Spatio-Temporal Dynamics of Soil Moisture in Silvopastoral System in the Loess Plateau of West Shanxi Province

Lei Yun†, Lubo Gao†, Huaxing Bi*, Qingke Zhu, Xiaoyan Wang
College of Soil and Water Conservation, Beijing Forestry University
Key Lab. Soil and Water Conservation and Desertification Combating, Ministry of Education
Beijing, China
E-mail: lepidus_qq@126.com

† Contributed equally to this work
*Corresponding author: Huaxing Bi. (E-mail: bhx@bjfu.edu.cn)

Abstract—The objective of this study was to investigate the spatio-temporal dynamics of soil moisture in silvopastoral system in the Loess Plateau of west Shanxi Province. Soil moisture in 0-100 cm layer was measured and analyzed in locust-natural grass system. The results showed as following: (1) There were significant differences of soil moisture in 0-100 cm layer in different phenological phases. Soil moisture contents in different patch types were different in silvopastoral system. The soil moisture contents of the grassland were significantly greater than the forestland's. (2) There were obvious hierarchy characteristics in soil profile in locust-natural grass system. The soil moisture contents and coefficient of variation both decreased with increase of soil depth. In horizontal direction, variations of soil moisture were relatively obvious in grassland, and soil moisture increased with the increase of the distance from forest edge to grassland. In forestland, variations of soil moisture were relatively complicated and soil moisture decreased with the increase of distance. Two-dimension isogram map gave a very strong visual impression, and it obtained good results in expressing the spatial structural characters.

Keywords—Silvopastoral system; Dynamics of soil moisture; Spatial and temporal change; Loess Plateau

I. INTRODUCTION

Silvopastoral system is a part of agroforestry systems, referring to the composite artificial vegetation or management mode that organically combined by forest and grassland in space [1]. Silvopastoral system could use light in a multi-level, making full use of natural resources, improving the conversion and utilization of primary products and relieving the contradiction between forestry and animal husbandry. In the same time, it can increase soil organic matter content and modify soil structure to create conditions for the healthy and stable development of forestry. As a traditional agroforestry management mode, silvopastoral system, because of its diversity of products, great efficiency and environmental improvement, has been used world widely [2]. As an indispensable part of vegetation restoration, artificial forest-grass planting model plays a very important role in economic development and ecological environment construction in some regions. It is one of the main modes of China's arid and semi-arid agroforestry [3].

As a key factor of soil-plant-atmosphere continuum and the vector of nutrient cycling of soil system, soil moisture not only directly affect the soil characteristics and plants growth, but also indirect effects the distribution of plants and the variation of ecosystem microclimate [4]. In Loess Plateau, because of little rainfalls and strong evaporation, water resource has become the major limiting factor of plant growth and distribution. Studies of soil moisture are the main content of environmental improvement and ecological construction in the Loess Plateau [5]. The abilities to use soil moisture change with plant species and the spatio-temporal dynamics of soil moisture are different, which often affect the storage, transportation and transformation of soil moisture [6]. In order to choose the right types of vegetation, the water utilization characteristics of different plant species in the specific region need to be studied. The researches on the dynamics of soil moisture of different vegetation in the Loess Plateau have started at an early period and have had a lot of conclusions [7-9], but mainly for a single system (such as forest, grassland, farmland, etc.). Relatively less work has been carried out on the spatio-temporal dynamics of soil moisture in silvopastoral system. By taking a typical locust-natural grass system in the Loess Plateau of west Shanxi Province as the research object, the characteristics of spatio-temporal dynamics of soil moisture in silvopastoral system were analyzed, in order to reveal the laws of soil moisture variation and improve the research of soil moisture in silvopastoral system. The scientific basis can be provided in vegetation restoration, rational land use, ecological construction and sustainable management technology of agroforestry system in loess region of west Shanxi Province.

II. AREA DESCRIPTION

The study chose a typical watershed, Caijiachuan, as its research area. Caijiachuan is located in Jixian, Shanxi, which is one of the National Stations of Forest Ecosystem. The 38 km² Caijiachuan watershed (36°14′-36°18′ N, 110°40′-110°48′ E) is a tributary of the Yellow River (Figure 1), located in the Loess Plateau, a temperate zone in western China. The topography of this watershed area is hilly and gully; the altitude is 900-1513 m. The site is dominated by a continental influence. Average annual rainfall and PET are 575.9 mm and 1857.7 mm, respectively.
The annual mean temperature is 10 °C. The vegetation of watershed is dominated by secondary forests (stone-earth area) and artificial afforestation (Loess area). Forest coverage is 39.8% of the total area. The main tree species are Betula platyphylla, Populus davidiana, Syzygium aromaticum, Ostryopsis davidiana, Robinia pseudoacacia, Pinus tabulaeformis, and Platycladus orientalis.

In silvopastoral demonstration area of tetraploid black locust plantation, a typical locust-natural grass planting model was selected as the research object. The main grass species were Setaria viridis, Bothriochloa ischaemum, Artemisia argyi, Artemisia sacrorum, Geranium wilfordii, etc. Table 1 is the basic situation of the research area.

### TABLE I. Basic situation of the observed sites

<table>
<thead>
<tr>
<th>Investigation target</th>
<th>Research object</th>
<th>Tree height</th>
<th>Diameter</th>
<th>Tree age</th>
<th>Forest density</th>
<th>Slope grade</th>
<th>Slope aspect</th>
<th>Altitude</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Locust-natural grass</td>
<td>(m)</td>
<td>(cm)</td>
<td>(year)</td>
<td>(tree number /hm²)</td>
<td>(°)</td>
<td>(°)</td>
<td>(m)</td>
</tr>
<tr>
<td></td>
<td>7.1</td>
<td>8.3</td>
<td>16</td>
<td>800</td>
<td>20</td>
<td>34 degree south by east</td>
<td>1036</td>
<td></td>
</tr>
</tbody>
</table>

### III. Research Methods

#### A. Layout of sampling points

Line transect method was used to set sampling points of soil moisture in silvopastoral system. Select the plot area of 30m×20m, with locust forest on the upper side of slope, with grass on the lower side. The juncture of locust forest and natural grass was defined as zero point. Based on the specific circumstances of the observed sites, the location of sampling points were lied in 16m on the direction of the forest and 11m on the direction of the grass, both with the interval of 1m. In order to obtain accurate results, three paralleled line transects were set in equal interval, with a total of 84 sampling points. For convenience, the direction of zero point to the forest was defined as positive direction, contrary to the negative direction (Figure 1).

![Figure 1. The setting of silvopastoral system soil moisture monitoring](image)

#### B. Sampling time and determination of soil moisture

Soil moisture was monitored in typical phenological phases from 2009 and 2010. Soil was removed using a drill and soil moisture content measured from 0 to 100 cm in 20 cm intervals.

### IV. Results and Analysis

#### A. Temporal variation of soil moisture

From the temporal variation of soil moisture of locust-natural grass system, it shows that the soil moisture contents of locust forest and grassland were different in different soil layers, but the trend of variation time had some similarity (Figure 2). Soil moisture had great fluctuations on the upper layer, however, deeper layers especially the layer of 80-100cm showed a trend of relative stable.

Taking observation time as the influencing factors, analysis of variance was carried on the soil moisture of 0-100cm layer of locust-natural grass system (Table 2). The results showed that the locust forest and grassland in locust-natural grass system and silvopastoral system itself had significantly changes on soil moisture along with time (p<0.01). Then taking patch types within the system as the influencing factors, analysis of variance was carried on the soil moisture of 0-100cm layer of locust forest and grassland within the silvopastoral system (Table 3). It shows that the soil moisture of grassland and locust forest were significant differences at the same time of observation (p<0.01). Soil moisture contents of the grassland were significantly greater than the forestland’s. This may be because the grass had a shallower root distribution and absorb less water, the forest had deeper root distribution with larger amounts of water consumption.

Taking average calculation of the soil moisture contents during the same growing season of 2009 and 2010, the soil moisture contents of 0-100cm layer of silvopastoral system were 12.68% in March, 12.34% in May, 9.64% in July and 12.71% in September. The overall trend of temporal variation of soil moisture decreased at the beginning and increased later.

The soil moisture had a lower content in the period from March to May. This mainly because: Soil defrosted during spring. With rising temperature, air was heated unevenly, and it was easy to form the topicality cyclone. In such situation, wind strengthened, the soil moisture capillary tube run strongly, soil evaporation became stronger, and water requirement by vegetation increased with the growth of plants. This meant that water demand and consumption increased. However, the lack of rainfall in this period resulted in decreasing total trend of soil moisture.

In the period May to September, the soil moisture content showed a decreased and then increased tendency. The soil moisture content resumed and was supplemented by the increasing precipitation during the rainy season (summer and autumn are rainy seasons in the Loess Plateau). In July, soil moisture increased, however, it could not reach...
the maximum level. It sometimes even decreased comparing with the previous period, due to little infiltration from little pre-rainfall, less soil water infiltration and high temperature resulting in strong evaporation and ET. In September, soil moisture supplied by rainfall was greater than soil moisture consumption, although the temperature was high and ET was strong in this period. Therefore, the soil moisture began to accumulate and reach a high level, even more than the end of March and early April.

**Figure 2.** Temporal dynamics of different layer of soil moisture in silvopastoral system (locust-natural grass)

**B. Spatial distribution of soil moisture**

1) **Characteristics of vertical distribution**

The statistical characters of soil moisture of each part in silvopastoral system can be seen in Table 4. Analysis of variance was carried on the soil moisture content of each layer of locust forest, grassland and locust-natural grass system in vertical direction (Table 5). The results showed that all of the 3 patterns of soil moisture were significant differences in vertical direction ($p<0.01$). In the three patterns, coefficients of variation of soil moisture contents were decreased with the increase of soil depth in the observation period, so was the soil moisture. The coefficients of variation of all layers in three patterns were greater than 0.1 and less than 1.0, belonging to intermediate variability.

**TABLE II.** Influence of sampling time on soil moisture of layer of 0-100 cm in silvopastoral system (locust-natural grass)

<table>
<thead>
<tr>
<th>Influencing factors</th>
<th>df</th>
<th>Locust forest</th>
<th>p</th>
<th>Natural grassland</th>
<th>p</th>
<th>Locust-natural grass</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation time</td>
<td>7</td>
<td>210.071</td>
<td>$p&lt;0.01$</td>
<td>128.170</td>
<td>$p&lt;0.01$</td>
<td>290.561</td>
<td>$p&lt;0.01$</td>
</tr>
</tbody>
</table>

**TABLE III.** Influence of patch types on soil moisture of layer of 0-100 cm in silvopastoral system (locust-natural grass)

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Patch types</td>
<td>1</td>
<td>32.370</td>
<td>$p&lt;0.01$</td>
<td>80.324</td>
<td>$p&lt;0.01$</td>
<td>154.347</td>
<td>$p&lt;0.01$</td>
<td>47.596</td>
<td>$p&lt;0.01$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2010-04-04</td>
<td>2010-06-01</td>
<td>2010-08-05</td>
<td>2010-09-18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>41.932</td>
<td>$p&lt;0.01$</td>
<td>67.873</td>
<td>$p&lt;0.01$</td>
<td>48.120</td>
<td>$p&lt;0.01$</td>
<td>24.123</td>
<td>$p&lt;0.01$</td>
</tr>
</tbody>
</table>

**TABLE IV.** Statistical characters of soil moisture in silvopastoral system (locust-natural grass)
2) Characteristics of horizontal distribution

The horizontal distributions of different depth of soil moisture in silvopastoral system can be seen in Figure 3. At different distances on both sides of the forest edge, all of the five layers had a similar distribution of soil moisture in horizontal direction. In the direction of the grassland, soil moisture increased with the distance from forest edge within 8 meters. At the range of 8m to 11m, soil moisture contents were gradually decreased. But the soil moisture showed a total trend of increasing. In the direction of locust forest, horizontal distribution of soil moisture contents were more complicated. There were obvious low points of soil moisture in the distance of 3m, 10m and 16m from forest edge, showing a wavy shape. From the whole aspect, soil moisture decreased with the distance from the forest edge.

3) Characteristics of two-dimensional distribution

Figure 4 is the two-dimension isogram of soil moisture content in silvopastoral system (locust-natural grass). Figure 4. Two-dimension isogram of soil moisture content in silvopastoral system (locust-natural grass).

V. CONCLUSION AND DISCUSSION

1) In different phenological phases, there were significant differences of soil moisture in 0-100cm layer in locust-natural grass system. In contrast, soil moisture had greater fluctuations in the upper layers, and relatively stable in the lower layers. Soil moisture contents of the grassland were significantly greater than locust forest.

2) In silvopastoral system, spatial distribution of soil moisture showed a similar regular pattern. In vertical direction, soil moisture were significant differences. Soil moisture contents and coefficients of variation decreased with the increase of soil depth, belonging to intermediate variability. In horizontal direction, soil moisture decreased in the direction of locust forest and increased in the direction of grassland. By drawing two-dimensional distribution isogram of soil moisture contents, the point data.
were turned into area data. The distribution, shape, size, and location of soil moisture were described intuitively.

Positive and negative effects of soil moisture are the focal points in the research of silvopastoral system. But they are always in dispute in the academic field. Some studies had suggested that silvopastoral system intensifies the water competition and led to the deterioration of soil moisture conditions[10-11]. But in some other researches, silvopastoral system was considered to be related to the enhancement of soil moisture content[12-14]. In water resource shortage areas, positive and negative effects of soil moisture in agroforestry system and soil water competition of vegetation have been still the main focus in the study of water ecological characteristics. Currently, in silvopastoral system, most of the mechanism researches of temporal and spatial distribution of soil moisture were based on soil moisture effect in the crop area and its relationship with transpiration water consumption of plants. Quantitative analysis of soil moisture in the view of the combined action of trees and crops was extremely rare in silvopastoral system[15].

In this paper, aiming at the combined action of locust forest and grassland, spatio-temporal dynamics of soil moisture in silvopastoral system were analyzed in order to improve the correlation study of soil moisture. In the conclusion, soil moisture contents in grassland were greater than that in locust forest. It showed that the higher soil moisture contents in grassland certainly played a positive contribution to the locust forest. This conclusion can be used as a case of the positive effect of soil moisture of agroforestry system. The additional focus in this paper was the soil moisture contents in the relative position. In fact, spatio-temporal variations of soil moisture were caused by a comprehensive effect of vegetation, meteorological (especially rainfall), terrain (slope degree, slope aspect, slope shape, altitude and geographic differentiation) and human activities in the multi-scale[16-18]. Therefore, carrying out researches on soil water characteristics of silvopastoral system combined with various factors will still be the working emphasis in the future.

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REFERENCES


