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Short Term Effects of Revegetation on Labile Carbon and Available Nutrients of Sodic Soils in Northeast China

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Abstract: In response to land degradation and the decline of farmers' income, some low quality croplands were converted to forage or grassland in Northeast China. However, it is unclear how such land use conversions influence soil nutrients. The primary objective of this study was to investigate the influences of short term conversion of cropland to alfalfa forage, monoculture Leymus chinensis grassland, monoculture Leymus chinensis grassland for hay, and successional regrowth grassland on the labile carbon and available nutrients of saline sodic soils in northeastern China. Soil labile oxidizable carbon and three soil available nutrients (available nitrogen, available phosphorus, and available potassium) were determined at the 0-50 cm depth in the five land uses. Results showed that the treatments of alfalfa forage, monoculture grassland, monoculture grassland for hay, and successional regrowth grassland increased the soil labile oxidizable carbon contents (by 32%, 28%, 15%, and 32%, respectively) and decreased the available nitrogen contents (by 15%, 19%, 34%, and 27%, respectively) in the 0–50 cm depth compared with cropland, while the differences in the contents of available phosphorus and available potassium were less pronounced. No significant differences in stratification ratios of soil labile carbon and available nutrients, the geometric means of soil labile carbon and available nutrients, and the sum scores of soil labile carbon and available nutrients were observed among the five land use treatments except the stratification ratio of 0-10/20-30 cm for available phosphorus and the values of the sum scores of soil labile carbon and available nutrients in the 0–10 cm depth. These findings suggest that short term conversions of cropland to revegetation have limited influences on the soil labile carbon and available nutrients of sodic soils in northeastern China.

Keywords: revegetation; Solonetz; stratification ratio; geometric mean; Songnen plain

1. Introduction

The structure, diversity, and production capacity of terrestrial ecosystems are strongly linked to the availability of soil nutrients, such as nitrogen, phosphorus, potassium, and soil organic carbon [1,2]. However, the soil labile carbon and soil nutrients' availability in terrestrial ecosystems are usually influenced by various direct and indirect soil disturbances [3,4]. Land use conversions are major drivers of changes in soil labile carbon and soil nutrient availability, resulting in the degradation of soil ecosystem services (nutrient cycle, water conservation, pollution purification, etc.) and global



environmental problems (soil degradation, climate change, water, soil erosion, etc.) [5,6]. One main mechanism by which they do this is by changing the quantity and quality of plant biomass supplied to the soils, affecting the rate of organic matter decomposition and the activity of soil microorganism and redistributing soil carbon and nutrients within soil profiles [7–9]. Another main mechanism is the impact of soil erosion, which preferentially removes the surficial and most carbon and nutrient rich material, thus accelerating the decline of the soil organic carbon and soil nutrient pool [10,11].

Characterizing the spatial and temporal variability of soil carbon and nutrients in relation to land use types is critical for predicting the influences of future land use conversion on soil quality changes and understanding how ecosystems' function [12]. Changes of soil organic carbon (soil microbial biomass carbon, particulate organic carbon, water extractable organic carbon, etc.) and total nutrients (total nitrogen, total phosphorus, total potassium, etc.) under different land uses in different spatial and temporal scales induced by long term land use conversions have been well addressed [13–17]. However, the evaluation of the short term effects of land uses on soil labile carbon and soil available nutrients are rare due to the high spatial variability and the errors in the measurement methods of these soil properties [18,19]. Moreover, due to regional differences in environment conditions, initial soil properties, and management years and intensity, inconsistent and contradictory responses of soil labile carbon and soil available nutrients to short term land use conversions were observed, which failed to demonstrate a clear relationship between short term land uses and changes in soil labile carbon and available nutrients [14,20]. For instance, Madejon et al. [14] in the southwest of Spain found that after three year plantation of fast growing trees decreased the contents of available nitrogen (AN), available phosphorus (AP), and available potassium (AK). Lu et al. [21] in Tibet, China, reported that short term (nine years) grazing exclusion had no impact on soil AN, AP, microbial biomass carbon, and other soil properties. However, the results of Wang et al. [20] in Shanxi Province, China, showed that three years of plantation of grass and alfalfa significantly increased the contents of soil organic carbon, AN, AP, and AK.

As one of the largest salt affected soil regions in China, Songnen plain has suffered from substantial land salinization and alkalization because of the influences of human activity in recent decades [22]. The increases in soil alkalinity and sodicity have adversely influenced the soil properties by promoting crusting and low permeability and infiltration rates [23], thus leading to the reduction of grain production. Furthermore, with an increase in corn production in China from 1.06×10^8 tons in 2003 to 2.25×10^8 tons in 2016 due to the increase of yield per unit and the planting area, oversupply resulted, causing a notable reduction in corn price and planting benefit to farmers [22]. Therefore, the croplands with poor quality soils were abandoned in the Songnen plain. To address these problems in the Songnen plain, the Chinese government implemented a range of policies and subsidies to guide farmers to improve the efficiency and sustainable development of agriculture through revegetation in the areas where the soils were not suitable for growing crops. Revegetation, the conversion of cropland to a vegetation covered land, has become a well explored approach to rehabilitate degraded soil ecosystems [15,24]. In addition to combatting erosion and protect soils, revegetation has substantial effects on the accumulation of soil organic carbon and nutrients and the improvement of soil microbial biomass and activity [13,15]. Deng et al. [15] in the Loess Plateau, China, found that the contents of soil organic carbon, total N, and total P at a depth of 0–20 cm increased by more than 13%, 10% and 11%, respectively, after 30 years of grassland restoration. Our previous study in the same site showed that soil microbial biomass carbon and enzyme activity at a depth of 0–20 cm increased by 36% and 56%, respectively, after five years of conversion of cropland to grassland [22]. However, the short term influences of revegetation on soil oxidizable carbon and available nutrients have yet to be quantified in northeastern China.

In this study, we hypothesized that five years of revegetation from cropland could increase the contents of soil available nutrients and soil labile carbon and therefore be beneficial to the sustainable use of saline sodic soils in northeastern China. To address this hypothesis, the objective of this research was to investigate the changes in the contents of labile oxidizable carbon (LOC), AN, AP, and AK

after conversion from cropland to alfalfa forage, monoculture *Leymus chinensis* grassland, monoculture *Leymus chinensis* grassland for hay, and successional regrowth grassland and examine whether short term revegetation could improve the LOC and soil available nutrients in the regions where the soils were not suitable for planting crops in northeastern China.

2. Materials and Methods

2.1. Study Area

The research was conducted in the Songnen plain located at the Grassland Farming and Ecological Research Station (123°31′ E, 44°33′ N) (Figure 1). The terrain surrounding the study area is relatively flat, and the altitude is approximately 145 m above sea level. The study area has a temperate, semiarid continental climate. The average annual temperature is 5.9 °C, and the mean annual precipitation is 427 mm (1980–2013). The soil is classified as Solonetz in the World Reference Base for Soil Resources with a soil texture of 22% sand, 33% silt, and 45% clay [25]. The main vegetation consists of perennial herbs such as *Leymus chinensis* and *Puccinellia tenuiflora*. Besides, some therophytes such as *Chloris virgata* and *Suaeda heteroptera* grow in the areas with higher soil pH and poor soil quality [26].



Figure 1. The location map of the study area.

2.2. Experimental Design

This experiment was organized as a completed block design with five land use treatments. In early May 2011, four adjacent blocks (each 60×50 m, 2 m buffer between the blocks) in the study area based on similar land use history were identified. Before this experiment (2004–2010), farmers grew rain fed maize (Zea mays L.) and sunflower (Helianthus annuus) in these blocks, following the traditional planting practices in Northeast China, which consists of plowing the soil down to 20 cm depth and applying 50–96 kg N ha⁻¹, 20–45 kg P ha⁻¹, and 15–45 kg K ha⁻¹ fertilizers into the soils. The soil properties in these four blocks were homogeneous due to the continuous plowing. The five land use treatments consisted of corn cropland (corn, used as an indication of how the revegetation influences the soils in this study), alfalfa perennial forage land (alfalfa), monoculture grassland of *Leymus chinensis* (MLG), monoculture grassland of Leymus chinensis for hay (Mowing) once a year (MLG + M), and successional regrowth grassland (SRG) (Figure 2). Leymus chinensis is the native vegetation and is usually used as forage grass for grazing animals in the Songnen grassland. In the mowing grassland, Leymus chinensis is harvested as hay, and farmers sell the hay to livestock farms. Alfalfa has high saline and alkaline tolerance, and it has been introduced into the Songnen grassland as a high forage plant due to the high N and protein content [22]. The planting of forage grass used in this study could improve the income of local farmers and the development of animal husbandry. In each block, two greater plots of 12×50 m were for corn and alfalfa treatments, while three plots of 6×50 m for land use treatments of MLG, MLG + M, and SRG. There was a 1 m buffer among the five plots. The was no irrigation under

the five land uses in this study. More information about the treatments of land uses is presented in Figure 3 [22,26].



Figure 2. Images of the land use treatments in this study. Corn, corn cropland; Alfalfa, alfalfa forage land; MLG, monoculture grassland; MLG + M, monoculture grassland for hay (Mowing); SRG, successional regrowth grassland.

Successional Monoculture		Monoculture	Alfalfa perennial forage	Corn cropland (Corn)	
regrowth grassland	grassland of Leymus	grassland of Leymus	(Alfalfa)		
(SRG)	chinensis for hay	chinensis (MLG)		Since 2011, the cropland	
	(MLG + M)		Before 2014, the Alfalfa	has been under continuous	
The cropland was	Carls of I	Seeds of <i>Leymus</i>	plots were no tillage	corn monoculture. The	
abandoned in 2011 in	Seeds of Leymus	Tzyalay wara sowed	practices were the same as	traditional cropland	
the SKG plots to	chinensis (1rin.)	in May 2011 with a	these of the proviously	prostice in the Songnon	
without any	in May 2011 with a	density of	described corn cropland.	grassland; this tradition	
disturbance. The	density of	approximately 2000	However, the growth of	consists of plowing the	
dominant species in	approximately 2000	seeds m ⁻² . Reseeding	corn was very poor in 2011	soil at least twice before	
the SRG plots include	seeds/m ² . Reseeding	had a positive effect	to 2013 due to the poor soil	the crop growing season	
Chloris virgate,	had a positive effect in	on the recovery of	conditions and short term	down to 20 cm and	
Sonchus brachyotus,	recovering the	vegetation, and the	land use, and the no tillage	fertilization (74 kg N ha ⁻¹ ,	
Chenopodium	vegetation. The	aboveground biomass	cropland was changed to	22 kg P ha^{-1} , and 41 kg K	
glaucum, etc. The	aboveground biomass	reached	alfalfa forage land in May	ha ⁻¹) twice per year at	
aboveground (348 g	was mowed for hay	approximately 100–	2014 with a sowing density	sowing and in mid-July.	
m ⁻²) and belowground	once a year at the peak	120 g m^{-2} in early	of approximately 1200	The corn straw was	
$(397 \text{ g m}^{-2}, 0-20 \text{ cm})$	biomass. The	September 2011. The	seeds m^{-2} . The	removed from the plots	
depth) biomass was	belowground (638 g	aboveground (381 g	aboveground (307 g m ⁻²)	after harvest, while the	
kept as litter to return	m^{-2} , 0–20 cm depth)	m ⁻²) and belowground	and belowground (321 g	corn root, stem base, and	
to the soil.	biomass was kept to	$(456 \text{ g m}^{-2}, 0-20 \text{ cm})$	m^{-2} , 0–20 cm depth)	aerial root (which is 137 g	
	return to the soils in	depth) biomass was	biomass were kept in these	m ²) were incorporated	
	these plots.	kept as litter to return	plots to increase soil	into soil during plowing.	
		to the soil.	tertility in 2014 and 2015.		

Figure 3. Detailed information and history of land use treatments in this study.

2.3. Soil Sampling and Analysis

Soil sampling was performed using an auger (4 cm in diameter) in early September 2015. The sampling depth was 0–50 cm with an interval of 10 cm increments. Five randomly distributed sub-samples from each plot were combined into a composite sample at each soil depth. After removing the visible vegetation materials and debris, soil samples were sieved through a 2 mm sieve, and then ground to pass through a 0.25 mm sieve for analyses.

Soil labile oxidizable carbon (LOC) was measured using the revised method defined by Chan et al. [27]. Available nitrogen (AN) was measured by the alkaline hydrolysis diffusion method [28]. The AN forms were primarily mixtures of ammonium nitrogen (NH₃-N), nitrate nitrogen (NO₃-N), and a small amount of water soluble organic nitrogen (e.g., amino acids and ammonium acyl, etc.). Available phosphorus (AP) was extracted with NaHCO₃ at pH 8.5 and measured using UV spectrophotometer [28]. The AP forms were primarily the calcium phosphates due to the higher soil pH (Table 1) in the study area. Available potassium (AK) was measured based on the ammonium acetate extracted and emission flame spectrophotometer method [28]. The AK forms were primarily

mixtures of exchangeable potassium and water soluble potassium. Furthermore, for the purpose of clearly understanding the nature of soils in the study area, a 1:5 soil:water solution was used to measure the soil pH and electrical conductivity (EC) using the PHS-3C instrument and the DDS-307 instrument, respectively.

Soil	Corn	Alfalfa	MLG + M	MLG	SRG	AN	IOVA		
Depth						F	Р		
pH									
0–10	9.36 (±0.14)	9.14 (±0.04)	9.16 (±0.10)	9.00 (±0.10)	9.05 (±0.26)	0.88	0.50		
10-20	9.83 (±0.17)	9.76 (±0.09)	9.93 (±0.09)	9.87 (±0.06)	9.39 (±0.43)	1.01	0.43		
20-30	10.06 (±0.08)	10.04 (±0.09)	10.03 (±0.04)	10.00 (±0.06)	9.96 (±0.08)	0.29	0.88		
30-40	10.11 (±0.04)	10.11 (±0.08)	10.03 (±0.03)	9.99 (±0.04)	10.02 (±0.03)	1.11	0.39		
40-50	10.06 (±0.06)	10.04 (±0.09)	9.99 (±0.04)	9.92 (±0.04)	9.98 (±0.05)	0.78	0.56		
EC									
0–10	204 (±16)	155 (±11)	162 (±5)	157 (±21)	164 (±24)	1.43	0.27		
10-20	330 (±56)	306 (±43)	398 (±53)	376 (±32)	335 (±101)	0.36	0.84		
20-30	391 (±49)	385 (±65)	531 (±55)	491 (±39)	435 (±95)	1.00	0.44		
30-40	389 (±31)	391 (±58)	576 (±46)	501 (±55)	492 (±75)	2.12	0.13		
40-50	350 (±17)	349 (±59)	481 (±56)	468 (±64)	452 (±45)	1.63	0.22		

Table 1. Mean values (±SE) of soil pH and electrical conductivity (EC) under different land uses.

Abbreviations: Corn, corn cropland; Alfalfa, alfalfa forage land; MLG, monoculture grassland; MLG + M, monoculture grassland for hay; SGR, successional growth grassland.

2.4. Statistical Analysis

The soil stratification by certain properties (e.g., SOC, total N, total P, etc.) is very common, and the stratification ratio (SR) is widely used as a crucial indicator of soil condition [15]. A higher SR of soil properties indicates better soil conditions, because SR of degraded soils is usually less than 2 regardless of climatic or soil conditions [15]. The improvement of soil quality under specific land use is conducive to plant growth and agricultural sustainability [29,30]. Revegetation on the cropland will increase the input of organic matter and thus alter the SR of soil properties, which will provide an indication of soil responses to specific plant cover. The SR were calculated for each land use as follows:

$$SR = ANt/ANs$$
 (1)

where AN_t is the content of LOC, AN, AP, and AK in the 0–10 cm depth; AN_s is the corresponding content of LOC, AN, AP, and AK in the 10–20 and 20–30 cm depth.

A unitary soil available nutrient is not complete to reveal the changes within the soil environment because soil available nutrients do not always respond similarly to different management practices [22]. Therefore, the comprehensive assessment of the responses of a series of soil available nutrients and LOC to factors of change is required. However, the various responses of LOC and soil available nutrients to land use change might result in inaccurate conclusions on soil quality and thus limit the suitability of LOC and soil available nutrients as soil quality indicators. The geometric mean and sum scores are two general indices to combine the variables with diverse units and ranges into one variable, which could clearly indicate the actual influences of environmental factor changes on these variables [31]. Here, the geometric means of LOC and available nutrients (GMSN) under different land uses and soil depths are calculated as follows:

$$GMSN = (LOC \times AN \times AP \times AK)^{1/4}$$
⁽²⁾

where LOC, AN, AP, and AK are oxidizable labile C, available nitrogen, available phosphorus, and available potassium, respectively.

all the measured soil available nutrients and LOC before the sum scores of LOC and available nutrients (SSAN) are calculated. The min-normalization is a well explored approach to convert the data with different units or variation ranges into a dimensionless pure value, so that the data can remove the unit limit and can be easily compared and weighted [26]. The SSAN under different land uses and soil depths is as follows:

$$S_i = X/X_{min}$$
(3)

$$SSAN = \sum_{i=1}^{n} S_i \tag{4}$$

where S_i is the score of LOC, AN, AP, and AK after data normalization; X is the measured value, and X_{min} is the minimum value of each soil nutrient observed in this study; n is the number of soil nutrients.

We used one way ANOVA to analyze the influences of land use types on the LOC and soil available nutrients, soil pH, EC, SR, GMSN, and SSAN. Mean differences of soil available nutrient contents, LOC, SR, GMSN, and SSAN among land use treatments were examined using the least significant difference test (LSD). All comparisons were considered significant if p < 0.05. The mean and standard error of each soil property measured were provided at each soil depth under a given land use treatment. All data analyses were performed with SPSS 16.0 for Windows (SPSS, Inc., Chicago, USA).

3. Results

3.1. Changes in Soil pH and EC

Soil pH in the study area was notably high (Table 1). The values of soil pH were all more than 9.00 at the 0–50 cm depth; especially at the 10–50 cm depths, the values were close to or more than 10.00. Soil pH was not affected by the land use conversions. The average values of soil pH at the 0–50 cm depth were 9.88, 9.82, 9.83, 9.76, and 9.68 for corn, alfalfa, MLG, MLG + M, and SRG treatment, respectively.

Similar to the soil pH, the EC values in the subsoil (10–50 cm) were higher than that at the surface soil (0–10 cm). The average values of EC in the 0–50 cm depth were 333, 317, 430, 399, and 376 μ S cm⁻¹ for corn, alfalfa, MLG, MLG + M, and SRG treatment, respectively (Table 1). There was no significant difference of EC among the land use treatments because of the narrow values of EC in the same soil depth.

3.2. Changes in LOC, AN, AP, and AK Content

The LOC content under the land use of SRG was remarkably higher than that under corn in the 0–10 cm depth, while it was significantly higher under alfalfa in the 10–20 cm depth than the corn and MLG + M treatment (Figure 4A). In the 20–50 cm depth, the highest LOC content was found under the MLG treatment. The average LOC contents in the 0–50 cm depth were 32% (0.56 g kg⁻¹), 28% (0.49 g kg⁻¹), 15% (0.26 g kg⁻¹), and 32% (0.57 g kg⁻¹) higher under alfalfa, MLG, MLG + M, and SRG treatment, respectively, than that under corn treatment.

Land use conversions significantly (F = 8.76, p = 0.001) changed the AN contents (Figure 4B). The highest AN content was found under corn treatment in the 0–50 cm depth. In addition, the AN contents under corn treatment in the 20–30 cm and 40–50 cm depth were significantly higher than those under all the revegetation land except the alfalfa treatment in the 20–30 cm depth. The average AN contents in the 0–50 cm depth were 15% (6.3 mg kg⁻¹), 19% (8.0 mg kg⁻¹), 34% (14.9 mg kg⁻¹), and 27% (11.8 mg kg⁻¹) lower under alfalfa, MLG, MLG + M, and SRG treatment, respectively, than under corn treatment.



Figure 4. Mean values of labile oxidizable carbon (LOC) (**A**) and available nitrogen (AN) (**B**) under different land uses. The bars represent standard errors. Values without a common letter within land use treatments differed according to the LSD test (p < 0.05). NS = not significant among different land uses. See Figure 2 for the abbreviations.

The differences of AP and AK contents among the soil depths in the 0–50 cm depth were very narrow except the 0–10 cm depth (Figure 5). Compared with the land uses of MLG, MLG + M, and SRG, land use of corn had a higher AP content at the 0–10 cm depth. However, land use treatments did not change the AP contents at the 10–50 cm depth (Figure 5A). The average AP contents in the 0–50 cm depth under the land uses of corn, alfalfa, MLG, MLG + M, and SRG were 4.1, 3.8, 3.4, 3.1, and 3.4 mg

 kg^{-1} , respectively. The highest AK contents were all found under the MLG treatment in the 0–50 cm depth (Figure 5B). However, significant differences were only found between MLG and corn treatment in the 20–40 cm depth and between MLG and alfalfa treatment in the 30–40 cm depth. The average AK contents in the 0–50 cm depth under corn, alfalfa, MLG, MLG + M, and SRG treatment were 102.9, 112.2, 137.5, 108.7, and 125.8 mg kg⁻¹, respectively.



Figure 5. Mean values of AP (**A**) and AK (**B**) under different land uses. AP represents available phosphorus. AK represents available potassium. The bars represent standard errors. NS = not significant among different land uses.

3.3. Changes in SR, GMSN, and SSAN

The SR of LOC, AN, and AK in the 0–10/10–20 cm and in the 0–10/20–30 cm (Figure 6) were not affected by the different land uses. Land uses of corn and alfalfa had remarkably higher SR values of AP in the 0–10/20–30 cm depth than the land uses of MLG, MLG + M, and SRG. However, the differences of the SR value for AP in the 0–10/10–20 cm depth were not significant among the five treatments. All the SR values of LOC, AN, AP, and AK in the 0–10/10–20 cm depth were all <2 except the values of AN under SRG treatment, AP under corn and alfalfa treatment, and AK under MLG treatment. However, the SR values of LOC, AN, AP, and AK in the 0–10/20–30 cm depth were all >2, except the values of AN under corn treatment and AP under MLG and MLG + M treatment.



Figure 6. Changes in the stratification ratio (SR) of 0-10/10-20 cm (**A**) and 0-10/20-30 cm (**B**) under different land uses. The bars represent standard errors. Values without a common letter within land use treatments differed according to the LSD test (p < 0.05). NS = not significant among different land uses.

Values of GMSN in the 0–50 cm depth and SSAN in the 10–50 cm depth were not influenced by the changes of land use (Figure 7). The highest GMSN value was found under alfalfa in 0–20 cm depth, while it was highest under MLG treatment in the 20–50 cm depth (Figure 7A). The average GMSN values in the 0–50 cm depth under corn, alfalfa, MLG, MLG + M, and SRG treatment were 13.1, 13.2, 13.3, 11.2, and 12.7, respectively. The SSAN values under corn and alfalfa treatment in the 0–10 cm

depth were markedly greater than the land use of MLG + M (Figure 7B). The average SSAN values in the 0–50 cm depth under corn, alfalfa, MLG, MLG + M, and SRG treatment were 9.5, 9.0, 9.7, 8.6, and 9.1, respectively.



Figure 7. Changes of GMSN (**A**) and SSAN (**B**) under different land uses. GMSN represent geometric means of LOC and available nutrients. SSAN represent sum scores of LOC and available nutrients. The bars represent standard errors. Values without a common letter within land use treatments differed according to the LSD test (p < 0.05). NS = not significant among different land uses.

4. Discussion

The low content of soil organic carbon can limit microbial biomass and activity, nutrient cycling, soil structure formation, etc., and therefore indirectly limit plant growth [22]. Increasing the content of soil organic carbon and soil available nutrients is the common approach to improve soil productivity and agricultural sustainability. Land use changes could significantly alter the inputs and outputs of soil organic matter, thus resulting in the variations in the content and circulation of soil labile carbon and soil nutrients [32,33]. The present study showed that conversion of cropland to revegetation land increased the LOC content in the 0–50 cm depth (Figure 4A). Moreover, the increase of LOC content mainly occurred in the surface soil. Compared with the corn treatment, the LOC contents under revegetation land were 33%, 33%, and 20% higher in the 0 to 10, 10 to 20, and 20 to 30 cm depths, respectively. However, there were no significant differences for LOC contents under revegetation treatments in the 30 to 40 and 40 to 50 cm depths. The higher LOC contents under revegetation land in surface soil (0–30 cm) were probably associated with the accumulation of above-

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and below-ground biomass incorporated into the surface soils [34,35]. In addition, revegetation on the cropland could reduce the loss of LOC in fine soil fractions caused by rain and wind erosion, thus increasing the LOC content [22,33]. Soil texture can affect the soil aggregation processes and, therefore, influences the soil capacity to sequester organic carbon [36]. Tian et al. [37] in the alpine grassland on the Tibetan Plateau reported that soil organic carbon and total nitrogen stocks positively correlated with clay content and silt content, while they negatively related to sand content. Land use changes can indirectly affect soil texture through the redistribution of soil by erosional processes or tillage. Revegetation on the cropland in this study could reduce the soil erosion by increasing the vegetation cover and decreasing soil disturbance, thus indirectly affecting the content of LOC and soil available nutrients.

Compared with corn treatment, revegetation did not increase the AN contents in the study area, and the corn treatment had the highest AN content in the 0 to 50 cm depth (Figure 4B). This might be due to the fertilization management in corn treatment, which applied approximately 74 kg N ha⁻¹ every year. Another reason for the higher AN contents under corn treatment could partially result from the short term revegetation under the revegetation land, which had limited effects on the accumulation of AN and other soil nutrients. Besides, no significant differences among the forage and grasslands also suggested negligible effects of short term revegetation on the AN contents in the study area. The higher AN contents under the corn treatment were similar to the results by Zhang et al. [38] in Guizhou, China, who also reported that the AN content under fertilized and plowed cropland was higher than that under grassland and forestland. Soil AP and AK contents were not significantly different under most land use treatments (Figure 5), indicating that the short term land use treatments did not change the AP and AK contents in northeastern China. Similar to the changes in AN content, the negligible effects of short term revegetation on soil AP and AK may be the primary reason for the narrow changes in AP and AK content under the five land use treatments. These results were in agreement with the findings of Zhao et al. [39] in another region of Songnen plain, who also found that the changes in AP and AK content under cropland and grassland were very limited.

The SR of soil parameters was used as an indicator of the dynamics soil quality, and it could detect the management induced changes in the soil profiles of agricultural systems [15]. The increase in SR values of LOC and soil nutrient indicated the improvement of soil quality due to the accumulation of LOC and soil nutrients in the surface soil [30,40]. Land use treatments had no significant effects on the SR values of LOC, AN, AP, and AK contents at depths of 0-10/10-20 cm and 0-10/20-30 cm except the SR of AP at the depth of 0-10/20-30 cm, suggesting that short term revegetation had limited effects on the soil available nutrients in northeastern China. Studies in Columbia and Georgia showed that the SR values of SOC and total nitrogen were >2 under no tillage management, indicting an improvement of soil quality [29]. Peregrina et al. [41], Corral-Fernandez et al. [42], Francaviglia et al. [40], and Deng et al. [15] confirmed this finding, arguing that a high SR value (usually >2) indicated a better soil quality and contribution to agriculture sustainability. Our results showed that the SR values of LOC and soil available nutrients at the depth of 0-10/10-20 cm were mostly <2, and the SR values at the depth of 0-10/20-30 cm were mostly >2, indicating that soils under the same land use treatments had different soil quality. Similarly, the study by Deng et al. [15] also found that the SR values at the depth of 0-20/20-40 cm were generally higher than those at the depth of 0–5/10–20 cm found by Wang et al. [43] in the same region of the Loess Plateau. The SR values of LOC and soil nutrients in different soil depths in response to land use treatment were not consistent, suggesting that standard SR values of soil properties are needed in future studies to make the comparisons of soil quality under different management practices and different regions easier. Therefore, the SR values at the depth of 0-10/10-20 cm may be well suitable as a standard for evaluating significant changes in surface soils induced by management practices.

In this study, three soil available nutrients including AN, AP, and AK contents and LOC were evaluated, but similar trends were not found (Figures 4 and 5). In fact, it is difficult to draw meaningful conclusions about soil quality changes when univariate indicators are used to analyze datasets involving

many soil properties and reveal the changes within the soil environment [44]. The two indices of GMSN and SSAN were able to overcome the above weaknesses, and they were used as useful indictors of soil quality in other studies [22,26,31]. However, the results in this study showed no significant differences of GMSN and SSAN among the five land use treatments at each soil depth except SSAN under the MLG + M treatment in the 0 to 10 cm depth (Figure 7), indicating that short term conversions of cropland to revegetation land had limited demonstrable influences on the soil available nutrients and LOC in the salt affected region of Songnen plain. The inconclusive results suggested that a long term study is needed to examine the responses of the LOC and soil available nutrients to long term revegetation in northeastern China.

5. Conclusions

The present results showed that revegetation on the cropland enhanced the LOC contents and decreased the AN contents in the 0–50 cm depth compared with the Corn treatment, and the changes in AP and AK contents were very limited after the land use conversions. The SR values in different soil depths in response to land uses were not consistent, suggesting that standard SR values of soil properties are needed in the future studies and that the SR values at the depth of 0–10:10–20 may be suitable as the standard considering the notable changes in surface soils induced by management practices. However, more studies are needed to examine if the SR value at the 0–10:10–20 cm is suitable in other managements or regions. The values of SR, GMSA, and SSAN were not affected by the land use changes, indicating short term revegetation on the cropland had limited influences on the changes in soil nutrients and LOC in northeastern China. Compared with AG treatment, values of GMSA and SSAN were slightly lower than other land use treatments. These results were mainly due to the very short term (five years) revegetation because revegetation may need more time to be incorporated. Therefore, more studies are needed to assess the long term (more than 10 years) effects of revegetation on soil properties in the Songnen grassland in the future. Although changes in soil available nutrients were given in this study, variations in soil microbial populations, which are more sensitive to changes in land uses than soil nutrients, were not mentioned. The influences of short term revegetation on soil quality need to be comprehensively assessed. In addition, we recommend that farmers in Northeast China should use revegetation to rehab grassland in areas with poor quality soils in the long run.

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