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Soil properties, water use efficiency and production potential of finger millet and pigeonpea intercropping under organic production in *Alfisols* of Karnataka

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Abstract
Field experiment was conducted at University of Agricultural Sciences, Bangalore with an objective to enhance productivity of finger millet intercropping in organic system of production during *Kharif* 2006 and 2007. Different organic manures at 50 kg N equivalent used in the experiment are FYM, sewage sludge, poultry manure compost, urban garbage compost, enriched urban garbage compost and vermicompost compared to inorganic fertilizers alone. Irrigation water was provided during dry spells throughout the crop growth period. Results indicated that grain yield of Finger millet (2498 kg ha^{-1}) and pigeonpea grain (370 kg ha^{-1}) were significantly influenced by application of sewage sludge followed by poultry manure compost. It also recorded greater soil microbial population *viz*., bacteria (23.54 x 10^7 cfu/g), fungi (25.65 x 10^4 cfu/g), actionomycetes population (23.04 x 10^3 cfu/g), microbial biomass carbon (2131.8 mg/g) and microbial biomass N (239.7 mg/g of soil), followed by poultry manure compost and lowest in inorganic fertilizer. Organic sources of nutrients improved soil physico-chemical properties *viz*, bulk density, water holding capacity, porosity and organic carbon. The highest organic carbon content was noticed with the application of sewage sludge (0.68%) followed by poultry manure.

Keywords: Finger millet, Pigeonpea, Sewage sludge, Poultry manure, vermicompost, WUE

Introduction
In recent energy crisis, hike in the prices of the inorganic fertilizers and declining soil health and productivity necessitate the use of organic manures compulsorily in agricultural crop production. The continuous use of inorganic fertilizers under intensive cropping system has caused widespread deficiency of secondary and micronutrients in soil (Anon, 2005) [2]. Green revolution brought about a great change in Indian agriculture, which was rightly termed as "from begging bowl to bread basket". This was mainly achieved with high yielding, fertilizer responsive crop cultivars and increased fertilizer use led to deterioration of land and soil health there by slowly reduced the productivity (Mukesh Kumar Pandey *et al.*, 2008) [12]. Ragi + Pigeonpea intercropping system (8:2) under rainfed condition is a common practices in southern Karnataka. It can be evaluated as an additive intercrop Pigeonpea would increase the productivity of soil and cropping system besides helps to supply protein to the farmers. The research evidences conspicuously indicated that the yield advantages are possible through protective irrigation in inter cropping over sole cropping. It is necessary to manage the soil moisture through protective irrigation. Although the millet crops are reported to be most tolerant to moisture stress but even for short period of moisture stress during critical stages of growth, markedly reduces the yield (Udayakumar *et al.*, 1986) [20]. The information on sustainable productivity of finger millet and pigeonpea with use of organic manures in finger millet based intercropping system is very meagre. The present study was undertaken to evaluate the Finger millet and Pigeonpea intercropping system under organic production system.

Materials And Methods

Experimental site

Field experiment was conducted during *Kharif* 2006 and 2007 at Gandhi Krishi Vignana Kendra, University of Agricultural Sciences, Bangalore. The soil of the experimental site was red sandy loam in texture classified under the order *Alfisols*, Vijapura series, isohyperthermic family of *oxihaplustaf* pH was slightly acidic (6.44) having low CEC (7.50 C mol kg^{-1}) with an EC of 0.23 dSm^{-1}. The organic carbon content was 0.47 per cent. The soil was low in available nitrogen (202.8 kg ha^{-1}), high in available phosphorus (26.2 kg ha^{-1}) and medium in available potassium (217.10 kg ha^{-1}). The average annual rainfall was 927 mm distributed in 62 rainy days (> 2.5 mm). An amount of 595 mm and 690 mm of rainfall was received during cropping period in 2006 and 2007 respectively. It was slightly lower than the normal rainfall (24.3 and 5 per cent respectively).

Treatments and design

The experiment was laid out in RCBD with four replications. The treatments comprised of different organic sources of nutrients such as FYM, sewage sludge, poultry manure compost (PMC), urban garbage compost, vermicompost (VC) and enriched urban garbage compost were applied equivalent to recommended N basis and compared with recommended inorganic fertilizers (50:40:25 kg NPK/ha). The information on nitrogen content and quantity of organic manure used in the experiment is presented in Table 1.

Enumeration of soil micro organisms

The rhizosphere soil samples collected from experiments were analyzed for different soil micro organisms *viz*., total bacteria, total fungi and total actinomycetes, using standard dilution plate count technique by using specific nutrient media such as Nutrient agar, Martin's Rose Bengal agar and Kuster's Agar respectively. The petri plates were incubated at 30 ^{0}C for mesophiles and 50 ^{0}C for thermophiles for three to six days and population was counted and expressed per unit dry weight of substrate,

The Finger millet grain equivalent yield of intercropping system was calculated by taking into account the seed yield of component crops and the prevailing market price of the both Finger millet and pigeonpea intercrops as follows. Soil sample was taken at four depths up to 60 cm at different intervals viz., 30, 60, 90 days after sowing & at harvest and average moisture content has been worked out in percent basis and converted into mille meter for calculating water use efficiency of crop. The total water use of water in terms of mille meter per hectare was calculated by adding effective rainfall and irrigation water applied by using relationship; total water used = Effective rainfall + Irrigation water applied. Water use efficiency was worked out as ratio of grain yield of crops and amount of water used. Plant biometric observations were recorded at 30, 60, 90 DAS and at harvest in both the component crops. The weather conditions were favorable for raising crops and protective irrigations were provided during dry spells. Both the component crops were free from pest and diseases by timely prophylactic measures.

Data analyses

The experimental data were analyzed statistically by following Fischer' s method of analysis of variance (ANOVA) wherever 'F' test was significant at P=0.05. The results have been compared among treatments based on critical difference at same level of significance.

Results And Discussion

Biological properties

Soil microbial population viz., bacteria, fungi and actinomycetes fluctuated in soils due to different organic nutrient sources. Organic matter in soil plays an important role in supplying nutrients to plants by a process called mineralization but under tropical conditions, the soil organic matter gets depleted faster due to rapid oxidation process (Lathwell and Bouldin, 1981) [10]. However, the rate of mineralization depends on rate of microbial activity, which in turn varies with kind of organic matter used its composition and local climatic condition.

Application of sewage sludge recorded highest Soil microbial population viz., bacteria, fungi, actinomycetes population, microbial biomass carbon and microbial biomass N (23.54 x 10^7 cfu/g, 25.65 x 10^4 cfu/g, 23.04 x 10^3 cfu/g, 2131.8 mg/g and 239.7 mg/g of soil**,** res**p**ectively) followed by poultry manure compost (22.94 x 10^7 cfu/g, 25.53 x 10^4 cfu/g, 22.70 x 10^3 cfu/g, 2022.2 mg/g and 229.6 mg/g of soil respectively) and lowest in inorganic fertilizer (14.14 x 10^7 cfu/g, 17.22 x 10^4 cfu/g, 14.68 x 10^3 cfu/g, 1385.7 mg/g and 172.2 mg/g of soil, respectively) (Table 2). Similar results were found by Anand (1995) [1] that among the microbial population relatively more bacteria in soil because of the availability of simpler carbon compounds for growth of the bacteria and constant activity throughout the crop growth period. The increase in fungal population in treatments amended with different organic substrates was due to synergistic effect in supplying nutrients to microorganisms as these organic manures had higher nutrient composition. This could be due to actinomycetes prefer neutral or alkaline pH and are able to degrade relatively complex organic substances (Anand, 1995) [1]. It may be due to a high microbial activity in soil as a result of faster mineralization and nitrification of dead cells there by an increase in NO_3-N. It was also reported by earlier workers (Powlson *et al*. (1987) [15]; Goyal *et al*. (1992) [8]. This was attributed to carbon-limited growth after decomposition of organic manures (Aoyama and Nozama, 1993) [3]

Soil Physico-chemical properties

Physico-chemical properties: Application of organic sources tended to improve soil physico-chemical properties *viz*., bulk density, water holding capacity, porosity, organic carbon and available NPK content of soil compared to initial status. Application of organic manures resulted in lower bulk density (1.40 to 1.43 g cm^{-3}) and higher water holding capacity (39.95 to 41.53%) and porosity (41.95 to 43.27%) after the harvest of crops as compared to inorganic fertilizer (Table 3)**.** They could have increased the looseness of soil resulting in increased soil volume and other favorable soil physical condition as compared to that of inorganic fertilizers. Therefore, it could be concluded that organic manures are good source of nutrients besides improving soil physical environment. Similar results were showed by Rukmanagada Reddy *et al.*, (2007) [17], Dinesh Kumar (2006) [6], Poornesh *et al*. (2004) [14], and Reddy *et al*. (1999) [7] Further, slow and steady rate of nutrient release into soil solution was also responsible for better absorption of nutrients by Fingermillet (Devagowda, 1997 and Dosani *et al*., 1999) [5, 7].

In the present investigation, the electrical conductivity and pH of the soil did not differ significantly among treatments. However, slight increase in pH was observed due to use of poultry manure compost, urban garbage compost and farm yard manure which could have been due to their alkaline nature. While application of recommended dose of fertilizer had maximum pH and electrical conductivity (6.63 and 0.24ds/m, respectively). Further, sewage sludge lowered the pH and EC of soil (6.33 and 0.21 ds/m, respectively) (Table 3). These results are in agreement with the findings of Rukmanagada Reddy *et al.*, (2007) [17], Dinesh Kumar (2006) [6], Poornesh *et al*. (2004) [14]. Soil organic carbon content was significantly improved by the application of organic manures *viz*., sewage sludge, poultry manure compost, enriched urban garbage compost, vermicompost, urban garbage compost and farm yard manure as compared to inorganic fertilizer application. The highest organic carbon content was noticed with the application of sewage sludge (0.68%) followed by poultry manure compost (0.67%). Nevertheless, application of nutrients in organic form would improve the crop growth and leaves behind several residues including crop roots. While, organics distinctly but not significantly had higher carbon content in soil. Perhaps, slow mineralization could lead to organic carbon accumulation in soil. The findings are in agreement with those of Dinesh Kumar (2006) [6]. Improved soil organic carbon could be mainly responsible for better soil aggregation, porosity, water holding capacity and nutrient storage in soils. Besides, microbial populations and other flora of rhizosphere could have been enhanced by soil carbon.

Yield of component crops

Among organic manures, application of either sewage sludge (equivalent to 50 kg N) or poultry manure compost produced higher grain and straw yield (Table 4) lowest by application of FYM. This could be ascribed to the higher nutrient composition (Table 1) coupled with pattern of nutrient release into soil solution to match the required absorption pattern (Anand, 1995) [1]. The production of photosynthates and their translocation to sink depends upon the availability of mineral nutrients besides soil moisture in finger millet. Masthan Reddy *et al*. (2005) [11], Poornesh *et al.* (2004) [14] reported application of different organic manures profound impact on finger millet productivity. Many of the earlier reports have also indicated that the soil physico-chemical and biological properties were improved with the favourable application of either sewage sludge or poultry manure *viz*., water storage, bulk density, organic carbon, available nutrients, soil pH, EC, CEC and microbial population of the rhizosphere (Jha *et al*., 2001) [9]. Further, slow and steady rate of nutrient release into soil solution was also responsible for better absorption of nutrients by finger millet (Devagowda, 1997 and Dosani *et al*., 1999) [5, 7].

Sewage sludge contains about 60 per cent of its nitrogen as uric acid, 30 per cent as more stable organic form of N and less than 10 per cent as mineral N. The uric acid rapidly converts N to ammonical form subsequently into available No_3 and also contain growth promoting hormones and produce better root growth than fertilizers application. Similar results of higher yield were reported by Dinesh Kumar (2006) [6] in finger millet. Favourable effects of sewage sludge and poultry manure compost on soil pH, EC, redox potential, CEC and microbial population of the rhizosphere is well documented by Reddy and Reddy (1998) [16] and Yogananda and Reddy (2004) [24]. Therefore, it could be concluded that sewage sludge and poultry manure compost serves as a good amendment as well as store house of nutrients for plant growth.

Application of sewage sludge produced significantly higher pigeonpea grain yield (370 kg/ha) followed by poultry manure compost (355 kg/ha) and lower in FYM application (263 kg/ha) (Table 4). Stalk yield of pigeonpea was also significantly higher with the application of sewage sludge (1407 kg/ha) and poultry manure compost over FYM (1021 kg/ha). The synchrony of improved plant nutrient release and its availability had a profound influence on crop yield. Similar results of higher yield were also reported by Umesh (2002) [22] in finger millet with pigeonpea intercrop; Dinesh Kumar (2006) [6] in soybean and Dosani *et al*. (1999) [7] in groundnut. Not only the amount of nutrients present in soil but also their availability in rhythm with the pattern of crop growth is important, which in turn could influence on plant growth (Sheshadri Reddy *et al*., 2004; Rukmanagada Reddy *et al.*, (2007) [18, 17].

Water relations

The total water used by the crop ranged from 311.3 mm under rainfed condition to 438.4 mm under protective irrigation. Efficient use of water has always been an important factor under water scarce condition. The water use efficiency varied between rainfed and protective irrigation. Higher water use efficiency (8.29 to 6.2 kg ha mm^{-1}) was recorded with protective irrigation as compared to rainfed condition (6.20 to 5.02 kg ha^{-1} mm). Increased WUE under protective irrigation was mainly due to higher yield as compared to rainfed condition. It was attributed to maintaining of favourable soil moisture for long period and more efficient nutrient use for producing high yields under protective irrigation. These results are in agreement with the earlier findings of Venkateswaralu *et al.* (1994) and Santosh Mujalde *et al.* (2004). Similarly, reported that in finger millet higher water use efficiency was recorded with protective irrigation as compared to rainfed condition due to favorable moisture throughout the crop growth period which enhances the growth and yield attributes of finger millet.

In the present study, moisture condition significantly influenced the grain and straw yield of finger millet. Protective irrigation registered significantly higher grain and straw yield (1934 to 2498 kg ha^{-1} and 3293 to 4065 kg ha^{-1}, respectively) as compared to rainfed condition (1520 to 1870 kg ha^{-1} and 2538 to 3045 kg ha^{-1}, respectively) (Table 4.26 and 4.53). The magnitude of improvement in protective irrigation recorded 23 to 29 per cent and 24 to 27 per cent higher grain and straw yield, respectively with above respect treatments. These results are in agreement with Krishnamurthy (1996) who reported that, the highest grain and straw yield with one protective irrigation at flowering stage during drought period which recorded 21.16 and 37.41 q ha^{-1} of grain and straw yield, respectively. The higher grain and straw yield due to protective irrigation as compared to rainfed condition could be attributed to the higher yield components such as number of productive tillers per plant, number of ears per plant, number of fingers per ear, grain yield per plant, length of ear and 1000 grain weight, ultimately resulting in high grain yield per hectare (Table 13 and fig 4). This was further evidenced by significant positive correlation between grain yield of finger millet and yield components under protective irrigation as compared to rainfed condition (Table 4.65). Hence, under rainfed condition prevalence of moisture stress results in reduction in cell expansion and photosynthetic leaf area reducing the crop growth. As a consequence of increase in respiration and reduction in photosynthetic rate under stress, there would be reduction in dry matter production and accumulation reported by Shreeshail Hangaragi (2006). Hence, higher finger millet grain and straw yield can be obtained with protective irrigation as compared to rainfed condition.

Soil moisture content

The moisture content in soil was significantly differed due to different organic nutrient management practices. At 30 DAS, among organic nutrient sources, application of sewage sludge recorded higher moisture content (10.80%) over recommended dose of fertilizer (9.66%). Similar trend was noticed all organic nutrient sources over recommended dose of fertilizer. Maximum moisture content was recorded in sewage sludge (17.38%) and intermediate between rests of the treatments. Application of 100 per cent organics recorded higher moisture content (21.51% to 20.16%) than 100 per cent inorganics (17.63%). However, maximum moisture content was recorded in sewage sludge (21.51%). At harvest, moisture content (9.33%) was noticed with application of inorganics alone, sewage sludge (10.08%) over rest of the treatments. The maximum water used by the crops (438.44 mm) over recommended dose of fertilizer (398.86 mm) under protective irrigation. Higher water use efficiency was recorded by application of poultry manure compost (5.93 and 8.24 kg ha mm^{-1}, respectively) and sewage sludge (5.70 and 8.04 kg ha mm^{-1}, respectively) under intercropped and finger millet grain equivalent yield.

Higher water use efficiency was recorded in poultry manure compost (6.01 kg ha mm^{-1}) followed by sewage sludge application (5.86 kg ha mm^{-1}, respectively). The protective irrigation, which helps in arresting the reduction in productivity by permitting better utilization of all other production factors and thus leads to increase in yield per unit area and time. These results are in agreement with Krishnamurthy (1996) who reported that the highest grain (21.2 q/ha) and straw yield (37.4 q/ha) with one protective irrigation at flowering stage during drought period. In the present study there was clear indication of crop experiencing favourable soil moisture due to the protective irrigation. The moisture stress at tillering, flowering and grain filling stages reduced the plant height, number of tillers, number of leaves, leaf area index, number of ear hill^{-1} and grain yield of finger millet as reported by (Chinnavenkata Reddy, 1976; Chandrashekar (1978) and Chandrashekarappa (1979).

Table 1: Nutrient Composition and quantity of organic manures used in the experiment

Treatment	2006		2007	
	N (%)	Quantity used (t/ha)	N (%)	Quantity used (t/ha)
Farm yard manure	0.55	9.1	0.47	10.6
Urban Garbage Compost	0.75	6.7	0.63	8.0
Sewage Sludge	1.43	3.5	1.24	4.0
Poultry Manure Compost	1.93	2.6	1.71	3.0
Enriched Urban Garbage compost	1.26	4	1.02	5.0
Vermicompost	1.4	3.6	1.33	3.5

Table 2: Physical and chemical properties of soil in Finger millet and Pigeonpea intercropping system under organic production system (Data pooled of 2 years)

Treatment	Bulk Density (g/cc)	Maximum Water Holding Capacity (%)	Soil Porosity (%)	Soil pH	Soil EC ds/m	Organic Carbon (%)
Recommended NPK	1.65	34.96	37.63	6.63	0.24	0.51
Farm yard manure	1.42	40..57	42.47	6.43	0.22	0.59
Urban garbage compost	1.43	39.95	41.95	6.40	0.22	0.59
Sewage sludge	1.40	41.53	43.27	6.33	0.21	0.68
Poultry manure compost	1.41	40.67	43.02	6.35	0.21	0.67
Enriched urban garbage compost	1.40	40.75	42.63	6.36	0.21	0.63
Vermicompost	1.41	40.47	42.24	6.36	0.21	0.62
S.Em. ±	0.03	0.69	0.79	0.21	0.01	0.01
C.D. at 5%	0.09	2.10	2.35	NS	NS	0.03

Note: Organic manures used were equivalent to recommended dose of 50 kg nitrogen ha^{-1}

Table 3: Soil biological properties of soil in Finger millet and Pigeonpea intercropping system under organic production system (Data pooled of 2 years)

	Bacteria (10^7 cfu/g soil)	Fungi (x 10^7 cfu/g soil)	Actinomycetes (x 10^7 cfu/g soil)	Microbial biomass- carbon (µg/ g soil)	Microbial biomass – nitrogen (µg/g soil)
Recommended NPK	14.14	16.22	13.68	1385.7	172.2
Farm yard manure	20.10	21.93	19.13	1823.1	212.3
Urban garbage compost	20.10	22.02	19.38	1834.8	212.6
Sewage sludge	23.54	25.65	23.04	2131.8	239.7
Poultry manure compost	22.94	25.53	22.70	2022.2	229.7
Enriched urban garbage compost	21.68	24.42	21.93	1936.2	221.3
Vermicompost	21.30	24.41	21.83	1912.1	219.4
S.Em ±	0.44	0.54	0.43	45.57	4.44
CD at 5%	1.31	1.63	1.28	136.53	13.31

Table 4: Productivity of Finger millet and Pigeonpea as influenced by application of different organic sources of nutrients (data pooled of 2 years)

Treatment	Finger millet		Pigeonpea		Finger millet grain equivalent yield (kg/ha)
	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Stalk yield (kg ha^{-1})	
Recommended NPK	2045	3293	295	1137	2864
Farm yard manure	1934	3307	263	1021	2663
Urban garbage compost	2019	3395	282	1095	2801
Sewage sludge	2498	4065	370	1407	3526
Poultry manure compost	2475	4009	355	1350	3461
Enriched urban garbage compost	2337	3769	335	1287	3266
Vermicompost	2305	3702	322	1239	3199
S.Em ±	51.7	83.7	7.63	29.83	
CD at 5%	155.1	251.1	22.85	89.46	

Note: Organic manures used were equivalent to recommended dose of 50 kg nitrogen ha^{-1}

Table 5: Total water used and water use efficiency (WUE) of finger millet as influenced by organic nutrient management in Finger millet and pigeonpea intercropping system under protective irrigation (Data pooled of 2 years)

Treatment	Effective rainfall (mm)	Irrigation water used (mm)	Total (mm)	WUE (kg ha^{-1} mm^{-1})	
				Pooled Data	FGEY
Recommended NPK	318.9	80.0	398.9	5.12	7.17
Farm yard manure	349.0	80.0	429.0	4.51	6.21
Urban garbage compost	337.7	80.0	417.7	4.83	6.72
Sewage sludge	358.4	80.0	438.4	5.70	8.04
Poultry manure compost	337.4	80.0	417.4	5.93	8.29
Enriched urban garbage compost	342.0	80.0	422.0	5.54	7.74
Vermicompost	348.4	80.0	428.4	5.42	7.50

Conclusion

Application of sewage sludge and poultry manure compost was found to be effective as organic manure in enhancing productivity of soil and intercropping yield in finger millet and pigeonpea. Further, these manures are also cost effective and a potential substitute for chemical fertilizers to replenishing nutrient requirement of crops and found to be sustainable.

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