LONG TERM EFFECT OF GRASS-BASED CROPPING SYSTEMS TO IMPROVES SOIL HEALTH AND SUSTAINABILITY

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SUMMARY

Good soil health is utmost essential to management strategies for tackling the issues of soil health deterioration and over exploitation of underground water resources, particularly in intensive cropping systems. Therefore, a long term four years study was conducted to evaluate soil health under different eight grass based cropping systems (GBCS) *i.e.* pearl millet napier (PN) hybrid sole crop (T_1), guinea grass sole crop (T_2), PN hybrid in paired rows + rice bean (*kharif*) - egyption clover (*rabi*) (T_3), PN hybrid in paired rows + *Desmanthus* (T_4), PN hybrid in paired rows + *Sesbania grandiflora* (T_5), guinea grass in paired rows + rice bean (*kharif*) - egyption clover (*rabi*) (T_6), guinea grass in paired rows + *Desmanthus* (T_7) and guinea grass in paired rows + *Sesbania grandiflora* (T_8). Soil samples were collected from 0-15, 15-30 and 30-45 cm at initial of experiment July 2016 and end of experiment June 2020. Results showed, that reduction in bulk density (BD), electrical conductivity, soil pH. The lowest BD 1.31 at 0-15, 1.42 at 15-30 and 1.46 at 30-40 cm soil depth was recorded with the application of PN hybrid in paired rows + *Desmanthus*, PN hybrid in paired rows + rice bean (*kharif*) - egyption clover (*rabi*) and PN hybrid in paired rows + *Sesbania grandiflora* respectively. Electrical conductivity and soil pH was not affected by GBCS and it's found non-significant. The enrichment of soil organic carbon (SOC), available nitrogen, phosphorus, potassium, total bacterial count, fungi, azoctobactor, actinomycetes and phosphorus solubilizing bacteria was mostly confined to upper surface soil layer (0-15 cm). The SOC content found non-significant but SOC stock in PN hybrid in paired rows + ricebean - Egyptian clover was recorded 15-20% higher than sole cropping system at 0-15 cm soil depth. Available nitrogen increased by 15 %, Phosphorus 09% and potash 10% in 0-15, 15-30 and 30-45 cm soil depth, respectively in PN hybrid in paired rows + ricebean - Egyptian clover over pearlmillet napier hybrid sole. Similarly soil micro flora like that total bacterial count, fungi, *Azoctobactor*, *Actinomycetes* and phosphorus solubilizing bacteria.

Key words: Grass based cropping systems, soil health and soil quality parameters

Sole growing of perennial fodder crops depletion of soil organic carbon with subsequent deterioration in soil health. The grass based-cropping system (GBCS) in India is important for the food security of million peoples as well as throughout year availability of green fodder. In Kymore Plateau and Satpura Hills of Madhya Pradesh conventional grass production practices often leads to changes in soil health governing properties like, soil structure, aggregation, porosity, strength, hydraulic conductivity, infiltration, bulk density, soil moisture content, soil organic carbon content, microbial biomass and their activities (Allen *et al.*, 1986).Stabilization of soil aggregates, food for beneficial organisms, slow-release source of nutrients, increased water holding capacity, increase in nutrient holding capacity by improving cation exchange capacity, binding of toxic material build carbon for several reasons *viz.* where perennial species growing continually rather than seasonally, minimal disturbance relative to cropping, no erosion, if well managed (Kane, 2015). Soil health is a dynamic and complex system, and its functions are mainly mediated by agricultural management practices (Doran and Zeiss, 2000). Soil with better health and quality will be able to produce higher crop yield under favourable as well as extreme climatic conditions and soil health acts as a critical component for adaptation and mitigation of climate change effects

by the crops (Congreves *et al.,* 2015). However, measurement and demonstrations of soil health related properties (physical, chemical and biological), and their interactions are very complex (Karlen *et al.,* 2003). The soils are very deep, colour ranges from dark brown (10YR3/1) to very dark grey (10YR4/3) in different horizons (Typic Haplusterts) soil is the most dominant soil texture of Kymore Plateau and Satpura Hills of Madhya Pradesh (Tripathi, 2006). The dominant soil constraints are unfavourable tilth, wide and deep shrinkage cracks, slow saturated hydraulic conductivity in sub soil and prone to erosion in the uplands (Tomar *et al.,* 1995). They are black due to compounds of iron and aluminum. These soils are deficient in nitrogen, phosphoric acid and organic matter but rich in calcium potash and magnesium. Maintenance of organic carbon in soil (SOC) is critically important for sustained agricultural productivity and environmental quality. Reduced soil disturbance and increased organic matter inputs in forage production systems may improve soil quality and crop production through their effects on soil organic matter (SOM) dynamics and nutrient cycling. Perennial forage crops are known to increase soil microbial substrate quality, availability and diversity and to augment root biomass carbon and nitrogen accumulation and thereby improve soil organic carbon (SOC) storage (Singh *et al.,* 2018 and Biradar *et al.,* 2019). The soil organic carbon and its fractions are good indicators of soil quality and environmental stability (Kumhar *et al.,* 2021a). Mixed forage of cereal legumes intercropping systems is an indispensable component of animal feed due to better agro qualitative attributes, especially protein. GBCS help in increasing the fodder yield and resource use efficiency through their vegetation cover, greater root production ability especially in the top 15 cm soil profile thus bind soil particles, help in soil conservation, sustainable fodder production, adapting to mitigating global climate change, improving water quality, availability and ensuring food security (Soni *et al.,* 2013). Reduced soil disturbance and increased organic matter inputs in forage production systems may improve soil quality and crop production through their effects on soil organic matter (SOM) dynamics and nutrient cycling (Meena *et al.,* 2023). Perennial forage crops are known to increase soil microbial substrate quality, availability and diversity and to augment root biomass carbon and nitrogen accumulation and thereby improve soil organic carbon (SOC) storage. Practices that sequester carbon in grasslands also tend to enhance

resilience in the face of climate variability, and are thus likely to enhance longer-term adaptation to changing climates. Carbon sequestration in the biosphere has now become an important strategy to offset the effect of increasing carbon dioxide (CO_2) in the atmosphere (Tanwar *et al.,* 2019). Maintenance of organic carbon in soil (SOC) is critically important for sustained agricultural productivity and environmental quality. Enhancing soil carbon sequestration in agricultural land is a strategy of vital importance to decelerate the observed climate changes. The soil organic carbon and its fractions are good indicators of soil quality and environmental stability. But the scenario of productivity of livestock is not satisfactory due to shortage in green forage availability (Hazra, 2019). Soil is considered a source and a sink for CO_2 sequestration (Kumhar *et al.,* 2020b). In addition, most of the forage grasses are of multi-cut type and they serve as vegetative mulch conditions for a longer period depending on the soil fertility and availability of water. Inclusion of perennial species in farming systems seems to be a feasible option to help mitigate the extensive impacts of these threats. To increase the production of biomass and maintain soil fertility. The cultivation of cover crops throughout the year like forages is also reported to increase soil carbon stocks in soils in many research papers (Bama and Babu, 2016). The data served as a base to determine carbon credit for forage crops which may offer benefits to the farmers besides sustaining soil fertility and environmental safety (Bama, 2014 and Kumhar *et al.,* 2021bc). The soil organic carbon and its fractions are good indicators of soil quality and environmental stability. Comprehensive information on long term effect of grass-based cropping systems on total organic carbon, physical and biological properties of a black soil in Kymore Plateau and Satpura Hills of Madhya Pradesh. Therefore, long term study on GBCSs for maintaining or enhancing soil physical, chemical and biological characteristics of black soil are needed. Hence, with the above information the present study has been undertaken.

MATERIALS AND METHODS

Site description and treatment details

The long-term field experiment was started in the *Kharif* season of 2016 at the Research Farm, Department of Agronomy, Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV) located at Jabalpur (22°49'

TABLE 1
Experimental details

Treatments	Cropping systems	Management systems
T_1	Pearlmillet Napier (PN) hybrid sole crop	Crop establishment methods : planting through rooted slips at a spacing of 50×50 cmCutting : Cutting from 5.0 cm stubble height using a serrated sickle, six cutting were taken in a year
T_2	Guinea grass (GG) sole crop	Crop establishment methods : planting through rooted slips at a spacing of 50×50 cmCutting : Cutting from 5.0 cm stubble height using a serrated sickle, six cutting were taken in a year
T_3	PN hybrid in paired rows + Ricebean - Egyption clover	Crop establishment methods : planting through rooted slips at a spacing of 50×50 cm, ricebean in rainy season (July–September) and Egyptian clover in winter season (November–March) two rows at 30 cm spacing were sown between rows of PN hybridCutting : Cutting from 5.0 cm stubble height using a serrated sickle, six cutting were taken in a year as well ricebean and Egyptian clover
T_4	PN hybrid in paired rows + *Desmanthus*	Crop establishment methods : planting through rooted slips at a spacing of 50×50 cm and hedge lucern two rows at 30 cm spacing were sown between rows of PN hybridCutting : Cutting from 5.0 cm stubble height using a serrated sickle, six cutting were taken in a year as well hedge lucern
T_5	PN hybrid in paired rows + *Sesbania grandiflora*	Crop establishment methods : planting through rooted slips at a spacing of 50×50 cm and *Sesbania* two rows at 30 cm spacing were sown between rows of PN hybridCutting : Cutting from 5.0 cm stubble height using a serrated sickle, six cutting were taken in a year as well *Sesbania*
T_6	GG in paired rows + Ricebean - Egyption clover	Crop establishment methods : planting through rooted slips at a spacing of 50×50 cm, ricebean in rainy season (July–September) and egyptianclover in winter season (November–March) two rows at 30 cm spacing were sown between rows of guinea grassCutting : Cutting from 5.0 cm stubble height using a serrated sickle, six cutting were taken in a year as well ricebean and Egyptian clover
T_7	GG in paired rows + *Desmanthus*	Crop establishment methods : planting through rooted slips at a spacing of 50×50 cm and hedge lucern two rows at 30 cm spacing were sown between rows of guinea grassCutting : Cutting from 5.0 cm stubble height using a serrated sickle, six cutting were taken in a year as well hedge lucern
T_8	GG in paired rows + *Sesbania grandiflora*	Crop establishment methods : planting through rooted slips at a spacing of 50×50 cm and *Sesbania* two rows at 30 cm spacing were sown between rows of guinea grassCutting : Cutting from 5.0 cm stubble height using a serrated sickle, six cutting were taken in a year as well *Sesbania*

and 20°80' North latitude and 78°21' and 80°58' East longitude at an attitude of 411.78 m above mean sea level) Madhya Pradesh, India. The region has a subtropical with hot and dry spell in April to June to wet summer spell in July to September and a cool and dry winter spell in October to March. Average rainfall of the area is 1350 mm, 75-85% of which occurred during Monsoon season. The soil is classified as Vertisol as per US classification of soil. The soil of experimental field was sandy clay loam in texture, medium in organic carbon with neutral pH. The initial soil properties of the experimental site obtained. The experiment was laid out in randomized block design with three replications (Table 1). The treatments are termed as grass-based cropping systems which were designed to address various drivers of current as well as future grass-based cropping system in this region.

Initially the experiment was started with eight grass based cropping systems in July 2016 under all India coordinated research project on forage crops and utilization, namely pearl millet napier (PN) hybrid sole crop (T_1), guinea grass sole crop (T_2), PN hybrid in paired rows + rice bean (*kharif*) - egyption clover (*rabi*) (T_3), PN hybrid in paired rows + *Desmanthus* (T_4), PN hybrid in paired rows + *Sesbania grandiflora* (T_5), guinea grass in paired rows + rice bean (*kharif*) - egyption clover (*rabi*) (T_6), guinea grass in paired rows + *Desmanthus* (T_7) and guinea grass in paired rows + *Sesbania grandiflora* (T_8). Land preparation was done by tilling the land once with tractor driven cultivator followed by harrowing twice by disc harrow to obtain a well pulverized and fine tilth and then leveling was done by planker just before the planting of grasses and sowing of intercrops. Guinea grass

and pearl millet napier hybrid was planted through rooted slips at a spacing of 50 cm × 50 cm. Inter row space was utilized for the planting of the hedge lucern, *Sesbania* and ricebean in rainy season (July– September) and egyptian clover in winter season (November–March), respectively. Two rows of hedge lucern, *Sesbania* and ricebean at 30 cm spacing were sown between rows of guinea grass and pearlmillet hybrid napier in the month of July every year. Rainy season (July–October) crops were grown while in winter (November–March) season the crops were irrigated as per need. Guinea grass and pearlmillet hybrid napier were harvested 6 times (normally 95– 96 days interval in winter season and 42–62 days interval in other season) in a year using serrated sickle up to 5.00 cm above ground surface. Guinea grass and PN hybrid remained dormant during winter season (November–March). Recommended dose of fertilizer (150-80-40 kg ha^{-1}of N-P$_2$O$_5$-K$_2$O) were applied in all grass-based cropping systems through urea, single super phosphate and muriate of potash. Nitrogen in the form of urea was applied as split dose after each cut whereas, phosphorus and potash were applied as basal in the form of single super phosphate and muriate of potash. All the observations were recorded and recommended package of practices as adopted in Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, were followed to raise the crops.

Soil sampling and analysis

Replicated soil samples (2 sub replications from each 3 replicated fields = 6 replications for each treatment) were collected from each treatment at three soil depth *viz*. 0-15, 15-30 and 30-45 cm with auger after crops harvesting during last week of May 2020. One part of the soil samples air-dried in shade, ground to pass through a 2-mm sieve, stored in plastic jars for laboratory analysis of selected soil samples chemical properties. Other part of the fresh soil sample was kept moist in polythene bags at 4 °C until the biochemical analysis. Soil bulk density was measured by core method (Bodman, 1942). Soil organic carbon (SOC) content was determined Walkey and Black method (Black, 1965). Available N in soil was determined by alkaline permanganate method (Subbiah and Asija, 1956), available phosphorus (P) by Calorimetric method of Olsen *et al.* (1954), available potassium (K) by Flame photometric method. Total bacteria count (10^5 x cfu/g soil) by Thornton's medium

(Thornton's, 1922), Fungi (10^3 x cfu/g soil) by Rose Bengal streptomycin agar media (Rao, 1963), Actinomycetes (10^3 x cfu/g soil) by Casenak Agar medium (Rao, 1963), Azotobacter 10^3 x cfu/g soil) by Jensen's media (Jensen, 1954) and Phosphorous solubilizing bacteria (10^3 x cfu/g soil) by Pikovskeya's medium.

Statistical analysis

Data analysis was performed using OP STAT windows version. Test of significance was performed for separation of treatments means at 5 % level of significance ($p < 0.05$) by prepared ANOVA table. The mean effects of grass-based cropping systems were determined using linear contrast or individual is given by DMRT.

RESULTS AND DISCUSSION

Soil physical properties as influenced by long term GBCS

Soil physical quality attributes such as bulk density (BD) was significantly affected by long term GBCS (Table 2). Soil bulk density statistical similar in all the soil layers (0-15, 15-30 and 30-45 cm). At 0-15 cm soil depth, BD PN hybrid in paired rows + ricebean - egyptian clover (1.40 Mg m^{-3}), PN hybrid in paired rows + *Desmanthus* (1.31 Mg/m^3) and GG in paired rows + ricebean - egyptian clover (1.39 Mg/m^3) was found slightly lower compared to GG sole crop. Compared to grass-based cropping systems, we obtained higher BD although statistical similar in GG sole crop (1.42 Mg/m^3) in top soil layer (0-15 cm) which may be due to the combined effect of inclusion of legume crops as intercrops. This is also supported by higher organic carbon found. In addition to irrigation water moves up through capillary rise and reaches soil surface and then evaporates due to evaporative demand which might lead to shrinkage thereby causing higher BD. Reduced the mass of soil per unit volume hence decreased the bulk density. The increase in bulk under cropping systems was observed by researcher. Increased BD was reported with increasing soil depth might be due to cumulative load of upper horizons or low organic matter. Findings are well supported by those reported by Kundu *et al.,* (2019) who also found higher bulk density of soil at lower depth.

TABLE 2

Effect of grass-based cropping systems on soil bulk density (Mg/m³) and electrical conductivity (dS/m[1] at 25⁰C) and pH

	Bulk density (Mg/m³)			(dS/m[1] at 25⁰C)			pH		
	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
Initial value	1.37	1.44	1.60	0.210	0.184	0.169	7.50	7.93	7.90
T_1	1.38 ab	1.46 a	1.51 ab	0.2030 a	0.184 a	0.169 a	7.09 a	7.28 a	7.49 a
T_2	1.42 a	1.46 a	1.51 ab	0.2103 a	0.183 a	0.162 a	7.02 a	7.42 a	7.20 a
T_3	1.35 abc	1.42 b	1.51 ab	0.2037 a	0.171 a	0.141 a	7.30 a	7.65 a	7.52 a
T_4	1.31 c	1.46 a	1.54 a	0.2017 a	0.174 a	0.149 a	7.27 a	7.43 a	7.54 a
T_5	1.37 abc	1.47 a	1.46 c	0.2073 a	0.177 a	0.153 a	7.13 a	7.32 a	7.63 a
T_6	1.39 ab	1.47 a	1.51 abc	0.2167 a	0.174 a	0.142 a	7.15 a	7.52 a	7.55 a
T_7	1.33 bc	1.47 a	1.47 bc	0.2143 a	0.176 a	0.149 a	7.41 a	7.19 a	7.45 a
T_8	1.35 abc	1.49 a	1.50 abc	0.8817 a	0.178 a	0.161 a	7.34 a	7.45 a	7.70 a

TABLE 3

Effect of grass-based cropping systems on soil organic carbon content and stock

	SOC content (g/kg[1])			SOC stock (Mg/kg[1])		
	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
T_1	0.7500 a	0.6500 a	0.6033 a	16.38 a	16.30 a	16.67 a
T_2	0.7200 a	0.6233 a	0.5567 a	14.72 ab	13.56 bc	12.67 b
T_3	0.7467 a	0.6300 a	0.5833 a	17.60 a	13.70 abc	13.19 b
T_4	0.7267 a	0.6233 a	0.5600 a	14.67 ab	13.58 bc	12.69 b
T_5	0.7267 a	0.6333 a	0.5733 a	14.82 ab	13.92 ab	12.94 b
T_6	0.7100 a	0.6100 a	0.5333 a	14.20 ab	13.39 bc	12.04 b
T_7	0.6967 a	0.6133 a	0.5167 a	14.34 ab	13.51 bc	10.33 b
T_8	0.6933 a	0.6000 a	0.5167 a	11.33 b	11.00 c	11.72 b

Soil chemical properties as influenced by long term GBCS

Long term GBCS have significant effect (p < 0.05) on soil chemical properties such as electrical conductivity, pH (Table 2), organic carbon content and stock (Table 3), available nitrogen, phosphorus and potash (Table 4). Soil pH under GBCS were found non-significant. Electrical conductivity was similar in all three-soil depth across the all GBCS (Table 2). The values of EC did not show remarkable alternation and this could be attributed to high buffering capacity of soil. Similar findings were also reported by Ghimire *et al.,* (2018).

Soil organic carbon (g/kg[1])

In top soil layer (0-15 cm), soil organic carbon (SOC) stock were significantly higher in all GBCS except GG sole crop. On average, SOC stock were 15-20 % hiver over GG sole crop at 0-15 cm soil depth (Table 3). At 15-30 cm soil depth, SOC stock were statistically similar irrespective of all GBCS. But 30-45 cm soil depth, highest stock was recorded in pearl millet napier (PN) hybrid sole crop. Overall, SOC content and stock under all GBCS sole crop and intercrops management systems was significantly higher over GG sole crop at soil surface (0-15, 15-30 and 30-45 cm) layer.

The beneficial effect of legume intercrops on SOC content and stock was reflected at 0-15, 15-30 and 30-45 cm soil layer. Adoption of legume inclusion in GBCS increased both SOC content and stock at 0-15, 15-30 and 30-45 cm soil depth. In GBCS need no tillage practices after establishment due to perennial in nature no tillage operation favor accumulation of organic carbon under legume inclusion because tillage operation expose SOC to air results higher oxidation

of organic carbon. Role of crop stubble and residue retention on improving SOC was also reported by many researchers Nishanth *et al.,* (2013). The soil organic carbon was decreased with increasing soil depths in all grass-based cropping systems. Several authors also reported that intercropping under perennial highlighted that inclusion of legumes in the cropping system helps in maintaining soil organic carbon, soil quality and crop productivity (Ganeshamurthy, 2019). Soil organic carbon can be accomplished by management practices that add high amounts of biomass to the soil, cause minimal soil disturbance, conserve soil and water, improve soil structure, and enhance soil faunal activity. A similar finding was also reported by Srinivasarao *et al.,* (2009). Inclusion of annual legume potentially increase soil C under grazed pastures through increased root mass inputs and rooting depth one of the causes of the soil organic matter increase observed in crop-pasture rotations (Picasso *et al.,* 2014). Aside from increasing SOC stocks, perennials could also contribute to reducing soil erosion and with the potentiality to contribute to food security improvement (Lal, 2004).

In spite of fertilizer application in all GBCS resulted in higher available nitrogen in PN hybrid in paired rows + ricebean - egyptian clover and available nitrogen was higher (10-20%) under legume inclusion GBCS over GG sole crops, at 0-15, 15-30 and 30-45 cm soil depth.

Available P content was generally found higher in surface soil and decreased with soil depth (Table 4). Available P under legume inclusion GBCS was higher by 2-10% over GG sole crop at all soil depth. The highest available P content was observed under PN hybrid in paired rows + ricebean - egyptian clover at

all depth of soil which was statistically significant over rest of treatment except 30-45 cm soil depth where PN hybrid in paired rows + ricebean - egyption clover was found statistically at par with PN hybrid in paired rows + *Desmanthus.* Soil available potassium was significantly (p< 0.05) higher in legume inclusion GBCS by 5-10% over GG sole crop at all soil depth. The increase in available N, P and K content under GBCS at 0-15, 15-30 and 30-45 cm soil layer might may due to inclusion in GBCS in soil and enhances nitrogen mineralization from crop residue and no tillage practices in perennial GBCS. Apart from this, residue retention improves organic matter content in soil which again reduces fixation of fertilizer P by soil colloids through making coatings over adsorption surface or production of organic anions which competes with phosphate anions for same adsorption sites. No tillage intensity increased available K in surface soil as reported many researchers. In general legume stubble K content determines the efficiency of residue cover to increase available K.

Soil biological properties as influenced by GBCS

The legume intercrop inclusion GBCS recorded on average 5-12% higher total bacterial count, fungi, Azoctobactor, Acinomycetes and phosphorus solubilizing bacteria at top (0-15 cm) soil layer. Top soil layer under legume intercrop inclusion GBCS was due to higher SOC content compared to GG sole crop (Choudhary *et al.*, 2018). No tillage in perennial GBCS and crop stubble retention at surface soil favors gradual decomposition of legume crop stubble which slowly release labile organic matter, thus serves as food for soil microbes. Addition of all legume as intercops (ricebean, egyptian clover, hedge lucern and *Sesbania*)

TABLE 4

Effect of long term GBCS on availability of soil primary nutrients at various soil depth

	Available nitrogen (kg/ha)			Available phosphorus (kg/ ha)			Available potassium (kg/ha)		
	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
Initial value	189.00	185.00	96.50	19.00	11.00	9.00	270.00	182.00	177.00
T_1	192.00 e	189.48 e	99.85 de	20.34 b	13.00 bc	9.67 bc	281.18 e	192.00 c	182.07 e
T_2	191.00 e	188.30 e	103.33 cd	19.95 b	12.00 c	9.50 c	279.11 e	190.00 c	180.37 e
T_3	224.00 a	221.92 a	99.85 de	24.33 a	16.18 a	12.00 a	300.00 a	219.38 a	209.97 a
T_4	217.33 bc	215.17 bc	103.33 cd	22.00 ab	14.82 ab	11.62 a	292.08 bc	215.00 ab	204.56 abc
T_5	212.33 c	209.80 cd	99.85 de	21.18 b	14.00 abc	10.63 abc	287.63 cd	212.35 b	200.27 cd
T_6	220.00 ab	217.99 ab	103.33 cd	23.00 ab	15.71 a	11.75 a	297.04 ab	216.87 ab	206.62 ab
T_7	214.33 bc	212.25 bc	99.85 de	21.70 ab	14.22 abc	11.37 ab	291.13 c	212.49 b	201.30 bcd
T_8	206.33 d	205.02 d	103.33 cd	20.49 b	13.96 abc	10.41 abc	283.10 de	211.57 b	197.70 d

TABLE 5

Effect of long term GBCS on biological soil quality parameters.

	Total bacterial count (10^5 x cfu/g soil)	Fungi (10^3 x cfu/g soil)	*Azatobacter* (10^3 x cfu/g soil)	*Actinomycetes* (10^3 x cfu/g soil)	Phosphorous solubilizing bacteria (10^3 x cfu/g soil)
Initial value	40.32	36.50	22.78	11.15	12.85
T_1	42.22 a	37.38 d	23.40 a	11.30 b	13.67 d
T_2	41.23 a	37.00 d	23.05 a	11.22 b	13.02 d
T_3	46.97 a	42.47 a	25.76 a	13.92 a	16.70 a
T_4	45.83 a	40.78 abc	25.22 a	12.67 ab	15.50 b
T_5	42.82 a	38.33 cd	23.83 a	11.68 ab	14.60 c
T_6	45.82 a	41.10 ab	25.52 a	13.52 ab	16.21 ab
T_7	44.02 a	38.67 bcd	24.15 a	12.52 ab	15.46 b
T_8	42.64 a	38.28 cd	23.65 a	11.59 ab	14.47 c

enhances soil carbon pools which might also be reason that explain higher soil microbes under PN hybrid + ricebean (*Kharif*)- egyptian clover (*Rabi*). Ricebean, egyptian clover, hedge lucern and *Sesbania* roots reaches at greater than 30 cm soil depth (Hazra *et al.,* 2019) and thus release of root exudates in the form of labile carbon provides food for the microbes at 0-15 cm depth. This may explain higher soil microbes in legume inclusion GBCS at top soil layer. At surface soil, on average legume inclusion intercrop GBCS recorded 5-12 % higher total bacterial count. Higher Azoctobactor, Acinomycetes and phosphorus solubilizing found under legume intercops GBCS was due to higher organic mateer content resulting from annual and perennial legume stubble and no tillage. Similar finding of higher *Azotobacter*, *Actinomycetes* and phosphorus solubilizing under GBCS were also reported by Kumhar *et al.,* 2020b.

CONCLUSIONS

Long term GBCS significantly improves soil quality at different layer (0-15, 15-30 and 30-45 cm soil depth). Significantly higher SOC stock, nutrient availability and biochemical parameter in top soil layer under inclusion of legume intercrops in GBCS and subsequently higher soil quality confirms our first hypothesis. Further selection of SOC stock, electrical conductivity and soil pH in minimum data set indicates that are key soil quality indicators for estimation of soil quality under legume intercrops in GBCS. All soil parameters at different (0-15, 15-30 and 30-45 cm soil depth) reflects improvement in overall soil quality as influenced by annual and perennial legume intercrops inclusion in GBCS. Therefore, by adopting legume intercrop GBCS for longer duration, we can enhance soil organic matter and plant available nutrients which are the pillers for sustainable crop production. Moreover, higher soil quality under PN hybrid + ricebean (*Kharif*)- egyptian clover (*Rabi*) cropping system indicates its potential to replace sole crop system followed in Kymore Plateau and Satpura Hills of Madhya Pradesh. As such maintaining throughout the year green fodder availability should be recommended and popularized among the farmers.

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