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Effect of Sunhemp Green Manuring and Intercropping on Soil Properties

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A B S T R A C T

The field experiment was conducted at the Research Farm of All India Coordinated Research Project for Dryland Agriculture (AICRPDA), College of Agriculture, Indore during *kharif* 2017. The experiment was laid out in a randomized block design (RBD) with eight treatments in three replications. The treatments studied were: T_1-Soybean + sunhemp (2:1) at 30 cm; T_2-Soybean + sunhemp (1:1) at 45 cm; T_3-Sole soybean at 45 cm; T_4-Maize + Sunhemp (2:1) at 45 cm; T_5-Maize + Sunhemp (1:1) at 30 cm; T_6-Sole Maize at 60 cm; T_7-Soybean + Maize (1:1) at 45 cm and T_8-Sole sunhemp at 30 cm. Soybean (JS 95-60) and Maize (K 604 hybrid) were grown as rainfed crops in *Kharif 2017* with 20:60:40 and 120:60:40 kg ha^{-1} recommended dose of $N:P_2O_5:K_2O$ fertilizers, respectively with Sunhemp as a green manure crop. The soil physio-chemical and microbial properties were studied at crop harvest. The results revealed that the green manuring and intercropping of sunhemp with soybean and maize crop improved the soil physical properties. The soil organic carbon found 20-28% higher under green manuring and intercropping. The application of green manure showed 13-15%, 21-36%, 4-5% and 3-14% higher soil available N, P, K and S after harvest of crops indicating increase in the soil available nutrient status. Similarly, the soil available N, P and K showed 7-13%, 18-35% and 2-5% increment under green manure intercropping. The treatments also showed significantly higher soil microbial population irrespective of the spacing and type of crop combinations (soybean/maize).

Introduction

A fertile and healthy soil is the basis for healthy plants, animals, and humans. The soil organic carbon is the very foundation for healthy and productive soils. The soil organic matter positively influences and modifies almost all the soil properties. Considering the role of soil organic matter in maintaining soil health, the agricultural practices that enhance the soil organic carbon are thus essential. On the other hand, reduced agricultural productivity, escalating production costs, heavy reliance on non-renewable resources, reduced microbial diversity, water contamination, chemical residues in food grains and health risk to the population are the major problems in front of the scientists and policy makers throughout the world. Hence it is therefore essential to think for substituting the nutrient requirement of the crops through different organic inputs. The soil organic carbon can be managed by many ways and practices such as regular application of organic manures, agriculture residue management, crop rotation, conservation agriculture, no or reduced tillage, biochar application and green manuring. Each management practice has its benefits and limitations depending upon the topography, climate, soil type, water availability, economic feasibility etc. Among these management practices the green manuring is the most economical and practically applicable method identified for enhancing the soil organic carbon. Addition of organic matter through green manures plays an important role in improving productivity of crop besides improvement in soil physico-chemical properties, which often deteriorate under intensive cropping involving inorganic fertilization (Hiremath and Patel, 1996). The beneficial effects of the green manuring and intercropping have already been studied in various part of the world in different soils and diverse crops (Muza, 1998; Hongal 2001; Hayder *et al.*, 2003) but the information is lacking in a vertisol especially under soybean-maize intercrop with sunhemp as a green manuring crop. Thus, in order to narrow the identified research gaps a field experiment was conducted.

Materials and Methods

The experiment was conducted during the *kharif* season of 2017-18 at the Research Farm of All India Coordinated Research Project for Dryland Agriculture (AICRPDA), College of Agriculture, Indore. The experimental site has almost uniform topography with light to medium black soils and geographically situated in Malwa Plateau in western parts of Madhya Pradesh on 22.43° N and 75.66° E with an altitude of 556 m amsl. The site is characterized with dry summers with the rising temperature up to 44°C or even higher during April-May. The winters are normal with temperature descending up to 10°C or even more during December and January. The average annual rainfall varies from 750 mm to 1000 mm and 90 % of this is received during the last week of June, July, August, September and first week of October through South-West monsoon.

The field experiment

The present field experiment was carried out with 8 treatments replicated thrice in a Randomized Block Design (RBD). The treatments involved T_1 (Soybean + sunhemp (2:1) at 30 cm); T_2 (Soybean + sunhemp (1:1) at 45 cm); T_3 (Sole soybean at 45 cm); T_4 (Maize + Sunhemp (2:1) at 45 cm); T_5 (Maize + Sunhemp (1:1) at 30 cm); T_6 (Sole Maize at 60 cm); T_7 (Soybean + Maize (1:1) at 45 cm); T_8 (Sole sunhemp at 30 cm). The green manurung crop sunhemp, soybean (cv. JS 95-60) and maize (cv. K 604 Hybrid) were sown in the last week of June. The soybean and maize were grown with 20:60:40 and 120:60:40 kg ha-1 recommended dose of N: P_2O_5:K_2O, respectively. The sunhemp was incorporated in the first week of August. Similarly, the soybean and maize crops were harvested in first week of October and November, respectively at maturity.

Soil sampling and analysis

Representative composite soil samples (0-15 cm depth) were collected with the help of stainless steel auger from the experimental plot before sowing and after harvesting of crop. The samples were mixed thoroughly and dried in air, crushed, sieved through 2 mm sieve. The samples were analyzed for physico-chemical and microbial properties following the standard methods. The initial characteristics of the soil of the experimental field are given in Table 1. The soil bulk density was determined by collecting the soil cores with manually operated core sampler. The drawn core samples were dried in the oven at 105°C for 24 hours and then dry weights were recorded. The bulk density was calculated as unit weight per volume outlined by Richards *et al.,* (1954). The soil samples from various treatments were collected with 10 cm increments up to a depth of 30 cm, with the help of a tube auger and the moisture content was determined by gravimetric method. The mean weight diameter of aggregates was calculated by following the procedure given by Yoder (1936) in which soil sample from each treatment were collected from 10 cm depth. At the time of sampling, soil samples were broken gently with cleavage and air dried in the laboratory. Air-dried samples were passed through 8mm sieve. The samples were cleaned by removing roots, lime concretions, etc. The nest of five sieves having 5,2,1,0.5 and 0.25 mm openings was sieve holders in the Yoder type wet sieving machine. Air –dried triplicate soil samples were used for the analysis. Out of them, one sample was kept for moisture content estimation and the remaining two were used for aggregate analysis. Soil sample was placed on 5mm sieve of the sieve set and was moist by a mist of water. Then sieve set was placed in Yoder type wet sieving machine. Immediately prior to sieving water level was raised rapidly to a point where it fairly covered the sample when the sieves were in their highest position. Subsequently, the Yoder`s wet sieving procedure was followed and the MWD was calculated as follows:

$$Mean\ weight\ diameter\ (MWD) = \sum_{i=1}^{n} (di \times Wi)$$

Where,

n = number of size fraction; di = mean diameter of each size range; Wi = fraction weight of aggregate in that size range of total dry weight of the sample analyzed.

Soil porosity was calculated using particle and bulk density of the soil. The soil pH was determined in (1:2) soil: water suspension using pH meter with glass electrode (Piper, 1950). Soil electrical conductivity was determined in the supernatant solution 1:2 soil: water suspension using electrical conductivity meter (Piper, 1950). Soil organic carbon was estimated by the Walkley and Black (1934) method. The soil available nitrogen was estimated by alkaline permanganate method (Subbiah and Asija, 1956). The determination of available phosphorus was done by using Olsen's reagent (0.5N sodium bicarbonate solution of pH 8.5) as stannous chloride reduced to blue colour, which is in proportion to the concentration of phosphate. The measurement was carried out using the spectrophotometer (Olsen *et al.*, 1954). The soil available potassium was determined by using 1N neutral ammonium acetate solution using flame photometer (Jackson, 1973). For determination of the soil available sulphur, soil was shaken with 0.15% $CaCl_2$ solution. The filtrate was analyzed for sulphur in which the turbidity produced due to precipitation of sulphate as barium sulphate measured on a spectrophotometer at a wave length of 420nm (Bradley and Lancaster, 1960). The soil microbial population was studied using different dilution methods. The samples were incubated using suitable media for respective microorganisms. The composition of the media used for studying different microorganisms are given in Table 2.

The data obtained were tabulated and subjected to statistical analysis of variance using the method suggested by Panse and Sukhatme (1967). The experimental data was statistically analyzed by adopting randomized block design. The critical difference values were computed at 5% level.

Results and Discussion

Soil physical properties

The data pertaining to the effect of green manuring and intercropping on soil physical properties viz. soil moisture, bulk density, soil porosity and mean weight diameter (MWD) has been presented in Table 3.

Soil moisture

The soil moisture content before and after harvest of the crop at 0-15 cm and 15-30 cm depth under different treatments has been shown in Table 3. The data revealed that, the soil moisture content before sowing in 0-15 cm and 15-30 cm soil depth was ranged 28.00-32.27% and 29.90-34.17%, respectively. The soil moisture after harvest in 0-15 cm and 15-30 cm ranged 16-24% and 17.67-24.67%, respectively under different treatments. In 0-15 cm soil depth, highest soil moisture content was observed in the treatment T_8 (Sole sunhemp at 30 cm) followed by treatment T_2 (Soybean + sunhemp (1:1) at 45 cm). The lowest soil moisture content was observed in the treatment T_6 in which sole maize was grown at 60 cm row to row spacing. The data revealed that, the soil moisture content after harvest in 0-15 cm was found to be 17-36% higher under green manuring in soybean crop while it was 20-35% higher under green manuring in maize crop than sole soybean and maize crop, respectively. Similarly, in 15-30 cm soil depth, the increment was 19-30% and 15-28% higher under soybean and maize crop, respectively as compared to respective sole cropping. The sole sunhemp cropping registered 35-40% and 33-37% higher soil moisture in 0-15 and 15-30 cm soil depth, respectively as compared to sole soybean and maize crop. The intercropping also showed 20-26% higher soil moisture in different depths as compared to sole cropping. Thus, the green manuring resulted in retention of soil moisture as compared to sole cropping. The maize grown at 60 cm row to row spacing showed lowest soil moisture in both the depth studied. The reduction of soil moisture in 0-15 cm soil depth was observed with the increase in row to row spacing. Similarly, the absence of green manuring crop also resulted in reduction in soil moisture content. Tsubo and Walker (2002) measured photosynthetic radiation above and beneath a maize-bean intercrop canopy and observed that the canopy reduces the soil evaporation resulting more moisture retention. This might explain the intercrop advantage on soil moisture retension. The intercropping utilizes available resources efficiently compared with each sole crop of the mixture (Dhima *et al.,* 2007; Mucheru-Muna *et al.,* 2010). Sharma *et al.,* (2010) and Ghanbari *et al.,* (2010) also found similar results.

Soil bulk density

The soil bulk density before sowing of crops ranged 1.22-1.27 Mg m^{-3} whereas it was ranged 1.31-1.40 Mg m^{-3} after harvest of the crops (Table 3). The soil bulk density was found lowest in the treatment T_8 (Sole sunhemp at 30 cm). The highest soil bulk density was observed in the treatment T_3 (1.40 Mg m^{-3}) in which sole soybean was grown at 45 cm row to row spacing. The soil bulk density in treatment T_8 significantly reduced over the other treatments. Similarly, the treatments involving the intercropping of sunhemp (T_1, T_2, T_4 and T_5) showed significant reduction in soil bulk density over the treatments with sole cropping and/or without sunhemp (T_3, T_6 and T_7). The sole sunhemp incorporation (Treatment T_8) resulted in significant reduction in bulk density of soil (5-10% reduction). Similarly, the soil bulk density was found to be 2-3%

and 1% lower under soybean and maize green manure incorporation as compared to the sole cropping (Table 3).

The soil bulk density is an important characteristic for successful root development (Kuchenbuch and Ingram, 2004). The reduction in soil bulk density was mainly attributed to the increase in soil organic carbon content (Tiarks *et al.,* 1974) due to incorporation of green manure. The soil organic carbon content is inversely proportional to bulk density (Baur and Black, 1994) which helps in improving the soil structure, soil aggregation, and a consequent increase in volume of micropores resulting in reduction in bulk density. Green manuring incorporation results in decreased bulk density, increased water stable aggregates, pore space, water intake and water retention (Selvi and Kalpana, 2009). The results of present study are in close agreement with the findings observed by Sharma *et al.,* (2010).

Soil porosity

The soil porosity analyzed after harvest of the crops ranged between 47.4% in treatment T_6 and 51.3% in treatment T_8 among different treatments under study (Table 3). The soil porosity remained unaffected irrespective either intercropping and/or green manuring. Soil porosity is the characteristic determined by the amount of pore, or open space between soil particles and generally not affected in short span of time. Selvi and Kalpana (2009) recorded similar findings with respect to the soil porosity.

Mean Weight Diameter (MWD)

The MWD was significantly influenced by green manure incorporation and green manure intercropping. The MWD was ranged between 0.67 mm in treatment T_6 and 1.59 mm in treatment T_8 among different treatments under study. The treatments T_1, T_2 and T_8 was found to be statistically at par with respect to the MWD but significantly superior over the other treatments under study. Similarly, the treatments T_3, T_4, T_5, T_6 and T_7 were also found statistically at par with each other. The application of green manure (incorporation of sole sunhemp) showed 67-127% higher MWD after harvest of crops indicating increase in the MWD. Similarly, the MWD under soybean+sunhemp and maize+sunhemp showed 107-113% and 21-31% increase as compared to sole soybean and sole maize, respectively (Table 3). It has been observed that the intercropping of soybean with green manure (T_1 and T_2) showed significantly higher MWD as compared to the intercropping of green manure with maize (T_4 and T_5). The increase in MWD of soil was mainly attributed to the increase in soil organic carbon content (Tiarks *et al.,* 1974) due to incorporation of green manure. The soil organic carbon helps in improving the soil structure, soil aggregation, and a consequent increase in volume of micropores resulting higher MWD. Similar results were obtained by Selvi and Kalpana (2009) and Sharma *et al.,* (2010).

Soil chemical properties

Soil pH and EC

The soil pH ranged between 7.26-7.53 among different treatments under study. The soil pH remained unaffected irrespective either intercropping and/or green manuring. The soil electrical conductivity (EC) after harvest of soybean, maize and sunhemp (green manuring crop) found reduced but not significantly affected. It was ranged between 0.19 dS m^{-1} and 0.25 dS m^{-1} among different treatments (Table 4). Soil pH and EC are the characteristics determined by parent material and generally not affected in short span of time. Similar results were obtained by Singh *et al.,* (2008). However, a decrease soil pH with application of green manures in long term has been reported by Kumar and Singh (2010) and Subehia and Dhanika (2013).

Soil organic carbon

The soil organic carbon after harvest of the crops ranged between 0.42% and 0.50% under different treatments (Table 4). The treatment T_8 (sole sunhemp at 30 cm), T_2 (Soybean + sunhemp (1:1) at 45 cm), T_1, T_4 and T_5 recorded significantly higher soil organic carbon as compared to the other treatments. The treatments without green manuring crop i.e. T_3, T_6 and T_7 showed significantly lower soil organic carbon. Thus, incorporation of green manure in plot significantly improved the organic carbon status of the soil.

The treatment T_8 (sole sunhemp at 30 cm) registered 20-28% higher soil organic carbon as compared to the sole soybean and maize cropping. Similarly, the sunhemp incorporation either with soybean or maize (Treatment T_2, T_1, T_4 and T_5) recorded significantly higher soil organic carbon as compared to the sole soybean and maize crops (Treatment T_3 and T_6). These treatments registered an increment of 20-28% in soil organic carbon content. Thus, incorporation of green manure in plot significantly improved the organic carbon status of the soil. The observed increase in SOC might be due to the buildup of carbon in soil as present experiment involved incorporation of phytomass of green manure. The sunhemp green manure crop produces 8.1–37.5 t ha^{-1} phytomass (Bin, 1983) and 3.2-6.3 t ha^{-1} dry biomass (Bharadwaj *et al.,* 1981). Besides the green manure incorporation, the root biomass and left over stubbles have also contributed to the increment in soil organic carbon (Aher *et al.,* 2015). Green manure builds up considerable soil organic carbon due to the addition of phytomass and biomass (Selvi and Kalpana, 2009). It was observed that soil organic carbon content in different soil layer in plots with green manuring increased to the extent of 25 to 50 % as compared to no green manuring (Sur *et al.,* 1993; Sharma *et al.,* 2000; Hebbi, 2000). Similar results were obtained by Aulakh *et al.,* (2001) and Chand *et al.,* (2011).

Soil available nutrients (N, P, K and S)

The soil available N before sowing of crops 205 kg ha^{-1} whereas it was ranged between 208.09 and 238.03 kg ha^{-1} after harvest of crops indicating increase in the soil available N status. The soil available N was significantly influenced by the application of green manure either alone or with intercropping with either soybean or maize. The treatments involving the sole or intercropping of sunhemp (green manure crop) showed significantly higher soil available N after harvest of the crops as compared to the treatments without green manure incorporation. The treatments involving intercrop of green manure with soybean (T_1 and T_2) reported significantly higher soil available N as compared to the green manure intercrop with maize (T_4 and T_5) irrespective of spacing. Soil available P before sowing of the crops was found in the 10.4 kg ha^{-1} whereas it was found between 10.49-16.45 kg ha^{-1} after harvest of crops under different treatments. The treatments T_1, T_2, T_5 and T_8 found at par with respect to the soil available P in soil but significantly superior over the other treatments (T_3, T_4, T_6 and T_7).The treatment T_7 recorded lowest soil available P (10.49 kg ha^{-1}). The soil available P was found in the order: $T_8>T_2>T_1>T_5>T_4>T_3>T_6>T_7$ (Table 4). The soil available potassium before sowing of crops was observed 560 kg ha^{-1}.The soil available K after harvest of crops was significantly influenced by intercropping and green manure incorporation in the different treatments. The treatments T_1, T_2, T_4, T_5 and T_8 were found to be statistically at par but statistically significant over the other treatments with respect to available K in soil. The treatments involving the incorporation of sunhemp as green manure either sole or as intercrop showed higher soil available K as compared to the other treatments (Table 4). The soil available Sulphur after harvest of crops ranged between 13.03-15.47 kg ha^{-1}.The treatments T_1, T_2, T_4, T_5 and were also found statistically at par (Table 4). The application of green manure (incorporation of sole sunhemp) showed 13-15%, 21-36%, 4-5% and 3-14% higher soil available N, P, K and S after harvest of crops indicating increase in the soil available nutrient status. The soil available N showed 9-11% and 7-9% higher under soybean+ sunhemp and maize + sunhemp as compared to sole soybean and sole maize, respectively. The soil available P also showed 18-35% increment under soybean+ sunhemp green manure intercropping whereas the increment in case of maize + sunhemp intercropping was 3-24%. The soil available S was not much benefited from the green manuring due to high initial S status of the experimental soil. The soil available K also showed an increment of 3-5% and 2-5% under soybean and maize green manure intercropping. Thus, the soil available nutrients were significantly influenced by the application of green manure either alone or with intercropping with either soybean or maize as compared to sole soybean and maize cropping. It has been observed that the incorporation of green manure as sole crop or as intercrop with either soybean or maize found beneficial with respect to the improvement in soil properties viz. soil bulk density, moisture content, organic carbon, and availability of major nutrients (N, P, K and S) as compared to the treatments without green manure.

The average increase in available nitrogen, phosphorous and potassium was around 40, 90 and 38 % respectively, over initial status of soil (Hebbi, 2000). The sunhemp green manure crop produces 8.1–37.5 t ha^{-1} phytomass (Bin, 1983), 3.2-6.3 t ha^{-1} dry biomass (Bharadwaj *et al.*, 1981) and accumulates 42-95 kg ha^{-1} N (Mishra and Nayak, 2004; Selvi and Kalpana, 2009).

Table.1 Initial soil properties of experimental field

Soil property	Value
Sand (%)	10.5
Clay (%)	38.3
Silt (%)	51.3
Electrical conductivity (dS m^{-1})	0.41
Soil pH	7.41
Organic Carbon (%)	0.46
Available Nitrogen (kg ha^{-1})	191.8
Available Phosphorus (kg ha^{-1})	12.16
Available Potassium (kg ha^{-1})	573.9
Available Sulphur (kg ha^{-1})	15.0
Bacteria ($\times 10^6$)	14.6
Fungi ($\times 10^3$)	12.4
Actinomycetes ($\times 10^4$)	12.6

Table.2 Chemical composition of standard media for fungi, bacteria and actinomycetes

Chemical composition	Rose Bengal (Fungi)	Thorntons media (Bacteria)	Caseinate Agar Media (Actinomycetes)
Glucose	10 gm	-	-
Peptone	5 gm	-	-
KH_2PO_4	1 gm	-	0.5 gm
$MgSO_4$	0.03 gm	0.2 gm	0.2 gm
Agar-Agar	15-18 gm	15-18 gm	15-18 gm
Distilled water	1000ml	1000 ml	1000 ml
$CaCl_2$	-	0.2 gm	-
$FeCl_2$	-	Trace	-
$NaCl_2$	-	0.1 gm	-
KNO_3	-	0.5 gm	-
Asparagin	-	0.5 gm	-
Mannitol	-	1 gm	-
Yeast extract	-	Trace	-
Sodium Caseinate	-	0.2 gm	-
$FeCl_3$	-	0.01 gm	-

Table.3 Soil physical properties as influenced by green manuring and intercropping

Treatment	Moisture (%)		Bulk density (Mg m^{-3})	MWD (mm)	Porosity (%)
	0-15	15-30			
T_1-Soybean + sunhemp (2:1) at 30 cm	20.3	22.3	1.36	1.49	50.88
T_2-Soybean + sunhemp (1:1) at 45 cm	23.7	24.3	1.35	1.45	50.87
T_3-Sole soybean at 45 cm	17.3	18.7	1.40	0.70	48.57
T_4-Maize + Sunhemp (2:1) at 45 cm	19.3	20.3	1.37	0.81	49.23
T_5-Maize + Sunhemp (1:1) at 30 cm	21.7	22.7	1.36	0.88	49.10
T_6-Sole Maize at 60 cm	16.0	17.7	1.38	0.67	47.40
T_7-Soybean + Maize (1:1) at 45 cm	19.0	20.7	1.38	0.95	49.07
T_8-Sole sunhemp at 30 cm	24.0	24.7	1.31	1.59	51.30
SEm (±)	1.22	1.45	0.015	0.11	1.04
CD (P=0.05)	3.71	4.4	0.048	0.33	NS

MWD-Mean weight diameter

Table.4 Soil chemical properties as influenced by green manuring and intercropping

Treatment	pH	EC	OC	N	P	K	S
T_1-Soybean + sunhemp (2:1) at 30 cm	7.38	0.22	0.56	228.0	16.1	582.3	15.3
T_2-Soybean + sunhemp (1:1) at 45 cm	7.53	0.20	0.58	234.0	16.3	585.5	15.5
T_3-Sole soybean at 45 cm	7.43	0.24	0.49	209.0	13.6	563.4	13.9
T_4-Maize + Sunhemp (2:1) at 45 cm	7.44	0.21	0.53	222.1	14.0	575.2	14.6
T_5-Maize + Sunhemp (1:1) at 30 cm	7.45	0.23	0.55	225.1	14.9	579.4	14.7
T_6-Sole Maize at 60 cm	7.38	0.25	0.42	206.6	12.1	561.2	13.0
T_7-Soybean + Maize (1:1) at 45 cm	7.51	0.23	0.44	208.1	10.5	561.2	13.4
T_8-Sole sunhemp at 30 cm	7.26	0.19	0.59	238.0	16.5	588.7	14.3
SEm(±)	0.06	0.02	0.03	4.8	0.7	6.4	0.5
CD (P=0.05)	NS	NS	0.10	14.4	2.0	20.1	1.5
Initial status	7.49	0.42	0.46	205.0	10.4	560.0	13.7

EC- Electrical conductivity (dS m^{-1}); OC- Organic carbon (%); N, P, K and S- Available nitrogen, phosphorous, potassium and sulphur, respectively (kg ha^{-1})

Figure.1 Soil bacterial population under green manuring and intercropping treatments at crop harvest *(T1-Soybean + sunhemp (2:1) at 30 cm; T2-Soybean + sunhemp (1:1) at 45 cm; T3-Sole soybean at 45 cm; T4-Maize + Sunhemp (2:1) at 45 cm; T5-Maize + Sunhemp (1:1) at 30 cm; T6-Sole Maize at 60 cm; T7-Soybean + Maize (1:1) at 45 cm; T8-Sole sunhemp at 30 cm; $CD_{0.05}$=7.96)*

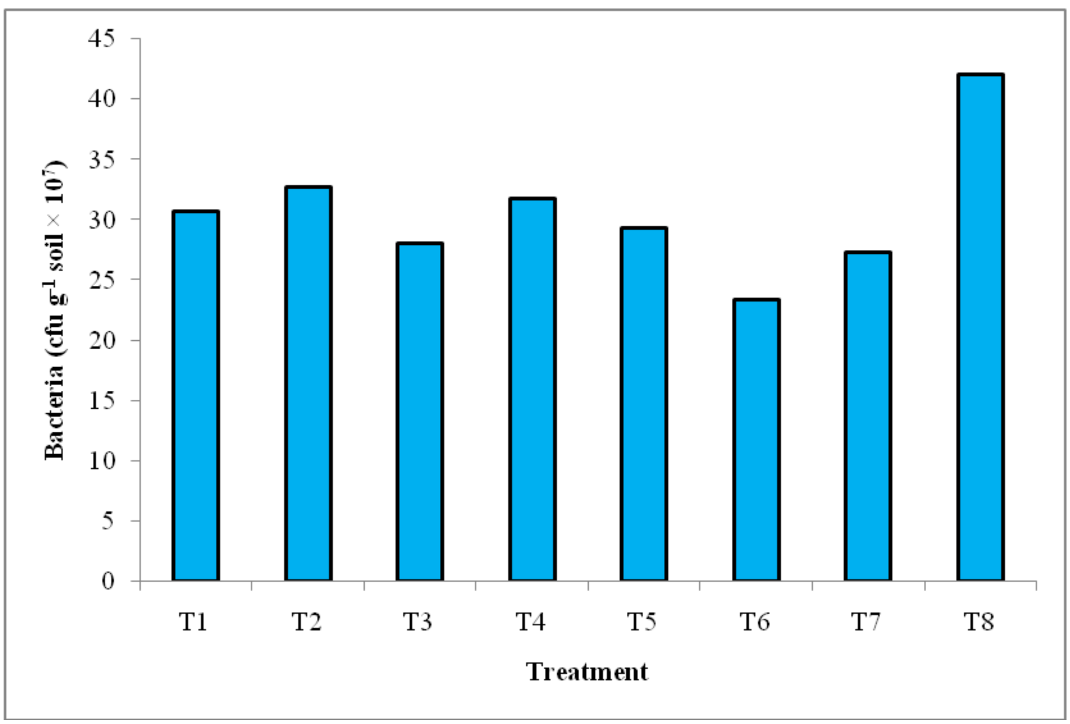


Figure.2 Soil fungal population under green manuring and intercropping treatments at crop

harvest *(T1-Soybean + sunhemp (2:1) at 30 cm; T2-Soybean + sunhemp (1:1) at 45 cm; T3-Sole soybean at 45 cm; T4-Maize + Sunhemp (2:1) at 45 cm; T5-Maize + Sunhemp (1:1) at 30 cm; T6-Sole Maize at 60 cm; T7-Soybean + Maize (1:1) at 45 cm; T8-Sole sunhemp at 30 cm; $CD_{0.05}$=2.42)*

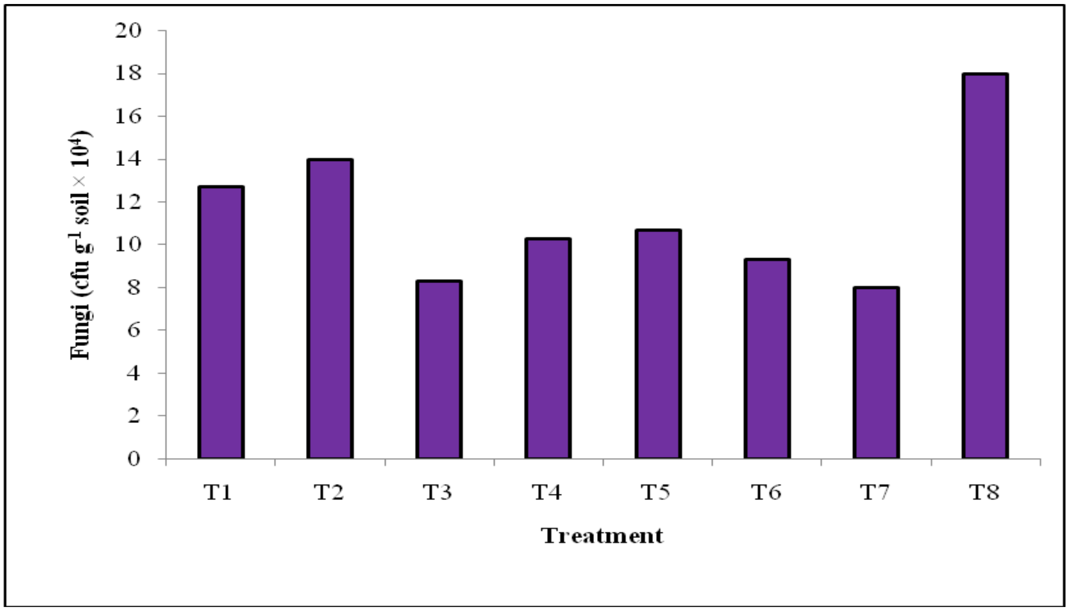
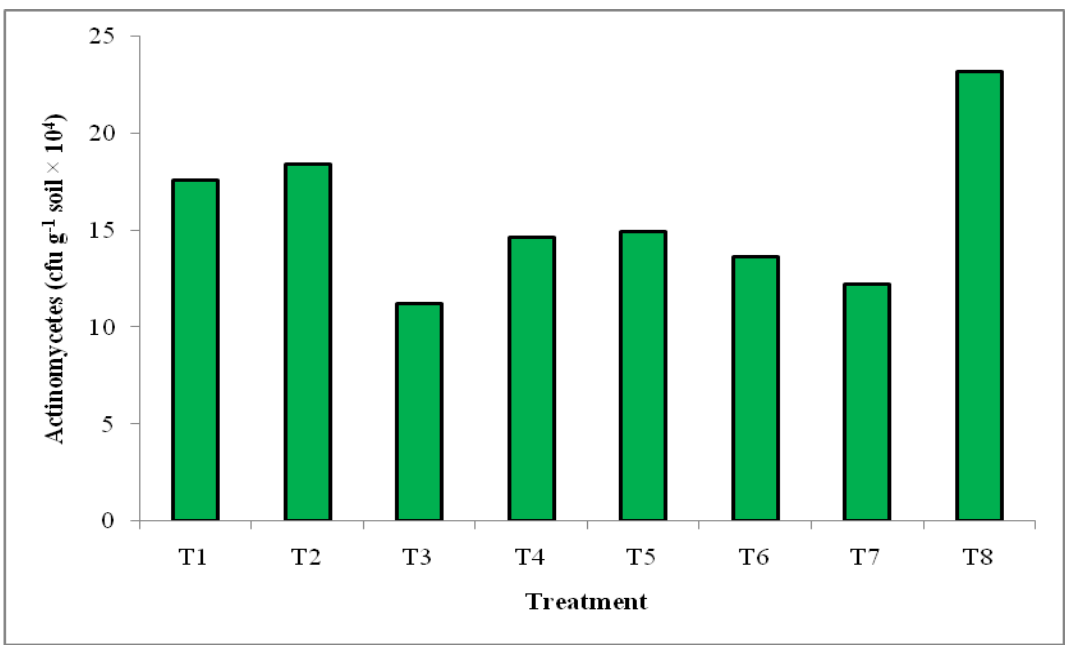


Figure.3 Soil actinomycetes population under green manuring and intercropping treatments at crop harvest *(T1-Soybean + sunhemp (2:1) at 30 cm; T2-Soybean + sunhemp (1:1) at 45 cm; T3-Sole soybean at 45 cm; T4-Maize + Sunhemp (2:1) at 45 cm; T5-Maize + Sunhemp (1:1) at 30 cm; T6-Sole Maize at 60 cm; T7-Soybean + Maize (1:1) at 45 cm; T8-Sole sunhemp at 30 cm; $CD_{0.05}$=2.64)*



The nutrients released from mineralization of phytomass and N fixation by legume might result in higher nutrient availability in soil after harvest of crop. On the other hand, N use efficiency of green manue is high as green manure N is less prone to loss mechanisms than mineral N fertilizer and may therefore contribute to enhanced soil N. Green manures increased the availability of P through the mechanism of reduction and favourable changes in soil pH. Similarly, the green manure mobilizes S, P, Si, Zn, Cu, Mn and other nutrient elements (Selvi and Kalpana, 2009). The enhanced soil nutrients under green manuring viz. available N, P, K and S (Hebbi, 2000; Sharma *et al.,* 2000; Nooli *et al.,* 2001; Biradar and Palled, 2003; Tsubo *et al.,* 2005; Dahmardeh *et al.,* 2010; Subehia and Dhanika, 2013; Ziblim *et al.,* 2013) have already been reported.

Soil microbial population (Bacteria, fungi and actinomycetes)

The soil microbial population viz. bacteria, fungi and actinomycetes after harvest of crops has been presented in Figure 1, 2 and 3. The population of soil bacteria ranged from 23.3 to 42.0 cfu g^{-1} soil $\times 10^7$. The highest bacterial population was observed under the treatment T_8 (sole sunhemp at 30 cm) whereas the lowest was observed under sole maize cultivation at 60 cm row to row spacing (T_6). The soil bacterial population was found in the order: Sole green manure>Intercropping with green manure> Intercropping>Sole cropping. The population of soil fungi and actinomycetes ranged between 8.0-18.0 cfu g^{-1} soil $\times 10^4$ and 11.2-23.2 cfu g^{-1} soil $\times 10^4$, respectively under different treatment combinations. The highest fungal and actinomycetes population was found under sole green manure cropping i.e. treatment T_8 whereas the lowest was observed under T_7 (Soybean + Maize (1:1) at 45 cm) and T_3 (Sole soybean at 45 cm), respectively. The treatments involving sole green manure incorporation (T_8) and green manure intercropping (T_1, T_2, T_4 and T_5) showed significantly higher soil fungal and actinomycetes population as compared to the other treatments (Fig. 2 and 3). It has been observed that the treatments with incorporation of green manure either alone or in combination as intercrop showed significantly higher soil microbial population irrespective of the spacing and type of crop combinations (soybean/maize).

The soil bacterial population was found in the order: Sole green manure>Intercropping with green manure> Intercropping>Sole cropping (Fig. 1). Similarly, the highest fungal and actinomycetes population was found under sole green manure cropping i.e. treatment T_8 whereas the lowest was observed under T_7 and T_3, respectively. It has been observed that the treatments with incorporation of green manure either alone or in combination as intercrop showed significantly higher soil microbial population irrespective of the spacing and type of crop combinations (soybean/maize). The increased microbial population under green manuring mainly attributed to the higher organic carbon especially biologically active phase of carbon which acted as source of energy for microbes proliferating in soil as reported by Rajannan and Oblisami (1979). Similarly, the significant positive correlation among soil organic carbon and microbial population has already been explored earlier by Graham and Haynes (2005). The enhanced microbial population upon application of different sources of organic matter is in close agreement with present results (Kannan *et al.,* 2006; Aher *et al.,* 2018).

In conclusions, the incorporation of sunhemp as green manure crop intercropped with soybean and maize showed positive response on physic-chemical and microbial properties of soil. The green manure intercrop treatments significantly enhanced soil organic carbon and improved physical, chemical and biological properties of soil and reflected as viable technique in improving soil health.

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