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Effects of artificially cultivated biological soil crusts on soil nutrients and biological activities in the Loess Plateau

YanMin ZHAO[1], QingKe ZHU[1*], Ping LI[2], LeiLei ZHAO[3], LuLu WANG[4], XueLiang ZHENG[5], Huan MA[1]

[1] College of Water and Soil Conservation, Beijing Forestry University, Beijing 100083, China;
[2] Key Laboratory of Forest Ecology and Environment State Forestry Administration, Research Institute of Forest Ecology, Environment and Protection, Chinese Academy of Forestry, Beijing 100091, China;
[3] Kunming Forest Exploration & Design Institute of State Forestry Agency, Kunming 650216, China;
[4] Anhui Survey and Design Institute for Water Resources and Hydropower, Hefei 230088, China;
[5] Planning and Design Institute of Forest Products Industry, State Forestry Administration, Beijing 100013, China

Abstract: Biological soil crusts (BSCs) play an important role in the early succession of vegetation restoration in the Loess Plateau, China. To evaluate the effects of artificially cultivated BSCs on the soil surface micro-environment, we obtained natural moss crusts and moss-lichen crusts from the Loess Plateau of Shaanxi province, and subsequently inoculated and cultivated on horizontal and sloping surfaces of loess soil in a greenhouse. The chemical and biological properties of the subsoil under cultivated BSCs were determined after 10 weeks of cultivation. The results indicated that BSCs coverage was more than 65% after 10 weeks of cultivation. Moss crust coverage reached 40% after 5 weeks of cultivation. Compared with the control, soil organic matter and available nitrogen contents in moss crust with the horizontal treatments increased by 100.87% and 48.23%, respectively; increased by 67.56% and 52.17% with the sloping treatments, respectively; they also increased in moss-lichen crust with horizontal and sloping treatments, but there was no significant difference. Available phosphorus in cultivated BSCs was reduced, soil pH was lower and cationic exchange capacity was higher in cultivated BSCs than in the control. Alkaline phosphatase, urease and invertase activities were increased in artificially cultivated BSCs, and alkaline phosphatase activity in all cultivated BSCs was obviously higher than that in the control. Numbers of soil bacteria, fungi and actinomycetes were increased in the formation process of cultivated BSCs. These results indicate that BSCs could be formed rapidly in short-term cultivation and improve the micro-environment of soil surface, which provides a scientific reference for vegetation restoration and ecological reconstruction in the Loess Plateau, China.

Keywords: biological soil crusts; soil nutrient; enzyme activity; soil microorganism; Loess Plateau

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Biological soil crusts (BSCs) are organic complexes composed mainly of bacteria, fungi, algae, lichens, mosses, other cryptogams and surface soil. BSCs not only conserve soil and water by resisting wind and water erosion (Eldridge and Leys, 2003; George et al., 2003; Zhang et al., 2010; Caballero et al., 2012), but also increase soil stability (West, 1990; Eldridge and Greene, 1994; Pietrasiak et al., 2013). BSCs affect nutrient cycling in ecological systems by fixing atmospheric nitrogen and carbon (DeFalco et al., 2001; Zhao et al., 2010; Su et al., 2011; Li et al., 2012; Delgado-Baquerizo et al., 2013; Maester et al., 2013). The development of BSCs affects soil aggregate stability, water retention and organic carbon content (Chamizo et al., 2012; Drahorad et al, 2013). BSCs also play an important role in water infiltration, evapotranspiration

*Corresponding author: QingKe ZHU (E-mail: zhuqingke@sohu.com)
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and soil water redistribution during vegetation restoration and ecological reconstruction in arid and semi-arid areas (Li et al., 2001; Maestre, 2002; Xiao et al., 2007; Wang et al., 2009; Colica et al., 2014). The cultivation and establishment of BSCs are currently being investigated to restore and improve the ecological environment in arid and semi-arid areas, especially desert regions (Bu et al., 2013). Man-made algal crust is known to be a feasible and effective method for fixing unconsolidated sand for desertification control (Rao et al., 2009). The development of artificially induced BSCs could increase soil moisture and nitrogen and phosphorus availability in Hopq Desert of northwestern China (Wu et al., 2013a).

The Loess Plateau is one of the regions with most serious soil erosion in the world. BSCs are universal and important components in this fragile ecological environment, and the study interest in the role of BSCs in ecological systems continues to increase. In the Loess Plateau, the researches focused on BSCs distribution and influencing factors (Jiao et al., 2007; Lv et al., 2010), anti-scour ability of BSCs (Bu et al., 2009), effects of BSCs on the distribution of soil microbes and soil enzyme activity (Meng et al., 2010; Bian et al., 2011), and soil physical and chemical properties (Cui et al., 2004; Zhang et al., 2005; Wang et al., 2010). These studies mainly concerned natural BSCs basing on observations from field experiments and multiple uncontrolled factors and natural events affected the BSCs formation and growth. Thus, the relationship between artificially cultivated BSCs and soil chemical properties and biological activity in the Loess Plateau is still not clear. Currently, soil and water conservation and desertification control projects usually use BSCs as an artificial auxiliary to promote the restoration of vegetation. Previous studies on the cultivation of artificial BSCs mainly involved the inoculation method and effects on soil enzymes. For example, Tang et al. (2007) found that the artificial algae crust increased soil enzyme activity in the Kubuqi Desert. Chen et al. (2009) studied the best inoculation method, appropriate temperature and soil water content for moss culturing. Under simulated rainfall, Xiao et al. (2011) found that the artificial cultured BSCs can decrease overland flow and delay the start time of runoff, protecting the steep slopes of the Loess Plateau. However, few studies focused on the effects of cultured BSCs on the micro-environment of topsoil in the Loess Plateau.

The Loess Plateau has many steep slopes, extremely steep slopes and road slopes, which are prone to water and soil erosion. In recent years, many studies focused on the development of steep slope greening technologies. However, the complete restoration of vascular plants under such environmental conditions is difficult, and then artificial BSCs can be used to provide a favorable soil environment for the establishment of vascular plants and protect steeply sloped soil from erosion by accelerating the succession of BSCs. The objectives of this study were to 1) explore the formation of BSCs and BSCs' effect on soil nutrition, enzyme activity and microbial population characteristics of the surface soil after a short-term cultivation; 2) determine the relationship between cultivated BSCs and soil nutrition and biological activity; and 3) explore the effects of BSCs on amelioration of soil micro-environment during the early stages of ecological system restoration. The results could provide a reference for the artificial restoration of BSCs on steep slopes and road slopes in the erosion region of the Loess Plateau, China.

1 Materials and methods

1.1 Study area

This study was conducted in a greenhouse in Wuqi county (36°33′33″–37°24′27″N, 107°38′57″–108°32′49″E), Shaanxi province. The area with the altitudes is between 1,233 and 1,809 m above sea level, and has a semi-arid, temperate, continental monsoon climate with an average annual precipitation of 483.4 mm. The precipitation occurs throughout the year, but the majority rainfalls occur during the hot summer months (July–August). The annual average temperature is 7.8°C, with a maximum temperature of 37.1°C during summer and a minimum temperature of around –25.1°C during winter. The landscape of the area is typical in the Loess Plateau, with many gullies and hills. Its community type is characterized by a forest-grassland ecotone. Since 1998, with China's Grain-for-Green Policy, sloping farmlands of the area were largely subjected to vegetation rehabilitation through enclosure and afforestation for controlling severe soil erosion. BSCs are widely distributed in the forest, on bare ground between vegetations, scarps, exposed road slopes and ditch edges. There are many types of crusts (cyanobacteria, lichen, moss and mixed) in the area. These crusts have an important function to the micro-environment of topsoil. The dominant moss composing BSCs in this area includes some species of *Barbula* genus.

1.2 Experimental design

1.2.1 Materials

To assess the regeneration capabilities of natural BSCs and explore the feasibility of artificially cultivated BSCs on scarps, we selected 2 types of natural BSCs (moss crust and moss-lichen mixed crust) to cultivate in the greenhouse. The dominant genera of moss and lichen selected were *Barbula* and *Endocarpon*, respectively. In March 2011, the samples of natural moss crust and moss-lichen mixed crust (about 2-cm of topsoil) were collected from the Hegou catchment in Wuqi county, Shaanxi province. All of the natural crust samples (as seed soil to regenerate BSCs) were crushed and sieved (2-mm) for inoculation. The subsoil for artificial cultivation of BSCs was collected from the Hegou catchment, and the natural BSCs of topsoil, roots and stones were removed from the subsoil prior to the experiment.

1.2.2 Treatment of cultivated BSCs

The subsoil was placed into wide-mouth plastic containers (70 cm×40 cm×10 cm) with small holes in the bottoms and tamped to a thickness of about 6 cm. Nine containers were set to horizontal and 6 containers were sloped (45°) to replace the natural scarp. The 45° slope was set to simulate steep slopes and road slopes in the field. The seed soil of moss and moss-lichen crusts was inoculated onto the tops of the horizontal and sloping containers, resulting in the following treatments: moss curst horizontal (moss-H) and moss curst sloping (moss-S) for the cultivation of moss crust, and moss-lichen curst horizontal (moss-lichen-H) and moss-lichen curst sloping (moss-lichen-S) for the cultivation of moss-lichen crust (Fig. 1a). A control container, without BSCs seed soil, was set to horizontal only. Three replicates per treatment were cultivated in the greenhouse for 10 weeks (Fig. 1b).

1.2.3 Inoculation

The amount of inoculated seed soil was 500 g/m^2. For the horizontal treatment, the seed soil was scattered uniformly before spraying with water. For the sloping treatment, to prevent the seed soil air-dried from the upper part of the sloping container, the seed soil was scattered from the upper to lower parts right after spraying with water. In the inoculation, 1,500 mL of water was sprayed for each container. Then, each container was covered with thin plastic film and sprayed with about 150 mL of water every 3 to 4 days so that moisture was kept constant during the entire cultivation period.

1.2.4 Coverage measurement and sampling

Regeneration was estimated by assessing the living cover of BSCs in the different slopes after 10 weeks of cultivation. At the beginning of the 5th week, the coverage of cultivated BSCs in each treatment was measured by the line intercept method every 2 weeks.

After cultivation for 10 weeks, soil samples (0–2 cm) without regenerated BSCs were collected from each container at 5 points along an S-shaped curve. The fresh samples were sealed in plastic bags and placed in a cooling box before transporting to the laboratory, where they were stored in a refrigerator at 4°C for soil microorganism analyses. The remaining soil samples were air-dried and sieved for soil chemical properties and enzymatic activities analyses.

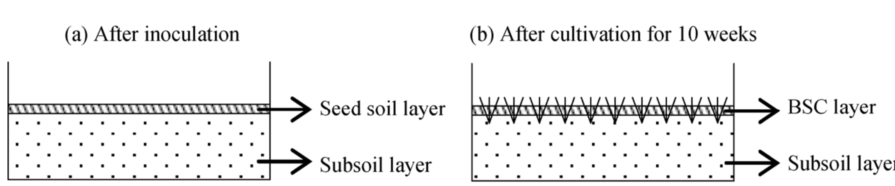

Fig. 1 Diagram of container with cultivated BSCs

1.2.5 Measurement of soil properties

Soil chemical properties were analyzed according to the method described by the Institute of Soil Science, Chinese Academy of Sciences (ISSCAS, 1978; Lu, 1999). Soil organic matter was measured by the potassium dichromate-sulfuric acid oxidation method. Available nitrogen was measured using a micro-diffusion method, in which ammonia was released from the soil sample by sodium hydroxide and then absorbed by boric acid. The ammonium borate product was titrated with 0.01 mol/L hydrochloric acid. Available phosphorus was extracted and measured in a buffered alkaline sollution with 0.5 mol/L sodium bicarbonate. The extracts were quantified calorimetically with a spectrophotometer at 660 nm. Available potassium was extracted by 1 mol/L ammonium acetate and measured with flame photometry. Cation exchange capacity (CEC) was determined by sodium acetate-flame spectrometry. Soil pH was measured in a 1:2.5 of soil: water suspension using a Crison Basic 20 pH meter (Lu, 1999).

Soil enzyme activity was determined by the method described previously (Guan, 1986). For the determination of alkaline phosphatase activity, 10-g air-dried soil (<1 mm) and 2-mL toluene were incubated in 10-mL disodium phenyl phosphate and 10 mL of 0.05 mol/L borate buffer at pH 9.6 at 37°C for 3 h. The samples were filtered, the filtrate was colored with 0.5 mL of 2% 4-aminoantipyrine and 8% potassium ferrocyanide and the released phenol was determined colorimetrically with a spectrophotometer (Hitachi, UV2300, Japan) at 510 nm (Guan, 1986; An et al., 2013). For the determination of urease activity, briefly, 5-g air-dried soil (<1 mm) was incubated in 5-mL of citrate solution at pH 6.7 and 5 mL of 10% urea solution at 37°C for 3 h. Following filtration, 1-mL filtrate with 4-mL sodium phenol solution and 3-mL sodium hypochlorite was added to a 50-mL flask and diluted to 50 mL with distilled water after 20 min. The released ammonium was colorimetrically quantified with a spectrophotometer (Hitachi, UV2300, Japan) at 578 nm (Guan, 1986; An et al., 2013). Invertase activity was measured by 3,5-dinitrosalicylic acid regent. Briefly, 5 g of air-dried soil (<1 mm), 15 mL of 8% sucrose, and 5-mL phosphate buffer at pH 5.5 were added to a 50-mL conical flask with 0.2-mL toluene. After shocking, the suspensions were incubated for 24 h at 37°C. Following filtration, 1-mL filtrate and 3-mL 3,5-dinitrosalicylic acid were added to a 50-mL flask and heated for 5 min at 100°C. The solution was immediately cooled and diluted to 50 mL with distilled water. Absorbance was then measured at 508 nm using a spectrophotometer (Guan, 1986; Zhang et al., 2013).

The numbers of cultural soil microorganisms were determined by the dilution-plate count method (Lin, 2010; Zhou et al., 2011; Das and Dkhar, 2012). Bacteria, fungi and actinomycetes were cultivated on beef extract-peptone medium, potato dextrose agar medium and Gause 1 medium, respectively, and replicated 3 times.

1.3 Data analysis

Data were analyzed using Excel 2010 and SPSS 18.0 software packages. Significant differences were compared using one-way analysis of variance followed by Fisher's least significant difference test ($P<0.05$) for soil chemical properties, enzyme activities and soil microorganisms. Results are presented as average values of the 3 replicates with standard deviation.

2 Results

2.1 Coverage changes in cultured BSCs

In each treatment, an increase in BSCs coverage after 10 weeks of cultivation was found (Fig. 2). Moss and lichen were not observed in the control treatment. Moss crust coverage was significantly ($P<0.01$) higher than that of moss-lichen crust after 5 weeks of cultivation, but there was no significant difference in BSCs coverage after sloping treatments. The difference indicated that the regeneration capacity of moss crust was superior to that of moss-lichen crust. BSCs coverage increased following the moss-lichen-S, moss-lichen-H, moss-S and moss-H treatments after 7 weeks of cultivation, and there were significant differences ($P<0.05$). In this period, slope and BSCs type were limiting factors for BSCs regeneration. In the 9th and 10th weeks, moss-lichen-S coverage was significantly ($P<0.05$) lower than that of other treatments, which showed that the difference caused by BSCs type and slope was gradually decreased.

During the entire cultivation period, the effect of slope on the regeneration of moss crust was not

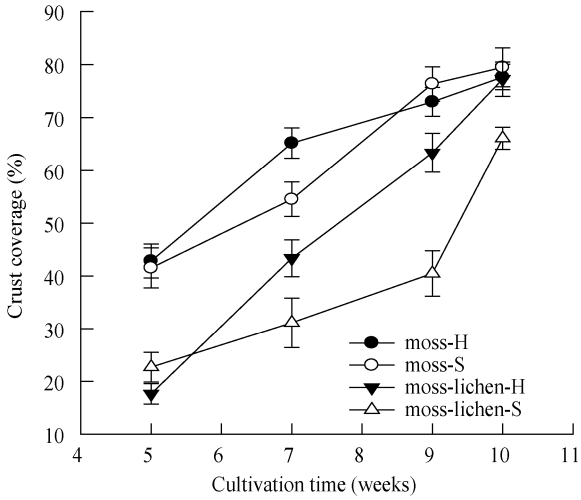

Fig. 2 Changes in BSCs coverage during the 10-week cultivation period with different treatments. Moss-H, moss crust horizontal; moss-S, moss crust sloping; moss-lichen-H, moss-lichen crust horizontal; moss-lichen-S, moss-lichen crust sloping.

significantly different, but the effect of slope on the regeneration of moss-lichen crust was significant, especially in moss-lichen-S, where the regeneration of moss-lichen crust was slower than that of moss-lichen-H. Within the same sloping treatments, the regeneration of moss crust was superior to that of moss-lichen crust. In the same cultivated period, especially under the scarp condition, the coverage of moss-S was significantly (P<0.05) higher than that of moss-lichen-S. Therefore, moss crust can be used as the biological material to reconstruct a stable environment on sites that are difficult to afforest in the Loess Plateau, China.

2.2 Effect of artificially cultivated BSCs on soil chemical properties

Table 1 shows that the organic matter of soil with BSCs was increased compared to that of the control. The organic matter of soil with moss crust treatment was significantly (P<0.05) higher than that of the moss-lichen and control treatments. This increase in organic matter in moss crust could be attributed to the formation of humic and fulvic acids from the seed soil layer and the regeneration of moss crust during early cultivation can be attributed to the rapid decomposition of the added organic matter. Soil available nitrogen content showed a similar distribution. Soil available nitrogen content was significantly (P<0.05) greater overall in moss crust than in moss-lichen crust and the control (Table 1). Soil available nitrogen contents in moss-lichen-H and moss-lichen-S increased by 14.6% and 3.9%, respectively, compared with the control.

Soil available phosphorus content in BSCs was lower than that in the control, but the difference was not significant (Table 1). Compared with the control, soil available potassium was increased in moss-H and moss-S, but decreased in moss-lichen-H and moss-lichen-S, but these changes were not significant. The pH of soils with BSCs cultivated was lower than that of the control, and the difference was still not significant among all treatments (Fig. 3). CEC ranged from 10.48 to 11.06 cmol/kg and was not significantly different among all treatments. Short-term artificial cultivation of BSCs could reduce soil pH and increase CEC compared with the control.

2.3 Effect of cultivated BSCs on enzyme activities

The activities of soil alkaline phosphatase, urease and invertase were generally higher in moss-H, moss-S, moss-lichen-H and moss-lichen-S than in the control (Table 2). Alkaline phosphatase activity in moss-H, moss-S, moss-lichen-H and moss-lichen-S was 6.52, 6.84, 5.52 and 6.05 times higher, respectively, than that in the control (Table 2). The formation of BSCs significantly increased soil alkaline phosphatase

Table 1 Changes in soil organic matter, available nitrogen, available phosphorus and available potassium with different treatments

Treatment	OM (g/kg)	AN (mg/kg)	AP (mg/kg)	AK (mg/kg)
Moss-H	6.95±0.31^{c}	33.40±4.02^{b}	8.95±0.70^{a}	125.41±2.57^{a}
Moss-S	5.13±0.18^{b}	30.32±3.46^{b}	8.26±1.24^{a}	125.61±2.66^{a}
Moss-lichen-H	3.94±0.66^{a}	22.84±2.87^{a}	8.59±1.01^{a}	121.28±2.65^{a}
Moss-lichen-S	3.70±0.14^{a}	20.71±2.47^{a}	7.82±0.55^{a}	120.69±3.07^{a}
Control	3.46±0.64^{a}	19.93±0.82^{a}	9.52±0.56^{a}	122.46±1.18^{a}

Note: Means with different lowercase letters indicate significant differences at P<0.05; mean±SD.

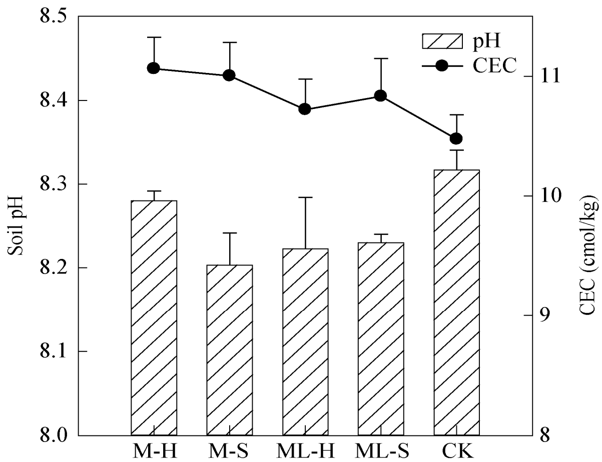

Fig. 3 Changes in soil pH and cationic exchange capacity (CEC) with different treatments. M-H, moss-H; M-S, moss-S; ML-H, moss-lichen-H; ML-S, moss-lichen-S; CK, the control.

activity ($P<0.05$). Urease activity in moss-H and moss-S was significantly greater ($P<0.05$) compared to the control.

Urease activity in moss-lichen-H and moss-lichen-S was increased by 16.12% and 31.66%, respectively, compared to the control. Soil urease in the moss treatments was significantly ($P<0.05$) higher than that in the moss-lichen treatment. Urease activity varied significantly among the four different treatments, with the highest value in moss-S (276.33 mg/(g·24 h)) and the lowest value in moss-lichen-S (188.29 mg/ (g·24 h)). Urease activity in moss crust significantly ($P<0.05$) increased than that in moss-lichen crust. There were no significant differences in urease activities between moss-H and moss-S.

However, the significant differences in soil invertase activity in the BSCs were not as great as the significant differences in alkaline phosphatase and urease activity. Invertase activities were significantly greater in moss-H and moss-lichen-S than those in moss-S, moss-lichen-H and the control treatments. The highest value of invertase activity was 38.04 mg/(g·24 h) in moss-lichen-S. The effect of slope on invertase activity is different with the different crust types.

2.4 Effect of cultivated BSCs on soil microorganisms

Microorganisms are the active components of soil, and their activities provide conditions for soil biochemical processes. The microorganism community is an important indicator to evaluate soil biological activity. Table 3 shows the mean number of 3 types of soil microorganisms. The order of microbial quantity found in each treatment was bacteria>actinomycetes>fungi.

The number of bacteria in cultivated BSCs was higher than that in the control. The numbers of bacteria in moss-H and moss-lichen-H were significantly ($P<0.05$) greater than those in the moss-S and moss-lichen-S treatments. These results indicate that the bacterial community was affected by slope factor. The influence of cultivated BSCs on fungus quantity was similar to that of bacteria. The number of fungi in cultivated BSCs, except moss-lichen-S, was significantly ($P<0.05$) higher than that in the control. The influence of cultivated BSCs on actinomycete quantity was different from that on bacteria and fungi. The number of actinomycetes in cultivated BSCs was higher than that in the control, but the numbers of actinomycetes in moss-H and moss-lichen-H treatments were significantly ($P<0.05$) lower than those in moss-S and moss-lichen-S treatments.

In the same crust types, the numbers of bacteria and fungi in the horizontal treatments were higher than those in the sloping treatments, but the numbers of actinomycetes in the sloping treatments were higher than those in the horizontal treatments. Within the same sloping treatments, the numbers of bacteria and actinomycetes in moss crust were higher than those in moss-lichen crust. In the horizontal treatment, however, the number of fungi in moss crust was lower than that in moss-lichen crust.

Table 2 Changes in soil enzyme activities with different treatments

Treatment	Alkaline phosphatase (μg/(g·12 h))	Urease (μg/(g·24 h))	Invertase (mg/(g·24 h))
Moss-H	997.09±154.55^b	270.56±3.95^c	34.93±3.75^b
Moss-S	1,045.56±156.28^b	276.33±28.67^c	32.38±0.44^a
Moss-lichen-H	843.60±206.71^b	188.29±15.07^a	31.99±3.07^a
Moss-lichen-S	924.39±183.90^b	213.50±15.17^b	38.04±1.24^b
Control	152.90±15.10^a	162.16±19.06^a	28.15±3.02^a

Note: Means with different lowercase letters indicate significant differences at $P<0.05$; mean±SD.

Table 3 Changes in numbers of soil microorganisms with different treatments

Treatment	Bacteria (×10^6 cfu/g)	Fungi (×10^3 cfu/g)	Actinomycetes (×10^4 cfu/g)
Moss-H	13.97±2.70^b	14.79±3.15^b	21.58±1.89^a
Moss-S	7.96±2.48^a	13.98±3.12^b	39.44±3.88^c
Moss-lichen-H	9.92±1.12^b	17.05±2.10^b	19.85±3.56^a
Moss-lichen-S	7.11±0.87^a	12.24±2.11^a	24.68±4.34^b
Control	4.71±2.70^a	7.43±1.23^a	15.19±3.68^a

Note: Means with different lowercase letters indicate significant differences at $P<0.05$; mean±SD.

2.5 Relationships among soil nutrient and biochemical parameters

Significant correlations were found among soil nutrient and biochemical parameters determined in this study (Table 4). Soil organic matter was significantly correlated with available nitrogen (R^2=0.853, P<0.01), urease (R^2=0.755, P<0.01) and bacteria (R^2=0.727, P<0.01). Negative correlations were found in available phosphorus with other soil parameters. Alkaline phosphatase was significantly correlated with available nitrogen (R^2= 0.520, P<0.05), urease (R^2=0.702, P<0.01), bacteria (R^2= 0.537, P<0.05) and actinomycetes (R^2=0.558, P<0.05).

3 Discussion

The results of our study showed whatever in horizontal or slope surfaces, the cover rate of inoculated moss and moss-lichen crusts reached more than 65% after 10 weeks of cultivation. Moss crust was much adapted to artificial cultivation due to its higher coverage rate under same cultivation conditions, compared with moss-lichen crust. This indicated that the revegetation of moss crust was feasible through sprinkling soil with natural moss crust under sufficient water conditions. This was mainly because moss owns the strong vegetation reproduction ability, and its thallus or leaf and stem can regenerate under suitable moisture condition (Bai et al., 2003; Li et al., 2008). Graf and Rochefort (2010) and Xiao et al. (2010) also found the similar results. The results showed that no significant difference between horizontal and sloping surface existed in the growth of moss curst, while it was reverse in the growth of moss-lichen crust. In addition, Rao et al. (2009) and Wang et al. (2009) found that artificial cultivated algal crust speeded up the recovery of BSCs. The cultivated algal curst was applied in mobile dune fixation in desert area. The finding suggested that it was possible to accelerate BSCs restoration for soil and water conservation in the Losses Plateau during moisture season through artificial BSCs cultivation. And the slope was not limiting factor as long as the appropriate pretreatment of soil surface. For further research, it is necessary to select the drought-resistant species of moss and improve the inoculation method of BSCs for growing in field.

Soil organic matter and available nitrogen contents significantly increased in BSCs treatments. And they were significant higher under moss crusts treatment than those in moss-lichen crusts treatment. This indicated

Table 4 Correlation coefficients among soil nutrients and soil microbial parameters

	OM	AN	AP	Alkaline phosphatase	Urease	Invertase	Bacteria	Fungi	Actinomycetes
OM	1.000	0.853**	0.012	0.483	0.755**	0.167	0.727**	0.296	0.194
AN		1.000	–0.036	0.520*	0.722**	0.145	0.708**	0.314	0.404
AP			1.000	–0.347	–0.197	–0.455	–0.077	–0.312	–0.277
Alkaline phosphatase				1.000	0.702**	0.510	0.537*	0.495	0.558*
Urease					1.000	0.334	0.505	0.440	0.658**
Invertase						1.000	0.143	0.387	0.291
Bacteria							1.000	0.460	–0.042
Fungi								1.000	0.380
Actinomycetes									1.000

Note: * and ** indicate significance at P<0.05 and P<0.01 levels, respectively.

the formation and development of artificially cultivated BSCs could enhance the accumulation of soil organic matter and available nitrogen, and the effect of moss crust was greater than that of moss-lichen crust. BSCs increased soil carbon pool by producing extracellular polysaccharides (Mager and Thomas, 2011). Exopolysaccharide content also increased from physical crust to the lichen and moss crusts (Chamizo et al., 2013). This is consistent with the results from Castillo-Monroy et al. (2010), Zhang et al. (2010) and Drahorad et al. (2013). These researches explained the increment in organic matter content of soil with BSCs (Thomas and Dougill, 2007; Drahorad et al., 2013). Many studies have confirmed the dominant source of soil nitrogen input is nitrogen fixation by BSCs, in xeric and nitrogen-limited ecosystem (Hawkes, 2003; veluci et al., 2006). BSCs through trapping aeolian dust also increases soil nutrient inputs, and well-developed BSCs are more effective in fixing nitrogen, trapping nutrient-enriched dust than that less-developed BSCs (Chamizo et al., 2012). Wu et al. (2013b) reported some microbes in the BSCs were an important contribution for the soil nitrogen content. These results might account for higher available nitrogen in moss crust than moss-lichen crust and the control. This is consistent with the result from Housman et al. (2006). CEC of soil with artificially cultivated BSCs was higher than that in the control, but the difference was not significant. This is consistent with the result from Chamizo et al. (2012). This increase in CEC was attributed to a parallel increase in soil organic matter with the formation and development of BSCs (Chamizo et al., 2012). The study of Miralles et al. (2009) also showed that a positive relationship between increased soil organic matter and CEC. Compared with the control, soil pH reduced in the BSCs treatments. Increasing dissolved carbon dioxide concentrations of soil microbe respiration resulted in the soil pH decrease (Bååth and Anderson, 2003). Wu et al. (2013b) also reported that soil pH in cultivated algal crusts was lower than that in controlled bare sandy soil. Therefore, this study indicated that cultivated BSCs could be favorable to the growth of vascular plants by increasing soil organic matter and available nitrogen, and affecting soil chemical properties.

Alkaline phosphatase, urease and invertase involved in phosphorus, nitrogen and carbon cycling showed higher activities in cultivated BSCs soil than that in the control soil. This had been reported by Wu et al. (2013a), whose research showed that man-made algal crusts significantly increased urease and phosphatase activities of surface soil in the Hopq Desert. Urease activity in moss crust soil was higher than that in moss-lichen crust and control soils. This apparently resulted from the increasing of soil available nitrogen (Wu et al., 2013a). Soil alkaline phosphatase activity in cultivated BSCs was significantly higher than that in the control. Alkaline phosphatase promotes the conversion of soil available phosphorus and has a positive effect on soil available phosphorus content (Zhang et al., 2012; Wu et al., 2013a). Soil available phosphorus content, however, was reduced under cultivated BSCs in this study. The result of Hao et al. (2005) also showed that soil phosphorus tended to decrease with increased cover of moss crust. It was possible because a large amount of available phosphorus was absorbed by moss during the growing process. Consequently, future research will need to explore how BSCs affect available phosphorus. Soil microbial numbers in all BSCs treatments was higher than that in the control. Since the formation and development of moss and moss-lichen crusts provided plant residue and humus, which were decomposed by microorganism and provided more growth resources for microorganism. Soil microbe promoted decomposition of humus and improved soil nutrient transformation and cycling, and was an important indicator of soil fertility (Yang et al., 2010). Our study also showed that the dominant community of microorganisms of cultivated BSCs soil was bacteria, followed by actinomycetes and fungi. It was closely consistent with the findings of Bian et al. (2011) and Ji et al. (2013).

In cultivation experiment, slope gradient had litter effect on moss crust than on moss-lichen crust. This indicated that moisture was a key factor for moss growth (Graf et al., 2010). Crust type had significant effect on soil organic matter and available nitrogen, but no significant difference on soil microbial properties. Therefore, the formation and development of moss crust could be preferable to improving soil micro-environment. Zhao et al. (2010) reported surface soil nutrients in moss crust were higher than that in lichen crust, and the results also confirmed by Guo et al. (2008a). The lichen crust will be our further research for exploring the ecological function of cultivated lichen crusts on soil micro-environments.

4 Conclusions

After a short-term cultivation, BSCs were quickly formed in horizontal and slope loess surfaces. The revegetation ability of moss crust was stronger than that of moss-lichen crust, and moss crust should be a better material applied in field. It was feasible to speed up BSCs revegetation in disturbed loess surface by artificial seeding moss crust to prevent erosion from water and wind in field. The formation of cultivated BSCs increased soil organic matter and available nitrogen, and affected soil chemical properties. Meanwhile, surface soil biological characteristics also were enriched by artificially cultivated BSCs. The slope gradient had little effect on BSCs coverage, soil nutrient content and biological characteristics. The results suggested that inoculation of BSCs ameliorated soil micro-environment, and was potential bioremediation technique during the early stage of ecological restoration of the eroded steep slopes in the Loess Plateau.

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