായി. ആനുകൂലിക ചെലവ് അനുപാതം ഏറ്റവും കൂടുതൽ ടി-3 ൽ ആയിരുന്നു.

കുറ്റിപയർ, ചെറു പയർ എന്നിവ ഉൾപ്പെടുന്ന കൃഷി സമ്പ്രദായം വേനൽ തരിശു പാടങ്ങളിൽ, തുവരയുമായി ഇടിവിള കൃഷിചെയ്യുന്നത് അനുയോജ്യമായി കാണപ്പെട്ടു. ഇത് മറ്റു സമ്പ്രദായങ്ങളെ അപേക്ഷിച്ചു ആദായകരവും മികച്ചതുമായി കണ്ടെത്തി.

APPENDIX

APPENDIX I

STANDARD WEEK WISE METEOROLOGICAL DATA DURING THE CROPPING PERIOD (January – June, 2022)

Standard week	Mean temperature		Total rainfall (mm)	Mean RH (%)	
	Max.	Min.		Max.	Min.
5 (27 Jan. – 2 Feb.)	31.0	23.0	0.0	87.7	64.2
6 (3 Feb. – 9 Feb.)	30.7	23.6	0.0	87.6	67.0
7 (10 Feb. - 16 Feb.)	30.6	23.9	36.3	88.3	67.2
8 (17 Feb. – 23 Feb.)	30.9	24.4	17.7	89.3	64.6
9 (24 Feb.-2 Mar.)	31.6	23.7	0.0	88.8	59.9
10 (3 Mar.- 9 Mar.)	31.2	23.6	0.0	88.8	64.3
11 (10 Mar. – 16 Mar.)	32.0	24.6	0.0	87.0	65.2
12 (17 Mar. -23 Mar.)	32.4	25.9	0.0	80.5	64.5
13 (24 Mar.-30 Mar.)	31.8	25.6	0.7	85.6	67.0
14 (31 Mar.-6 Apr.)	32.2	24.9	42.9	88.5	70.3
15 (7 Apr.- 13 Apr.)	31.7	23.7	36.3	89.3	74.5
16 (14 Apr. – 20 Apr.)	31.3	24.5	85.0	89.1	71.2
17 (21 Apr.- 27 Apr.)	32.4	25.8	18.8	89.9	69.6
18 (28 Apr.- 4 May)	32.8	26.6	19.8	84.5	69.4
19 (5 May- 11 May)	32.3	26.1	16.5	85.3	69.1
20 (12 May- 18 May)	30.4	23.9	165.1	91.8	75.2
21 (19 May – 25 May)	29.3	24.5	96.7	91.9	78..8
22 (26 May- 1 Jun.)	30.1	24.8	34.5	91.1	77.8
23 (2 Jun.- 8 Jun.)	30.6	25.3	29.4	90.2	76.3

APPENDIX II

AVERAGE INPUT COST AND MARKET PRICE OF PRODUCE

Items	Cost (₹)
Inputs	
Labour wages	1000 day^{-1}
FYM	1800 t^{-1}
Urea	8 kg^{-1}
Muriate of potash	34 kg^{-1}
Rajphos	15 kg^{-1}
Red gram seed	180 kg^{-1}
Bush cowpea seed	180 kg^{-1}
Fodder cowpea seed	180 kg^{-1}
Green gram seed	180 kg^{-1}
Finger millet seed	90 kg^{-1}
Produce	
Red gram	120 kg^{-1}
Bush cowpea	70 kg^{-1}
Fodder cowpea	7 kg^{-1}
Green gram	80 kg^{-1}
Finger millet	40 kg^{-1}

APPENDIX III

PLANT POPULATION OF RED GRAM AND INTERCROPS IN TREATMENTS- Plants per Ha

Treatments	Red gram	Bush cowpea	Green gram	Fodder cowpea	Finger millet
T_1: red gram + bush cowpea	83,333	1,48,148	-	-	-
T_2: red gram + green gram	83,333	-	1,77,777	-	-
T_3: red gram + fodder cowpea	83,333	-	-	1,48,148	-
T_4: red gram + finger millet	83,333	-	-	-	1,77,777
T_5: sole crop of red gram	83,333	-	-	-	-
T_6: sole crop of bush cowpea	-	2,22,222	-	-	-
T_7: sole crop of green gram	-	-	2,66,666	-	-
T_8: sole crop of fodder cowpea	-	-	-	2,22,222	-
T_9: sole crop of finger millet	-	-	-	-	2,66,666