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Variation of Nutrients and Selected Soil Properties in Reclaimed Soil of Different Ages at a Coal-mining Subsidence Area on the Loess Plateau, China

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Abstract

Reclaiming the subsidence area that results from coal-mining could alleviate the shortage of arable land in China. This study examined the effects of fertilization and reclamation age on soil nutrients and other properties in the 0–100 cm profile at an underground coal mine site on the Loess Plateau of China. Soil samples were collected representing three successive reclamation ages (1, 3 and 7 years) and an undisturbed reference farmland soil. Treatments included chemical fertilizers only (CF), organic fertilizers only (OF), a combination of 50% chemical fertilizers and 50% organic fertilizers (COF) and a no-fertilizer control (CK). The study showed that Soil pH and electrical conductivity ranged from 8.03 to 8.43 and 0.11 to 0.25 dS/m, respectively, and no significant differences were found due to any soil depths, fertilizer treatments, reclamation ages. Nutrient contents tended to increase over time as a whole. Additionally, applying manure had a better effect on increasing, available phosphorus and potassium, organic matter and cation exchange capacity in the 0-20 cm soil layer (topsoil) than did applying only chemical fertilizer or a combination of chemical and organic fertilizer; however, no obvious change was found in the properties of the 20–100 cm soil layers for any treatments. Given the above, it is feasible for coal-mining subsidence areas to be reclaimed and returned to farmland on the Loess Plateau of China.

Keywords: soil fertility, reclaimed soil, coal-mining subsidence area, fertilizer, reclamation age

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INTRODUCTION

China is the world's biggest producer and consumer of coal. The excessive exploitation of coal resources inevitably caused severe negative impacts on soil quality and crop productivity in addition to a series of environmental issues such as the removal of vegetation cover, soil erosion and depletion of groundwater resources. Approximately 96% of China's coal mines are underground, the reclamation techniques for underground coal mining are comprised of two types: "filling" reclamation using coal ash, gangue, or other material, and "non-filling" reclamation without using such materials. Because of the abundant soil resources, two "non-filling" reclamation methods are used on the Loess Plateau, and these are TSR (in which topsoil is stripped and replaced immediately onto a rehabilitation area) and SHM (in which the soil horizon is mixed during soil handling). However, soil profile reconstruction has resulted in the degradation of soil physical properties (such as bulk density), pH, nutrient contents and microbial diversity. Therefore, exploring suitable ways to improve soil structure and fertility of reclaimed areas has become crucial.

Biological reclamation is an effective method for accelerating soil formation processes. The selection of appropriate vegetation and soil amendments is indispensable in stabilizing a bare area and remediating adverse physical and chemical properties. Planting appropriate tree species could augment organic matter accumulation, nutrient cycling, and enzyme activity (Mukhopadhyay et al. 2016, Zhen et al. 2015). In midwestern North America, crested wheatgrass *(Agropyron Cristatum* (L.) Gaertn) is considered an acceptable species for revegetation and reclamation of disturbed lands due to the plant's ease of establishment, high forage production, and ability to rapidly stabilize barren soils (Ambrose and Wilson 2003, Gasch et al. 2016, Willms et al. 2005). One of the most significant restrictive factors for restoring mine areas is the low soil

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organic matter content. The combined addition of organic wastes and biochar have shown great potential for increasing and improving organic carbon fractions in mine soils (Rodríguez-Vila et al. 2016).

Most studies about reclaimed mine land have been conducted to analyze heavy metal pollution and water pollution, or to examine soil fertility focusing mainly on the effects of vegetation (such as tree or shrub) on soil physicochemical and biological properties; these studies have mainly concentrated on the surface soil layer (Wick et al. 2016, Yuan et al. 2016). Nevertheless, research on disturbed land to be reclaimed for arable agricultural production is quite scarce. Moreover, the recovery of reclaimed soil productivity depends on local climate (in particular, precipitation and evaporation), soil amendment methods, and vegetation types.

This study was conducted at a long-term experimental base in Shanxi Lu'an coal mine in the Loess Plateau. The objectives of the study were to: (1) analyze the vertical distributions of nutrients and selected soil properties in the 1-m soil profile and the change characteristics with time during the reclamation process, and (2) measure the effects of organic manure and chemical fertilizers on reclaimed soil fertility. The study results should provide a theoretical basis for rapidly improving soil fertility in reclaimed land.

MATERIALS AND METHODS

Site Description

The study area is located at the Luojianggou underground mine (E 113°01′13″, N 36°28′11″) affiliated with Shanxi Lu'an Group, in northern China. This area is categorized as a semi-arid region, with an average annual precipitation of 500 mm, the average annual evaporation is approximately 1100 mm, and the mean daily temperature is 8–10 °C. The Luojianggou coal mine began collapsing in the 1970s, but became stable near the year 2000. The rehabilitation was initiated mainly using the TSR methods in 2009. According to natural terrain conditions, topsoil was first removed, and higher ground areas were excavated to fill the low-lying areas. Finally, stored soil was spread on top of the overburden to a depth of 30 cm. The whole reconstructed soil depth exceeded 100 cm. Since 2009, Spring maize (*Zea mays* L.), as the typical local crop, has been annually planted to improve and utilize the reclaimed soil from May to October, and all the corn straw was crushed and returned to fields by corn combine while harvesting. The fallow period lasts from November to April the following year. At present, there are 1-year reclamation soil rehabilitated in 2015, 3-years reclamation soil rehabilitated in 2013, and 7-years reclamation soil rehabilitated in 2009. The soil is calcareous cinnamon soil in type and silt loam in texture.

Soil Sampling and Analysis

Three different reclamation-year sample plots (1 year, 3 years, and 7 years) and one undisturbed sample plot were chosen. On these, four treatments were conducted to assess the soil fertility during the reclamation process. The treatments were denoted as CK (no fertilizers applied); CF (chemical fertilizer applied); OF (organic fertilizer applied); and COF (50% chemical fertilizer and 50% organic fertilizer applied), and each treatment had three replications. The organic fertilizer was rotted chicken manure (N 1.6%, P_2O_5 1.5 %, and K_2O 0.8%), and applied at the rate 1200 kg/ha for OF treatment. The fertilizer application rate of CF and COF treatments were calculated according to the amounts of nutrients in OF treatment, so the CF, OF and COF treatments had equal amounts of nutrients, i.e. N at 204 kg/ha, P_2O_5 at 180 kg/ha, and K_2O at 96 kg/ha. Fertilization was finished by fertilizing and sowing machine, and the application depth was around 20 cm.

Soil samples for analyzing the soil nutrient change properties were taken from 100-cm deep soil profiles. Three samples were collected in each plot (May 2016) at 20-cm intervals (0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm, and 80–100 cm), and samples at each interval were composited into five mixed samples per plot. The mixed samples were air-dried, screened through both a 2-mm sieve and a 0.1-mm sieve and then homogenized prior to analysis.

Soil pH (soil: water 1:2.5) was measured using an acidometer. The electrical conductivity (EC) (soil: water 1:5) was measured using a conductivity meter. The cation exchange capacity (CEC) was determined by 1 mol/L pH 8.2 NaOAc extraction followed by flame photometry. Total organic matter was determined by oxidizing a soil solution with $K_2Cr_2O_7$ and concentrated H_2SO_4, and then titrating the solution with $FeSO_4$.The available potassium was extracted using 1 mol/L NH_4OAc and measured by flame emission spectrometry. The available P (Olsen-P) was extracted from a 1:10 ratio of air-dried soil to 0.5 mol L^{-1} sodium bicarbonate ($NaHCO_3$) and analyzed using the "Mo-Sb-Ascorbic acid" colorimetry method. As described by Zhao et al., nitrate N (NO_3^--N) and ammonium N (NH_4^+-N) were extracted from a 1:10 ratio of fresh soil to 1.0 mol L^{-1} potassium chloride (KCl) and analyzed

Table 1. Variability of soil pH and electrical conductivity (EC) under different fertilizer treatments, soil depths, and reclamation ages

Reclamation age	**Soil depth (cm)**	**Soil pH**				**Soil EC （dS/m）**			
		CK	**CF**	**OF**	**COF**	**CK**	**CF**	**OF**	**COF**
1 yr	0-20	8.21a a	8.18a a	8.24a a	8.32a c	0.15a a	0.17a a	0.25a a	0.16a b
	20-40	8.27a a	8.19a a	8.30a a	8.34a c	0.13b a	0.19a a	0.21a ab	0.20a ab
	40-60	8.37a a	8.24a a	8.31a a	8.43a a	0.12b a	0.18ab a	0.19a b	0.19a ab
	60-80	8.32a a	8.26a a	8.35a a	8.41a ab	0.12b a	0.16ab a	0.19a b	0.21a a
	80-100	8.22a a	8.24a a	8.35a a	8.36a bc	0.14b a	0.15ab a	0.18a b	0.17ab ab
3 yrs	0-20	8.35a a	8.26ab a	8.17b a	8.24ab a	0.11a a	0.12a a	0.19a a	0.18a a
	20-40	8.39a a	8.25a a	8.23a a	8.20a a	0.11a a	0.15a a	0.13a a	0.18a a
	40-60	8.36a a	8.21a a	8.27a a	8.16a a	0.13a a	0.18a a	0.13a a	0.17a a
	60-80	8.30a a	8.23a a	8.22a a	8.11a a	0.15a a	0.17a a	0.16a a	0.19a a
	80-100	8.23a a	8.26a a	8.22a a	8.10a a	0.16a a	0.17a a	0.16a a	0.18a a
7 yrs	0-20	8.21a b	8.12ab a	8.03b c	8.15a b	0.13a a	0.15a a	0.13a a	0.11a a
	20-40	8.29a ab	8.11b a	8.12b b	8.18b a	0.12a a	0.14a a	0.13a a	0.12a a
	40-60	8.34a a	8.26a a	8.15a b	8.17a a	0.11a a	0.14a a	0.13a a	0.12a a
	60-80	8.35a a	8.24b a	8.17b b	8.20b a	0.13a a	0.16a a	0.13a a	0.12a a
	80-100	8.32a a	8.26a a	8.29a a	8.27a a	0.16a a	0.15a a	0.14a a	0.13a a
Undisturbed Field	0-20	—	8.16_b	—	—	—	0.15_a	—	—
	20-40		8.24_a				0.13_a		
	40-60		8.30_a				0.13_a		
	60-80		8.27_a				0.14_a		
	80-100		8.28_a				0.17_a		

[a] Different superscript letter in the same row indicate significant differences in fertilizer treatments at $P < 0.05$;

[b] Different subscript letters in the same column indicate significant differences in soil depth at $P < 0.05$;

[c] Fertilizer treatments are CK (no fertilizer); CF (chemical fertilizer); OF (organic fertilizer); and COF (50% chemical fertilizer and 50% organic fertilizer). The same as below.

using a continuous flow analyzer (AA3 Segmented Flow Analyser, SEAL, Norderstedt, Germany) (Zhao et al. 2016).

Statistical Analysis

All data and graphics for the experiment were carried out in Microsoft Excel 2003®. Analysis of variance (ANOVA) was conducted, and the means were compared using the Tukey test in the SPSS® 13.0 software (SPSS, Inc. Chicago, IL, USA). Significant effects were reported at the 0.05 level.

RESULTS AND DISCUSSION

Variability of Soil pH and EC

Soil pH and EC greatly influence crop growth and soil chemical properties, and are vital indicators for evaluating reclaimed soil. Soil pH and EC ranged from 8.03 to 8.43 and 0.11 to 0.25 dS m^{-1} across all soil depths, fertilizer treatments, reclamation age and the undisturbed soil, respectively (**Table 1**), there were no significant differences in soil pH or EC. However, other studies have demonstrated that reclaimed soil has a significantly higher pH than undisturbed soil. This pH increase may be due to backfilling of subsurface horizons using spoil material, thereby increasing the pH value of reclaimed soil at a depth of 20–30 cm. Furthermore, the salts migrating upward from overburden materials directly below the topsoil influence soil pH of the topsoil over time (Shrestha and Lal 2011). In comparison, the reclaimed soil depth at the Luojianggou mine in the Loess Plateau exceeds 100 cm, and the pH does not easily change owing to the soil buffering capacity. The absence of a significant change in soil EC was due to the thick layer of raw soil used as cover material, for which the EC value was very low. Similarly, Wang et al. reported that the EC of reclaimed soil ranged from 0.11 to 0.21 dS/m at Pingshuo opencast coal mine located on the east Loess Plateau (Wang et al. 2015). By an agricultural standard, soil having an EC of 4 dS/m or greater is considered saline (Shrivastava and Kumar 2015). The EC values in all soils of the present study were less than 0.25 dS/m, which were well within the range for optimum plant growth. A similar finding that long-term (> 10 years) reclamation practices did not appear to have influenced pH and EC was also observed by Anderson et al. (2008).

Variability of NO_3^--N and NH_4^+-N

This study showed that the NO_3^--N content significantly increased in the 0–100 cm soil layers in response to fertilization treatments and reclamation age (**Fig. 1**). There was also a substantial increase in the amount of residual NO_3^--N in the 20–60 cm layers under the CF and COF treatments and in undisturbed soil. The findings suggest that the N application rate that was used might be excessive to the requirements of the crop in the reclaimed ecosystem, and exhibited spatial stratification. The NO_3^--N content in the 20–60

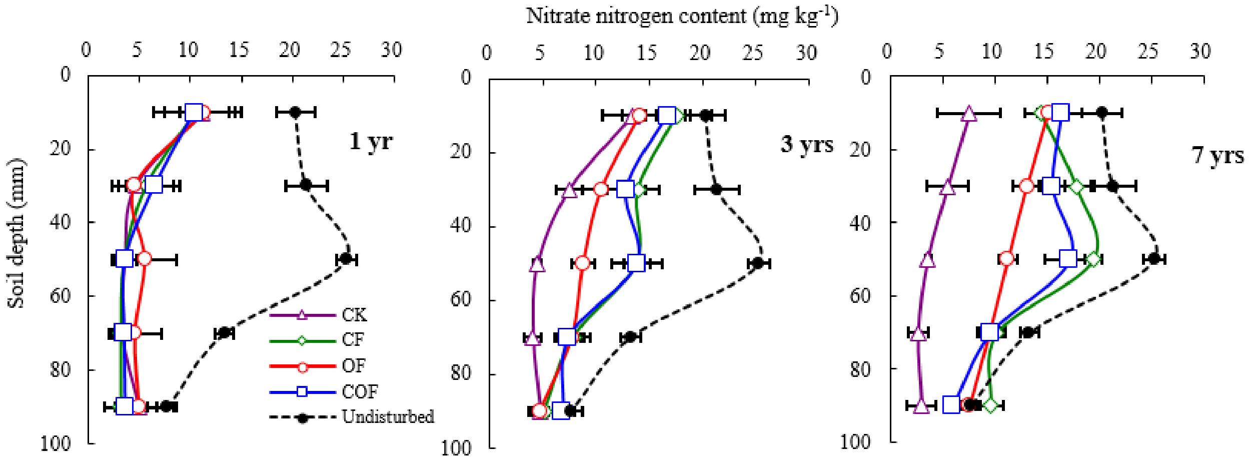

Fig. 1. Variability of nitrate nitrogen as affected by different fertilizer treatments and reclamation age

cm layers of undisturbed soil was between 20 and 25 mg/kg, and presented a risk of N leaching. Although the annual precipitation is slightly less in Loess Plateau region than elsewhere, approximately 60% of the annual rainfall is concentrated in July, August and September. Therefore, the residual NO_3^--N in the 20–60 cm layers has a potential risk of leaching.

The NO_3^--N content in 7-years reclaimed soil under the COF treatment was significantly greater than under the OF treatment ($P < 0.05$) (**Fig. 1**). Except for NO_3^--N from mineral fertilizer, the combination of mineral fertilizer and manure better accelerates N mineralization than manure fertilizer alone (Zhang et al. 2009). NH_4^+-N is the first inorganic N form to be released from the decomposition of organic matter. Subsequently, NH_4^+-N in soil solution will quickly be converted to NO_3^-N (King and Torbert 2007). Durani et al. (2016) reported that inorganic fertilizer plus farmyard manure considerably increased the concentration of soil NO_3^--N beyond the increase due to fertilizers alone. On the contrary, Basso and Ritchie (2005) reported that manure applications yielded higher soil NO_3^--N than inorganic fertilizer. Similarly, Poudel et al. (2002) found that continuous organic fertilizer additions resulted in larger pools of potentially mineralizable N than did a conventional fertilizer system in which only mineral N was used. However, Zhao et al. (2011) reported that under normal conditions adding manure or straw to inorganic fertilizer on an equal total N basis resulted in contents and accumulation of NO_3^--N in the soil profile that were similar to those resulting from inorganic fertilizer alone. Consequently, the accumulation of NO_3^--N is associated with specific soil environments.

In this study, soil NH_4^+-N content was lower than NO_3^--N content (**Fig. 2**), which is consistent with findings of Durani et al. (2016) Soil NH_4^+-N content greatly depends on soil moisture and soil aeration conditions. Furthermore, NH_4^+-N is easily nitrified to NO_3^--N in calcareous soil with high pH (Iqbal et al. 2012). No significant difference was observed in NH_4^+-N contents among any treatments on 1-year, 3-years or 7-years reclaimed soil. However, the NH_4^+-N content of the 0–60 cm layer for all treatments increased as reclaimed years increased. The elevated level of NH_4^+-N was probably caused by fertilizer accumulation and returned maize straw. In regard to the undisturbed soil amended with long-term mineral fertilizer applications at rates used by local farmers, soil NH_4^+-N content in topsoil was higher than that of other soil layers. This pattern was probably attributable to poor mobility of NH_4^+-N adsorbed by negatively charged soil colloids.

Variability of Available P and Available K

Soil P has been identified as another limiting factor in restoring the fertility of newly reclaimed land. The deficiency of available P is serious in calcareous soil with a high pH in northwest China. This study also found that the available P in newly reclaimed (i.e., 1-year age) soil was low (**Table 2**), but increased gradually as reclamation time increased due to repeated fertilization.

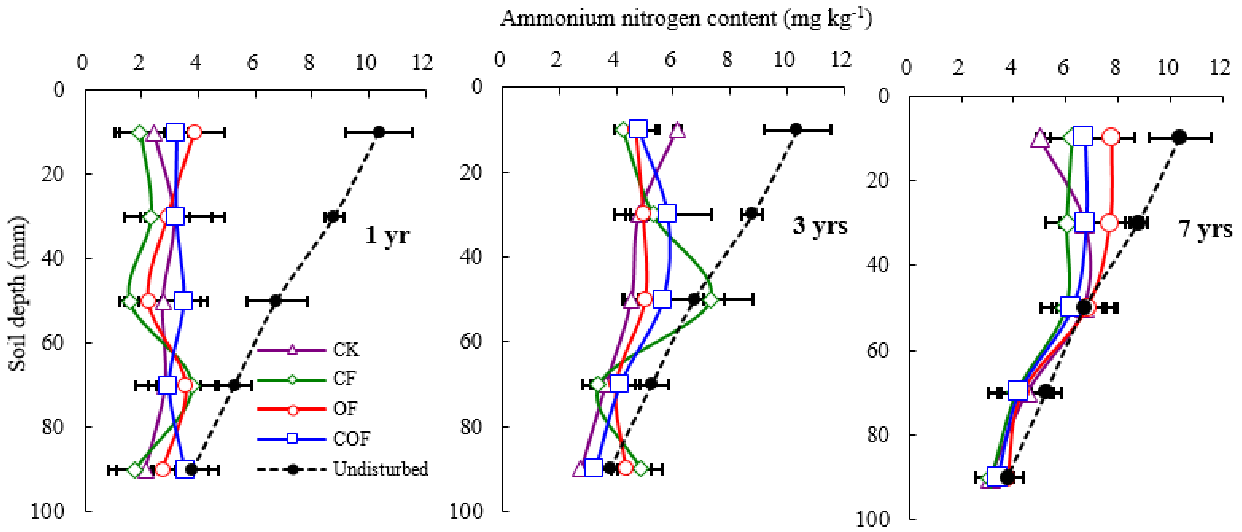

Fig. 2. Variability of ammonium nitrogen as affected by different fertilizer treatments and reclamation age

Table 2. Variability of available soil P and available soil K under different fertilizer treatments, soil depths, and reclamation ages

Reclamation age	**Soil depth (cm)**	**Available P (mg/kg)**				**Available K (mg/kg)**			
		CK	**CF**	**OF**	**COF**	**CK**	**CF**	**OF**	**COF**
1 yr	0-20	3.86b a	3.04ab a	5.75a a	4.91ab a	113.77b a	111.02ba a	143.79a a	123.76ab a
	20-40	2.85a a	3.48a a	5.05a a	4.37a a	101.60b ab	103.44a a	115.27a b	107.38a b
	40-60	3.10b a	2.79b a	5.89a a	3.80b a	90.10a b	105.56a ab	98.28a bc	91.00a c
	60-80	2.98b a	3.36ab a	4.51a a	4.18ab a	91.90a b	91.91a bc	91.91a c	86.45a c
	80-100	4.12ab a	3.36b a	4.94a a	4.24ab a	90.10a b	91.00a c	81.90a c	82.81a c
3 yrs	0-20	5.49b a	6.77ab a	8.44a a	7.59ab a	123.50c a	136.67b a	160.67a a	141.33b a
	20-40	4.05a a	5.56a a	6.11a ab	5.83a a	107.33a b	105.33a b	112.67a b	101.50a b
	40-60	4.50a a	5.48a a	6.23a ab	3.36a b	101.50a b	95.50a bc	97.83a c	102.67a b
	60-80	4.94a a	6.52a a	4.26a ab	3.23a b	87.50a c	86.17a cd	95.33a c	86.33a c
	80-100	3.36a a	4.17a a	4.45a a	3.48a a	79.33a d	75.83a d	86.33a c	87.50a c
7 yrs	0-20	7.08c a	9.43b a	12.0a a	11.8ab a	136.83c a	155.33bc a	182.50a a	171.50ab a
	20-40	6.27a a	7.29a b	7.48a b	6.85a b	114.83ab b	102.67b b	114.33ab b	124.00a b
	40-60	6.27a a	7.60a ab	5.42a b	5.80a b	99.00b b	86.33b c	95.50b bc	114.33a bc
	60-80	4.65a a	6.03a b	6.82a b	5.19a b	103.83a b	93.83a bc	90.83a c	102.50a cd
	80-100	5.59a a	7.37a ab	6.11a b	4.91a b	99.33a b	98.00a bc	78.17b c	96.67a d
Undisturbed Field	0-20	—	16.16$_{a}$	—	—	—	200.23$_{a}$	—	—
	20-40		10.14$_{b}$				170.56$_{b}$		
	40-60		8.30$_{c}$				112.14$_{c}$		
	60-80		6.67$_{c}$				109.17$_{c}$		
	80-100		7.13$_{c}$				100.45$_{c}$		

Poultry manure has been shown to greatly increase available P in topsoil compared to other fertilization treatments due to the high concentration of P in the manure; furthermore, because this manure contains consistently more inorganic P than organic P, most of the inorganic P is easily released during rainfall (Sharpley and Moyer 2000). The above mentioned results are consistent with Edmeades's (2003) findings that excessive accumulation of some nutrients (particularly P) could arise from the long-term use of manures. Also, manure with carboxyl and phenolic hydroxyl groups could shift the form of soil P, which could enhance P solubility. In China, opencast mining degrades 2 to 11 times more land than underground mining, and land disturbed from opencast mining is generally reclaimed by planting trees, shrubs, or herbs that require minimal fertilization. Accordingly, citing the Pingshuo opencast coal mine in China as an example, the available P in reclaimed topsoil has not presented any notable change in regard to reclamation time due to the dearth of fertilization (Li 2006, Zhao et al. 2013). In the present study, the increase of available P in the CK treatment over time meant that available P in reclaimed soil might still derive from mineral weathering, P desorption or organic P mineralization and fertilization through the process of soil development.

Table 3. Variability of soil organic matter and cation exchange capacity (CEC) under different fertilizer treatments, soil depths, and reclamation ages

Reclamation age	Soil depth (cm)	Organic matter (g/kg)				CEC (cmol/kg)			
		CK	CF	OF	COF	CK	CF	OF	COF
1 yr	0-20	9.61a a	9.74a a	10.33a a	10.06a a	19.92a a	19.76ba a	20.07a a	20.16a a
	20-40	9.17a a	10.01a a	8.59a ab	7.67a ab	20.05a a	20.54a a	21.22a a	20.39a a
	40-60	9.24a a	9.36a a	7.78a ab	8.11a ab	20.21ab a	18.41b a	21.10a a	19.6ab a
	60-80	8.98a a	7.89ab b	8.50ab b	6.86b ab	18.95a a	19.75a a	18.86a a	20.04a a
	80-100	7.51a a	7.81a b	6.95a b	7.34a b	16.95a a	18.86a a	17.80a a	19.68a a
3 yrs	0-20	9.74c a	11.82bc a	14.48a a	12.68ab a	22.78b a	24.90ab a	25.94a a	24.54ab a
	20-40	9.44a a	9.67a ab	9.75a b	9.70a b	20.87a a	22.47a ab	22.54a b	21.44a ab
	40-60	9.67a a	9.75a ab	8.26b b	9.75a b	21.34a a	20.68a bc	19.08a c	21.47a ab
	60-80	9.21a a	9.36a ab	9.55a b	8.03a bc	20.75a a	21.09a c	18.84a c	21.70a ab
	80-100	7.97a a	8.95a b	8.98a b	8.74a c	19.79a a	19.61a c	19.50a c	19.37a b
7 yrs	0-20	10.92c a	12.94bc a	16.54a a	14.17b a	24.31c a	27.75b a	33.45a a	29.01b a
	20-40	9.81a ab	9.67a ab	11.74a b	10.29a b	22.20b ab	25.97ab ab	27.34a b	26.98a ab
	40-60	7.96a c	9.21a b	9.21a bc	9.22a b	19.80a bc	23.05a ab	24.31a bc	23.61a ab
	60-80	8.58a bc	7.58a b	8.62a c	8.78a b	19.25a bc	20.87a b	21.35a c	20.91a b
	80-100	9.39a b	7.55a b	7.50a c	9.73a b	18.38b c	22.20a b	22.39a c	22.15a b
Undisturbed Field	0-20	—	15.68_{a}	—	—	—	32.17_{a}	—	—
	20-40		12.35_{b}				25.54_{b}		
	40-60		10.28_{bc}				23.63_{bc}		
	60-80		8.45_{c}				22.18_{bc}		
	80-100		9.16_{c}				20.35_{c}		

Available K occurs in relatively high levels in the Loess Plateau of China due to the local parent material and climatic characteristics during natural succession. Inputs of organic materials also cause a build-up of available soil K because manure or straw generally contains high amounts of K. The findings of the present study demonstrated that available K gradually decreased as soil depth in the 0–100 cm profile increased (**Table 2**), but available K in topsoil significantly increased over time. Hence, applying manure could further improve the soil K content compared with other treatments, as shown by Diacono and Montemurro (2010). In contrast, high levels of plant production and removal of aboveground biomass would cause available soil K to decrease in the Loess Plateau of China (Fan et al. 2005). Whether a decline actually occurs in any one field is largely dependent on management, weathering of soil minerals and whether or not straw is returned, which may make up some of the K deficit (Gosling and Shepherd 2005). Therefore, available soil K in the CK treatment of the present study also showed an upward trend with reclamation age.

Variability of Organic Matter and CEC

The formation and accumulation of OM are the major processes that determine the direction and speed of initial pedogenesis. The study of OM in reclaimed mined lands has formed the foundation for further research on carbon sequestration in terrestrial C cycling (Das and Maiti 2016). In the present study, the OM content in topsoil gradually increased as reclamation age increased (**Table 3**); however, manure application also played a prominent role in the increase of soil OM contents in topsoil, the OM content under OF treatment with 7 years reclamation reached 16.5 g kg-1, which was 17%, 28% and 52% higher than those of COF, CF and CK, respectively ($P<0.05$). Other similar studies indicated that the combined addition of organic wastes and biochar had a greater potential for both increasing and improving organic carbon fractions in mine soils than did application of either material separately (Asensio et al. 2014, Rodríguez-Vila et al. 2016). In the 7-years reclamation soil of the present study, the OM content of the surface layer was significantly higher than the deeper layers, which indicated that topsoil was used as farming land. Sequentially, decomposition and transition of the organic solids from manure, aboveground vegetation products and plant roots occurred mainly in the topsoil.

The CEC represents the capacity of soil to store and supply nutrients, a property that is considered to be an important indicator of soil fertility for newly reclaimed soil in particular. The CEC has been shown to depend on soil texture, organic matter components and their interaction (Yao et al. 2011). In the present study, CEC varied from 17 to 21 cmol kg^{-1}, and no significant difference was found in between soil depth and fertilization treatments for 1 year reclaimed soils. (**Table 3**), which agrees with the findings of Munawar et al. (2011). In contrast, there was a statistically significant increase in CEC of the 0–20 cm soil layer with reclamation age in the OF treatment, and followed a similar trend as soil OM. This result might be explained by the fact that the OF treatment contributed more to CEC potential than other fertilization treatments in topsoil. The present study also found that the CEC value was mostly greater than 20 cmol kg^{-1} in the 0–100 cm soil profile due to the thick loess layer. Additionally, CEC values decreased as soil depth increased, which might be explained by the decrease of OM or clay content as soil depth increases (Ellis and Atherton 2003).

CONCLUSION

It is feasible for coal-mining subsidence areas to be reclaimed and returned to farmland on the Loess Plateau of China, so as to restore arable land resources and improve environmental quality. Application of fertilizers can increase the nutrient content in reclaimed topsoil with time. Applying only manure has a better effect on increasing available P and K, OM and CEC in topsoil than applying only chemical fertilizer or a combination of chemical fertilizers and organic manure. The values were close to those in undisturbed soil and were 79% (available P), 33% (available K), 51% (OM) and 38% (CEC) higher than those in the CK treatment after 7 years of reclamation. However, no obvious change was found in the 20–100 cm soil layers for any treatments. A substantial NO_3^--N residual was found in the 20–60 cm layers under the CF and COF treatments for both the 7-years soil and the undisturbed soil, which suggested that the N application rates used might exceed crop requirements in the reclaimed ecosystem creating a potential risk of N leaching. There were no significant differences in soil pH and EC across any soil depths, fertilizer treatments, reclamation ages or the undisturbed soil in this study because the loess was backfilled and covered with soil material that had a high pH and low EC. In general, the combination of reasonable organic fertilization and return of straw to the soil could effectively improve reclaimed soil fertility. These management practices also could further achieve carbon sequestration in reclaimed coalmines, an outcome that is consistent with recent Chinese Ministry of Agriculture policies regarding the reduction of applied amounts of chemical fertilizers and pesticides.

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