Changes in Soil Physical Properties of Forestland after 22 Years of the Grain-for-Green Program in the Western Shanxi Loess Region (Postprint)

Authors: Zhang Xiaoxia, Yang Zongru, Zha Tonggang, Zhang Zhiqiang, Wang Gaomin, Zhu Yushen, Lü Zhiyuan

Date: 2017-02-09T00:00:00+00:00

Abstract

Changes in the soil physical properties of reforested lands constitute an important component for evaluating reforestation measures and their ecological benefits. This study selected three typical forest stands formed 22 years after reforestation in the loess region of western Shanxi, including naturally recovered Quercus wutaishanica forest, artificial mixed forest of Pinus tabuliformis and Robinia pseudoacacia, and artificial pure forest of Robinia pseudoacacia, with cropland serving as a control. Through field investigation and sampling analysis, the effects of reforestation on soil physical properties including bulk density, total porosity, and capillary porosity were examined from both depth and magnitude perspectives. The results demonstrated that: (1) Regarding soil bulk density, naturally recovered forest exhibited significant changes ($P < 0.05$) in soil layers above 80 cm compared with cropland, with an average reduction of 28.78%, and the most pronounced change occurred in the 10-20 cm soil layer; significant changes in artificial forests relative to cropland occurred in soil layers above 60 cm, with mixed and pure forests decreasing by 10.58% and 8.34%, respectively, and the soil layer showing the greatest change was 20-40 cm; (2) The total soil porosity of the three reforested lands showed significant increases ($P < 0.05$) above 80 cm compared with cropland, with the magnitude of increase following the order: naturally recovered forest (35.53%) > mixed forest (15.04%) > pure forest (13.68%), and the 20-40 cm soil layer exhibited the greatest change; (3) Soil capillary porosity in naturally recovered forest, mixed forest, and pure forest reached 1.36, 1.13, and 1.12 times that of cropland, respectively. The soil layers showing significant changes were above 80 cm for naturally recovered forest and above 60 cm for artificial forests, with the most pronounced change occurring at 40-60 cm for both; (4) Soil organic matter and clay content exerted significant influences on soil physicochemical properties. For variations in soil bulk density, total porosity, and capillary porosity, increases in organic matter could explain over 31% of the variation, while the explanatory power of clay content reached 44%-51%, both at extremely significant levels ($P < 0.01$). Naturally recovered forest exerted greater influence than artificial forests on both the magnitude of change and the depth of soil layers affected regarding soil physical properties.

Full Text

Preamble

ACTA ECOLOGICA SINICA ChinaXiv Cooperative Journal
Vol. 37, No. 2, Jan. 2017
DOI: 10.5846/stxb201507291596

Changes in the Physical Properties of Forestland Soil After 22 Years Under the Conversion of Cropland to Forestland Project in the Loess Region of Western Shanxi Province

Zhang Xiaoxia[1], Yang Zongru[2], Zha Tonggang[1], Zhang Zhiqiang[1], Wang Gaomin[3], Zhu Yushen[1], Lü Zhiyuan[3]*

[1]Key Laboratory of Soil and Water Conservation & Desertification Combating, Ministry of Education, College of Soil and Water Conservation, Beijing Forestry University, Beijing 100083, China
[2]Forestry Service Center of Jixian County, Shanxi Province
[3]College of Forestry, Beijing Forestry University, Beijing 100083, China

Abstract

Soil physical properties, including particle size distribution, bulk density, and porosity, are interconnected and critically influence soil fertility and hydrological processes such as surface runoff, infiltration, groundwater recharge, and water yield. Severe soil erosion on the Loess Plateau has led to significant degradation of soil physical properties, manifested as increased bulk density, reduced aggregate stability, and diminished water retention capacity. Large-scale vegetation restoration efforts like China' s Conversion of Cropland to Forestland Project (CCFC) inevitably alter soil properties through changes in vegetation coverage, litter accumulation, root penetration, and soil biological activity.

This study investigated the depth and extent of CCFC impacts on soil physical properties in western Shanxi Province by examining three typical forest types established on former cropland 22 years ago: a naturally recovered *Quercus wutaishanica* forest (NR), an artificial mixed forest of *Pinus tabuliformis* and *Robinia pseudoacacia* (MF), and an artificial pure *Robinia pseudoacacia* forest (PF), with cultivated land (CK) as the control. Through field sampling and laboratory analysis, we measured soil bulk density, total porosity, and capillary porosity across soil profiles.

The results revealed: (1) Compared to cultivated land, soil bulk density above 80 cm depth in the natural recovery forest decreased significantly ($p < 0.05$), with an average reduction of 28.78% and the greatest change occurring in the 10–20 cm layer. In artificial forests (MF and PF), significant reductions were observed above 60 cm depth, with decreases of 10.58% and 8.34% respectively, peaking in the 20–40 cm layer. (2) Total soil porosity above 80 cm increased significantly in all three forest types compared to cultivated land ($p < 0.05$), with the magnitude of change following the order: NR (35.53%) > MF (15.04%) > PF (13.68%). The most pronounced changes occurred in the 20–40 cm and 40–60 cm layers. (3) Soil capillary porosity in NR, MF, and PF was 1.36, 1.13, and 1.12 times that of cultivated land, respectively. Significant changes extended to 80 cm depth in NR and 60 cm in artificial forests, with the most dramatic changes in the 40–60 cm layer. (4) Soil organic matter and clay content had significant effects on physical properties. Increases in organic matter explained up to 31% of the variation, while clay content explained 44%–51% of changes in bulk density, total porosity, and capillary porosity ($p < 0.01$). Natural recovery forests demonstrated greater influence on soil physical properties than artificial forests, attributable to thicker litter and humus layers, superior biodiversity, more frequent microbial activity, and more developed root systems.

Keywords: Loess region of western Shanxi Province; Conversion of Cropland to Forestland Project; soil physical properties; depth; extent

---

1. Study Area Overview

The study was conducted in the Caijiachuan watershed of Jixian County, Linfen City, Shanxi Province (110°27 -111°07 E, 35°53 -36°21 N). This region represents a typical Loess residual tableland-gully area with elevations ranging from 900 to 1510 m. The area experiences a warm temperate continental climate with an average annual precipitation of 575.9 mm, characterized by high inter-annual variability. July precipitation accounts for 60% of the annual total, while the average annual temperature is 10°C with 2563.8 hours of sunshine and 172 frost-free days. Cinnamon soil (brown earth) is the predominant soil type. Since the implementation of the CCFC in 1992, forest and grassland coverage has increased significantly, gradually alleviating soil erosion and improving the ecological environment. Dominant vegetation types include naturally recovered *Quercus wutaishanica*, artificial pure forests of *Robinia pseudoacacia*, *Pinus tabuliformis*, and *Platycladus orientalis*, and mixed conifer-broadleaf forests. Understory vegetation includes *Spiraea salicifolia*, *Rosa xanthina*, *Forsythia suspensa*, and *Hippophae rhamnoides*. Cultivated land primarily consists of conventionally farmed corn (*Zea mays*) using extensive cultivation practices.

---

2. Sample Selection and Soil Sample Collection

We employed a combination of field investigation and laboratory analysis. Based on principles of typicality and representativeness, we selected three forest sites converted from corn cropland in 1992 within the Caijiachuan watershed, plus a cornfield control. The forests included: (1) naturally recovered *Quercus wutaishanica* forest (NR), (2) artificial mixed forest of *Pinus tabuliformis* and *Robinia pseudoacacia* (MF), and (3) artificial pure *Robinia pseudoacacia* forest (PF). All sites had similar slope, aspect, and elevation. We conducted surveys and tree measurements at each plot, recording altitude with GPS (eTrex Vista), slope and aspect with a geological compass, diameter at breast height (DBH) with calipers, and tree height with a Blume-Leiss altimeter. Canopy density was measured using a canopy densitometer. Basic plot information is presented in .

TABLE:1 Basic information of the research sites

Soil investigations employed the profile method. Within each plot, we randomly selected three sampling points for typical soil profile surveys. Soil samples were collected at 0-10 cm, 10-20 cm, 20-40 cm, 40-60 cm, 60-80 cm, and 80-100 cm depths. From each layer, we collected one ring sample for bulk density analysis and one analysis sample for physicochemical property determination, yielding 18 ring samples and 18 analysis samples per vegetation type.

---

3. Experimental Data Measurement

Soil bulk density, total porosity, and capillary porosity were determined using the ring knife method. Soil organic matter content was measured by the potassium dichromate oxidation-external heating method. Clay content was analyzed using the pipette method.

---

4. Data Processing

Data were organized using Excel 2010. One-way ANOVA in SPSS 18.0 was used to test for significant differences in soil physical properties among vegetation types, with Duncan' s method for multiple comparisons at $p < 0.05$. Origin 9.0 software was used for graphical presentations.

---

5. Effects of Vegetation Type on Soil Bulk Density

Soil bulk density generally increased with depth across all vegetation types. However, 22 years after conversion, forestland showed significantly altered vertical distribution patterns compared to cultivated land. While cultivated land exhibited an initial increase followed by decrease due to tillage activities and plow pan formation, forestland bulk density showed a consistent increasing trend with depth.

TABLE:2 shows the influence of vegetation type on soil bulk density across different layers (mean ± SD). In the 0-60 cm layer, all forest types had significantly lower bulk density than cultivated land, though the magnitude varied. Natural recovery forest showed significantly lower bulk density than both artificial forests in the 10-20 cm layer, while differences between mixed and pure forests were not significant. Compared to cultivated land, natural recovery forest decreased bulk density by 7.46%, 12.03%, 35.93%, and 41.40% at 0-10 cm, 10-20 cm, 20-40 cm, and 40-60 cm depths, respectively. Mixed and pure forests showed reductions of 4.63% and 10.95% at 10-20 cm, 36.36% and 16.36% at 20-40 cm, and 15.20% and 11.73% at 40-60 cm, respectively. The ranking of bulk density at 40-60 cm was NR < MF < PF < CK. In the 60-80 cm layer, artificial forests had lower bulk density than the control but differences were not significant, while natural recovery forest remained significantly lower. Below 100 cm, no significant differences existed between forestland and cultivated land, with only 1.95% average change.

FIGURE:1 illustrates the influence extent of vegetation type on soil bulk density. Natural recovery forest showed significant effects down to 60 cm, with an average change magnitude of 28.78%. The maximum change rate (41.40%) occurred at 20 cm, decreasing to 18.30% at 60 cm, 16.35% at 80 cm, and 6.39% at 100 cm. Artificial forests affected soil bulk density to 60 cm depth, with average change magnitudes of 10.58% (mixed) and 8.34% (pure).

---

6. Effects of Vegetation Type on Soil Total Porosity

The vertical distribution of total soil porosity was significantly altered by afforestation compared to cultivated land. Porosity generally decreased with depth, with the rate of change in mixed forest showing an initial increase followed by decrease.

FIGURE:2 and **FIGURE:3** present the significance and influence extent of vegetation type on total porosity. Natural recovery forest had the greatest influence, followed by mixed forest and then pure forest. All forest types showed significantly higher total porosity than cultivated land in the 0-10 cm layer, with no significant differences among artificial forests but both differing significantly from natural recovery forest. The influence extent ranking was NR (36.69%) > MF (8.82%) > PF (7.10%). In the 10-20 cm and 20-40 cm layers, all three vegetation types significantly affected total porosity, with influence extents exceeding 20%. The maximum change (51.63%) occurred in the natural recovery forest at 40-60 cm, where influence extents reached 21.11%, 8.42%, and 10.56% for NR, MF, and PF, respectively. In the 60-80 cm layer, all forests differed significantly from the control, with influence extents of 14.48%, 5.31%, and 3.70%, respectively. Below 80–100 cm, no significant differences existed between any forest type and cultivated land.

Natural recovery forest increased total porosity by 23.35%–51.63% in the 0–40 cm layer, while mixed and pure forests increased it by 14.48% and 10.56%, respectively. The influence depth reached 80 cm for all forest types. Average total porosity increases across 0–60 cm were 35.53% for natural recovery forest, 15.04% for mixed forest, and 13.68% for pure forest.

---

7. Effects of Vegetation Type on Soil Capillary Porosity

Soil capillary porosity increased significantly with depth across all vegetation types after conversion. **FIGURE:4** and **FIGURE:5** show the significance and influence extent. Natural recovery forest had greater influence than artificial forests, with significant differences extending to 80 cm depth compared to 60 cm for artificial forests. In the 0–60 cm layer, all forest types differed significantly from the control, with influence extents of 16.21% (NR), 2.65% (MF), and 6.69% (PF). In the 60–80 cm layer, only natural recovery forest differed significantly from the other three vegetation types. Below 80–100 cm, no significant differences existed.

The influence extent peaked at 40 cm for natural recovery forest (57.12%) and at 60 cm for artificial forests (27.12% for MF, 25.46% for PF). The influence then decreased, dropping to 2.65% at 80 cm and 5.50% at 100 cm for mixed forest, and to 4.76% at 100 cm for pure forest. Natural recovery forest increased capillary porosity by 27.41% on average, with a minimum increase of 6.80% in the 0–10 cm layer. Average capillary porosity in NR, MF, and PF was 1.36, 1.13, and 1.12 times that of cultivated land, respectively.

---

8. Discussion

Afforestation effectively improves soil physical properties including bulk density, porosity, and water-holding capacity through litter input, root activity, improved soil hydrothermal conditions, enhanced microbial activity, and reduced human disturbance. This study demonstrates that natural recovery and artificial forests influence soil physical properties to depths of 80 cm and 60 cm, respectively, with corresponding influence magnitudes of 28.78%, 35.53%, and 36.00% for bulk density, total porosity, and capillary porosity in natural recovery forests, and 9.46%, 12.50%, and 14.36% in artificial forests.

Increases in soil organic matter and clay content, along with improved soil structure, are considered primary mechanisms for soil physical property improvement following afforestation in the Loess region. Correlation analysis of our samples indicates that organic matter increases explain up to 31% of the variation in physical properties, while clay content increases explain 44%-51% of changes in bulk density, total porosity, and capillary porosity, with correlations reaching extremely significant levels ($p < 0.01$). Vegetation roots and litter increase organic matter and clay content, improving colloidal conditions that promote aggregation and formation of water-stable aggregates with optimal particle size distribution. This mechanism is crucial for soil physical property changes in Loess region forestland.

Natural recovery forests demonstrated greater influence depth and magnitude than artificial forests, affecting soil physical properties to 80 cm depth compared to 60 cm for artificial forests. This is primarily attributed to thicker litter and humus layers, superior biodiversity, more frequent microbial activity, and more developed root systems in natural recovery forests. These findings align with studies in similar regions, though the magnitude of change varies due to complex input mechanisms of organic matter and clay across different study areas.

---

9. Conclusions

After 22 years of afforestation in the Loess region of western Shanxi Province, forestland soil physical properties including bulk density, total porosity, and capillary porosity have changed significantly compared to cultivated land. Natural recovery and artificial forests significantly altered soil bulk density to depths of 80 cm and 60 cm, respectively. Natural recovery forest reduced bulk density by an average of 28.78%, with maximum changes in the 10–20 cm layer, while mixed and pure forests reduced bulk density by 10.58% and 8.34%, respectively, peaking in the 20–40 cm layer.

All three forest types significantly increased total soil porosity to 80 cm depth ($p < 0.05$), with influence magnitudes of NR (35.53%) > MF (15.04%) > PF (13.68%). The most pronounced changes occurred in the 20–40 cm and 40–60 cm layers. Soil capillary porosity was significantly affected to 80 cm in natural recovery forest and 60 cm in artificial forests ($p < 0.05$), with NR, MF, and PF showing values 1.36, 1.13, and 1.12 times that of cultivated land, respectively. Maximum changes occurred in the 40–60 cm layer.

Increases in soil organic matter explained up to 31% of the variation in physical properties, while clay content increases explained 44%-51% of changes, with correlations reaching extremely significant levels ($p < 0.01$). Overall, natural recovery forests exerted greater influence on soil physical properties than artificial forests in both magnitude and depth.

References

[1] Forest Hydrology. China Forestry Publishing House, 1993.

[2] Wang Y Q, Shao M A. Spatial variability of soil physical properties in a region of the Loess Plateau of PR China subject to wind and water erosion. Land Degradation and Development, 2013, 24(3): 296-304.
[3] Effects of different land use patterns on soil properties in Ziwuling. Journal of Natural Resources, 2006, 21(6): 965-972.
[4] Relative soil water deficit under different artificial vegetation restoration in semi-arid loess hilly region. 2011, 31(11): 3060-3068.
[5] Water-holding capacity of typical forestland 22 years after conversion from cropland in the Loess region of western Shanxi. Beijing Forestry University, 2015, 37(5): 88-95.
[6] Gairola S U, Soni P. Role of soil physical properties in ecological succession of restored mine land—A case study. International Journal of Environmental Sciences, 2010, 1(4): 475-480.
[7] Wang L, Mu Y, Zhang Q F, Jia Z K. Effects of vegetation restoration on soil physical properties in the wind-water erosion region of the northern Loess Plateau of China. Clean-Soil, Air, Water, 2012, 40(1): 7-15.
[8] Effects of vegetation restoration on soil physical properties in water-wind erosion crisscross region. 2010, 30(16): 4306-4316.
[9] Relationship between soil aggregates and soil properties during vegetation restoration in Loess hilly region. 2006, 37(1): 45-50.
[10] Relationship between understory vegetation, ground cover, and soil physical properties in eucalyptus plantations. Chinese Journal of Ecology, 2006, 25(6): 607-611.
[11] Relationship between ground cover and soil physical properties. 2010, 30(20): 5475-5484.
[12] Peng S L, Chen A Q, Fang H D, Wu J L, Liu G C. Effects of vegetation restoration types on soil quality in Yuanmou dry-hot valley, China. Soil Science and Plant Nutrition, 2013, 59(3): 347-360.
[13] Effects of different topographic positions and land use patterns on soil physical properties in Loess tableland region. Chinese Journal of Applied Ecology, 2006, 26(11): 3685-3695.
[14] Effects of human disturbance on soil physical properties of *Pinus tabuliformis* plantations in Ziwuling, Loess Plateau. 2008, 19(6): 1303-1308.
[15] Study on soil physical characteristics and water dynamics under different vegetation types in Daqing Mountains. PhD Dissertation, Inner Mongolia Agricultural University, 2010.
[16] Analysis of soil physical properties under different land use types in typical watershed of Loess Plateau. Research of Soil and Water Conservation, 2010, 17.
[17] Effects of vegetation restoration on degraded soil improvement in dry-hot valleys. 2015, 35(15): 5157-5167.
[18] Study on soil physical property recovery characteristics after conversion of cropland to forestland in Loess hilly region—A case study in Wuqi County, Shaanxi Province. Journal of Natural Resources, 2005, 20(2): 272-278.
[19] Study on soil property changes after conversion of sloping cropland to forestland in Loess region. 2006, (3): 17-18.
[20] Research methods for forest ecosystem positioning. China Forestry Pub-

lishing House, 1992: 65–99.
[21] Pipette method for soil particle analysis. China Science and Technology Press, 1994.
[22] Soil physical properties of moso bamboo forest and their influencing factors. Forestry Science and Technology Development, 2014, 23(8): 52–55.
[23] Pérez-Bejarano A, Mataix-Solera J, Zornoza R, Guerrero C, Arcenegui V, Mataix-Beneyto S, Amat-Amat S. Influence of plant species on physical, chemical and biological soil properties in a Mediterranean forest soil. European Journal of Forest Research, 2010, 129(1): 15–24.
[24] Li X G, Li F M, Zed R, Zhang Z Y, Bhupinderpal-Singh. Soil physical properties and their relations to organic carbon pools as affected by land use in an alpine pastureland. Geoderma, 2007, 139(1/2): 98–105.
[25] Zhao H L, Guo Y R, Zhou R L, Drake S. The effects of plantation development on biological soil crust and topsoil properties in a desert in northern China. Geoderma, 2011, 160(3/4): 367–372.
[26] Bowman R A, Vigil M F, Nielsen D C, Anderson R L. Soil organic matter changes in intensively cropped dryland systems. Soil Science Society of America Journal, 1999, 63(1): 186–191.
[27] Soil physical properties under different vegetation types in Manas River basin fan margin zone. 2013, 33(1): 195–204.
[28] Correlation analysis between soil organic matter and other soil physical and chemical properties under different vegetation types.
[29] Dixon J B. Role of clay particles in soil. Progress in Soil Science, 1992, 20(3): 33–35.
[30] Albiach R, Canet R, Pomares F, Ingelmob F. Organic matter components and aggregate stability after the application of different amendments to a horticultural soil. Bioresource Technology, 2001, 76(2): 125–129.
[31] Whalley W R, Dumitru E, Dexter A R. Biological effects of soil compaction. Soil and Tillage Research, 1995, 35(1/2): 53–68.
[32] Spatial-temporal heterogeneity analysis of soil moisture in Loess region of western Shanxi. Research of Soil and Water Conservation, 2006, 13(6): 51–54.
[33] Li Y Y, Shao M A. Change of soil physical properties under long-term natural vegetation restoration in the Loess Plateau of China. Journal of Arid Environments, 2006, 64(1): 77–96.
[34] Spatial distribution of soil organic matter and its correlations in Dongting Lake wetlands. Modern Agricultural Sciences, 2009, 16(2): 21–23.
[35] Spatiotemporal variation and causes of soil physical properties in karst peak-cluster depressions of northwest Guangxi. Chinese Journal of Applied Ecology, 2010, 21(9): 2249–2256.
[36] Effects of different land use patterns on soil physical properties in Loess region of western Shanxi. Journal of Soil and Water Conservation, 2013, 27(3): 125–131.

Note: Figure translations are in progress. See original paper for figures.