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Impact of Long-term Fertilizer Application on Soil Fertility and Productivity of Finger Millet under Monocropping and Finger Millet-Groundnut Rotation in *Alfisols*

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ABSTRACT: The experiment was conducted during *kharif* 2019 in the long-term field experiment plots maintained since 1978 at the All India Coordinated Research Project for Dryland Agriculture (AICRPDA), UAS, Bangalore to study the impact of long-term fertilizer application on soil fertility and productivity of finger millet under finger millet monocropping and finger millet-groundnut rotation in *Alfisols*. The experiment was laid out in a RCBD with three factors combination consisting of two sources of organic manure (S_1: FYM @ 10 t/ha, S_2: maize residue @ 5/ha), two cropping system (R_1: finger millet - groundnut rotation, R_2: finger millet monocropping) and five nutrient management (T_1: absolute control, T_2: Organic manure, T_3: Organic manure + 50% RDF, T_4: Organic manure + 100% RDF, T_5: RDF). Among the source of organic manures, application of farmyard manure FYM @ 10 t/ha recorded significantly higher grain (3312 kg/ha) and straw yield (3991 kg/ha) and improved the soil available N 155.5 (kg/ha), P_2O_5 (130.4 kg/ha), K_2O (137.6 kg/ha), Ca (2.06 c mol/kg), Mg (0.95 c mol/kg), S (11.03 mg/kg), Fe (17.31 mg/kg), Mn (17.31 mg/kg), Cu (0.95 mg/kg) and Zn (1.35 mg/kg). The physical properties viz., bulk density values were reduced to (1.34 Mg/m^3), whereas MWHC (43.6%), FC (10.0%) and PWP (5.1%) showed higher values with application of FYM @ 10 t/ha as compared to maize residue @ 5 t/ha application. Finger millet - groundnut rotation recorded significantly higher finger millet yield and soil fertility status than monocropping. Among, nutrient management techniques, application of organic manure + 100% RDF recorded significantly higher finger millet grain (4329 kg/ha) and straw yield (5335 kg/ha). Overall, integration of FYM 10 t/ha with 100% RDF was found superior for finger millet productivity, sustainable soil health and among cropping system, finger millet-groundnut rotation was superior compared to finger millet monocropping. The sustainable yield index (0.73) was superior with application of FYM 10 t/ha +100% RDF under rotation cropping system.

Keywords: Crop rotation, nutrient management, organic manure, productivity, soil health, sustainability

Introduction

Soil health is a fundamental determinant of agricultural sustainability, particularly in regions like India where over 60% of cultivation occurs under rainfed conditions. Rainfed agriculture often faces challenges related to climatic variability, necessitating crops that can adapt to stresses such as drought, flooding, and temperature extremes while maintaining productivity. In this context, soil fertility plays a pivotal role in sustaining yields and ensuring long-term agricultural viability. However, declining soil health due to inadequate organic matter application and imbalanced use of inorganic fertilizers has become a critical concern, particularly in fragile ecosystems like drylands (Ramachandrappa *et al.,* 2016). Organic matter serves as the corner stone of healthy soils, influencing physical, chemical, and biological properties essential for crop productivity. The indiscriminate reliance on chemical fertilizers, spurred by the Green Revolution, has led to nutrient imbalances and declining soil fertility in many areas. Practices such as the integrated use of organic and inorganic nutrient sources have emerged as sustainable alternatives, capable of enhancing nutrient-use efficiency, replenishing soil organic matter, and maintaining long-term soil productivity (Shanmugavel *et al*., 2023). Finger millet (*Eleusine coracana*), a vital crop for food security in Southern India, exemplifies the importance of sustainable soil fertility management. In India, finger millet is cultivated over an area of 1.19 million hectares with a production of 1.98 million tonne with an average productivity of 1661 kg/ha. Finger millet is one of the important cereals grown on the *Alfisols* of Southern Karnataka. In Karnataka, finger millet is grown in an area of 7.64 lakh ha with a production of 11.96 lakh tones and the productivity is 1647 kg/ha. Rainfed finger millet alone contributes 95.7% of the total area with production of 11.30 lakh tones. The major area under finger millet is covered in central (Zone 4), eastern (Zone 5) and southern (Zone 6) dry zones of Karnataka. Crop rotation, especially involving legumes, offers an opportunity to restore soil fertility by enhancing nitrogen fixation and organic matter inputs. Integrating legume-based rotations with finger millet can potentially reduce dependence on external nutrient sources, improve nutrient cycling, and provide a balanced diet for farm families. Studies have demonstrated that crop rotation and the application of organic manures can sustainably improve soil fertility, enhance productivity by up to 30%, and positively influence soil physical and biological properties (Thakur *et al*., 2011). Long-term fertilizer experiments (LTFE) provide invaluable insights into the impacts of continuous nutrient application under varied cropping systems. Such studies are crucial for understanding the complex interplay between organic and inorganic nutrient sources on soil fertility and crop productivity. Combining organic manures with chemical fertilizers is essential to achieve higher yields, improve soil health, and optimize nutrient-use efficiency, thereby ensuring sustainability in rainfed agriculture (Ramachandrappa *et al*., 2016; Shanmugavel *et al*., 2023). This study explores the long-term effects of fertilizer application on the soil fertility and productivity of finger millet under monocropping and finger millet-groundnut rotation systems in *Alfisols*.

Materials and Methods

The experiment was conducted during *kharif* 2019 in the long-term experiment plots maintained since 1978 at the All India Coordinated Research Project for Dryland Agriculture, Bangalore located in the Eastern Dry Zone of Karnataka constituting hot moist semi-arid climate. The annual average rainfall of the experimental site is 926 mm and annual potential evapotranspiration during *kharif* season is 503 mm. The length of growing period varies from 120–150 days. The experiment was laid out in a RCBD with factors concept, having three factors combination consisting of two source of organic manure (S_1: FYM @ 10 t/ha, S_2: maize residue @ 5 t/ha), two cropping system (R_1: finger millet (Var: GPU28)-groundnut (Var: GKVK-5) rotation, R_2: finger millet monocropping) and five nutrient management (T_1: absolute control, T_2: organic manures, T_3: organic manure + 50% RDF, T_4 : organic manure+ 100% RDF,T_5: recommended dose fertilizer [RDF] (50:40:37.5 kg/ha NPK applied in form of Urea/DAP/MOP). The level of significance used in 'F' and 't' tests was 5% and critical difference values were calculated wherever 'F' test was found significant as described by Panse and Sukhatme (1985). Sustainability yield index (SYI) was calculated for treatment as suggested by Singh *et al.* (1990). The sustainable yield index (SYI) was calculated using productivity of finger millet over 42 years. This was done to offset annual variations in the yield, and to highlight the performance of the treatments during the entire experimental period. The sustainable yield index is calculated using the following equation:

$$\textbf{\textit{Sustainable yield index}} = \frac{(A\text{-}SD)}{Ymax}$$

where, A= average yield over the years for a particular treatment; SD=standard deviation for the treatment; Y max=maximum yield (average) obtained in any of the treatments during year of experiment (Sharma *et al.*, 2005).

Results and Discussion

Effect of organic sources of nutrients on finger millet yield, economics and soil properties

Application of FYM @ 10 t/ha recorded significantly higher grain and straw yield (2922 kg/ha and 3991 kg/ha, respectively), net returns (Rs. 76317/ha) and BC ratio (3.07) than maize residue @ 5 t/ha (2110 kg/ha and 2218 kg/ha, Rs. 41043, 2.12, respectively) (Table 1). This might be due to the higher concentration of nitrogen in FYM (0.5%) than maize residue (0.3%). Similar findings were also reported by Ramamoorthy *et al.* (2009). Further due to termites, the maize residue was attacked by termites as soon as it was applied to the soil and decomposed early. Application of FYM @ 10 t/ha recorded significantly higher pH (5.36), electrical conductivity (0.07 dS/m) and organic carbon (0.37%), available nitrogen (155.5 kg/ha), available phosphorus (130.4 kg/ha) and available potassium (137.6 kg/ha) compared to maize residue @ 5 t/ha (Table 2 and Fig 1). Bayu *et al.* (2006) reported substantially higher P and K in soil with the use of FYM in semiarid regions of Ethiopia. The increase in the availability of nutrients through addition of FYM may be due to the decomposition of organic manures accompanied by release of nutrients due to action of organic acids (Hemalatha and Chellamuthu, 2013). The secondary nutrients viz., exchangeable calcium and available sulphur were found to be significantly influenced with the different organic sources application (Table 3). Significantly higher exchangeable calcium (2.06 c mol/kg), exchangeable magnesium (0.95 c mol/kg) and available sulphur (11.06 kg/ha) were noticed with the application of FYM @ 10 t/ha compared to maize residue @ 5 t/ha. The organic source significantly influenced the availability of Zn, Fe, Cu and Mn content in soils (Table 3). Significantly higher available Fe, Mn, Cu and Zn was recorded with application of FYM @ 10 t/ha due to formation of water-soluble complexes called chelates preventing their action with the other soil constituents (Han *et al.,* 2010). The decrease in bulk density and particle density (1.34 and 3.09 g/cc, respectively) was recorded with application of FYM @ 10 t/ha (Table 4). This could be ascribed to the greater level of organic carbon content maintained as a result of continuous application of FYM. Application of FYM @ 10 t/ha has significantly increased in maximum water holding capacity (43.6%), field capacity (10.0%) and permanent wilting point (5.1%) (Table 4).

Long term effect of different cropping system on finger millet yield and soil properties

Among the cropping systems, finger millet- groundnut rotation recorded significantly higher grain and straw yield (3055 kg/ha and 3834 kg/ha, respectively) and also higher net returns and BC ratio (Rs. 68865 and 3.34, respectively) than monocropping (2368 kg/ha, 3080 kg/ha, 48495 and 1.85 respectively) (Table 1). Prasad *et al.* (2000) reported that more accountable in sequential cropping systems especially when a cereal crop is preceded by a legume. In the present investigation, finger millet grown under groundnut rotation recorded significantly higher available nitrogen (148.72 kg/ha) and available potassium (133.34 kg/ha) than monocropping system (132.22 kg/ha and 125.76 kg/ha, respectively) (Fig 1). This was attributed to the additional nitrogen fixed with legume rotation near the rhizosphere of the plants which resulted in enhanced available of water, minerals and higher organic carbon. Similar increase in organic carbon with legume rotation was reported by several researchers (Zhang *et al.,* 2024). Exchangeable calcium and magnesium content was found significantly higher (2.08 c mol/kg and 0.98c mol/kg, respectively) in finger millet monocropping system than finger millet (Table 3) groundnut rotation cropping system which may be due to groundnut required higher calcium for proper seed development (Arnold *et al.*, 2017). Available micronutrient (Fe, Cu, Mn and Zn) was found significantly influenced by the cropping system. Finger millet- groundnut cropping system recorded significantly higher available Fe (17.25 mg/kg), available Cu (0.9 mg/kg), available Mn (9.70 mg/kg) and available Zn (1.36 mg/kg) than finger millet-groundnut rotation cropping system (Table 3). Effect of finger millet-groundnut rotation cropping system improved the physical parameters of the soil like maximum water holding capacity (43.67%) and bulk density (1.35 g/cc) and particle density (3.05 g/cc) than the mono cropped finger millet (Table 4). These results are in conformity with the findings of Ghosh and Singh (1994).

Table 1: Effect of different organic source, cropping system and nutrient management on finger millet yield

Treatment	Grain yield	Straw yield	Gross returns	Net returns	B:C ratio
	(kg/ha)		(₹/ha)		
Source of organic manure (S)					
S_1: FYM @ 10 t/ha	3312	3991	98736	76317	3.07
S_2: Maize residue @ 5 t/ha	2110	2922	63462	41043	2.12
S.Em.±	120	122	-	-	-
CD (P=0.05)	356	361	-	-	-
Cropping system (R)					
R_1: Finger millet-groundnut rotation	3055	3834	91284	68865	3.34
R_2: Finger millet monocropping	2368	3080	70914	48495	1.85
S.Em.±	120	122	-	-	-
CD (P=0.05)	356	361	-	-	-
Nutrient management (T)					
T_1: Control	209	346	6381	-7389	0.29
T_2: Only organic manure	2718	3607	81520	56350	2.70
T_3: Organic manure+ 50% Rec. NPK	3650	4480	108923	81911	3.33
T_4: Organic manure+ 100% Rec. NPK	4329	5335	129226	100453	3.73
T_5: Only 100% Rec. NPK	2649	3516	79446	62076	2.92
S.Em.±	190	193	-	-	-
CD (P=0.05)	563	572	-	-	-

Table 2: Effect of different organic source, cropping system and nutrient management on soil chemical properties

Treatment	pH	EC (dS/m)	OC (%)
Source of organic manure (S)			
S_1: FYM @ 10 t/ha	5.36	0.07	0.37
$S_{2:}$ Maize residue @ 5 t/ha	4.48	0.05	0.36
S.Em.±	0.05	0.01	0.01
CD at 5 %	0.15	0.02	NS
Cropping system (R)			
R_1: Finger millet-groundnut rotation	4.87	0.06	0.38
R_2: Finger millet monocropping	4.96	0.06	0.35
S.Em.±	0.05	0.01	0.01
CD at 5 %	NS	NS	NS
Nutrient management (T)			
T_1: Control	4.63	0.03	0.15
T_2: Only organic manure	5.61	0.04	0.39
T_3: Organic manure + 50% Rec. NPK	5.12	0.10	0.46
T_4: Organic manure + 100% Rec. NPK	4.95	0.09	0.56
T_5: Only 100% Rec. NPK	4.28	0.03	0.26
S.Em.±	0.08	0.01	0.02
CD at 5 %	0.23	0.04	0.05

Effect of INM practices on finger millet yield and soil properties

Application of organic manure +100% recommended dose of fertilizer recorded significantly higher grain (4329 kg /ha) and straw yield (5335 kg/ha) of finger millet. Higher net returns (Rs. 100453/ha) and BC ratio (3.73) were recorded in T_4 (organic manure+ 100% Rec. NPK) compared to other treatments (Table 1). Inorganic fertilizer and in combination with organic source might have increased due to sustained nutrient supply and better utilization of applied nutrients through improved microbial activity that involved nutrient transformation and fixation (Shirale *et al*., 2014). Integrated nutrient management with application of organic manure + 100% recommended fertilizer significantly influenced pH, EC, organic carbon, available N, available P, and available K (Table 2 and Fig 1). The organic carbon content of soil was higher (0.56%) with application of organic carbon + 100% recommended fertilizer. The increase in available N (178.4 kg/ha), available P (255.0 kg/ha) and available K (163.5 kg/ha) concentration in organic carbon + 100% recommended fertilizer, which could be due to higher microbial activity induced by the addition of organic matter, and soluble inorganic form of nutrients, which speed up nutrients cycling (Melero *et al.,* 2007).

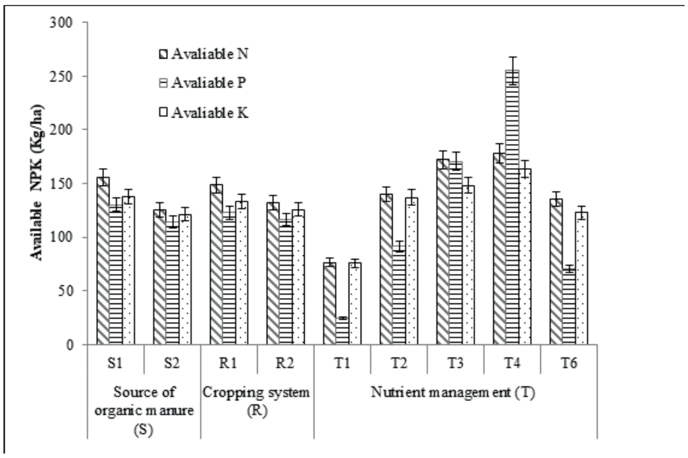

Fig. 1: Effect of different organic source, cropping system and nutrient management on available NPK in soil

The different nutrient management practices significantly influenced the availability of secondary nutrients and micronutrient in the soil (Table 3). The exchangeable calcium and magnesium were recorded higher with application of organic carbon + 100 % recommended fertilizer (2.83 c mol/kg and 1.37c mol/kg). Significantly higher available S (15.6 kg/ha) was observed with organic manure + 100% recommended fertilizer (Table 3). Application of organic manure + 100 % recommended fertilizer recorded higher available Fe (22.14 mg/kg), available Mn (11.17 mg/kg), available Cu (1.11 mg/kg) and available Zn (2.15 mg/kg). The results on physical properties revealed that different nutrient management practices significantly influenced the soil bulk density, particle density, maximum water holding capacity, field capacity and permanent wilting point (Table 4). Application of INM treatments (T_3 & T_4) and organic matter (T_2) recorded significantly lower bulk density and particle density and higher maximum water holding capacity, field capacity and permanent wilting point. Lowering of bulk density in organic manure applied with NPK treated plots may be due to higher organic carbon, more pore space and good soil aggregation as reported by Thakur *et al.* (2011).

Table 3: Effect of different organic sources, cropping system and nutrient management on secondary and micronutrient status in soil

Treatment	Exchangeable		Available				
	Ca	Mg	S	Fe	Cu	Mn	Zn
	(c mol/kg)		(mg/kg)				
Source of organic manure (S)							
S_1: FYM @ 10 t/ha	2.06	0.95	11.03	17.31	0.95	9.86	1.35
S_2: Maize residue @ 5 t/ha	1.42	0.77	9.64	15.02	0.83	8.83	1.22
S.Em.±	0.09	0.03	0.46	0.48	0.03	0.22	0.01
CD at 5 %	0.26	0.09	1.35	1.43	0.09	0.65	0.04
Cropping system (R)							
R_1: Finger millet-groundnut rotation	1.40	0.74	10.51	17.25	0.98	9.70	1.36
R_2: Finger millet monocropping	2.08	0.98	10.17	15.07	0.80	8.99	1.22
S.Em.±	0.09	0.03	0.46	0.48	0.03	0.22	0.01
CD at 5 %	0.26	0.09	NS	1.43	0.09	0.65	0.04
Nutrient management (T)							
T_1: Control	0.80	0.48	4.57	8.40	0.70	6.22	0.26
T_2: Only organic manure	1.70	0.84	10.47	17.50	0.89	9.51	1.65
T_3: Organic manure+ 50% Rec. NPK	2.30	1.02	12.19	19.76	0.99	10.35	1.90
T_4: Organic manure+ 100% Rec. NPK	2.83	1.37	15.64	22.14	1.11	11.17	2.15
T_5: Only 100% Rec. NPK	1.08	0.59	8.82	13.02	0.77	9.47	0.49
S.Em.±	0.14	0.05	0.72	0.76	0.05	0.35	0.02
CD at 5 %	0.42	0.14	2.14	2.26	0.14	1.03	0.06

Table 4: Effect of different organic source, cropping system and nutrient management on soil physical properties

Treatment	BD	PD	MHWC	FC	PWP
	Mg/m³		(%)		
Source of organic manure (S)					
S_1: FYM @ 10 t/ha	1.34	3.09	43.67	10.09	5.19
S_2: Maize residue @ 5 t/ha	1.40	3.13	42.27	9.40	4.73
S.Em.±	0.003	0.01	0.003	0.13	0.086
CD at 5 %	0.01	NS	0.01	0.37	0.25
Cropping system (R)					
R_1: Finger millet-groundnut rotation	1.35	3.06	43.67	9.89	5.01
R_2: Finger millet monocropping	1.38	3.15	42.26	9.61	4.91
S.Em.±	0.003	0.01	0.003	0.13	0.09
CD at 5 %	0.01	0.04	0.01	NS	NS
Nutrient management (T)					
T_1: Control	1.40	3.16	41.62	7.48	3.74
T_2: Only organic manure	1.34	2.97	42.78	11.16	5.65
T_3: Organic manure+ 50% Rec. NPK	1.36	3.00	42.99	10.98	5.59
T_4: Organic manure+ 100% Rec. NPK	1.34	3.12	45.66	10.93	5.73
T_5: Only 100% Rec. NPK	1.41	3.29	41.78	8.19	4.09
S.Em.±	0.01	0.02	0.01	0.20	0.14
CD at 5 %	0.02	0.07	0.02	0.59	0.40

Sustainable yield index (SYI)

Among the organic sources, application of FYM @ 10 t/ha recorded a greater SYI of 0.36 compared to maize residue (0.19). Greater SYI was obtained with finger millet- groundnut cropping system (0.33) compared to finger millet monocropping system (0.22). The carbon biomass added by the groundnut crop residue may have contributed to increase SYI in the subsequent crop of finger millet (Aditi *et al.,* 2023). Furthermore, application of organic manure + 100% recommended fertilizer improved SYI of finger millet (0.55) compared to the use of only recommended rates of NPK through manufactured fertilizers (0.29), possibly due to greater availability of nutrients (Fig 2).

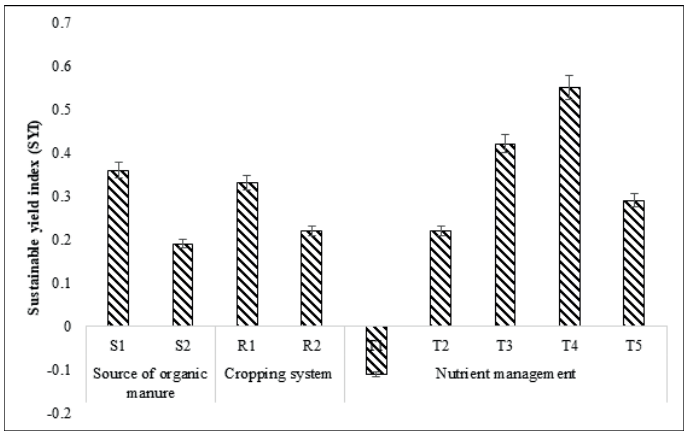

Fig. 2: Effect of different organic sources, cropping system and nutrient management on Sustainable yield index

Conclusion

Application of FYM @ 10 t/ha + 100% NPK was found to sustain finger millet productivity and enhance soil nutrient status under dryland production. The SYI was higher with application of FYM @ 10 t/ha + 100% NPK in rotation compared with monocropping. Hence, application of FYM @ 10 t/ha + 100% NPK along with crop rotation is a viable option for sustaining the yield of an important staple food crop and maintaining soil health. In places where the availability of FYM is a major concern due to a decline in the livestock population, crop residues may be considered as an alternative organic material input for sustainable crop production.

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