Assessment of GMean biological soil quality indices under conservation agriculture practices in rainfed Alfisol soils

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The present study was conducted in the year 2009–10 with the objective to monitor the effect of restorative soil management practices on biological soil quality. The experiment was initiated in 1995 in a strip–split–split plot design with three replications. Sorghum and castor were grown in two-year rotations. The procedure comprised of two tillage treatments: conventional tillage (CT) and minimum tillage (MT; main plots), three residues treatments: sorghum stover (SS), Gliricidia loppings (GL), no residue (NR; sub-plots), and two nitrogen levels 0 (N0) and 90 kg ha^{-1} (N90) (sub–sub–plots). After 15th year of the experiment, activities of the soil enzymes (acid phosphatase, alkaline phosphatase, aryl sulphatase, dehydrogenase and urease), microbial biomass carbon (MBC), labile carbon (LC) and organic carbon (OC) were studied. In this study, soil management treatments significantly influenced the soil enzyme activities. Enzyme activity was significantly correlated with MBC, LC and OC. The biological soil quality has been assessed in terms of GMeanBSQI (geometric mean of biological soil quality index). From the view point of GMeanBSQI, the order of superiority of soil management treatments was: MT (0.82) > CT (0.69). The performance of the residues was in the order GL (0.87) > SS (0.75) > NR (0.65). Nitrogen @ 90 kg ha^{-1} (0.81) proved superior to no nitrogen (N0; 0.70). Among all the treatment combinations, MTGLN90 was found to be the most superior management option for ensuring higher GMean in rainfed Alfisol soils. The linear regression functions of GMeanBSQI with sorghum grain and castor bean yields were developed. Thus, the present study indicates that crop residue management under minimum tillage is of great significance in improving the biological soil quality indicators and indices. The results obtained and the methodology chosen here are significant in improving biological soil quality index and crop productivity through appropriate soil management.

Keywords: Biological soil quality crop yield, labile carbon pools, soil enzyme activity, soil management.

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ALFISOL soils of semi-arid tropical regions are on the verge of degradation because of several natural processes and anthropogenic interventions leading to low productivity and environmental degradation. The causes for soil degradation include: soil erosion due to water, low soil organic matter and consequent decrease in soil fertility, salinity, alkalinity, acidity, intensive cultivation, indiscriminate use of toxic chemicals, viz. insecticides and pesticides, higher depletion of nutrients by crops than application to soil, etc. To counter these adverse effects, several ameliorative measures are in vogue, viz. conservation tillage, application of crop residues, use of organic manure, including *in situ* green manuring, balanced fertilization, use of chemical soil amendments, appropriate soil and water management practices, selection of cropping systems, etc. These practices help in improving soil quality traits which ultimately ensure improved soil quality, productivity and environmental safety.

Rainfed agriculture is dependent on irregular rainfall, which is the only source of water. The amount of rainfall available for the growth of the plant depends on the rate of infiltration and its storage in the soil profile, which is dependent on the type of soil and surface treatment. Semi-arid soils are mostly shallow with poor organic matter content. Soil organic matter is the significant component of soil quality that determines nutrient availability, soil aggregate stability, favourable uptake of water and water-holding properties[1]. Improved awareness on the importance of soil conditions to maintain sustainability of agricultural systems and environmental quality has encouraged interest in maintaining soil quality.

Biological soil quality is the third most important indicator of soil quality. Soil organic matter (SOM), an important biological indicator of soil quality, is a direct product of the biological activity of plants, micro flora and fauna and numerous biological factors which affect soil functions like aeration and fertility[2]. It also influences physical, chemical and microbiological properties as well as availability of nutrients in the soil. SOM pools are comprised of a small-sized labile pool with fast turnover and a large-sized recalcitrant fraction with slow turnover[3]. Labile carbon (LC) is defined as microbial degradable carbon. This fraction of carbon is mostly associated with growth of microorganisms and is accessible for chemical and physical degradation by soil microbes. Measuring the labile pool signifies the influence of soil management treatments on soil C dynamics and their response to global warming. Thus, the improvement and assessment of this pool in the soil as affected by conservation agricultural practices assume importance. Further, the assessment of soil enzyme activity also serves as an early indicator of changes in soil quality. This communication deals with the effect of long-term conservation agriculture practices on biological soil quality indices in rainfed Alfisols, using linear scoring technique and GMean BSQI approach.

The present study was conducted at Hayathnagar Research Farm of Central Research Institute for Dryland Agriculture, Hyderabad, India. Experimental soils represent Hayathnagar soil series (Typic Haplustalf). These soils were mildly acidic to neutral (pH 6.5). These were also low in organic carbon (OC) and available nitrogen. However, the contents of available phosphorus and potassium were in medium range. The experiment was conducted by following a strip split–split plot statistical design. Three replications were maintained from the inception of the experiment (1995). Sorghum (*Sorghum vulgare* (L.)) and castor (*Ricinus communis* (L.)) were the test crops. These were grown in a two-year rotation. The experiment comprised of two main tillage treatments: minimum tillage (MT) and conventional tillage (CT). Weed control was done manually and also using chemical spray. In the sub-plot treatments, residues of dry sorghum stover (SS) @ 2 t ha^{-1} and fresh *Gliricidia* loppings (GL) @ 2 t ha^{-1} were applied. No residue (NR) or control plots were also maintained. Sub-sub plots (3.5 m × 6 m) treatments consisted of application of N @ 0 (N0) and 90 kg ha^{-1} (N90). After two weeks of germination of the crop, residues were spread on the surface in the respective treatment. Application of nitrogen was made in two equal splits, 50% at sowing and the remaining 50% at 45 days after sowing (DAS). In the present study, we adopted 12 treatment combinations for evaluation. The application of phosphorus was @ 13 kg P ha^{-1}. Crops were sown during the second or third week of June every year. The crops, viz. Sorghum and castor were harvested at ground level during the second or third week of October and February respectively, every year.

Soil samples were collected (0–15 cm depth) after 15th year (2010) of experimentation. Samples were air-dried, processed and passed through a 2 mm sieve and analysed for enzyme activity and labile carbon. Some portion of the sample was stored at 5°C in a refrigerator for 3–4 days and analysed for microbial biomass carbon (MBC). For estimation of soil organic carbon, samples passed through 0.5 mm sieve were used.

Assay of phosphomonoesterase activity was based on colorimetric estimation[4,5]. Intensities of the yellow colour that developed were measured at 415 nm. Arylsulphatase activity was estimated by measuring *p*-nitrophenol released by it[6]. Urease activity was measured by colorimetric method after incubating the soil at 37°C for 2 h with urea solution[7]. Estimation of MBC was done using chloroform fumigation technique[8,9] and DHA by triphenyl tetrazolium chloride method (TTC)[10]. Labile carbon was analysed by adopting the protocol recommended by Weil *et al.*[11]. Organic carbon was analysed using standard procedure[12].

Strip–split plot design was adopted for the present study and the differences in means were compared using least significant difference (LSD) test ($P < 0.05$)[13]. Simple correlation coefficients were computed using SPSS 16.0 software. To calculate GMeanBSQI, all the values of soil enzyme concentrations, MBC and LC were divided by their respective highest values and the maximum value was assigned a score of 1.0 (ref. 14). The scores thus achieved were used to calculate GMeanBSQI (ref. 15). This mean is considered as a general index to collate and integrate information from different variables which possess differential units. The expression is as follows

$$\text{GMeanBSQI} = (\text{AcP, AlkP, ArylS, DHA, Ure, MBC, LC})^{1/7},$$

where AcP, AlkP, ArylS and Ure, respectively represent acid phosphatase, alkaline phosphatase, aryl sulphatase, and urease. This integrated GMeanBSQI was considered as soil quality index of enzyme and microbial activities. Further, to study the quantitative relationships between seed/grain yield of castor and sorghum, linear regression functions were fitted.

Residue application alone significantly influenced acid and alkaline phosphatase activity. Among the residues, GL application showed significantly higher acid phosphatase (298.1 µg PNP g^{-1} h^{-1}) and alkaline phosphotase (177.8 mg kg^{-1}) activities compared to SS and NR (Table 1). Previous studies have also revealed that addition of organic amendments increases enzyme activity in soil two to four-fold[16]. In the present study, tillage, residues and N levels significantly influenced aryl sulphatase activity. Minimum tillage helped in maintaining significantly higher arylsulphatase activity (190.5 µg PNPg^{-1} h^{-1}) compared to CT (174.4 µg PNP g^{-1} h^{-1}). Among the residues applied, GL showed significantly higher arylsulphatase activity (195.1 µg PNP g^{-1} h^{-1}) compared to SS (186.8 µg PNP g^{-1} h^{-1}). Earlier reports also confirmed higher arylsulphatase activity in reduced till systems[17].

Here, we have also studied the dehydrogenase assay in soils. Dehydrogenase activity was found significantly higher under MT (2.17 mg TPF g^{-1} h^{-1}) compared to CT (1.34 mg TPF g^{-1} h^{-1}). Further, application of GL recorded significantly higher dehydrogenase activity (2.29 mg TPF g^{-1} h^{-1}) compared to SS (1.69 mg TPF g^{-1}h^{-1}) which was 4% and 9% respectively higher over NR. It was found that N applied @ 90 kg ha^{-1} showed significantly higher DHA (1.98 mg TPF g^{-1} h^{-1}) compared to control (1.53 mg TPF g^{-1} h^{-1}).

Urease activity was 25% higher in MT (13.2 µg NH_4 g^{-1} h^{-1}) compared to CT (10.6 µg NH_4 g^{-1} h^{-1}) (Figure 1). In case of residue treatments, it was observed that application of GL and SS recorded 12% and 36% higher urease activity respectively, compared to control. The components of SOM, such as humic acid can stabilize soil urease[18], accounting for the increase in extracellular urease activity under MT. Similarly, N applied @ 90 kg ha^{-1} significantly increased urease activity by 25%

over N0. It was also confirmed that application of urea to soils containing greater quantities of organic matter results in activation of urease enzyme[19].

On an average, minimum tillage, surface residue application and N levels significantly influenced soil MBC, but none of the interaction effects was statistically significant. MT recorded significantly higher (23%) soil MBC (218.2 mg kg^{-1}) compared to CT (176.9 mg kg^{-1}). The larger pool of MBC in minimum tillage provides beneficial conditions in the soil environment for development, proliferation and activity of soil microorganisms. Long-term application of GL over a period also maintained significantly highest MBC (231.4 mg kg^{-1}) followed by SS (201.2 mg kg^{-1}). The significant increase in MBC with application of nitrogen was also observed. Greater contents of soil MBC were obtained with addition of compost or farmyard manure[20]. However, MBC plays a significant role in positively influencing soil quality index, wherein the soil microflora and fauna are the reason behind these soil organic matter transformations[21].

Labile carbon is the component of soil organic carbon that is closely linked to soil fertility due to its capacity to supply nutrients to plant and soil microbes. It is sensitive to management practices and hence considered as a good indicator of biological soil health. MT recorded significantly higher LC (239.1 mg kg^{-1}) compared to CT (204.7 mg kg^{-1}). Significantly higher LC was found with GL (252.2 mg kg^{-1}) and SS (214.8 mg kg^{-1}) compared to NR (198.8 mg kg^{-1}), which was 26% and 8% higher respectively. Increase in LC was also observed with N applied @ 90 kg ha^{-1}. Thus, it is inferred that adequate amount of fertilizer N can help improve labile carbon in soil, which could be attributed to increased root biomass resulting in higher input to soil carbon and energy source to microorganisms in the soil.

Minimum tillage recorded significantly higher (7.3% higher) soil OC (6.0 g kg^{-1}) compared to CT (5.59 g kg^{-1}). Among the residues, application of GL significantly influenced higher soil OC (6.7 g kg^{-1}) content followed by SS (6.2 g kg^{-1}) which were respectively, 49% and 39% higher than control or no residue application. N application @ 90 kg ha^{-1} maintained significantly higher (6.1 kg ha^{-1}) OC content compared to N0 (5.5 g kg^{-1}) and registered an increase of 10.7%. Increased soil OC with reduced tillage in combination with application of crop residues was also reported earlier[21].

Significant positive correlations were obtained between soil enzyme activities and MBC. This specifies that the activity of the enzymes depends on the active microorganisms in the soil which forms the major source of soil enzymes (Table 2). Enzyme activities were also found to be significantly correlated with labile carbon and organic carbon.

Geometric mean of biological parameters is one of the important integrated indices of the status of biological functioning in the soil. Thus, in this study, GMean BSQI as influenced by tillage, residue and N levels was estimated (Figure 2). MT recorded higher GMean BSQI (0.82) compared to CT (0.69), which was 19% higher (Table 3). Higher GMean BSQI in MT could possibly be attributed to minimum disturbance in the soil rhizosphere resulting in greater microbial activity. Among the residues, surface application of GL (0.87) and SS (0.75) resulted in 34% and 15% GMean BSQI respectively, over NR (0.65). The increased enzyme activity in soils treated with organic residues might be due to greater microbial activity compared to direct application of enzymes from organic sources[16]. N application @ 90 kg ha^{-1} also proved effective in increasing GMean BSQI (0.81) by 16% over N0 (0.70). From the point of view of GMean BSQI, the superiority of soil management treatments in terms of their performance is as follows: MT (0.82) > CT (0.69). The performance of the residues is in the order GL (0.87) > SS (0.75) > NR (0.65). Nitrogen @ 90 kg ha^{-1} (0.81) proved superior to N0 (0.70). When tillage, residues and N levels were considered together, MTGLN90 (1.0) could be considered as the most superior management option for ensuring higher GMean BSQI and ultimately higher biological soil quality in these rainfed Alfisol soils.

In the present study, a quantitative relationship between GMean BSQI and sorghum as well as castor grain yield has been established.

$$Y_{\text{Sorghum}} = 69.67 + 1363\ (\text{GMeanBSQI}) \quad (R^2 = 0.20).$$

$$Y_{\text{Castor}} = -509.56 + 2124.4\ (\text{GMeanBSQI}) \quad (R^2 = 0.28).$$

Though the R^2 value was insignificant, it was observed that GMean BSQI as influenced by soil management practices could explain the variation in yield of sorghum and castor up to 20% and 28% respectively.

To summarize, minimum tillage, surface application of GL @ 2 t ha^{-1} and N @ 90 kg ha^{-1} were found to be superior in positively influencing the activity of arylsulphatase, urease, dehydrogenase enzymes as well as MBC and LC. Enzyme concentrations significantly correlated with MBC, LC and OC. Addition of organic amendments and adoption of management practices that increase soil organic matter led to increased enzyme activity. The present study clearly indicates that conservation agriculture practices have significantly contributed in influencing soil enzyme activities and labile pools of carbon, which in turn have played an important part in influencing the biological soil quality, expressed as GMeanBSQI. Thus, the information generated in the present study would be useful in influencing the biological soil quality indicators, indices and corresponding biological soil functions which help in improving the productivity of crops such as sorghum and castor in these abiotically stressed soils.

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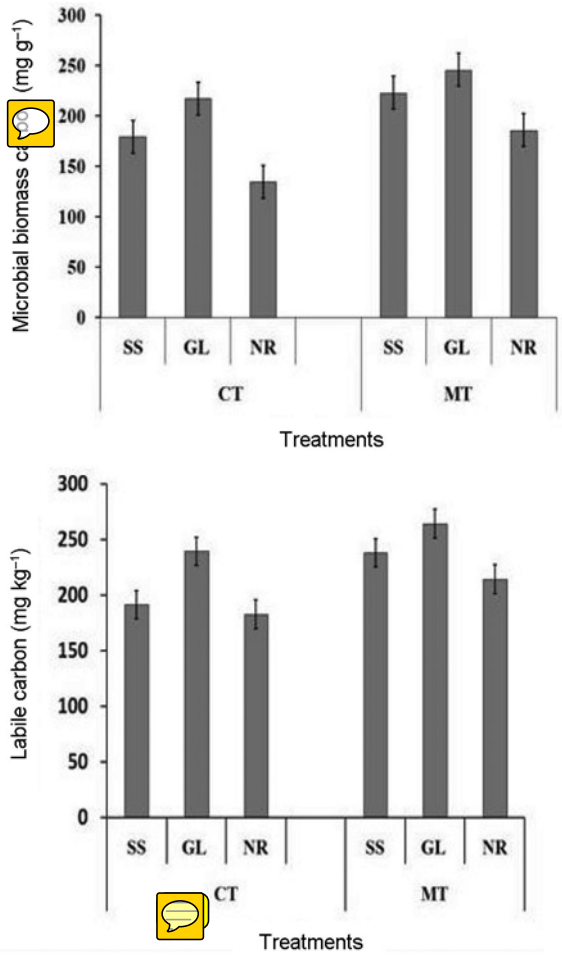

Figure 1. Effect of soil management practices on soil enzyme, MBC, LC and OC under sorghum–castor rotation.

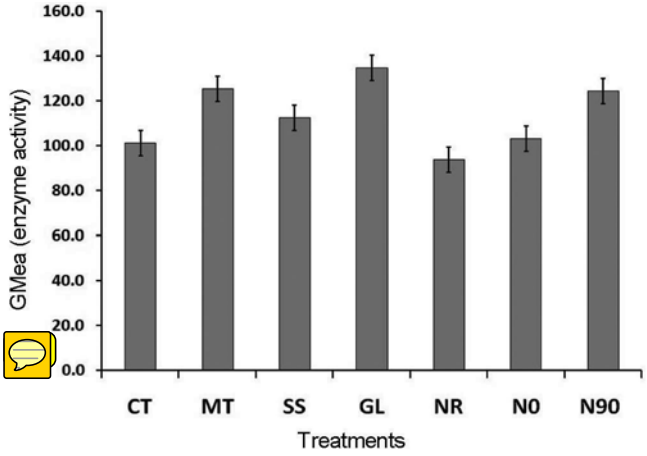

Figure 2. Eftfect of soil management practices on biological activity (GMeanBSQI) under sorghum–castor rotation.

Table 3. Geometric mean of biological soil quality index (GMeanBSQI) as influenced by soil management practices

Treatment	GMeanBSQI
Conventional tillage	0.69
Minimum tillage	0.82
Sorghum stover	0.75
Glyricidia loppings	0.87
No residue	0.65
N0 (No nitrogen)	0.70
N90 (N @ 90 kg ha^{-1})	0.81

Table 1. Long-term effect of soil management practices on soil enzyme, microbial biomass activity and organic carbon

Tillage	Residues	N level	AcP	AlkP	ArylS	DHA	Ure	MBC	Labile carbon (LC)	OC
Conventional tillage	SS	N0	261.1	145.6	175.0	1.08	9.31	163.6	182.4	5.83
		N90	284.3	168.9	188.6	1.53	11.9	194.8	200.5	6.28
	GL	N0	271.2	170.1	175.0	1.18	11.7	198.6	231.7	6.25
		N90	303.8	180.4	196.0	2.12	13.1	235.8	247.8	6.90
	NR	N0	244.6	129.3	144.4	0.88	7.72	121.3	167.0	3.78
		N90	266.7	141.4	167.5	1.26	9.68	147.7	199.1	4.49
Minimum tillage	SS	N0	284.3	153.6	182.2	1.95	10.8	204.4	227.9	6.16
		N90	263.0	176.1	201.5	2.21	13.9	241.8	248.4	6.60
	GL	N0	294.5	174.1	191.3	2.84	13.5	233.0	251.5	6.38
		N90	322.8	186.7	218.1	3.00	17.4	258.3	277.8	7.27
	NR	N0	255.2	133.7	160.3	1.26	10.3	174.3	198.7	4.59
		N90	261.6	146.5	189.4	1.73	13.3	197.4	230.6	5.02
Tillage (*T*)			NS	NS	*	**	*	*	NS	**
Residue (*R*)			**	*	**	**	**	**	**	**
Nitrogen (*N*)			NS	NS	**	**	**	**	**	**
T × *R*			NS	NS	NS	NS	NS	NS	NS	**
T × *N*			NS	NS	NS	NS	NS	NS	NS	**
R × *N*			NS	NS	NS	NS	NS	NS	NS	**
T × *R* × *N*			NS	NS	NS	NS	NS	NS	NS	**

SS, Sorghum stover; GL, Glyricidia loppings; NR, No residue; N0, N30, N60 and N90, Nitrogen levels (kg ha^{-1}); NS, Non-significant at $P > 0.05$. AcP, Acid phosphatase (µg PNPg^{-1} h^{-1}); AlkP, Alkaline phosphatase (µg PNPg^{-1} h^{-1}); ArylS, Aryl sulphatase (µg PNP g^{-1} h^{-1}); DHA, Dehydrogenase activity(mg TPF 24 h^{-1} g^{-1}); Ure, Urease (µg NH_4 g^{-1} h^{-1}); MBC, Microbial biomass carbon (mg kg^{-1} of soil); LC, Labile carbon (mg kg^{-1}); OC, Organic carbon (g kg^{-1}). *Significant difference at $P = 0.05$. **Significant difference at $P = 0.01$.

Table 2. Correlation between soil enzymes, MBC, LC and OC

	AcP	AlkP	ArylS	DHA	Ure	MBC	LC	OC
AcP								
AlkP	0.817*	1						
ArylS	0.791*	0.875*	1					
DHA	0.812*	0.762*	0.847*	1				
Ure	0.768*	0.835*	0.938*	0.871*	1			
MBC	0.777*	0.905*	0.929*	0.886*	0.924*	1		
LC	0.775*	0.847*	0.880*	0.897*	0.933*	0.949*	1	
OC	0.818*	0.943*	0.880*	0.736*	0.773*	0.900*	0.795*	1

*Correlation is significant at 0.01 level.