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Short communication

Interaction of soil water storage and stoichiometrical characteristics in the long-term natural vegetation restoration on the Loess Plateau

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ABSTRACT

Knowledge of the soil water and stoichiometrical characteristics (SC) during long-term natural vegetation restoration is essential for managing the restoration of vegetation. To evaluate the response of soil water storage (SWS), soil organic carbon (SOC), total nitrogen content (TN) and total phosphorous content (TP) to long-term natural vegetation restoration (~160 a), we examined the soil moisture and SC in areas with different restoration ages located in the central part of the Loess Plateau, China. Our results showed that the SWS decreased significantly with vegetation restoration and that the C:P ratio, N:P ratio, TN and TP increased significantly. The SWS increased gradually, whereas the SOC, C:P ratio, N:P ratio, TN and TP in each restoration stage decreased significantly with increasing soil depth in the 0–60 cm soil layer. These parameters tended to be stable in the soil layer below 60 cm. Vegetation acts as a link between SWS and soil SC, and they interact with each other indirectly. SWS and SWC showed an significant positive relationship ($P < 0.01$), whereas SWS and SOC, TN, TP, C:P ratio, and N:P ratio showed significant negative relationships ($P < 0.01$), thus, SOC, TN and TP are the key chemical factors affecting SWS.. These results could help estimating the productivity and sustainability of semiarid ecosystems and improve future eco-environmental reconstructions.

1. Introduction

Soil erosion is a modern global problem that induces severe economic consequences (Montgomery, 2007), environmental effects (Lal, 1995), and accelerated degradation of soil quality (An et al., 2008). In the Loess Plateau of China there are extreme environmental problems (Kimura et al., 2007), especially in the region severely affected by wind and water erosion covering ca. 178 million square meters (35°25′–40°38′N, 103°00′–113°53′E), about 29% of the total area of the plateau in the transitional zone between arid and semi-arid areas (Li et al., 2003). Secondary succession can lead to the recovery of the properties of degraded soil and maintain soil fertility (Wang et al., 2011a; Deng et al., 2013; Zhang and Shangguan, 2016). To control soil erosion and ecosystem degradation, a large area of agricultural land on the Loess Plateau has been converted to other uses during the past few decades. For example, farmland has been converted into grasslands, shrublands and forests with natural vegetation (Zhou et al., 2012; Feng et al., 2013; Deng et al., 2014). Information on the secondary forest succession processes on the Loess Plateau is of great significance, as it could reveal the relationship between the succession of vegetation and the evolution of soil ecological functions, thereby proving guidance for eco-environmental reconstruction (Zhang et al., 2016).

Soil water is a critical variable in studies of hydrological processes and the soil–plant–atmosphere continuum, especially in arid and semi-arid regions of the world such as the Loess Plateau of China where groundwater is buried below the thick unsaturated loessial soil (Jia and Shao, 2014). It directly controls the main source of water consumed by vegetation and the availability of water to plants (Martinez-Fernandez and Ceballos, 2003). Furthermore, soil water is the most limiting factor in the production and restoration of vegetation on the Loess Plateau (Xia and Shao, 2008; Gao et al., 2011; Jia and Shao, 2013a) and heavily influences the spatial and temporal distribution patterns of vegetation. Soil water storage (SWS), which is associated with the soil water content (SWC), is critical for sustaining rain-fed agriculture on the Loess Plateau (Yang, 2001). Long-term vegetation restoration has had significant effects on the SWS in grasslands and forests, and the SWS has decreased significantly with vegetation restoration (Zhang et al., 2016). Information on the dynamics of soil moisture needed for vegetation restoration in arid and semi-arid regions is essential for estimating the productivity and sustainability of semiarid ecosystems.

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Ecological stoichiometry provides a powerful framework for studying how vegetation types affect the balance of essential nutrients (e.g., carbon (C), nitrogen (N) and phosphorous (P)) during long-term natural vegetation succession, in which the cycling dynamics of soil nutrients may affect successional patterns, plant production and ecosystem processes (Peltzer et al., 2010; Osman and Barakbah, 2011; Yuan and Chen, 2012b). Soil organic carbon (SOC) is the largest C stock in the terrestrial ecosystem (Batjes, 1996). Deng et al. (2014) found that changes of land use types have a significant effect on the global C cycle through changing soil C accumulation rates and turnover. The afforestation of formerly arable affected the redistribution of SOC in the soil profile, but the SOC did not increase over three decades (Vesterdal et al., 2002), however, Murty et al. (2002) observed that 24% of the SOC stock has been lost from forestland to cropland and Guo and Gifford (2002) found 59% has been lost from pastureland to cropland globally. As the higher SOC stocks and recalcitrance, the deeper soil layers play a vital role in SOC sequestration and storage (SOCS) (Rumpel and Kögel-Knabner, 2011). Changes in the plant species composition with the vegetation restoration can alter soil aggregation (An et al., 2010), root system and litter input (Schedlbauer and Kavanagh, 2008), which will further change the stabilization and storage of SOC (Blanco-Canqui and Lal, 2004). Galloway et al. (2004) reported that N is the most common limiting element for plant production in the terrestrial biosphere and N dynamics are a key parameter in the regulation of long-term terrestrial C sequestration (Luo et al., 2004). In agricultural ecosystems, soil total nitrogen (TN) and total phosphorus (TP) are the major determinants and indicators of soil fertility and quality, which are closely related to soil productivity. The reduction of TN and TP levels can result in a decrease in soil nutrient supply, fertility, porosity, penetrability, and, consequently, in soil productivity (Wang et al., 2009). Thus, information on the spatial distribution of STN and STP is needed for the purpose of evaluating potential crop yields. Soil C:N:P stoichiometry is essential for understanding the nutrient cycling in terrestrial ecosystems (Tian et al., 2010; Yuan and Chen, 2012a). However, the mechanism of how Soil C:N:P stoichiometry changes with natural vegetation restoration is still unclear for Loess Plateau. The study of ecological stoichiometry is crucial in accelerating scientific understanding of nutrient biogeochemistry and associated behavior during nutrient circulation (Jeyasingh and Weider, 2007; Bradshaw et al., 2012). However, at present, soil C, N, and P stoichiometrical characteristics with respect to vegetation restoration have yet to be fully described (Jiao et al., 2013).

Vegetation can affect the SWS, SWC, SOC, TN, TP and other SC through the physiological activity of roots, the addition of leaf litter and the affected soil physical properties, such as soil bulk density, particle composition, hydraulic conductivity, etc. Additionally, soil water and SC inevitably influence plant growth. Thus, although SWS and SC seemingly cannot directly interact, they influence each other indirectly. Information about the change of soil SC in the long-term natural vegetation restoration could provide a powerful framework for studying how vegetation types affect the balance of essential nutrients, help estimating the productivity and sustainability of semiarid ecosystems and improve future eco-environmental reconstructions. In the Ziwuling Forest Region of the Loess Plateau, there has an intact series in the naturally recovering vegetation restoration on the Loess Plateau. In this study, we hypothesized that SWS and soil SC can negatively interact each other and both vary with natural vegetation restoration on the Loess Plateau, and our aim was to reveal the SWS response dynamics and SC to different vegetation restoration stages and the relationships between them. The specific objectives of the study were to investigate (1) the spatio-temporal dynamics of SWS and SC along with vegetation restoration, (2) the relationships between SWS and SC during the conversion of grassland to forestland, and (3) the key chemical factors affecting the SWS.

2. Materials and methods

2.1. Study area

The study was conducted on the Lianjiabian Forest Farm of Heshui County in Gansu Province, China (35°03′–36°37′ N, 108°10′–109°18′E, 1,211–1,453 m a.s.l.). The Ziwuling forest region covers a total area of 23,000 km^2. It has an mean rainfall of 587 mm, mean temperature of 10 °C and cumulative temperature of 2,671 °C. The soils of the region are largely Loessial (Jia et al., 2005). In this area, the forest canopy density ranges from 80% to 95% (Cheng et al., 2012), and secondary forests have naturally regenerated from grassland to shrubland to climax forest (Q. *liaotungensis*) through approximately 160 years (Wang et al., 2010a). Shrub and herbaceous communities recovery times were estimated from the local elders and descriptions found in contracts between farmers and local governments and forest community recovery times were estimated by counting the growth rings and consulting related written sources (Wang et al., 2010b). Throughout the region, *Bothriochloa ischaemum* (Linn.) Keng, *Carex lanceolata* Boott, *Potentilla chinensis* (Ser) and *Stipa bungeana* Trin are the dominate herb species, *Sophora davidii* (Franch.) Skeels, *Hippophae rhamnoides* (Linn.), *Rosa xanthina* Lindl and *Spiraea pubescens* Turcz are the dominate shrub species, *Populus davidiana* Dode and *Etula platyphylla* Suk communities dominate the pioneer forests, and. the climax vegetation is the *Quercus liaotungensis* Koidz forest (Table 1).

2.2. Experiment design and soil sampling

A field survey was undertaken between August 1 and August 15, 2014. Five 20 m × 20 m plots were chosen in each forest community, five 5 m × 5 m plots were chosen in the shrub communities, and five 2 m × 2 m plots were chosen in the herbaceous communities. All of the plots faced northeast and the slope gradient is less than 20°. Four soil sites were selected in areas with vegetation that had been allowed to grow for approximately 10, 50, 110 and 160 years naturally.

Soil samples were taken at five points: the four corners and the center of the soil sampling sites described above. The soil samples were taken at 20-cm intervals to a depth of 2 m using a drill and stored in sealed aluminum cases for measuring the SWC. Undisturbed soil cores were collected using a soil bulk sampler for measuring the soil bulk density at 0–60 cm. To measure SOC, TN and TP, disturbed soil samples

Table 1
Geographical and vegetation characteristics at different restoration stages in the Ziwuling forest region of the Loess Plateau.

Restoration stages	Latitude	Longitude	Altitude	Aspect	Slope	Coverage	Main plant species
	(N)	(E)	(m)		(°)	(%)	
G(10 a)	36°05′04.0″	108°31′37.4″	1348	NE	14	85	*Lespedeza bicolorr*
S(50 a)	36°04′14.4″	108°32′01.4″	1354	NE	18	90	*H. rhamnoides*
F1(110 a)	36°03′05.3″	108°32′31.8″	1437	NE	10	90	*P. davidiana, Q. liaotungensis*
F2(160 a)	36°02′57.5″	108°32′13.7″	1449	NE	18	95	*Q. liaotungensis*

Note: G represents the grass restoration stage, S represents the shrub restoration stage, F1 represents the early forest stage, and F2 represents the climax forest stage. Numbers in parentheses following the restoration stage are the ages after cropland abandonment. G, S and F stand for grassland, shrub and forest, respectively.

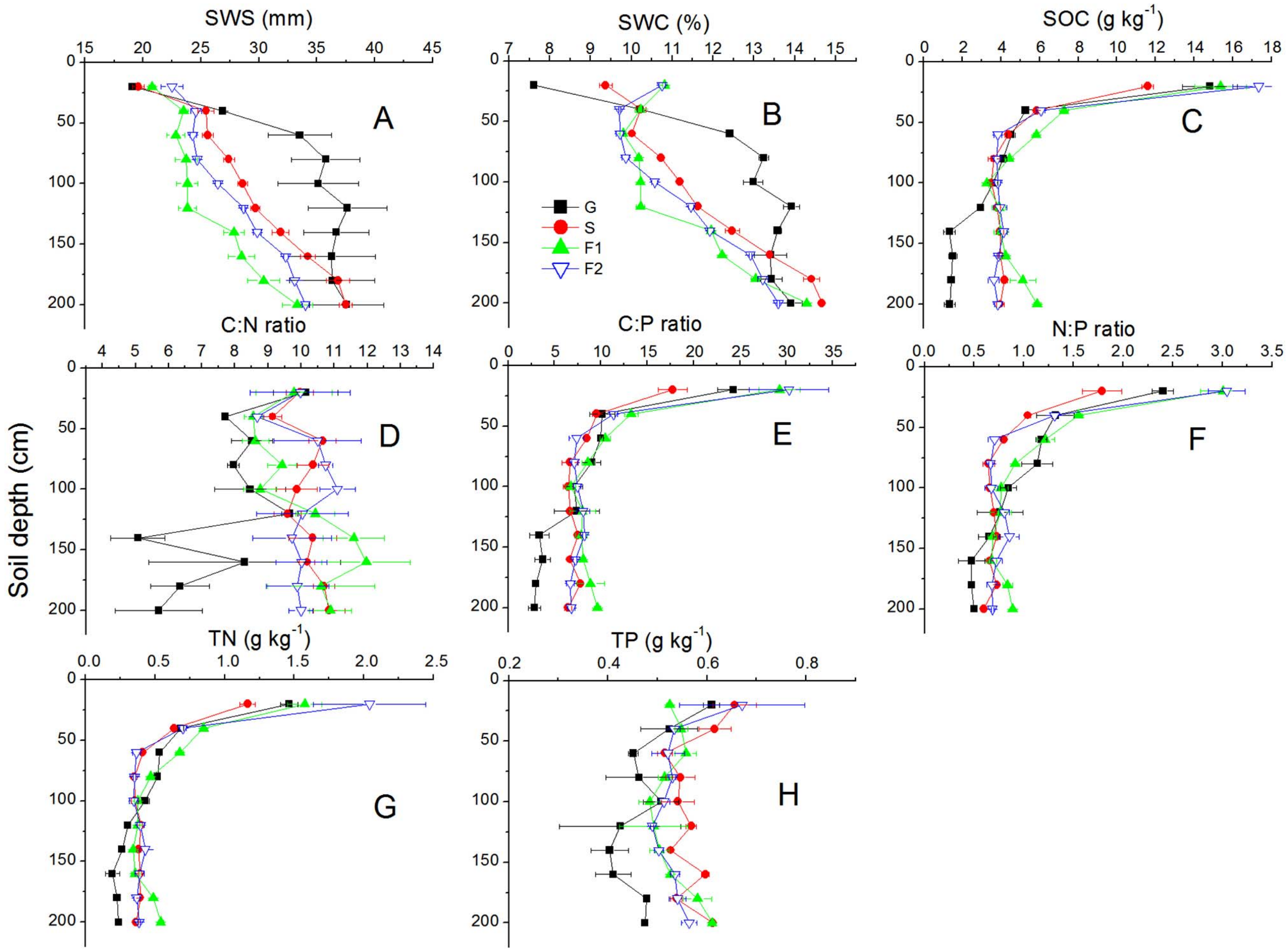

Fig. 1. Vertical variations in (A) soil water storage (SWS), (B) soil water content (SWC), (C) soil organic carbon content (SOC), (D) C:N ratio, (E) C:P ratio, (F) N:P ratio, (G) total nitrogen content (TN) and (H) total phosphorous content (TP) for the 0–200 cm soil depth in each restoration stage (see Table 1). The values are in the form of mean ± SE, with a sample size of n = 5.

were also taken at 20-cm intervals to a depth of 2 m using a drill and sieved through a 2-mm screen.

2.3. Laboratory assay

The SWC was measured gravimetrically (Jia et al., 2012). The SOC was assayed by dichromate oxidation (Kalembasa and Jenkinson, 1973). The total nitrogen content (TN) was measured according to the semi-micro Kjeldahl method (Jackson, 1973). The total phosphorous content (TP) was measured via colorimetry following digestion with perchloric acid and sulfuric acid.

2.4. Soil water storage

SWS in this study was calculated by the following equation (Jia and Shao, 2013a):

$$sws = \theta v \cdot h \cdot 10$$

where *SWS* is the soil water storage value at a specific depth (mm), θv is the volumetric soil water content at a specific depth ($cm^3\ cm^{-3}$), and h is the soil depth increment (cm).

2.5. Statistical analysis

Pearson's test was adopted to determine whether there were significant correlations between soil water storage and the soil properties measured in the study. Differences were evaluated at the 0.05 significance level. When significance was observed at the $P < 0.05$ level, the Tukey's post hoc test was used to carry out the multiple comparisons. A one-way ANOVA was used to analyze the means of the same soil layers across the different restoration stages.

3. Results

3.1. Vertical dynamics of soil water and stoichiometrical characteristics

Both SWS and the stoichiometry in different soil layers varied significantly at each natural vegetation restoration stage. Vertical variations in the SWS and SC in the 0–200 cm soil layer in the four restoration stages are shown in Fig. 1. With increasing soil depth, the SWS (Fig. 1a) and SWC (Fig. 1b) increased gradually in each restoration stage, whereas the SWS and SWC in the grassland tended to be stable in the soil layer below 80 cm. However, the SOC (Fig. 1c), C:P ratio (Fig. 1e), N:P ratio (Fig. 1f), TN (Fig. 1 g) and TP (Fig. 1 h) in each restoration stage decreased with increasing soil depth in the 0–200 cm soil layer, and all of them decreased significantly in the 0–60 cm soil layer. Below 60 cm, they tended to be stable. The C:N ratio (Fig. 1d) in the 0–200 cm soil layer fluctuated irregularly in each restoration stage.

3.2. Temporal dynamics of soil water and stoichiometrical characteristics

In association with the long-term natural vegetation restoration, both the SWS and SC varied significantly among the different soil layers. The temporal dynamics of SWS and stoichiometry in the

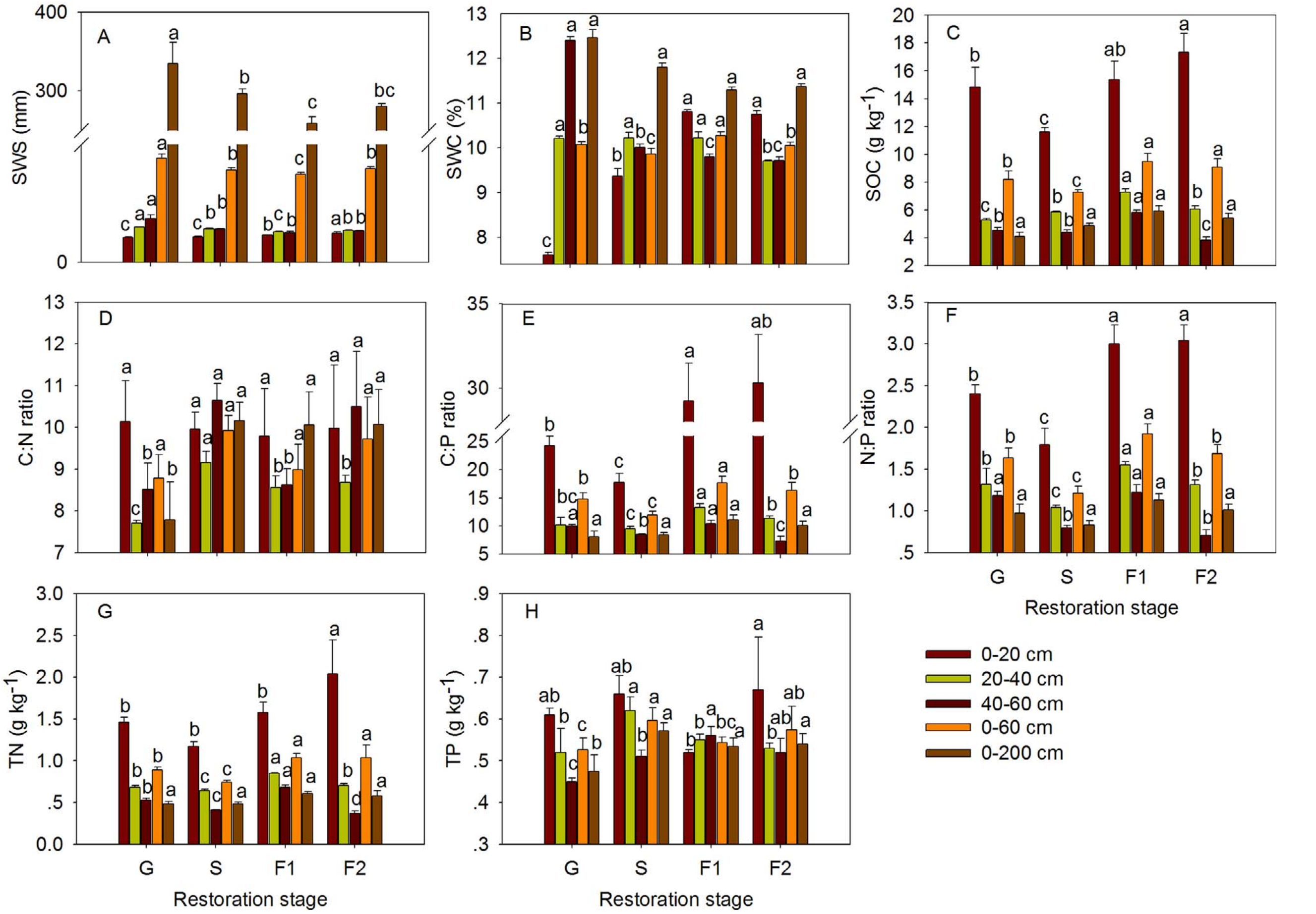

Fig. 2. (A) Soil water storage (SWS), (B) soil water content (SWC), (C) soil organic carbon content (SOC), (D) C:N ratio, (E) C:P ratio, (F) N:P ratio, (G) total nitrogen content (TN) and (H) total phosphorous content (TP) in the different soil layers in each restoration stage (see Table 1). Values are in the form of mean ± SE, with a sample size of n = 5. Different lower-case letters above the bars represent significant differences among the same soil layer in different restoration stages ($P < 0.05$).

different soil layers are shown in Fig. 2. With increasing restoration age, the SWS (Fig. 2A) and SWC (Fig. 2B) increased in the 0–20 cm soil layer, whereas the SWS decreased in the 20–40 cm, 40–60 cm, 0–60 cm and 0–200 cm soil layers. Similarly, the SWC also decreased in the 20–40 cm, 40–60 cm, and 0–60 cm layers but not in the 0–200 cm soil layer. The SOC (Fig. 2C) showed an increasing trend in the five soil layers but not in the 0–200 cm soil layer. The C:N ratio (Fig. 2D) in the grassland was lower than that in the shrubland and forestland only in the 20–40 cm and 0–200 cm; in the other soil layers, no significant difference was present. The C:P ratio (Fig. 2E), N:P ratio (Fig. 2F) and TN (Fig. 2G) showed the same clear increasing trends in the 0–20 cm, 20–40 cm, 40–60 cm and 0–60 cm soil layers. However, all three varied slightly among the different restoration stages in the 0–200 cm soil layer. TP (Fig. 2H) generally showed an increasing trend in all five soil layers with natural vegetation restoration.

3.3. Relationships between soil water storage and stoichiometrical characteristics

The significant correlation between SWS and SC over long-term natural vegetation restoration and the relationship between soil water storage and SC at all restoration stages for the 0–200 cm soil layer are shown in Fig. 3. SWS and SWC (Fig. 3A) showed an significant positive relationship ($P < 0.01$), whereas SWS and SOC (Fig. 3B), SWS and TN (Fig. 3C), SWS and TP (Fig. 3D), SWS and the C:P ratio (Fig. 3F), and SWS and the N:P ratio (Fig. 3G) showed significant negative relationships ($P < 0.01$). However, SWS and the C:N ratio showed a negative relationship with no significance in the 0–200 cm soil depth in the long-term natural vegetation restoration ($P > 0.05$).

4. Discussion

Different land use types in the long-term natural vegetation restoration can have significant influence on the SWS. The increase in tree biomass can drastically decrease the water content of soils (Honda and Durigan, 2016). This study found that the SWS in the 0–200 cm soil layer significantly decreased with the vegetation restoration stages from grassland to forestland (Fig. 2A). This is because SWC showed the same trend along with the vegetation restoration. The SWS exhibits an significant positive relationship with the SWC ($P < 0.01$) (Fig. 3A). In this study, the SWC in each restoration stage varied significantly among the different soil layers in the 0–200 cm soil depth, the SWC in shallow layers was lower than that in deep layers, the reason would be that the soil moisture in the upper soil layers was more influenced by vegetation transpiration and soil evaporation (Meerveld and McDonnell, 2006; Seneviratne et al., 2010), Oki and Kanae (2006) found that vegetation transpiration and soil evaporation combined could consume as much as 60% of total precipitation which is the sole water source in the upper layers and transpiration and evaporation could consume 90% of total precipitation in the Loess Plateau (Wang et al., 2011b), this is consistent with the previous research in arid and semi-arid areas (Mishra and Singh, 2010), and the SWC variation among the soil layers near the soil surface was higher than that in the deeper soil layers due to the frequent exchange of water and energy in the soil surface layers (Jia and Shao, 2013b). The SWC in the forest stage was significantly lower than those at the shrub stage or grass stage ($P < 0.05$), which is similar to

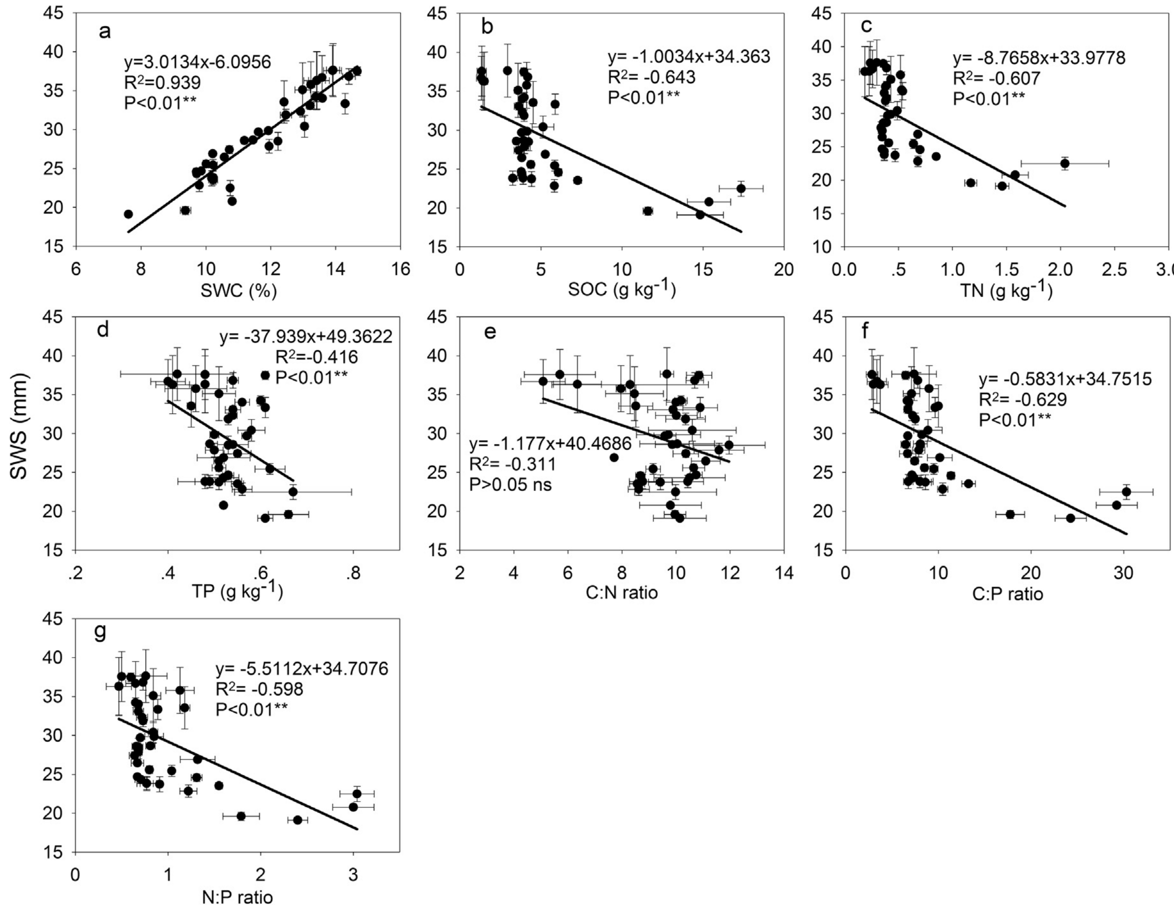

Fig. 3. Relationships between soil water storage (SWS) and (a) soil water content (SWC), (b) soil organic carbon content (SOC), (c) total nitrogen content (TN), (d) total phosphorous content (TP), (e) C:N ratio, (f) C:P ratio and (g) N:P ratio for the 0–200 cm soil depth in all restoration stages. Capped horizontal and vertical lines represent the SE.

the results of Wang et al. (2006) because of the higher root densities resulting in a greater transpiration ability (Wang et al. 2010b).

In this study, the SOC in the 0–60 cm soil layer significantly decreased in all stages of restoration (Fig. 1C), this is because of the decreasing organic material inputs transformed from the roots and root exudates (Nelson et al., 2008) with the increasing soil depth, however, the SOC transformed by plant litter increased with natural vegetation restoration (Castro et al., 2010). This finding is consistent with the results of Deng et al. (2013). In our study, soil TN increased with vegetation restoration, decreased with soil depth, and tended to be stable in the soil layers below 60 cm. The trend was the same as that of SOC. This is consistent with the results of Deng et al. (2013). Fu et al. (2010) reported that vegetation restoration would improve SOC and TN sequestration over the long term because of the resulting reduction of the losses of SOC and TN to soil erosion. On the contrary, soil organic carbon and nitrogen losses are influenced by vegetation removal in semiarid regions (Murty et al., 2002). In general, in this study, the soil TP in the 0–200 cm soil depth in the grass restoration stage was lower significantly than that in the shrub and forest restoration stages, and the N:P ratio showed a similar trend to those of soil TP and the C:P ratio, which may be because trees produce much more aboveground and belowground biomass than grasses or shrubs (Qi et al., 2015). The dead roots, decomposed litter, and root secretions in the soil changed the soil TP, N:P ratio and C:P ratio during the vegetation restoration restoration in the study area. However, the C:N ratio fluctuated irregularly in the 0–200 cm soil depth in each restoration stage, which may be due to the same variation dynamics in SOC (Fig. 1C) and TN (Fig. 1G).

The interactions between soil water and vegetation are essential for ecological processes in semiarid regions (Yang et al., 2014). In this study, the soil water and SC exhibited significant relationships in the 0–200 cm soil depth in the long-term natural vegetation restoration (Fig. 3). Spatiotemporal patterns of soil water can significantly influence vegetation, and vice versa. This finding was attributed to that plant growth conditions can change the spatial pattern of soil water (Yang et al., 2012) and vegetation types can significantly influence the soil water dynamics (Chen et al., 2007) in semi-arid regions. Ordonez et al. (2010) found that leaf N and P concentrations showed strong relationships with soil P; thus, soil P can affect the growth of the vegetation. Meanwhile, vegetation absorbs soil C, N and P through roots, thereby changing the soil C, N and P concentrations and their ratios. Hence, SWS and soil SC interact with each other indirectly because vegetation acts as a link between them. SWS and SWC showed an significant positive relationship ($P < 0.01$), whereas SWS and SOC, TN, TP, C:P ratio, and N:P ratio showed significant negative relationships ($P < 0.01$) (Fig. 3). Therefore, SWS had significant relationships with the SC besides SWC, and SWC, SOC, TN, and TP were the important factors affecting the SWS.

Overall, our study reveals that the soil water and SC were affected by different vegetation types during long-term natural vegetation restoration on the Loess Plateau of China. The SWS and soil chemical factors, such as SOC, TN and TP, would interact each other. The information would provide the reference for agriculture management and restoration processes in arid and semi-arid lands. To better understand the relationship between SWS and SC, further study is needed to address the functional mechanism between soil water and C, N and P.

5. Conclusions

Long-term vegetation restoration has had significant effects on the SWS and SC of areas transitioning from grassland to forest. The SWS significantly decreased with vegetation restoration, whereas the C:P ratio, N:P ratio, TN and TP clearly increased. Only the grassland SWC tended to be stable in the soil layer below 80 cm. With increasing soil depth in the 0–60 cm soil layer in each restoration stage, the SWS increased gradually, whereas the SOC, C:P ratio, N:P ratio, TN and TP decreased significantly before stabilizing in the soil layer below 60 cm. Vegetation acts as a link between SWS and soil SC, and they interact with each other indirectly. SWS and SWC showed an significant positive relationship ($P < 0.01$), whereas SWS and SOC, TN, TP, C:P ratio, and N:P ratio showed significant negative relationships ($P < 0.01$), thus, SOC, TN and TP are the key chemical factors affecting SWS. The results of this study could provide a powerful framework for studying how vegetation types affect the balance of essential nutrients, help estimating the productivity and sustainability of semiarid ecosystems and improve future eco-environmental reconstructions.

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References

An, S.S., Mentler, A., Mayer, H., Blum, W.E., 2010. Soil aggregation, aggregate stability, organic carbon and nitrogen in different soil aggregate fractions under forest and shrub vegetation on the Loess Plateau, China. Catena 81, 226–233.
An, S., Zheng, F., Zhang, F., Pelt, S.V., Hamer, U., Makeschin, F., 2008. Soil quality degradation processes along a deforestation chronosequence in the ziwuling area, China. Catena 75 (3), 248–256.
Batjes, N.H., 1996. Total carbon and nitrogen in the soils of the world. Eur. J. Soil Sci. 47, 151–163.
Blanco-Canqui, H., Lal, R., 2004. Mechanisms of carbon sequestration in soil aggregates. Crit. Rev. Plant Sci. 23, 481–504.
Bradshaw, C., Kautsky, U., Kumblad, L., 2012. Ecological stoichiometry and multielement transfer in a coastal ecosystem. Ecosystems 15, 591–603.
Castro, H., Fortunel, C., Freitas, H., 2010. Effects of land abandonment on plant litter decomposition in a Montado system: relation to litter chemistry and community functional parameters. Plant Soil 333, 181–190.
Chen, L., Huang, Z., Gong, J., Fu, B., Huang, Y., 2007. The effect of land cover/vegetation on soil water dynamic in the hilly area of the Loess Plateau, China. Catena 70, 200–208.
Cheng, J.M., Cheng, J., Shao, H.B., Zhao, L.P., Yang, X.M., 2012. Soil seed banks and forest restoration direction reflect soil quality in Ziwuling Mountain, Loess Plateau, China. Clean — Soil Air. Water 40, 140–147.
Deng, L., Wang, K.B., Chen, M.L., Shangguan, Z.P., Sweeney, S., 2013. Soil organic carbon storage capacity positively related to forest succession on the Loess Plateau, China. Catena 110, 1–7.
Deng, L., Wang, K.B., Shangguan, Z.P., 2014. Long-term natural succession improves nitrogen storage capacity of soil on the Loess Plateau, China. Soil Res. 52, 262–270.
Feng, X., Fu, B., Lu, N., Zeng, Y., Wu, B., 2013. How ecological restoration alters ecosystem services: an analysis of carbon sequestration in China's Loess Plateau. Sci. Rep. 3, 2846.
Fu, X.L., Shao, M.A., Wei, X.R., Horton, R., 2010. Soil organic carbon and total nitrogen as affected by vegetation types in Northern Loess Plateau of China. Geoderma 155, 31–35.
Galloway, J.N., Dentener, F.J., Capone, D.G., Boyer, E.W., Howarth, R.W., Seitzinger, S.P., Asner, G.P., Cleveland, C.C., Green, P.A., Holland, E.A., Karl, D.M., Michaels, A.F., Porter, J.H., Townsend, A.R., Vöosmarty, C.J., 2004. Nitrogen cycles: past, present, and future. Biogeochemistry 70, 153–226.
Gao, X.D., Wu, P.T., Zhao, X.N., Shi, Y.G., Wang, J.W., 2011. Estimating spatial mean soil water contents of sloping jujube orchards using temporal stability. Agric. Water Manage. 102, 66–73.
Guo, L.B., Gifford, R.M., 2002. Soil carbon stocks and land use change: a meta-analysis. Glob. Change Biol. 8, 345–360.
Honda, E.A., Durigan, G., 2016. Woody encroachment and its consequences on hydrological processes in the Savannah. Phil. Trans. R. Soc. B 371 (1703).
Jackson, M.L., 1973. Soil Chemical Analysis. Prentice-Hall, Engewood Cliffs, NJ.
Jeyasingh, P.D., Weider, L.J., 2007. Fundamental links between gens and elements: evolutionary implications of ecological stoichiometry. Mol. Ecol. 16, 4649–4661.
Jia, G.M., Cao, J., Wang, C.Y., Wang, G., 2005. Microbial biomass and nutrients in soil at the different stages of secondary forest succession in Ziwulin, northwest China. For. Ecol. Manage. 217, 117–125.
Jia, X.X., Wei, X.R., Shao, M.A., Li, X.Z., 2012. Distribution of soil carbon and nitrogen along a revegetational succession on the Loess Plateau of China. Catena 95, 160–168.
Jia, Y.H., Shao, M.A., 2013a. Temporal stability of soil water storage under four types of revegetation on the northern Loess Plateau of China. Agric. Water Manage. 117, 33–42.
Jia, Y.H., Shao, M.A., 2013b. Spatial pattern of soil moisture and its temporal stability within profiles on a loessial slope in northwestern China. J. Hydrol. 495, 150–161.
Jia, Y.H., Shao, M.A., 2014. Dynamics of deep soil moisture in response to vegetational restoration on the Loess Plateau of China. J. Hydrol. 519, 523–531.
Jiao, F., Wen, Z.M., An, S.S., Yuan, Z., 2013. Successional changes in soil stoichiometry after land abandonment in Loess Plateau, China. Ecol. Eng. 58 (10), 249–254.
Kalembasa, S.J., Jenkinson, D.S., 1973. A comparative study of titrimetric and gravimetric methods for the determination of organic carbon in soil. J. Sci. Food Agric. 24, 1085–1090.
Kimura, R., Bai, L., Fan, J., Takayama, N., Hinokidani, O., 2007. Evapo-transpiration estimation over the river basin of the Loess Plateau of China based on remote sensing. J. Arid Environ. 68 (1), 53–65.
Lal, R., 1995. The role of residues management in sustainable agricultural systems. J. Sustain. Agric. 5 (4), 51–78.
Li, Z., Yue, L., Xia, B., 2003. The study of land desertification in transitional zones between the MU US Desert and the Loess Plateau using RS and GIS—a case study of the Yulin region. Environ. Geol. 44 (5), 530–534.
Luo, Y.Q., Su, B., Currie, W.S., Dukes, J.S., Finzi, A., Hartwig, U., Hungate, B., Mcmurtrie, R.E., Oren, R., Parton, W.J., Pataki, D.E., Shaw, M.R., Zak, D.R., Field, C.B., 2004. Progressive nitrogen limitation of ecosystem responses to rising atmospheric carbon dioxide. Bioscience 54, 731–739.
Martinez-Fernandez, J., Ceballos, A., 2003. Temporal stability of soil moisture in a large-field experiment in Spain. Soil Sci. Soc. Am. J. 67, 1647–1656.
Meerveld, H.J.T., Mcdonnell, J.J., 2006. On the interrelations between topography, soil depth, soil moisture, transpiration rates and species distribution at the hillslope scale. Adv. Water Resour. 29, 293–310.
Mishra, A.K., Singh, V.P., 2010. A review of drought concepts. J. Hydrol. 391, 202–216.
Montgomery, D.R., 2007. Soil erosion and agricultural sustainability. Proc. Natl. Acad. Sci. U.S.A. 104 (33), 13268–13272.
Murty, D., Kirschbaum, M.U.F., Mcmurtrie, R.E., Mcgilvray, H., 2002. Does conversion of forest to agricultural land change soil carbon and nitrogen? A review of the literature. Glob. Change Biol. 8, 105–123.
Nelson, J.D.J., Schoenau, J.J., Malhi, S.S., 2008. Soil organic carbon changes and distribution in cultivated and restored grassland soils in Saskatchewan. Nutrient Cycl. Agroecosyst. 82, 137–148.
Oki, T., Kanae, S., 2006. Global hydrological cycles and world water resources. Science 313, 1068–1072.
Ordonez, J.C., Bodegom, P.M.V., Witte, J.P.M., Bartholomeus, R.P., Han, F.V.D., Rien, A., 2010. Leaf habit and woodiness regulate different leaf economy traits at a given nutrient supply. Ecology 91 (11), 3218–3228.
Osman, N., Barakbah, S.S., 2011. The effect of plant succession on slope stability. Ecol. Eng. 37, 139–147.
Peltzer, D.A., Wardle, D.A., Allison, V.J., Baisden, W.T., Bardgett, R.D., Chadwick, O.A., Condron, L.M., Parfitt, R.L., Porder, S., Richardson, S.J., Turner, B.L., Vitousek, P.M., Walker, J., Walker, L.R., 2010. Understanding ecosystem retrogression. Ecol. Monogr. 80, 509–529.
Qi, Y., Yang, F., Shukla, M.K., Pu, J., Chang, Q., Chu, W., 2015. Desert soil properties after thirty years of vegetation restoration in northern Shaanxi Province of China. Arid Land Res. Manage. 29 (4), 454–472.
Rumpel, C., Kögel-Knabner, I., 2011. Deep soil organic matter—a key but poorly understood component of terrestrial C cycle. Plant Soil 338, 143–158.
Schedlbauer, J.L., Kavanagh, K.L., 2008. Soil carbon dynamics in a chronosequence of secondary forests in northeastern Costa Rica. For. Ecol. Manage. 255, 1326–1335.
Seneviratne, S.I., Corti, T., Davin, E.L., Hirschi, M., Jaeger, E.B., Lehner, I., Orlowsky, B., Teuling, A.J., 2010. Investigating soil moisture-climate interactions in a changing climate: a review. Earth Sci. Rev. 99, 125–161.
Tian, H.Q., Chen, G.S., Zhang, C., Melillo, J.M., Hall, C.A.S., 2010. Pattern and variation of C:N: P ratios in China's soils: a synthesis of observational data. Biogeochemistry 98, 139–151.
Vesterdal, L., Ritter, E., Gundersen, P., 2002. Change in soil organic carbon following afforestation of former arable land. For. Ecol. Manage. 169, 137–147.
Wang, B., Liu, G.B., Xue, S., Zhu, B.B., 2011a. Changes in soil physico-chemical and microbiological properties during natural succession on abandoned farmland in the Loess Plateau. Environ. Earth Sci. 62, 915–925.
Wang, K.B., Shao, R.X., Shangguan, Z.P., 2010a. Changes in species richness and community productivity during succession on the Loess Plateau (China). Pol. J. Ecol. 58, 549–558.
Wang, L., Wei, S.P., Horton, R., Shao, M.A., 2011b. Effects of vegetation and slope aspect on water budge in the hill and gully region of the Loess Plateau of China. Catena 87, 90–100.
Wang, Y.Q., Zhang, X.C., Cong, W., Wei, Q.C., 2006. Spatial variability of soil moisture on slope-land under different land uses on the Loess Plateau. Trans. CSAE 22 (12), 65–71.
Wang, Y.Q., Zhang, X.C., Huang, C.Q., 2009. Spatial variability of soil total nitrogen and soil total phosphorus under different land uses in a small watershed on the Loess Plateau, China. Geoderma 150 (1), 141–149.
Wang, Y.Q., Shao, M.A., Shao, H.B., 2010b. A preliminary investigation of the dynamic characteristics of dried soil layers on the Loess Plateau of China. J. Hydrol. 381, 9–17.
Xia, Y.Q., Shao, M.A., 2008. Soil water carrying capacity for vegetation: a hydrologic and biogeochemical process model solution. Ecol. Model. 214, 112–124.
Yang, L., Wei, W., Chen, L.D., Wang, J.L., 2014. Response of temporal variation of soil moisture to vegetation restoration in semi-arid Loess Plateau, China. Catena 115,

123–133.

Yang, W.Z., 2001. Soil water resources and afforestation in Loess Plateau. J. Nat. Resour. 16, 433–436.

Yang, L., Wei, W., Chen, L., Jia, F., Mo, B., 2012. Spatial variations of shallow and deep soil moisture in the semi-arid Loess Plateau, China. Hydrol. Earth Syst. Sci. 16, 3199–3217.

Yuan, Z.Y., Chen, H.Y., 2012a. A global analysis of fine root production as affected by soil nitrogen and phosphorus. Proc. R. Soc. Biol. Sci. Ser. B 279, 3796–3802.

Yuan, Z.Y., Chen, H.Y.H., 2012b. Fine root dynamics with stand development in the boreal forest. Funct. Ecol. 26, 991–998.

Zhang, Y.W., Deng, L., Yan, W.M., Shangguan, Z.P., 2016. Interaction of soil water storage dynamics and long-term natural vegetation succession on the Loess Plateau, China. Catena 137, 52–60.

Zhang, Y.W., Shangguan, Z.P., 2016. The coupling interaction of soil water and organic carbon storage in the long vegetation restoration on the Loess Plateau. Ecol. Eng. 91, 574–581.

Zhou, D., Zhao, S., Zhu, C., 2012. The grain for green project induced land cover change in the Loess Plateau: a case study with Ansai County Shanxi Province, China. Ecol. Indic. 23, 88–94.