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Impact of land-use on carbon storage as dependent on soil texture: Evidence from a desertified dryland using repeated paired sampling design

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ABSTRACT

Desertification resulting from land-use affects large dryland areas around the world, accompanied by carbon loss. However it has been difficult to interpret different land-use contributions to carbon pools owing to confounding factors related to climate, topography, soil texture and other original soil properties. To avoid such confounding effects, a unique systematic and extensive repeated design of paired sampling plots of different land-use types was adopted on Ordos Plateau, N China. The sampling enabled to quantify the effects of the predominant land-use types on carbon storage as dependent on soil texture, and to define the most promising land-use choices for carbon storage, both in grassland on sandy soil and in desert grassland on brown calcareous soil. The results showed that (1) desertification control should be an effective measure to improve the carbon sequestration in sandy grassland, and shrub planting should be better than grass planting; (2) development of man-made grassland should be a good choice to solve the contradictions of ecology and economy in desert grassland; (3) grassland on sandy soil is more vulnerable to soil degradation than desert grassland on brown calcareous soil. The results may be useful for the selection of land-use types, aiming at desertification prevention in drylands. Follow-up studies should directly investigate the role of soil texture on the carbon storage dynamic caused by land-use change.

1. Introduction

Drylands cover about 41% of the Earth's land surface and are homeland for about 35% of the global population (MEA, 2005). About 25% of dryland areas around the world are suffering from desertification resulting to large extent from human activities (UNCCD, 1994; D'Odorico et al., 2013). Desertification can result in loss of soil resources and/or a shift in vegetation composition (e.g. from grassland to shrubland) (Schlesinger et al., 1990; van Auken, 2000; Todd, 2006), consequently a reduction in carbon storage and associated water regulation (MEA, 2005), which are among the most important ecosystem services (Costanza, 2008). It is estimated that desertification affects about 1.137 Bha of soil and an additional 2.576 Bha of rangeland vegetation in drylands around the world and the total historic loss of C due to desertification until the end of the second millennium may have amounted to 18–28 Pg (Lal, 2001).

Desertification typically results from the compound effect of climate change and land-use (D'Odorico et al., 2013). In dryland regions, the deterioration of land-use/land-cover in conjunction with drought conditions causes desertification, and limits carbon storage; while optimization of land-use/land-cover is conducive to the prevention of desertification, and thereby increasing carbon storage (MEA, 2005). Cultivation and grazing are probably the most important factors affecting desertification and carbon

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storage, especially for grasslands in semiarid regions (He et al., 2008; Jin et al., 2013). Restoring systems through the adoption of appropriate land-use practices such as revegetation would increase the pool of C in soil and biomass and yield significant ecosystem carbon gains (Nosetto et al., 2006). For instance, desertification control was shown to have great potential for sequestering soil C and improving soil quality in northwest China (Su et al., 2010), and gradually increased soil carbon sequestration due to the rapid recovery of vegetation in eroded areas in subtropical China (Shi et al., 2009). Understanding the effects of land-use change on desertification and on Earth surface carbon storage, will provide the scientific foundation with the underlying mechanisms for prevention of desertification and sustainable development prospects in drylands.

Land-use change affects directly the amount of carbon stored in terrestrial ecosystems (Houghton and Hackler, 1999). For instance, forest conversion to agricultural land leads to large losses of C in the tropics; and these losses occur at relatively fast rates and can become more frequent in the coming decades because of global warming (Grünzweig et al., 2004). A global synthesis of results from 115 studies containing over 300 data points showed that management-related improvements of carbon storage included fertilization (39% of studies), improved grazing management (24%), conversion from cultivation (15%) and native vegetation (15%), sowing of legumes (4%) and grasses (2%), earthworm introduction (1%), and irrigation (1%) (Conant et al., 2001). The fact that such a wide range of measures can all enhance soil C pools, suggests that grasslands can generally become significant carbon sinks with the implementation of improved land-use management (Conant et al., 2001). Tanentzap and Coomes (2012) suggested that herbivores can reduce terrestrial carbon stocks across vegetation types, but reductions in carbon stocks might disappear given sufficient periods of time for systems to respond to herbivory and not drop below the carrying capacity. Compared with other land-use conversions, the conversion from cropland to shrubland was more favorable for soil carbon sequestration in semiarid loess hills, while creating wild grassland through land abandonment might be a promising choice as well (Chen et al., 2007).

A dryland may contain several parts differing in soil textures, even in a small horizontal space (Kong et al., 2009); for example, soils on Ordos Plateau, N China comprise brown calcareous (pedocal) soil, sandy soil and dark loess soil (Zheng et al., 2006). Soil texture has been suggested to be among the key factors to attain elevated SOC concentrations in different land-use types under different management intensities (Kong et al., 2009). Models of terrestrial biogeochemistry have generally shown that soil organic matter (SOM) increases linearly with clay content at regional and global scales (Schimel et al., 1994). Clay soils tend to have higher cation exchange capacity, net primary productivity (NPP), and litter decomposition rates under natural conditions (Uehara, 1995). In contrast, while sandy soils are often associated with high fine root biomass due to greater C allocation to roots for nutrient and water capture (Cuevas and Medina, 1988), they may also have slower litter turnover rates due to nutrient and water limitations on decomposition (Cuevas and Medina, 1986). Interestingly, a field investigation showed that sandy soils stored approximately as much C as clay soils (Silver et al., 2000). Also, results from a 40-year chronosequence of 62 former agricultural fields in western Minnesota indicated that soil texture may not be a significant factor influencing SOM accumulation rates on decadal time scales while former agricultural fields were converted to perennial grassland (McLauchlan, 2006). Estimates of carbon storage rates do not differ much between soils with different textures, largely because the amount of rapidly cycling carbon remains approximately constant (Telles et al., 2003).

In most previous studies on land-use effects on soil carbon in drylands it has been difficult to interpret the land-use contribution to soil carbon pools owing to confounding factors related to climate, topography, soil texture and other original soil properties. In the present study we could avoid such confounding effects by adopting a unique systematic and extensive repeated design of paired sampling plots of different land-use types, both in grassland on sandy soil and in desert grassland on brown calcareous soil on Ordos Plateau, N China. This area has suffered severe land degradation and soil erosion evidently related to unsustainable land-use (Wu and Ci, 2001; Xu, 2004). The specific objectives of our study are (1) to quantify the effects of land-use on carbon storage as dependent on soil texture; (2) to define a ranking from poorest to most promising land-use choice for carbon storage of different soil textures in dryland. Cultivation and grazing are expected to have the strongest impact on carbon storage in desert grassland, while cultivation and desertification are expected to have significant effects on carbon storage in sandy grassland.

2. Methods

2.1. Study area

Ordos Plateau is a geographically distinctive area with unique climate, geology and soils, located in the southern part of Inner Mongolia in northern China (longitude 106.3–112.2° E, latitude 37.4–40.8° N). The climate is continental, with extreme seasonal and diurnal temperature variation and low rainfall. The continental and dry nature of the climate is weakened markedly from west to east, with annual precipitation from 100 to 150 mm in the west to 300–400 mm in the east. The hours of sunshine range from 2900 to 3200 per year, and there are 130–165 frost-free days per year (Zheng et al., 2006).

Ordos Plateau hosts many ecosystem types. The Mu Us sandland is the main body of the plateau, dominated by sandy grassland (Zhang, 1994), similar to sandy grassland in the central and northeastern Europe (Faust et al., 2012); in the west of the plateau dominates desert grassland neighbored by steppe desert, while typical grassland is the dominant ecosystem in the east of the plateau (Chen, 1964) and the Kubuqi sandy desert occupies the north Ordos Plateau. In past centuries Ordos plateau was a lush place, known for its fine pastures with ample water and abundant grass. But today, land-use practices involving the widespread cultivation of crops and overgrazing of grasslands have induced and exacerbated desertification in this landscape (Zhang, 1994). Other major land-use problems for the Ordos plateau include unconstrained collection of medicinal plants and mining. Sandy grassland on sandy soil (humus content <0.1%, content of <0.05 mm particles less than 30%) and desert grassland on brown calcareous soil (humus content from 1.5 to 4%, content of <0.05 mm particles more than 40%) are now the more productive and widely distributed ecosystem types on Ordos Plateau, since the typical steppe has been severely damaged by coal mining.

2.2. Field sampling and laboratory analysis

Our sampling of soil and vegetation carbon pools followed a systematic and extensive repeated design of paired plots of different land-use types in each of the two main soil textures (Fig. 1). Sandy grassland (on sandy soil) and desert grassland (on brown calcareous soil) ecosystems on Ordos Plateau were chosen for investigation. For each of the ecosystem types, we selected 5 pairwise comparisons of land-use types (Table 1, Appendix Fig. 1). In sandy grassland these pairs were: 1) farmland vs. abandoned farmland, 2) farmland vs. natural grassland, 3) farmland vs.

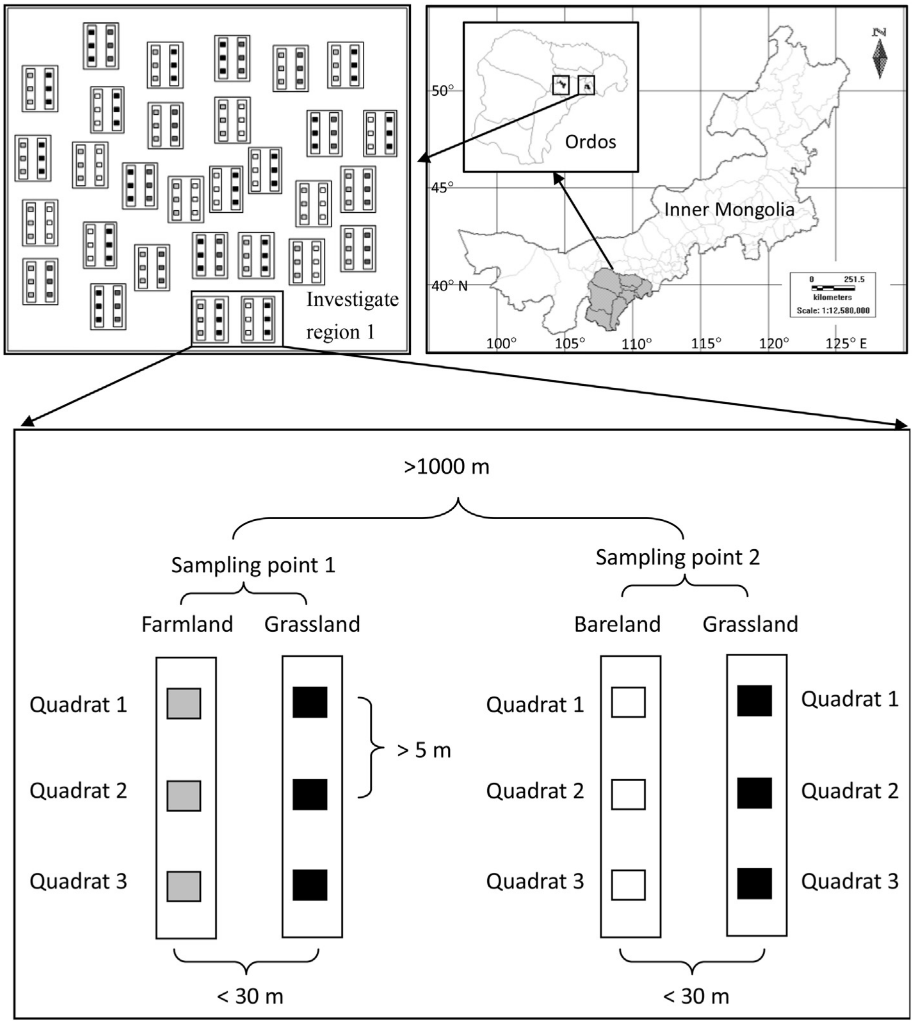

Fig. 1. Field sampling design. There were 6 sampling points per combination, and the interval between every two sampling points was more than 1 km. In each sample point, 3 quadrat pairs (1 m × 1 m) were established corresponding to the comparison land-use types. Two quadrats of each quadrat pairs were in the same aspect and with the same altitude, and the distance between them were less than 30 m. The distance between quadrats of the same land-use type was at least 5 m.

shrubland, 4) natural grassland vs. shrubland on fixed sandy dunes and 5) bare land vs. natural grassland on mobile sandy dunes. In desert grassland the pairs were: 1) farmland vs. abandoned farmland, 2) farmland vs. natural grassland, 3) over-grazed grassland vs. moderate grazing grassland, 4) moderate grazing grassland vs. enclosed grassland, and 5) artificial grassland vs. natural grassland.

There were 6 sampling points per combination, and the interval between every two sampling points was more than 1 km. In each sample point, 3 pairs of 1 m × 1 m quadrats were established for each land-use type comparison. Throughout the two quadrats of each quadrat pair had the same aspect and altitude, and the distance between them was less than 30 m. The distance between quadrats of the same land-use type was at least 5 m (Fig. 1).

From 18 Aug. to 21 Oct. 2009, respectively for each quadrat, all living biomass was harvested, dried in oven at 70 °C for 48 h to constant mass and weighed. Three 7-cm diameter soil cores were taken and divided into five strata as 0–10 cm, 10–20 cm, 20–40 cm, 40–60 cm and 60–100 cm depth; the three samples per stratum were mixed in situ to make one composite sample. Plant roots were hand-sorted for lab analyses, and the soil samples were weighed. In the lab, roots were dried in oven at 70 °C for 48 h to constant mass and weighed. Soil was dried in oven at 105 °C to constant mass and weighed. The soil carbon (C) concentration was determined by the potassium dichromate wet digestion method (Institute of Soil, Academia Sinica, 1978).

2.3. Data analyses

We calculated aboveground plant C density, 0–100 cm belowground plant C density, 0–100 cm soil C density and total C density in each quadrat. To convert plant mass to C stocks, a C content of 45% (ww^{-1}) was assumed (Fang et al., 2007), and soil carbon density was calculated through soil volume weight and soil carbon concentration of different soil layers.

Statistical analyses were performed using SPSS13.0 software (SPSS Inc., USA, 2004). We analyzed the effect of land-use type on plant and soil carbon density with a paired samples T test for each land-use type comparison; one-way analysis of variance (ANOVA) was used to test the difference of plant and soil carbon density between sandy and desert grassland, among different land-use type in sandy and desert grassland, and among different ecosystems in sandy (mobile dune, fixed dune, and farmland) and desert grassland (artificial grassland, farmland and natural grassland), followed by LSD tests.

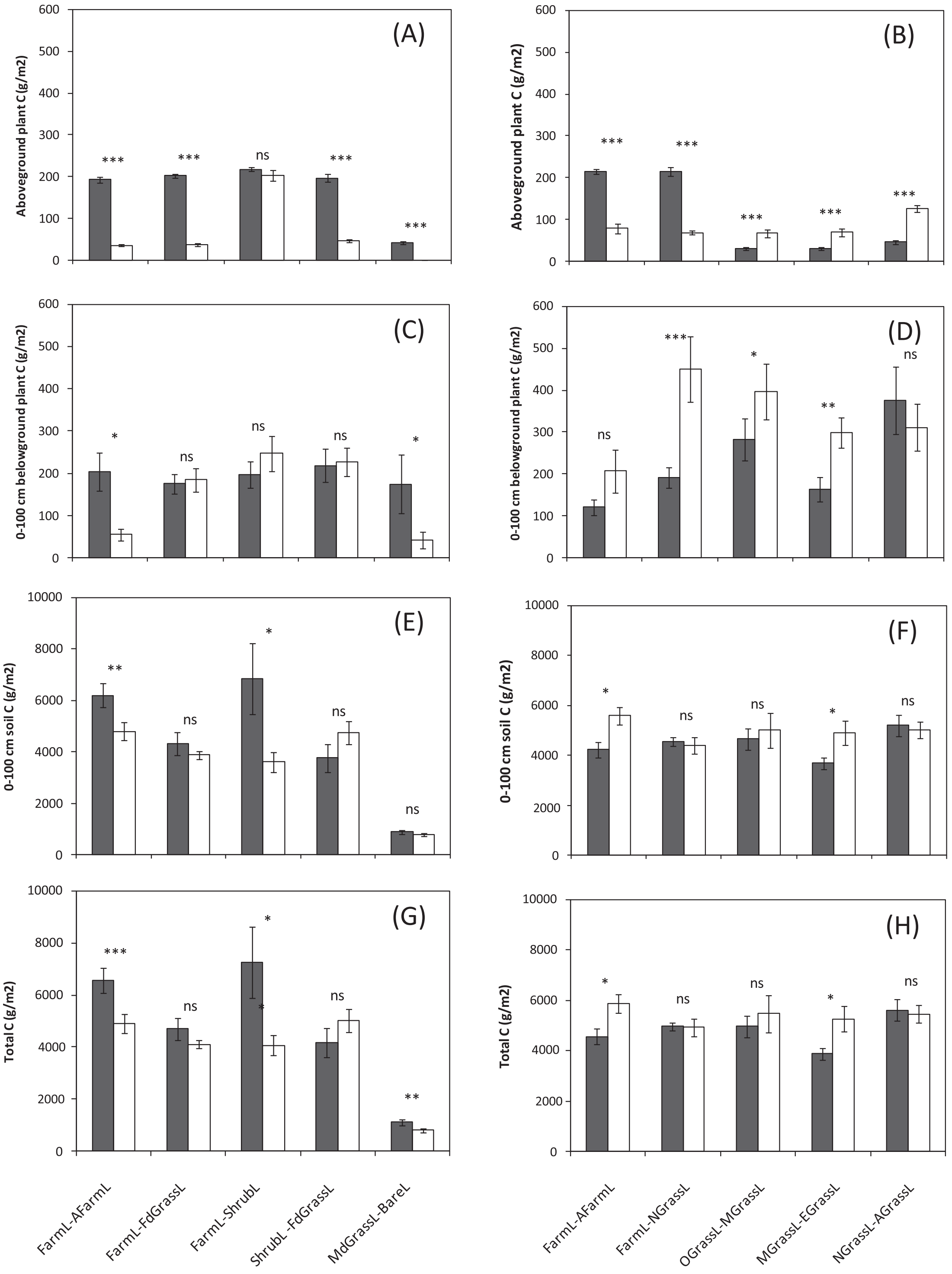

Fig. 2. The aboveground plant C, 0–100 cm belowground plant C, 0–100 cm soil C, and total C of different pairs of land-use type in sandy grassland and desert grassland ecosystem using paired samples T test. FarmL: farmland; AFarmL: abandoned farmland; ShrubL: shrubland in fixed dune; FdGrassL: grassland in fixed dune; BareL: bare land in mobile dune; MdGrassL: grassland in mobile dune; NGrassL: natural grassland; OGrassL: overgrazed grassland; MGrassL: moderately grazed grassland; EGrassL: enclosed grassland; AGrassL: artificial grassland. ***p ≦ 0.001; **0.001 < p ≦ 0.01; *0.01 < p ≦ 0.05; ns p > 0.05.

3. Results

3.1. Variation in carbon density between land-use types by soil texture

Overall, land-use types affected significantly plant and soil C density in sandy grassland, and significantly affected plant C density in desert grassland (Table 2). With a view to aiding land managers directly, we also integrated our results into a decision tree (Fig. 5) for choice of landuse depending on texture and aims. It shows the sequences of plant carbon density and soil carbon density under different land-use type at sandy and clay soil textures, and identifies sensible land-use type depending on what needs to

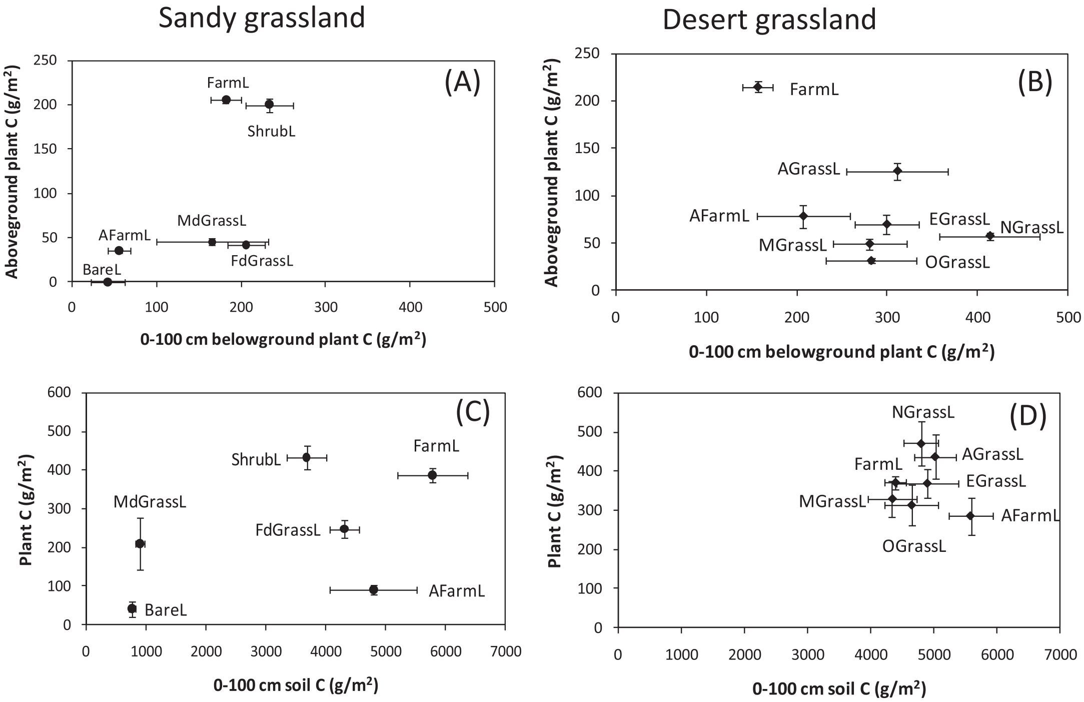

Fig. 3. The aboveground plant C, 0–100 cm belowground plant C of different land-use type in sandy grassland(A) and desert grassland(B), and 0–100 cm soil C and total plant C of different land-use type in sandy grassland(C) and desert grassland(D). FarmL: farmland; AFarmL: abandoned farmland; ShrubL: shrubland in fixed dune; FdGrassL: grassland in fixed dune; BareL: bare land in mobile dune; MdGrassL: grassland in mobile dune; NGrassL: natural grassland; OGrassL: overgrazed grassland; MGrassL: moderately grazed grassland; EGrassL: enclosed grassland; AGrassL: artificial grassland.

be maximized (productivity versus C storage and soil integrity) at two contrasting soil textures.

In paired comparisons, fixed sandy grassland, abandoned farmland had significantly lower plant C density and soil C density than active farmland (Fig. 2A, C, E); grassland in fixed sand dunes had significantly lower aboveground plant C density (Fig. 2A) and similar belowground plant C density, soil C density, and total C density than active farmland (Fig. 2C, E, G); while shrubland had significantly lower soil C density and total C density (Fig. 2E, G) with similar plant C density both aboveground and belowground (Fig. 2A, C). Shrubland had significantly higher aboveground plant C density than grassland in fixed sand dunes (Fig. 2A), but similar belowground plant C density, soil C density and total C density (Fig. 2C, E, G). In the mobile sand dune, plant C density and total C density were significantly different between grassland and bare land (Fig. 2A, C, G), but soil C density did not differ between them (Fig. 2E). In summary, in sandy grassland, the sequence of aboveground plant C density was farmland > shrubland > grassland in fixed or mobile sand dune > abandoned farmland > bare land; for belowground plant C density the order was shrubland > grassland in fixed sand dune > farmland > grassland in mobile sand dune > abandoned farmland > bare land (Figs. 3A and 5), and for soil C density the order was farmland > abandoned farmland > grassland in fixed sand dune > shrubland > grassland in mobile sand dune > bare land (Figs. 3C and 5).

In desert grassland, abandoned farmland had significantly lower aboveground plant C density (Fig. 2B), similar belowground plant C density (Fig. 2D), and significantly higher soil C density and total C density (Fig. 2F, H) compared with active farmland; natural grassland had significantly lower aboveground plant C density (Fig. 2B), significantly higher belowground plant C density (Fig. 2D) and similar soil C density and total C density than active farmland (Fig. 2F, H). Compared with moderately grazed grassland, overgrazed grassland had significantly lower plant C density both above- and belowground (Fig. 2B, D), and similar soil C density and total C density (Fig. 2F, H), while enclosed grassland had significantly higher plant C density, soil C density and total C density (Fig. 2B, D, E, H). Artificial grassland had significantly higher aboveground plant C density (Fig. 2B), but similar belowground plant C density, soil C density and total C density (Fig. 2D, E, H) compared with natural grassland. In summary, in desert grassland, the sequence of aboveground plant C density was farmland > artificial grassland > abandoned farmland > enclosed grassland > natural grassland > moderately grazed grassland > overgrazed grassland; for belowground plant C density the order was natural grassland > artificial grassland > enclosed grassland > overgrazed grassland and moderately grazed grassland > abandoned farmland > farmland (Figs. 3B and 5). Soil C density did not vary substantially between different land-use types (Figs. 3D and 5).

3.2. *Carbon density within the soil profile*

In sandy grassland, soil C concentration of different soil layers in mobile sand dune was significantly lower than in fixed sand dune, and there was no significant difference between grassland and bare land in mobile sand dune (Fig. 4A). Above 40 cm, soil C concentration of all land-use types decreased with soil depth in fixed sand dune, while below 40 cm there was no significant change (Fig. 4A). In desert grassland, changes of soil C concentration of different land-use types with soil depth were less pronounced (Fig. 4B), but soil C concentration was significantly higher at 10–20 cm below enclosed grassland and at 60–100 cm below enclosed grassland and overgrazed grassland (Fig. 4B).

Belowground plant C density in both sandy and desert grassland decreased with the increase of soil depth, but in grassland in mobile sand dune in sandy grassland and enclosed grassland in desert

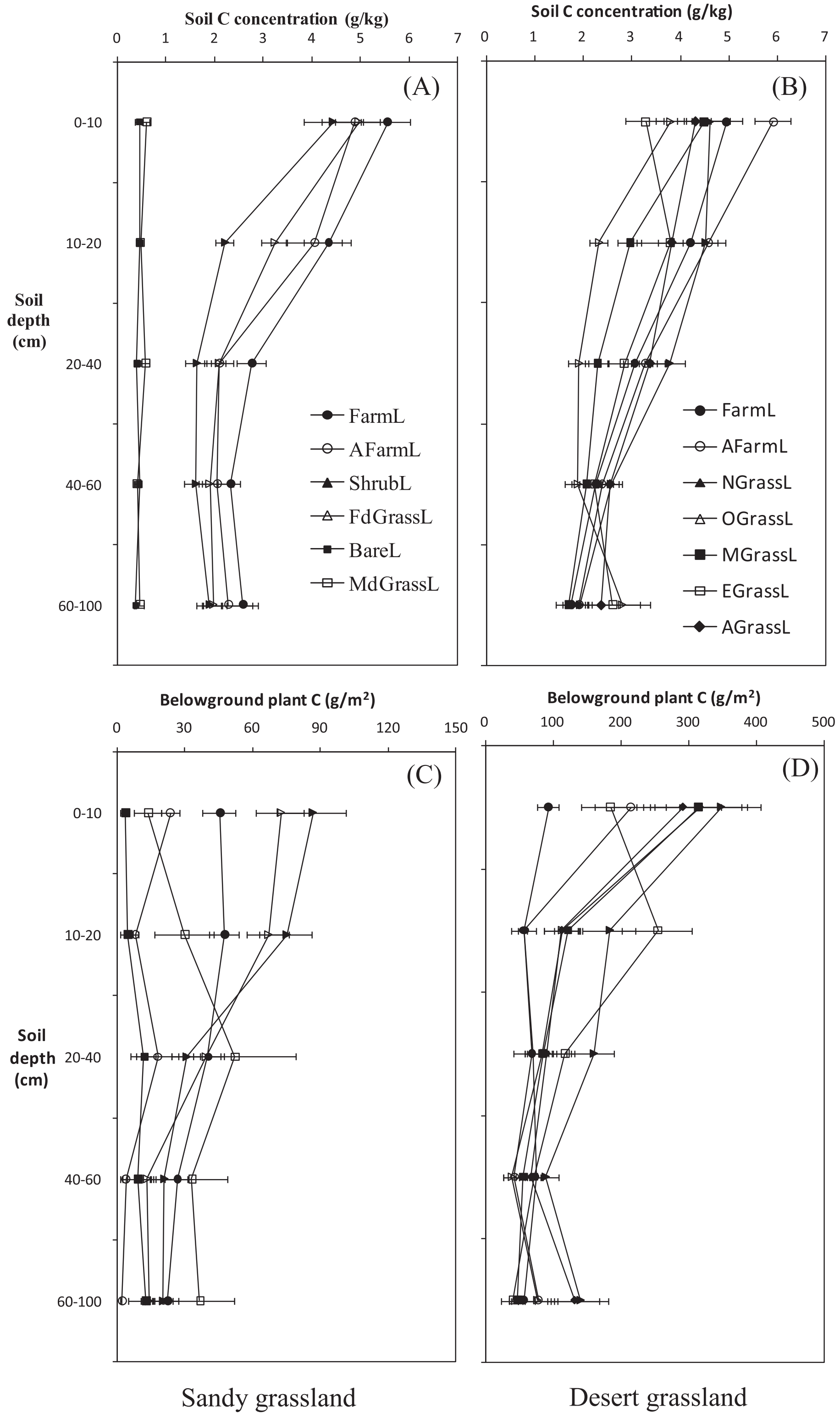

Fig. 4. The soil C concentration of different soil layer in sandy grassland(A) and desert grassland(B), and belowground plant C of different soil layer in sandy grassland(C) and desert grassland(D). FarmL: farmland; AFarmL: abandoned farmland; ShrubL: shrubland in fixed dune; FdGrassL: grassland in fixed dune; BareL: bare land in mobile dune; MdGrassL: grassland in mobile dune; NGrassL: natural grassland; OGrassL: overgrazed grassland; MGrassL: moderately grazed grassland; EGrassL: enclosed grassland; AGrassL: artificial grassland.

grassland it had initially increased and then decreased with the increase of soil depth (Fig. 4C, D).

4. Discussion

Our systematic and extensive repeated design of paired sampling has revealed consistent variation in soil and plant carbon

Table 1
Characteristics of each land-use type in sandy grassland and desert grassland in Ordos Plateau.

Land-use type	Plant cover	Dominant plant species	Soil type	Characteristic
Sandy grassland				
Farmland	>90%	*Zea mays*	Sand	Seeding and fertilizing Harvest every year Fixed dunes
Abandoned farmland	60–90%	*Corispermum* spp. and *Setaria viridis* or *Artemisia scoparia* and *Chloris virgata* or *Bassia dasyphylla* or *Artemisia argyi*	Sand	Fertilizing >3 years ago Moderate grazing Fixed sand dunes
Natural grassland in fixed dunes	50–80%	*Poa sphondylodes* or *Pennisetum centrasiaticum* or *Leymus secalinus* or *Setaria viridis*	Sand	Lightly grazed Fixed sand dunes
Shrubland	60–90%	*Artemisia ordosica*	Sand	Lightly grazed Fixed sand dunes
Bare land	0–1%	Nothing or *Agriophyllum squarrosum*	Sand	Mobile sand dunes
Grassland in mobile dunes	5–10%	*Agriophyllum squarrosum* or *Psammochloa villosa*	Sand	Lightly grazed Mobile sand dunes
Desert grassland				
Farmland	>90%	*Zea mays*	Clay	Seeding and fertilizing Harvest every year
Abandoned farmland	50–80%	*Salsola collina* and *Saussurea amara* or *Chenopodium glaucum* or *Cleistogenes songorica* or *Artemisia sieversiana* or *Leymus secalinus*	Clay	Fertilizing >3 years ago Moderately grazed
Natural grassland	50–90%	*Stipa breviflora* or *Leymus secalinus* or *Allium mongolicum* or *Pennisetum centrasiaticum*	Clay	Lightly grazed
Overgrazed grassland	15–30%	*Lespedeza davurica* or *Cynanchum komarovii* or *Phragmites communis* or *Artemisia argyi* or *Leymus secalinus*	Clay	overgrazed
Moderately grazed grassland	50–80%	*Phragmites communis* or *Leymus secalinus* or *Potentilla bifurca* or *Calamagrostis pseudophragmites*	Clay	Moderately grazed
Enclosed grassland	60–90%	*Leymus secalinus* or *Pennisetum centrasiaticum* or *Stipa breviflora*	Clay	Grazing prohibited for >5 years
Artificial grassland	60–90%	*Astragalus adsurgens*	Clay	Seeding and fertilizing Mowing 1–2 times per year since 2 year after seeding

stocks as dependent on different land-use types in sandy versus clayey soils on Ordos Plateau, N China. Here we discuss these findings in the context of previous literature, and recommend promising land-use choices on both soil textures depending on whether the aim is to maximize soil stability, productivity or carbon storage.

Land-use and land-cover transformations, always accompanied by changes in the Earth's carbon cycle, have played an important role in sustainable development of human society (Canadell et al., 2004; IPCC, 2013). Also, land-use type is often closely related to soil texture (McLauchlan, 2006; Kong et al., 2009). For example, for grasslands on sandy soil, which have strong temporal and spatial heterogeneity of water availability and different degrees of desertification (Dong et al., 2012), the prevention of desertification had to be a priority for land-use choice, and agricultural development is only possible in inter-dune lowland with more favorable water regimes (Zhang, 1994; Su et al., 2010); while in desert grassland with clay soil texture, agricultural development and grazing are the major land-use types (Kang et al., 2007). Focusing on carbon storage, different land-use types were shown previously to have different effects on carbon storage of grassland (Conant et al., 2001; Saha, 2011), but unlike our study, the previous studies could not avoid confounding effects of climatic, topographic, pedological, biotic, historic or other factors. Our standardized, replicated and paired sampling design (the distance between two quadrats of each quadrat pair always being less than 30 m) enabled us to quantitatively determine effects of land-use on carbon storage at given soil texture, also effectively avoiding confounding effects of climate, topography and original soil properties. Ideally soil texture itself would have been replicated spatially as well, but this was impossible in Inner Mongolia, where a given same soil texture stretches over vast areas.

Sandy grasslands are typically covered by aeolian mobile dunes (with a vegetation cover <15%), semi-fixed dunes (vegetation cover 15–40%) and fixed dunes (vegetation cover >40%) (Wang et al., 2009). They cover a huge area stretching over about 10 degrees of latitude, and 16 degrees of longitude in China (Dong et al., 2012). Sandy grassland ecosystems are vastly different in carbon sequestrating capacity under different succession stages. Even with the same amount of plant carbon, grassland in fixed dunes had an order of magnitude larger soil carbon pool than grassland in mobile dune systems (Fig. 3C). This means sandy grassland may have great potential of carbon sequestration once the mobile dunes can be fixed, just like in the eroded areas in subtropical China (Shi et al., 2009) and the edge of Badan Jaran Desert (Su et al., 2010). Thus, desertification control may be an effective measure to improve carbon sequestration in sandy grassland. There was no significant difference in C sequestration between land-use types with natural vegetation, such as shrubland and grassland in fixed sand dunes, even though aboveground plant C was much greater in the former (Figs. 2A and 5); this can be attributed to stocks of aboveground perennial woody biomass in shrubland in contrast to the herbaceous biomass of grassland with annual dieback aboveground (Conti et al., 2013). Therefore, in the context of desertification control, planting shrubs may be better than planting or seeding grass in sand grassland, as woody biomass prevents soil erosion throughout the year, and especially during early spring when stormy weather is common. And shrubs have stronger drought resistance than grass, since shrubs' deeper roots can easily penetrate the dry sand surface, and use the deeper water efficiently.

In desert grassland, grazing intensity (as related to livestock density) had no significant effect on soil C (Fig. 5), may be because of the complex relationship between grazing and soil C (Reeder et al., 2004; Frank, 2008); however grazing significantly decreased both aboveground and belowground plant C (Fig. 5). Prohibition of grazing may be effective in order to improve ecosystem carbon sequestration. Artificial grassland had much higher productivity (aboveground plant C) than natural grassland, and maintained similar belowground plant C, soil C and total C to natural grassland (Fig. 5). Considering the low precipitation in desert grassland, development of artificial grassland in a smaller water-rich region, can use water efficiently, produce enough forage and reduce the grazing pressure. Development of artificial grassland in desert grassland may thus be a good choice to meet the demand of forage grass while preventing desertification.

Human activity, like cultivation with fertilization and harvesting, had significant effect on the carbon sequestration of sandy grassland, including aboveground plant C, belowground plant C, soil C and total C; however it had no significant effect on soil C and total C of desert grassland (Fig. 5). We also found a significant decrease of belowground plant C and soil C in sandy grassland, but not in desert grassland, after cessation of agriculture (Figs. 2 and 5). This implies that sandy grassland ecosystems may be more sensitive to change, and thereby possibly more vulnerable.

Table 2

Effects of different ecosystems and land-use type on carbon density of sandy grassland and desert grassland ecosystems in Ordos Plateau using one-way ANOVA.

		Soil C density		Aboveground plant C density		Belowground plant C density		Total C density	
		F	Sig.	F	Sig.	F	Sig.	F	Sig.
Sandy grassland vs. desert grassland ($F_{1,358}$)		7.20	**0.008**	7.30	**0.007**	25.99	**<0.001**	8.68	**0.003**
Land-use types	In sandy grassland ($F_{4,175}$)	12.06	**<0.001**	495.86	**<0.001**	7.55	**<0.001**	13.44	**<0.001**
	In desert grassland ($F_{6,173}$)	1.41	0.213	105.26	**<0.001**	4.08	**0.001**	1.31	0.253

Bold type means significant in $P < 0.05$.

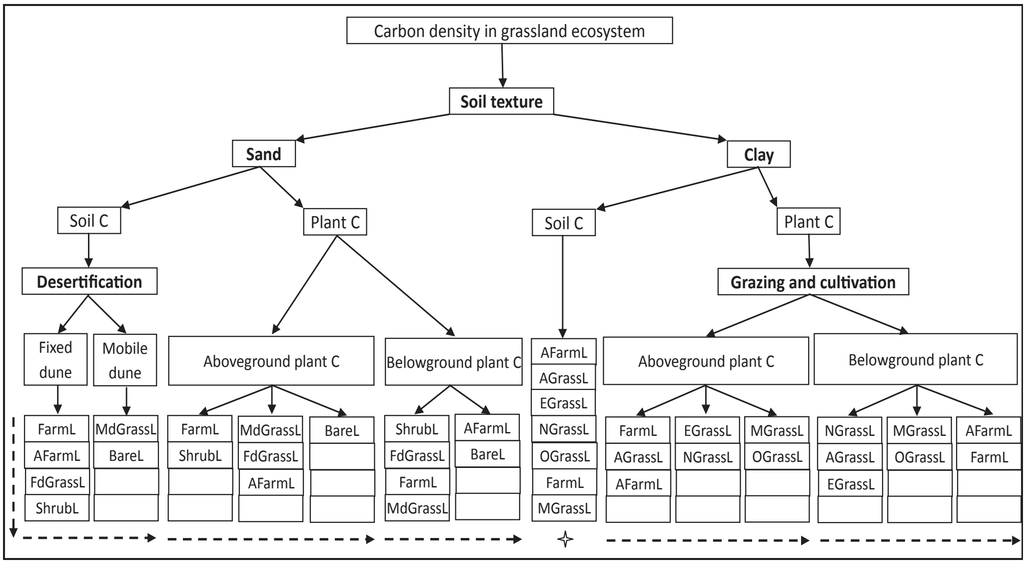

Fig. 5. Decision tree for sensible land management depending on what needs to be maximized (productivity versus C storage and soil integrity) at two contrasting soil textures. FarmL: farmland; AFarmL: abandoned farmland; ShrubL: shrubland in fixed dune; FdGrassL: grassland in fixed dune; BareL: bare land in mobile dune; MdGrassL: grassland in mobile dune; NGrassL: natural grassland; OGrassL: overgrazed grassland; MGrassL: moderately grazed grassland; EGrassL: enclosed grassland; AGrassL: artificial grassland. - - - -▶ means C density change from high to low; ✧ means similar soil C density.

Land-use types were often very carefully chosen for certain purposes, such as for desertification control, biodiversity conservation, production of commercially marketed goods, etc. And many management practices were implemented to achieve these ends, in view of each land-use type. The aboveground and belowground plant C and soil C of different land-use types in sandy grassland and desert grassland were compared in our studies. Results showed that effects of land-use type on carbon storage were closely related with soil texture, suggesting that prevention of desertification in drylands needed to adjust measures to different soil textures. And a decision tree for sensible land management depending on what needs to be maximized (productivity versus C storage and soil integrity) was constructed in our studies. Our results may serve as a reference for the selection of land-use types for preventing and controlling desertification in drylands around the world, such as in West, Central and East Asia and North America (Golodets et al., 2013; Liu et al., 2013), which feature similar vegetation types and similar overuse by livestock.

Effects of land-use change on carbon storage, such as conversion from farmland to grassland, desertification control and prohibition of grazing, are a time-dependent dynamic process (McLauchlan, 2006; Shi et al., 2009; Tanentzap and Coomes, 2012). Our study was limited to the comparison of different land-use types, failing to consider the maintenance time of each land-use type, such as the duration of grazing, cultivation, abandonment and vegetation restoration. Although challenging to study in a standard way such as in the current study, we recommend follow-up investigation into the interactive effects of soil texture, land-use type and land-use duration on the carbon storage in semi-arid and arid ecosystems.

In sum, our results showed that effects of land-use on carbon storage were closely related with soil textures. In sandy grassland, desertification control should be an effective measure to improve the carbon sequestration and shrub planting should be better than grass planting; and in desert grassland, development of man-made grasslands should be a good choice to solve the contradictions of ecology and economy. We believe that these findings will help to better understand effects of land-use on ecosystem function like soil carbon storage as depended on soil texture, and to select the most promising land-use type in dryland.

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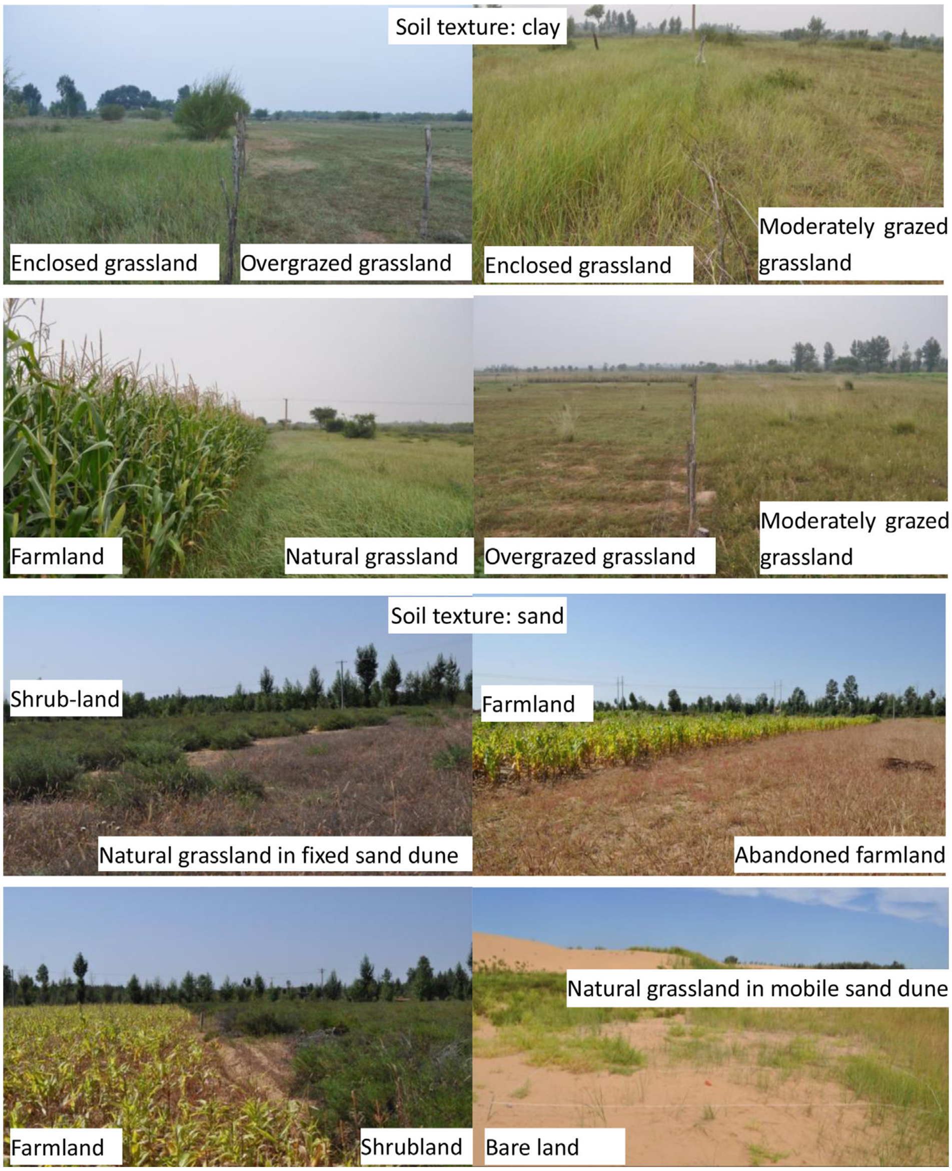
Appendix Fig. 1



Appendix Fig. 1. Different land-use types in Ordos Plateau.

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