PRODUCTIVITY AND BIOLOGICAL EFFICIENCY OF INTERCROPPING FINGER MILLET (*Eleusine coracana* (L.) Gaertn.) WITH PULSES

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by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Productivity and biological efficiency of intercropping finger millet (*Eleusine coracana* (L.) Gaertn.) with pulses"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled **"Productivity and biological efficiency of intercropping finger millet (*Eleusine coracana* (L.) Gaertn.) with pulses"** is a record of research work done independently by Mr. Dhimmagudi Ramamohan Reddy under my guidance and supervision and it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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We, the undersigned members of the advisory committee of Mr. Dhimmagudi Ramamohan Reddy, a candidate for the degree of **Master of Science in Agriculture** with major in Agronomy, agree that the thesis entitled **"Productivity and biological efficiency of intercropping finger millet (*Eleusine coracana* (L.) Gaertn.) with pulses"** may be submitted by Mr. Dhimmagudi Ramamohan Reddy, in partial fulfilment of the requirement for the degree.

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Dhimmagudi Ramamohan Reddy

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviation / Symbol	**Expansion**
%	per cent
@	at the rate of
₹	Indian rupee
°C	degree Celsius
AMF	arbuscular mycorrhizal fingu
BCR	benefit cost ratio
CD	critical difference
Cm	centimetre
DAS	days after sowing
DMP	dry matter production
dS m^{-1}	deci siemens per metre
EC	electrical conductivity
et al.	co-workers
Fig.	figure
FYM	farmyard manure
g	gram
ha^{-1}	per hectare
i.e.	that is
K/ K_2O	Potassium
kg	kilogram
kg ha^{-1}	kilogram per hectare
LAI	leaf area index

LER	land equivalent ratio
ATER	area time equivalent ratio
RCC	relative crowding coefficient
A	aggressivity
PYD	percentage yield difference
FMEY	finger millet equivalent yield
m^{-2}	per square metre
MOP	Muriate of potash
N	Nitrogen
nos.	numbers
NS	not significant
P/ P_2O_5	Phosphorus
RH	relative humidity
SE m	standard error of mean
t ha^{-1}	tonnes per hectare
viz.	namely
WSE	weed smothering efficiency

APPENDIX

Introduction

1. INTRODUCTION

Millets are regarded as one of the ancient foods known to mankind. But industrialization and consequent urbanization caused side-lining of millets in favour of the fine cereals, *viz*., rice and wheat. Millets have been designated as super cereals by virtue of their better adaptation to wide range of soils and climate, shorter duration, ability to withstand salinity, water logging and drought and also due to their exceptional nutritional profile. The hardy nature of millets has gained them the recognition as the staple food of people living in the drier parts of the world. Millets are also known as 'famine reserves' due to their prolonged shelf life of more than two years without deterioration (Sahu and Sharma, 2013). In the recent years, the yield plateau of the major cereals together with the climate change concerns, the potential of millets have been identified as pivotal for addressing the agrarian and nutritional challenges. Further, millets are nutritionally comparable or even superior to rice and wheat with respect to protein, energy, vitamins and minerals (Sehgal and Kawatra, 2003). Thus, millets which were once christened as poor man's food is acquiring acceptance in the food basket of the rich as the keystone towards a healthy and sustainable food revolution.

Finger millet (*Eleusine coracana* (L.) Gaertn.), popularly known as *Ragi* (from the Sanskrit word *Rajika*) is cultivated in the tropical and subtropical regions. The crop has been reported to thrive on hardly 28 per cent of the water requirement of rice (Triveni *et al*., 2017). Devi *et al*. (2014) have reported that on an average, finger millet contains carbohydrates (76.3%), protein (9.2%), fat (1.29%), minerals (2.24%), ash (3.9%) and calcium (0.33%). Finger millet contains 30 times more calcium than rice (MINI, 2009). In India, finger millet occupies an area of 1.19 million hectares accounting for a production of 1.98 million tonnes and an average productivity of 1661 kg ha^{-1} (Sakamma *et al*., 2018). As for Kerala, finger millet was reported in an area of 33 ha covering the districts of Palakkad and Idukki with a production of 42 t (FIB, 2019). The Kerala State Department of Agriculture has earmarked more area for growing millets so as to promote these crops in the eat-smart strategy envisaged by the State.

The ever shrinking per capita land availability warrants both temporal and spatial intensification of agricultural systems (Kiwia *et al*., 2019). Crop diversification through intercropping has been acknowledged as a principal pillar for ensuring sustainable development (Jensen *et al*., 2015). Intercropping ensures enhanced stability than sole cropping with respect to soil fertility maintenance, yield improvement and economic returns (Machado, 2009). Intercropping is being practiced world over as the means of maximizing and sustaining land productivity. Specific planting geometry and selection of compatible crops is important for successful intercropping (Kaushik and Gautam, 1987). Crops which vary in their growth habits are grown together so that they complement one another resulting in higher resource use efficiency. Legumes assume paramount importance in intercropping systems involving cereals / millets because of their ability to fix and transfer nitrogen.

Millets + legumes intercropping systems also help in conserving moisture, improving the physical properties of the soil and in building up soil fertility (Dass and Sudhishri, 2010). Further, sole cropping of millets like finger millet is usually not appreciably remunerative and it fails to satisfy the diverse consumer demand. The initial slow growth phase of finger millet can be utilized for raising short duration pulses. Moreover, intercropping with fast growing pulses will also help in reducing the weed problems.

Modern nutrient management concept banks on striking a balance between fertilizing the soil and crop. Interaction of Arbuscular mycorrhizal fungi (AMF) and crops is a well-known phenomenon. Combining intercropping with biofertilization has been observed to enhance crop productivity and soil fertility (Wezel *et al*., 2014). Linking cereal – legume intercropping through common mycorrhizal network improves the productivity of crops (Hauggaard-Nielsen and Jensen, 2005). Specific interactions between root and microbes have also been reported to affect nutrient mobilization and result in efficient acquisition of nutrients (Li *et al*., 2014). However, very limited studies have been conducted on the effect of AMF on finger millet and finger millet based intercropping systems involving pulses.

Keeping the above in view the present study entitled "Productivity and biological efficiency of intercropping finger millet (*Eleusine coracana* (L.) Gaertn.) with pulses" was undertaken with the following objectives :

- To assess the productivity of intercropping finger millet with pulses
- To study the effect of AMF on the performance of finger millet under intercropping
- To work out the biological efficiency and economics of the intercropping systems.

Review of Literature

2. REVIEW OF LITERATURE

Climate variability is an unequivocal phenomenon that poses severe threat to food security. Millets and pulses assume paramount importance as climate resilient crops since soft cereals like rice and wheat are vulnerable to changes in climate. Further, the health and nutrition benefits of these crops are added advantages. Among millets, finger millet (*Eleusine coracana* (L.) Gaertn.) forms staple food in the drier parts of India, Africa and some of the other Asian countries. In Kerala, the low per capita land availability clubbed together with the risk involved in raising sole crops, has made farmers to venture into intercropping. Crop diversification through intercropping not only increases the cropping intensity, but is also a form of biological insurance against risks and abnormal rainfall in rainfed areas. Intercropping helps in optimising resource utilization, both in spatial and temporal dimensions. However, the compatibility and complimentarity of crops need to be assessed for successful intercropping. In the present study attempt was made to assess the productivity and biological efficiency of intercropping finger millet with pulses. The research work done in this area is reviewed in this chapter.

2.1 IMPORTANCE OF FINGER MILLET

Finger millet (*Eleusine coracana* (L.) Gaertn.) production plays a key role in Indian economy due to growing demand for its grains by virtue of its inherent adaptation to wide variety of environmental conditions and its nutraceutical properties.

2.1.1 Finger Millet as a Climate Resilient Crop

Finger millet has been recognized as an important tropical coarse cereal with adaptations to thrive in water deficient as well as nutrient deficient soils of the arid and semi-arid regions of India (Mandal and Swamy, 2005).

Among the coarse cereals or millets, finger millet ranks fourth following sorghum, pearl millet and foxtail millet (Upadhyaya *et al*., 2007). Finger millet has been recognized as a famine crops since the grains possess long storage life of more than 10 years without deterioration with resistance to storage pests. Thus the crop is capable of ensuring year round supply of food supply (Mgonja *et al*., 2007).

Dida *et al*. (2008) observed that finger millet which is widely cultivated in South Asia and Africa under diverse agro-climatic conditions, accounted for approximately 10 per cent of the total millet production in the world.

Finger millet is a dynamic crop that can thrive under adverse environmental conditions. Further the crop can be cultivated solely as organic since the dependence on chemical fertilizers is negligible (Gull *et al*., 2014). Finger millet genotypes with high water use efficiency and elevated carbon dioxide fixation rates with lower leaf area have been recorded to perform better in semi-arid conditions (Gupta *et al*., 2014).

Capacity of finger millet to tolerate drought was attributed to its efficient antioxidant potential and enhanced signal perception (Chandra *et al*., 2016).

It is estimated that finger millet is grown annually over an area of 1.27 million hectares with a total production of 1.93 million tonnes with an average yield of 1.60 tonnes per hectare (DES, 2017).

Prakasha *et al*. (2018) appraised finger millet as a crop with adaptation to different agro-climatic conditions, freedom from major pests and diseases, drought tolerance, weed suppression capacity and ability to grow on marginal soils.

Stomatal conductance, dry matter accumulation, shoot length and stomata per unit leaf area were identified as the key characters which decide the adaptation of finger millet to diverse environments (Panda *et al*., 2020).

2.1.2 Finger Millet as a Nutri-cereal

Finger millet grains are rich sources of protein, vitamins, minerals, fiber content and energy. Hence it usually forms an integral component in the diet of pregnant women and lactating mothers (Vadivoo *et al*., 1998).

Fernandez *et al*. (2003) highlighted the superiority of finger millet over rice and wheat due to the presence of essential amino acids such as methionine and tryptophan.

Belton and Taylor (2004) reported that supplementing the nutritional profile of finger millet proteins from legumes such as green gram, soybeans and chickpeas improved the protein quality.

Diets with prominence for finger millet are capable of providing energy throughout the day due to its slow digestibility. The plant is also recognized as diaphoretic, diuretic and vermifuge (Dida and Devos, 2006).The gluten free nature of finger millet makes it beneficial for patients ailing from celiac diseases (Pagano, 2006). Further, the risk of diabetes and gastrointestinal tract inflictions could be successfully curtailed with regular consumption of finger millet.

Chethan and Malleshi (2007) observed that while whole meal of finger millet contained upto 2.3 ± 0.3 gallic acid equivalents (gae), the seed coat faired with 6.4 ± 1.5 gae, signifying high antioxidant levels. The high polyphenol content in the seed coat of finger millet confers it with anti-cancer, anti-diabetic and anti-oxidant activities. Finger millet also contains manganese, phosphorus and iron, copper, chromium, magnesium, molybdenum, zinc and selenium (Shashi *et al*., 2007; Tripathi and Platel, 2010).

Some genotypes of finger millet have been reported to contain as high as 450 mg calcium per 100g of grains (Gupta *et al*., 2011; Kumar *et al*., 2014). This makes finger millet beneficial for preventing osteoporosis.

High fibre content of finger millet upholds slow digestion and stability in blood sugar levels (Devi *et al*., 2014).

Finger millet contains 10 times more calcium than brown rice, wheat and maize and three times more than milk. Phytochemicals present in finger millet act as antioxidants maintaining physiological balance and defending oxidative damage (Prajapati *et al*., 2019).

The comparison made between the nutritional profile of rice and finger millet revealed the superiority of the latter in terms of total, soluble and insoluble dietary fibre, total flavonoid and phenolic contents (Lansankara *et al*., 2020).

2.2 EFFECT OF ARBUSCULAR MYCORRHIZAL FUNGI ON CROPS

Arbuscular mycorrhizal fungi (AMF) form a symbiotic relationship with terrestrial plants by extending hyphae into the soil, which helps to enhance nutrient and water uptake through better soil voyaging.

Pulses are unique in that they are able to establish symbiotic relationship with nitrogen fixing rhizobia and AMF. Thus including pulses in cropping systems could prove beneficial to the system as a whole (Shibata and Yano, 2003).

As a biofertilizer, AMF may play a essential role in the redistribution and use of available water by forming common mycorrhizal network and a bridge between the deep-rooted and the shallow-rooted plants (Egerton-Warburton *et al*., 2007).

Arbuscular mycorrhizal fungi help to improve sustainability of crop production, particularly under stress conditions (Dimkpa *et al*., 2009; Gianinazzi *et al*., 2010; Smith and Smith, 2011).

In the presence of AMF, when deep rooted crops like legumes are intercropped with shallow rooted crops like cereals and millets, the deep rooted crops serve as hydraulic lifts and mediate bio-irrigation prospects (Sekiya *et al*., 2011).

Arbuscular mycorrhizal fungi has been reported to form symbiotic networks and mutualistic associations with the roots of the host plants and enhance plant growth, nutrient uptake and resistance to stress (Bender *et al*., 2016).

In the presence of a common mycorrhizal network (CMN), with or without plant growth promoting rhizobacteria (PGPR), it was observed that biomass production of finger millet in finger millet + pigeon pea intercropping system was not affected by moisture stress. But in the absence of biofertilization, the biomass production was nearly less than 50 per cent compared to stress free condition. AMF was observed to increase the uptake of nitrogen and phosphorus by both the component crops (Saharan *et al*., 2018).

At present a complete insight about the effects of inclusion of AMF in cereal – legume intercropping systems is lacking. Thus a thorough comprehension about the interaction between AMF and plant species and plant species among themselves in the presence of AMF is highly imperative.

2.3 INTERCROPPING FINGER MILLET WITH PULSES

Indian farmers are mostly small and marginal with low per capita availability of land and other resources. Intercropping has been identified as one of the best options for increasing productivity per unit area. World over, intercropping is recognized as a viable option to combat the vagaries of climate and as a means of biological insurance against crop failure. It facilitates efficient utilization of land, light, water, nutrients and labour, meeting the meet domestic needs of the farmer on one hand and sustaining soil fertility on the other.

Intercropping is a promising technique for enhancing crop production over space and time, especially in subsistence farming. The major objectives of intercropping are to produce an additional crop, to optimize the utilisation of natural resources, to stabilize crop yields and to realise higher economic returns. Finger millet is an important coarse cereal of tropics, grown mostly under rainfed conditions. Considering the risks faced by the crop, intercropping other crops like pulses with finger millet is considered as rule for minimizing the risk and enhancing the economic benefits (Reddy and Willey, 1981).

Intercropping of finger millet with pulses and oilseeds offered greater scope for increasing resource utilization efficiency. However, the system productivity depended upon the judicious selection of intercrops (Natarajan, 1992; Aravazhi *et al*., 1997; Sadashiv, 2004).

Growth, growth attributes, yield attributes and yield of finger millet were remarkably higher in sole crop compared to intercropping (Ramamoorthy *et al*., 2004; Nigade *et al*., 2012).

2.3.1 Growth and Growth Attributes of Finger Millet and Pulses

Maximum crop growth rate was recorded in finger millet + groundnut followed by finger millet + pigeon pea during 80-100 days. The differential growth behaviour of legumes was mainly responsible for wide variations in different growth attributes (Siddeswaran *et al*., 1989).

Sole crop of groundnut registered the maximum dry matter and leaf area index at early stages of crop growth. Sole crop of groundnut, finger millet + pigeon pea and finger millet + groundnut were at par with respect to dry matter production at 100 to 120 DAS. Intercropping of finger millet with legumes showed higher leaf area index (Maitra *et al*., 2001).

Ramamoorthy *et al*. (2004) recorded significantly greater plant height in sole crop of finger millet as compared to finger millet + field bean (indeterminate type) intercropping system.

Finger millet intercropped with peas showed significantly taller plants (68.67 cm) of finger millet over sole finger millet (64.67 cm). But it was on par with finger millet intercropped with cluster bean, soybean, French bean and horse gram (Girish, 2004).

Kiroriwal and Yadav (2013) observed higher dry matter accumulation in finger millet + black gram intercropping system than sole crop of finger millet and attributed it to the weed suppressing ability of intercropping than monocropping.

In an intercropping experiment conducted by Pradhan *et al*. (2014) with sesame, soybean, black gram, horse gram, pigeon pea and niger, they observed that finger millet plants were taller in sole crop and shortest under finger millet + niger. Further, sole crop of finger millet produced highest number of tillers per hill (2.37) compared to the finger millet + soybean (4:1), sesame (4:1), black gram (4:1), horse gram (4:1), pigeon pea (4:1), and niger (4:1) intercropping.

Murali *et al*. (2014) reported significantly more number of primary branches per plant for pigeon pea when raised as intercrop with finger millet.

Sao*et al*. (2016) observed that days to maturity was positively influenced by plant height, main ear length, numbers of fingers per ear and days to flowering.

Kumar and Ray (2020) reported that all the growth attributes of finger millet were superior under sole cropping. Among the intercropping systems tested, finger millet + black gram in 6:2 ratio recorded taller plants with more number of tillers per hill.

2.3.2 Yield and Yield Attributes of Finger Millet and Pulses

Grain and straw yield of finger millet were observed to decrease significantly reduced when intercropped with legumes compared with the sole crop of finger millet. This reduction was attributed to the decrease in plant density under intercropping compared to the sole crop (Singh and Arya, 1999; Mitra *et al*., 2001).

In a field experiment conducted by Maitra *et al*. (2001) to study the performance of intercropping legumes in finger millet, it was noted that sole crop of finger millet produced more number of ears m^{-2} . However, finger millet + pigeon pea intercropping recorded more fingers per ear. Among the legumes, pigeon pea recorded more number of pods per plant, green gram recorded higher number of seeds per pod and groundnut the highest test weight. Finger millet + groundnut, finger millet + pigeon pea and sole finger millet also gave higher yield.

Mandal and Swamy (2005) observed that paired row planting of groundnut + finger millet (2:2) registered significantly higher total yield than groundnut + finger millet (2:1) and groundnut + soybean (2:2).

Dass and Sudhishri (2010) reported significant effect for intercropping on finger millet with respect to the yield attributes, *viz*., number of fingers per ear and grains per ear. But thousand grain weight remained unaltered. Intercropping black gram with finger millet significantly improved number of fingers per ear over broadcast sown finger millet alone. Pigeon pea as intercrop with finger millet in 3:2 ratio was observed to reduce the number of fingers per ear.

Number of pods per plant and grain yield of pigeon pea were observed to be significantly higher when intercropped with finger millet (Murali *et al*., 2014).

Grain yield of cowpea was observed to be significantly higher under sole cropping than under intercropping with millets (De Oliveira *et al*., 2017) and it was attributed to the greater plant stand since variation could not be observed in the number of pods per plant, number of grains per pod and thousand grain weight.

Kumar and Ray (2020) observed the highest grain and straw yields in sole crop of finger millet. Among the intercropping treatments, yield of finger millet was the maximum (2010 kg ha^{-1}) for finger millet + black gram (6:2) followed by finger millet + black gram (4:2). Grain and straw yield of finger millet were reduced significantly, when intercropped with legumes compared with the sole crop of finger millet. They also reported higher yields for sole crop of legumes. Among the legumes intercropped, while soybean (4:2) recorded the highest yield under intercropping, groundnut (6:2) recorded the lowest.

2.3.3 Competition Indices

2.3.3.1 Land Equivalent Ratio

Jadhav *et al*. (1992) reported higher LER for finger millet + okra (4:2) intercropping system as compared to finger millet + black gram (4:2), finger millet + groundnut (4:2) and finger millet + cowpea (4:2).

Finger millet + pigeon pea (8:2) intercropping had higher LER than finger millet + field bean (8:2) intercropping system and sole crop of finger millet (Shankaralingappa and Hegde, 1992).

Mohapatra and Haldar (1998) reported higher LER for finger millet + soybean (5:2) intercropping system than 3:2 row ratio, finger millet + rice bean at 5:2 and 3:2 row ratios and sole crop of finger millet.

Finger millet + pigeonpea (4:1) intercropping recorded the highest LER (1.48) indicating 48 per cent higher land use efficiency than sole cropping. The higher LER of finger millet + pigeonpea intercropping system revealed superior biological efficiency of the crops intercropped and was possibly due to temporal and spatial complementarity effect leading to yield advantages (Singh and Arya, 1999).

Maitra *et al*. (2001) and Sarangi *et al*. (2002) observed higher LER with intercropping of medium duration finger millet with short duration pigeon pea in 8:2 row ratio as compared to medium duration finger millet + medium duration pigeon pea in the same row ratio and sole crop of finger millet.

Intercropping finger millet with pigeon pea resulted in the highest LER (1.34) than finger millet + black gram, in all the row proportions tested (Dass and Sudhishri, 2010).

Intercropping cowpea in millets resulted in higher LER and was identified as beneficial in improving land use and agricultural diversification, with high yields of millets and cowpea (De Olveira *et al*., 2017).

2.3.3.2 Relative Crowding Coefficient

Relative crowding coefficient is the degree of relative dominance of one species over the other in a mixture.

Maitra *et al*. (2001) found that intercropping finger millet + pigeon pea showed higher yield advantage (49.85) than finger millet + green gram (5.81), finger millet + groundnut (9.16) and finger millet + soybean (6.40).

Relative crowding coefficient was higher for finger millet, when intercropped with castor, indicating the aggressive nature of finger millet in combination with castor (Umesh *et al*., 2012).

Finger millet recorded higher RCC values in finger millet + horse gram intercropping system (Pradhan *et al*., 2018).

2.3.3.3 Aggressivity

Aggressivity is a measure of how much the relative yield increase in one species is greater than that of the other species in an intercropping system.

Maitra *et al*. (2001) observed finger millet to be dominated by legumes as indicated by negative aggressivity (-2.44) values of finger millet and positive values (2.44) for legumes.

In a study conducted to assess the performance of finger millet and groundnut based strip cropping in ratio 6:4, 8:4, 10:4 and 12:4, Jakhar *et al*. (2015) observed that aggressivity (A) values for all the strip cropping ratios were negative, indicating dominance of finger millet over groundnut.

Dass and Sudhishri (2010) reported the dominant nature of black gram and pigeon as indicated by negative aggressivity values in finger millet + black gram and finger millet + pigeon pea intercropping systems.

Pradhan *et al*. (2014) observed positive aggressivity values for intercropping finger millet with sesame, horse gram, black gram, pigeon pea and niger, except soybean. This indicated the dominant behavior of soybean over finger millet.

2.3.3.5 Competition Ratio

Competitive ratio (CR) is used to assess the competition between different species in intercropping systems. It represents the ratio of individual land equivalent ratios of two component crops taking into account the proportion in which the crops were sown.

Jakhar *et al*. (2015) observed higher competition ratio (1.33) for finger millet when intercropped with groundnut in 6:4 proportion. This indicated the better competitiveness of finger millet as compared to groundnut.

Competitive ratio values for finger millet were less than unity in finger millet + groundnut in 2:1 and 3:1 proportions and it was lowest with finger millet + groundnut (3:1) (Bhagat *et al*., 2018).

2.3.3.6 Finger Millet Equivalent Yield

Finger millet equivalent yield (FMEY) was higher for finger millet + okra (4:2) intercropping system as compared to finger millet + black gram (4:2), finger millet + groundnut (4:2) and finger millet + cow pea (4:2) (Jadhav *et al*., 1992). Highest FMEY was obtained under finger millet + pigeon pea intercropping system in 8:2 row ratio as compared to finger millet + field bean in 8:2 row ratio and sole crop of finger millet (Shankaralingappa and Hedge, 1992).

Shivkumar and Yadahalli (1996) at Bangalore, reported that intercropping of pigeon pea with finger millet in 5:2 row ratio gave higher FMEY as compared to that of finger millet + field bean 5:2 intercropping system and sole crop of finger millet.

Shashidhara *et al*. (2000) stated that finger millet + pigeon pea in 4:2 row ratio resulted in higher FMEY 1663 kg ha^{-1}as compared to 3:1 (1486 kg ha^{-1}) and 5:1 (1527 kg ha^{-1}) row ratios and sole crop of finger millet.

Intercropping of finger millet with pigeon pea in 4:1 row proportion recorded higher FMEY as compared to 5:2 row ratio and sole crop of finger millet (Jena *et al*., 2000).

Field experiments conducted at Coimbatore by Ramamoorthy *et al*. (2004) showed that intercropping of finger millet + field bean (determinant type) in 8:2 row ratio resulted in higher FMEY (4516 kg ha^{-1}) than finger millet + field bean (indeterminate type) intercropping system in 8:2 row ratio (3731 kg ha^{-1}) and sole crop of finger millet (2589 kg ha^{-1}).

Dass and Sudhishri (2010) studied the effect of intercropping finger millet with black gram and pigeon pea in 4:2 ratio, and observed that fingermillet + pigeonpea and fingermillet + blackgram resulted in 77.7 per cent and 67.4 per cent higher fingermillet equivalent yield (FMEY) respectively over broadcast sown fingermillet.

Kumar and Ray (2020) reported that the highest finger millet equivalent yield was obtained when the crop was intercropped with black gram in 4:2 row proportions.

2.3.4 Economics

Intercropping cowpea in finger millet at 2:1 row ratio resulted in higher net returns (₹ 2648 ha^{-1}) than the sole crop of finger millet and at 3:1 and 6:1 row ratios (Reddy *et al*., 1983).

Finger millet + groundnut intercropping in 1:1 proportion recorded the maximum net return of ₹ 1948.74 ha^{-1} and was at par with that of 2:1 proportion of the same crop combination (Thorat *et al*., 1986).

Mahadkar and Khanvilkar (1988) recorded maximum net returns from finger millet + black gram intercropping in 1:1 (₹ 1715.96ha^{-1}), 2:1 (₹ 1562.11ha^{-1}) and 3:1 (₹1477.15ha^{-1}) row proportions.

Shankarlingappa and Hegde (1992) reported higher gross returns for finger millet + pigeon pea (8:2) intercropping system than finger millet + field bean intercropping in the same row ratio and sole crop of finger millet.

Jadhav *et al*. (1992) reported that intercropping of finger millet with black gram and okra in 4:2 row proportion gave the maximum net returns of ₹ 3615 and ₹ 3579 $ha^{-1}$with a benefit cost ratio of 2.21 and 1.45 respectively.

Shashidhara *et al*. (2000) reported higher net returns and B:C ratio (4.29) in intercropping finger millet with pigeon pea at 4:2 row ratio compared to 3:1 and 5:1 row ratios.

Maitra *et al*. (2001) reported that intercropping finger millet with pigeon pea and groundnut at 4:1 row proportion produced higher net returns and benefit : cost ratio than finger millet + green gram, finger millet + soybean and sole finger millet.

Ramamoorthy *et al*. (2004) reported higher net returns and benefit: cost ratio with strip cropping of finger millet + pigeon pea than under sole crop of finger millet.

Relay cropping of wheat in finger millet (transplanted) + pigeon pea (4:1) registered higher gross returns (₹ 58799 ha^{-1}), net returns (₹ 23149 ha^{-1}) and benefit: cost ratio (1.65) compared to relay cropping of wheat in finger millet (direct sown) + pigeon pea (4:1), which recorded gross returns of ₹ 56274 ha^{-1}, net returns of ₹ 20274 $ha^{-1}$and a benefit: cost ratio of 1.56 (Prakash *et al*., 2005).

Finger millet + pigeon pea (transplanted) resulted in maximum net returns (₹ 26218 ha^{-1}) and benefit cost ratio (2.49) than finger millet + direct sown pigeon pea (Murali *et al*., 2014).

Jakhar *et al*. (2015) reported maximum net returns and benefit cost ratio from strip cropping of finger millet + groundnut at 6:4 row ratio.

Finger millet based intercropping systems accounted for higher economic returns than sole cropping. Among the intercropping systems, finger millet + pigeon pea/ soybean/ black gram/ bean/ okra recorded higher economic returns than finger millet with field bean/ cowpea/ green gram (Bhagat *et al*., 2019).

Literature search revealed that finger millet was one among the multitude of millets which has been highly appreciated for its climate resilient features and nutraceutical properties. Finger millet was observed to be seldom raised as a sole crop, but frequently intercropped with pulses. Biofertilizers like AMF not only improved the nutrient uptake but also served as a bio-irrigation channel helping crops to tide over drought. The present study has been proposed to assess the productivity and biological efficiency of intercropping finger millet with pulses in the presence of AMF.

Materials and Methods

3. MATERIALS AND METHODS

The study entitled "Productivity and biological efficiency of intercropping finger millet (*Eleusine coracana* (L.) Gaertn.) with pulses" was undertaken during the period from February to May 2020, with the objectives to assess the productivity of intercropping finger millet with pulses, to study the effect of arbuscular mycorrhizal fungi (AMF) on the performance of finger millet under intercropping and to work out the biological efficiency and economics of the intercropping systems. This chapter deals with the materials used and the methods employed for the study.

3.1 SITE OF FIELD EXPERIMENT

The field experiment was conducted at the Integrated Farming System Research Station (IFSRS), Karamana, Thiruvananthapuram, Kerala, India. The experimental field was geographically located at 8°28'25'' N latitude and 76°57'32'' E longitude, at an altitude of 5 m above mean sea level.

3.1.1 Soil

Before the experiment a composite soil sample was collected from a depth of 0-15 cm and characterized for its mechanical composition (Table 1a) and chemical properties (Table 1b). Rating was done as per the Package of Practices Recommendations of the Kerala Agricultural University (KAU, 2016).

The soil of the experimental site was sandy clay loam in texture, strongly acidic in reaction, high in organic carbon, low in available nitrogen and medium in available phosphorus and potassium status.

3.1.2 Climate and Season

A warm humid tropical climate prevailed over the experimental area. The experiment was conducted during the period from the February to May 2020. Weather data pertaining to maximum and minimum temperature, relative humidity and rainfall were collected from the agrometeorological observatory at IFSRS, Karamana. The data was tabulated based on the standard meteorological weeks and are presented in Appendix I and graphically in Fig.1.

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

Sl .No.	Fraction	Content in soil (%)	Method adopted
1	Coarse sand	46.83	Bouyoucos Hydrometer method (Bouyoucos, 1962)
2	Fine sand	9.75	
3	Silt	8.42	
4	Clay	34.12	

Textural class: sandy clay loam

Table 1b. Chemical properties of soil of the experimental site

Sl. No	Parameter	Content	Rating	Method adopted
1	Soil reaction (pH)	5.03	Strongly acidic	1:2.5 soil solution ratio using pH meter (Jackson, 1973)
2	Electrical conductivity ($dS\ m^{-1}$)	0.19	Normal	1:2.5 soil solution ratio using conductivity bridge (Jackson, 1973)
3	Organic carbon (%)	1.58	High	Walkley and Black rapid titration method (Jackson, 1973)
4	Available N ($kg\ ha^{-1}$)	248.74	Low	Alkaline permanganate method (Subbiah and Asija, 1956)
5	Available P ($kg\ ha^{-1}$)	22.42	Medium	Bray colorimetric method (Jackson,1973)
6	Available K ($kg\ ha^{-1}$)	142.81	Medium	Ammonium acetate method (Jackson, 1973)

The mean maximum and minimum temperature ranged from 32.4^{o}C to 33.7^{o}C and 23.4^{o}C to 26.9^{o}C respectively and mean RH I and RH II ranged from 79.4 per cent to 95.9 per cent and 68.7 per cent and 86.0 per cent, respectively. A total rainfall of 211.6 mm was received during the experimental period.

3.1.3 Cropping History of Experimental Site

The site where the experiment was carried out was previously under a bulk crop of rice.

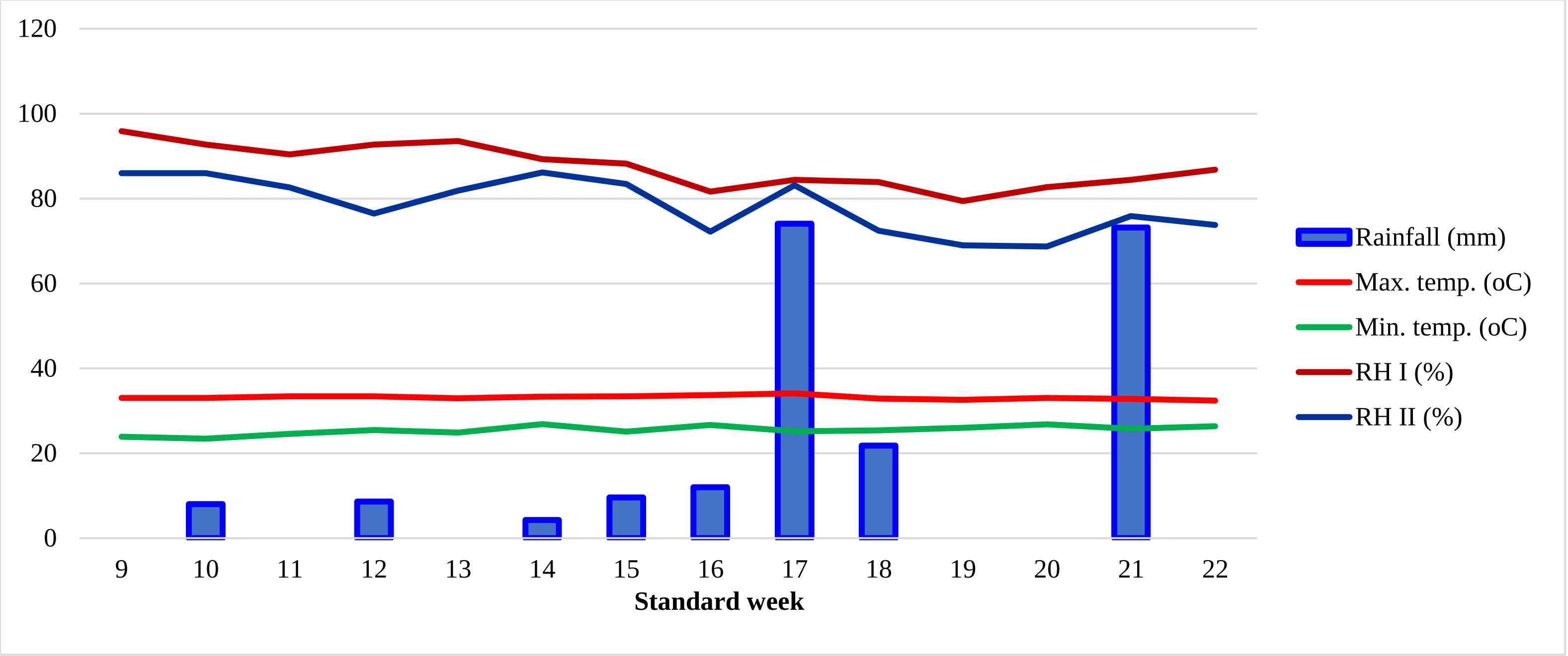

Fig. 1. Standard week wise weather data during the cropping period (February to May 2020)

3.2 MATERIALS

3.2.1 Crop and Variety

Finger millet was intercropped with pulses, *viz*., green gram, black gram and cowpea. The important characters of the crop varieties chosen for the study are given in Table 2.

3.2.2 Biofertilizers

Arbuscular mycorrhizal fungi (AMF) was obtained from the Department of Agricultural Microbiology, College of Agriculture, Vellayani.

3.2.3 Manures and Fertilizers

Farmyard manure (FYM) containing 0.52 per cent N, 0.20 per cent P_2O_5 and 0.43 per cent K_2O was used as organic manure. The recommended dose of N, P and K were supplied as Urea (46 per cent N), Rajphos (20 per cent P_2O_5) and Muriate of potash (60 per cent K_2O) respectively.

3.3 METHODS

3.3.1 Design and Layout

The study comprised intercropping finger millet with three pulses, *viz*., green gram, black gram and cowpea, in the ratio 4:1. Finger millet was raised with and without AMF.

The layout particulars are given below

Design	:	Randomised Block Design
Treatments	:	11
Replication	:	3
Plot size	:	6.0 m x 4.5 m
Location	:	IFSRS, Karamana
Season	:	Summer 2019-‘20
Variety	:	Finger millet (PPR 2700)
		Green gram (CO 8)
		Black gram (DU 1)
		Cowpea (Kanakamony)

Table 2. Salient characters of crop varieties chosen for the study

S. No.	Crop	Variety	Description	Source of seed
1	Finger millet	PPR 2700	*Eleusine coracana* L. (Gaertn.); Medium tall; erect plant type; dark green foliage; average duration of 100-105 days; large and compact ear head; resistant to pink stem borer and all three types of blast disease; released from Agricultural Research Station, Perumallappalli, Andhra Pradesh.	Acharya N.G. Ranga Agricultural University, Andhra Pradesh
2	Green gram	CO 8	*Vigna radiata*; High yielding; average duration of 55-60 days; suited to rainfed conditions; resistant to yellow mosaic and stem necrosis; released from Coastal Saline Research Centre, Ramanathapuram, Tamil Nadu.	Onattukara Regional Agricultural Research Station, Kayamkulam, Alappuzha
3	Black gram	DU 1	*Vigna mungo*; High yielding; erect growth habit; bold seeded; average duration of 60-65 days; suited for *kharif*, *rabi* and summer paddy fallows; moderately susceptible to *Cercospora* leaf spot and powdery mildew; released from University of Agricultural Sciences, Dharwad, Karnataka.	Onattukara Regional Agricultural Research Station, Kayamkulam, Alappuzha
4	Cowpea	Kanakamony	*Vigna unguiculata*; Erect, slightly trailing; dual purpose type; duration of 75-80 days; seed colour red; moderately resistant to drought; released from Regional Agricultural Research Station, Pattambi, Kerala.	Onattukara Regional Agricultural Research Station, Kayamkulam, Alappuzha

3.3.1.1 Treatments

T_1 : Finger millet as sole crop (without AMF)

T_2 : Finger millet as sole crop (with AMF)

T_3 : Finger millet (without AMF) + green gram

T_4 : Finger millet (with AMF) + green gram

T_5 : Finger millet (without AMF) + black gram

T_6 : Finger millet (with AMF) + black gram

T_7 : Finger millet (without AMF) + cowpea

T_8 : Finger millet (with AMF) + cowpea

T_9 : Green gram as sole crop

T_{10} : Black gram as sole crop

T_{11} : Cowpea as sole crop

3.3.2 Crop Management

All the crops, *viz*., finger millet, green gram, black gram and cowpea were raised as per the Package of Practices Recommendations of Kerala Agricultural University (KAU, 2016).

3.3.2.1 Main Field

The experimental area was ploughed twice, levelled, weeds and stubbles were removed and the soil was brought to a fine tilth. The plots were laid out in to three blocks of eleven plots each. The plots were separated with bunds of 30 cm height and width. Irrigation and drainage channels of 50 cm width were provided alternatively between the rows.

3.3.2.2 Seeds and Sowing

Seeds of finger millet were soaked overnight in water and sown on the next day at 60 kg ha^{-1} (sole crop) and 50 kg ha^{-1} (intercrop). Solid row planting was adopted with a row to row spacing of 25 cm. Thinning was done at 15 days after sowing (DAS) so as maintain a plant to plant spacing of 15 cm within a row. Seeds of pulses were dibbled at a spacing of 25 cm x 15 cm. In the case of intercropping, one row of pulse crop was sown after every four rows of finger millet. Green gram and black gram were sown at the rate of 20 kg ha^{-1} for sole crop and 6 kg ha^{-1} for intercrop. Cowpea was sown at the rate of 50 kg ha^{-1} for sole crop and 14 kg ha^{-1} for intercrop.

3.3.2.3 Application of AMF

Arbuscular mycorrhizal fungi (AMF) was applied to finger millet at the time of sowing. AMF at the rate of 10 kg ha^{-1} (NIPHM, 2015) was mixed with powdered organic manure and applied along the line of sowing of finger millet.

3.3.2.4 Application of Manures and Fertilizers

Both finger millet and pulses were supplied with full dose of manures and fertilizers as per the package of practices recommendation of Kerala Agricultural University (KAU, 2016). Liming was done at the rate of 250 kg ha^{-1} along with the last ploughing. The manure / nutrient schedule is given in Table 3.

3.3.2.5 Irrigation

Irrigation was given at weekly interval for sole crop of finger millet and at biweekly intervals for sole crop of pulses. Weekly irrigation was given for intercropping systems.

3.3.2.6 Weed Management

Weeding was done twice at 20 DAS and 40 DAS for finger millet. In the case of pulses, one weeding was done at 20 DAS.

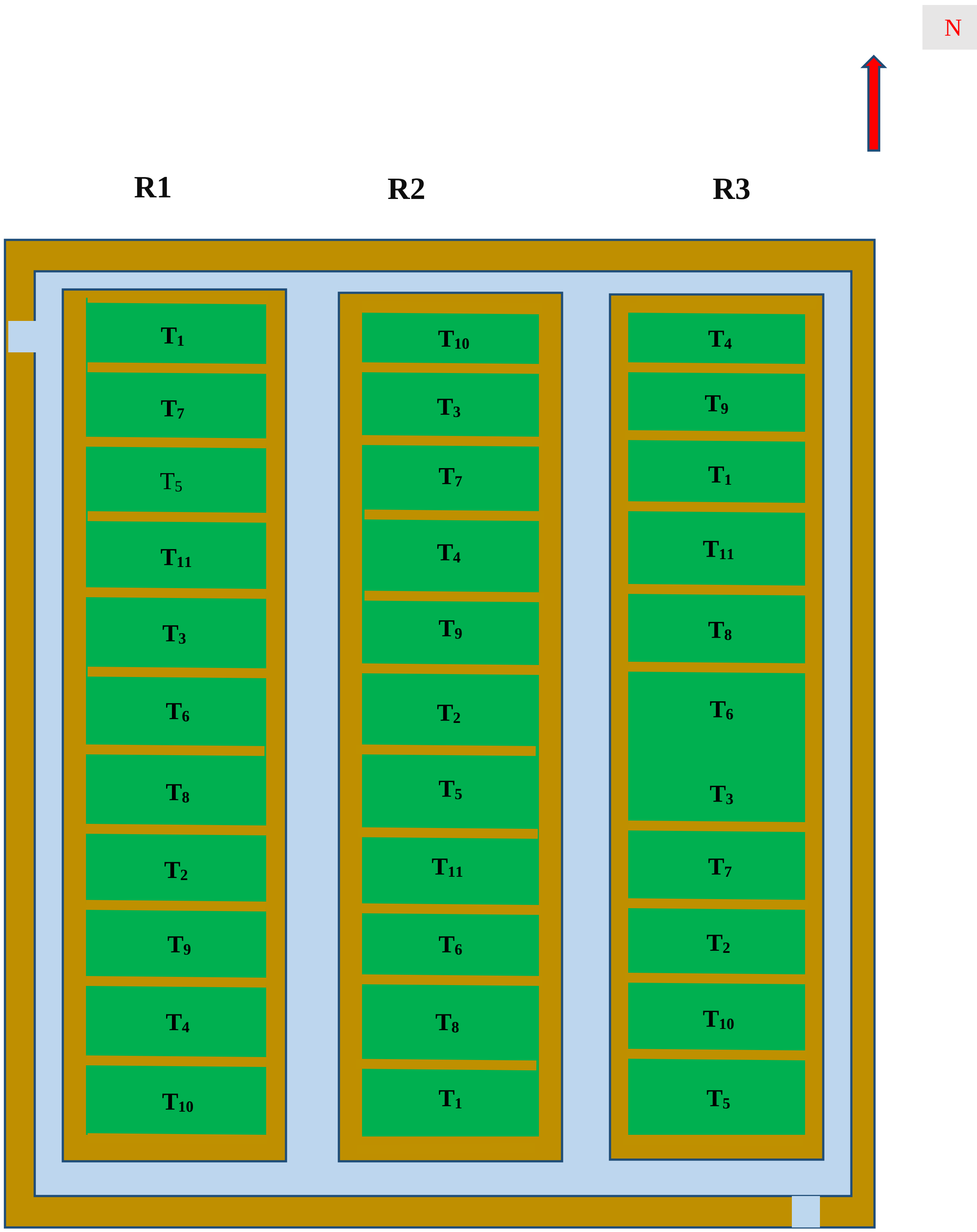

Fig. 2. Layout plan of field experiment.

Channel

Bund

3.3.2.7 Decapitation

Decapitation was done for cowpea when the crop began to exhibit trailing tendency at around 30 to 45 DAS.

3.3.2.8 Plant Protection

Aphid infestation noted in pulses was managed with thiamethoxam at the rate of 2g per 10L of water.

3.3.2.9 Harvest

Finger millet was harvested when the ears turned brown with hard grains. Pulses were harvested when 70 to 80 per cent of the pods turned brown with hard seeds inside. The total duration was 97 days for finger millet, 64 days each for green gram and black gram and 82 days for cowpea. Two border rows were left on all the sides and the net plot area was harvested, threshed, winnowed and sun dried separately. The weight of grains / seeds and straw / haulm from individual plots were recorded and expressed in t ha^{-1} for finger millet and kg ha^{-1} for pulses, on dry weight basis.

3.4 OBSERVATIONS

Two rows from all sides of each plot were left as border rows. Five plants each of finger millet and pulses were selected randomly from the net plot area of each plot and tagged as sample plants. Observations were recorded from the sample plants and the mean values were worked out.

3.4.1 Finger Millet

3.4.1.1 Growth and Growth Attributes

3.4.1.1.1 Plant Height

Plant height was measured from the base to the growing tip of the top most leaf at 30 and 60 DAS and from the base to the tip of the longest ear at harvest. Plant height was recorded in centimetres (cm).

Table 3. Manure / nutrient schedule for finger millet and pulses

Crop	Organic manure ($t\ ha^{-1}$)	NPK recommendation ($kg\ ha^{-1}$)	Time and method of application
Finger millet	5	45 : 22.5 : 22.5	Organic manure – basal ½ N, full P, full K – basal ½ N – 3 weeks after sowing
Green gram	20	20 : 30 : 30	Organic manure – basal ½ N, full P, full K – basal ¼ N as 2% urea spray at 15 DAS ¼ N as 2% urea spray at 30 DAS
Black gram	20	20 : 30 : 30	Organic manure – basal ½ N, full P, full K – basal ¼ N as 2% urea spray at 15 DAS ¼ N as 2% urea spray at 30 DAS
Cowpea	20	20 : 30 : 10	Organic manure – basal ½ N, full P, full K – basal ½ N – 15 days after sowing

3.4.1.1.2 Tillers per Plant

Tillers were counted at 30 DAS, 60 DAS and harvest and the mean was expressed as number of tillers per plant.

3.4.1.1.3 Leaf Area Index

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

3.4.1.1.4 Days to 50 per cent flowering

Days to 50 per cent flowering was recorded from the day of sowing till the day when ear heads with pollen appeared in more than half of the plants present in the field.

3.4.1.1.5 Days to 50 per cent maturity

Days to 50 per cent maturity was recorded from the day of sowing till the day when more than 50 per cent of the ear heads became mature with hard grains.

3.4.1.1.6 Total Dry Matter Production

Total dry matter production was computed at 30 and 60 DAS and at harvest. Ten whole plants were uprooted at random from the area set apart for destructive sampling, cleaned free of other debris, air dried for two days and oven dried at 65 ± 5^{o}C until constant weights were attained. The mean weight was expressed as total dry matter production in kg ha^{-1}.

3.4.1.1.7 Crop Growth Rate

Crop growth rate (CGR) was calculated for the time periods from 30 to 60 DAS and 60 DAS to harvest. CGR was calculated based on dry weight as per the formula suggested by Watson (1952) and expressed in g m^{-2} day^{-1}.

$$CGR \quad \frac{W_2 - W_1}{p\,(t_2 - t_1)}$$

where,

W_2 - dry weight of the plant at the time, t_2 (g)

W_2 - dry weight of the plant at the time, t_1 (g)

$t_2 - t_1$ - change in time (days)

p - ground area on which W_1 and W_2 are recorded

3.4.1.1.8 Relative Growth Rate

Relative growth rate (RGR) was calculated for the time periods from 30 to 60 DAS and 60 DAS to harvest. The difference in dry weight in time and space expressed as g g^{-1} day^{-1} gave the relative growth rate of the crop, as follows (Evans, 1972).

$$RGR = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

where,

W_2 - dry weight of the plant at the time, t_2 (g)

W_2 - dry weight of the plant at the time, t_1 (g)

$t_2 - t_1$ - change in time (days)

3.4.1.2 Yield Attributes and Yield

Yield attributes and yield per plant were recorded from the sample plants.

3.4.1.2.1 Productive Tillers per Plant

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

3.4.1.2.2 Fingers per ear

The number of fingers was counted from the ear heads of the sample plants and the mean number was computed.

3.4.1.2.3 Ear Length

Length of the ear heads in sample plants was measured and the mean length was expressed in centimeters (cm).

3. 4.1.2.4 Finger Length

Length of the individual fingers of the ear heads in sample plants was measured and the mean length expressed in centimeters (cm).

3.4.1.2.5 Grain Yield per Plant

All the ear heads from the sample plants were harvested, threshed, sun-dried and the weight of grains was recorded and expressed as grain yield per plant in grams (g).

3.4.1.2.6 Thousand Grain Weight

Three composite samples of one thousand seeds each was taken from the net plot yield of each treatment, weighed and the mean expressed in grams (g).

3.4.1.2.7 Grain Yield ha^{-1}

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

3.4.1.2.8 Straw Yield ha^{-1}

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

3.4.2 Pulses

Green gram, black gram and cowpea were the pulses intercropped in finger millet.

3.4.2.1 Growth and Growth Attributes

Observations were recorded from five randomly selected plants in the net plot area.

3.4.2.1.1 Plant Height

Height of the sample plants was recorded from the base to the growing tip at 30 and 60 DAS and harvest and the mean expressed in centimeters (cm).

3.4.2.1.2 Primary Branches per Plant

The number of primary branches of the sample plants was counted at 30 and 60 DAS and harvest and the mean was calculated.

3.4.2.1.3 Leaf Area Index

Length (L) and breadth (B) of the third leaf from the top was measured from the sample plants and total number of green leaves was counted. Leaf area index (LAI) was calculated as follows.

$$LAI = \frac{L \times B \times K \times \text{number of leaves per plant}}{\text{Land area occupied}}$$

where,

K - constant factor

0.6306 for green gram and black gram (Puttasamy *et al*., 1976)

0.75 for cowpea (Olal, 2015)

3.4.2.1.4 Dry Matter Production

At harvest the sample plants were pulled out, air dried for two days followed by drying in an oven at 65 ± 5^{o}C till constant weight was attained. The dry weight was expressed as dry matter production in kg ha^{-1}.

3.4.2.1.5 Rooting Depth

The depth of rooting was measured as per the method suggested by Misra and Ahmed (1989). At harvest, the sample plants were uprooted, cleaned and length was measured from the base of the plant to the tip of the longest root and the mean expressed as rooting depth in centimeters (cm).

3.4.2.1.6 Root Volume

Root volume per plant was found out by displacement method (Misra and Ahmed, 1989) and expressed in cm^3 $plant^{-1}$.

3.4.2.1.7 Nodules per Plant

The number of nodules was counted from the sample plants uprooted at harvest and the mean was worked out and expressed as number of nodules per plant.

3.4.2.2 Yield Attributes and Yield

3.4.2.2.1 Pods per Plant

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

3.4.2.2.2 Seeds per Pod

The seeds were counted from twenty randomly selected pods and the mean expressed as number of seeds per pod.

3.4.2.2.3 Hundred Seed Weight

One hundred fully bold seeds were counted, weighed and the weight was expressed in grams (g).

3.4.2.2.4 Seed Yield

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

3.4.2.2.5 Haulm Yield

Haulm, the crop residue left over after removal of seeds was sun dried and weighed and the weight was expressed as haulm yield in kg ha^{-1}.

3.4.2.2.6 Harvest Index

Harvest index (HI) was calculated by the formula suggested by Donald and Hamblin (1976), as the ratio between seed yield and biological yield

$$HI = \frac{\text{Seed yield}}{\text{Seed yield + Haulm yield}}$$

3.4.3 Observation on Weeds

3.4.3.1 Weed Density

Weed count was taken at 30 DAS with a quadrate of 0.25 m^2. The number of weeds within the quadrate was counted and weed density was calculated and expressed in number per square metre.

3.4.3.2 Weed Dry Weight

The weed samples collected at 30 DAS were dried in an oven at 65±5°C, weighed and the dry weight was expressed in g m^{-2}.

3.4.3.3 Weed Smothering Efficiency

Weed smothering efficiency (WSE) was calculated by using the formula give below.

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

where,

W_1 - weed dry weight in sole crop

W_2 - weed dry weight in intercrop

3.4.4 Intercropping Indices

3.4.4.1 Land Equivalent Ratio

Land equivalent ratio (LER) was calculated as per the formula suggested by Willey (1979).

$$LER = L_f + L_p = \frac{Y_{fp}}{Y_{ff}} + \frac{Y_{pp}}{Y_{pf}}$$

where,

L_f, L_p - LER for fingermillet and pulses

Y_{fp} - intercrop yield of finger millet

Y_{pf} - intercrop yield of pulses

Y_{ff} - sole crop yield of finger millet

Y_{pp} - sole crop yield of pulses

3.4.4.2 Area Time Equivalent Ratio

Area time equivalent ratio (ATER) was calculated by the method proposed by Hiebsch and Mc Collum (1987).

$$ATER = \frac{(Ry_f \text{ x } t_f) + Ry_p \text{ x } t_p)}{T}$$

where,

Ry - relative yield *i.e.*, ratio between intercrop yield and sole crop yield

Ry_f - relative yield of finger millet

Ry_p - relative yield of pulses

t_f - duration of finger millet (days)

t_p - duration of pulses (days)

T - duration of intercropping system (days).

3.4.4.3 Relative Crowding Coefficient

Relative crowding coefficient (RCC), denoted as ‘K’ was computed based on the formula put forth by de Wit (1960).

$$K_{fp} = \frac{Y_{fp} \text{ x } Z_{pf}}{(Y_{ff} - Y_{fp})\, Z_{fp}}$$

$$K_{pf} = \frac{Y_{pf} \text{ x } Z_{fp}}{(Y_{pp} - Y_{pf})\, Z_{pf}}$$

$$K = K_{fp} \text{ x } K_{pf}$$

where,

K_{fp} - relative crowding coefficient of finger millet intercropped with pulses

K_{pf} - relative crowding coefficient of pulses intercropped with finger millet

Y_{ff} - sole crop yield of finger millet

Y_{fp} - intercrop yield of finger millet

Y_{pp} - sole crop yield of pulses

Y_{pf} - intercrop yield of pulses

Z_{fp} - sown proportion of finger millet

Z_{pf} - sown proportion of pulses

3.4.4.4 Aggressivity

Aggressivity (A) was computed by using the formula proposed by McGilchrist (1965).

$$A_{fp} = \frac{Y_{fp}}{Y_{ff} \times Z_{fp}} - \frac{Y_{pf}}{Y_{pp} \times Z_{pf}}$$

$$A_{pf} = \frac{Y_{pf}}{Y_{pp} \times Z_{pf}} - \frac{Y_{fp}}{Y_{ff} \times Z_{fp}}$$

where,

A_{fp} - aggressivity of finger millet

A_{pf} - aggressivity of pulses

Y_{ff} - sole crop yield of finger millet

Y_{fp} - intercrop yield of finger millet

Y_{pp} - sole crop yield of pulses

Y_{pf} - intercrop yield of pulses

Z_{fp} - sown proportion of finger millet

Z_{pf} - sown proportion of pulses

3.4.4.5 Competition Index

Competition index (CI) was computed using the formula suggested by Donald (1963).

$$CI = \frac{(Y_{ff} - Y_{fp}) \times (Y_{pp} - Y_{pf})}{Y_{ff} \times Y_{pp}}$$

where,

Y_{ff} - sole crop yield of finger millet

Y_{fp} - intercrop yield of finger millet

Y_{pp} - sole crop yield of pulses

Y_{pf} - intercrop yield of pulses

3.4.4.6 Competition Ratio

Competition ratio (CR) was calculated based on the formula suggested by Willey *et al*. (1980).

$$CR_f = \frac{Y_{fp}}{Y_{ff} \times Z_{fp}} \div \frac{Y_{pf}}{Y_{pp} \times Z_{pf}}$$

$$CR_p = \frac{Y_{pf}}{Y_{pp} \times Z_{pf}} \div \frac{Y_{fp}}{Y_{ff} \times Z_{fp}}$$

where,

CR_f - competition ratio of finger millet

CR_p - competition ratio of pulses

Y_{ff} - sole crop yield of finger millet

Y_{fp} - intercrop yield of finger millet

Y_{pp} - sole crop yield of pulses

Y_{pf} - intercrop yield of pulses

Z_{fp} - sown proportion of finger millet

Z_{pf} - sown proportion of pulses

3.4.4.7 Finger Millet Equivalent Yield

Finger millet equivalent yield (FMEY) was computed based on the seed yield of the intercropped pulses and prevailing market price of finger millet and pulses, based on the crop equivalent yield concept suggested by Lal and Ray (1976) and Verma and Modgal (1983).

$$\text{FMEY} = Y_{fp} + Y_{pf} \times \left\{ \frac{P_p}{P_f} \right\}$$

where,

Y_{fp} - intercrop yield of finger millet

Y_{pf} - intercrop yield of pulses

P_p - market price of pulses

P_f - market price of finger millet

3.4.4.8 Percentage Yield Difference

Percentage yield difference (PYD) was computed based on the formula suggested by Afe and Atanda (2015).

$$\text{PYD} = 100 - \left[\left\{ \frac{Y_{ff} - Y_{fp}}{Y_{ff}} + \frac{Y_{pp} - Y_{pf}}{Y_{pp}} \right\} \frac{\times 100}{1} \right]$$

where,

Y_{ff} - sole crop yield of finger millet

Y_{pp} - sole crop yield of pulses

Y_{fp} - intercrop yield of finger millet

Y_{pf} - intercrop yield of pulses

3.5 INCIDENCE OF PESTS AND DISEASES

Aphid infestation was observed in pulses. It was managed with thiamethoxam at the rate of 2g per 10L of water.

3.6 PLANT ANALYSIS (FINGER MILLET AND PULSES)

Plant samples were collected after harvest, dried in a hot air oven at 65 ± 5°C to constant weight, ground and sieved through 0.5 mm sieve. The required quantity of samples were weighed, subjected to acid extraction and analysed. Grain /

seed and straw / haulm were analysed separately. Nitrogen, phosphorus and potassium content in the samples were analysed adopting standard analytical procedures (Table 4).

Table 4. Standard analytical procedures adopted for plant analysis

Nutrient	Method adopted
Nitrogen	Microkjeldahl distillation after digestion in H_2SO_4 (Jackson, 1973)
Phosphorus	Nitric-perchloric (9:4) acid digestion and colorimetry using vanado-molybdo phosphoric yellow colour method (Jackson, 1973)
Potassium	Nitric-perchloric (9:4) acid digestion and flame photometry (Jackson, 1973)

3.6.1 Nitrogen Uptake

Nitrogen uptake was computed as the sum of the products of dry weight of grain/ seed and straw / haulm of finger millet and pulses and the respective nitrogen content and expressed in kg ha^{-1}. The sum of nitrogen uptake of finger millet and the intercropped pulse gave the total nitrogen uptake of the intercropping system *per se*.

3.6.2 Phosphorus Uptake

Phosphorus uptake was computed as the sum of the products of dry weight of grain / seed and straw / haulm of finger millet and pulses and the respective phosphorus content and expressed in kg ha^{-1}. The sum of phosphorus uptake of finger millet and the intercropped pulse gave the total phosphorus uptake of the intercropping system *per se*.

3.6.3 Potassium Uptake

Potassium uptake was computed as the sum of the products of dry weight of grain / seed and straw / haulm of finger millet and pulses and the respective potassium content and expressed in kg ha^{-1}. The sum of potassium uptake of finger millet and the intercropped pulse gave the total potassium uptake of the intercropping system *per se*.

3.6.4 Crude Protein

The nitrogen content of grain in finger millet and seeds in pulses was multiplied by a factor of 6.25 to compute the crude protein content (Simpson *et al.*, 1965) and expressed in percentage.

3.7 SOIL ANALYSIS

After the experiment, soil samples were collected from each plot separately and analysed for organic carbon, soil reaction (pH), electrical conductivity, available nitrogen, available phosphorus and available potassium status, adopting standard procedures as mentioned in Table 1b.

3.8 ECONOMIC ANALYSIS

The economics of cultivation was articulated in terms of gross returns, net returns, benefit cost ratio (BCR) and monetary equivalent ratio, based on cost of cultivation and prevailing price of the produce.

3.8.1 Gross Returns

Gross returns was computed as the product of the grain yield (finger millet) / seed yield (pulses) and prevailing market price of the respective crops, and was expressed in ₹ ha^{-1}.

3.8.2 Net Returns

Net returns was computed by subtracting cost of cultivation from gross returns and expressed as ₹ ha^{-1}.

3.8.3 Benefit Cost Ratio

Benefit cost ratio (BCR) was calculated as the ratio between gross returns and cost of cultivation.

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

3.8.4 Monetary Equivalent Ratio

Monetary equivalent ratio (MER) was computed based on the formula proposed by Adetiloye and Adekunle (1989).

$$MER = \frac{r_f + r_p}{R_f}$$

where,

R_f - highest sole crop monetary return obtained from finger millet

rf, rp - monetary returns of finger millet and pulses under intercropping

3.9 STATISTICAL ANALYSIS

The data generated from the field experiment were statistically analyzed using analysis of variance technique (ANOVA) as applied to randomized block design (Panse and Sukhatme, 1985) and the significance was tested using F test (Snedecor and Cochran, 1967). Wherever the F value was found significant, critical difference was worked out at five percent and one per cent probability levels. The computed parameters on LER, ATER, RCC, A, CI, CR, FMEY, PYD, gross returns, net returns, BCR and MER were not statistically analysed.

Results

4. RESULTS

The study on “Productivity and biological efficiency of intercropping finger millet (*Eleusine coracana* (L.) Gaertn.) with pulses” was carried out, at IFSRS, Karamana, Thiruvananthapuram, Kerala, during the period from February to May, 2020. The study was aimed at assessing the effect of intercropping finger millet with pulses, studying the effect of AMF on the performance of finger millet under intercropping and working out the biological efficiency and economics of the intercropping systems. The results of the study are presented in this chapter.

4.1 EFFECT OF INTERCROPPING ON FINGER MILLET

4.1.1 Growth and Growth Attributes

4.1.1.1 Plant Height

The results on the effect of intercropping on plant height of finger millet are presented in Table 5.

The effect of intercropping on plant height of finger millet exhibited significance only at 30 DAS. Plants were recorded to be significantly taller (17.81 cm) in sole crop of finger millet treated with AMF (T_1). However, it was on par with T_4, T_1, T_7, T_6 and T_8. While plants were observed to be taller with AMF treatment in the case of finger millet + green gram (T_4) and finger millet + black gram (T_6), taller plants were registered in finger millet (without AMF) + cowpea combination (T_7).

4.1.1.2 Tillers per plant

The data on the number of tillers per plant as influenced by intercropping are presented in Table 5.

The tiller count recorded at 30 and 60 DAS was observed to vary significantly with intercropping. At 30 DAS, the number of tillers was significantly more (2.47 per plant) in sole crop of finger millet treated with AMF (T_2) and T_8 (finger millet with AMF + cowpea). It remained at par with finger millet with AMF + black gram (T_6). At 60 DAS, tiller count was observed to be superior in T_8 (4.40 per plant) and was comparable with T_2 and T_4. Irrespective of the intercrop, in all the treatments, tiller count was observed to be higher when finger millet was inoculated with AMF.

4.1.1.3 Leaf Area Index

The results recorded on the effect of intercropping on leaf area index (LAI) of finger millet are presented in Table 6 and graphically in Fig.3.

As in the case of plant height, LAI was also observed to differ significantly with intercropping at 30 DAS. Finger millet treated with AMF raised as sole crop (T_2) registered significantly higher LAI (0.80) and remained comparable with T_1 (0.75) and T_4 (0.68). The trend in the effect of AMF was similar to that of plant height, since LAI was higher with AMF treatment, with respect to sole crop of finger millet (T_2), finger millet + green gram (T_4) and finger millet + black gram (T_6).

4.1.1.4 Days to 50 per cent flowering

The effect of intercropping on the time taken by finger millet to reach 50 per cent flowering is presented in Table 7.

Intercropping and AMF application had no significant effect on the number of days taken by finger millet to reach 50 per cent flowering stage as evidenced by comparable values recorded by sole crop and intercropped situations.

4.1.1.5 Days to 50 per cent maturity

The data on the response of finger millet to intercropping with respect to number of days taken to reach 50 per cent maturity are presented in Table 7.

Both intercropping and AMF application failed to evoke any significant variation in the total duration of finger millet.

4.1.1.6 Total Dry Matter Production

The data pertaining to total dry matter production of finger millet in response to intercropping are presented in Table 6 and graphically in Fig.4.

Unlike plant height and LAI, total dry matter production recorded at 30 and 60 DAS and at harvest, varied significantly with intercropping. Sole crop of finger millet (with AMF) recorded superior values for total dry matter production at all the three growth stages. Among the intercropping treatments, finger millet (with AMF) + cowpea (T_8) resulted in significantly higher total dry matter production at 30 DAS (942 kg ha^{-1}), 60 DAS (3148 kg ha^{-1}) and at harvest (4635 kg ha^{-1}). Between the treatments, with and without AMF for finger millet, AMF application was observed to increase the total dry matter production of finger millet in combination with all the three intercrops tested. Further, the total dry matter production recorded by finger millet (with AMF) intercropped with green gram, black gram and cowpea were at par.

4.1.1.7 Crop Growth Rate

The results on the effect of intercropping on crop growth rate (CGR) of finger millet at 30 to 60 DAS and 60 DAS to harvest are presented in Table 8.

Crop growth rate of finger millet was significantly higher in sole crop of finger millet with AMF (T_2), both at 30 to 60 DAS (6.373 g m^{-2} day) and 60 DAS to harvest (5.830 g m^{-2} day). While it was on par with T_1 (sole crop of finger millet without AMF) at 30 to 60 DAS, it was comparable with T_1 and T_4 (finger millet with AMF + green gram) at 60 DAS to harvest. Application of AMF to finger millet was observed to increase its CGR, irrespective of sole cropping or intercropping.

4.1.1.8 Relative Growth Rate

The data on relative growth rate (RGR) of finger millet as influenced by intercropping are presented in Table 8 and graphically in Fig.5.

Sole cropping of finger millet (with AMF) (T2) registered significantly higher RGR, both at 30 to 60 DAS and 60 DAS to harvest. Among the intercropping treatments tested, finger millet (with AMF) + cowpea registered higher RGR for finger millet during both the growth periods. Further, AMF application was observed to increase the RGR of finger millet intercropped with green gram (T_4), black gram (T_6) and cowpea (T_8).

4.1.2 Yield Attributes and Yield

4.1.2.1 Productive Tillers per Plant

The results on the effect of intercropping on the number of productive tillers per plant are presented in Table 9.

Productive tiller count was noted to be significantly higher (3.20 per plant) for sole crop of finger millet treated with AMF (T_2). It was comparable (2.90 per plant) with T_8 (finger millet treated with AMF + cowpea). Intercropping finger millet with cowpea produced higher number of productive tillers per plant compared to intercropping with green gram and black gram. Further, application of AMF was observed to increase the number of productive tillers per plant of finger millet, irrespective of the pulse intercropped.

4.1.2.2 Fingers per Ear

Response of finger millet to intercropping with pulses with respect to number of fingers per ear is presented in Table 9.

There was no significant difference in the number of fingers per ear, either with sole cropping or with intercropping of finger millet with pulses along with or without AMF.

4.1.2.3 Ear Length

The results on the ear length of finger millet as influenced by intercropping with pulses are presented in Table 10.

Ears of finger millet were observed to be significantly longer (12.40 cm) with sole cropping of finger millet along with application of AMF (T_2). It was on par with T_8 (finger millet with AMF + cowpea) and T_1 (sole crop of finger millet without AMF). Among the different intercropping systems, ear length recorded in T_8 (11.47 cm) was comparable with that of T_6 (10.07 cm) and T_5 (9.97 cm), which were finger millet + black gram, with and without AMF, respectively. In general, AMF application was observed to improve the ear length.

4.1.2.4 Finger Length

The results on the effect of intercropping finger millet on the finger length are presented in Table 10.

Fingers were significantly longer (8.73 cm) in T_2 (sole crop of finger millet with AMF. Among the intercropping treatments, finger millet (with AMF) + cowpea (T_8) registered a finger length of 7.70 cm, which was significantly more than the others. However, it was at par with the finger length recorded by sole crop of finger millet without AMF (T_1).

4.1.2.5 Grain Yield per Plant

Grain yield per plant recorded by finger millet in response to intercropping with pulses is presented in Table 10.

Sole cropping of finger millet along with application of AMF (T_2) produced significantly higher grain yield per plant (7.62 g), followed by sole crop without AMF (T_1) (6.60 g). When the intercropping treatments were compared, it was observed that intercropping finger millet (with AMF) + cowpea (T_8) registered higher grain yield per plant (6.14 g) and it was comparable with finger millet (with AMF) intercropped with green gram (T_4) and black gram (T_6) respectively. Application of AMF was noted to result in higher grain yield per plant of finger millet, both under sole and intercropped conditions.

4.1.2.6 Thousand Grain Weight

The results on the effect of intercropping of finger millet with pulses on thousand grain weight of finger millet are presented in Table 10.

Both sole cropping and intercropping had no significant effect on the test weight of finger millet.

4.1.2.7 Grain Yield ha^{-1}

The data on the effect of intercropping of finger millet on its grain yield are presented in Table 11 and graphically in Fig.6.

Grain yield was significantly higher (2.03 t ha^{-1}) when finger millet was raised as a sole crop along with application of AMF (T_2). It was followed by T_1 (sole crop of finger millet without AMF). Among the intercropping systems, T_8 (finger millet with AMF + cowpea) registered higher grain yield (1.64 t ha^{-1}) and was comparable with T_4 (finger millet with AMF + green gram) and T_6 (finger millet with AMF + black gram). The superiority of application of AMF to finger millet was evidenced by the higher grain yield registered with these treatments, irrespective of sole cropping or intercropping.

4.1.2.8 Straw Yield ha^{-1}

Results on straw yield of finger millet as influenced by intercropping with pulses are presented in Table 11 and graphically in Fig.6.

Sole crop of finger millet (with AMF) (T_2) produced considerably higher straw yield (4.76 t ha^{-1}), followed by T_1 (4.05 t ha^{-1}). As in the case of grain yield, intercropping cowpea in finger millet (with AMF) (T_8) recorded higher straw yield (3.82 t ha^{-1}) when compared to the other intercropping systems. Statistically, it remained at par with T_4 and T_6. Application of AMF was found to increase the straw yield of sole crop and intercrop of finger millet.

4.2 PERFORMANCE OF PULSES UNDER INTERCROPPING

4.2.1 Growth and Growth Attributes

4.2.1.1 Plant Height

The results on the effect of intercropping on plant height of pulses, *viz*., green gram, black gram and cowpea are presented in Table 12.

Sole cropped green gram plants (T_9) were observed to be significantly taller at 60 DAS (34.31 cm) and at harvest (43 cm). At harvest, plant height recorded by T_4 (finger millet with AMF + green gram) was comparable with that of the sole crop of green gram.

Plant height was significantly more (31.12 cm) for sole crop of black gram (T_{10}) at 60 DAS. Between the two intercropping treatments, black gram was observed to be taller in T_6 (finger millet with AMF + black gram).

Cowpea was observed to register significantly taller plants at 60 DAS (38.62 cm) when intercropped with finger millet (with AMF) (T_8). It was at par with sole crop of cowpea (T_{11}).

4.2.1.2 Primary Branches per Plant

The response of intercropped pulses, *viz*., green gram, black gram and cowpea with regards to the number of primary branches per plant is presented in Table 12.

The number of primary branches per plant did not exhibit any significant variation between intercropping treatments and between intercrop and sole crop of green gram, at 30 and 60 DAS and at harvest.

Black gram was observed to elicit significant response to intercropping at 60 DAS and at harvest. Primary branches were noted to be considerably more in sole crop of black gram (T_{10}) at 60 DAS (5.40 per plant) and at harvest (7.38 per plant). However, it was comparable with the count of primary branches per plant recorded in T_6, wherein black gram was intercropped with finger millet (with AMF).

Cowpea failed to exhibit response to intercropping in terms of number of primary branches per plant at 30 and 60 DAS and at harvest.

4.2.1.3 Leaf Area Index

The results on the variation in leaf area index (LAI) of pulses, *viz*., green gram, black gram and cowpea, intercropped with finger millet are presented in Table 13.

Sole crop of green gram (T_9) had significantly higher LAI at 30 DAS (0.74) and at harvest (2.14). Between the two intercropping treatments, LAI of green intercropped in finger millet (with AMF) (T_4) was observed to be higher than T_3.

Leaf area index of black gram raised as sole crop (T_{10}) was observed to be substantially greater at 60 DAS (2.55) and at harvest (1.38). At 60 DAS, LAI was observed to be higher in T_6 (finger millet with AMF + black gram) than T_5.

As in the case of black gram, LAI was significantly higher for sole cropped cowpea (T_{11}), at 60 DAS (2.81) and at harvest (1.47). Further, LAI recorded at 60 DAS was superior for T_8 (cowpea intercropped in finger millet with AMF) than T_7 (cowpea intercropped in finger millet with AMF).

4.2.1.4 Dry Matter Production

The data on the dry matter production of green gram, black gram and cowpea in response to intercropping with finger millet are presented in Table 13 and graphically in Fig.7.

Dry matter production of green gram was significantly higher (3484 kg ha^{-1}) for the sole crop (T_9) compared to intercropping. Dry matter production recorded in T_3 (finger millet without AMF + green gram) remained at par with T_4.

Sole crop of black gram (T_{10}) produced significantly higher dry matter production at harvest (3300 kg ha^{-1}). Further, the dry matter production of black gram intercropped with finger millet, both with and without AMF (T_3 and T_4) was at par.

Dry matter production recorded by T_{11} (sole crop of cowpea) was observed to be significantly higher (3202 kg ha^{-1}). Between the two intercropping treatments, T_8 (finger millet with AMF + cowpea) had higher dry matter production (2674 kg ha^{-1}) than T_7 (2586 kg ha^{-1}).

4.2.1.5 Rooting Depth

The results in terms of rooting depth of pulses (green gram, black gram, cowpea) in response to intercropping are presented in Table 14.

Rooting depth of green gram was observed to be significantly more (37.08 cm) in T4 (finger millet with AMF + green gram), followed by sole crop (34.01 cm).

Sole crop of black gram (T_{10}) produced deeper roots (29.51 cm). Between the two intercropping treatments, roots of black gram were observed to be deeper (27.21 cm) when intercropped in finger millet (with AMF) (T_6).

Roots of cowpea were noted to be significantly deeper (50.33 cm) under sole cropping (T11). Under intercropping, rooting depth of cowpea was significantly more (46.34 cm) with AMF (T_8) than without AMF (T_7) (43.22 cm).

In general, among the three pulses tested, rooting depth was observed to be more for cowpea when compare to green gram and black gram.

4.2.1.6 Root Volume

The results on variation in the root volume of pulses, *viz*., green gram, black and cowpea in response to intercropping are presented in Table 14.

Green gram intercropped in finger millet (with AMF) (T_4) had significantly higher root volume (3.48 cm^3 per plant), followed by sole crop (T_9).

Sole crop of black gram (T_{10}) was observed to possess substantially higher root volume (3.13 cm^3 per plant). Between the two intercropping treatments, root volume was higher (2.80 cm^3 per plant) in T_6 (finger millet with AMF + black gram) than T_5 (2.23 cm^3 per plant).

As in the case of black gram, sole crop of cowpea (T_{11}) had significantly higher root volume (12.64 cm^3 per plant). Further, intercropping cowpea in finger millet (with AMF) (T_8) was noted to increase the root volume of cowpea.

By and large, it was observed that among the three pulses tested as intercrop in finger millet, cowpea had higher root volume than green gram and black gram.

4.2.1.7 Nodules per Plant

The results on the effect of intercropping on the number of nodules per plant in pulses are presented in Table 14.

Number of nodules per plant was significantly higher (23.43) in green gram intercropped with finger millet (with AMF) (T_4), followed by the sole crop (22.30).

Sole crop of black gram (T_{10}) was observed to produce significantly more number of nodules per plant (27.70) at harvest. It was followed by T_6 (finger millet with AMF + black gram).

Cowpea did not exhibit significant response to intercropping with respect to the number of nodules produced per plant at harvest

4.2.2 Yield Attributes and Yield

4.2.2.1 Pods per Plant

The results on the number of pods per plant, produced by the intercropped pulses, such as green gram, black gram and cowpea are presented in Table 15.

Green gram raised as sole crop (T_9) was observed to be superior (36.88) with respect to number of pods per plant. Significant variation was not noticed between the two intercropping systems (T_3 and T_4) involving green gram.

Sole crop black gram (T_{10}) proved to be superior (31.23) in terms of number of pods per plant. Finger millet (without AMF) + black gram (T_5) produced more number of pods per plant (29.20) than T_6 (27.20).

The number of pods per plant produced by cowpea was found to be comparable between the two intercropping treatments and between intercropping and sole cropping as evidenced by lack of significant response to the treatments.

4.2.2.2 Seeds per Pod

Table 15 presents the results on the effect of intercropping on the number of seeds per pod recorded in green gram, black gram and cowpea.

Significantly more number of seeds per pod was recorded (13.44) in sole crop of green gram (T_9). Raising green gram as intercrop in finger millet (with AMF) (T_4) produced more number of seeds per pod (11.27) than T_3 (10.10).

The effect of intercropping could not evoke significant response in black gram in terms of number of seeds per pod.

Intercropping cowpea in finger millet (with AMF) (T_8) was observed to produce significantly more number of seeds per pod (11.80). It was followed by sole crop of cowpea (10.93)

4.2.2.3 100 Seed Weight

The results on 100 seed weight of pulses (green gram, black gram, cowpea) as influenced by intercropping are presented in Table 15.

No significant variation could be observed in the 100 seed weight of green gram, black gram and cowpea in response to intercropping or sole cropping.

4.2.2.4 Seed Yield

The data on the effect of intercropping on seed yield of green gram, black gram and cowpea are presented in Table 16 and graphically in Fig.8.

Seed yield of green gram was observed to be significantly higher (784 kg ha^{-1}) with sole crop (T_9). Seed yield recorded with intercropping green gram in finger millet was comparable, both with (460 kg ha^{-1}) and without AMF application (454 kg ha^{-1}).

Black gram recorded significantly higher seed yield (891 kg ha^{-1}) when raised as a sole crop (T_{10}). Between the two intercropping treatments, T_6 (finger millet with AMF + black gram) proved to be superior (510 kg ha^{-1}).

Sole crop of cowpea (T_{11}) registered significantly higher seed yield (1342 kg ha^{-1}). The treatments, T_7 (finger millet without AMF + cowpea) and T_8 (finger millet with AMF + cowpea) were comparable, with 1008 kg ha^{-1} and 1001 kg ha^{-1} seed yield respectively.

4.2.2.5 Haulm Yield

Table 16 and Fig.8 expounds the effect of intercropping on the haulm yield of pulses, *viz*., green gram, black gram and cowpea.

As in the case of seed yield, haulm yield of green gram was also observed to be significantly higher (2299 kg ha^{-1}) in sole crop (T_9). Intercropping green gram in finger millet (without AMF) (T_3) resulted in substantially higher haulm yield (1712 kg ha^{-1}) than T_4 (1503 kg ha^{-1}).

Haulm yield was significantly higher (1498 kg ha^{-1}) in sole crop of black gram (T10). Haulm yield recorded with intercropping black gram in finger millet with AMF (978 kg ha^{-1}) and finger millet without AMF (994 kg ha^{-1}) were comparable.

The response of cowpea with respect to haulm yield was similar to that of black gram. Sole crop of cowpea (T_{11}) recorded significantly higher haulm yield (2135 kg ha^{-1}). Haulm yield of cowpea was observed to be on par when raised as intercrop in finger millet, without AMF (T_7) and with AMF (T_8).

4.2.2.6 Harvest Index

The results on the effect of intercropping on harvest index of green gram, black gram and cowpea are presented in Table 16.

Harvest index of green gram was observed to be superior (0.26) with sole crop (T_9). Between the two intercropping treatments, T_4 (green gram raised as intercrop in finger millet with AMF) resulted in higher harvest index (0.23) than T_3 (0.21).

Sole crop of black gram (T_{10}) had significantly higher harvest index (0.36). Finger millet (with AMF) + black gram (T_5) was superior in terms of harvest index (0.34) when compared to T_6 (finger millet without AMF + black gram (0.32).

Cowpea raised as sole crop (T_{11}) proved to be superior with respect to harvest index (0.39). Both the intercropping treatments recorded similar values for harvest index (0.35).

4.3 OBSERVATION ON WEEDS

4.3.1 Weed Density

The data on weed density as influenced by intercropping finger millet with pulses are presented in Table 17.

Weed density was significantly higher in sole crop of finger millet, irrespective of AMF application as noted from the comparable values for weed density in T_1 (164.96 m^{-2}) and T_2 (154.88 m^{-2}).

Weed density was observed to be significantly lower (98.62 m^{-2}) in sole crop of cowpea (T_{11}), followed by T_8 (finger millet with AMF + cowpea) and T_7 (finger millet without AMF + cowpea).

Among the sole crops, weed density recorded in green gram and black gram was comparable. Between the intercropping treatments, T_3 and T_4 (green gram) and T_7 and T_8 (cowpea) were observed to be at par.

4.3.2 Weed Dry Weight

The results pertaining to the effect of intercropping finger millet with pulses on weed dry weight are presented in Table 17 and graphically in Fig.9.

Sole crop of cowpea (T_{11}) had significantly lower weed dry weight (22.97 g m^{-2}). It was on par with T_8 (finger millet with AMF + cowpea) and T_7 (finger millet without AMF + cowpea).

Weed dry weight was notably higher in sole cropping of finger millet, with higher values for T_1 (finger millet as sole crop without AMF) (47.21 g m^{-2}) than T_2 (finger millet as sole crop with AMF) (39.01 g m^{-2}).

In general, treatments wherein finger millet was treated with AMF recorded lower weed dry weight, irrespective of the pulse intercropped.

4.3.3 Weed Smothering Efficiency

The results on the effect of intercropping on weed smothering efficiency (WSE) are presented in Table 17.

Intercropping, in general exhibited a higher WSE than sole cropping. Weed smothering efficiency (WSE) was observed to be the highest (42.92%) for T_7 (finger millet without AMF + cowpea) followed by T_8 (40.35%). Between intercropping systems involving green gram and black gram, WSE was better for green gram than black gram.

Irrespective of the pulse intercropped WSE showed lower values when finger millet was inoculated with AMF. However, the degree of variation between WSE, with and without AMF was lesser for intercropping with cowpea.

4.4 INTERCROPPING INDICES

4.4.1 Land Equivalent Ratio

The effect of intercropping finger miller with pulses on land equivalent ratio (LER) is presented in Table 18 and graphically in Fig.10.

The highest LER (1.59) was observed for T_7 (finger millet without AMF + cowpea), followed by T_8 (finger millet with AMF + cowpea). Intercropping finger millet with green gram recorded an LER of 1.38 and 1.36 respectively for finger millet without AMF (T_3) and finger millet with AMF (T_4). Comparatively, LER was lower for intercropping black gram in finger millet.

4.4.2 Area Time Equivalent Ratio

The results on the area time equivalent ratio (ATER) of intercropping finger millet with pulses are presented in Table 18 and graphically in Fig.10.

Intercropping finger millet with cowpea resulted in the highest ATER compared to green gram and black gram. The highest ATER of 1.50 was recorded in T_8 (finger millet with AMF + cowpea) followed by 1.47 in T_7 (finger millet without AMF + cowpea). ATER values were lowest for intercropping with black gram. In general, AMF was observed to increase ATER, irrespective of the pulse intercropped with finger millet.

4.4.3 Relative Crowding Coefficient

The relative crowding coefficient (RCC) of intercropping pulses in finger millet is presented in Table 18.

Between the two component crops, *viz*., finger millet and pulses, pulses recorded higher RCC values indicating their dominance. Among the three pulses tested, cowpea resulted in higher RCC values of 12.28 (T_7) and 12.39 (T_8). All the intercropping systems were observed to record yield advantage since the RCC was more than 1.0. Finger millet + cowpea intercropping had the highest values of 16.01 (T_7) and 12.67 (T_8). It was followed by intercropping with green gram and black gram respectively.

4.4.4 Aggressivity

Table 18 and Fig.11 presents the data on the aggressivity of intercropping finger millet with pulses.

All the three pulse crops, *viz.*, green gram, black gram and cowpea revealed their dominant behavior as indicated by the positive (+) sign as against the negative (-) for finger millet. Among the intercropping systems tested, aggressivity was observed to be the highest (+0.54) for cowpea in finger millet + cowpea (T_7 and T_8). It was followed by aggressivity value of + 0.39 for green gram in T_4 (finger millet with AMF + green gram) and +0.38 each for green gram and black gram in T_3 (finger millet without AMF + green gram) and T_6 (finger millet with AMF + black gram) respectively.

4.4.5 Competition Index

The results pertaining to the effect of intercropping finger millet with pulses are presented in Table 19.

Competition index of finger millet was observed to be affected by intercropping with pulses. Lower values for competition index indicate advantage in intercropping. Competition index was observed to be lower when finger millet was intercropped with cowpea, as indicated by 0.041 (T_7) and 0.050 (T_8). It was followed by competition indices of 0.850 (T_3) and 0.093 (T_4) for intercropping with green gram. Competition index was comparatively higher for intercropping finger millet with black gram.

4.4.6 Competition Ratio

Competition ratio (CR) of intercropping finger millet with pulses, *viz.*, green gram, black gram and cowpea are presented in Table 19.

Competition ratio is an indicator of the degree of competition between two crop components in intercropping systems. Between finger millet and pulses, CR values were higher for pulses, with cowpea recording the highest CR of 3.71 (T_8) and 3.60 (T_7). It was followed by 3.03 for T_4 (finger millet with AMF + green gram), 2.98 for T_6 (finger millet with AMF + black gram), 2.90 for T_3 (finger millet without AMF + green gram) and 2.70 for T_5 (finger millet without AMF + black gram).

4.4.7 Finger Millet Equivalent Yield

The data on the finger millet equivalent yield (FMEY) as influenced by intercropping finger millet with pulses are presented in Table 19 and graphically in Fig.12.

Among the pulses tested, intercropping finger millet with cowpea produced the highest FMEY followed by black gram and green gram. The treatment, T_8 (finger millet with AMF + cowpea) resulted in the highest FMEY (3388 kg ha^{-1}) followed by T_7 (3234 kg ha^{-1}). Intercropping finger millet (with AMF) with black gram (T_6) and green gram (T_4) produced FMEY of 2708 kg ha^{-1} and 2497 kg ha^{-1} respectively. It was observed that irrespective of the pulse intercropped, application of AMF to finger millet enhanced the FMEY of the respective intercropping system.

4.4.8 Percentage Yield Difference

The results on the effect of intercropping finger millet with pulses on the percentage yield difference (PYD) are presented in Table 19.

The results of the study showed that PYD values were higher for intercropping with cowpea, with the highest PYD of 58.61 per cent in T_7 (finger millet without AMF + cowpea), followed by T_8 (55.11%). It was followed by green gram and black gram. Inoculating finger millet with AMF was observed to reduce the PYD in conjunction with all the three pulses tested.

4.5 INCIDENCE OF PESTS AND DISEASES

Pulses were observed to be infested with aphids at the pre-flowering stage. It was managed with thiamethoxam (2g 10L^{-1}).

4.6 PLANT ANALYSIS

4.6.1 Nitrogen Uptake

4.6.1.1 Finger Millet

The results on the effect of intercropping finger millet with pulses on nitrogen uptake of finger millet are presented in Table 20.

Sole crop of finger millet with AMF (T_2) resulted in significantly higher nitrogen uptake (68.75 kg ha^{-1}), followed by T_8 (finger millet with AMF + cowpea).

The treatments T_1, T_4 and T_6 were comparable. In general, application of AMF to finger millet was noted to increase the nitrogen uptake.

4.6.1.2 Intercrops

Table 20 presents the variation in nitrogen uptake by the intercropped pulses, *viz*., green gram, black gram and cowpea.

Nitrogen uptake was observed to be significantly higher in sole cropping. Among the sole crops, nitrogen uptake was observed to be more for cowpea (67.90 kg ha^{-1}). While nitrogen uptake recorded by green gram (T_3 and T_4) and cowpea (T_7 and T_8) were at par, in the case of black gram T_6 was significantly superior to T_5.

4.6.1.3 Total Nitrogen Uptake

Total nitrogen uptake of the intercropping systems is presented in Table 20 and graphically in Fig.13.

Among the intercropping systems, T_8 (finger millet with AMF + cowpea) recorded significantly higher nitrogen uptake (112.26 kg ha^{-1}), followed by T_7 (98.83 kg ha^{-1}). Irrespective of the intercropping systems tested, AMF application had a positive effect of nitrogen uptake.

4.6.2 Phosphorus Uptake

4.6.2.1 Finger Millet

The data on the effect of intercropping on phosphorus uptake of finger millet are presented in Table 20.

Phosphorus uptake was substantially higher (13.68 kg ha^{-1}) for sole crop of finger millet (with AMF) (T_2). Across the intercropping systems, T_8 (finger millet with AMF + cowpea) recorded higher phosphorus uptake (12.07 kg ha^{-1}). By and large, phosphorus uptake of finger millet showed a positive response as evidenced by higher uptake values.

4.6.2.2 Intercrops

Phosphorus uptake of intercropped pulses as influenced by intercropping in finger millet is detailed in Table 20.

Among the three pulses raised as intercrop along with finger millet, cowpea had significantly higher phosphorus uptake (9.97 kg ha^{-1}) when intercropped in finger millet with AMF (T_8), followed by T_7 (finger millet without AMF + cowpea). Between green gram and black gram, phosphorus uptake was observed to be higher for green gram.

4.6.2.3 Total Phosphorus Uptake

The results on total phosphorus uptake of intercropping systems are presented in Table 20 and graphically in Fig.13.

Finger millet (with AMF) + cowpea (T_8) resulted in significantly higher phosphorus uptake (22.04 kg ha^{-1}), followed by 19.05 kg ha^{-1} in T_7 (finger millet without AMF + cowpea), 16.21 kg ha^{-1} in T_4 (finger millet with AMF + green gram) and 15.18 kg ha^{-1} in T_6 (finger millet with AMF + black gram). As in the case of nitrogen uptake, AMF application indicated categorical influence on phosphorus uptake also.

4.6.3 Potassium Uptake

4.6.3.1 Finger Millet

The results on potassium uptake of finger millet as influenced by intercropping are presented in Table 21.

Finger millet raised as sole crop along with AMF application (T_2) resulted in significantly higher potassium uptake (64.63 kg ha^{-1}). It was followed by T_8 (finger millet with AMF + cowpea), which recorded a potassium uptake of 54.79 kg ha^{-1}. The effect of AMF in enhancing the uptake of potassium is evident from the data.

4.6.3.2 Intercrops

Potassium uptake of intercropped pulses, *viz.*, green gram, black gram and cowpea are presented in Table 21.

Among the sole crops of pulses, cowpea (T_{11}) had the highest potassium uptake of 57.07 kg ha^{-1}. Comparing the intercropping systems, cowpea in T_8 (finger millet with AMF + cowpea) proved superior with potassium uptake of 50 kg ha^{-1}, followed by cowpea in T_7 (finger millet without AMF + cowpea) (41.51 kg ha^{-1}) .

Potassium uptake of green gram and black gram raised along with finger millet, both with and without AMF were at par.

4.6.3.3 Total Potassium Uptake

The data on the total potassium uptake of finger millet intercropping systems are presented in Table 21 and graphically in Fig.13.

Among the intercropping systems tested, T_8 (finger millet with AMF + cowpea) recorded significantly higher total potassium uptake (104.79 kg ha^{-1}). It was followed by T_7 (finger millet without AMF + cowpea). While potassium uptake of T_3 and T_4 (finger millet without and with AMF respectively) were comparable, T_6 (finger millet with AMF + black gram) was superior to T_5 (finger millet without AMF + black gram). On the whole, AMF application was observed to improve the potassium uptake of the intercropping systems.

4.6.4 Crude Protein

4.6.4.1 Finger Millet

Table 21 presents the results of the effect of intercropping on crude protein content of finger millet.

Sole crop of finger millet with AMF (T_2) proved significantly superior in terms of crude protein content (9.44%). It was on par with T_8 (9.32%) and T_6 (9.23%). Application of AMF was observed to increase the crude protein content of finger millet.

4.6.4.2 Intercrops

Crude protein content of pulses as influenced by intercropping with finger millet is presented in Table 21.

Crude protein content of green gram was not influenced by intercropping and crude protein content of sole crop (T_9) and intercrop (T_3, T_4) were comparable. Between black gram and cowpea, significantly higher crude protein content was recorded in cowpea in T_8 (20.63%), followed by T_7 (20.12%). Crude protein content of pulses intercropped in finger millet with AMF proved to be higher than those intercropped in finger millet without AMF.

4.7 SOIL ANALYSIS

4.7.1 Organic Carbon

The data on the effect on intercropping finger millet with pulses on the organic carbon content of soil after the experiment are presented in Table 22.

Intercropping had no significant effect on the post-experiment organic carbon status of the soil.

4.7.2 Soil Reaction

The effect of intercropping on soil reaction (pH) is presented in Table 22.

Soil reaction recorded after the experiment failed to vary significantly among the intercropping and sole cropping treatments.

4.7.3 Electrical Conductivity

The results on the variation in electrical conductivity under the influence of intercropping are presented in Table 22.

Neither intercropping nor sole cropping had any significant effect on the electrical conductivity of the soil after the experiment.

4.7.4 Available Nitrogen

The results on the effect of intercropping on the available nitrogen status of the soil are presented in Table 22.

Available nitrogen status was significantly higher after the sole crop of cowpea (T_{11}). Soil available nitrogen was comparable after the sole crops of green gram (T_9) and black gram (T_{10}). Among the intercropping systems, T_8 (finger millet with AMF + cowpea) resulted in considerably higher available nitrogen in soil after the crop. It was on par with T_5 and T_7.

4.7.5 Available Phosphorus

Table 22 presents the data on the effect of intercropping finger millet with pulses on the available phosphorus status of soil after the experiment.

The available phosphorus of soil was comparable after the sole crops of green gram, black gram and cowpea. Across the intercropping systems, the treatment, T_6

(finger millet with AMF + black gram) resulted in significantly higher available phosphorus and remained at par with T_3 and T_8.

4.7.6 Available Potassium

The data pertaining to available potassium status of soil as influenced by intercropping finger millet with pulses are presented in Table 22.

Available potassium status of soil after the experiment did not vary significantly with intercropping and sole cropping.

4.8 ECONOMIC ANALYSIS

4.8.1 Gross Returns

Gross returns as influenced by intercropping finger millet with pulses are presented in Table 23.

Intercropping, irrespective of the pulse crop resulted in higher gross returns than sole crop of finger millet. Among the intercropping systems, gross returns were observed to be the highest (₹135670 ha^{-1}) for T_8 (finger millet with AMF + cowpea) followed by T_7 (₹ 129360 ha^{-1}). Among the sole crops, cowpea resulted in higher gross returns, followed by black gram and green gram.

4.8.2 Net Returns

Table 23 presents the data on net returns as influenced by intercropping finger millet with pulses

Net returns followed the same trend as gross returns, with T_8 resulting in the highest value (₹ 47499 ha^{-1}), followed by T_7 (₹ 41773 ha^{-1}). While the sole crops of pulses registered loss with negative values for net returns, sole crop of finger millet resulted in low net returns. Net returns were observed to be higher with AMF application.

4.8.3 Benefit Cost Ratio

Benefit cost ratio (BCR) as influenced by intercropping finger millet with pulses is given in Table 23 and graphically in Fig.14.

Intercropping cowpea in finger millet resulted in higher BCR of 1.54 (T_8) and 1.48 (T_7). Sole crop of pulses registered BCR of less than 1.0. In general, AMF application to finger millet was observed to increase the BCR.

4.8.4 Monetary Equivalent Ratio

The effect of intercropping finger millet with pulses on monetary equivalent ratio (MER) is presented in Table 23.

Monetary equivalent ratio was noticed to be the highest (1.44) when cowpea was intercropped in finger millet with AMF (T_8). It was followed by T_7 (1.38). MER was observed to be the least for T_3 (0.99).

Table 5. Effect of intercropping on plant height and tillers per plant of finger millet

Treatment	Plant height (cm)			Tillers per plant (nos)		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
T_1 : Finger millet as sole crop (without AMF)	17.62	63.00	91.77	1.37	3.20	5.00
T_2 : Finger millet as sole crop (with AMF)	17.81	67.06	90.36	2.47	3.97	5.83
T_3: Finger millet (without AMF) + green gram	15.69	59.78	92.87	1.80	3.50	5.40
T_4 : Finger millet (with AMF) + green gram	17.78	65.66	97.14	1.87	3.77	5.67
T_5: Finger millet (without AMF) + black gram	15.80	63.93	94.08	1.23	3.13	5.08
T_6 : Finger millet (with AMF) + black gram	17.17	67.16	97.90	1.97	3.43	5.30
T_7 : Finger millet (without AMF) + cowpea	17.33	65.51	93.45	1.73	3.53	5.45
T_8 : Finger millet (with AMF) + cowpea	16.95	68.56	90.08	2.47	4.40	5.40
T_9 : Green gram as sole crop	-	-	-	-	-	-
T_{10} : Black gram as sole crop	-	-	-	-	-	-
T_{11} : Cowpea as sole crop	-	-	-	-	-	-
SE m (±)	0.45	2.84	2.33	0.19	0.22	0.23
CD (0.05)	1.375	NS	NS	0.588	0.660	NS

NS – Not significant

Table 6. Effect of intercropping on leaf area index and total dry matter production of finger millet

Treatment	Leaf area index			Total dry matter production (kg ha^{-1})		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
T_1 : Finger millet as sole crop (without AMF)	0.75	2.47	3.18	1005	3355	4942
T_2 : Finger millet as sole crop (with AMF)	0.80	3.01	3.87	1174	3921	5775
T_3: Finger millet (without AMF) + green gram	0.62	2.11	3.08	810	2705	3984
T_4 : Finger millet (with AMF) + green gram	0.68	2.38	3.18	908	3034	4469
T_5: Finger millet (without AMF) + black gram	0.60	2.23	2.89	770	2572	3788
T_6 : Finger millet (with AMF) + black gram	0.64	2.32	3.25	898	2999	4417
T_7 : Finger millet (without AMF) + cowpea	0.65	2.50	3.09	847	2828	4165
T_8 : Finger millet (with AMF) + cowpea	0.57	2.30	2.93	942	3148	4635
T_9 : Green gram as sole crop	-	-	-	-	-	-
T_{10} : Black gram as sole crop	-	-	-	-	-	-
T_{11} : Cowpea as sole crop	-	-	-	-	-	-
SE m (±)	0.041	0.25	0.24	15	49	72
CD (0.05)	0.126	NS	NS	45.2	150.5	221.4

NS – Not significant

Table 7. Effect of intercropping on days to 50 per cent flowering and 50 per cent maturity in finger millet

Treatment	Days taken	
	50 per cent flowering	50 per cent maturity
T_1 : Finger millet as sole crop (without AMF)	40.33	92.47
T_2 : Finger millet as sole crop (with AMF)	39.33	96.00
T_3 : Finger millet (without AMF) + green gram	42.67	99.00
T_4 : Finger millet (with AMF) + green gram	42.00	97.00
T_5 : Finger millet (without AMF) + black gram	42.00	94.62
T_6 : Finger millet (with AMF) + black gram	40.67	96.37
T_7 : Finger millet (without AMF) + cowpea	42.00	100.24
T_8 : Finger millet (with AMF) + cowpea	40.67	95.00
T_9 : Green gram as sole crop	-	-
T_{10} : Black gram as sole crop	-	-
T_{11} : Cowpea as sole crop	-	-
SE m (±)	0.92	1.88
CD (0.05)	NS	NS

NS – Not significant

Table 8. Effect of intercropping on crop growth rate and relative growth rate of finger millet

Treatment	Crop growth rate (g m^{-2} day^{-1})		Relative growth rate (g g^{-1} day^{-1})	
	30 – 60 DAS	60 DAS to harvest	30 – 60 DAS	60 DAS to harvest
T_1 : Finger millet as sole crop (without AMF)	5.337	5.257	0.307	0.182
T_2 : Finger millet as sole crop (with AMF)	6.373	5.830	0.414	0.275
T_3: Finger millet (without AMF) + green gram	4.500	4.693	0.325	0.174
T_4 : Finger millet (with AMF) + green gram	4.797	5.383	0.347	0.183
T_5: Finger millet (without AMF) + black gram	4.690	4.543	0.313	0.161
T_6 : Finger millet (with AMF) + black gram	4.993	4.197	0.350	0.175
T_7 : Finger millet (without AMF) + cowpea	4.733	4.340	0.337	0.197
T_8 : Finger millet (with AMF) + cowpea	4.807	4.530	0.377	0.246
T_9 : Green gram as sole crop	-	-	-	-
T_{10} : Black gram as sole crop	-	-	-	-
T_{11} : Cowpea as sole crop	-	-	-	-
SE m (±)	1.352	0.328	0.005	0.004
CD (0.05)	1.0771	1.0030	0.0162	0.0151

Table 9. Effect of intercropping on productive tillers per plant and fingers per ear, nos

Treatment	Productive tillers per plant	Fingers per ear
T_1 : Finger millet as sole crop (without AMF)	2.07	9.86
T_2 : Finger millet as sole crop (with AMF)	3.20	11.47
T_3: Finger millet (without AMF) + green gram	1.80	9.45
T_4: Finger millet (with AMF) + green gram	2.77	11.31
T_5: Finger millet (without AMF) + black gram	1.97	10.67
T_6 : Finger millet (with AMF) + black gram	2.50	10.36
T_7 : Finger millet (without AMF) + cowpea	2.50	11.02
T_8 : Finger millet (with AMF) + cowpea	2.90	11.71
T_9 : Green gram as sole crop	-	-
T_{10} : Black gram as sole crop	-	-
T_{11} : Cowpea as sole crop	-	-
SE m (±)	0.14	1.24
CD (0.05)	0.414	NS

NS – Not significant

Table 10. Effect of intercropping on ear length, finger length, grain yield per plant and thousand grain weight of finger millet

Treatment	Ear length (cm)	Finger length (cm)	Grain yield per plant (g)	Thousand grain weight (g)
T_1 : Finger millet as sole crop (without AMF)	11.03	7.27	6.60	2.80
T_2 : Finger millet as sole crop (with AMF)	12.40	8.73	7.62	2.78
T_3 : Finger millet (without AMF) + green gram	8.63	6.30	5.28	2.80
T_4 : Finger millet (with AMF) + green gram	9.47	6.90	5.91	2.76
T_5 : Finger millet (without AMF) + black gram	9.97	6.47	5.01	2.81
T_6 : Finger millet (with AMF) + black gram	10.07	6.67	5.85	2.80
T_7 : Finger millet (without AMF) + cowpea	9.23	6.37	5.51	2.81
T_8 : Finger millet (with AMF) + cowpea	11.47	7.70	6.14	2.80
T_9 : Green gram as sole crop	-	-	-	-
T_{10} : Black gram as sole crop	-	-	-	-
T_{11} : Cowpea as sole crop	-	-	-	-
SE m (±)	0.56	0.26	0.10	0.01
CD (0.05)	1.720	0.794	0.307	NS

NS – Not significant

Table 11. Effect of intercropping on grain yield and straw yield of finger millet, t ha^{-1}

Treatment	Grain yield	Straw yield
T_1 : Finger millet as sole crop (without AMF)	1.76	4.05
T_2 : Finger millet as sole crop (with AMF)	2.03	4.76
T_3: Finger millet (without AMF) + green gram	1.41	3.28
T_4 : Finger millet (with AMF) + green gram	1.58	3.68
T_5: Finger millet (without AMF) + black gram	1.34	3.12
T_6 : Finger millet (with AMF) + black gram	1.56	3.64
T_7 : Finger millet (without AMF) + cowpea	1.47	3.43
T_8 : Finger millet (with AMF) + cowpea	1.64	3.82
T_9 : Green gram as sole crop	-	-
T_{10} : Black gram as sole crop	-	-
T_{11} : Cowpea as sole crop	-	-
SE m (±)	0.03	0.06
CD (0.05)	0.082	0.181

Table 12. Effect of intercropping on plant height and primary branches of pulses

Treatment	Plant height (cm)			Primary branches per plant (nos)		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
T_1 : Finger millet as sole crop (without AMF)	-	-	-	-	-	-
T_2 : Finger millet as sole crop (with AMF)	-	-	-	-	-	-
T_3 : Finger millet (without AMF) + green gram	15.21	32.90	40.57	3.82	4.87	6.91
T_4 : Finger millet (with AMF) + green gram	15.65	32.99	41.51	3.75	4.64	6.78
T_5 : Finger millet (without AMF) + black gram	15.53	28.23	36.27	3.51	4.84	6.38
T_6 : Finger millet (with AMF) + black gram	15.88	29.03	36.43	3.80	5.14	6.87
T_7 : Finger millet (without AMF) + cowpea	20.15	36.95	61.93	4.04	8.20	11.71
T_8 : Finger millet (with AMF) + cowpea	19.60	38.62	61.77	3.92	8.61	12.33
T_9 : Green gram as sole crop	15.82	34.31	43.00	3.61	4.69	7.19
T_{10} : Black gram as sole crop	16.19	31.12	37.68	4.00	5.40	7.38
T_{11} : Cowpea as sole crop	20.32	37.96	61.38	4.05	8.84	12.38
SE m (±)*	0.23	0.32	0.50	0.15	0.13	0.28
SE m (±)**	0.30	0.60	0.44	0.14	0.12	0.17
SE m (±)***	0.44	0.30	0.78	0.17	0.27	0.26
CD (0.05)*	NS	1.010	1.608	NS	NS	NS
CD (0.05)**	NS	1.904	NS	NS	0.407	0.556
CD (0.05)***	NS	0.955	NS	NS	NS	NS

* Green gram ** Black gram *** Cowpea NS – Not significant

Table 13. Effect of intercropping on leaf area index and dry matter production of pulses

Treatment	Leaf area index			Dry matter production (kg ha^{-1})
	30 DAS	60 DAS	At harvest	
T_1 : Finger millet as sole crop (without AMF)	-	-	-	-
T_2 : Finger millet as sole crop (with AMF)	-	-	-	-
T_3: Finger millet (without AMF) + green gram	0.53	2.62	1.84	1957
T_4 : Finger millet (with AMF) + green gram	0.62	2.73	1.94	1850
T_5: Finger millet (without AMF) + black gram	0.62	1.99	1.05	1350
T_6 : Finger millet (with AMF) + black gram	0.64	2.14	1.04	1353
T_7 : Finger millet (without AMF) + cowpea	0.84	1.92	1.11	2586
T_8 : Finger millet (with AMF) + cowpea	0.82	2.45	1.10	2674
T_9 : Green gram as sole crop	0.74	2.96	2.14	3484
T_{10} : Black gram as sole crop	0.69	2.55	1.38	3300
T_{11} : Cowpea as sole crop	0.84	2.81	1.47	3202
SE m (±)*	0.03	0.10	0.04	43
SE m (±)**	0.02	0.12	0.05	49
SE m (±)***	0.04	0.11	0.10	68
CD (0.05)*	0.106	NS	0.133	137.9
CD (0.05)**	NS	0.388	0.170	156.5
CD (0.05)***	NS	0.347	0.316	217.0

* Green gram ** Black gram *** Cowpea NS – Not significant

Table 14. Effect of intercropping on rooting depth, root volume and nodules per plant of pulses

Treatment	Rooting depth (cm)	Root volume (cm^3 per plant)	Nodules per plant (nos)
T_1 : Finger millet as sole crop (without AMF)	-	-	-
T_2 : Finger millet as sole crop (with AMF)	-	-	-
T_3: Finger millet (without AMF) + green gram	33.61	2.62	21.70
T_4 : Finger millet (with AMF) + green gram	37.08	3.48	23.43
T_5: Finger millet (without AMF) + black gram	21.90	2.23	25.33
T_6 : Finger millet (with AMF) + black gram	27.21	2.80	26.07
T_7 : Finger millet (without AMF) + cowpea	43.22	9.87	25.10
T_8 : Finger millet (with AMF) + cowpea	46.34	10.64	24.23
T_9 : Green gram as sole crop	34.10	3.14	22.30
T_{10} : Black gram as sole crop	29.51	3.13	27.70
T_{11} : Cowpea as sole crop	50.33	12.64	23.60
SE m (±)*	0.25	0.05	0.11
SE m (±)**	0.54	0.02	0.39
SE m (±)***	0.43	0.10	0.52
CD (0.05)*	0.781	0.172	0.352
CD (0.05)**	1.723	0.078	1.237
CD (0.05)***	1.381	0.325	NS

* Green gram ** Black gram *** Cowpea NS – Not significant

Table 15. Effect of intercropping on number of pods per plant, seeds per pod and hundred seed weight of pulses

Treatment	Pods per plant (nos)	Seeds per pod (nos)	Hundred seed weight (g)
T_1 : Finger millet as sole crop (without AMF)	-	-	-
T_2 : Finger millet as sole crop (with AMF)	-	-	-
T_3: Finger millet (without AMF) + green gram	30.93	10.10	3.72
T_4 : Finger millet (with AMF) + green gram	31.57	11.27	3.74
T_5: Finger millet (without AMF) + black gram	29.20	8.07	5.63
T_6 : Finger millet (with AMF) + black gram	27.20	8.78	5.60
T_7 : Finger millet (without AMF) + cowpea	23.93	10.07	13.00
T_8 : Finger millet (with AMF) + cowpea	24.90	11.80	12.94
T_9 : Green gram as sole crop	36.88	13.44	3.73
T_{10} : Black gram as sole crop	31.23	9.53	5.64
T_{11} : Cowpea as sole crop	23.80	10.93	12.95
SE m (±)*	0.97	0.05	0.01
SE m (±)**	0.56	0.39	0.01
SE m (±)***	0.68	0.74	0.09
CD (0.05)*	3.105	0.151	NS
CD (0.05)**	1.791	NS	NS
CD (0.05)***	NS	0.526	NS

* Green gram ** Black gram *** Cowpea NS – Not significant

Table 16. Effect of intercropping on seed yield, haulm yield and harvest index of pulses

Treatment	Seed yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	Harvest index
T_1 : Finger millet as sole crop (without AMF)	-	-	-
T_2 : Finger millet as sole crop (with AMF)	-	-	-
T_3: Finger millet (without AMF) + green gram	454	1712	0.21
T_4 : Finger millet (with AMF) + green gram	460	1503	0.23
T_5: Finger millet (without AMF) + black gram	457	994	0.32
T_6 : Finger millet (with AMF) + black gram	510	978	0.34
T_7 : Finger millet (without AMF) + cowpea	1008	1852	0.35
T_8 : Finger millet (with AMF) + cowpea	1001	1866	0.35
T_9 : Green gram as sole crop	784	2299	0.26
T_{10} : Black gram as sole crop	891	1498	0.36
T_{11} : Cowpea as sole crop	1342	2135	0.39
SE m (±)*	8	36	0.01
SE m (±)**	6	27	0.01
SE m (±)***	22	49	0.01
CD (0.05)*	24.0	115.3	0.007
CD (0.05)**	18.1	87.3	0.014
CD (0.05)***	71.0	155.5	0.011

* Green gram ** Black gram *** Cowpea

Table 17. Effect of intercropping on weed density, weed dry weight and weed smothering efficiency (WSE)

Treatment	Weed density (nos m^{-2})	Weed dry weight (g m^{-2})	WSE (%)
T_1 : Finger millet as sole crop (without AMF)	12.88 (164.96)	47.21	-
T_2 : Finger millet as sole crop (with AMF)	12.48 (154.88)	39.01	-
T_3: Finger millet (without AMF) + green gram	11.98 (142.45)	31.18	33.25
T_4 : Finger millet (with AMF) + green gram	11.71 (136.19)	29.37	23.21
T_4 : Finger millet (without AMF) + black gram	12.12 (145.92)	35.00	24.38
T_6 : Finger millet (with AMF) + black gram	11.47 (130.56)	31.53	17.24
T_7 : Finger millet (without AMF) + cowpea	11.35 (127.94)	26.72	42.92
T_8 : Finger millet (with AMF) + cowpea	11.01 (120.25)	23.03	40.35
T_9 : Green gram as sole crop	12.52 (155.86)	37.70	-
T_{10} : Black gram as sole crop	12.24 (148.80)	37.98	-
T_{11} : Cowpea as sole crop	9.96 (98.62)	22.97	-
SE m (±)	0.18	2.02	-
CD (0.05)	0.522	5.989	-

Weed density : square root transformation; actual values in parentheses

Table 18. Effect of intercropping on land equivalent ratio (LER), area time equivalent ratio (ATER), relative crowding coefficient (K) and aggressivity (A)

Treatment	LER	ATER	Relative crowding coefficient			Aggressivity	
			K_{fp}	K_{pf}	K	A_{fp}	A_{pf}
T_1 : Finger millet as sole crop (without AMF)	-	-				-	-
T_2 : Finger millet as sole crop (with AMF)	-	-				-	-
T_3 : Finger millet (without AMF) + green gram	1.38	1.18	1.01	5.58	5.70	- 0.38	+ 0.38
T_4 : Finger millet (with AMF) + green gram	1.36	1.16	0.87	5.70	4.96	- 0.39	+ 0.39
T_5 : Finger millet (without AMF) + black gram	1.27	1.10	0.83	4.23	3.50	- 0.32	+ 0.32
T_6 : Finger millet (with AMF) + black gram	1.34	1.14	0.87	5.51	5.08	- 0.38	+ 0.38
T_7 : Finger millet (without AMF) + cowpea	1.59	1.47	1.29	12.28	16.01	- 0.54	+ 0.54
T_8 : Finger millet (with AMF) + cowpea	1.55	1.50	1.03	12.39	12.67	- 0.54	+ 0.54
T_9 : Green gram as sole crop	-	-				-	-
T_{10} : Black gram as sole crop	-	-				-	-
T_{11} : Cowpea as sole crop	-	-				-	-

K_{fp}, A_{fp} – relative crowding coefficient and aggressivity of finger millet in combination with pulse(s) respectively

K_{pf}, A_{pf}– relative crowding coefficient and aggressivity of pulse (s) in combination with finger millet respectively

Table 19. Effect of intercropping on competition index (CI), competition ratio (CR), finger millet equivalent yield (FMEY) and percentage yield difference (PYD)

Treatment	CI	CR		FMEY	PYD
		CR_f	CR_p	(kg ha^{-1})	(%)
T_1 : Finger millet as sole crop (without AMF)	-	-	-	1760	-
T_2 : Finger millet as sole crop (with AMF)	-	-	-	2033	-
T_3: Finger millet (without AMF) + green gram	0.085	0.345	2.90	2315	37.77
T_4 : Finger millet (with AMF) + green gram	0.093	0.331	3.03	2497	36.19
T_5: Finger millet (without AMF) + black gram	0.117	0.370	2.70	2365	27.24
T_6 : Finger millet (with AMF) + black gram	0.099	0.335	2.98	2708	28.01
T_7 : Finger millet (without AMF) + cowpea	0.041	0.278	3.60	3234	58.61
T_8 : Finger millet (with AMF) + cowpea	0.050	0.270	3.71	3388	55.11
T_9 : Green gram as sole crop	-	-	-	1568	-
T_{10} : Black gram as sole crop	-	-	-	1764	-
T_{11} : Cowpea as sole crop	-	-	-	2349	-

CR_f – competition ratio of finger millet

CR_p – competition ratio of pulse(s)s

Table 20. Effect of intercropping on uptake of nitrogen and phosphorus, kg ha^{-1}

Treatment	Nitrogen uptake			Phosphorus uptake		
	Finger millet	Pulse	Total	Finger millet	Pulse	Total
T_1 : Finger millet as sole crop (without AMF)	54.47	-	54.47	9.27	-	9.27
T_2 : Finger millet as sole crop (with AMF)	68.75	-	68.75	13.68	-	13.68
T_3 : Finger millet (without AMF) + green gram	43.06	34.37	77.43	8.51	4.81	13.32
T_4 : Finger millet (with AMF) + green gram	54.25	36.66	90.91	10.53	5.62	16.21
T_5 : Finger millet (without AMF) + black gram	41.19	24.66	65.86	6.84	4.31	11.15
T_6 : Finger millet (with AMF) + black gram	52.46	28.49	80.95	10.02	5.15	15.18
T_7 : Finger millet (without AMF) + cowpea	46.41	52.42	98.83	10.29	8.76	19.05
T_8 : Finger millet (with AMF) + cowpea	57.21	55.05	112.26	12.07	9.97	22.04
T_9 : Green gram as sole crop	-	55.27	55.27	-	7.92	7.92
T_{10} : Black gram as sole crop	-	54.05	54.05	-	9.10	9.10
T_{11} : Cowpea as sole crop	-	67.90	67.90	-	11.59	11.59
SE m (±)*	0.84	-	-	0.16	-	-
SE m (±)**	-	0.81	-	-	0.11	-
SE m (±)***	-	0.84	-	-	0.14	-
SE m (±)****	-	1.28	-	-	0.25	-
SE m (±) #		-	1.75		-	0.33
CD (0.05)*	2.586	-	-	0.494	-	-
CD (0.05)**	-	2.574	-	-	0.365	-
CD (0.05)***	-	2.678	-	-	0.446	-
CD (0.05)****	-	4.093	-	-	0.798	-
CD (0.05) #		-	5.194		-	0.966

* Finger millet ** Green gram *** Black gram **** Cowpea

Total uptake

Table 21. Effect of intercropping on uptake of potassium and crude protein content

Treatment	Potassium uptake (kg ha^{-1})			Crude protein^ (%)	
	Finger millet	Pulse	Total	Finger millet	Pulse
T_1 : Finger millet as sole crop (without AMF)	52.56	-	52.56	8.81	-
T_2 : Finger millet as sole crop (with AMF)	64.63	-	64.63	9.44	-
T_3 : Finger millet (without AMF) + green gram	44.29	27.21	71.50	8.75	20.08
T_4 : Finger millet (with AMF) + green gram	49.69	26.26	75.96	9.15	20.34
T_5 : Finger millet (without AMF) + black gram	41.50	17.29	58.80	8.75	19.75
T_6 : Finger millet (with AMF) + black gram	50.59	17.79	68.38	9.23	19.94
T_7 : Finger millet (without AMF) + cowpea	47.98	41.51	89.49	8.92	20.12
T_8 : Finger millet (with AMF) + cowpea	54.79	50.00	104.79	9.32	20.63
T_9 : Green gram as sole crop	-	40.23	40.23	-	20.34
T_{10} : Black gram as sole crop	-	35.82	35.82	-	19.50
T_{11} : Cowpea as sole crop	-	57.07	57.07	-	20.11
SE m (±)*	0.81	-	-	0.08	-
SE m (±)**	-	0.66	-	-	0.08
SE m (±)***	-	0.59	-	-	0.04
SE m (±)****	-	1.31	-	-	0.07
SE m (±) #		-	1.64		-
CD (0.05)*	2.473	-	-	0.240	-
CD (0.05)**	-	2.114	-	-	NS
CD (0.05)***	-	1.871	-	-	0.111
CD (0.05)****	-	4.168	-	-	0.227
CD (0.05) #	-	-	4.857	-	-

* Finger millet ** Green gram *** Black gram **** Cowpea

Total uptake ^ on dry weight basis

NS – not significant

Table 22. Effect of intercropping on organic carbon (OC), soil reaction (pH), electrical conductivity (EC) and available NPK status of soil after the experiment

Treatment	OC (%)	pH	EC (dS m^{-1})	Available nutrient (s) (kg ha^{-1})		
				N	P	K
T_1 : Finger millet as sole crop (without AMF)	1.53	5.12	0.19	203.82	25.31	131.78
T_2 : Finger millet as sole crop (with AMF)	1.54	5.13	0.18	207.63	26.10	128.24
T_3 : Finger millet (without AMF) + green gram	1.55	5.12	0.17	216.31	28.24	128.07
T_4 : Finger millet (with AMF) + green gram	1.53	5.14	0.18	202.84	23.21	129.63
T_5 : Finger millet (without AMF) + black gram	1.55	5.10	0.18	227.88	24.24	128.40
T_6 : Finger millet (with AMF) + black gram	1.55	5.11	0.18	212.79	28.27	130.47
T_7 : Finger millet (without AMF) + cowpea	1.54	5.10	0.17	224.05	22.87	130.08
T_8 : Finger millet (with AMF) + cowpea	1.56	5.11	0.17	228.51	27.45	129.79
T_9 : Green gram as sole crop	1.55	5.12	0.18	228.47	32.50	128.52
T_{10} : Black gram as sole crop	1.53	5.12	0.18	229.69	31.32	130.54
T_{11} : Cowpea as sole crop	1.55	5.130	0.18	248.65	32.49	132.72
SE m (±)	0.01	0.01	0.01	2.22	0.81	0.93
CD (0.05)	NS	NS	NS	6.605	2.393	NS

NS – Not significant

Table 23. Effect of intercropping on, gross returns, net returns, benefit cost ratio (BCR) and monetary equivalent ratio (MER)

Treatment	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	BCR	MER
T_1 : Finger millet as sole crop (without AMF)	70400	436	1.01	-
T_2 : Finger millet as sole crop (with AMF)	81200	10486	1.15	-
T_3: Finger millet (without AMF) + green gram	92720	8304	1.10	0.99
T_4 : Finger millet (with AMF) + green gram	100002	14427	1.17	1.06
T_5: Finger millet (without AMF) + black gram	94730	10314	1.12	1.01
T_6 : Finger millet (with AMF) + black gram	108300	23300	1.27	1.15
T_7 : Finger millet (without AMF) + cowpea	129360	41773	1.48	1.38
T_8 : Finger millet (with AMF) + cowpea	135670	47499	1.54	1.44
T_9 : Green gram as sole crop	62720	-24440	0.72	-
T_{10} : Black gram as sole crop	80190	-6970	0.92	-
T_{11} : Cowpea as sole crop	93940	-5259	0.95	-

Intercropping cowpea in finger millet resulted in higher BCR of 1.54 (T_8) and 1.48 (T_7). Sole crop of pulses registered BCR of less than 1.0. In general, AMF application to finger millet was observed to increase the BCR.

4.8.4 Monetary Equivalent Ratio

The effect of intercropping finger millet with pulses on monetary equivalent ratio (MER) is presented in Table 23.

Monetary equivalent ratio was noticed to be the highest (1.44) when cowpea was intercropped in finger millet with AMF (T_8). It was followed by T_7 (1.38). MER was observed to be the least for T_3 (0.99).

Discussion

5. DISCUSSION

The investigation entitled "Productivity and biological efficiency of intercropping finger millet (*Eleusine coracana* (L.) Gaertn.) with pulses" was carried out to assess the effect of intercropping finger millet with pulses, to study the effect of arbuscular mycorrhizal fungi (AMF) on the performance of finger millet under intercropping and to work out the biological efficiency and economics of the intercropping systems. The results of the study are discussed concisely in this chapter.

5.1 EFFECT OF INTERCROPPING ON FINGER MILLET

5.1.1 Growth and Growth Attributes

Between the sole crops of finger millet, without and with AMF (T_1 and T_2), growth attributes such as plant height, tillers per plant, LAI (Fig.3), total dry matter production, crop growth rate and relative growth rate (Fig.5) were observed to be significantly higher with application of AMF. Crop growth rate and RGR were enhanced to the tune of 19.42 per cent and 34.85 per cent respectively. The total dry matter produced by finger millet at harvest (Fig.4) was 16.86 per cent higher with AMF. Irrespective of the pulse intercropped, AMF improved the growth attributes of finger millet.

Arbuscular mycorrhizal fungi have been reported to possess consistent impact on stomatal conductance, transpiration, CO_2 exchange (Sharma *et al*., 2014), photosynthesis and chlorophyll content (Panwar, 1991) and consequently plant growth. Inoculating AMF has been observed to result in significant increase in growth rate and dry matter production of crops (Mudalagiriyappan *et al*., 1997). Increase in crop growth rate and relative growth rate are mainly mediated by an increase in leaf area index and consequent improvement in radiation use efficiency. Similar results have been reported by Chavan *et al*. (2019).

Intercropping pulses with finger millet was observed to enhance the growth attributes of the crop. Among the intercropping systems, T_8 (finger millet with AMF + cowpea) registered the highest dry matter production. The higher LAI, tiller count, crop growth rate and relative growth rate supported by this treatment might have contributed to the higher dry matter production. Dry matter production and light interception are directly related and light interception is mainly dependent on the LAI (Ewert, 2004; Portes and de Melo, 2014).

5.1.2 Yield Attributes and Yield

Productive tiller count, ear length, finger length, grain yield per plant, grain yield and straw yield (Fig.6) were superior for sole crop of finger millet treated with AMF (T_2) compared to that without AMF (T_1). Grain yield and straw yield of sole crop of finger millet inoculated with AMF was 15.34 per cent and 17.53 per cent greater than those without AMF. Thousand grain weight was not affected by sole cropping or intercropping. Inoculation with AMF was observed to improve the yield of finger millet intercropped with green gram, black gram and cowpea. Compared to sole crop, yield reduction of finger millet (without AMF) was to the tune of 20.01, 24.05 and 16.38 percent respectively with green gram, black gram and cowpea. However, the same with AMF was only 10.42, 11.36 and 7.01 per cent. This point towards the effect of AMF in enhancing competitive ability of finger millet under intercropped situation.

Roots of crops and AMF have been reported to establish a symbiotic relationship resulting in better plant nutrition and productivity (Auge, 2001). Further, increase in productivity in response to AMF has been mainly attributed to the ability of AMF in enhancing the uptake of relatively immobile nutrients clubbed together with the rapid translocation of the mobile nutrients (Tobar *et al*., 1994; Liu *et al*., 2000). Similar results have been reported by Ramakrishnan and Bhuvaneswari (2014) in finger millet.

Among the intercropping systems, T_8 (finger millet with AMF + cowpea) recorded superiority in yield attributes and yield. This might be due to a better complementarity between finger millet and cowpea in utilizing the basic resources like water, nutrients and sunlight, as suggested by Kumar and Ray (2020). The positive impact of AMF in improving the yield attributes of finger millet was observed across all the intercropping systems, irrespective of the pulse. This could be attributed to the role of AMF in promoting inter-specific root interactions between finger millet and pulses, effecting nutrient mobilization in the rhizosphere (Wasaki *et al*., 2003), resulting in better growth and productivity of finger millet.

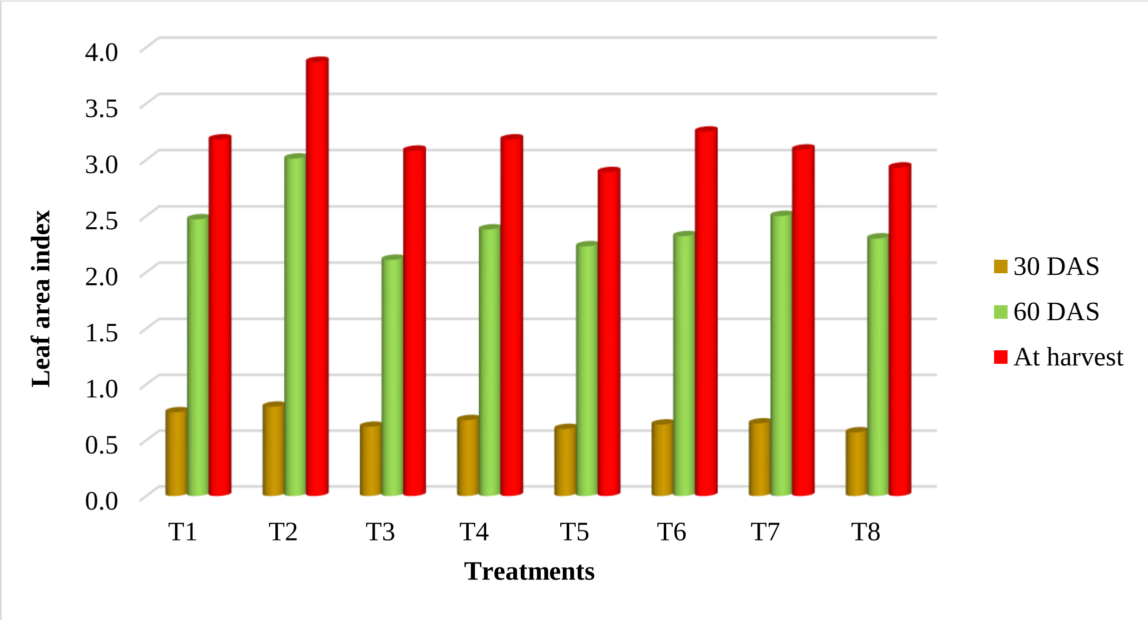

Fig.3. Effect of intercropping on leaf area index of finger millet

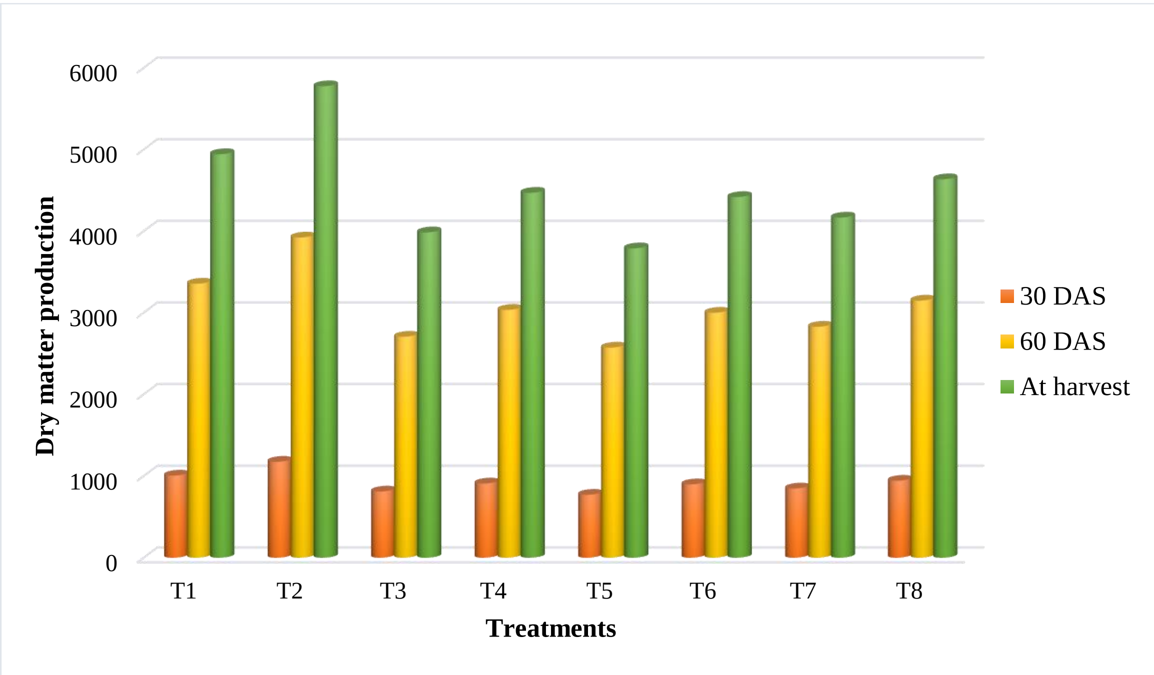

Fig.4. Effect of intercropping on dry matter production of finger millet, kg ha^{-1}

Yield is a function of yield attributes like the number of productive tillers, fingers per ear head, ear length, finger length and thousand grain weight. Except thousand grain weight, all the yield attributes were observed to be superior in T_8. This might have contributed to the higher yield in this treatment. These results are in conformity to those reported by Om *et al*. (1997). The lack of variation in the thousand grain weight or test weight might be due to the fact that test weight is a prime yield determinant, which has been identified as a genetic character of crops least affected by the environment (Ashraf *et al*., 1999).

Cereals and millets prefer soils with high nitrogen availability. However, legumes like pulses have an upper hand in soils with low nitrogen status by virtue of their symbiotic liaison with nitrogen fixing bacteria. In the present study the initial soil analysis revealed lower nitrogen status. Thus intercropping nitrogen loving finger millet with pulses might have self-regulated, based on the nitrogen availability in the soil as suggested by Chapman *et al*. (1996).

Intercropping systems are capable of harnessing the benefit of the phenomenon of hydraulic lift or hydraulic redistribution or bio-irrigation (Liste and White, 2008). Deep rooted plants like legumes can lift water from the deeper moist soil layers towards the top soil layers along a water potential gradient. This will benefit the shallow rooted crops, whose roots occupy the top layers of the soil. Since the study was undertaken during the summer season, the bio-irrigation prospects might have benefitted finger millet intercropped with pulses, Further, the rooting depth of cowpea was observed to be more when compared to green gram and black gram (Table 14). Thus intercropping with cowpea might have benefitted finger millet more than the other two pulses. Weed suppression ability of intercrops is yet another factor that contributes towards yield improvement. Among the intercropping systems, weed density and weed dry weight were the lowest with cowpea as the intercrop in finger millet, both with and without AMF. The weed suppressing ability of intercropping over monocropping has been previously reported by Yih (1982).

The affirmative effect of AMF in improving the productivity of finger millet could also be attributed to the possibility of formation of a common network of mycorrhiza which serve as a bridge between the deep-rooted pulse and the shallow rooted finger millet. The effectiveness of such networks in regulating moisture and nutrient supply in intercropping have been reported by Querejeta *et al*. (2012).

5.2 PERFORMANCE OF PULSES UNDER INTERCROPPING

5.2.1 Growth and Growth Attributes

Sole crop of pulses was observed to record taller plants with more LAI and dry matter production (Fig.7), when compared to the respective intercrops. The number of primary branches showed significant variation with more number in sole crop of black gram. Between intercropping in finger millet with and without AMF, in general, growth and growth attributes of all the three pulses were observed to better in the treatments with AMF.

Geren *et al*. (2008) and Refay *et al*. (2013) have reported that LAI, crop growth rate and net assimilation rate of component crops decreased in intercropping compared to sole cropping. Finger millet, being taller might have also had a shading effect on the intercropped pulses, resulting in reduction in the growth of pulses under intercropped condition. The better performance of sole cropped pulses could also be attributed to the belowground interactions reported in millet – legume intercropping systems. In general, cereals and millets possess greater rooting densities (Anil *et al*., 1998). Thus, when pulses were intercropped with finger millet, a competition might have emerged affecting the growth of pulses under intercropped condition. However, the presence of mycorrhiza has been observed to assist the intercropped legumes to subvert this competition and result in better growth and development as suggested by Bethlenfalvay (1992).

Rooting depth and root volume of black gram and cowpea were observed to be more for sole cropping, followed by intercropping with finger millet (with AMF). The reverse trend was seen in green gram. A specific trend could not be observed with respect to the number of nodules per plant.

Intercropping legumes and non-legumes can regulate the root growth of both the components in mixture. In legume + non-legume mixtures, Tosti and Thorup-Kristensen (2010) confirmed that the root growth of the non-legume enhanced compared to the legume. This suggests the existence of a competition between the roots of the component crops in intercropping. Thus the better root growth of pulses

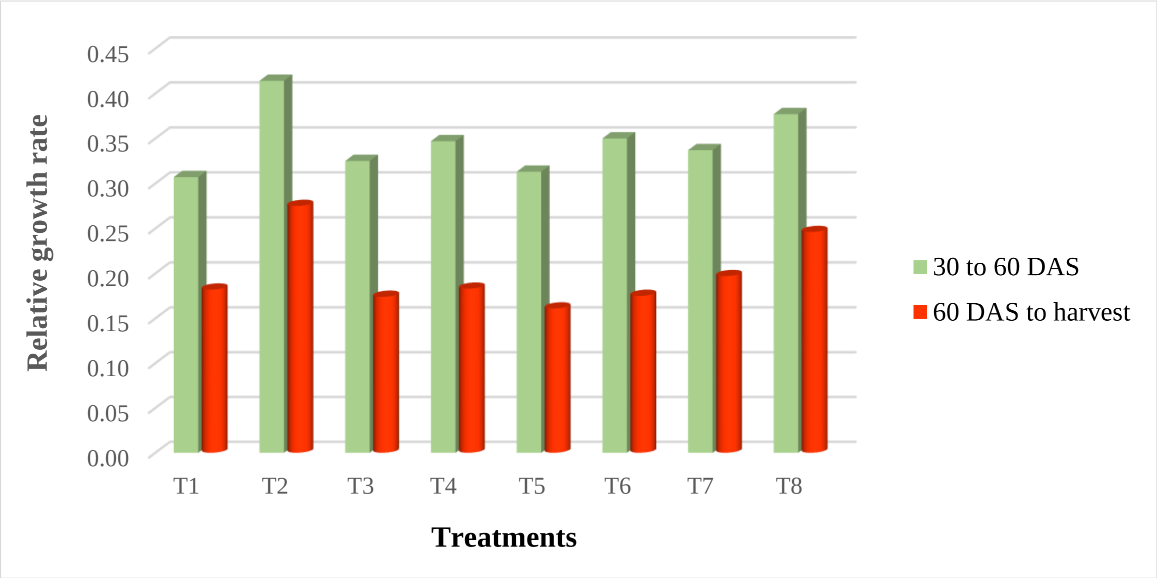

Fig.5. Effect of intercropping on relative growth rate of finger millet, g g^{-1} day^{-1}

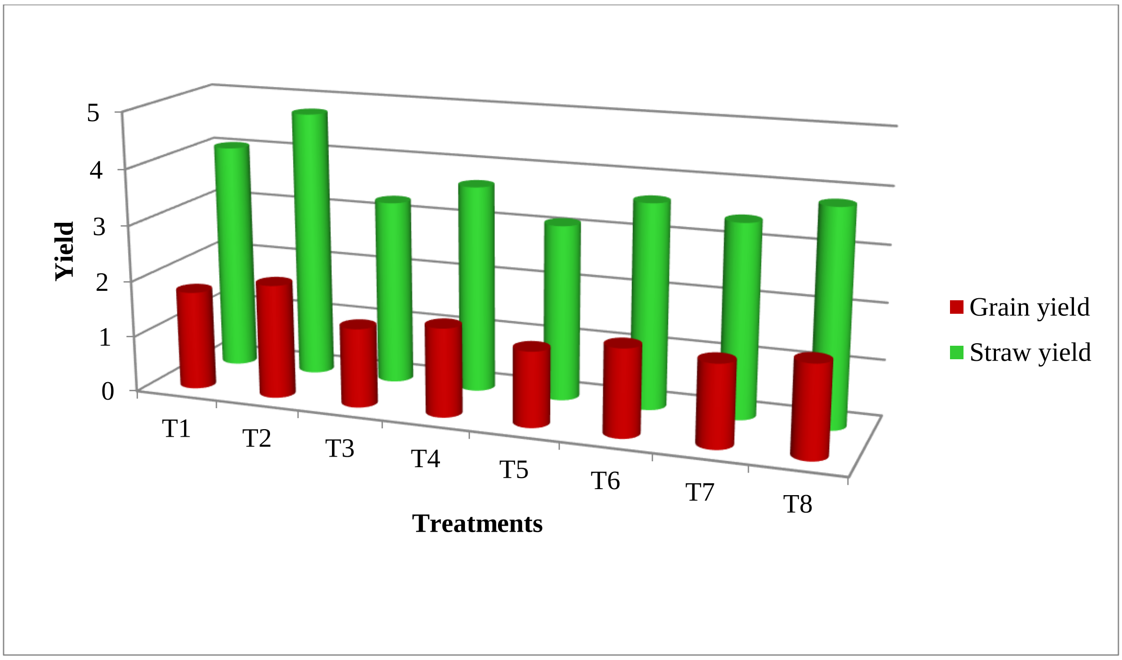

Fig.6. Effect of intercropping on grain yield and straw yield of finger millet, t ha^{-1}

under sole cropping might be due to the lack of competition. Effect of AMF in increasing root biomass has been reported by Tian-Tian *et al*. (2019).

5.2.2 Yield Attributes and Yield

The number of pods per plant was significantly higher in sole crop of green gram and black gram. While the number of seeds per pods was higher for sole crop in green gram, it was noted to be higher in cowpea when intercropped with finger millet (with AMF). Hundred seed weight remained unaffected by the treatments. Seed yield (Fig.8) and harvest index of green gram, black gram and cowpea was significantly more in the sole crop. Between the two intercropping systems (*i.e*., along with finger millet with and without AMF), black gram recorded superior seed yield when intercropped in finger millet (with AMF). In the case of green gram and cowpea, seed yield in the two intercropping systems were comparable. Haulm yield (Fig.8) of all the three pulses were higher for the sole crop. Inoculating finger millet with AMF did not elicit a specific response in haulm yield of pulses.

The results of higher yields of sole crops compared to intercropping were in agreement with those of Ndakidemi and Dakora (2007). The yield advantage of sole crops could be due to higher plant density and also due to absence of competition with the main crop of finger millet. Sole crop of pulses had higher LAI and dry matter production. Tajul *et al*. (2013) observed that yield and dry matter production is a function of the photosynthetic surface, which increases with population density. Similar results were reported by Lucus and Remison (1984). Makoi *et al*. (2009) have opined that the shading effects of the main crop could lead to a reduction in the photosynthetic efficiency of the intercropped pulses, resulting in low productivity. The higher harvest index recorded by green gram and black gram intercropped with finger millet inoculated with AMF might be due to enhanced photosynthesis and better translocation of accumulates towards the sink. The capacity of AMF to regulate the production of osmoregulatory substances and maintain photosynthesis and translocation of photosynthates has been reported by Bearden and Petersen (2000) and Asghari *et al*. (2005).

5.3 OBSERVATION ON WEEDS

Weed density and weed dry weight (Fig.9) were considerably higher in sole crop of finger millet. On the contrary, sole crop of cowpea registered significantly lower values for weed density and weed dry weight. Among the three pulses intercropped with finger millet, cowpea was the most efficient in reducing the weed population. The effect of green gram and black gram as intercrops were at par. Inoculation of finger millet with AMF was observed to record lower weed density and dry weight.

The erect growth habit of finger millet might have allowed more light to penetrate into the inter-row spaces, which benefitted the weeds in the sole crop, though the crop was planted at a closer spacing. Cowpea, being a fast growing crop might have covered the ground rapidly and served as live-mulch when intercropped with finger millet. Living mulches help in weed suppression by competing for the use of growth resources, and altering the environmental factors that affect weed germination and establishment (Liebman and Davis, 2000). Similar effect of cowpea in reducing the weed biomass by restricting the availability of uncovered spaces between the main crop has been reported by Jamshidi *et al*. (2013). Intercropping might suppress weeds better than sole crops both by producing higher crop yield and less weed growth by grabbing resources from weeds and also by suppressing weeds through allelopathy (Yih, 1982). Intercrops may also provide yield advantages without reducing weed growth below levels seen in respective monocrops by using resources that are not exploited by weeds and converting them into economic dry matter more efficiently than sole crops (Liebman and Elizabeth, 1993). Less weed under sole cropped pulses over sole crop of finger millet may be due to better weed smothering efficiency of pulse crops (Sheaffer *et al*., 2002; Midya *et al*., 2005). Less weed biomass production and weed density under intercropping system is due to greater inter-specific competition clubbed together with the complementarity between intercrops that improve the competitive ability of crops towards weeds (Hauggaard-Nielsen *et al*., 2003b).

Weed smothering efficiency (WSE) was higher for finger millet intercropped with pulses than sole crop of finger millet. This could be attributed to the better coverage of the inter-row spaces on account of higher plant density under

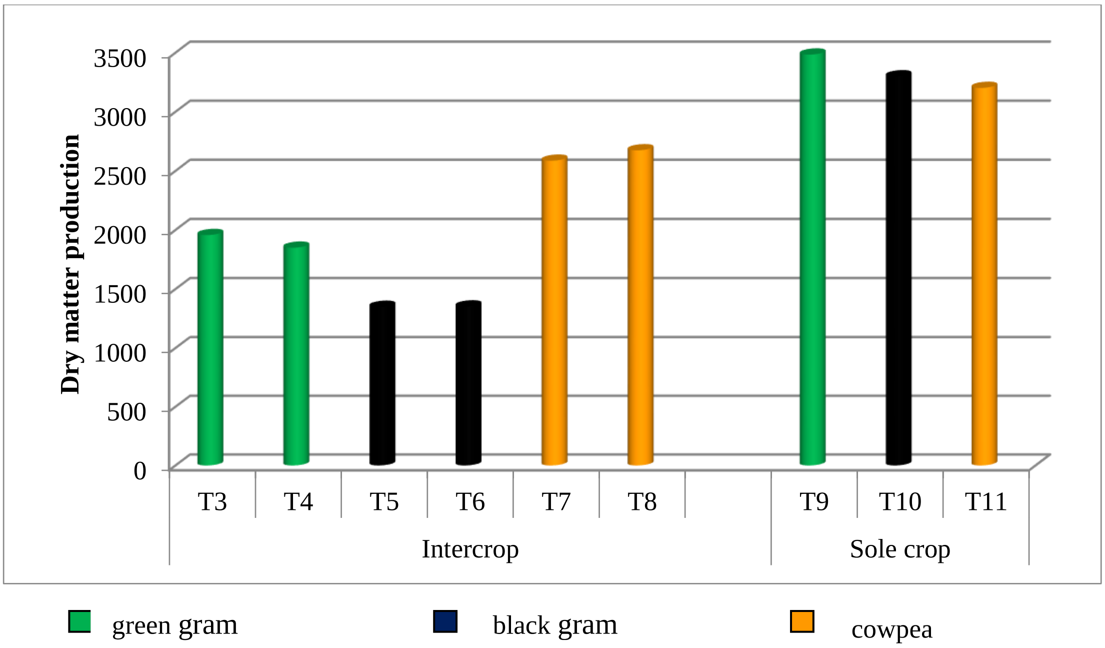

Fig.7. Effect of intercropping on dry matter production of pulses, kg ha^{-1}

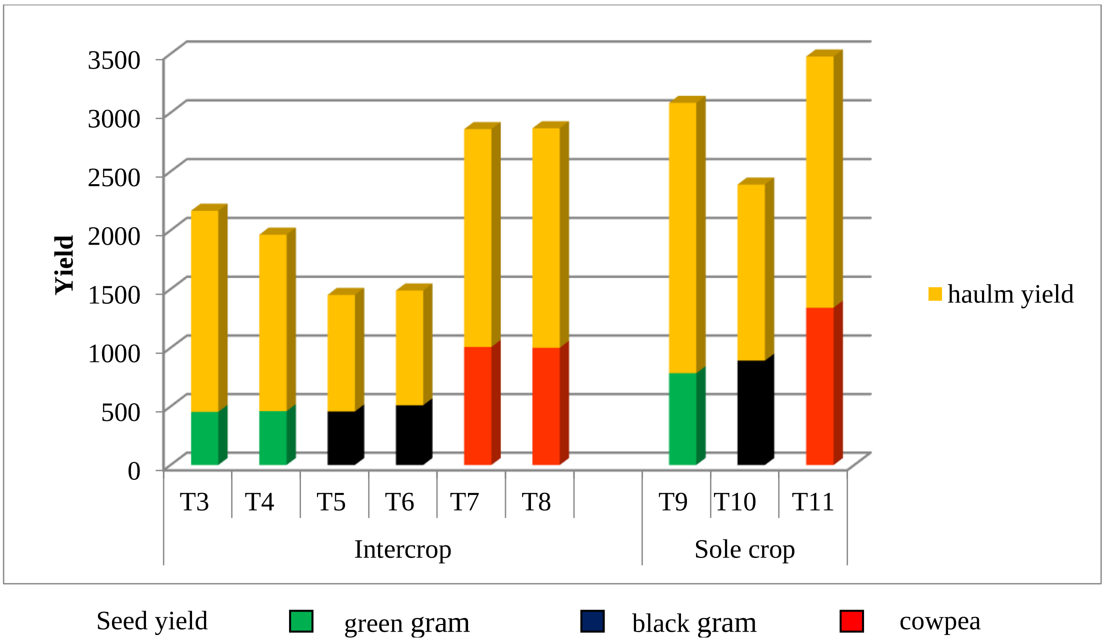

Fig.8. Effect of intercropping on seed yield and haulm yield of pulses, kg ha^{-1}

intercropping. This might have increased the competitive ability of the crops and thereby suppressed the weeds. This is in conformity with the findings of Velayutham *et al*. (2002) and Rathika *et al*. (2013). Further, the fast growing nature of the intercropped pulses would also have curtailed the availability of light, thereby inhibiting the germination and growth of weeds. Similar observations were made by Bilalis *et al*. (2010) and Geetha *et al*. (2018). However, the present study revealed that the pulses, *viz*., green gram, black gram and cowpea varied in their weed smothering capacity, with cowpea emerging out as the best competitor against weeds, with higher WSE values than the other two.

Another noteworthy observation that could be made in the present investigation was the decrease in WSE when pulses where intercropped in finger millet inoculated with AMF as compared to the crop without AMF inoculation. The variation in WSE without and with AMF was to the tune of 30.20 per cent for green gram, 29.29 per cent for black gram and 5.99 per cent for cowpea. This pointed towards the possibility of the development of symbiotic relationship between the weeds and AMF. Vatovec *et al*. (2005) have reported about interactions between weeds and AMF. They also observed that the response of weeds to AMF decreased under lower light and temperature. The low light and temperature under the dense canopy of cowpea might have reduced the response of weeds to AMF. This could be the reason for better weed suppression by cowpea than green gram or black gram.

5.4 INTERCROPPING INDICES

5.4.1 Land Equivalent Ratio

Land equivalent ratio (LER) is the relative area required under sole cropping to produce the yield realized under intercropping (Fig.10). LER values greater than unity denotes yield advantage.

Intercropping finger millet (without AMF) + cowpea (T_7) recorded the highest LER (1.59), followed by T_8 (finger millet with AMF + cowpea). Intercropping finger millet with green gram recorded an LER of 1.38 and 1.37 respectively for finger millet without AMF (T_3) and finger millet with AMF (T_4). Comparatively, LER was lower for intercropping black gram in finger millet.

The general observation was that LER which is based on the actual crop yields were greater than unity, signifying that all three intercrops, *viz*., green gram, black gram and cowpea were capable of utilizing the available resources efficiently than expected, compared to their respective sole crop yields. According to Vandermeer (1989), intercrops that result in LER values greater than unity are considered to over yield, gaining their advantage through the 'competitive production principle' and/or the 'facilitative production principle'. The higher LER in intercropping than sole cropping could be attributed to the better utilization of both natural and supplemental resources. Higher LER of intercropping with pulses compared to sole cropping has been reported by Jabbar *et al*. (2009) in direct seeded rice and by Dass and Sudhishri (2010) in finger millet.

5.4.2 Area Time Equivalent Ratio

Area time equivalent ratio is considered as a more realistic index for assessing the yield advantage of intercropping over sole cropping with respect to variation in time taken by the component crops in the intercropping systems (Aasim *et al*., 2008). Thus, when there is notable variation in the growth duration of the component crops, time becomes a crucial element and ATER is regarded as a more suitable index to assess the efficiency of the system (Ofori and Stern, 1987).

The ATER values (Table 18) showed that ATER of all the intercropping systems was lower than LER (Fig.10). This indicated the possibility of over estimation of resource utilization by LER. Bantie (2014) also observed that ATER was free of over estimation of resource utilization on account of variation in duration of the component crops, contrary to LER. ATER was recorded to be higher when finger millet was intercropped with cowpea, followed by green gram and black gram. This might be because of the efficient utilization of land, water, light and added nutrients by the finger millet + cowpea intercropping system. Similar results have been reported by Seran and Brintha (2009).

5.4.3 Relative Crowding Coefficient

Relative crowding coefficient (RCC) denoted as 'K' has been recognized as a powerful tool to assess the competitive interactions of species involved in

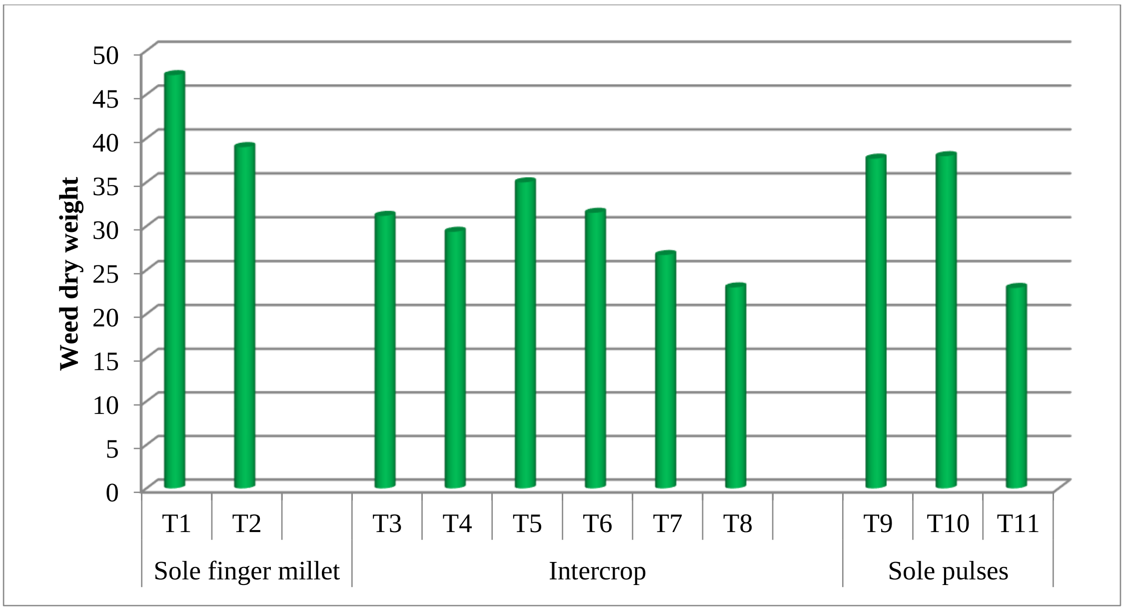

Fig.9. Effect of intercropping on weed dry weight, g m^{-2}

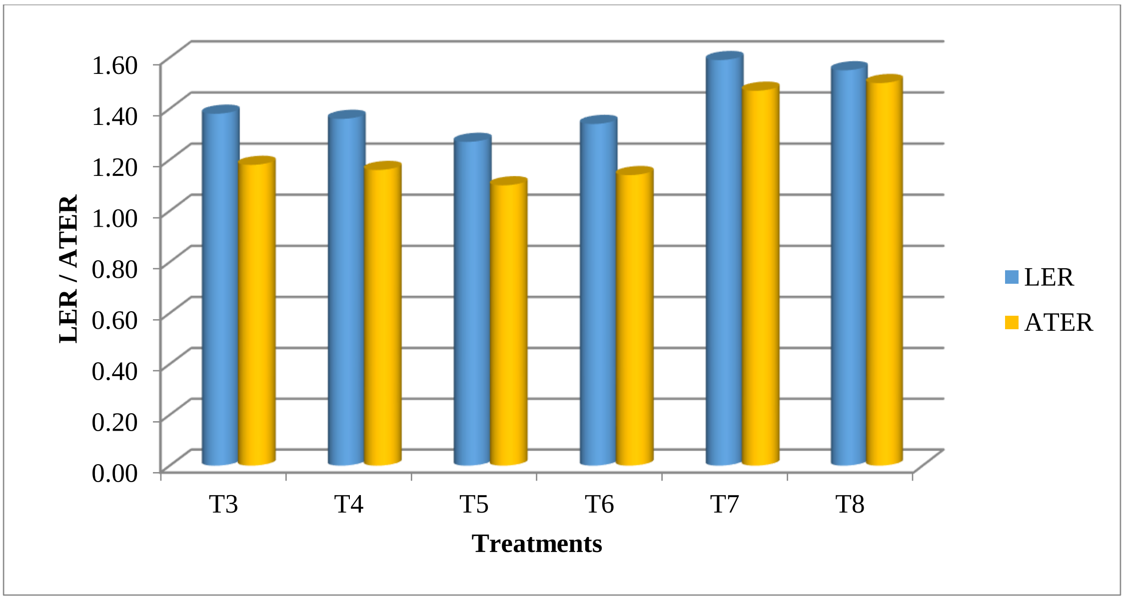

Fig.10. Effect of intercropping on land equivalent ratio (LER) and area time equivalent ratio (ATER)

intercropping systems. The RCC for each crop species provides a measure whether that crop has produced more or less than expected. K values of more than unity denotes yield advantage and vice versa. The component crop with higher K value is judged as the dominant one with higher competitiveness and consequently dominating the other.

It was noted that, in all the intercropping systems evaluated in the present study, green gram, black gram and cowpea recorded higher RCC (K_{pf}) values, indicating their competitiveness and dominance over finger millet. Of the three pulses, cowpea appeared to be the most dominant one with higher K values. Hence it could be inferred that in general, these three pulses and cowpea in particular were capable of utilizing the available resources more competitively and efficiently than finger millet.

Product of the K values of the component crops (K_{fp} x K_{pf}) was greater than one with all the intercropping systems tested, indicating yield advantage. Across the intercropping systems, yield advantage was higher for finger millet + cowpea (T7 and T_8). These results are in conformity with those reported by Mahadkar and Khanvilkar (1988) and Kumar and Ray (2020) who also observed yield advantage in intercropping finger millet with pulses.

5.4.4 Aggressivity

Aggressivity (A) is a focal competitive function used to assess the competitive ability of a crop when grown along with another crop. Aggressivity values with positive (+) sign denotes the dominant species and negative (-) sign denotes the dominated species. When the numerical values are greater, it indicates greater difference in the competitive abilities of the component crops.

The data presented in Table 18 showed that the competitive ability of finger millet and pulses were not equal. All the three pulses exhibited dominant nature as indicated by the positive (+) sign as against the negative (-) sign for finger millet (Fig.11). Aggressivity values were highest (+ 0.54) for finger millet + cowpea. Green gram and black gram were less competitive. The higher aggressivity of cowpea was also evident from its greater ability to suppress weeds. Gomma (1991) and Shahid and

Saeed (1997) have also documented the dominant nature of cowpea, green gram and mashbean in intercropping systems.

5.4.5 Competition Index

Competition index (CI) represents per plant yield of crops in intercropping and their respective sole crop yield on unit area basis. It is the product of two equivalence factors, which when less than unity indicates yield advantage.

The present study revealed that the CI of all the intercropping systems was less than 1. Hence all the systems had yield advantage. Lower values for CI indicate yield advantage. Across the intercropping systems tested, finger millet + cowpea (T_7 and T_8) were observed to be more advantageous with lower values for CI. Similar observations have been made by Keerthanapriya *et al*. (2019), in intercropping little millet with different crops under rainfed conditions.

5.4.6 Competition Ratio

Competition ratio (CR) is another index to measure competition in intercropping systems. It indicates the number of times by which one component crop is more competitive than the other in an intercropping system. It signifies the ratio of individual land equivalent ratios of the component crops and the proportion of component crops in the mixture. Higher CR values points towards more degree of competitiveness.

The higher CR values for pulses, *viz*., green gram, black gram and cowpea than finger millet indicated that the pulses were more competitive than finger millet. Competition ratio was highest (3.71) for T_8 (cowpea grown in combination with finger millet (with AMF), followed by T_7 (3.60). The higher competitiveness of cowpea might be due to the higher LAI and better light interception leading to higher photosynthesis and dry matter accumulation. Lower CR values were recorded by green gram and black gram. Conversely CR of finger millet was observed to be higher when intercropped with green gram and black gram, than with cowpea. In the light of several intercropping experiments, Layek *et al*. (2018) concluded that the CR of cereals and legumes maintained an inverse relationship.

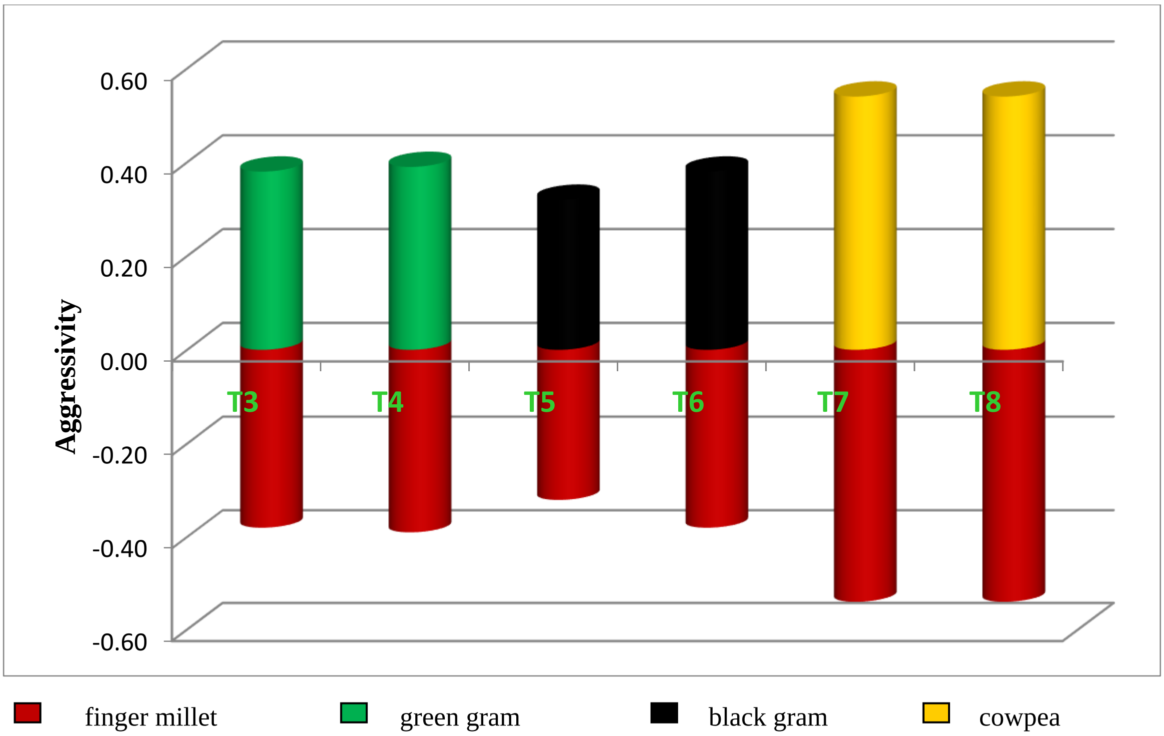

Fig.11. Effect of intercropping on aggressivity of finger millet and pulses

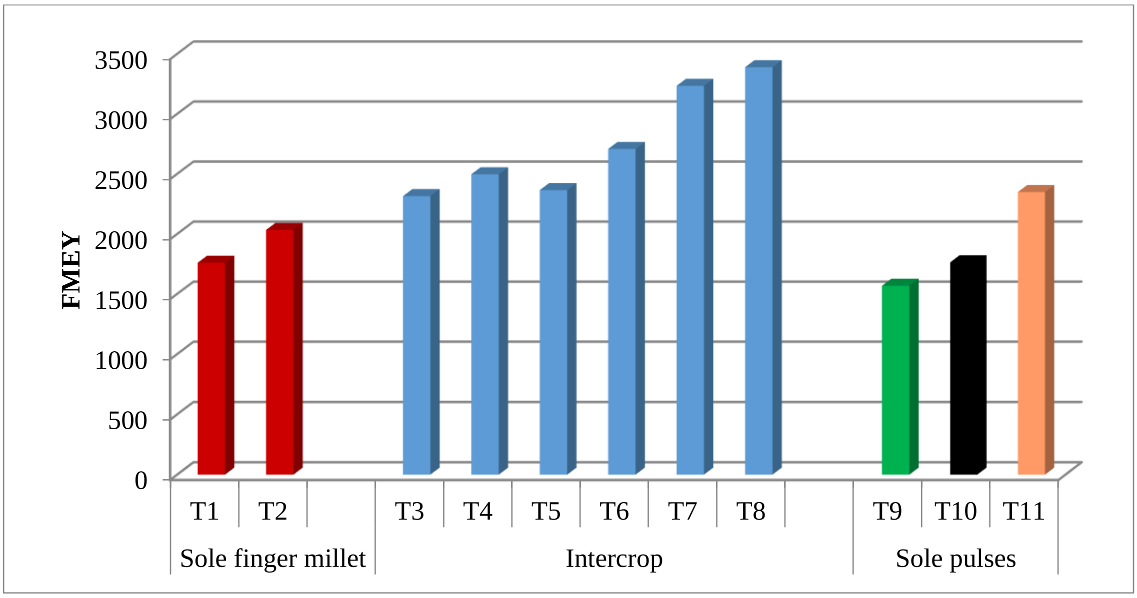

Fig.12. Effect of intercropping on finger millet equivalent yield (FMEY), kg ha^{-1}

5.4.7 Finger Millet Equivalent Yield

Crop equivalent yield has been identified as one among the efficient indices capable of assessing the overall production potential of intercropping systems.

Intercropping finger millet with cowpea produced the highest finger millet equivalent yield (FMEY) followed by intercropping with black gram and green gram (Fig.12). The treatment, T_8 (finger millet with AMF + cowpea) registered the highest FMEY (3388 kg ha^{-1}) followed by T_7 (3234 kg ha^{-1}). Irrespective of the pulse intercropped, AMF inoculation in finger millet enhanced the FMEY of the intercropping systems. In spite of higher market price of green gram and black gram, the higher FMEY recorded with cowpea might be due to higher yield realized in the finger millet + cowpea intercropping system, through better utilization of the available resources. Higher FMEY in intercropping revealed the fact that the overall productivity was higher for intercropping than sole cropping of finger millet.

5.4.8 Percentage Yield Difference

Percentage yield difference (PYD) is defined as the yield difference between sole crop in pure stand and intercrop (s), expressed in percentage. Irrespective of the proportion of crops, planting time and planting geometry, the reduction in yield of one crop gets compensated with increase in yield of the other.

It was worthy to note that PYD followed the same trend as LER, with T_7 (finger millet without AMF + cowpea) having the highest value (58.61%) followed by T_8 (finger millet with AMF + cowpea). This pointed towards the fact that the yield reduction of finger millet was compensated by increase in yield of cowpea. Since, PYD followed the same trend as LER and ATER, finger millet + cowpea resulted in higher intercropping efficiency, both in land and time dimensions. These results are in conformity with response of maize + cowpea intercropping, reported by Afe and Atanda (2015).

5.5 PLANT ANALYSIS

5.5.1 Nutrient Uptake

Component crop wise analysis revealed that sole crops of finger millet and pulses recorded higher uptake of nitrogen, phosphorus and potassium (Fig.13). This was a reflection of the higher total dry matter production of sole crops by virtue of higher plant density under sole cropping, compared to intercropping. Nutrient uptake is a function of total dry matter production and nutrient content in plants. Hence the higher dry matter production recorded in the sole crops might have contributed to the higher nutrient uptake also. Linear relation between dry matter production and nutrient uptake has been reported previously by Salvi *et al*. (2014). Pulses intercropped in finger millet inoculated with AMF resulted in higher nutrient uptake. Hyphal network of AMF allied with roots of one plant is capable of infecting the roots of other plants growing in its vicinity (Newman, 1988). Thus AMF inoculation in finger millet might have benefitted the intercropped pulses also.

Perusal of data on the total uptake of nitrogen, phosphorus and potassium revealed the superiority intercropping over sole cropping. Across the intercropping treatments, T_8 (finger millet with AMF + cowpea) followed by T_7 (finger millet without AMF + cowpea) proved superior. The higher dry matter production might be one of the reasons for higher nutrient uptake, as explained earlier. Further among the three pulses intercropped, cowpea might have had a perfectly co-ordinated interspecies interaction with finger millet, resulting in improved sharing of resources and temporal optimization leading to better growth and nutrient uptake, as suggested by Wang *et al*. (2018).

Regardless of the intercropping system, inoculating finger millet with AMF resulted in higher uptake of nitrogen, phosphorus and potassium. AMF has been reported to increase the absorbing capacity of roots and thereby improve nutrient uptake (Bisleski, 1973). Further, Harley and Smith (1983) have also highlighted the association between AM symbiosis and increased nutrient uptake by the hyphae from the soil. Sitaramaiah *et al*. (1998) and Mallik (2000) have also reported that the principal advantage of AMF is its capacity to explore soil extensively and increase the uptake of N, P and K.

5.5.2 Crude Protein

Crude protein content of finger millet and pulses was higher in the presence of AMF. The positive effect of AMF in improving nutrient acquisition by plants has been discussed earlier. Protein content in seeds has been reported to be highly

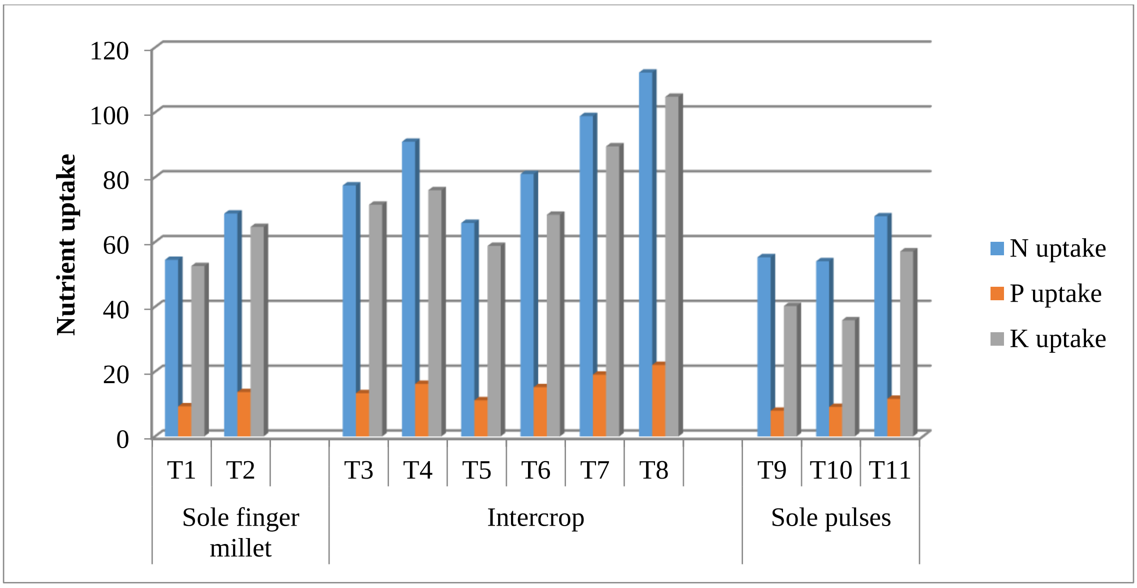

Fig.13. Effect of intercropping on uptake of nitrogen, phosphorus and potassium, kg ha^{-1}

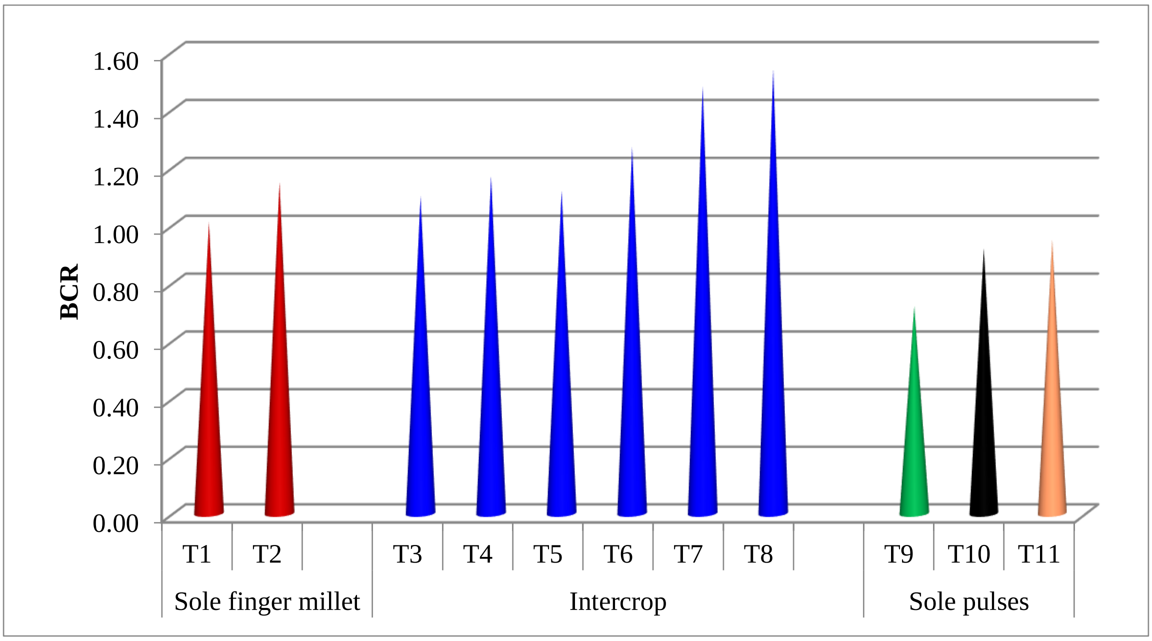

Fig.14. Effect of intercropping on benefit cost ratio (BCR)

correlated with the phosphorus availability and uptake by crops (Al-Karaki and Clark, 2000). Role of mycorrhiza in increasing phosphorus availability and content in plants has been documented by Al-Karaki *et al*. (2004). Thus, the better phosphorus nutrition mediated by AMF might have contributed towards high crude protein content.

5.6 SOIL ANALYSIS

Soil analysis after the experiment failed to exhibit significant variation in organic carbon, soil reaction (pH), electrical conductivity and available potassium.

Compared to finger millet, available nitrogen status of the soil was observed to be higher after pulses and finger millet + pulses. Sole crop of cowpea was observed to leave the soil more fertile with respect to available nitrogen. This could be linked to the report of Jensen *et al*. (2020) which states that sole and intercropped grain legumes fixed an additional 126 and 68 kg N ha^{-1}.

Intercropping pulses and cereals / millets has been identified to possess potential to improve the use efficiency of nitrogen sources on account of competitive, complementary and facilitative interactions between them. Competitive interactions result in non-proportional sharing of nitrogen between cereals and pulses (Jensen, 1996). As a result cereals acquire much larger portion of the soil nitrogen and the pulse compensates this through nitrogen fixation (Hauggaard-Nielsen *et al*., 2008). Peoples *et al*. (1995) had also reported that pulses generally take more than half of their nitrogen requirements from the atmosphere and hence place less demand on the soil for nitrogen, compared to cereals and millets. An additional advantage of intercropping has been identified as its ability to reduce leaching of nitrates to the tune of 10 to 16 per cent (Hauggaard-Nielsen *et al*., 2003a). The self-regulation capacity of cereal-legume mixtures reduce the quantity of reactive nitrogen in the soil and thereby reduce leaching and denitrification losses of nitrogen (Chapman *et al*., 1996).

The available phosphorus of soil was higher and comparable after the sole crops of green gram, black gram and cowpea. This could be attributed to the lower uptake of phosphorus by the sole crops of pulses compared to the intercrops. Across the intercropping systems, the treatment, T_6 (finger millet with AMF + black gram) resulted in significantly higher available phosphorus and remained at par with T_3 and

T_8. A definite trend was not observed in the available phosphorus status, possibly due to phosphorus fixation.

5.7 ECONOMIC ANALYSIS

Intercropping, irrespective of the type of pulse resulted in higher gross returns, net returns and benefit cost ratio (Fig.14) than sole crops of finger millet and pulses. Across the different intercropping treatments, T_8 (finger millet with AMF + cowpea) resulted in higher gross returns and net returns, followed by T_7 (finger millet without AMF + cowpea). The higher returns realized from intercropping justified the hypothesis that though the yield of finger millet would be reduced under intercropping, higher monetary returns could be expected by the positive interaction between finger millet and pulses. Cowpea was observed to be the remunerative intercrop for finger millet.

Monetary equivalent ratio (MER) is the sum of the ratio of monetary returns of intercrop to highest sole crop monetary returns from the land area occupied by the intercrops per unit time. Intercropping systems with monetary equivalent ratio of more than 1 are considered as remunerative (Adetiloye and Adekunle, 1989). Finger millet intercropped with cowpea showed higher MER, than intercropping green gram or black gram. Further, the highest MER was obtained with intercropping cowpea in finger millet inoculated with AMF.

The present study revealed that inoculating finger millet with AMF enhanced the competitiveness of finger millet as evidenced by the comparatively lower reduction in yield under intercropping. Further, intercropping finger millet with pulses, in general and with cowpea, in particular resulted in higher productivity and economic returns than sole crops of finger millet and pulses.

Summary

6. SUMMARY

The study on "Productivity and biological efficiency of intercropping finger millet (*Eleusine coracana* (L.) Gaertn.) with pulses" was carried out, at the Integrated Farming System Research Station (IFSRS), Karamana, Thiruvananthapuram, Kerala, during the period from February to May 2020, with the objectives to assess the productivity of intercropping finger millet with pulses, to study the effect of arbuscular mycorrhizal fungi (AMF) on the performance of finger millet under intercropping and to work out the biological efficiency and economics of the intercropping systems. The study was carried out in randomised block design with 11 treatments, replicated thrice. The treatments were : T_1 – finger millet as sole crop (without AMF); T_2 – finger millet as sole crop (with AMF); T_3 – finger millet (without AMF) + green gram; T_4 – finger millet (with AMF) + green gram; T_5 – finger millet (without AMF) + black gram; T_6 – finger millet (with AMF) + black gram; T_7 – finger millet (without AMF) + cowpea; T_8 – finger millet (with AMF) + cowpea; T_9 –green gram as sole crop; T_{10} – black gram as sole crop; T_{11} – cowpea as sole crop.

The results of the study revealed that intercropping had significant effect on the growth and growth attributes of finger millet. The effect of intercropping on plant height and leaf area index (LAI) of finger millet exhibited significance only at 30 days after sowing (DAS). Tiller count was observed to vary significantly with intercropping at 30 and 60 DAS, whereas dry matter production varied significantly at 30 and 60 DAS and at harvest. Plants were significantly taller (17.81 cm) in sole crop of finger millet inoculated with AMF (T_2). The number of tillers was substantially more (2.47 per plant) in sole crop of finger millet when inoculated with AMF (T_2) and T_8 (finger millet with AMF + cowpea) at 30 DAS. Sole crop of finger millet treated with AMF (T_2) also exhibited significantly superior LAI at 30 DAS and dry matter production at all the above growth stages. Crop growth rate and relative growth rate of finger millet were significantly higher in sole crop of finger millet with AMF (T_2), both from 30 to 60 DAS and from 60 DAS to harvest. Between the treatments, with and without AMF, finger millet was observed to respond positively with increase in

tiller production, LAI, total dry matter production, crop growth rate and relative growth rate, in combination with all the three intercropped pulses. No significant variation was observed in the time taken by finger millet to reach 50 per cent flowering and 50 per cent maturity.

Yield attributes of finger millet revealed significant variation in response to intercropping with pulses and AMF application. Productive tiller count, ear length, finger length and grain yield per plant were noted to be significantly higher for sole crop of finger millet treated with AMF (T_2). When the intercropping treatments were compared, it was observed that intercropping finger millet (with AMF) + cowpea (T_8) resulted in higher productive tiller count (2.90 per plant), longer ears (11.47 cm), finger length and higher grain yield per plant (6.16 g). In general, application of AMF was found to show affirmative effect on the yield attributes of finger millet. There was no significant difference in the number of fingers per ear and thousand grain weight, either with sole cropping or with intercropping of finger millet with pulses along with or without AMF. Grain yield (2.03 t ha^{-1}) and straw yield (4.76 t ha^{-1}) were significantly higher when finger millet was raised as sole crop with AMF application. Among the intercrops, finger millet (with AMF) + cowpea (T_8) resulted in significantly superior grain yield and straw yield. Superiority of AMF application to finger millet with respect to yield was evidenced by the higher grain yield and straw yield registered with these treatments, irrespective of sole cropping or intercropping.

Growth and growth attributes of pulses, *viz.*, green gram, black gram and cowpea varied significantly when intercropped with finger millet. Significantly taller plants were observed in sole crop of green gram at 60 DAS and harvest and in black gram at 60 DAS. However, significantly taller plants of cowpea at 60 DAS was recorded in T_8 (finger millet with AMF + cowpea), which was comparable with cowpea as sole crop (T_{11}). The number of primary branches per plant of black gram varied significantly with intercropping, whereas green gram and cowpea failed to elicit any variation in the number of primary branches. Sole crop of black gram (T_{10}) had considerably more number of primary branches at 60 DAS (5.40 per plant) and harvest (7.38 per plant), which was comparable with the count of primary branches per plant recorded when black gram was intercropped to finger millet (with AMF) (T_6).

Leaf area index was observed to be superior in the sole crop of pulses. Across the intercropping treatments, intercropping of finger millet (with AMF) with pulses resulted in significantly superior LAI. Similar trend was observed with respect to dry matter production. Rooting depth of green gram (37.08 cm) intercropped with finger millet was found to be significantly more, whereas significantly longer roots were observed with the sole crop of black gram and cowpea. Significantly superior root volume (3.48 cm^3 per plant), was recorded in green gram intercropped in finger millet (with AMF) (T_4), whereas the sole crop of black gram and cowpea produced significantly superior root volume. In general, among the three pulses tested, rooting depth and root volume was observed to be more for cowpea when compared to green gram and black gram. A similar trend was observed with the number of nodules per plant in green gram and black gram. Cowpea did not show variation in the number of nodules per plant, in response to intercropping.

Yield attributes and yield of pulses also varied significantly. The number of pods per plant and number of seeds per pod were significantly more in sole crop of green gram, whereas no significant variation was observed in black gram with respect to the number of seeds per pod. In the case of cowpea, intercropping in finger millet (with AMF) (T_8) was observed to register significantly more number of seeds per pod (11.80). However no variation could be observed in the number of pods per plant between intercropping and sole cropping of cowpea. Seed yield, haulm yield and harvest index were observed to be significantly superior with the sole crop of all the three pulses, *viz*., green gram, black gram and cowpea.

Sole crop of cowpea (T_{11}) resulted in significantly lower weed density (98.62 m^{-2}) and weed dry weight (22.97 g m^{-2}). Finger millet inoculated with AMF recorded lower weed dry weight, irrespective of the pulse intercropped whereas weed density did not show significant variation with AMF application. Intercropping, in general exhibited a higher weed smothering (WSE) than sole cropping. WSE was the highest for T_7 (finger millet without AMF + cowpea), followed by T_8. Irrespective of the pulse intercropped, WSE showed lower values when finger millet was inoculated with AMF. However, the degree of variation between WSE with and without AMF was lesser for intercropping with cowpea.

Land equivalent ratio (LER) was observed to be highest (1.59) for T_7 (finger millet without AMF + cowpea). Relative crowding coefficient (RCC) was higher for T_7 (finger millet without AMF + cowpea) and T_8 (finger millet with AMF + cowpea). Area time equivalent ratio (ATER) and percentage yield difference (PYD) were also higher in T_8. Considering the intercropping of finger millet with pulses, all the three pulses exhibited their dominant behavior as indicated by the positive (+) aggressivity, which was the highest (+ 0.54) for cowpea intercropped with finger millet (T_7 and T_8). Lower competition indices of 0.041 (T_7) and 0.050 (T_8) were observed for intercropping finger millet with cowpea. Competition ratio (CR) was higher for T_7 and T_8. Finger millet (with AMF) + cowpea (T_8) had the highest (3388 kg ha^{-1}) finger millet equivalent yield (FMEY) followed by finger millet (without AMF) + cowpea (T_7). It was observed that inoculating finger millet with AMF enhanced FMEY, irrespective of the pulse intercropped.

Sole crop of finger millet with AMF (T_2) exported significantly higher nitrogen, whereas among the intercrops, sole crop of cowpea resulted in significantly superior nitrogen uptake. Total nitrogen uptake was significantly higher (112.26 kg ha^{-1}) in T_8 (finger millet with AMF + cowpea). Irrespective of the pulse intercropped, AMF inoculation had a pronounced effect on nitrogen uptake. Substantially higher phosphorus uptake (13.68 kg ha^{-1}) was observed for sole crop of finger millet (with AMF) (T_2). Among the three pulses raised as intercrop, cowpea had significantly higher phosphorus uptake (9.97 kg ha^{-1}) when intercropped in finger millet with AMF (T_8). Total phosphorus uptake was also significantly higher in T_8. Uptake of potassium by finger millet and the total potassium uptake showed similar results as nitrogen and phosphorus. However, the uptake of potassium was significantly higher with the sole crop of cowpea. The effect of intercropping on crude protein content followed the same trend as nitrogen uptake.

Neither intercropping nor sole cropping had significant effect on the organic carbon, soil reaction, electrical conductivity and available potassium content of soil after the experiment. Sole crop of cowpea resulted in significantly higher available nitrogen content in soil after the experiment. Among the intercropping systems, T_8 (finger millet with AMF + cowpea) resulted in considerably higher available nitrogen in soil after the crop. Available phosphorus content was observed to be comparable after the sole crops of green gram, black gram and cowpea. Considering the intercropping systems, the treatment, T_6 (finger millet with AMF + black gram) resulted in significantly higher available phosphorus and remained at par with T_3 and T_8.

Gross returns and net returns were observed to be significantly superior in T_8 (finger millet with AMF + cowpea). Application of AMF to finger millet resulted in higher net returns than finger millet without AMF. Benefit cost ratio also followed a similar trend. Higher monetary equivalent ratio (MER) was elicited when cowpea was intercropped in finger millet with AMF (T_8). However, least MER was observed with T_3.

The present study revealed that intercropping finger millet with pulses resulted in higher overall productivity. Inoculating finger millet with AMF at the rate of 10 kg ha^{-1} enhanced the growth and yield of the crop. Intercropping cowpea in finger millet (inoculated with AMF) in the ratio 4 :1, resulted in higher crop equivalent yield and economics.

FUTURE LINE OF WORK

- The extent and degree of root colonisation by AMF may be investigated in finger millet, intercrops and weed flora.
- Productivity of intercropping finger millet can be tested with other short duration crops.
- The effect of intercropping on the nutritional quality of finger millet may be investigated.
- The feasibility of raising finger millet as intercrop in coconut garden could be explored.

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7. REFERENCES

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Appendices

APPENDIX I

Weather data during the cropping period

(February to May, 2020)

Standard week	Temperature (^{o}C)		Relative humidity (%)		Rainfall (mm)
	Maximum	Minimum	RH I	RH II	
09	33.1	23.9	95.9	86.0	0.0
10	33.0	23.4	92.7	86.0	8.0
11	33.4	24.6	90.4	82.6	0.0
12	33.4	25.4	92.7	76.4	8.6
13	32.9	24.9	93.6	81.9	0.0
14	33.4	26.9	89.3	86.1	4.3
15	33.4	25.1	88.2	83.4	9.6
16	33.7	26.7	81.6	72.2	12.0
17	34.1	25.2	84.4	83.1	74.1
18	32.9	25.4	83.9	72.4	21.8
19	32.6	26.0	79.4	69.0	0.0
20	33.0	26.8	82.7	68.7	0.0
21	32.8	25.8	84.4	75.9	73.2
22	32.4	26.4	86.8	73.8	0.0

APPENDIX II

Average input cost and market price of produce

Sl. No	Items	Cost (₹)
I	**INPUT**	
A	Seed	
	Finger millet	90 per kg
	Green gram	180 per kg
	Black gram	180 per kg
	Cowpea	300 per kg
B	Labour	
	Man	700 per day
	Woman	500 per day
C	Manures, fertilizers and AMF	
	FYM	5 per kg
	Lime	15 per kg
	Urea	8 per kg
	Rock phosphate	10 per kg
	Muriate of potash	17 per kg
	AMF	75 per kg
II	**OUTPUT**	
	Market price of finger millet	40 per kg
	Market price of green gram	80 per kg
	Market price of black gram	90 per kg
	Market price of cowpea	70 per kg

PRODUCTIVITY AND BIOLOGICAL EFFICIENCY OF INTERCROPPING FINGER MILLET (*Eleusine coracana* (L.) Gaertn.) WITH PULSES

by

DHIMMAGUDI RAMAMOHAN REDDY

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ABSTRACT

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ABSTRACT

The study entitled "Productivity and biological efficiency of intercropping finger millet (*Eleusine coracana* (L.) Gaertn.) with pulses" was undertaken at College of Agriculture, Vellayani, during 2018 – 2020. The main objectives were to assess the productivity of intercropping finger millet with pulses, to study the effect of arbuscular mycorrhizal fungi (AMF) on the performance of finger millet under intercropping and to work out the biological efficiency and economics of the intercropping systems.

The field experiment was carried out at the Integrated Farming System Research Station, Karamana, during February to May 2020. The study comprised intercropping finger millet (var. PPR 2700) with three pulses, *viz*., green gram (var. CO 8), black gram (var. DU 1) and cowpea (var. Kanakamony), in the ratio 4:1. Finger millet was raised with and without AMF. The experiment was laid out in randomised block design with 11 treatments, replicated thrice. The treatments were T_1 – finger millet as sole crop (without AMF), T_2 – finger millet as sole crop (with AMF), T_3 – finger millet (without AMF) + green gram; T_4 – finger millet (with AMF) + green gram, T_5 – finger millet (without AMF) + black gram, T_6 – finger millet (with AMF) + black gram, T_7 – finger millet (without AMF) + cowpea, T_8 – finger millet (with AMF) + cowpea and T_9, T_{10} and T_{11} were sole crops of green gram, black gram and cowpea respectively.

The results of the study revealed that sole crop of finger millet inoculated with AMF (T_2) resulted in significantly taller plants, higher tiller count, leaf area index (LAI), dry matter production, crop growth rate, relative growth rate, productive tiller count, ear length, finger length, grain yield per plant, grain yield (2.03 t ha^{-1}) and straw yield (4.76 t ha^{-1}). Among the intercropping systems tested, T_8 (finger millet with AMF + cowpea) produced higher productive tiller count (2.90 per plant), longer ears (11.47 cm), finger length, grain yield per plant, grain yield (1.64 t ha^{-1}) and straw yield (3.82 t ha^{-1}).

Growth, growth attributes, yield attributes and yield of pulses varied significantly with intercropping. Leaf area index was superior with sole cropping. Among the intercropping treatments, intercropping of finger millet (with AMF) +

pulses resulted in significantly superior LAI and dry matter production. In general, among the three pulses tested, rooting depth and root volume were higher for cowpea than green gram and black gram. Number of pods per plant and number of seeds per pod were significantly more in sole crop of green gram. In the case of cowpea, T_8 produced significantly more number of seeds per pod. Seed yield, haulm yield and harvest index were observed to be significantly superior for the sole crop of pulses. .

Sole crop of cowpea (T_{11}) resulted in significantly lower weed density (98.62 m^{-2}) and weed dry weight (22.97 g m^{-2}). Finger millet inoculated with AMF recorded lower weed dry weight, irrespective of the pulse intercropped. Weed smothering efficiency was the highest for finger millet intercropped with cowpea.

Land equivalent ratio (1.59) and relative crowding coefficient (16.01) were the highest for T_7, followed by T_8. While area time equivalent ratio and percentage yield difference were higher in T_8, competition index was lower. All the three pulses exhibited dominance as indicated by positive (+) aggressivity, the highest being for cowpea (+ 0.54). Competition ratio also followed the same trend. Finger millet (with AMF) + cowpea (T_8) had the highest (3388 kg ha^{-1}) finger millet equivalent yield (FMEY) followed by T_7. Irrespective of the pulse intercropped, inoculating finger millet with AMF enhanced the FMEY.

The treatment, T_8 (finger millet with AMF + cowpea) resulted in significantly higher uptake of nitrogen, phosphorus and potassium. Sole crop of cowpea registered significantly higher available nitrogen content in soil after the experiment. Among the intercropping systems, T_8 and T_6 resulted in considerably higher available nitrogen and available phosphorus respectively.

Gross returns, net returns and monetary equivalent ratio were higher in T_8 (finger millet with AMF + cowpea). Inoculating finger millet with AMF resulted in higher net returns and benefit cost ratio.

The present study revealed that intercropping finger millet with pulses resulted in higher overall productivity. Inoculating finger millet with AMF at the rate of 10 kg ha^{-1} enhanced the growth and yield of the crop. Intercropping cowpea in finger millet (inoculated with AMF) in the ratio 4:1, resulted in higher crop equivalent yield and economics.