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Eco-friendly Approach for Efficient Utilization of Growth Resources as Influenced by Integrated Nutrient Management in Cotton and Soybean Intercropping System

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Authors' contributions

This work was carried out in collaboration between all authors. Author AMP designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors VVA and DNK managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

Field experiment was conducted to study the integrated nutrient management on resource use efficiency of system, soil moisture content and available soil nutrients in cotton and soybean intercropping system. The experiment was conducted at plot number '101' of 'D' block, All India Coordinated Research Project on soybean, Main Agricultural Research Station, University of Agricultural Sciences, Dharwad, Karnataka (India) during *kharif* 2015 and 2016. According to the treatments, the organic manure (FYM) and green leaf manures (gliricidia and pongamia) were applied 15 days before sowing of the crop. Vermicompost was spot applied to soil before dibbling

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of seeds in cotton and soybean intercropping system in 1:2 row proportion, soybean introduced as intercrop in cotton with row spacing of cotton 120 cm and soybean 30 cm.
The highest canopy index was observed in T_3 and all the INM treatments were superior over T_1 (100 % RDF for cotton and soybean), except in T_4 in 2016-17. The higher system productivity index was observed in T_3 (150 % RDF for cotton and soybean), T_2 (125 % RDF for cotton and soybean) and T_{17} (T_1 + Vermicompost 1.25 t ha^{-1} + Gliricidia 2.5 t ha^{-1}). This proved that T_3, T_2 and T_{17} were more beneficial over others in increasing the productivity of intercropping system. Soil moisture content did not differ significantly due to INM treatments during both the years and in pooled data at all stages. Maximum water holding capacity (Maximum WHC) differed significantly due to INM treatments during both the years and in pooled data. Integrated nutrient management improved the available nutrient status in the soil.
Integrated nutrient management ensures better availability of moisture, nutrients and improved the performance of cotton and soybean intercropping system. Farmers can adopt a fertilizer dose of 125 : 62.5 : 62.5 N, P_2O and K_2O kg ha^{-1} in cotton and soybean intercropping system or 100 : 50 : 50 N, P_2O_5 and K_2O kg ha^{-1} along with Gliricidia + Pongamia 2.5 t ha^{-1} each for cotton and soybean intercropping for profitable yields.

Keywords: Canopy index; system productivity index; integrated nutrient management; cotton and soybean intercropping system.

1. INTRODUCTION

Agricultural productivity mainly depends on the factors that are efficiently used in the production process. Therefore, intensification of agricultural land and expansion of technology use must be accompanied by resource use efficiency that enhances productivity. Resource use efficiency is a holistic approach to resource use and environmental management that seeks to identify and implement activities that reduce energy, water and other resource use and to minimize waste [1]. Cotton (*Gossypium sp.)* is one of the most important textile fibers in the world, accounting for around 35 percent of total world fiber use. It is a major cash crop in the world and cultivated commercially in more than 50 countries. World cotton area is almost stagnant from last five decades but production has been markedly increased because of steep rise in productivity due to introduction of insect resistant transgenic technology *i.e. Bacillus thuringiensis* (Bt) particularly in Asian countries like India, China and Pakistan. Climate change impacts agriculture by the need to develop existing practices, including field cropping, to minimize greenhouse gas emissions and thus meet the mitigation strategy for climate change. Farmers must adapt agronomic technologies to overcome the impacts of climate change to secure sufficient food production for the growing world population. Intercropping represents a within-field diversification strategy that is based on ecological intensification. To meet the projected target of cotton production by 2025 A.D. many approaches were evaluated, among them intercropping, an agronomic approach was found to be better way. Intercropping helps in the total production of different commodities with higher returns under dryland conditions, besides better utilization of natural and scarce resources per unit time [2]. Companion crops under intercropping use growth resources differently when grown together and complement sometimes each other and make better overall use of resources when compared to sole crops. Intercropping of cotton with short duration legume like soybean was found more remunerative than sole cotton [3] and [4]. The increased productivity per acreage in intercropping can also contribute to higher soil organic matter accumulation and carbon sequestration [5], which is important for greenhouse gas mitigation in agriculture in low-carbon soils. Intercropping in cotton may also have adverse effect on the cotton crop, but could be adequately compensated by the extra yield from intercrops. Application of organic manures along with inorganic fertilizers helps to rejuvenate the degraded soils and ensures sustainability in crop production. Suitable management practices like intercropping and judicious combination of organic and inorganic manures are considered ecologically viable, economically feasible and avoid environmental pollution. In addition, combination of organic and inorganic manures works like slow release fertilizers for providing balanced nutrients to plants. Considering these facts in view the present study was undertaken.

2. MATERIALS AND METHODS

Two years field experiment was carried out to study the INM practices on resource use

efficiency, soil moisture and availability of nutrients in soil with 1:2 row proportion during *kharif* 2015 and 2016 at plot 101 'D' block, All India Co-ordinated Research Project on Soybean, Main Agricultural Research Station, University of Agricultural Sciences, Dharwad, Karnataka (India), which is located at latitude of 15^0 26' N and 75^0 07' E longitude with an altitude of 678 m above mean sea level. Soil was clay with pH 7.3, 0.51% organic carbon, 281 kg ha^{-1} available N, 34 kg ha^{-1} available P_2O_5 and 312 kg ha^{-1} available K_2O and 0.35 dsm^{-1} EC. The physical and chemical properties of soil before sowing were furnished in the Table 1. The experiment was laid out in randomised complete block design with three replications and twenty treatments as given in the tables. Sowing was done by adopting 120 cm x 60 cm row spacing for cotton and soybean introduced as intercrop with 40 cm x 10 cm in 1:2 row proportions during *kharif* season on 9.7.2015 and 12.6.2016. Organic manure (FYM) and green leaf manures (gliricidia and pongamia) were applied 15 days before sowing of the crop according to the treatments. Vermicompost was spot applied to soil before dibbling of seeds. RDF was applied to both crops in intercropping system according to population (100:50:50 and 40:80:25 kg N, P_2O_5 and K_2O ha^{-1} for Cotton and Soybean, respectively).

2.1 System Productivity Index

2.1.1 Canopy index

Canopy index was worked out by using following formula as indicated by [9].

$$CI = \frac{\text{Leaf area of both the crops}}{\text{Land area of both the crops}}$$

CI = Sum of all LAI of crops in intercropping system

2.1.2 System productivity index (SPI)

System productivity index standardizes the yield of intercrop in terms of that of sole crop. SPI was calculated according to the formula of [9].

$$SPI = \left(\frac{S_A}{L_B} \right) \times L_b + S_a$$

Where, S_A and L_B are the mean yields of sole crops and S_a and L_b are their yields in intercropping.

2.2 Soil Moisture Content

The soil moisture content in volume basis was measured from 0 to 30 cm and 30 to 60 cm depth using theta probe at 30, 60 and 90 DAS and at harvest in cotton and and soybean intercropping system and expressed in percentage on volume basis (%).

2.3 Available Soil Nutrients

Available nitrogen in the soil was estimated by modified alkaline permanganate method [10]. The available phosphorus in the soil samples was extracted with Olsen's reagent (0.5 N $NaHCO_3$). Available potassium in soil was extracted by neutral normal ammonium acetate and subsequent estimation was by flame photometer [8].

2.4 Statistical Analysis and Interpretation of Data

Statistical analysis was carried out based on mean values obtained. The level of significance used in 'F' and 'T' test was P= 0.05. The treatment means were compared by Duncan's Multiple Range Test (DMRT) at 0.05 level of probability [7].

3. RESULTS AND DISCUSSION

3.1 Canopy Index and System Productivity Index (SPI)

Canopy index differed significantly due to INM treatments during both the years (Table 2). Among the different treatments, T_3 (150 % RDF for cotton and soybean) recorded the highest canopy index during both years and in pooled data. The results are in agreement with the findings of [11], where higher canopy index was in combined application of organic and in organic nutrients. In the present study, higher system productivity index was observed in T_3, T_2 and T_{17}. SPI differed significantly due to INM treatments during both the years (Table 2). Among the intercropping systems, T_3 (150 % RDF for cotton and soybean) recorded higher SPI and it was on par with T_2 (125 % RDF for cotton and soybean) and T_{17} (T_1 + Vermicompost 1.25 t ha^{-1} + Gliricidia 2.5 t ha^{-1}) during both years and in pooled data. This proved that T_3, T_2 and T_{17} were more beneficial over others in increasing the productivity of intercropping system. This was supported by higher biomass production and leaf

Table 1. Physical and chemical properties of the soil experimental site (0-30 cm depth)

Particulars	Value	Methods employed
1. Physical properties		
Particle size distribution		
Coarse sand (%)	6.25	
Fine sand (%)	14.32	
Silt (%)	27.14	International pipette method [6]
Clay (%)	52.47	
Textural class	Clay	
2. Chemical properties		
Organic carbon (%)	0.51	Walkey and Black method [7]
pH (1:2.5, Soil: Water)	7.30	Potentiometric method using pH meter [7]
Electrical conductivity (dS m^{-1}) at 25^0C	0.35	Conductivity using EC bridge [7]
Available N (kg ha^{-1})	281	Alkaline permanganate method [8]
Available P_2O_5 (kg ha^{-1})	34	Olsen's method [7]
Available K_2O (kg ha^{-1})	312	Flame photometry method [7]

area in these treatments for efficient utilization of solar radiation in the intercropping system. Similar results were observed by Singh et al. (2015), who reported that cotton + peanut intercropping system maintained system productivity index (SPI) of near 25 per cent substitution of RDN through FYM and the highest SPI over other fertility levels. Results are in conformity with the findings of [11] also, who found that application of 50 per cent RDF + vermicompost 1.5 tonnes per hectare recorded higher cotton equivalent yield and SPI over RDF alone.

3.2 Soil Moisture Content

Soil moisture content did not differ significantly due to INM treatments during both the years and in pooled data at all stages (Tables 3 and 4). However at 30 DAS, the highest soil moisture content was recorded in T_{18} (T_1 + Vermicompost 1.25 t ha^{-1} + Pongamia 2.5 t ha^{-1}) during 2015-16 and in pooled data at 0-30 cm depth and T_{16} (T_1 + Gliricidia 2.5 t ha^{-1} + Pongamia 2.5 t ha^{-1}) during 2016-17 and in pooled data at 30-60 cm depth. At 60 DAS, T_3 (150 % RDF for cotton and soybean) recorded the highest soil moisture content during 2015-16 and in pooled data at 0-30 cm depth and T_{15} (T_1 + FYM 2.5 t ha^{-1} + Vermicompost 1.25 t ha^{-1}) during 2016-17 and in pooled data at 30-60 cm depth. At 90 DAS, the highest soil moisture content was recorded in T_{18} during 2015-16 and in pooled data at 0-30 cm depth and T_{17} during 2016-17 and in pooled data at 30-60 cm depth. At harvest, the highest soil moisture content was recorded in T_{18} during 2015-16 and in pooled data at 0-30 and 30-60 cm depth (Tables 3 and 4). INM with green manures reduces evaporation loss of water. It also facilitates better mineralization of nutrients in soil.

3.3 Soil Properties

Use of organic manures along with recommended dose of fertilizers upon releases nutrients present in them on decomposition and help in enriching soil. Biodegradation of manures exerted favorable effect on the release of nutrients, which depended on type, quantity of residues and stage of decomposition [12]. Soil pH did not differ significantly due to INM treatments during both the years and in pooled data (Table 5). Electrical conductivity did not differ significantly due to INM treatments during both the years and in pooled data. Organic carbon (OC) differed significantly due to INM treatments during both the years, except in pooled data (Table 5). Among the different treatments, T_{17} (T_1 + Vermicompost 1.25 t ha^{-1} + Gliricidia 2.5 t ha^{-1}), T_{18} (T_1 + Vermicompost 1.25 t ha^{-1} + Pongamia 2.5 t ha^{-1}) and T_{16} (T_1 + Gliricidia 2.5 t ha^{-1} + Pongamia 2.5 t ha^{-1}) recorded higher OC compared to rest of the intercropping treatments and sole crops during both years. However, OC did not differ significantly due to INM treatments in pooled data. The highest OC value was observed in T_{18} in pooled data. The substantial quantity of addition of organic manures with these treatments enhanced the soil organic carbon over RDF alone. Maximum water holding capacity (Maximum WHC) differed significantly due to INM treatments during both the years and in pooled data (Table 4). Among the different treatments, T_{17} (T_1 + Vermicompost 1.25 t ha^{-1} + Gliricidia 2.5 t ha^{-1}), T_{18} (T_1 + Vermicompost 1.25 t ha^{-1} + Pongamia 2.5 t ha^{-1})

Table 2. Canopy index and system productivity index as influenced by INM in cotton and soybean intercropping system

Treatments	Canopy index			System productivity index		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T_1: 100% RDF for cotton and soybean	4.77f	4.59b	4.68c	2,491i	3,984i	3,238f
T_2: 125% RDF for cotton and soybean	5.19ab	5.36a	5.28a	2,884a	4,266a	3,575ab
T_3: 150% RDF for cotton and soybean	5.24a	5.37a	5.31a	2,896a	4,297a	3,596a
T_4: 100% FYM and RDF for cotton and soybean (RC)	5.19ab	4.59b	4.89bc	2,852ab	4,146de	3,499c
T_5: T_1 + FYM 2.5 t ha^{-1}	5.00de	4.95ab	4.98a-c	2,612f-h	4,052h	3,332e
T_6: T_1 + FYM 5 t ha^{-1}	5.01de	4.99ab	5.00ab	2,632fg	4,061gh	3,347de
T_7: T_1 + Gliricidia 2.5 t ha^{-1}	4.97e	5.11a	5.04ab	2,599gh	4,121d-f	3,360de
T_8: T_1 + Gliricidia 5 t ha^{-1}	4.99de	5.13a	5.06ab	2,619f-h	4,139de	3,379de
T_9: T_1 + Pongamia 2.5 t ha^{-1}	4.95e	5.06a	5.01ab	2,561h	4,084f-h	3,322e
T_{10}: T_1 + Pongamia 5 t ha^{-1}	4.96e	5.09a	5.02ab	2,591gh	4,104e-g	3,348de
T_{11}: T_1 + Vermicompost 1.25 t ha^{-1}	5.05c-e	5.02ab	5.03ab	2,668ef	4,067gh	3,367de
T_{12}: T_1 + Vermicompost 2.5 t ha^{-1}	5.05c-e	5.05a	5.05ab	2,719de	4,079f-h	3,399d
T_{13}: T_1 + FYM 2.5 t ha^{-1} + Gliricidia 2.5 t ha^{-1}	5.13a-c	5.24a	5.19ab	2,782c	4,167cd	3,474c
T_{14}: T_1 + FYM 2.5 t ha^{-1} + Pongamia 2.5 t ha^{-1}	5.09b-d	5.23a	5.16ab	2,775cd	4,165cd	3,470c
T_{15}: T_1 + FYM 2.5 t ha^{-1} + Vermicompost 1.25 t ha^{-1}	5.15a-c	5.21a	5.18ab	2,817bc	4,163cd	3,490c
T_{16}: T_1 + Gliricidia 2.5 t ha^{-1} + Pongamia 2.5 t ha^{-1}	5.09b-d	5.26a	5.17ab	2,792bc	4,207bc	3,500c
T_{17}: T_1 + Vermicompost 1.25 t ha^{-1} + Gliricidia 2.5 t ha^{-1}	5.18ab	5.30a	5.24a	2,855ab	4,254ab	3,555ab
T_{18}: T_1 + Vermicompost 1.25 t ha^{-1} + Pongamia 2.5 t ha^{-1}	5.16a-c	5.02ab	5.09ab	2,840a-c	4,217b	3,528bc
T_{19}: Cotton sole crop (100 % RDF and FYM)	2.60g	2.75c	2.67d	-	-	-
T_{20}: Soybean sole crop (100 % RDF and FYM)	4.77f	4.96ab	4.87bc	-	-	-
Mean	**4.93**	**5.00**	**4.95**	**2,668**	**4,040**	**3,373**
S.Em. ±	**0.03**	**0.13**	**0.21**	**20.8**	**15.6**	**18.4**
C.V. (%)	**2.04**	**4.79**	**3.42**	**8.32**	**9.51**	**8.22**

Means followed by the same letters do not differ significantly (0.05) by DMRT; RC – Recommended Check

Table 3. Soil moisture content (volume basis) at 0 – 30 cm depth as influenced by INM in cotton and soybean intercropping system

Treatments	Soil moisture content (%)											
	30 DAS			60 DAS			90 DAS			At harvest		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T_1: 100% RDF for cotton and soybean	30.1a	32.1a	31.1a	31.6a	32.6a	32.1a	27.1a	28.1a	27.6a	27.0a	28.9a	28.0a
T_2: 125% RDF for cotton and soybean	31.2a	33.4a	32.3a	32.2a	33.3a	32.7a	27.4a	28.4a	27.9a	27.1a	28.6a	27.8a
T_3: 150% RDF for cotton and soybean	31.3a	33.4a	32.4a	34.1a	33.2a	33.6a	27.2a	28.3a	27.7a	26.1a	28.5a	27.3a
T_4: 100% FYM and RDF for cotton and soybean (RC)	32.3a	34.3a	33.3a	32.6a	33.4a	33.0a	30.1a	31.2a	30.7a	29.1a	31.3a	30.2a
T_5: T_1 + FYM 2.5 t ha^{-1}	30.1a	32.1a	31.1a	32.2a	33.1a	32.7a	29.4a	30.5a	29.9a	26.2a	30.2a	28.2a
T_6: T_1 + FYM 5 t ha^{-1}	30.2a	32.3a	31.2a	32.0a	33.0a	32.5a	29.4a	30.4a	29.9a	26.1a	30.2a	28.2a
T_7: T_1 + Gliricidia 2.5 t ha^{-1}	32.4a	34.8a	33.6a	32.2a	33.3a	32.8a	29.5a	30.4a	30.0a	29.0a	31.0a	30.0a
T_8: T_1 + Gliricidia 5 t ha^{-1}	32.5a	35.3a	33.9a	32.2a	33.3a	32.8a	29.6a	31.1a	30.3a	29.7a	31.3a	30.5a
T_9: T_1 + Pongamia 2.5 t ha^{-1}	32.1a	34.3a	33.2a	32.3a	33.2a	32.8a	30.4a	30.5a	30.5a	28.3a	31.3a	29.8a
T_{10}: T_1 + Pongamia 5 t ha^{-1}	32.5a	34.8a	33.7a	32.4a	33.4a	32.9a	29.4a	30.7a	30.0a	28.4a	30.4a	29.4a
T_{11}: T_1 + Vermicompost 1.25 t ha^{-1}	30.4a	35.5a	32.9a	32.1a	33.1a	32.6a	29.4a	30.6a	30.0a	28.0a	30.2a	29.1a
T_{12}: T_1 + Vermicompost 2.5 t ha^{-1}	32.2a	34.5a	33.4a	32.5a	33.3a	32.9a	29.3a	30.2a	29.7a	28.2a	29.3a	28.7a
T_{13}: T_1 + FYM 2.5 t ha^{-1} + Gliricidia 2.5 t ha^{-1}	32.1a	35.1a	33.6a	32.1a	33.8a	33.0a	30.3a	31.4a	30.9a	29.0a	31.2a	30.1a
T_{14}: T_1 + FYM 2.5 t ha^{-1} + Pongamia 2.5 t ha^{-1}	32.1a	35.3a	33.7a	32.3a	33.7a	33.0a	30.1a	31.0a	30.5a	29.2a	31.1a	30.1a
T_{15}: T_1 + FYM 2.5 t ha^{-1} + Vermicompost 1.25 t ha^{-1}	31.4a	34.5a	33.0a	32.3a	33.5a	32.9a	30.1a	30.4a	30.2a	28.2a	31.3a	29.7a
T_{16}: T_1 + Gliricidia 2.5 t ha^{-1} + Pongamia 2.5 t ha^{-1}	31.6a	35.1a	33.4a	32.3a	32.8a	32.6a	30.1a	31.3a	30.7a	28.5a	30.4a	29.5a
T_{17}: T_1 + Vermicompost 1.25 t ha^{-1} + Gliricidia 2.5 t ha^{-1}	31.1a	33.3a	32.2a	31.8a	33.7a	32.8a	30.3a	31.5a	30.9a	29.5a	31.3a	30.4a
T_{18}: T_1 + Vermicompost 1.25 t ha^{-1} + Pongamia 2.5 t ha^{-1}	33.2a	35.1a	34.2a	32.3a	33.1a	32.7a	30.4a	31.4a	30.9a	30.0a	31.3a	30.7a
T_{19}: Cotton sole crop (100 % RDF and FYM)	30.2a	32.3a	31.2a	30.7a	31.4a	31.1a	26.6a	29.1a	27.9a	27.3a	29.2a	28.2a
T_{20}: Soybean sole crop (100 % RDF and FYM)	30.3a	32.3a	31.3a	31.0a	31.0a	31.0a	26.4a	27.4a	26.9a	-	-	-
Mean	**31.5**	**34.0**	**32.8**	**32.2**	**33.1**	**32.7**	**29.1**	**30.2**	**29.8**	**26.8**	**30.4**	**29.31**
S.Em. ±	**2.27**	**1.82**	**2.06**	**1.15**	**0.70**	**0.95**	**1.17**	**1.95**	**1.61**	**1.59**	**1.09**	**1.36**
C.V. (%)	**12.4**	**9.35**	**7.67**	**6.22**	**5.95**	**7.22**	**7.53**	**11.1**	**7.34**	**10.2**	**6.22**	**7.22**

Means followed by the same letters do not differ significantly (0.05) by DMRT; RC – Recommended Check

Table 4. Soil moisture content (volume basis) at 30-60 cm depth as influenced by INM in cotton and soybean intercropping system

Treatments	Soil moisture content (%)											
	30 DAS			60 DAS			90 DAS			At harvest		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T_1: 100% RDF for cotton and soybean	30.3a	33.1a	31.7a	32.1ab	33.4ab	32.7a-c	27.9a	28.3a	28.14	27.4a	28.1b	27.8a
T_2: 125% RDF for cotton and soybean	31.4a	33.6a	32.5a	32.6ab	33.5ab	33.1a-c	28.4a	28.3a	28.4a	27.3a	28.4b	27.8a
T_3: 150% RDF for cotton and soybean	31.5a	33.9a	32.7a	32.5ab	33.5ab	33.0a-c	28.3a	28.7a	28.5a	27.2a	29.4ab	28.3a
T_4: 100% FYM and RDF for cotton and soybean (RC)	33.0a	34.9a	34.0a	33.2a	34.3a	33.7ab	30.5a	32.2a	31.3a	30.1a	32.1a	31.1a
T_5: T_1 + FYM 2.5 t ha^{-1}	30.4a	33.3a	31.9a	32.7a	33.4ab	33.0a-c	30.3a	31.2a	30.7a	29.1a	31.2ab	30.1a
T_6: T_1 + FYM 5 t ha^{-1}	30.6a	33.3a	32.0a	32.6ab	33.4ab	33.0a-c	30.2a	31.4a	30.8a	29.2a	31.2ab	30.2a
T_7: T_1 + Gliricidia 2.5 t ha^{-1}	31.9a	35.3a	33.6a	33.1ab	34.1a	33.6ab	30.4a	32.3a	31.4a	29.4a	32.2a	30.8a
T_8: T_1 + Gliricidia 5 t ha^{-1}	32.1a	35.5a	33.8a	33.3a	34.1a	33.7ab	30.7a	31.6a	31.2a	29.9a	32.3a	31.1a
T_9: T_1 + Pongamia 2.5 t ha^{-1}	32.2a	34.9a	33.6a	33.0a	34.0a	33.5ab	30.5a	31.0a	30.7a	29.8a	31.4ab	30.6a
T_{10}: T_1 + Pongamia 5 t ha^{-1}	32.0a	35.1a	33.6a	32.2a	34.a	33.2ab	30.3a	31.2a	30.8a	29.6a	30.9ab	30.2a
T_{11}: T_1 + Vermicompost 1.25 t ha^{-1}	31.2a	33.4a	32.3a	32.6ab	33.8a	33.2ab	30.2a	31.5a	30.9a	29.4a	31.3ab	30.4a
T_{12}: T_1 + Vermicompost 2.5 t ha^{-1}	32.4a	35.4a	33.9a	33.0ab	34.1a	33.5ab	30.4a	30.9a	30.6a	29.2a	31.5ab	30.3a
T_{13}: T_1 + FYM 2.5 t ha^{-1} + Gliricidia 2.5 t ha^{-1}	33.1a	35.2a	34.2a	33.3a	34.2a	33.7ab	31.12a	32.4a	31.7a	30.2a	32.2a	31.2a
T_{14}: T_1 + FYM 2.5 t ha^{-1} + Pongamia 2.5 t ha^{-1}	33.2a	35.5a	34.4a	33.4a	34.1a	33.8ab	31.9a	32.2a	32.1a	30.5a	32.4a	31.4a
T_{15}: T_1 + FYM 2.5 t ha^{-1} + Vermicompost 1.25 t ha^{-1}	33.1a	35.4a	34.2a	33.3a	34.3a	33.8a	30.2a	32.4a	31.3a	30.2a	32.1a	31.1a
T_{16}: T_1 + Gliricidia 2.5 t ha^{-1} + Pongamia 2.5 t ha^{-1}	33.3a	36.8a	35.0a	32.5a	33.6a	33.0a-c	31.2a	32.4a	31.8a	29.2a	31.3ab	30.2a
T_{17}: T_1 + Vermicompost 1.25 t ha^{-1} + Gliricidia 2.5 t ha^{-1}	32.4a	34.5a	33.5a	32.7ab	33.4ab	33.0a-c	31.2a	33.4a	32.3a	30.2a	32.2a	31.2a
T_{18}: T_1 + Vermicompost 1.25 t ha^{-1} + Pongamia 2.5 t ha^{-1}	33.5a	36.3a	34.9a	32.3b	33.6a	33.0a-c	31.2a	32.3a	31.8a	30.4a	32.3a	31.4a
T_{19}: Cotton sole crop (100 % RDF and FYM)	30.6a	33.2a	31.9a	30.6b	31.3c	30.9c	27.9a	29.1a	28.5a	27.8a	29.3ab	28.6a
T_{20}: Soybean sole crop (100 % RDF and FYM)	31.8a	33.2a	32.5a	31.7ab	31.5bc	31.6bc	28.1a	28.3a	28.2a	-	-	-
Mean	**32.0**	**34.1**	**33.3**	**32.6**	**33.6**	**33.2**	**30.0**	**31.1**	**30.2**	**27.8**	**31.2**	**30.2**
S.Em. ±	**3.11**	**1.31**	**2.39**	**0.67**	**0.62**	**0.64**	**1.52**	**1.55**	**1.54**	**1.54**	**1.01**	**1.30**
C.V. (%)	**16.8**	**10.4**	**7.85**	**6.26**	**5.94**	**6.02**	**8.75**	**8.63**	**6.85**	**9.72**	**6.81**	**7.20**

Means followed by the same letters do not differ significantly (0.05) by DMRT; RC – Recommended Check

Table 5. Soil pH, electrical conductivity, organic carbon and maximum water holding capacity as influenced by INM at the end of each year of experimentation

Treatments	Soil pH			Electrical conductivity (dS m^{-1})			Organic carbon (%)			Maximum water holding capacity (%)		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T_1: 100% RDF for cotton and soybean	7.31a	7.33a	7.32a	0.34a	0.36a	0.35a	0.51gh	0.52e	0.51a	42.1c	43.3gh	42.7c
T_2: 125% RDF for cotton and soybean	7.32a	7.33a	7.32a	0.36a	0.38a	0.37a	0.51gh	0.51e	0.51a	42.1c	43.1h	42.6c
T_3: 150% RDF for cotton and soybean	7.33a	7.36a	7.35a	0.35a	0.39a	0.37a	0.51h	0.51e	0.51a	42.1c	44.0g	43.1c
T_4: 100% FYM and RDF for cotton and soybean (RC)	7.30a	7.30a	7.30a	0.34a	0.35a	0.35a	0.51d-f	0.55b-d	0.53a	45.2ab	47.3b-e	46.2ab
T_5: T_1 + FYM 2.5 t ha^{-1}	7.31a	7.31a	7.31a	0.36a	0.34a	0.35a	0.51f-h	0.55b-d	0.53a	44.3ab	46.7d-f	45.5b
T_6: T_1 + FYM 5 t ha^{-1}	7.32a	7.29a	7.31a	0.34a	0.31a	0.33a	0.51e-h	0.55b-d	0.53a	44.3ab	46.8d-f	45.6b
T_7: T_1 + Gliricidia 2.5 t ha^{-1}	7.30a	7.29a	7.29a	0.32a	0.32a	0.32a	0.51d-g	0.55b-d	0.53a	45.1ab	47.1c-f	46.1ab
T_8: T_1 + Gliricidia 5 t ha^{-1}	7.30a	7.20a	7.25a	0.35a	0.33a	0.34a	0.51d-f	0.54d	0.53a	45.0ab	47.2c-e	46.1ab
T_9: T_1 + Pongamia 2.5 t ha^{-1}	7.28a	7.28a	7.28a	0.32a	0.32a	0.32a	0.51e-h	0.54cd	0.53a	45.0ab	47.2c-e	46.1ab
T_{10}: T_1 + Pongamia 5 t ha^{-1}	7.30a	7.27a	7.28a	0.31a	0.31a	0.31a	0.51e-h	0.55b-d	0.53a	45.3ab	47.2c-e	46.2ab
T_{11}: T_1 + Vermicompost 1.25 t ha^{-1}	7.26a	7.27a	7.27a	0.32a	0.29a	0.31a	0.51e-h	0.55b-d	0.53a	44.8ab	46.3ef	45.6b
T_{12}: T_1 + Vermicompost 2.5 t ha^{-1}	7.30a	7.29a	7.30a	0.31a	0.30a	0.31a	0.51e-h	0.55b-d	0.53a	44.8ab	46.8d-f	45.8ab
T_{13}: T_1 + FYM 2.5 t ha^{-1} + Gliricidia 2.5 t ha^{-1}	7.31a	7.27a	7.29a	0.34a	0.28a	0.31a	0.52bc	0.56a-c	0.54a	45.2ab	47.9a-c	46.5ab
T_{14}: T_1 + FYM 2.5 t ha^{-1} + Pongamia 2.5 t ha^{-1}	7.29a	7.30a	7.30a	0.32a	0.30a	0.31a	0.52c-e	0.55a-d	0.54a	45.4ab	47.6a-d	46.5ab
T_{15}: T_1 + FYM 2.5 t ha^{-1} + Vermicompost 1.25 t ha^{-1}	7.28a	7.26a	7.27a	0.32a	0.28a	0.30a	0.52cd	0.55a-d	0.53a	45.3ab	47.2c-e	46.2ab
T_{16}: T_1 + Gliricidia 2.5 t ha^{-1} + Pongamia 2.5 t ha^{-1}	7.27a	7.26a	7.27a	0.32a	0.27a	0.30a	0.53ab	0.56ab	0.54a	46.2a	48.2ab	47.2a
T_{17}: T_1 + Vermicompost 1.25 t ha^{-1} + Gliricidia 2.5 t ha^{-1}	7.26a	7.25a	7.26a	0.31a	0.31a	0.31a	0.53a	0.57a	0.55a	46.2a	48.5a	47.4a
T_{18}: T_1 + Vermicompost 1.25 t ha^{-1} + Pongamia 2.5 t ha^{-1}	7.33a	7.24a	7.29a	0.30a	0.32a	0.31a	0.53a	0.56ab	0.55a	46.2a	48.4a	47.3a
T_{19}: Cotton sole crop (100 % RDF and FYM)	7.30a	7.32a	7.31a	0.30a	0.31a	0.31a	0.51f-h	0.51e	0.51a	44.1b	46.2f	45.1b
T_{20}: Soybean sole crop (100 % RDF and FYM)	7.27a	7.30a	7.28a	0.34a	0.32a	0.33a	0.51f-h	0.51e	0.51a	44.1b	46.2f	45.1b
Mean	**7.30**	**7.30**	**7.29**	**0.33**	**0.30**	**0.32**	**0.51**	**0.54**	**0.53**	**44.6**	**46.7**	**45.7**
S.Em. ±	**0.04**	**0.02**	**0.08**	**0.007**	**0.006**	**0.01**	**0.001**	**0.007**	**0.005**	**0.60**	**0.30**	**0.47**
C.V. (%)	**1.01**	**0.92**	**0.66**	**6.01**	**7.12**	**3.53**	**5.60**	**4.45**	**7.15**	**5.62**	**6.13**	**5.34**

Means followed by the same letters do not differ significantly (0.05) by DMRT; RC – Recommended Check
Initial soil pH, EC and organic carbon were 7.30, 0.35 ds m^{-1} and 0.51 %, respectively

Table 6. Available N, P_2O_5 and K_2O in soil as influenced by INM at the end of each year of experimentation

Treatments	Available nutrients								
	Nitrogen (kg ha^{-1})			P_2O_5 (kg ha^{-1})			K_2O (kg ha^{-1})		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T_1: 100% RDF for cotton and soybean	229i	201j	215i	33.5kl	34.3g	33.9h-j	313i	315i	314h
T_2: 125% RDF for cotton and soybean	239hi	229i	234h	37.1g-i	39.4d-f	38.3d-g	323e-g	326gh	324e-g
T_3: 150% RDF for cotton and soybean	269ef	239f-h	254e-g	45.2a	42.3cd	43.8ab	325d-f	330f-h	328c-f
T_4: 100% FYM and RDF for cotton and soybean (RC)	271d-f	242ef	257d-f	35.3i-k	39.2d-f	37.3e-h	323e-g	336e-g	329c-f
T_5: T_1 + FYM 2.5 t ha^{-1}	245gh	233hi	239h	36.8g-j	42.2cd	39.5c-f	316g-i	329f-h	323fg
T_6: T_1 + FYM 5 t ha^{-1}	256fg	235g-i	246f-h	41.2c-e	44.4a-c	42.8a-c	323e-g	329f-h	326d-g
T_7: T_1 + Gliricidia 2.5 t ha^{-1}	267ef	246e	256d-g	31.2l	35.3fg	33.2ij	324ef	347b-d	335a-c
T_8: T_1 + Gliricidia 5 t ha^{-1}	295a-c	277c	286b	42.2b-d	40.2c-e	41.2b-d	336a	349a-d	343a
T_9: T_1 + Pongamia 2.5 t ha^{-1}	278c-e	242ef	260de	31.2l	35.4fg	33.3ij	320e-h	351a-c	335a-c
T_{10}: T_1 + Pongamia 5 t ha^{-1}	294a-c	298a	296ab	38.2f-h	43.3b-d	40.8b-d	325d-f	357ab	341ab
T_{11}: T_1 + Vermicompost 1.25 t ha^{-1}	247gh	240e-g	244gh	31.2l	33.8g	32.5j	318f-	339d-f	329c-f
T_{12}: T_1 + Vermicompost 2.5 t ha^{-1}	265ef	244ef	254e-g	39.2e-g	41.5cd	40.4b-e	320f-h	345c-e	333b-e
T_{13}: T_1 + FYM 2.5 t ha^{-1} + Gliricidia 2.5 t ha^{-1}	267ef	241e-g	254e-g	34.4jk	37.0e-g	35.7g-j	326c-e	355a-c	340ab
T_{14}: T_1 + FYM 2.5 t ha^{-1} + Pongamia 2.5 t ha^{-1}	278c-e	256d	267cd	36.0h-j	37.0e-g	36.5f-i	327b-e	360a	343a
T_{15}: T_1 + FYM 2.5 t ha^{-1} + Vermicompost 1.25 t ha^{-1}	243g-i	246e	244f-h	40.5d-f	42.2cd	41.4b-d	324ef	346b-e	335a-d
T_{16}: T_1 + Gliricidia 2.5 t ha^{-1} + Pongamia 2.5 t ha^{-1}	289a-c	298a	294ab	44.3ab	47.1ab	45.7a	331a-d	352a-c	342a
T_{17}: T_1 + Vermicompost 1.25 t ha^{-1} + Gliricidia 2.5 t ha^{-1}	286b-d	262d	274c	41.2c-e	43.4b-d	42.3a-c	333ab	352a-c	342a
T_{18}: T_1 + Vermicompost 1.25 t ha^{-1} + Pongamia 2.5 t ha^{-1}	297ab	284b	291ab	43.2a-c	48.3a	45.7a	332a-c	353a-c	342a
T_{19}: Cotton sole crop (100 % RDF and FYM)	305a	299a	302a	34.6jk	36.8e-g	35.7g-j	326b-e	333fh	330c-f
T_{20}: Soybean sole crop (100 % RDF and FYM)	209j	207j	208i	33.3kl	35.2fg	34.2h-j	316hi	322hi	319gh
Mean	**266**	**251**	**261**	**37.5**	**39.9**	**38.9**	**324**	**341**	**333**
S.Em. ±	**5.24**	**3.41**	**8.52**	**0.78**	**1.29**	**2.29**	**2.11**	**3.28**	**5.85**
C.V. (%)	**9.73**	**11.0**	**9.82**	**13.6**	**12.9**	**12.6**	**9.41**	**8.72**	**9.10**

Means followed by the same letters do not differ significantly (0.05) by DMRT; RC – Recommended Check; Initial N, P_2O_5 and K_2O was 281, 34 and 312 kg per hectare, repectively

and T_{16} (T_1 + Gliricidia 2.5 t ha^{-1} + Pongamia 2.5 t ha^{-1}) recorded significantly higher maximum WHC compared to rest of the intercropping treatments and sole crops during 2016-17 (Table 5). The highest maximum WHC value was observed in T_{17} during 2015-16 and in pooled data. All the treatments with organics in any form recorded significantly higher maximum water holding capacity compared to all treatments receiving only chemical fertilizers (T_1, T_2 and T_3) in both years and in pooled data. The substantial quantity of addition of organic manures with these treatments enhanced the soil organic carbon over RDF alone. The higher maximum WHC in INM treatments compared to chemical fertilizers alone was traced back to improved organic carbon content in soil as in 2016-17, which might have resulted in more moisture retention in soil. The results are in agreement with the findings of [13], who observed that recycling ensures the return of major portion of nutrients recovered by the crop back to mother earth. Similarly, [14] and [15] observed higher organic matter in soil due to application of FYM and vermicompost after the harvest of wheat crop, which was attributed to addition of more biomass.

3.4 Soil Available Nutrients

Available soil nitrogen differed significantly due to INM treatments during both the years and in pooled data (Table 6). Among the different treatments, cotton sole crop recorded significantly higher available soil nitrogen in both years and in pooled data and it was on par with T_{18} (T_1 + Vermicompost 1.25 t ha^{-1} + Pongamia 2.5 t ha^{-1}) compared to rest of the intercropping systems and sole soybean during 2015-16 and in pooled data. Available soil phosphorus differed significantly due to INM treatments during both the years and in pooled data (Table 6). Among the different treatments, T_3 (150 % RDF for cotton and soybean) and T_{16} (T_1 + Gliricidia 2.5 t ha^{-1} + Pongamia 2.5 t ha^{-1}) during 2015-16 and in pooled data and T_{18} during 2016-17 recorded significantly higher available soil phosphorus with the later being on par with T_{16} (T_1 + Gliricidia 2.5 t ha^{-1} + Pongamia 2.5 t ha^{-1}). Available soil potassium differed significantly due to INM treatments during both the years and in pooled data (Table 6). Among the different treatments during 2015-16, T_8 (T_1 + Pongamia 2.5 t ha^{-1}) recorded significantly higher available soil potassium and it was on par with T_{17} (T_1 + Vermicompost 1.25 t ha^{-1} + Gliricidia 2.5 t ha^{-1}). During 2016-17, T_{14} (T_1 + FYM 2.5 t ha^{-1} + Pongamia 2.5 t ha^{-1}) recorded significantly higher available soil potassium and it was on par with T_{10} (T_1 + Pongamia 5 t ha^{-1}). In pooled data, T_8 (T_1 + Gliricidia 5 t ha^{-1}), T_{17} (T_1 + Vermicompost 1.25 t ha^{-1} + Gliricidia 2.5 t ha^{-1}), T_{18} (T_1 + Vermicompost 1.25 t ha^{-1} + Pongamia 2.5 t ha^{-1}), T_{16} (T_1 + Gliricidia 2.5 t ha^{-1} + Pongamia 2.5 t ha^{-1}), T_{14} (T_1 + FYM 2.5 t ha^{-1} + Pongamia 2.5 t ha^{-1}) and T_{10} (T_1 + Pongamia 5 t ha^{-1}) recorded higher available soil potassium compared to rest of the intercropping systems and sole cotton and soybean crops. The results suggested that addition of organics not only increased the availability of these nutrients in soil, but also favored the release of nutrients from organic sources through mineralization by microorganisms and uptake by the crop. Besides supplying the nutrients, manures also improved the soil moisture content at 30-60 cm depth. Improved organic carbon content in soil might have, improved the water holding capacity of soil, ultimately reflected in higher soil moisture in INM treatments. Results are in agreement with the findings of [16] and [17], who also reported that integrated application of vermicompost + gliricidia equivalent to RDF recorded higher available N, P_2O_5 and K_2O over RDF + FYM (5 t ha^{-1}).

4. CONCLUSION

Integrated nutrient management ensures better availability of moisture, nutrients and improved the performance of cotton and soybean under intercropping system. Study found that application of fertilizer dose of 125 : 62.5 : 62.5 N, P_2O and K_2O kg ha^{-1} in cotton and soybean intercropping system or 100 : 50 : 50 N, P_2O_5 and K_2O kg ha^{-1} along with Gliricidia + Pongamia 2.5 t ha^{-1} each for cotton and soybean intercropping was profitable that growing either of the sole crops.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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