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Differential Responses of β-glucosidase, SOC and MBC of Degraded Soil under Various Treatments in a North-Western Arid Region, India

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Abstract Soil degradation due to various natural and anthropogenic activities in arid ecosystems is a matter of serious concern resulted huge impact on functioning of soil ecosystems. Soil microorganisms are underlying entities which mediate the balanced terrestrial nutrient cycling and biotic and abiotic variations. In order to understand the behaviour of such degraded soil towards amendments (organic and inorganic) and deterioration soil quality due to prolonged moisture deficiency, present study was designed to investigate mechanistic role of different kind of amendments; therefore, soil was collected from a barren area under the influence of Aeolian desertification process from north-western part of India (Sirsa, Haryana). In this experiment, proper moisture and favourable environmental conditions were provided to soil under organic and inorganic treatments in an earthen pot according to randomized block design. Whereas, soil under water stress treatment (WS) was kept in fully enclosed area till monitoring period. Results indicated a significant improvement in soil organic carbon (SOC), microbial biomass carbon (MBC) contents and β-glucosidase activity (BG) due to incorporation of organic as well as inorganic sources. This confirms the concurrent responses of these parameters in response to increasing nutrient availability. Moreover, extreme decline of MBC, BG and SOC values due to water deficiency indicates poor microbial activities of the barren soil. Thus, in present study, relationships between SOC with MBC and BG and MBC between BG under different treatments have shown different levels of significance, but corresponding parameters when subjected together (across treatments) exhibited strong linearity suggesting more hopes for carbon (C) sequestration in the arid ecosystem. In conclusion, different kind of treatments may provide different level of nutrient availability and ecological niche, therefore, more information needed to understand mechanism of nutrient conversion under differential responses of treatments to achieve successful restoration of barren soil.

Keywords: *Barren soil, β-glucosidase activity, MBC, arid, SOC, C-sequestration*

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1. Introduction

Anthropogenic activities are not the only reason for soil degradation and desertification processes on the earth; climatic extremities have also caused significant alterations of soil ecosystems into unproductive form viz. barren or desertified or recalcitrant soil. Since, desertified lands are mostly the outcome of very low rainfall, poor nutrient capital, drought, dry winds, excess evaporation, and moreover by anthropogenic activities such as vegetation destruction and over-grazing that exacerbated the problem in serious [1,2].

Nutrient cycles of barren ecosystems are mainly under the control of climatic conditions, water availability and types of vegetation [3]. Therefore, many soil ecosystems are under serious threat of ever increasing soil desertification due to climate change [4,5]. Desertified soils are generally sandy in texture and fail to hold the water and nutrient supply and are very poor in soil nutrients basically C, N and P and microbial activity because of poor content of clay particles in soil composition [2]. Such degraded lands can be converted into productive and functional by increasing vegetation cover which may contribute substantial amounts of organic matter content which in turn increases probabilities of more C sequestration towards soil capital. Present study focused on one such sandy soil ecosystem which is presumably the result of accumulation of sand due to Aeolian processes from the adjacent state of Rajasthan- the home of Thar Desert [6,7]. Moreover the study area receives less than 300 mm rainfall per year and faces high wind erosion, which might be a major cause of desertification [3]. Therefore, the objective of present study is, to understand how application of various sources of nutrients may enhance functioning of the soil. How soil organic carbon (SOC), Microbial biomass carbon (MBC) and β-glucosidase activity responds toward organic and inorganic amendments after treatments (days after treatments, DAT). Microbial and extracellular enzymatic activities are quick respondents to change in chemical structure of soil. Therefore, by understanding the behaviour of most important C sequestering enzymes in desertified soil, we can improve the nutrient inflow and C retention of such degraded soils. Although, many studies however mainly focused on restoration by various revegetation/restoration techniques [8], but improving soil organic matter content via various soil amendments is less discussed in the literature pledged more attention for future research, as it can be a feasible option to recover soil and may attract more soil biota leading to the replenishment of soil nutrient stock in short range of time [9,10]. Therefore, in this study, we hypothesize that soil amendments promote the microbial activity in barren soil; hence increase in β-glucosidase activity enhances the SOC content in barren soil under different amendments and emphasized to answer of the following questions:

1. Does β-glucosidase activity responds better towards organic amendments instead of chemical fertilizers?
2. Is there any relationship between SOC, MBC and β-glucosidase activity in barren soil under effect of treatments and DAT?
3. To what extent increase in β-glucosidase activity enhances SOC and MBC in barren soil?
4. Is there any indication for soil biological fertility during establishment of relationships between MBC vs β-glucosidase activity or SOC vs β-glucosidase activity?

2. Material and Methods

2.1. Study Site

Present study was figured out from a barren land selected from district Sirsa (29°33′03.4″N, 75°03′60.0″E), Haryana, India. The study area is located at the Northern border of Thar Desert and the soil is semi- desert sandy type [11]. Climate of study site is hot dry arid with extreme temperatures and rare rainfall. Temperature of study site ranged between 3-47°C and mean annual rainfall is less than 300 mm; most of which mainly falls during the monsoon months (i.e. July–September). Soil of study area is desertified-sandy and is covered mainly by spiny bushes such as *Echinops echinatus* belonging to family Asteraceae.

2.2. Experimental Design and Treatments

Soil was collected in March, 2014 from selected study site randomly by selecting 10 sub-sites in order to perform unbiased sampling. Soil sampled from 0-10 cm depth and from various directions, was collected on a large polyethylene sheet and was mixed thoroughly then packed in big plastic bags. Soil was transported to laboratory and was kept in fenced experimental enclosure in 18 pots of size 20 cm × 20 cm (depth × diameter) in a randomised block design (RBD) for further study to see the effect of different treatments, each pot contained 6 kg fresh soil. A portion of collected soil was sieved through 2 mm mesh size sieve and stored in a refrigerator at 4°C for physico-chemical and enzymatic analyses in laboratory.

Out of total 18 pots, 15 pots were kept in a fully protected experimental enclosure (covered with net) in RBD to prevent any physical encroachment either by animals or by human intervention but allowing the natural abiotic environmental conditions and three pots were kept in completely enclosed experimental dome where no precipitation was allowed for the treatment of water stress.

The experimental design was comprised of five treatments (three replicates for each treatment) (1) Full dose (FD-NPK) 120:60:60 i.e. fertilizer is supplied at the rate of 120 kg nitrogen (N) per hectare, 60 kg phosphorus (P) per hectare and 60 kg potassium (K) per hectare. Source of N taken as urea fertilizer (NH_2CONH_2), whereas single super phosphate (P_2O_5) is taken as the source of P and K is supplied in the form of muriate of potash (K_2O). (2) NPK half dose (HD-NPK) 60:30:30 i.e. 60 kg N per hectare 30 kg P per hectare and 30 kg K per hectare, respectively. Organic fertilizers (3) in the form of litter collected from study site i.e. twigs and leaves of spiny bushes naturally growing in selected area and (4) farmyard manure (FYM) composed of garden litter at different stages of decomposition and is rich source of labile nutrients; 10 g kg^{-1} of both plant litter and FYM were supplied to the soil surface of each replicate, and (5) treatment of water stress (WS); all pots containing soil for water stress treatment were kept in enclosed area in same RBD, where no precipitation was available and no water was supplied. Treatments were given in September 2014 once a year and soils were randomly sampled from each replicate every month after treatment up to 370 days. Soil kept in pots was not sieved and no procurement was done for seed bank removal. Therefore, in order to maintain uniformity in the experimental design, pots were manually cleared from any growing seedlings till completion of study (370 days). After treatments, soil samples were brought to laboratory for analyses at interval of each month.

2.3. Soil Sampling and Analyses

For the estimation of bio- and physico-chemical parameters, soil samples were collected from zero days (0), to 370 days at interval of each month after treatment (i.e. 0, 30, 62, 90, 125, 154, 187, 215, 243, 273, 306, 334 and 370 days, respectively). From each replicate pot, soil samples were collected from depth with help of auger (a cylindrical steel made pipe, 4.0 cm in diameter and 12.0 cm in length); and transported to laboratory in air tight polyethylene bags; then fresh moist soils (nearly 24% moisture content) were sieved through 2 mm mesh screen after removing the visible plant debris by hand. After sieving, soils were stored at 4°C in refrigerator for further analyses.

β-glucosidase activity was measured by method given by Eivazi and Tabatabai (1988), its activity is expressed in µg p-nitrophenyl β-D-glucopyranoside (PNP) released per gram dry soil per day (µg PNP g^{-1} d^{-1}) [12]. SOC was analysed by digestion method; soil samples were digested through block digester (KEL PLUS 12, Pelican Equipments, Chennai, India) with sulphuric acid and aqueous potassium dichromate mixture following method of Moore and Chapman (1986) [13]. Microbial biomass carbon (MBC) was analyzed by dichromate digestion method in fumigated and un-fumigated samples by Vance et al. (1987) through block digester [14]. All the results were expressed on dry soil basis.

2.4. Statistical Analyses

SPSS-PC statistical software was used for all statistical analyses. To observe effects of treatments and temporal variations on different biochemical parameters of barren soil, the data was subjected to General Linear Model (GLM) for multivariate analysis of variance (ANOVA). Data transformation and normality test was done to normalize values wherever was needed in the analyses. Mean values of all the parameters were tested for differences among combinations by Tukey's honestly significant difference (HSD) mean separation test (IBM, SPSS, version 20.0).

3. Results

3.1. Soil Organic Carbon (SOC)

Significant variation was observed in SOC content of soil due to treatments and DAT (Table 1). SOC of barren soil varied from 0.44-4.56 (g kg^{-1} dry soil) across treatments and DAT, wherein maximum value was found in FD-NPK treated soil while minimum in soil under treatment of water stress. FYM treated soil showed significantly higher SOC (43%) and soil under treatment of water stress exhibited 33% lower value as compared to control, while soils under treatment of FD-NPK, HD-NPK, OM and control showed no significant difference in SOC content at 30 DAT. At 370 DAT, value was 39% higher than control in FD-NPK treated soil (Figure 1a); while soil under treatment of HD-NPK (Figure 1b) showed highest SOC content at 370 DAT, value was 23% higher from control. OM and FYM treated soil (Figure 1c and Figure 1d respectively) exhibited 35% higher SOC content from control at 370 DAT. Soil under FYM treatment showed highest SOC content at 334 DAT, that was 25% more than control at same DAT (Figure 1e), Whereas, soil under OM treatment, SOC content was 48% higher at 243 DAT (from control). However water stress treatment was not influential to promote because water scarcity always declined nutrient availability and microbial diversity, so under this treatment, SOC content was significantly declined from its initial values (56%) at 370 DAT) (Figure 1f). Due to contrasting variation in the values of corresponding parameter, ANOVA revealed significant differences through treatments and DAT variables. Due to significant variations exhibited by both variables, their interaction (treatment × DAT) was highly significant (Table 1). Moreover, significant differences were found for SOC when data was pooled across DAT (Table 2) and treatments (Table 3).

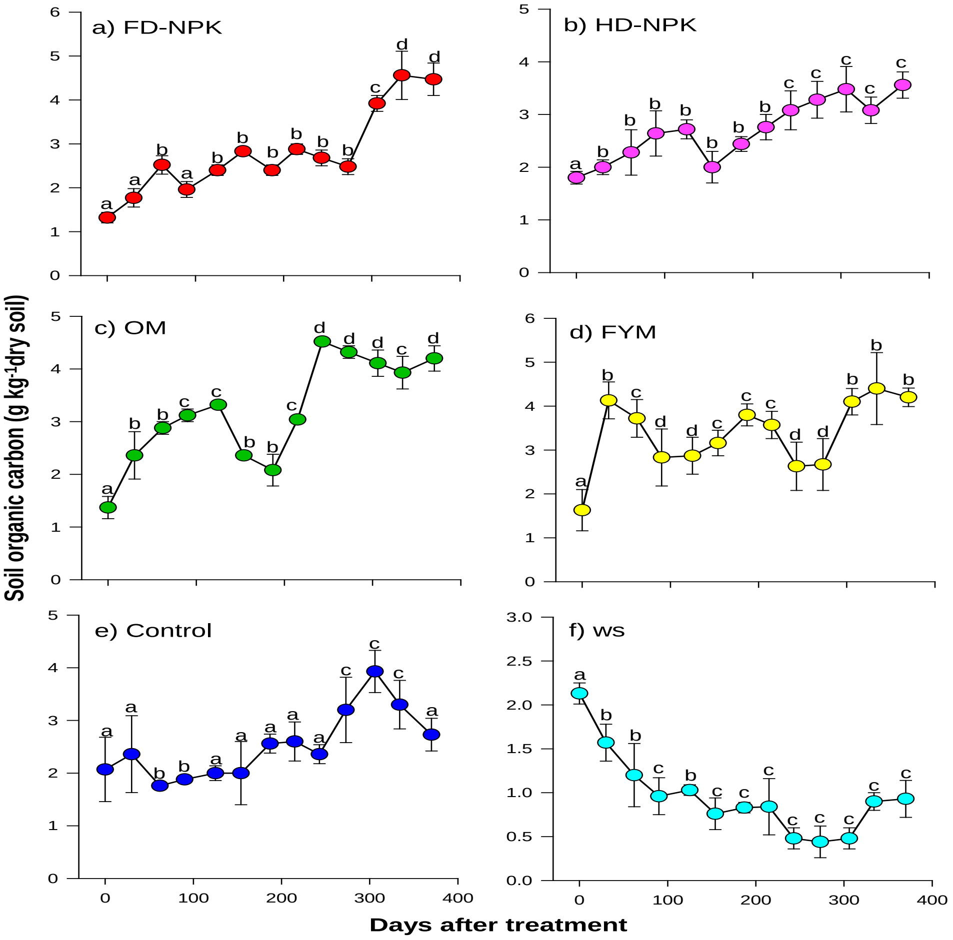

Figure 1. Variation in of soil organic carbon (SOC) of barren soil under different treatments. Values presented in the symbols are means of three replicates (n = 3) with ± 1SD. Each symbol placed with same letters is not significantly different with each other at $p<0.05$ probability level

Table 1. Summary of ANOVA results for different treatments on selected barren soil.

Source	Dependent variables	*df*	Mean square	F	*P*
Treatment					
	BG	5	1286799.005	3996.595	0.000
	SOC	5	28.560	270.491	0.000
	MBC	5	53234.592	847.581	0.000
DAT					
	BG	12	48481.844	150.577	0.000
	SOC	12	4.482	42.446	0.000
	MBC	12	2354.251	37.483	0.000
Treatment × DAT					
	BG	60	32593.921	101.232	0.000
	SOC	60	1.231	11.661	0.000
	MBC	60	971.650	15.470	0.000
Residual					
	BG	156	321.974		
	SOC	156	0.106		
	MBC	156	62.808		

Table 2. Effects of Treatments on Soil Organic Carbon, Microbial Biomass Carbon and β-glucosidase Activity of Barren Soil under Different Treatments. Values are Means of Replicates across Days After Treatment (DAT, n= 39). Same Letters Suffixed in each Column are not Significantly Different at p<0.05 Probability Level

Treatment	SOC (g kg^{-1})	MBC (µg g^{-1})	β-glucosidase (µg PNP g^{-1}d^{-1})
FD-NPK	2.78^{a}	132.67^{a}	437.55^{a}
HD-NPK	2.70^{a}	109.90^{b}	355.50^{b}
OM	3.20^{b}	92.49^{b}	423.78^{a}
FYM	3.36^{b}	126.59^{a}	616.08^{c}
Control	2.52^{c}	100.33^{b}	222.56^{d}
WS	0.97^{d}	29.95^{c}	94.63^{e}

3.2. Microbial Biomass Carbon (MBC)

MBC of soil was highest at 334 DAT in FD-NPK treated soil, whereas, lowest was found at 370 DAT under treatment of water stress; values for corresponding parameter ranged from 10.33-189.33 (µg g^{-1} dry soil). At 30 DAT, FD-NPK treated soil (Figure 2a) exhibited 30% higher amount of MBC and FYM treated soil (Figure 2d) showed slightly higher (37%) from control, while HD-NPK treated soil (Figure 2b) showed poor increase (15% from control), but, soil under OM treatment (Figure 2c) did not show any significant increase due to slow releasing of nutrients to the microbes. Soil under water stress treatment (Figure 2f) was not able to attract more microbial diversity hence, its values were declined 43% in MBC content at 30 DAT. FD-NPK treated soil at 370 DAT had augmented 42% more MBC from control, while FYM treated soil was not so efficient as of FD-NPK thus 22% more MBC at same day. Whereas, MBC content of soils under HD-NPK and OM treatments was not significantly varied from control (Figure 2e) at 370 DAT, as usual, treatment of water stress had significantly reduced 89% MBC content from control. Analysis of variance indicated highly significant due to treatments, DAT and their interactions just because of wide variation in the amount of MBC under various treatments and with respect to days after treatments (Table 1). In order to get satisfactory effects of both variables effect, data were pooled across DAT, MBC content under OM treated and water stressed soil were significantly lower from remaining other treatments, while, under FD-NPK and FYM treatments values for the same parameter was significantly higher (Table 2). Across treatments, MBC content was however significantly lower at 125 and 273 DAT than other days of treatments where it remained almost in same range (Table 3).

Table 3. Effects of DAT on Soil Organic Carbon, Microbial Biomass Carbon and β-glucosidase Activity of Barren Soil under Different Treatments. Values are Means of Replicates across Treatments (n=18). Same letters Suffixed in a Column are not Significantly Different at p<0.05 Probability Level

DAT (days)	SOC (g kg^{-1})	MBC (µg g^{-1})	β-glucosidase (µg PNP g^{-1} dry soil d^{-1})
0	1.72^{a}	79.39^{a}	316.56^{a}
30	2.36^{b}	108.44^{b}	350.80^{b}
62	2.39^{b}	102.50^{b}	361.70^{b}
90	2.23^{b}	92.22^{ab}	382.35^{b}
125	2.39^{b}	85.67^{a}	287.21^{c}
154	2.19^{b}	97.39^{ab}	270.01^{c}
187	2.35^{b}	107.50^{b}	312.07^{a}
215	2.61^{c}	116.44^{b}	367.29^{b}
243	2.63^{c}	97.28^{ab}	363.65^{b}
273	2.73^{c}	84.94^{a}	366.03^{b}
306	3.34^{d}	111.72^{b}	407.66^{d}
334	3.36^{d}	107.22^{b}	430.42^{d}
370	3.35^{d}	91.78^{ab}	442.81^{d}

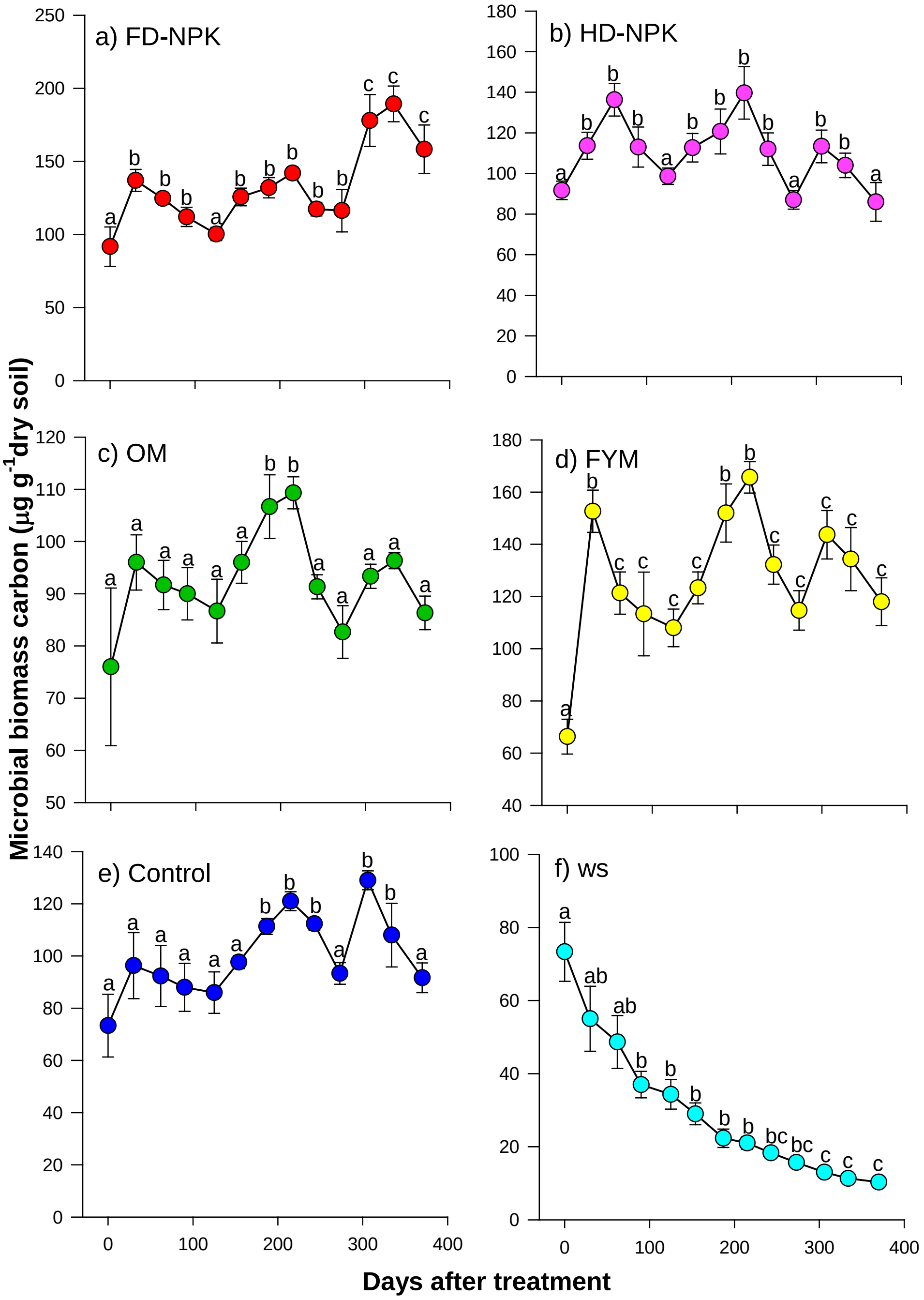

Figure 2. Variation in microbial biomass carbon (MBC) of barren soil under different treatments. Values presented in the symbols are means of three replicates (n = 3) with ± 1SD. Each symbol placed with same letters is not significantly different with each other at $p<0.05$ probability level

3.3. β-glucosidase Activity

Activity of β-glucosidase (µg $g^{-1}d^{-1}$ dry soil) varied from 960.45 in FYM treated soil to 1.51 in soil under water stress. However, soil under FD-NPK and HD-NPK treatments (Figure 3a and Figure 3b) showed 23% and 22% higher BG from control at 30 DAT, while FYM treatment was more efficient which showed 33% higher enzymatic activity (Figure 3d). But, soil under OM treatment (Figure 3c) exhibited no significant difference as from control (Figure 3e) at 30 DAT might be due to slow release of nutrients via mineralization. Under water stress treatment (Figure 3f), BG activity was reduced 33% from control at 30 DAT. Lowest enzymatic activity in four treatments (FD-NPK, HD-NPK, OM and FYM) was observed at 154 DAT but highest was found in FYM treated soil (67% from control) at 370 DAT, followed by OM treated soil (43%), FD-NPK (34% more from control) and under HD-NPK treatment exhibited only 10% higher (from control) enzymatic activity. ANOVA indicated significant variations due to treatments, DAT and their interaction in β-glucosidase activity (Table 1). Across DAT, FYM treated soil showed significantly higher enzymatic activity; whereas, treatment of water stress showed significantly lower BG (Table 2). Moreover, when data was pooled across treatments, a significant decrease in BG was observed at 125 and 154 DAT, whereas corresponding parameter at 306, 334 and 370 DAT showed significantly higher activities (Table 3).

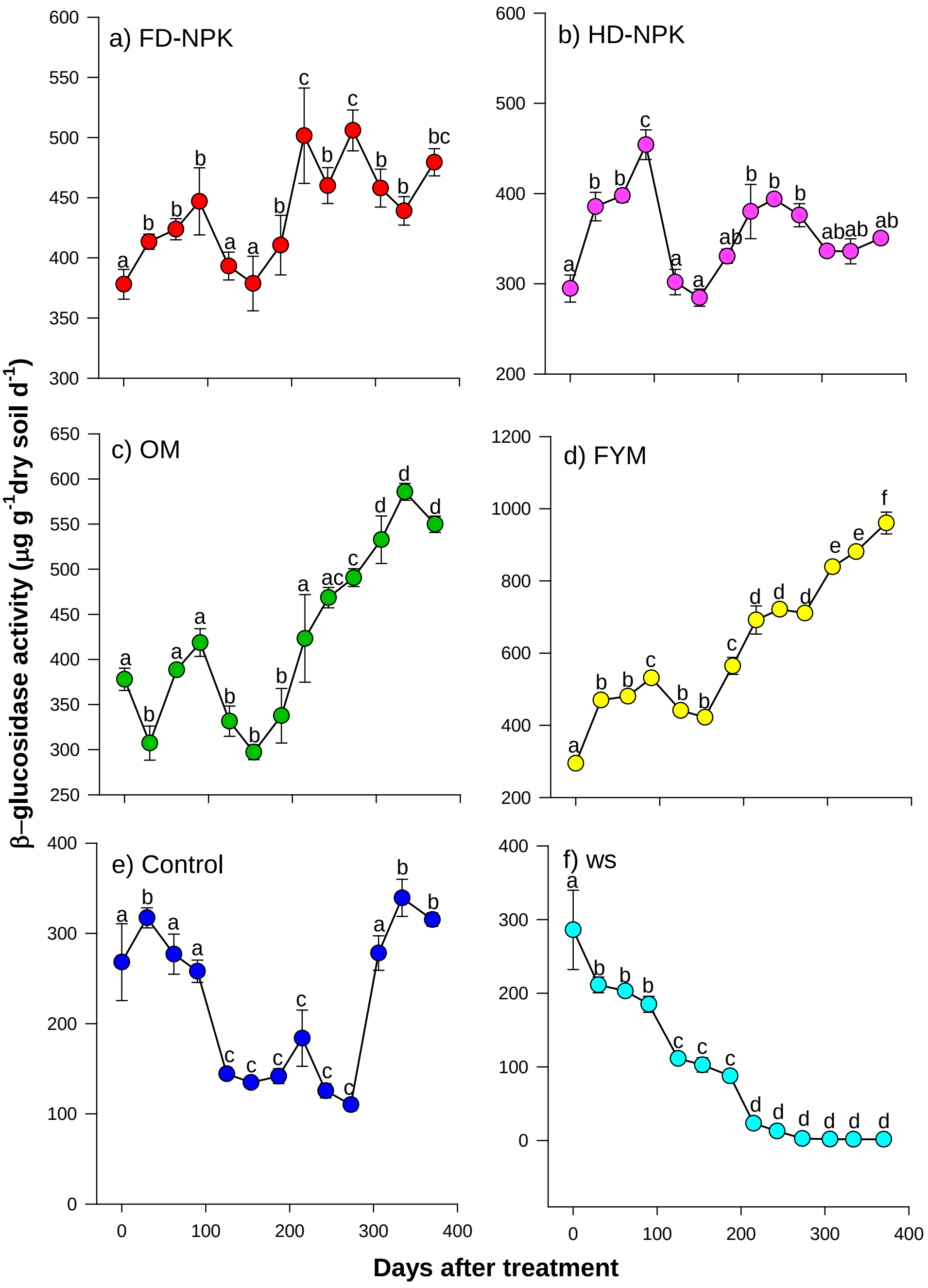

Figure 3. Variation in β-glucosidase activity (BG) of barren soil under different treatments. Values presented in the symbols are means of three replicates (n = 3) with ± 1SD. Each symbol placed with same letters is not significantly different with each other at p<0.05 probability level

3.4. Relationships with Soil Organic Carbon, Microbial Biomass Carbon, and β-glucosidase Activity under Each Treatment

In order to further understand the interrelationship between SOC, MBC and BG, data was subjected to regression analysis of separate treatments as well as pooled across treatments. This may explained the correct interpretation of the parameters such as MBC and BG, since both can be indexed as functional indicator of SOC that might be actually affected by selected amendments and water scarcity. Interestingly, soil under treatment of water stress have shown a strong relationships with all three parameters (SOC-MBC: R^2=0.7129, p<0.001; SOC-BG: R^2=0.7485, p<0.001; MBC-BG: R^2= 0.9557, p<0.0001). But principally, it has been very clear that water scarcity promotes soil degradation in turn desertification of the soil ecosystem. Due to lack of soil water, cycling of nutrient could not be possible and no microbial diversity at any scale could develop in the soil. This relationship perhaps developed significantly because wide variation in the values at initial stage when application of treatments was provided and some quantity of water might be available in the initial soil. Moreover, contrasting treatments responded differently with respect to days of treatments. Hence, at initial and last period of treatments, values were increased for all parameters but consistently lowered for other DAT (Table 3). Only two relationships (SOC-MBC) under FD-NPK and (SOC-BG) under OM exhibited significance while corresponding parameters under remaining treatments behaved independently (Table 4). In this study, exhibiting independent relationships between SOC-MBC and MBC-BG under OM and FYM treatments indicates some unanswerable questions.

When, corresponding parameters were regressed across treatments, very interesting significant relationships were observed with SOC-MBC (Fig. 4, R^2=0.4193, p<0.0001), SOC-BG (Figure 5, R^2=0.4912, p<0.0001) as well as MBC-BG (Figure 6, R^2=0.6624, p<0.0001). Establishment of significant relationship across treatments was probably due to differential responses for the parameters (SOC, MBC and BG) under different treatments which provided different level of nutrient availability to the microbes available in the soil, moreover, a significant fluctuation was found in the values for the same parameters with respect to DAT.

Table 4. Relationships of Microbial Biomass Carbon with Soil Organic Carbon, β-glucosidase with Soil Organic Carbon and β-glucosidase with Microbial Biomass Carbon under Various Treatments of Barren Soil

Dependent variable (*Y*)	Source of variation (*X*)	Treatment	n	Intercept (*a*)	Slope (*b*)	Coefficient of variation (R^2)	Statistics	
							F-	*P-*
MBC^1	SOC	FD-NPK	13	4.408 ± 0.114	0.168 ± 0.038	0.6664	19.9759	0.0012
		HD-NPK	13	5.124 ± 0.202	-0.152 ± 0.072	0.3110	4.5139	0.0596
		OM	13	4.726 ± 0.084	-0.056 ± 0.024	0.3446	5.2586	0.448
		FYM	13	4.492 ± 0.198	0.107 ± 0.056	0.2699	3.6977	0.0834
		Control	13	4.293 ± 0.127	0.127 ± 0.048	0.4099	6.9477	0.0249
		WS	13	2.169 ± 0.227	1.225 ± 0.246	0.7129	24.8319	0.0006
BG^1	SOC	FD-NPK	13	6.002 ± 0.089	0.029 ± 0.029	0.0920	1.0129	0.3379
		HD-NPK	13	5.858 ± 0.208	0.008 ± 0.073	0.0012	0.0116	0.9162
		OM	13	5.249 ± 0.153	0.234 ± 0.044	0.7352	27.7633	0.0004
		FYM	13	5.780 ± 0.442	0.187 ± 0.124	0.1859	2.2842	0.1616
		Control	13	4.839 ± 0.450	0.189 ± 0.168	0.1126	1.2686	0.2863
		WS	13	0.656 ± 0.661	3.856 ± 0.706	0.7485	29.7682	0.0003
BG^2	MBC^2	FD-NPK	13	5.479 ± 0.712	0.124 ± 0.145	0.0681	0.7309	0.4126
		HD-NPK	13	4.965 ± 1.184	0.194 ± 0.251	0.565	0.5989	0.4569
		OM	13	9.911 ± 3.561	-0.854 ± 0.784	0.1059	1.1841	0.3020
		FYM	13	4.165 ± 2.816	0.461 ± 0.577	0.0600	0.6385	0.4428
		Control	13	6.450 ± 4.099	-0.238 ± 0.886	0.0072	0.0721	0.7937
		WS	13	-8.346 ± 0.774	3.693 ± 0.251	0.9557	215.8146	<0.0001

^{1}lnY= a+bX , ^{2}lnY= a+blnX.

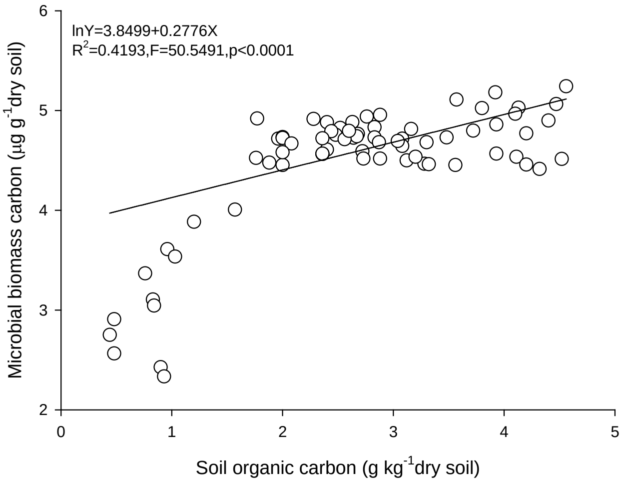

Figure 4. MBC as a function of SOC across different treatments of barren soil. In this relationship, mean values of each treatment across DAT (n = 72) were regressed for relationship between both parameters

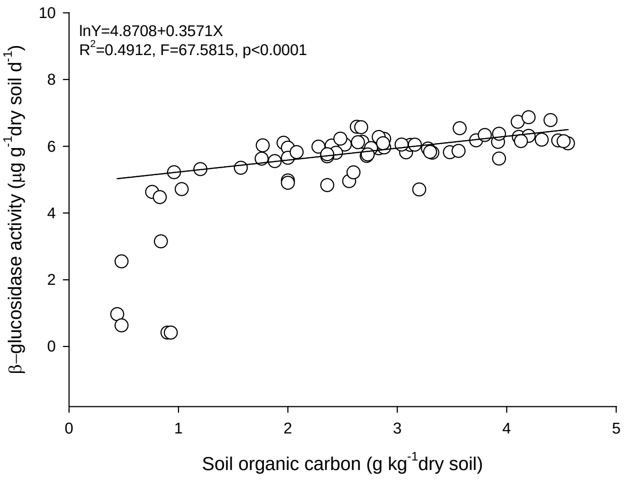

Figure 5. β-glucosidase activity as a function to sequester carbon from SOC across different treatments of barren soil. In this relationship, mean values of each treatment across DAT (n = 72) were regressed for relationship between both parameters

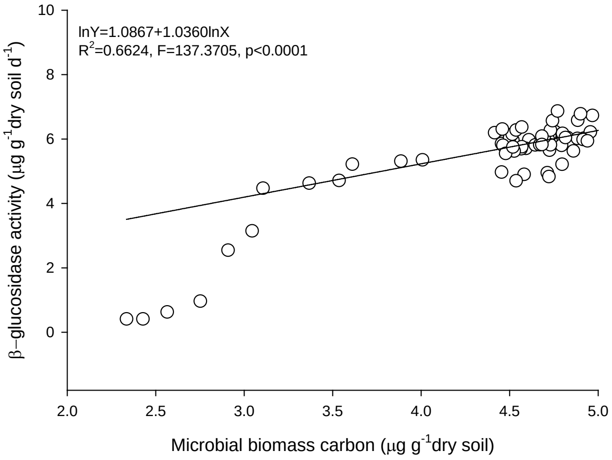

Figure 6. β-glucosidase activity as a functional indicator of MBC across different treatments of barren soil. In this relationship, mean values of each treatment across DAT were regressed for relationship between both parameters

4. Discussion

4.1. Differential Response of SOC under Treatments

Several studies in literature showed significant enhancement of SOC content of sandy desertified soil due to various soil amendments that promoted substantial growth and development of microbial diversity and retention of nutrients and moisture availability [15,16,17]. On the other hand, increase in SOC content under both organic and inorganic treatments and significant decrease under water stress explains more microbial activity and C sequestration in presence of adequate moisture and sources of labile nutrients [18] provided satisfactory evidences for effects of amendments towards soil improvement. In our study, with agreement to this explanation, we found significant effect of DAT and treatments on SOC content of soil, this was however tested through Analysis of variance which showed very strong differences due to both variables. However, decline in SOC of soil under prolonged deficient condition of water ascribed to reduced biological activity and C sequestration due to inability of microbes to access the substrate available and degeneration of cellular integrity because of inability to perform basic metabolic functions in water deficiency [19]. Our results are in agreement with Li et al. (2018) and support the view point, that water stress reduces the overall soil carbon sequestration by decreasing biological activities of soil biota in desertified sandy soil resulted very low SOC content (1.15 g kg^{-1}) under no treatment, whereas, various organic amendments in their study showed an increase in the SOC content from 1.18 to 4.88 (g kg^{-1}) [17]. According to Delgado-Baquerizo et al. (2013), aridity may damage organic carbon content of dry-land soils with unprecedented rates, because insufficient amount of water content would not be able to attract microbial population [4]. Although sandy soils are not good in holding nutrients, but organic amendments that increased the SOC content of soil significantly in our study which might be due to retention of moisture in organic matter ultimately increasing the water holding capacity of soil [10,15].

4.2. Differential Response of MBC under Treatments

In general, microbial biomass consists mostly of Fungi and Bacteria (Saprotrophs) which decompose plant residues and organic matter in soil. This process releases nutrients, such as carbon (C), nitrogen (N) and phosphorus (P) into the soil that are available for plant uptake. When microorganisms die, these nutrients are released in forms that can be taken up by plants. The microbial biomass carbon can be taken as functional index for recovery of degraded/ impoverished soil. Soil amendments via various sources of organic matter and chemical fertilizers considerably altered the microbial behaviour in soil, in turn modifying the nutrient composition, which may also lead to changes in physical structure of soil.

Differential response of soil nutrients towards various amendments are mainly decided by microbial selection of nutrient source, accumulation and mineralization of organic matter and variability of abiotic components. In present study, MBC significantly increased from its initial value in response to inorganic and organic amendments and considerably declined due to water stress; however, no significant change was found in control soil. Both findings are ascribed to changed microbial activity in response to soil amendments and water stress explaining their sensitivity towards these two factors. Significant decline in MBC content might be due to inhibition of microbial population because of inability to perform basic metabolic functions in poor availability of moisture regimes. In agreement with our study, Hueso et al. (2011) reported a significant reduction in corresponding parameter (63%) after 60 days of water stress in semiarid soil of Santomera, Spain [15]. Moreover, reduction of 86% in the same parameter from its initial value was found in soil under water stress for 370 days. Since, prolonged water stress can be a deteriorating factor for microbial growth and development, which may result a favour for desertification. On the other hand, increase in availability of labile nutrients in response to organic as well as inorganic amendments in our study, significantly increased MBC content of soil, which clearly indicated that selected barren soil responded significantly towards nutrient addition irrespective of the type of amendments. However, no significant variation from control in MBC content under OM treated soil at 30 DAT; this may be due to least breakdown of litter thus insufficient amount of nutrients were supplied for soil microorganisms. Such behaviour firstly explains that microorganisms tend to grow with much higher rate in labile nutrient rich amendments instead of decomposing complex substrates. Secondly, highest MBC under FD-NPK and FYM treated soils further indicates that microbes in present soil do not discriminate between the sources of nutrients i.e. whether it’s from organic or inorganic source; in conformity with this, some researches favoured our same ideas [17,18].

4.3. Differential Response of β-glucosidase Activity under Treatments

β-glucosidase activity came out to be most sensitive parameter towards soil amendments and water scarcity. In our study, it was found a significant increase by β-glucosidase activity under organic and inorganic treatments which is as a result of increased requirement of nutrient accumulation due to increased microbial growth in response to available labile sources of nutrients. Availability of rich nutrient sources caused enhanced microbial activity in the soil that may increase microbial release of extracellular enzymes in order to accumulate more nutrients to support further growth and development. Increased β-glucosidase activity in response to organic and inorganic amendments but decreased under prolonged water scarcity explains firstly, the inability of microbes to release enzymes in water deficit conditions and secondly, increase in carbon sequestration due to availability of carbon rich substrate as well as nitrogen rich chemical fertilizer. Thus, present observations are also in agreement with studies that support the viewpoint of enhanced microbial activity and C sequestration in response to increased N availability [18]. Furthermore, activity of corresponding enzyme was significantly higher than control in soils under FD-NPK, HD-NPK and OM treatments. Significantly higher BG in comparison to other treatments was observed under FYM treated soil, supporting an idea that direct availability of labile nutrients triggered soil biota to produce more extracellular enzymes in order to accumulate more nutrients to support increasing microbial growth and their diversity. Moreover, re-vegetation experiments are also based on the same criterion of increasing organic matter content in soil to enhance microbial and enzymatic activity of desertified lands [20]. Thus, present study strongly suggests the use of organic amendments which are rich in labile nutrients to enhance SOC and enzymatic activities of degraded lands, which will lead to improved physical and biological conditions of the soil.

Interestingly, analysis of variance supported all the observations, as significant effect of treatments as well as DAT that clearly reflected on SOC, MBC and β-glucosidase activity; due to which, interaction of both variables also significantly influenced the variations of these parameters (Table 1). Similarly, data pooled across DAT and treatments were strongly influenced to SOC, MBC and BG, respectively. Similar observations from some studies from other parts of the world strengthen more evidence [15,16,19]. However, significant relationship showed by SOC and MBC and β-glucosidase activity under water stress treatments due to simultaneous decline in the values of corresponding parameters, this decline was perhaps due to unfavourable conditions for microbial activity under water scarcity (Table 4). Furthermore, insignificant relationships were regressed in corresponding parameters under FD-NPK, HD-NPK, OM and FYM treatments; this might be an outcome of decoupling of enzyme nutrient relationship by sudden increase in available nutrients and also due to abiotic factors which significantly affects the enzymatic release. In order to understand relationship with these parameters more realistically, data was pooled across treatments then subjected to get regression equation, behind this equation an idea was hypothesized that each treatments are reflecting a variation towards SOC, MBC and BG, then, relationships with corresponding parameters will have strong differential response. In conformity with this, a report from dryland soils of China also responded positive effect to nutrient availability and soil moisture [2,21], and further justified by other works from same country that improvement in microbial and enzymatic activity can be achieved by supplying labile sources of nutrients for long time [22].

5. Conclusions

In this study, it was found that soil amendments irrespective treatment types provided a positive response towards improving soil properties except water stress. Since, farmyard manure (FYM) is a by-product of decomposed plant residues provides source of carbon and nutrients to soil biota in the soil with consistent pace while source of nutrients from chemical fertilizers provides available nutrients quickly and in ample quantity of instant form, but, FYM is stored with high amount of labile nutrients, which needed more enzymatic involvement. Therefore, in present study, β-glucosidase activity was significantly higher in FYM than other treatments, confirming evidently for amendment of degraded or desertified soil would have been a good option to restore biological fertility in short range of time. Furthermore, present study not only presented the improving soil health through amendment with appropriate water supply, but also given an idea about deterioration of soil quality when soil faces further water stress, that may cause severe effects of desertification. Specifically, more information needed to understand mechanism of nutrient conversion under various treatments for differential responses of soil parameters (mainly SOC, MBC and BG) to achieve successful restoration of barren soil because, different soil types may require different level of treatments and management.

Competing Interests

Authors declare that they have no competing interests.

Authors' Contributions

ANS designed experimental plan, RK performed field study and drafted manuscript, AK and RC helped in sample preparation and laboratory analyses; ANS and CN helped in preparation and finalized the manuscript. All authors have equal role in preparation and finalizing the manuscript.

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References

[1] Kaul, R.N. “Sand dune stabilization in Thar Desert of India: A synthesis”. Annals of Arid Zone, 35(3): 225-240, 1996.

[2] Jia, X., Zha, T., Gong, J., Wang, B., Zhang, Y., Wu, B., Qin, S. and Peltole, H. “Carbon and water exchange over a temperate semi-arid shrubland during three years of contrasting precipitation and soil moisture patterns”. Agriculture and Forest Meteorology, 228-229: 120-129, 2016.

[3] Schlesinger, W.H., Reynolds, J.F., Cunningham, G.L., Huenneke, L.F., Jarrell, W.M., Virginia, R.A. and Whitford, W.G. “Biological feedbacks in global Desertification”. Science, 247, 4946: 1043, 1990.

[4] Delgado-Baquerizo, M., Maestre, F.T., Gallardo, A., Bowker, M.A. Wallenstein, M.D., Quero, J.L., Ochoa, V., Gozalo, B., Garcia-Gomez, M., Soliveres, S., Garcia-Palacios, P., Berdugo, M., Valencia, E., Escolar, C., Arredondo, T., Barraza-Zepeda, C., Bran, D., Carreira, J.A., Chaieb, M., Conceicao, A.A., Derak, M., Eldridge, D.J., Escudero, A., Espinosa, C.I., Gaitan, J., Gatica, M.G., Gomez-Gonzalez, S., Guzman, E., Gutierrez, J.R., Florentino, A., Hepper, E., Hernandez, R.M., Huber-Sannwald, E., Jankju, M., Liu, J., Mau, R.L., Miriti, M., Monerris, J., Naseri, K., Noumi, Z., Polo, V., Prina, A., Pucheta, E., Ramirez, E., Ramirez-Collantes, D.A., Romao, R., Tighe, M., Torres, D., Torres-Diaz, C., Ungar, E.D., Val, J., Wamiti, W., Wang, D. and Zaddy, E. “Decoupling of soil nutrient cycles as a function of aridity in global drylands”. Nature, 502: 672-676, 2013.

[5] Qi, Y., Chen, T., Pu, J., Yang, F., Shukla, M.K. and Chang, Q. “Response of soil physical, chemical and microbial biomass properties to land use changes in fixed desertified land”. Catena, 160: 339-344, 2018.

[6] Kumar, A., Mishra S., Rawat, K.S. and Singh, V. “Assessment of Aeolian sand affected wasteland area in Sirsa district using remote sensing and GIS”. Journal of Agricultural Physics, 11: 84-87, 2011.

[7] Saini, H.S. and Mujtaba, S.A.I. “Depositional history and palaeoclimatic variations at the northeastern fringe of Thar Desert, Haryana plains, India”. Quaternary InternationalI, 250: 37-48, 2012.

[8] Zhang, Y., Cao, C., Han, X. and Jiang, S. “Soil nutrient and microbiological property recoveries via native shrub and semi-shrub plantations on moving sand dunes in Northeast China”. Ecological Engineering, 53: 1-5, 2013.

[9] Bhattacharya, S.S., Kim, K.H., Das, S., Uchimiya, M., Jeon, B.H., Kwon, E. and Szulejko, J.E. “A review on the role of organic inputs in maintaining the soil carbon pool of the terrestrial ecosystem”. Journal of Environmental Management, 167: 214-227, 2016.

[10] Reichert, J.M., Amado, T.J.C., Reinert, D.J., Rodrigues, M.F. and Suzuki, L.E.A.S. “Land use effects on subtropical, sandy soil under sandyzation/ desertification processes”. Agriculture, Ecosystems and Environment, 233: 370-380, 2016.

[11] Sidhu, G.S., Sharma, A.C. and Dhingra, D.R. “Soils of Haryana, In: Soils of India”. Fertiliser association of India, New Delhi, 1972.

[12] Eivazi F, Tabatabai MA (1988) Glucosidases and galactosidases in soils. Soil Biol Biochem 20:601-606.

[13] Moore, P.D., Chapman, S.B. (eds) (1986) Chemical analysis. In: Methods in Plant Ecology. Blackwell Scientific Publications, Oxford, UK pp. 315-317.

[14] Vance, E.D., Brookes, P.C. and Jenkinson, D.S. “An extraction method for measuring soil microbial biomass C”. Soil Biology and Biochemistry, 19: 703-707, 1987.

[15] Hueso, S., Hernandez, T. and Garcia, C. “Resistance and resilience of the soil microbial biomass to severe drought in semiarid soils: The importance of organic amendments”. Applied Soil Ecology, 50: 27-36, 2011.

[16] Bastida, F., Torres, I.F., Hernandez, T. and Garcia, C. “The impacts of organic amendments: Do they confer stability against drought on the soil microbial community?” Soil Biology & Biochemistry, 113: 173-183, 2017.

[17] Li, Z., Schneider, R.L., Morreale, S.J., Xie, Y., Li, C. and Li, J. “Woody organic amendments for retaining soil water, improving soil properties and enhancing plant growth in desertified soils of Ningxia, China”. Geoderma, 310: 143-152, 2018.

[18] Sall, S.N., Masse, D., Diallo, N.H., Sow, T.M.B., Hien, E. and Guisse, A. “Effects of residue quality and soil mineral N on microbial activities and soil aggregation in a tropical sandy soil in Senegal”. European Journal of Soil Biology, 75: 62-69, 2016.

[19] Ren, C., Zhao, F., Shi, Z., Chen, J., Han, X., Yang, G., Feng, Y. and Ren, G. “Differential responses of soil microbial biomass and carbon-degrading enzyme activities to altered precipitation”. Soil Biology & Biochemistry, 115: 1-10, 2017.

[20] Zhang, Y.L., Chen, L.J., Chen, X.H., Tan, M.L., Duan, Z.H., Wu, Z.J., Li, X.J. and Fan, X.H. “Response of soil enzyme activity to long-term restoration of desertified land”. Catena, 133: 64-70, 2015.

[21] Li, J., Tong, X., Awasthi, M.K., Wu, F., Ha, S. Ma, J., Sun, X. and He, C. “Dynamics of soil microbial biomass and enzyme activities along a chronosequence of desertified land revegetation”. Ecological Enggineering, 111: 22-30, 2018.

[22] Zuo, X., Zhang, J., Zhou, X., Zhao, X., Wang, S., Lian, J., Lv, P. and Knops, J. “Changes in carbon and nitrogen storage along a restoration in a semiarid sandy grassland”. Acta Oecologica, 69: 1-8, 2015.