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# Effects of different management practices on vertical soil water flow patterns in the Loess Plateau

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ABSTRACT

Different management practices are adopted to ensure sustainable development in agriculture and to maintain ecological environment security. However, the soil water infiltration types under different management practices were still unclear. This study was designed to assess the effect of different management practices on the water flow behavior of soil. Four management practices were carefully selected. Plot 1 was uncultivated field, Plot 2 contained alfalfa (*Medicago sativa L.*) and was untilled for two years (alfalfa field), Plot 3 contained maize (*Zea mays L.*) with conventional tillage from 2008 to 2015 (conventional tillage field), and Plot 4 contained maize with conservation tillage from 2008 to 2015 (conservation tillage field). Soil physical properties (e.g., gravimetric water content, soil bulk density, total porosity, and saturated water content) in the top 50 cm layer were measured following conventional methods A dye tracer was introduced to these plots, and the different types of water flows were visualized using classified dye-stained patterns. In the uncultivated field, preferential flow was triggered by wetting front instabilities and generally confined to the upper 15 cm of the soil profile. The presence of preferential paths (alfalfa taproot) in the alfalfa field resulted in high and continuous preferential flow. The macropore flow bypassed the compacted soil and was confined into two isolated patches, making it the dominant flow behavior in the conventional tillage field. Conservation tillage systems enhanced the continuity and connectivity of the macropore system and converted the shape of the preferential flow to an inverted triangular distribution. The order of continuity and connectivity degree for the macropore system from highest to lowest was alfalfa field, conservation tillage field, uncultivated field, and conventional tillage field. Above mentioned results that were newly achieved from this study highlighted a significant change in soil water storage and flow behaviors with different management practices compared with those of uncultivated land. The present study suggests that local governments and farmers would prefer alfalfa field and conservation tillage field to other management measures.


## 1. Introduction

The continuous expansion of uncultivated land areas is a result of the unreasonable use and exploitation of land, and this phenomenon has resulted in the reduction of farmland areas and the destruction of the ecological environment of the Loess Plateau in Northwestern Shanxi Province, China (Qiao et al., 2000; Yuan et al., 2004). The local climate in the Loess Plateau is characterized by highly concentrated rainfall from July to August, and the soil is classified as sandy-loam chestnut loessal soil (Xue et al., 2013). Heavy rainfall and erodible soil make soil erosion and surface runoff highly likely, causing solutes (e.g., residual pesticides and nitrate nitrogen) to migrate and leach in the soil profile. Consequently, water flow and solute migration influence the utilization efficiency of agricultural resources. To ensure sustainable agricultural development and secure the ecological environment, local farmers have been adopting different management practices to utilize and develop uncultivated land (Li et al., 2015; Yuan et al., 2016).

Management practices involve different crops (e.g., corn and alfalfa) and different tillage systems (e.g., conventional tillage involves moldboard ploughing and harrowing; conservation tillage refers to management practice with low soil disturbance, shallow tillage depth, and lack of topsoil inversion), all of which has different influences on the physical and hydraulic properties of soil

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(Andreini and Steenhuis, 1990; Marshall et al., 2014). With regard to different crops and root systems, old root channels, which have openings at the soil surface (Wang et al., 1996) and decaying roots at a large penetration depth in a vertical direction (Mitchell et al., 1995) are generally considered as soil macropores. Jabro et al. (2009) reported that conventional tillage is one of the most important practices in conventional tillage systems. On the one hand, this practice affects the physical and hydraulic properties of soil (e.g., pore size, porosity, and infiltration), destroys most of the preferential paths at the soil surface, and reduces the number of pathways for water to move through gravity into the soil profile (Cullum, 2009). Moreover, conventional tillage increases soil erosion and surface runoff. On the other hand, conservation tillage has shown advantages in the modification of numerous physical properties, such as aggregate stability (Angers and Mehuys, 1988), soil structure (Gibbs and Reid, 1988), soil infiltration rate (Meek et al., 1990), total porosity, and continuous macropores (Cullum, 2009). Such tillage practices leave the structure of surface soils largely intact, yield large amounts of continuous macropores, reduce soil erosion and surface runoff, and increase infiltration. Simply put, different management practices would influence soil water flow behavior differently because of the variations in soil structure and porosity.

The soil water infiltration process generally includes matrix flow and preferential flow. The former is a relatively slow and even movement of water and solutes through the bulk soil (Allaire et al., 2009; Stamm et al., 1998). Preferential flow describes the physical phenomenon of rapid water and solute transfer in the soil. It occurs in most soils and is often attributed to macropore flow through cracks, fissures, or voids and between peds or through biopores, such as earthworm burrows and root channels (Beven and Germann, 1982; Flury and Flühler, 1995). However, preferential flow in soils is not restricted to macropore flow. Non-homogeneous infiltration and wetting front instabilities can also lead to preferential flow (Bundt et al., 2001). According to Beven and Clarke (1986), the macropore-matrix transfer process refers to the absorption of water into the surrounding matrix through the macropore walls with the help of capillary forces. Lateral flow refers to the infiltration of laterally moving water (Ritsema et al., 1995; Oostindie et al., 2013; Wine et al., 2012).

Although Sasal et al. (2006) noted that the infiltration rate was influenced by no-till management, the soil water infiltration types under different management practices were still unclear. Different management practices can be used to develop and utilize uncultivated land. It would be of great importance to obtain a better understanding of how soil water flow behaves under different management practices. In this study, an uncultivated land served as the reference, and three soil plots with different tillage regimes were selected as the management practices. A traditional method involving a dye tracer was conducted on these four soil plots. The study was divided into two parts: one, the water losing capacity and associated soil physical properties was analyzed among the four plots; and two, the soil water flow behaviors were interpreted from the classified dye-stained patterns. This study aimed to assess the effect of different management practices on the water flow behaviors based on a comparative analysis of water content variation and flow type in the soil profiles of four land-management systems.

## 2. Materials and methods

### 2.1. Experimental site

The study area was located in the Shi Zuitou county of Shanxi Province, North China. Its specific geographic position is between 111°28′–113°E and 38°44′–39°17′N, which covers the semi-arid and sandy area of the Loess Plateau in North China. The area has an arid continental climate with an annual average temperature of 5.0 °C, −14 °C in January and 19 °C in July, and annual sunshine of 2870 h. Annual average precipitation in the area is between 450 and 500 mm $yr^{-1}$. Rainfall is concentrated in July and August and accounts for approximately 44% of the total annual precipitation. In accordance with the Chinese Soil Classification System (Gansu Provincial Soil Survey Office, 1992), the soil in the study area was classified as sandy-loam chestnut loessal soil, which is similar to Anthropic Camborthids according to Soil Taxonomy (Soil Survey Staff, 1998). The resulting soil has loose texture, high porosity, strong permeability and ventilation, low fertility, and low soil organic matter.

### 2.2. Experimental design

#### 2.2.1. Plots and soil physical properties

A wide field covering 100 m (length) × 80 m (width) of land that has been uncultivated and undisturbed for 50 years was used in this study. To utilize the uncultivated field, it was divided into four plots. One plot was planted with alfalfa (*Medicago sativa* L.) without tillage from 2013 to 2015 (alfalfa field), another was planted with maize (*Zea mays* L.) with conventional tillage from 2008 to 2015 (conventional tillage field), another was planted with maize (*Zea mays* L.) with conservation tillage from 2008 to 2015 (conservation tillage field), and the last plot remained uncultivated (uncultivated field). Our experiments were conducted in these four plots. Soil particle size distributions of the four plots are provided in Table 1.

**Table 1**
Soil particle size (mean ± SE, n = 3) of the experimental sites.

| Soil depth (cm) | Particle size | Treatments | | | |
|---|---|---|---|---|---|
| | | Uncultivated field | Alfalfa field | Conventional tillage field | Conservation tillage field |
| 0–10 | Clay (%) | 0.70 ± 0.11 | 2.38 ± 0.03 | 1.90 ± 0.04 | 3.06 ± 0.19 |
| | Silt (%) | 1.97 ± 0.05 | 6.97 ± 0.62 | 12.99 ± 0.14 | 15.44 ± 0.65 |
| | Sand (%) | 97.33 ± 1.03 | 90.65 ± 0.20 | 85.11 ± 0.14 | 81.50 ± 2.48 |
| 10–20 | Clay (%) | 0.62 ± 0.31 | 2.39 ± 0.02 | 2.05 ± 0.05 | 2.78 ± 0.24 |
| | Silt (%) | 2.79 ± 0.99 | 14.18 ± 0.22 | 15.11 ± 0.13 | 13.98 ± 0.61 |
| | Sand (%) | 96.59 ± 1.30 | 83.43 ± 0.58 | 87.53 ± 0.54 | 83.24 ± 0.84 |
| 20–30 | Clay (%) | 1.02 ± 0.29 | 1.60 ± 0.11 | 1.33 ± 0.04 | 0.85 ± 0.12 |
| | Silt (%) | 2.19 ± 0.60 | 8.35 ± 1.29 | 8.48 ± 0.03 | 3.77 ± 0.49 |
| | Sand (%) | 96.79 ± 1.33 | 90.05 ± 1.45 | 90.24 ± 0.57 | 95.38 ± 0.59 |
| 30–40 | Clay (%) | 0.85 ± 0.01 | 1.27 ± 0.06 | 1.14 ± 0.07 | 1.49 ± 0.13 |
| | Silt (%) | 1.99 ± 0.22 | 6.79±0.40 | 7.92 ± 0.28 | 5.74 ± 0.72 |
| | Sand (%) | 97.16 ± 0.28 | 91.94 ± 0.46 | 90.13 ± 0.42 | 92.77 ± 0.80 |
| 40–50 | Clay (%) | 1.03 ± 0.19 | 2.86 ± 0.15 | 0.41 ± 0.43 | 0.98 ± 0.17 |
| | Silt (%) | 2.71 ± 1.21 | 3.56 ± 0.32 | 6.49 ± 0.38 | 5.39 ± 0.75 |
| | Sand (%) | 96.26 ± 1.38 | 93.58 ± 0.45 | 95.61 ± 0.06 | 93.63 ± 0.92 |