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Impact of sand burial on maize (*Zea mays* L.) productivity and soil quality in Horqin sandy cropland, Inner Mongolia, China

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Abstract: Croplands are often suffering from sand burial in dry regions of northern China. For studying this phenomenon, we carried out a case study of field experiment including four sand burial levels, i.e. shallow (1–3 cm), moderate (8–12 cm) and deep (15–20 cm) sand burials, and no sand burial (control, CK), in a typical agro-pastoral transitional zone in Naiman Banner of eastern Inner Mongolia. The aim of this study was to assess the impacts of sand burial on maize (*Zea mays* L.) productivity and the soil quality along a gradient of burial depths. Results showed that there was a strong negative effect of sand burial on maize productivity and soil quality, which significantly declined (P<0.05) under moderate and deep sand burial treatments. In comparison with the CK, the maize yield and above-ground biomass reduced by 47.41% and 39.47%, respectively. The soil silt and clay, soil water, soil organic carbon and total nitrogen contents under deep sand burial decreased by 67.85%, 40.32%, 86.52% and 82.11%, respectively, while microbial biomass carbon, microbial abundance and enzyme activity decreased by 89.78%, 42.28%–79.66% and 69.51%–97.71%, respectively. There was no significant effect on crop productivity and soil quality with shallow sand burial treatment. The correlations analysis showed that there was significant positive correlations of both maize yield and above-ground biomass with soil silt and clay, soil organic carbon and total nitrogen contents, pH, electrical conductivity, soil water content, microbial abundance and biomass and all tested soil enzyme activities. Stepwise regression analysis indicated that soil water and total nitrogen contents, urease, cellobiohydrolase and peroxidase activities were key determining factors for maize productivity. This combination of factors explains reason of the decreased maize productivity with deep sand burial. We found that degradation of cropland as a result of sand burial changed soil physical-chemical properties and soil enzyme activities in the plow layer, and decreased overall maize productivity. Furthermore, decreased soil enzyme activity was a better indicator to predict sandy cropland degradation.

Keywords: sand burial; soil quality; enzyme activity; maize productivity; sandy cropland

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Horqin Sandy Land is located in the semiarid agro-pastoral zone of Inner Mongolia in northern China. During recent few decades, it has undergone severe desertification primarily due to

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overgrazing and over-cultivation and large area of natural sandy grassland has been converted into cropland as a consequence of rapid population growth (Zhao et al., 2015). It is reported that during windy season, the rate of airborne dust deposition varies greatly from 13 to 1,254 kg/(hm^2•d), averaging at 232 kg/(hm^2•d). As a result of the deposition, cropland has become degraded and crops are often suffering from sand burial and air-borne sand arises (Li et al., 2004). In this region, maize (*Zea mays* L.) monoculture dominates the cultivated land. It is therefore critical to study the sand burial effects on maize productivity and soil quality in Horqin sandy cropland.

Previous researches mainly focused on the effect of sand burial on plant growth and its eco-physiological properties, as well as on soil physical-chemical properties in arid and semiarid areas (Brown, 1997; Zhao et al., 2006; Zhao et al., 2007a; Qu et al., 2012). These researches suggested that shallow sand burial increased crop survival rate, height and biomass in comparison with deep sand burial (Zhao et al., 2007a). However, sand burial resulted in the decrease of yield productivity and delayed corn life cycle, and the deep sand burial reduced soil clay content and organic matter significantly. Plant antioxidant enzyme activity increased after sand burial in a short time, whereas decreased significantly after 12 days (Qu et al., 2012), and this enzyme activity was lower in sand burial treatments than in the control without burial. Thus far, however, these studies mainly focused on plant eco-physiological properties and soil physical-chemical properties. To date, few studies have been conducted on the impacts of sand burial on soil quality that comprehensively and inclusively account for soil physical-chemical properties, microbial attributes and enzyme activities in degraded sandy cropland.

Soil quality, described as physical-chemical properties (soil particle size distribution, pH value, C and N contents, etc.), microbial attributes (biomass, abundance and diversity) and enzyme activity, is a key link between environment and plant in natural and agriculture ecosystem (Karlen et al., 1997; Stenberg, 1999; Chapin et al., 2002). Soil organic matter, aggregation and pH value have been mostly used to assess soil quality in the early research (Karlen et al., 1997). However, soil microbial attributes are increasingly being used as bio-indicators for monitoring soil quality, due to their sensitivity and rapid response to disturbance (Schloter et al., 2003; Garbisu et al., 2011; Gómez-Sagasti et al., 2012). Soil enzymes, produced by microbiota play an important role in material cycle and energy flow in the soil environment, and they are specific biological catalysts in soil biochemical reactions (Burns, 1978; Sinsabaugh et al., 2008). It was reported that soil quality can be significantly affected by tillage (Kandeler et al., 1999), cropping systems (Moore et al., 2000) and land use (Acosta-Martínez et al., 2003). Hence, it is necessary to examine a suite of soil indicators together (physical-chemical, microbiological and enzymatic indicators) to determine what changes in soil quality best indicate cropland degradation, particularly in semiarid regions (García-Orenes et al., 2010).

There were a great number of literatures on the effects of sand burial on plant properties in arid and semiarid areas. However, there is still more to learn about the impacts of sand burial on soil quality, and to ascertain which soil properties can be best predict sandy cropland degradation. The objectives of this study were: (1) to investigate maize productivity and soil quality along a sand burial depth gradient in a sandy cropland; and (2) to find the determining factor of soil properties for predicting sandy cropland degradation. We tested two hypotheses in this study based on previous works related to plant responses to sand burial: (1) shallow sand burial would not degrade soil quality whereas deep sand burial would degrade soil quality; and (2) soil organic carbon and total nitrogen would be the main factors that influence crop productivity in sandy cropland.

1 Materials and methods

1.1 Study area

The study area is located in the village of Yaoledianzi, the middle part of Naiman Banner (42°55′N, 120°42′E; 360 m asl) in Horqin Sandy Land, Inner Mongolia, northern China. The climate is characterized by a temperate continental monsoon, with a mean annual precipitation of 366 mm, of which 70%–80% falls during the growing season from June to September. Mean annual pan-evaporation is around 1,935 mm, five times greater than the mean annual precipitation. Annual mean temperature is approximately 6.4°C, and the lowest monthly mean temperature is –13.1°C in January, while the highest is 23.7°C in July. Annual mean wind velocity ranges from 3.2 to 4.1 m/s, and the dominant wind is southwest and south in summer and autumn and northwest in winter and spring. Wind erosion often occurs from winter to next spring before the rainy season arrives (Zhu and Chen, 1994). The zonal soil is sandy Chestmut, which is sandy in texture, light yellow in color and loose in structure, and is vulnerable to wind erosion (Zhao et al., 2007b). Thickness of the soil layer in the cropland is about 30–45 cm. Maize (*Zea mays* L.) monoculture dominates the cultivated land and yields vary greatly in different types of croplands, depending on soil properties and terrain (Li et al., 2004).

1.2 Experimental design and soil sampling

A maize cropland which lies to the northeast part (leeward direction) of mobile dunes was selected. Maize was sown on 15 May 2009 in rows parallel to the prevailing wind direction with a row spacing of 40 cm and individual seed spacing of 20 cm. The study site was about 100 m×500 m, and five similar sites were set. The croplands were covered by sand from the mobile dunes in the wind season, and the sand burial depth is the deepest near the mobile dunes and it getting shallower along the wind direction. Sand burial in the cropland is natural and we divided the cropland area into four sections: deep, moderate and shallow sand burials, and no sand burial as a control (Fig. 1). The description of the sand burial cropland was shown in Table 1. The tillage treatment was the same for all four burial levels.

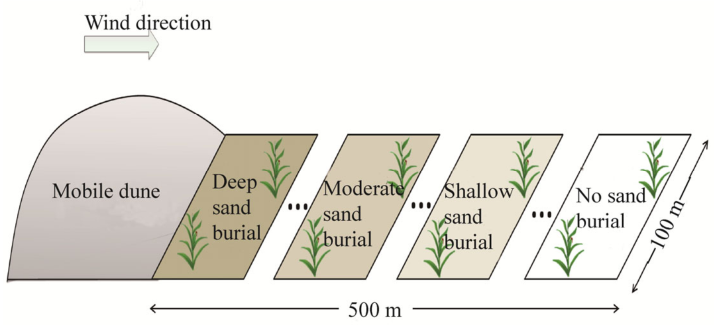

Fig. 1 Illustration of the experimental design

Table 1 Sand burial treatments in the cropland

Sand burial treatment	Depth of sand burial (cm)	Description of the site
CK	0	No sand burial
Shallow sand burial	2±1[a]	Lower than 50% of the field ridge
Moderate sand burial	10±2[b]	Almost even with the field ridge
Deep sand burial	16±4[c]	More than 5 cm higher than the field ridge

Note: Values (mean±SE) with different letters within a column are significantly different at $P<0.05$ level.

Soil samples were obtained in late August, and maize yield and above-ground biomass were measured at plant maturity in early October, 2009. Three lines were established in each site of the four sand burial treatment areas, respectively, and the distance between each line was about 10 m. Five quadrats (1 m×1 m) were set in each line, and soil cores were collected to a depth of 0–20 cm, and a pooled sample was made by mixing five sub-samples from different quadrats along the line. Every pooled sample was sieved with a 2-mm mesh to remove rocks and plant materials, and stored separately in two ziplock bags. One was air-dried for analyzing soil physical-chemical properties (particle size distribution, organic carbon, total nitrogen, pH and electronic conductivity), and the other was stored at 4°C for determination of microbial attributes (i.e. bacteria, actinomycetes, fungi, cellulose decomposers and azotobacters abundance, and microbial biomass carbon) and enzyme activities (dehydrogenase, peroxidase, protease, urease and cellobiohydrolase).

1.3 Laboratory analyses

1.3.1 Maize productivity

Above-ground biomass was measured by using the clipping method (all green parts above-ground were cut) in early October at plant maturity, and the seed was separated as maize was harvested. The samples were oven-dried at 85°C for 24 h before weighing (Zhao et al., 2007b).

1.3.2 Soil physical-chemical properties

Soil particle size distribution was determined by the pipette method in a sedimentation cylinder, using sodium hexamethaphosphate as dispersing agent (Institue of Soil Sciences, 1978). Soil water content (SWC) was conducted at 105°C for 24 h to a constant weight. Soil organic carbon (SOC) was measured by the dichromate oxidation method of Walkey and Black (Nelson and Sommers, 1982) and total nitrogen (TN) was determined by the Kjeldahl procedure (Institue of Soil Sciences, CAS, 1978). Soil pH and electrical conductivity (EC) were determined in a 1:1 soil-water slurry and in a 1:5 soil-water aqueous extract (Multiline F/SET-3, Germany), respectively.

1.3.3 Soil microbial attributes

Microbial biomass carbon (MBC) was assessed by the chloroform fumigation-extraction method (Vance et al., 1987). Culturable soil microbial abundance was determined as colony-forming unites (CFU) by the pour plate method (Xu and Zheng, 1986; Collins et al., 1995). Nutrient agar (for bacteria), modified Gause's synthetic agar (for actinomycetes), rose bengal agar (for fungi), modified Ashby N-free agar (for azotobacters) and Hutchinson agar (for cellulose decomposers) mediums were used to culture microbial groups.

1.3.4 Soil enzyme activities

Soil enzyme activities were assayed by using the methods of Tabatabai (1982) and Guan (1986). Dehydrogenase (DEH) activity was measured by the triphenyltetrazolium chloride method, peroxidase (PER) activity was measured by the potassium permanganate titration method, protease (PRO) activity was measured using the gelatin hydrolyzation method, urease (URE) activity was measured using the nesslerization colorimetric analysis, cellobiohydrolase (CEL) activity was measured using the anthrone colorimetric analysis.

1.4 Data analyses

Data were analyzed and described by SPSS 17.0 and Origin 8.0 for Windows. Values were assigned as mean±SE, and significant differences of mean values were calculated by one-way analyses of variance (ANOVA). Least significant difference (LSD) tests were performed for evaluating differences among individual treatments. Correlations between maize productivity and soil qualities were analyzed by using Pearson's 2-tailed tests. Stepwise regression analysis assigned maize productivity as dependent variables, and soil quality including soil physical-chemical properties, microbial attributes and enzyme activities as independent variables. Independent variables were allowed to enter the model when $P<0.05$ and it is removed when $P>0.10$.

2 Results

2.1 Soil quality under different sand burial levels

2.1.1 Soil physical-chemical properties

Silt and clay (<0.05 mm) content accounted for less than 7% of the soils (Fig. 2). A significantly higher soil silt and clay content was found in shallow sand burial cropland in comparison with the deep sand burial cropland ($P<0.05$). The deep sand burial had the highest fine sand (0.1–0.25 mm) content (78.54%), which was similar to that in the CK but significantly higher than those in other burial levels. The content of fine to coarse sand (0.1–2 mm) was significantly higher in the deep sand burial (94.17%) than in the CK (57.81%). The lowest content of medium to coarse sands (0.25–2 mm) was found in the shallow sand burial (11.87%), and this content was significantly lower than that in the CK (22.19%).

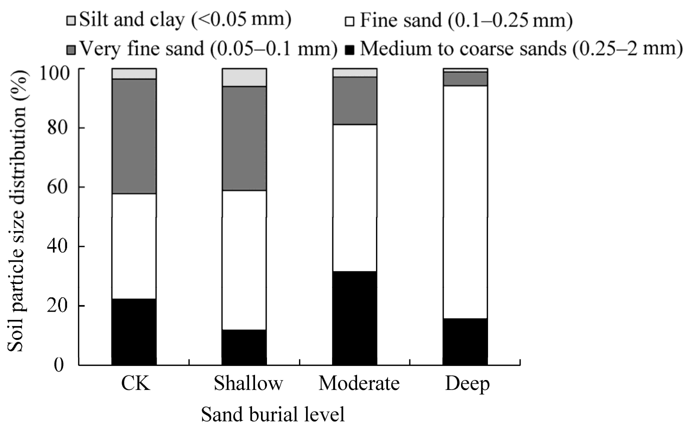

Fig. 2 Soil particle size distribution in different sand burials. CK, no sand burial treatment.

Soil water content decreased significantly with increasing sand burial depths. It was 40% less in deep sand burial cropland than in the CK. Soil pH values ranged from 7.7 (deep) to 8.5 (moderate), and were significantly lower in the deep sand burial. Soil organic carbon and total nitrogen contents decreased in the following order: shallow>CK>moderate>deep, and electrical conductivity showed a similar trend, but with CK>shallow.

Table 2 Soil physical-chemical properties in different sand burial croplands

Item	Sand burial level				*F*-value	*P*
	CK	Shallow	Moderate	Deep		
SWC (%)	8.17±0.11^{a}	7.78±0.13^{a}	6.24±0.09^{b}	4.87±0.18^{c}	128.46	<0.001
pH	8.33±0.07^{a}	8.35±0.05^{a}	8.47±0.07^{a}	7.73±0.09^{b}	22.96	<0.001
EC (mS/cm)	129.35±4.18^{a}	104.82±6.70^{b}	81.20±6.45^{c}	41.00±4.66^{d}	44.46	<0.001
SOC (g/kg)	7.19±0.33^{a}	9.96±0.21^{b}	2.91±0.06^{c}	0.97±0.02^{d}	416.38	<0.001
TN (g/kg)	0.68±0.02^{a}	0.72±0.02^{a}	0.26±0.02^{b}	0.12±0.01^{c}	263.58	<0.001
C/N	10.59±0.65^{a}	13.89±0.24^{b}	11.59±1.20^{a}	8.10±0.58^{c}	10.16	<0.001

Note: Values with different letters within a row are significantly different at *P*<0.05 level. Mean±SE. SWC, soil water content; EC, electrical conductivity; SOC, soil organic carbon; TN, total nitrogen.

2.1.2 Soil microbial attributes

Soil microbial abundance and biomass significantly decreased with increasing sand burial depths (Table 3). Microbial biomass carbon was approximately 15% higher in the shallow sand burial cropland than in the CK, and was significantly lower (37% and 90%, respectively) in the moderate and deep sand burial croplands than in the CK. The ratio of microbial biomass carbon to soil organic carbon (MBC:C) was significantly higher in the moderate sand burial than in the other burial levels. The abundance of bacteria and actinomycete (>95% of the total microbial abundance) was the highest in the shallow sand burial cropland among all the four treatments. The abundance of fungi, azotobacter and cellulose decomposer (<5% of the total microbial abundance) significantly decreased with increasing sand burial depths. Fungi and azotobacter abundance decreased by approximately 80% in the deep sand burial cropland compared with the CK.

2.1.3 Soil enzyme activities

The shallow sand burial had little impact on soil enzyme activities, but the moderate and deep sand burials significantly decreased the soil enzyme activities (Table 4). There was no significantly different enzyme activity in the shallow sand burial cropland in comparison with the CK (*P*>0.05). Deep sand burial decreased soil enzyme activities significantly in comparison with the CK (*P*<0.001), and with activities of only 21.78% for dehydrogenase, 9.02% for peroxidase, 30.49% for protease, 2.39% for urease and 18.69% for cellobiohydrolase, respectively.

Table 3 Soil microbial attributes in different sand burial croplands

Sand burial level	Bacteria (×10^3 CFU/g dry soil)	Actinomycete (×10^3 CFU/g dry soil)	Fungi (×10^3 CFU/g dry soil)	Azotobacter (CFU/g dry soil)	Cellulose decomposer (CFU/g dry soil)	MBC (mg/kg)	MBC:C
CK	1,005.28±39.33^a	428.04±41.85^{ab}	22.60±1.34^a	70±5^a	218±16^a	401.92±17.79^a	5.62±0.26^a
Shallow	1,285.60±62.44^b	531.75±45.74^a	19.25±0.90^b	49±4^b	192±9^b	458.14±28.06^a	4.60±0.27^a
Moderate	790.73±54.24^c	339.55±33.15^b	12.71±0.66^c	30±2^c	164±8^c	253.50±32.65^b	8.63±0.99^b
Deep	580.29±29.70^d	131.11±13.93^c	4.96±1.51^d	14±2^d	87±6^d	41.06±9.65^c	4.23±0.97^a
F-value	39.26	22.56	78.14	46.43	66.86	61.33	7.75
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002

Note: MBC, microbial biomass carbon; MBC:C, the ratio of microbial biomass carbon to organic carbon. Values with different letters within a column are significantly different at $P<0.05$ level. Mean±SE.

Table 4 Soil enzyme activities in different sand burial croplands

Soil enzyme activity	Sand burial level				*F*-value	*P*
	CK	Shallow	Moderate	Deep		
Dehydrogenase (mg/(kg•24h))	37.62±5.82^{ab}	44.57±6.42^a	29.65±4.38^b	9.91±1.61^c	9.27	<0.001
Peroxidase (mol/(g•h)	9.22±1.55^a	10.77±2.33^a	6.12±1.48^a	0.83±0.16^b	7.64	0.002
Protease (mg/(kg•24h))	75.66±11.68^a	76.48±10.65^a	52.01±8.51^a	23.25±8.81^b	7.47	0.002
Urease (mg/(kg•24h)	393.88±58.64^a	387.38±54.97^{ab}	254.36±45.94^b	9.97±1.57^c	15.04	<0.001
Cellobiohydrolase (mg/(kg•24h))	97.07±14.67^a	84.15±10.86^a	37.94±5.70^b	16.81±1.53^b	15.57	<0.001

Note: Values with different letters within a column are significantly different at $P<0.05$ level. Mean±SE.

2.2 Changes of maize productivity under different sand burial levels

Maize yield and above-ground biomass significantly decreased along with the increasing sand burial depths in sandy croplands (Fig. 3). The crop yield and above-ground biomass decreased by 47.41% and 39.47% in deep sand burial cropland in comparison to the CK. Above-ground biomass was slightly higher for CK in comparison with shallow sand burial, and the shallow sand burial had the highest crop yield among the four burial levels. It seems that crops suffered from shallow sand burial are more likely to produce seeds. However, the values for the shallow sand burial did not differ significantly from those in the CK. Moderate and deep sand burial levels reduced both maize yield and above-ground biomass significantly in comparison with the CK and shallow sand burial.

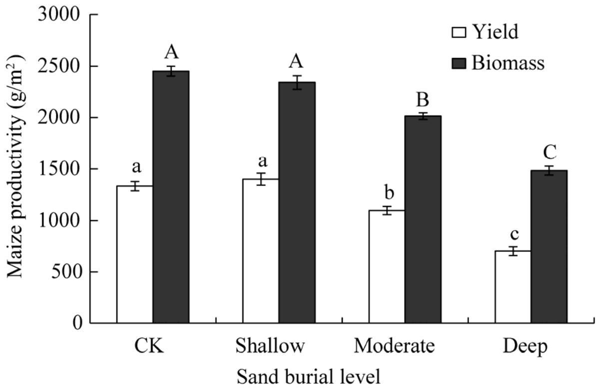

Fig. 3 Maize yield and above-ground biomass in different sand burials. Values with different letters are significantly different at $P<0.05$ level. Error bars indicate the standard errors of the means.

2.3 Relationships between maize productivity and soil quality

Pearson's correlation analysis showed that maize yield and above-ground biomass were positively correlated with very fine sand, slit and clay contents, soil organic carbon and total nitrogen contents, pH value, electrical conductivity, water content of soil, bacteria, actinomycete, fungi, azotobacter, cellulose decomposer abundance, microbial biomass carbon, dehydrogenase, peroxidase, protease, urease and cellobiohydrolase. Only negative correlations were found between maize productivity and coarse sand and fine sand contents (Table 5).

Table 5 Pearson's correlations among maize productivity and soil quality

	Yeild	Biomass	C_{sand}	F_{sand}	V_{Fsand}	S_{clay}	SOC	TN	pH	EC	SWC
Yield	1.000	0.851**	–0.426*	–0.779**	0.856**	0.843**	0.873**	0.874**	0.458*	0.814**	0.923**
Biomass	0.851**	1.000	–0.310	–0.899**	0.895**	0.855**	0.818**	0.913**	0.419*	0.836**	0.883**
	Bac	**Act**	**Fun**	**Azo**	**Cel**	**MBC**	**DEH**	**PER**	**PRO**	**URE**	**CEL**
Yield	0.874**	0.838**	0.880**	0.849**	0.770**	0.849**	0.877**	0.879**	0.875**	0.850**	0.853**
Biomass	0.865**	0.803**	0.869**	0.870**	0.818**	0.829**	0.852**	0.841**	0.854**	0.866**	0.811**

Note: C_{sand}, medium to coarse sand; F_{sand}, fine sand; V_{Fsand}, very fine sand; S_{clay}, silt and clay; SOC, soil organic carbon; TN, total nitrogen; EC, electrical conductivity; SWC, soil water content; Bac, bacteria; Act, actimomycete; Fun, fungi; Azo, azotobacter; Cel, cellulose decomposer; MBC, microbial biomass carbon; DEH, dehydrogenase; PER, peroxidase; PRO, protease; URE, urease; CEL, cellobiohydrolase; * and ** indicate significance at P<0.05 and P<0.01 levels, respectively.

Stepwise regression analysis showed that maize productivity (yield and above-ground biomass) were significantly correlated with soil water content, soil total nitrogen, urease, cellobiohydrolase and peroxidase activities. Equations were built to quantify the relationship between crop productivity and soil factors.

$$\text{Yield}= -281.64+212.30\times \text{SWC}+0.79\times \text{URE}-3.55\times \text{CEL}\ (R^2=0.928, F=102.79, P<0.001), \quad (1)$$

$$\text{Biomass}=1464.25+2.70\times \text{URE}-33.856\times \text{PER}+313.81\times \text{N}\ (R^2=0.953, F=161.36, P<0.001). \quad (2)$$

In these two models, maize yield was significantly affected by soil water content, urease and peroxidase. Maize above-ground biomass was significantly affected by urease, peroxidase, and soil total nitrogen. Although soil water content and total nitrogen contents explained the highest proportion of the variance, both yield and biomass were significantly affected by enzyme activities. In total, enzyme activities (urease, cellobiohydrolase and peroxidase) comprised 2/3 of the variables in each equation. URE activity influenced both maize yield and biomass.

3 Discussion

3.1 Impacts of sand burial on soil physical-chemical properties

Su et al. (2004) suggested that soil particle size distribution dominated organic matter breakdown in sandy land ecosystems, since it affects the movement and retention of water, air and heat, and consequently determine the composition and distribution of microorganisms in sandy soil. In our study, the wind carried sands to the study site from mobile dunes, and deposited silt and clay further downwind. Thus, the silt and clay contents were the highest in shallow sand burial cropland among the four treatments. In addition, the soil texture coarsened with the increasing distance upwind (Hennessy et al., 1986). On the other hand, soil silt and clay contains higher nutrient in comparison to sand particles (Su et al., 2004). Thus, the contents of soil organic carbon and total nitrogen decreased significantly (by 86.52% and 82.11%, respectively) in the deep sand burial compared to the CK. Moreover, soil carbon and nitrogen contents in the shallow sand burial cropland were higher than in the CK. The coarser the soil texture, the lower the water holding capacity (Larney et al., 1998). This explains why soil water content was only 60% in the deep sand burial cropland in comparison with the CK (Table 2).

3.2 Impacts of sand burial on soil microbial attributes and enzyme activities

Heretofore, little was known about the direct effects of sand burial on soil microbial attributes and enzyme activity. Soil texture affects soil microbial structure, and fungi obtain larger proportion in a loamy fine sand soil in comparison to a silt clay loam soil (Bach et al., 2010). Fungi directly alter soil aggregate, because their hyphae are the primary binding agents responsible for aggregate formation, especially for soils with low clay and high sand content (Degens et al., 1996). Soil microorganisms are fundamental for maintaining soil functions because they represent the main source of soil enzymes that regulate the transformation of soils elements (Böhme and Böhme, 2006), and they also control the decomposition of organic matter (Powlson et al., 1987). Most enzymes in the agricultural soil are secreted by microbes (Aon and Colaneri, 2001). Enzyme activities can affect soil functions (Trasar-Cepeda et al., 2000), and are correlated with soil properties (Pajares et al., 2011). In our study, soil microbial abundance and biomass carbon decreased by 42.28%–79.66% and by 89.78% in the deep sand burial cropland compared with the CK, respectively (Table 3). Soil enzyme activities decreased much more severely than microbial attributes, decreasing from 69.51% to 97.61% from the CK to deep sand burial cropland. The decrease of the urease activity among the five tested soil enzyme activities was the maximum (Table 4).

Tillage management can significantly influence crop productivity (Paul et al., 2013). A reduction in soil organic carbon is often the major reason for crop productivity losses (Gomes et al., 2003). Soil organic matter is one of the limiting factors for plant productivity in the nutrient-poor sandy soils in arid and semiarid ecosystems (Wezel et al., 2000). Stepwise regression analysis suggested that soil water content was the main factor that influenced maize yield, and soil total nitrogen was one of the limiting factors for above-ground biomass of maize. In the present study, tillage treatment was the same for the four kinds of cropland under different sand burial levels. It was previously reported that soil water and nitrogen were the critical limiting factors for plant growth in Horqin Sandy Land (Zhao et al., 2015).

Shallow sand burial did not significantly affect maize productivity, although there was a slight increase in maize yield and a slight decrease in above-ground biomass of maize. However, moderate and deep sand burials significantly decreased both yield and above-ground biomass. Maize yield decreased by 17.63% and 47.41% in the moderate and deep sand burial croplands compared with the CK, respectively (Fig. 3). In Naiman Banner, large areas of sand dunes were bulldozed and converted into croplands by planting maize (Li et al., 2014). As a result, cropland in this region has been subject to burial during the wind season.

The sand burial reduces the productivity and yield production in the sandy croplands as the consequence of reducing soil organic matter, microbial abundance and enzyme activities. Our results therefore suggest a potential risk of soil degradation and crop productivity reduction when sandy dunes are reclaimed as cropland. Some management practices including straw barriers establishment along the sandy cropland edge, intercropping cultivation, and spring irrigation have been experimentally carried out to protect cropland degradation in Horqin Sandy Land (Li et al., 2004; Su et al., 2004; Zhao et al., 2006).

4 Conclusions

Sand burial, except for the shallow burial, in sandy cropland significantly decreased maize productivity and soil quality in Horqin Sandy Land, Inner Mongolia. Soil water and total nitrogen contents, and the urease, cellobiohydrolase and peroxidase activities were the key factors that determine maize productivity after sand burial. We found that degradation of cropland as a result of sand burial changed soil physical-chemical properties and soil enzyme activities in the plow layer, and decreased overall maize productivity. Furthermore, soil enzyme activity was an important indicator to predict sandy cropland degradation.

Acknowledgements

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