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CHANGES IN SOIL FACTORS AT EARLY STAGE OF SPONTANEOUS HERBAL RECOVERY IN A COAL GANGUE YARD

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Key words: Spontaneous herbal recovery, Soil factors, Herbal biomass, Coal gangue yard, Early stage

Abstract

The five-year dynamics of a plant-soil system were monitored in the coal gangue yard at Sima Coal Mine of Lu'an Group, Shan'xi, China, from 2009 to 2013. The fixed plots of the system consisted of three platforms established in 2009, 2010, and 2011. The research method involved using spatial dynamics to represent temporal changes. Herbs maintained spontaneous recovery after reforestation. As a whole, soil moisture and desity content decreased with soil age, but soil total porosity, total organic C, organic matter, total N, available phosphorus, and available potassium increased. The soil field capacity deceased in the first three years, but increased in later years. Particulate organic C contents fluctuated. The soil was alkaline, pH values ranged from 8.50 to 8.03 and reduced with soil age. The differences in soil factors between the fifth year of herbal recovery and native soil were statistically significant. At the early stage of spontaneous herbal recovery, the biomass growth in *Leymus chinensis* (Trin.) Tzvelev was enhanced by better porosity and permeability, rich total organic C, organic matter, available phosphorus, and available potassium. The biomass accumulation of *Setaria viridis* (L.) P. Beauv. was affected significantly by permeability. During the three-year herbal recovery period, the biomass of *Puccinellia distans* (Jacq.) Parl. increased with better permeability, higher total organic C, readily oxidized organic C, total N, and available potassium, but decreased in later years. Higher particulate organic C content in the soil had an adverse effect on *Artemisia lavandulaefolia* DC.. Moreover, the biomass decrease in *Melilotus officinalis* (L.) Pall. was associated not only with the evident increase of organic matter and total organic C contents, but also with rich available phosphorous, available potassium, and total N.

Introduction

Reclamation success depends on the topsoil's physical and chemical properties in a coal gangue yard (Wei and Wang 2009). The dynamics of the soil factors were of primary importance for selecting a reasonable reclamation project. There are many studies about the changes in soil properties with mine soil age, such as analysis, assessment, and prediction of topsoil factors (Ding *et al*. 2007, Huo 2006, Hong *et al*. 2000, Xie *et al*. 2012, Li 2011, Han 2010, Wang *et al*. 2001, Wang *et al*. 2011), and about the influences of covering thickness (Liu 2010, Liu *et al*. 2010), restoration modes (Marcin and Maria 2010), and microbial properties (van der Wal *et al*. 2009, F. Gil-Sotres *et al*. 1993, Gil-Sotres *et al*. 1992) on soil performance. These studies suggested that during the recovery process, soil moisture, total porosity, total nitrogen, available phosphorus, and available potassium increase; soil density is the only exception (Wang *et al*. 2007). On the contrary, there are some reports that indicated that total soil porosity decreased and soil density gradually increased with soil age (Xie *et al*. 2012). These results were attributed to soil age and plant species. However, no studies have made a detailed examination of the topsoil's physical and chemical properties during the early stage (less than 5 years) of spontaneous herbal recovery.

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The dynamics of plant biomass not only reflect changes in the soil environment, but also present the responses of species to soil factors (Binkley and Giardin 1998, Augusto *et al*. 2002, Hall *et al*. 2004, Yang *et al*. 2012, Zhang *et al*. 2004, Zhao *et al*. 2014, Wang *et al*. 2011). Previous studies suggested that during 22 to 50 years of spontaneous recovery, above ground biomass, soil organic C, total N, available phosphorus, and available potassium contents all showed increasing trends; soil pH was the only exception (Zhang 2010, Wu *et al*. 2008). Soil factors improved in volatility (Wu *et al*. 2008). In a study of Du *et al*. (2007), positive correlations were found among soil age, soil moisture, total N, available potassium, and plant biomass; total N had the most important effects on biomass. Overall, these various study sites mainly involved desertification, abandoned land, and metal or nonmetal degraded mining sites for more than five years of recovery. The effects of soil factors on herbal biomass were still unsystematic during the first few years of spontaneous herbal recovery.

In this study, the five-year dynamics of the plant-soil system were monitored in the coal gangue yard at Sima Coal Mine of Lu'an Group, Shan'xi, China, from 2009 to 2013. The fixed plots of the system consisted of three platforms established in 2009, 2010, and 2011, respectively. The research method involved using spatial dynamics to represent temporal changes (Alvey *et al*. 2003, Jin *et al*. 2013, Li and Ma 2002, Aplet and Vitousek 1994, Pichett 1982, Elgersma 1998, Hao *et al*. 2015). Herbs maintained spontaneous recovery after reforestation. The objective of this study was to know the dynamics of soil factors and the effect of soil properties on herbal biomass, in order to not only reveal the changing characteristics of soil factors and the relationships between vegetation and soil factors with soil age, but also to provide basic data for ecological performance assessment (Hao *et al*. 2013).

Materials and Methods

The study was carried out in the coal gangue yard at Sima Coal Mine of Lu'an Group, Shan'xi, China. The climate is temperate, with a 9°C mean and a – 29°C minimum annual temperature. The frost-free period is 160 days. The depth of frozen earth ranged from 50 to 75 cm. Annual rainfall ranged from 340 to 833 mm, and the annual evaporation capacity was 1,558 mm. The original soil type was loess-like calcareous soil. The soil erosion modulus was from 500 to 1,000 $t{\cdot}(km^2{\cdot}a)^{-1}$. The original landforms were mainly ravines covered by native secondary plants, such as *Periploca sepium* Bunge., *Vitex negundo* L. var. *heterophylla* (Franch) Rehd., *Sophora davidii* (Franch.) Skeels, *Bothriochloa ischaemum* (L.) Keng, *Artemisia lavandulaefolia* DC., *Leymus chinensis* (Trin.) Tzvelev, *Melilotus officinalis* (L.) Pall., and so on.

The coal gangue yard consisted of three platforms with a stair-step shape established in 2009, 2010 and 2011, respectively. The area of each platform was 1,500 m^2 (50 m long, 30 m wide). The altitude difference between adjoining platforms was 10 m. The reclamation procedure included forming and leveling the surface of each platform. During the forming process, the thickness of each coal gangue lay was 3 m. This was covered with soil (50 cm thickness), ending with a soil thickness of 80 cm. The soil was taken from surrounding loess-like calcareous soil. *Populus tomentosa* Carr. (no canopy, 3.5 m height) were grown on each platform. The distances between the arbors and rowledges were 1.5 m and 2 m, respectively.

At the middle of the platform, one sample polt (400 m^2) consisted of 16 subsamples (area of each subsample = 25 m^2) established 1 m^2 qual rats was set at the corners of the subsample for herb samples. Moreover, six herbal samples were established in a native second community on the north of the coal gangue yard using GPS. The distance between the native second community and the coal gangue yard was about 1,000 m.

Investigations of herbal species in each sampling unit were repeated each year during the summer from 2011 to 2013. Nine typical sampling units (area of each typical sample = 1 m^2) were set either on each platform or native soil to obtain herbal biomass. Herbal biomass was measured as described by Hao *et al*. (2013).

Three typical samples of the topsoil (20 cm) were collected after clearing away the surface litter in each platform by GPS. Each typical sample consisted of three subsamples (area of each subsamples = 0.04 m^2). The subsamples were located in the typical sample point around 20 cm. The sampling was then repeated each year from 2011 to 2013 during the summer. Moreover, in the summer of 2011, three typical contrasted sampling units were established in native soil on the north of coal gangue yard. The distant was about 1,000 m between native soil and coal gangue yard. These typical samples were air-dried and used for physical and chemical analysis. Soil moisture content, field capacity, and density were determined according to Xie *et al*. (2012). Soil total porosity was calculated as described by Zhang (2006). The contents of total organic C, organic matter, readily oxidized organic C, particulate organic C, total N, available phosphorus, available potassium, and soil pH were determined as described by Su (2010).

Data analysis and drawings were completed by the Excel and SPSS 11.5 packages. The correlations and differences between variables were calculated according to Pearson's coefficient (Hao *et al*. 2013) and LSD (Liu *et al*. 2014), respectively. A probability level of 0.05 was always used as the threshold for significance.

Results and Discussion

Soil moisture content tended to decrease in the first four-year recovery and then increased in the fifth year (Fig. 1a). Although the penetration and expansion of plant roots improved topsoil structure in the first four years, the low weathering degree of coal gangue led to poor water retention. However, water retention capacity improved as the gangue's weathering degree enhanced in the fifth year which caused increase in moisture content. Our results were in agreement with Wang *et al*. (2007), who also found that water retention capacity increased after subsequent years.

The soil field capacity has distinct effects on soil structure and properties (Cai *et al*. 2009). Field capacity maintained relatively high (21.50%) levels in the fourth or fifth year compared to the first three years (Fig. 1b). This suggests that better topsoil structure and a higher degree of gangue weathering improved water-holding capacity.

Contrary to total porosity (Fig. 1d), soil density gradually decreased with soil age (Fig. 1c). Zhang *et al*. (2013) reported that total porosity increased and soil density decreased in three years recovery in a coal gangue yard. Wang *et al*. (2007) and Han (2010) also found that there is a significant negative relationship ($p < 0.01$) between soil density and soil age. This correlation was also revealed between total porosity and density in the present study. The reason for this is that better soil porosity and permeability is caused by strong and deep herbal roots and extensive litter decomposition and coal gangue weathering. However, Liu *et al*. (2014) reported that total porosity decreased with soil age. The reason for this is that the study timing was 30 years and the herbs were *Heteropappus altaicus* (Willd.) Novopokr., *Chloris virgata* Sw., *Cynodon dactylon* (L.) Pers., and so on. In our study, the difference in the soil's physical properties between the native soil and the fifth year of recovery was statistically significant ($p < 0.01$), due to poorer soil properties in the five-year soil than the native soil.

The soil's total organic C, as the core of soil quality, showed an increasing trend (from 8.738 to 15.248 g/kg) at the early stage of recovery (Fig. 1e). There are many reasons for this. For example, coal gangue contains carbonaceous material, and plant litter accumulates (Wei *et al*. 2008, Yuan *et al*. 2012).

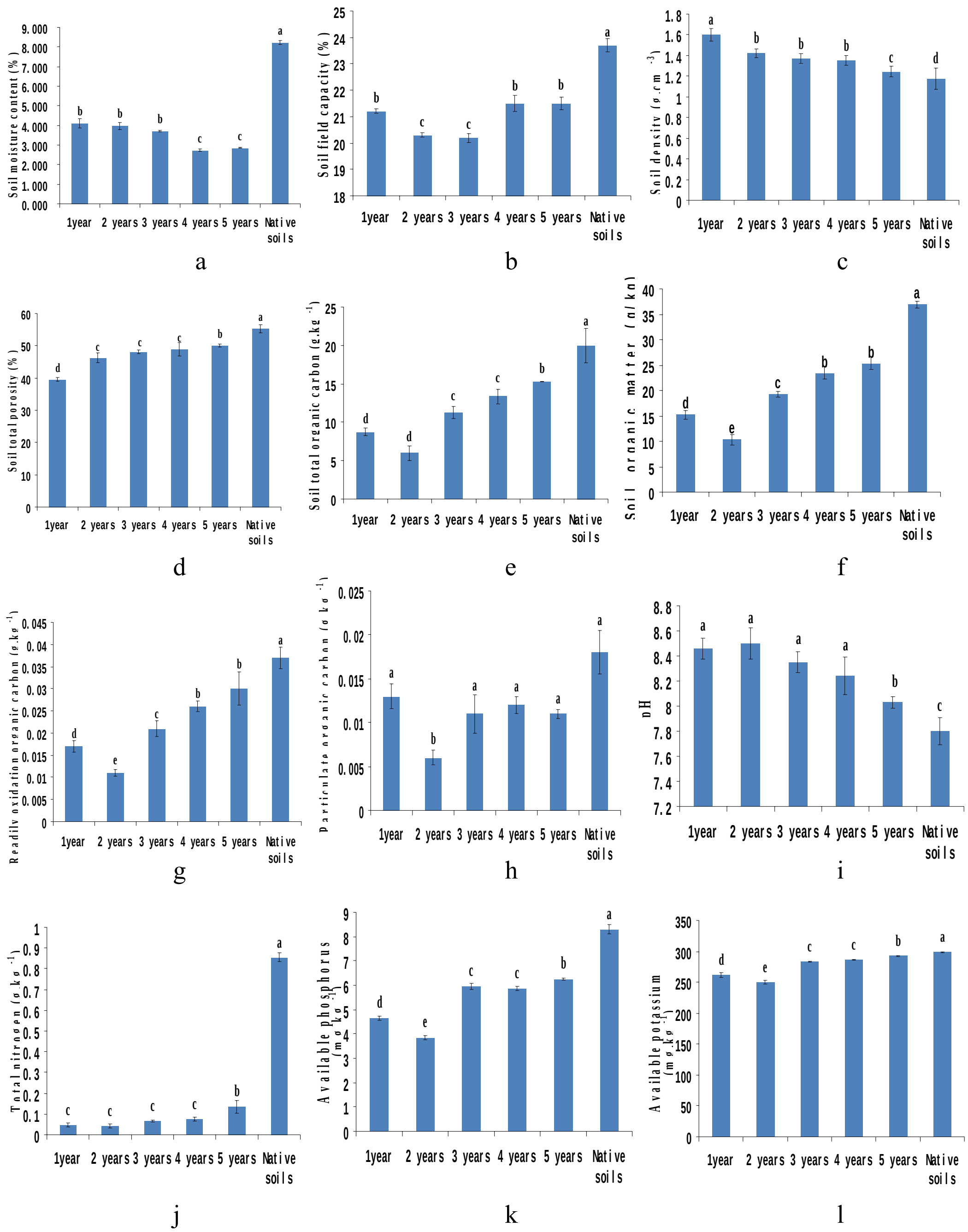

Fig. 1. Mean contents of soil moisture (a), field capacity (b), density (c), total porosity (d), total organic carbon (e), organic matter (f), readily oxidized organic carbon (g), particulate organic carbon (h), soil pH (i), total N (j), available phosphorus (k), available potassium (l) in 1 to 5 years of recovery and native soil. Whiskers indicate standard deviations. Bars with the different letters have significant difference ($p < 0.01$).

In a spontaneous recovery experiment in the coal gangue yard, Li (2011), Zhang *et al*. (2013), and Wang *et al*. (2013) reported a significant increase in soil organic matter content for the first three years. In our study, soil organic matter content was the lowest (10.308 $g \cdot kg^{-1}$) in the second year and the highest (25.367 $g \cdot kg^{-1}$) in the fifth year (Fig. 1f). Organic matter decreased due to the mineralization of organic materials and the leaching of topsoil. However, increasing organic matter content depends on rich litter, root exudates, and coal gangue mixed with coal. Differences in organic matter content between the fifth year and native soil were statistically significant (Fig. 1f).

Readily oxidized organic C content increased with soil age (from 0.017 to 0.030 $g \cdot kg^{-1}$) (Fig. 1g) due to the fact that gangue weathering was enhanced by climate factors (light, rainfall, etc.) and plant residues returned to the soil (Han *et al*. 2008). Differences in the soil's total organic C and readily oxidized organic C content between the fifth year and native soil were significant ($p < 0.01$). Particulate organic C was sensitive to the environment. The humification rate of vegetation litter sped up under suitable natural conditions, so that the particulate organic C content decreased in the second year and differed significantly from both other years and native soil ($p < 0.01$) (Fig. 1h).

During the spontaneous herbal recovery process, the soil was alkaline. The soil pH values varied from 8.50 to 8.03 and reduced with soil age. There were significant differences in the pH values between the fourth and fifth year ($p < 0.01$) (Fig. 1i). This indicated that the topsoil structure improved after vegetation recovery, resulting in better soil water-holding capacity. Suitable climate factors quickened coal gangue weathering. During this process, sodium, potassium, and other base materials were leached, and in turn aluminum ions were replaced. The alkaline topsoil became weaker with soil age (Ding *et al*. 2007). Similar results were reported by Ding *et al*. (2007), who found that the pH value was lower (8.39) in the fifth year of recovery than in the first year (9.95) in the Fu'shun coal gangue yard. Zhang *et al*. (2013) found that the soil pH value decreased in three-year recovery. Furthermore, Han (2010) also reported that pH reduced gradually with soil age. However, the pH value was slightly lower (7.80) in native soil than the fifth year.

Previous studies have indicated that the contents of total N, available phosphorus, and available potassium increase mostly in the first five years of recovery (Gil-Sotres *et al*. 1993, Shelby *et al*. 2012, Ding *et al*. 2007, Hong *et al*. 2000, Zhang 2006, Liu *et al*. 2014). Similar results are reported in the present study. Although total N (Fig. 1j), available phosphorus (Fig. 1k), and available potassium (Fig. 1k) contents decreased in the second year, they tended to increase (0.135 $g \cdot kg^{-1}$, 6.260 $mg \cdot kg^{-1}$, 292.620 $mg \cdot kg^{-1}$, respectively, in the fifth year). The reason for this is as follows. The growth of vegetation depleted soil nitrogen, phosphorus, and potassium in the first two years. From then on, microorganisms gradually decomposed extensive litter and roots from *M.. officinalis*, *Medicago sativa* L., and *P. distans* and released a large amount of nitrogen. Moreover, symbiotic nitrogen fixation between nitrogen-fixing bacteria and legumes reduced the legumes' nitrogen absorption. With a higher speed of coal gangue weathering, phosphorus, potassium, and other base materials were gradually released. There were significant differences in total N, available phosphorus, and available potassium contents between the five-year recovery soil and the native soil ($p < 0.01$), and the recovered soil could not attained the level of the native soil possessed.

Unlike the relationship between available phosphorus and available potassium, soil pH was negatively associated with total N and available phosphorus ($p < 0.01$). Furthermore, the absence of a linear relationship between soil organic matter and available phosphorus is in agreement with Wang *et al*. (2001), who found that a complex correlation, not a linear relationship, was present between soil organic matter and available phosphorus with soil age. In the present study, there was no relationship between soil organic matter and available potassium. Contrary to our study, Wang *et al*. (2001) and Ding *et al*. (2007) reported negative significant correlation between organic matter and available potassium. This indicates that differences in soil texture and plant species have important effects on the relationships between soil factors.

Leymus chinensis (Trin.), (L.), *Puccinellia distans* (L.), *Artemisia lavandu laefolia* (DC.), *Melilotus officinalis* (L.), and *Medicago sativa* (L.) are common herbs on each platform.

The total and above ground biomass growth in *L. chinensis* was enhanced with soil age (Fig. 2a). Biomass was negatively associated with soil density and pH ($p < 0.05$) and positively with soil total porosity, total organic C, organic matter, readily oxidized organic C, available phosphorus, and available potassium ($p < 0.05$). This is because *L. chinensis* is a kind of rhizomatous perennial grass. The roots multiplied greatly under better soil porosity and permeability, rich total organic C, available phosphorus, and available potassium. However, in the third year, below ground biomass decreased. There were significant differences in the biomass of *L. chinensis* growing in the five-year soil and the native soil.

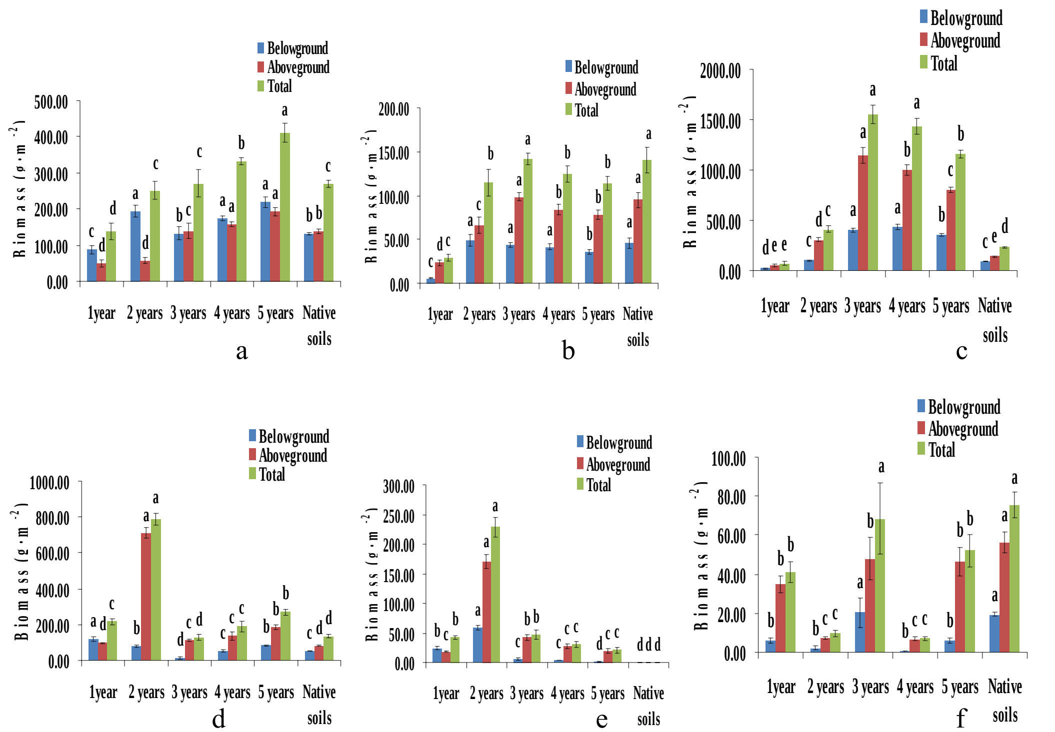

Fig. 2 Mean biomass of *Leymus chinensis* (a), *Setaria viridis* (b), *Puccinellia distans* (c), *Artemisia lavandulaefolia* (d), *Melilotus officinalis* (e), *Medicago sativa* (f) growing in 1 to 5 years of recovery and native soil. Whiskers indicate standard deviations. Bars with the different letters have significant differences ($p < 0.01$).

The biomass of *S. viridis* tended to increase before decreasing (Fig. 2b). The proportion of above ground biomass to total biomass ranged from 57.00 to 70.00%, similar to that in the native soil. The growth of *S. viridis* was associated with soil total porosity ($p < 0.05$). This analysis indicated that the better the permeability, the higher biomass.

The biomass growth of *P. distans* was evident in the first three years, and then decreased slowly. The belowground biomass was nearly constant within a certain region (from 350 to 450 $g{\cdot}m^{-2}$) for the last two years (Fig. 2c). There were significant differences in biomass between the fifth year soil and the native soil ($p < 0.01$).

The total biomass and above ground biomass of *A. lavandulaefolia* were the highest in the second year (787.50 and 709.50 $g{\cdot}m^{-2}$, respectively), but decreased in the third year and increased slowly for the last two years. The below ground biomass of *A. lavandulaefolia* was the lowest in the third year (15.40 $g{\cdot}m^{-2}$) and increased to 85.32 $g{\cdot}m^{-2}$ with soil age. The proportion of below ground biomass to total biomass increased from 9.90% in two years to 31.73% in five years, similar to that in native soil (39.04 %) (Fig. 2d). *A. lavandulaefolia* is a kind of perennial grass. The below ground parts of *A. lavandulaefolia* had to accumulate sufficient nutrients for the next year's growth. The total biomass and above ground biomass showed a negative significant correlation with particulate organic C ($p < 0.01$). This study suggested that an increase of particulate organic C in soil has adverse effects on *A. lavandulaefolia*.

The biomass of *M. officinalis* was highest (58.00 $g{\cdot}m^{-2}$) in the second year and reduced evidently from then on (Fig. 2e). There was a negative significant correlation with both aboveground biomass and particulate organic C ($p < 0.01$). Belowground biomass had a negative relationship with total organic C, organic matter, readily oxidized organic C, available phosphorus, and available potassium ($p < 0.05$). This study suggested that an increase of total organic C, organic matter, particulate organic C, readily oxidized organic C, available phosphorus, and available potassium in soil has an adverse effect on *M. officinalis*. It is interesting to not find *M. officinalis* in the native soil.

The biomass growth in *M. sativa* fluctuated with soil age. Total biomass was lower in the fifth year (52.10 $g{\cdot}m^{-2}$) than in native soil (75.45 $g{\cdot}m^{-2}$). In turn, significant differences were present in the fifth year and in native soil ($p < 0.01$) (Fig. 2f). The absence of a correlation between the biomass of *M. sativa* and soil factors indicated that the dynamics of biomass might be affected by the biological characteristics of *M. sativa* and the timing and method of this study.

As a whole, soil moisture and density contents decreased with soil age, but soil total porosity, total organic C, organic matter, total N, available phosphorus, and available potassium increased. Soil field capacity deceased in the first three years, but increased in later years. Particulate organic C contents fluctuated. The soil was alkaline. Soil pH values ranged from 8.50 to 8.03 and reduced with soil age. The differences in soil factors between the fifth year herbal recovery soil and the native soil were statistically significant.

At the early stage of spontaneous herbal recovery, biomass growth in *L. chinensis* was enhanced by better porosity and permeability, rich total organic C, organic matter, available phosphorus, and available potassium. Permeability significantly affected the biomass accumulation of *S. viridis*. During the three-year herbal recovery period, the biomass of *P. distans* increased with better permeability, higher total organic C, readily oxidized organic C, total N, and available potassium, but decreased in later years. Higher particulate organic C content in soil had been found to have an adverse effect on *A. lavandulaefolia*. Moreover, the biomass decrease in *M. officinalis* was associated not only with an evident increase of organic matter and total organic C contents, but also with rich available phosphorous, available potassium, and total N.

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