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Influence of organic nutrient sources and moisture management on productivity, biofortification and soil health in pearl millet (*Pennisetum glaucum*) + clusterbean (*Cyamopsis tetragonaloba*) intercropping system of semi-arid India

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ABSTRACT

A field experimentation was carried out at New Delhi, India for three years (2010-12) under rainfed semi-arid conditions to assess the effect of three organic nutrient sources and two moisture management practices on productivity, biofortification and soil health under pearl millet [*Pennisetum glaucum* (L.) R. Br. emend Stuntz] + clusterbean [*Cyamopsis tetragonaloba* (L.) Taub] intercropping system (PCIS). In current study, the pearl millet grain yield under sole pearl millet was at par with PCIS while its stover yield reduced by 5%. Under PCIS, inclusion of clusterbean led to significant reduction in clusterbean yield compared to its sole stand, however, PCIS system productivity was more over their sole crop stands, indicating that additive series of PCIS may bring more net economic gains over their sole stands in semi-arid ecology of India. The coarse cereal-legume interactions under PCIS have also led to improved protein content in pearl millet (11.2%) over its sole stand (10.7%). Zinc (Zn) and iron (Fe) deficiency is a common feature in semi-arid India and the crops grown as well. Study revealed that Zn and Fe content in pearl millet were increased by 6.5 and 1.6%, respectively, by the inclusion of clusterbean in PCIS. Plant growth, yield attributes and yield of pearl millet and clusterbean crops showed an improvement under flat sowing + organic mulching (FS+OM) over ridge and furrow sowing (RFS) but the differences were non-significant. Among organic nutrient sources, leaf compost (LC) @ 10 t/ha and FYM @ 10 t/ha produced significantly more system productivity in terms of pearl millet-equivalent-yield (PEY) than 100% RDF and control. Protein content both in pearl millet and clusterbean, and Zn and Fe biofortification in pearl millet grains was higher under FYM treated plots closely followed by LC, and leaf + cowdung mixture compost. Application of organics especially FYM @ 10 t/ha also resulted in improved soil health in terms of bulk density, soil organic carbon and NPK status after three years experimentation.

Key words: Biofortification, Clusterbean, Intercropping, Moisture, Nutrient management, Organic, Pearl millet

In rainfed drylands of India, pearl millet [*Pennisetum glaucum* (L.) R. Br. emend Stuntz] and clusterbean [*Cyamopsis tetragonaloba* (L.) Taub] are two major crops occupying prestigious place in the rural economy of these regions. At present, pearl millet is being grown in about 8.7 m ha area with production of 10.1 mt and yield of 1 156 kg/ha (Economic Survey of India 2015). Clusterbean is cultivated in 4.25 m ha area with production of 2.42 mt and yield of 567 kg/ha (NIAM 2013-14). Both these crops can thrive well under moisture stress conditions, thus, valued for their stover and fodder for livestock in drylands. Intercropping of these two crops may prove win-win proposition for sustainable farming system in rainfed drylands. Both the crops possess high production potential particularly in soils characterized with poor soil texture and fertility, intense ambient temperature, heat stress and chronic soil moisture deficit as well (Bana *et al*. 2014). At the same time, increased cost of production, deteriorated soil productivity and environmental quality urge for a sound crop management strategy under such production and climate vulnerabilities. Soil fertility and nutrient availability to plants are strongly influenced by nutrient management practices and cropping systems in an agro-ecology (Bhandari *et al.* 2002). Thus, for long-term sustainability of pearl millet-based cropping systems in semi-arid ecologies we need to enhance soil organic carbon (SOC) and nutrient buffering by using organic nutrient sources like farmyard manures (FYM), biocompost, and legume inclusion in cropping systems in one hand; and by adopting appropriate land configurations and organic mulching as

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well for moisture conservation on the other. Organic manures helps in improving soil fertility, soil structure, water holding capacity and root proliferation (Bana 2006). There is a need to revamp the age-old practice of under-feeding of rainfed crops in drylands with appropriate production strategy in order to harness good yields, maintain soil fertility and also supplement essential nutrients for more productivity and quality on sustainable basis. Since, information on nutrient management through organic sources in pearl millet and clusterbean under sole and intercropping systems is meager, thus, present study assessed the effect of different organics on productivity, quality and soil health under pearl millet + clusterbean intercropping system besides its economic feasibility in semi-arid drylands of India.

MATERIALS AND METHODS

A three year field experimentation was carried-out at Indian Agricultural Research Institute (IARI), New Delhi [28°40' N latitude; 77°12' E longitude; 228.6 m altitude; characterized with semi–arid and sub–tropical climate, hot dry summers and severe cold winters] during *kharif* (rainy) seasons of 2010 to 2012 under rainfed semi-arid conditions. The mean annual rainfall is about 650 mm, of which nearly 80% is received during south–west monsoon (July to September) and the rest during October to May. The mean daily US Weather Bureau Class 'A' open pan evaporation value reaches as high as 10.9 mm in the month of June and as low as 1.5 mm in January. The annual pan evaporation is about 850 mm. The rainfall for the cropping seasons was recorded at meteorological observatory of IARI, New Delhi showing that total rainfall during the *kharif* seasons of 2010, 2011 and 2012 was 893.8, 574, 483.2 mm, respectively. Mechanical composition and physico-chemical properties of soil at the experimental site is illustrated in Table 1.

Prior to start of the experiment, two exhaustive crops, viz. pearl millet during *kharif* and wheat during *rabi* (winter) season were grown to bring the uniformity in soil fertility of the field. After harvesting of wheat, the composite initial soil samples from plough layer (0–15 cm) were collected and analyzed for physicochemical properties following standard procedures suggested by Rana *et al.* (2014) (Table 1). The experiment was laid-out in split-plot design and replicated thrice. Pearl millet Pusa composite 443 and clusterbean HG 563 were planted in sole and intercropping systems under two moisture conservation practices, viz. flat sowing + organic mulching (FS+OM) and ridge and furrow sowing (RFS). Five nutrient management treatments [control, 100% recommended dose of fertilizer (RDF) (N, P_2O_5 and K_2O @ 60:40:40 kg/ha, respectively), leaf and cow dung mixture compost @10 tonnes/ha (LCMC), leaf compost @10 tonnes/ha (LC) and farmyard manure @ 10 tonnes/ha (FYM)] were applied in sub-plots randomly. The sub-plot size was 5×4 m. Pearl millet and clusterbean were sown using seed @ 4 kg/ha and 20 kg/ha, respectively. Planting of pearl millet was done at a row-to-row distance of 50 cm. Under RFS, furrows were made 50 cm apart. Organic mulching was done @ 3 tonnes/ha using crop residues of previous season crop. The intercropping was done in 1:1 row ratio with additive series. N content in LC, LCMC and FYM were 0.6, 0.45 and 0.5 %, respectively. The organics were applied as per treatments and incorporated manually. The N, P_2O_5 and K_2O @ 30, 40 and 40 kg/ha was applied in 100% RDF treatment as basal and the rest N (30 kg/ha) as top dress at 30 days after sowing (DAS) after first weeding during all the three years. The sources of N, P_2O_5 and K_2O were urea, single superphosphate and muriate of potash. Weed management was done manually using wheel hand hoe at 25 DAS. Data obtained from current field experimentation were statistically analyzed, using the F-test as per the procedure given by Gomez and Gomez (1984). Tukey's honestly significant difference test was used as a post-hoc mean separation test ($P < 0.05$) using SAS 9.1 (SAS Institute, Cary, NC). The Tukey procedure was used where the ANOVA was significant.

Table 1 Physicochemical properties of soil at the experimental site

Particulars	Value
Mechanical composition	
Sand (%)	58.7
Silt (%)	13.8
Clay (%)	27.5
Textural class	Sandy-loam
Physical properties	
Bulk density (g/cm^3)	1.57
Permanent wilting point (%)	6.50
Field capacity (% by weight)	19.2
Chemical properties	
pH (1:2; soil:water ratio)	7.2
Electrical conductivity (dS/m)	0.33
Organic C (%)	0.31
Available N (kg/ha)	202
Available P (kg/ha)	10.7
Available K (kg/ha)	226

RESULTS AND DISCUSSION

Growth and productivity

Intercropping systems: The results of three years' study show that plant height, tillers/m row length, drymatter accumulation (DMA) and earhead length in pearl millet increased markedly under pearl millet + clusterbean intercropping system (PCIS) as well as under moisture and nutrient management practices (Table 2). PCIS (1:1) resulted in significantly more number of pearl millet tillers/m row length and more DMA as compared to sole cropping. Chlorophyll meter (SPAD) value of pearl millet at flowering also showed significant superiority under PCIS than sole stand of both the crops. Plant height, earhead length, grain weight per earhead and 1,000-grain weight were higher under PCIS than sole cropping but with non-significant differences. Grain yield under sole pearl millet was

Table 2 Growth and yield attributes of pearl millet and clusterbean as influenced by intercropping, moisture and nutrient management (mean of 3 years)

Treatment	Pearl millet							Clusterbean			
	Plant height (cm)	Tillers/m row length	Drymatter accumulation (g/plant)	Chlorophyll meter value(SPAD)	Earhead length (cm)	Grain weight/ earhead (g)	1 000-grain wt. (g)	Plant height (cm)	Pods/ plants	Seeds/pod	1 000-grain wt. (g)
Cropping system											
Pearl millet sole	226.0_{a}	21.2_{b}	76.1_{a}	51.6_{b}	22.3_{a}	19.5_{a}	8.32_{a}	66.3_{b}	58.3_{a}	6.2_{a}	29.5_{a}
Clusterbean sole								72.5_{a}	30.6_{b}	5.5_{b}	29.5_{a}
Pearl millet + clusterbean	230.4_{a}	23.0_{a}	82.5_{b}	54.1_{a}	22.9_{a}	19.2_{a}	8.35_{a}				
Moisture conservation practices											
Ridge and furrow sowing	231.1_{a}	22.2_{a}	80.8_{a}	52.3_{a}	22.7_{a}	19.5_{a}	8.35_{a}	69.9_{a}	44.1_{a}	5.8_{a}	29.4_{a}
Flat sowing + Mulching	225.3_{a}	22.0_{a}	77.8_{a}	53.4_{a}	22.5_{a}	19.2_{a}	8.32_{a}	68.9_{a}	44.7_{a}	5.8_{a}	29.6_{a}
Nutrient management practices											
Control	187.9_{c}	16.5_{c}	66.7_{c}	46.6_{b}	19.3_{b}	16.2_{b}	7.94_{a}	58.3_{b}	26.2_{c}	3.8_{b}	28.3_{a}
100% RDF	224.9_{b}	22.3_{b}	79.0_{b}	52.8_{a}	22.5_{a}	19.3_{a}	8.40_{a}	70.9_{a}	46.7_{b}	6.1_{a}	29.6_{a}
Leaf compost (10 tonnes/ha)	246.3_{a}	24.4_{a}	84.2_{a}	55.5_{a}	23.9_{a}	20.6_{a}	8.47_{a}	73.1_{a}	50.6_{a}	6.5_{a}	29.9_{a}
Leaf and cowdung mix compost (10 tonnes/ha)	239.8_{ab}	23.5_{ab}	83.2_{ab}	54.5_{a}	23.5_{a}	20.3_{a}	8.43_{a}	72.1_{a}	48.9_{ab}	6.3_{a}	29.9_{a}
FYM (10 tonnes/ha)	242.0_{a}	23.8_{ab}	83.4_{a}	54.9_{a}	23.6_{a}	20.3_{a}	8.45_{a}	72.6_{a}	49.7_{ab}	6.4_{a}	29.8_{a}

*Means followed by a similar lowercase letter within a column are not significantly different ($P<0.05$) according to Tukey's HSD test.

statistically at par with PCIS (Table 3), however, the stover yield of pearl millet got reduced by 5.03% due to minimal competition under OCIS (Kumar *et al*. 2015a). This indicates that there is a nominal yield penalty in pearl millet under PCIS additive series. The favorable effect of clusterbean inclusion in PCIS got reflected in growth, yield attributes and yield of pearl millet owing to synergistic cereal-legume association as a result of soil N enrichment by biological nitrogen fixation mechanism of the said legume and improved rhizosphere microbial activity (Ghosh *et al.* 2007, Bana *et al.* 2013). In clusterbean, the plant height was higher under PCIS than the sole clusterbean stand owing to shading effect of taller plants of pearl millet causing competition for light and space (Table 2). Similarly, pods/ plant, seeds/pod and 1 000-grain weight reduced significantly under PCIS than sole stand, again indicating, dominating effect of tall growing pearl millet over clusterbean with consequent reduction in yield attributing characters. Similarly, the reduction in clusterbean grain and stover yield was to the tune of 47.3 and 53.1% under PCIS due to tall growing nature of pearl millet and consequent competition (Kumar *et al.* 2013).

Moisture management practices: There was slight increase in growth, yield attributing characters and yield of pearl millet and clusterbean due to flat sowing + organic mulching (FS+OM) over ridge & furrow sowing (RFS) but the differences were non-significant. The improvement in growth and yield attributing characters of both the crops due to organic mulching is ascribed to favourable soil-moisture conditions maintained for relatively longer period. The enhanced nutrient supply through decomposition of organic matter together with favourable moisture conditions created conducive environment to plant growth and development (Choudhary *et al.* 2014a, Das *et al.* 2014). Similarly in RFS, the proper drainage of excess water coupled with adequate aeration at the time of excess rainfall, and moisture conservation under stress conditions led to favourable crop microclimate resulting in its' at par performance with organic mulching (Kumar *et al.* 2015a).

Organic nutrient management: Application of LC @ 10 tonnes/ha resulted in improved plant growth, higher yield attributing characters and enhanced yield of pearl millet as well as clusterbean both under sole and PCIS; followed by FYM @ 10 tonnes/ha, LCMC compost (10 tonnes/ha) and 100% RDF, respectively (Table 2). The gains in grain and stover yield of both the crops were statistically significant by the application of organic sources of nutrients (Table 3). The grain yields were significantly higher under LC and FYM treatments as compared to 100% RDF and control. The LCMC, however, gave higher yield than control but remained at par to 100% RDF. The pearl millet grain yield improvement with LC and FYM were 40 and 38.3% over control; and 10.7 and 9.3%, respectively, over 100% RDF. In clusterbean, respective gains in grain yield due to LC application were 43.6 and 6.8% over control and 100% RDF. Application of organic sources resulted in balanced supply of macro and micronutrients improving

Table 3 Yield and quality of pearl millet and clusterbean as influenced by intercropping, moisture and nutrient management (mean of 3 years)

Treatment	Pearl millet					Clusterbean		
	Grain yield (tonnes/ha)	Stover yield (tonnes/ha)	Protein content (%)	Fe content (mg/kg)	Zn content (mg/kg)	Grain yield (tonnes/ha)	Stover yield (tonnes/ha)	Protein content (%)
Cropping systems								
Pearl millet sole	2.95_a	7.55_a	10.66_a	51.4_a	35.5_b			
Clusterbean sole						0.95_a	3.07_a	25.7_a
Pearl millet + clusterbean	2.69_a	7.17_b	11.16_a	52.2_a	37.8_a	0.50_b	1.44_b	25.3_a
Moisture conservation practices								
Ridge and furrow sowing	2.79_a	7.38_a	10.82_a	51.6_a	36.0_a	0.72_a	2.25_a	25.1_a
Flat sowing + Mulching	2.85_a	7.35_a	11.00_a	52.0_a	37.2_a	0.73_a	2.27_a	25.9_a
Nutrient management practices								
Control	2.22_c	5.90_c	10.26_c	48.1_c	32.2_c	0.55_c	1.70_b	23.8_c
100% RDF	2.81_b	7.35_b	10.85_b	50.7_b	35.3_b	0.74_b	2.32_a	25.7_b
Leaf compost (10 tonnes/ha)	3.11_a	8.01_a	11.18_a	53.3_a	38.5_a	0.79_a	2.45_a	26.0_a
Leaf and cowdung mix compost (10 tonnes/ha)	2.90_b	7.67_{ab}	11.11_{ab}	52.8_a	38.0_a	0.76_{ab}	2.37_a	25.9_a
FYM (10 tonnes/ha)	3.07_a	7.90_a	11.17_a	54.2_a	39.2_a	0.78_{ab}	2.45_a	26.1_a

*Means followed by a similar lowercase letter within a column are not significantly different ($P<0.05$) according to Tukey's HSD test.

bio-chemical properties of the soil (Chaudhary and Gautam 2007, Bana *et al*. 2012). Likewise, organics improve the soil water holding capacity, thereby, reduce moisture stress in plant tissues sufficient enough to regulated optimum photosynthetic activity for greater accumulation of photosynthates and maintaining cordial source-sink relationships (Havlin *et al.* 1999, Choudhary and Suri 2014).

Agronomic biofortification vis-à-vis crop quality

Intercropping systems: The PCIS (1:1) improved the pearl millet grain quality and Fe and Zn biofortification as compared to sole stand (Table 3). However, the quality of clusterbean grain did not influence significantly under PCIS. Protein content in pearl millet increased from 10.7% in sole stand to 11.2% under PCIS. Zn content in pearl millet also increased by 6.5% under PCIS. There was improvement in Fe content in pearl millet grain, but the differences were non-significant.

Moisture management practices: Protein content in grains of both the crops as well as Zn and Fe content in pearl millet grains increased nominally under FS+OM as compared to RFS but both remained statistically at par. Biological nitrogen fixation by the legume with coarse cereal in PCIS might have increased the nitrogen concentration in rhizosphere and consequent improvement in nitrogen and protein content of the pearl millet grain (Kumar *et al.* 2016). Moreover, legume inclusion and crop residue application as organic mulch might have also lowered the soil pH through CO_2 liberation and organic acid secretions during decomposition and its decomposition products might have raised the solubility and availability of non-labile nutrient pool especially Zn and Fe to plants (Choudhary *et al.* 2014b, Paul *et al.* 2014).

Organic nutrient management: Grain quality of pearl millet and clusterbean improved significantly through organic sources (Table 3). Maximum protein content in pearl millet and clusterbean, and higher Fe and Zn content in pearl millet grain were recorded with FYM closely followed by LC and LCMC. The grain quality in both the crops was statistically better under organic nutrition as compared to 100% RDF except protein content in pearl millet under LCMC, which was at par with 100% RDF. Higher protein content in pearl millet and clusterbean grains under organic nutrition might be due to more nutrient uptake through effective root systems and increased nutrient concentrations in soil solution. Quality improvement through organic sources might be due to better microbial activity and atmospheric N fixation. The microbes secrete many growth promoting substances which accelerate the physiological processes like carbohydrate and protein synthesis. Moreover, the organic acids released during decomposition and mineralization give rise to natural complexing agents that solubilize the nutrients in rhizosphere and render in Zn and Fe available to plants (Mekki *et al.* 1999, Kumar *et al.* 2015b, c).

System productivity and profitability

Intercropping systems: PCIS resulted in higher system productivity in terms of pearl millet grain equivalent yield (PEY), more net returns and better benefit: cost ratio (BCR) as compared to sole crops (Table 4). The PCIS led to significant penalty in clusterbean yield, but overall, the system productivity under PCIS was found comparatively higher. This shows that even under additive series of PCIS, there is net economic gain over the sole cropping of pearl millet and clusterbean (Kumar *et al.* 2015a).

Table 4 System productivity, economics and water-use efficiency of pearl millet and clusterbean as influenced by intercropping, moisture and nutrient management (mean of 3 years)

Treatment	Pearl millet grain equivalent yield (PEY) (tonnes/ha)	Net returns (₹/ha)	B:C ratio	Water use efficiency (WUE)(kg/ha-mm)
Cropping system				
Pearl millet sole	2.95[c]	39736	2.26	8.30
Clusterbean sole	4.84[b]	47051	2.94	11.12
Pearl millet + clusterbean	5.24[a]	66994	3.52	11.42
Moisture conservation practices				
Ridge and furrow sowing	4.31[a]	51393	2.98	10.00
Flat sowing + Mulching	4.37[a]	51127	2.84	10.55
Nutrient management practices				
Control	3.36[c]	37975	2.43	8.56
100% RDF	4.37[b]	51401	2.89	10.37
Leaf compost (10 tonnes/ha)	4.75[a]	56048	2.93	10.99
L and C Mix Compost (10 tonnes/ha)	4.53[ab]	54170	3.08	10.62
FYM (10 tonnes/ha)	4.70[a]	56706	3.22	10.86

*Means followed by a similar lowercase letter within a column are not significantly different ($P<0.05$) according to Tukey's HSD test.

Moisture management practices: Though, there is 0.06 tonnes/ha improvement in system productivity under FS+OM over RFS but this difference is not significant. In terms of net returns and BCR, the two moisture management practices remained on par (Kumar *et al.* 2015a).

Organic nutrient management: LC and FYM @ 10 tonnes/ha produced significantly more PEY than 100% RDF and control. LCMC produced significantly higher yield than control. The PEY in this treatment was little higher than 100% RDF but the differences were non-significant. The respective system productivity improvement due to LC, FYM and LCMC was 41.3 and 8.7%, 39.8 and 7.5%, and 34.8 and 3.7%, over control and RDF, respectively. Moreover, there was a gain of ₹ 2 769–5 305/ha in system net returns due to organic nutrition over 100% RDF. The BCR was also marginally high with organic sources and the improvement was ₹ 0.04–0.33 per ₹ invested. These findings are in close conformity with the results of Mekki *et al*. (1999) and Bana *et al.* (2012).

System water-use efficiency

Intercropping systems: The system water-use efficiency (SWUE) was influenced favorably by intercropping, organic mulching and organic nutrition (Table 4). PCIS system resulted in highest SWUE (11.42 kg/ha mm) and it was 3.12 and 0.3 kg/ha-mm more than sole crops. The improvement in SWUE is attributed to higher system yield per unit of moisture consumption under intercropping system as compared to their sole cropping.

Moisture management practices: The FS+OM resulted in 5.5% higher SWUE (10.55 kg/ha-mm) over RFS. The improvement in SWUE is ascribed to favorable soil-moisture conditions maintained for relatively longer period under flat bed with crop residue mulching. The enhanced nutrient supply through decomposition of organic matter together with lower consumptive use and higher grain yield than ridge and furrow planting had resulted in improvement in water use efficiency (Meena *et al.* 2006, Choudhary *et al.* 2014b).

Organic nutrient management: Nutrient management practices enhanced the SWUE by 1.81–2.43 kg/ha-mm over control. The maximum SWUE was recorded with LC (10.99 kg/ha-mm) followed by FYM (10.86 kg/ha-mm), LCMC (10.86 kg/ha-mm) and 100% RDF (10.37 kg/ha-mm). Organic nutrient sources increased the SWUE by 2.4-5.9% over 100% RDF. The increment in SWUE due to nutrient management practices could be attributed to higher yield and enhanced soil organic matter which might have facilitated favourable soil-moisture conditions maintained for relatively longer period (Rana *et al*. 2012, Choudhary *et al.* 2014b, Paul *et al.* 2014).

Soil physico-chemical properties

After three year of experimentation, available NPK status and soil organic carbon (SOC) increased remarkably under PCIS over sole crop stands, organic mulching and nutrient management practices (Table 5). PCIS resulted in enhanced SOC after three year of cropping. The SOC content (%) was 0.02, 0.04 and 0.05% higher than the initial value (0.31%) under sole pearl millet, sole clusterbean and PCIS (Fig 1). Similarly, available N (227 kg/ha), available P (12.4 kg/ha) and available K (236 kg/ha) in the soil after three years was also found highest under PCIS. Sole clusterbean was statistically at par with PCIS but significantly superior to sole pearl millet in term of NPK status and SOC after harvest. This improvement could be attributed to grater root biomass in the plough layer and biological N fixation through legume as also reported by Bana and Shivay (2012) and Kumar *et al.* (2015c).

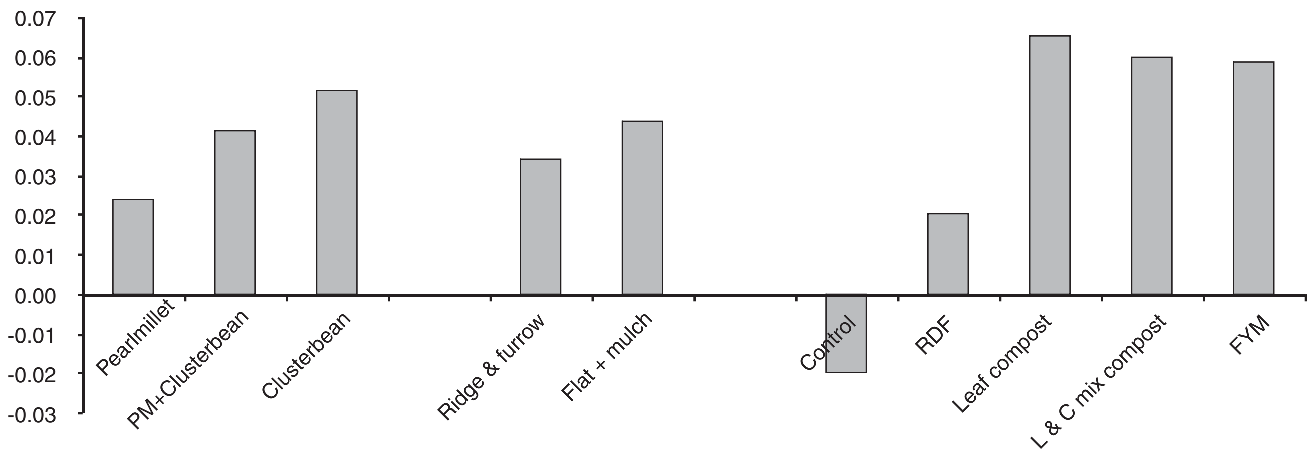

Fig 1 Soil organic carbon changes (±) as influenced by cropping system, nutrient management and moisture management practices after three years of experimentation

Table 5 Soil fertility status after three cropping seasons as influenced by intercropping, moisture management and nutrient management

Treatment	Organic carbon (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
Cropping systems				
Pearl millet sole	0.33_b	200_b	11.4_b	225_b
Clusterbean sole	0.35_a	224_a	12.3_a	235_a
Pearl millet + clusterbean	0.36_a	227_a	12.4_a	236_a
Moisture conservation practices				
Ridge and furrow sowing	0.34_a	213_b	11.8_b	229_a
Flat sowing + Mulching	0.35_a	221_a	12.3_a	235_a
Nutrient management practices				
Control	0.29_c	195_c	9.5_c	215_b
100% RDF	0.33_b	212_b	11.8_b	229_a
Leaf compost (10 tonnes/ha)	0.38_a	230_a	13.0_a	239_a
L and C Mix Compost (10 tonnes/ha)	0.37_a	222_{ab}	12.8_{ab}	237_a
FYM (10 tonnes/ha)	0.37_a	227_a	13.0_a	238_a
Initial value	0.31	202	10.7	226

*Means followed by a similar lowercase letter within a column are not significantly different ($P<0.05$) according to Tukey's HSD test.

The FS+OM resulted in enhanced SOC and available NPK as compared to RFS. The SOC, available NPK also increased significantly due to different nutrient management practices with leaf compost as *numero uno*. The organic carbon content was reduced by 0.02% in control treatment (0.29%) from the initial value 0.31% (Fig 1). However in the rest of nutrient management treatments, the SOC increased by 0.02-0.07% in three years from its initial status. Organic nutrient sources proved superior in terms of soil fertility status after harvest of third season. Maximum available N (230 kg/ha), available P (13.0 kg/ha) and available K (238 kg/ha) were recorded with LC followed by FYM, LCMC and 100% RDF. The per cent increase in available N, P and K was 17.9, 36.8 and 11.2%, respectively, over control and 8.5, 10.2 and 4.4%, respectively, over 100% RDF. This increment might be due to high C:N ratio of organics resulting in SOC build-up in soil, The higher available NPK might be due to increased microbial activity on organic sources leading to greater mineralization of applied and inherent nutrients (Bana and Gautam 2009, Suryavanshi *et al.* 2015). The improvement in SOC, in turn, resulted in build-up in soil fertility and consequently more yield. The correlation studies shows that the changes in SOC are strongly correlated with soil nutrient status with correlation coefficient (R^2) values of available N, P and K with SOC as 0.83, 0.95 and 0.94, respectively.

Soil bulk density (SWD) was also favorably influenced by cropping system, moisture management practices and organic nutrient sources. However, the changes in SWD due to cropping system and moisture management practices were non-significant. PCIS resulted in lowest SWD (1.37 g/cc) followed by sole clusterbean (1.4 g/cc). Highest SWD (1.44 g/cc) was recorded under sole pearl millet. Among moisture management practices, SWD was less under FS+OM. The LC and FYM resulted in lowest SWD (1.37 g/cc) followed by LCMC and 100% RDF. The reduction in SWD in these treatments, by and large, may be attributed to higher SOC, better aggregation and increased root growth in the treated plots. The SOC and SWD correlation study shows that as the SOC increased the SWD decreased almost proportionately. The correlation coefficient (R^2) value of SWD and SOC was recorded 0.80, indicating, a very strong correlation between these two parameters. Meena *et al*. (2012) also reported similar results in pigeonpea-wheat system in sandy-loam soils of Indo-gangetic plains.

The present study demonstrates that the PCIS in additive series resulted in higher system productivity, grain biofortification and more net income over the sole stands of pearl millet and clusterbean in semi-arid ecology of India. Though the yield improvement and biofortification under flat sowing + mulching are non-significant over ridge and furrow sowing, but considering its noteworthy role in improving water use efficiency and soil nutrient status it can be advocated for moisture scarce rainfed drylands. Leaf compost or FYM @ 10 tonnes/ha enhances system productivity, grain quality and soil health in terms of bulk density, organic carbon and NPK status. These results concluded that for sustainable production of improved quality pearl millet and for maintaining soil physicochemical properties, intercropping of clusterbean and input of organic manures are of major importance and should be advocated in the nutrient management.

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