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The effects of different land uses on soil hydraulic properties in the Loess Plateau, Northern China

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Abstract

Some agriculture practices are unsuitable in the northern hilly region of the Chinese Loess Plateau and have resulted in the degradation of the native vegetation ecosystems and unfavorable soil hydraulic properties, which cause serious soil losses. The objective of this study was to ascertain the influence of land use changes on soil infiltration rate and other related soil properties in this region. A total of 90 infiltration tests were run on six different land uses (natural grassland, apple orchard, abandoned apple orchard, farmland wheat, farmland maize, and scrub grassland). For studying the infiltration rate, a triplicate of infiltration tests had been taken using a disc permeameter with different pressure heads. Infiltration rate was high in abandoned apple orchard (10 mm min^{-1}) whereas very low in apple orchard (0.6 mm min^{-1}). The statistical analysis showed that the main soil properties were affected by changes of land use types or vegetation cover. Compared with that in the natural grassland and abandoned apple orchard sites, a notable reduction of soil root biomass, infiltration, and bulk density in apple orchard was recorded. The root image analysis showed that the natural grassland and abandoned apple orchard have strong root systems, that is, root length density 6.97 ± 0.344 cm cm^{-3}, root surface area 1.56 ± 0.24 cm^2 cm^{-3}, and average root diameter 0.814 ± 0.24 mm, in comparison with other sites. The limited root length density, root surface area, and average diameter were recorded in apple orchard 0.51 ± 0.03 cm cm^{-3}, 0.49 ± 0.12 cm^2 cm^{-3}, and 1.88 ± 0.24 mm. Conclusively, our study suggests that converting farmland apple orchard into grassland or scrubland may change soil hydraulic properties, which may help to reduce soil losses in the Loess Plateau.

KEYWORDS

root image analysis, soil infiltration, soil water characteristic curve, Win-Rhizo

1 | INTRODUCTION

Land use systems and land degradation are a global issue in the 21st century because the degradation of land quality has an adverse influence on agriculture production, agriculture ecosystems, and the quality of human life (Kumar, Huang, Cai, & Miklavcic, 2014). The effects of land degradation on agriculture production lie on the negative changes of the land use systems on-site, where degradation

occurs (e.g., erosion) and off-site, where sediments are deposited (Kumar et al., 2014). The alteration of land use, primarily through conversion of natural vegetation, may exert a great impact on the various natural phenomenons and environmental processes, and unsuitable agriculture practices may result in degradation of naturally restored plant ecosystems (Yu et al., 2015). Vegetation restoration practice has been carried on the Chinese Loess Plateau from 1999, with the starting project entitled 'grain for green' (Kalhoro et al., 2017; Y. Li et al., 2016).

The soil is a heterogeneous mixture of soil particles, soil pores (macro, micro, and meso), dead plant material, soil fauna, and flora. All these factors control changes in the soil characteristics solute transportation (Jarvis & Messing, 1995; Wahl, Bens, Schafer, & Huttl, 2003) and soil loss through erosion (Lavelle, Rouland, Binet, Diouf, & Kersante, 2004). The impact of the different types of plant communities and vegetation restoration on soil are important and active indicators to improve permeability and reduce soil losses (Huang, Tian, Wu, Liu, & Dang, 2016).

Rainfall and infiltration are important sources of water generally in the arid and semiarid parts of the world, particularly in the present study area (X. Y. Li et al., 2011). Accumulative infiltration is needed for agriculture crop cultivation, vegetation restoration, conservation, and sustainable development (Leung, Garg, Coo, Ng, & Hau, 2015). 'Accumulative infiltration' has become synonymous with the decreasing of runoff and soil losses (wind and water erosion; X. Zhao, Wu, Gao, Tian, & Li, 2014). Type of vegetation could effect on soil hydraulic properties especially on infiltration rate and soil water characteristic curve (SWCC; Gonzalez-Sosa et al., 2010). Degradation of soil is the indication of soil and vegetation loss, which in turn aggravate soil erosion (Mchunu & Chaplot, 2012). In grassland, root distribution could recover soil physicochemical properties and that is in favor of infiltration rate (Kodesova, Jirk, Kodes, Muhlhanselova, & Zigova, 2011). Indeed, from the last few decades, Chinese government pay more attention to reduce soil losses and initiate many projects (Zhou, Zhao, & Zhu, 2012).

The available published evidence and experiences have shown that the plant restoration has a direct effect on soil losses and affects the soil infiltration rate (Y. Y. Li & Shao, 2006). Soil hydraulic conductivity had a significant effect on water budget (B. Wang, Liu, Xue, & Zhu, 2010), surface and subsurface runoff of water (Ren, Zhu, Wang, & Cheng, 2016), and that associated with soil erosion (Chartier, Rostagno, & Pazos, 2011; Michaelides, Lister, Wainwright, & Parsons, 2009). However, in the field study, unsaturated soil hydraulic conductivity is key component to estimate the flow of solute transportation in soil (Y. Zhao, Wu, Zhao, & Feng, 2013). The number of procedures and methods has been used in measuring infiltration rates and unsaturated hydraulic conductivity, among which disc permeameter (DP) is more common due to being easy to handle, cheap, and less time consuming. DP was designed by Commonwealth Scientific and Industrial Research. It contains a nylon mesh to supply membrane, the water reservoir, and bubble tower, the reservoir connecting each other, which have an open and closed system (Huang et al., 2016). SWCC also play a key role in soil hydraulic function and meanwhile for sustainable agriculture production (Shwetha & Varija, 2015) that showed the interlink between soil water potential and volumetric content. In

the forest restored area such as the Loess Plateau, the flow of water is key parameter in terms of management of water resources (Fisher & Binkley, 2013).

Root is also an essential driver of soil structure and soil pore formations (Scholl et al., 2014). The properties of roots (root area, root length density, and average root diameter) were directly correlated with soil pore and structure formations (Jegou, Schrader, Diestel, & Cluzeau, 2001; Scholl et al., 2014). Many procedure and methods were used to calculate the root characteristics, and among them, computer tomography scanning is more common and is used for the calculation of the distributed roots and also for the evaluation of different root parameters (Himmelbauer, Loiskandl, & Kastanek, 2004).

Chinese Loess Plateau has experienced extensive vegetation restoration. Former studies paid great attention to soil properties (Zhi, Liu, Zhang, & Zhang, 2009), water storage (Chen, Wang, Wei, Fu, & Wu, 2010), plant nutrition, soil quality (Jiao, Wen, & An, 2011), soil aggregation, and plant restoration (Kalhoro et al., 2017), whereas limited research has been conducted to estimate the effect of different land uses on soil hydraulic properties such as infiltration rate, SWCC, root biomass, and related characteristic of roots. Therefore, the present study has been carried out on six different land use systems that are traditionally used as natural grassland, apple orchard, abandoned apple orchard, farmland maize, farmland wheat, and scrub grassland. The main objectives of this study were (a) to provide valuable information on the flow of water as infiltration rate into the soil, (b) to estimate the effect of land use on water holding capacity, soil porosity, and impact on the plant, and (c) to estimate the effect of root biomass of different plant communities on different land uses.

2 | MATERIALS AND METHODS

2.1 | Research study area

Field experiments were conducted in the Agriculture Ecological Experimental Research Station of Chinese Academy of Science. Changwu County of the Chinese Loess Plateau is located in the southern part of the Loess Plateau (107° 40′–107° 42′ E and 35° 12′–35° 16′ N) and covering an area of 525 km^2 with altitude between 946 and 1,226 m (Figure 1), whereas mean annual rainfall 582 mm occurred between May and September. The mean annual temperature was 9.20°C. Before the start of the field experiment, field survey visits were conducted to generate basic data that are related with land uses, and finally, six types of different land uses were selected, and the study sites are labeled as natural grassland (NGL), scrub grassland (SGL), apple orchard (AO), abandoned apple orchard (AAO), farmland wheat (Flw), and farmland maize (Flm), which were distributed within 2-km radius. The historical information was collected from the local farmers at the time of soil sampling, detail of which is described as follows: NGL, before the year 2000, the land was used as apple orchard; however, during 2000, all the standing apple plants were removed from the field, and it is natural grassland since the last 15 years. SGL, it is situated on the high slope
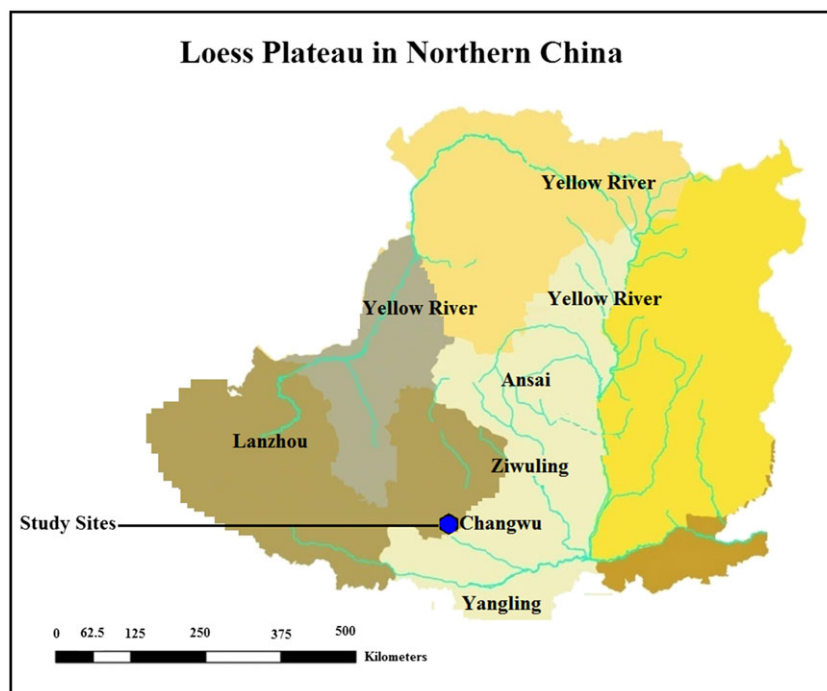
FIGURE 1 Geographical map of the study area, Changwu County, Loess Plateau [Colour figure can be viewed at wileyonlinelibrary. com]

and with high water erosion particularly during monsoon; therefore, the land was not in use since the last 20 years. AO, in 2006, apple tree plant was established since then as an apple orchard, but before, this land was used as crop cultivation (wheat, maize, and millet). AAO, before 1999, the land was utilized as apple orchard; however, since the last 16 years, the apple utilization has been abandoned. Flw, presently, the land has been used for the cultivation of wheat, but 4–5 years ago, the land was utilized as an apple orchard. Flm, for the last 20 years, the land has not been recycled and used as the cultivation of maize crop. Overall, the allocated sites had been utilized for more than 15 years except for AO, which became a newly established apple orchard 8 years ago.

2.2 | Field experiment and soil sampling

Three plots were selected in each site with 108 soil core sample collected at 0–10, 10–20, 20–30, 30–40, 40–50, and 50–60 cm of the soil layer. Stainless auger and steel rings (5 cm in diameter and height) were used to calculate soil physicochemical properties, such as soil particle size distribution (sand, silt, and clay), soil organic matter (SOM), SWCC, soil total porosity (STP), and soil bulk density (BD). Collected soil samples were transported to the laboratory for further analysis. After being placed in water for 12 hr, the wet and dry weight of the soil samples were noted to calculate the STP (%). After 24 hr of oven drying at 105°C, soil BD was determined (Goossens & Buck, 2009; Himmelbauer et al., 2004; Shwetha & Varija, 2015). STP and SOM were determined by international procedures and calculated by the following formulas George, Rolf, and John (2013).

$$\text{Soil Total Porosity (STP)} = \left(1 - \frac{BD}{ds}\right) \times 10, \quad (1)$$

$$\text{Bulk Density (BD)} = \frac{W}{V}, \quad (2)$$

where BD is the bulk density Mg m^{-3}, ds is the soil particle density (equal to 2.56, in this study), W is the oven dry weight of sample, and V is the sample volume cm^3.

$$\text{Oxidizable Organic Carbon (\%)} = \frac{[V_b - V_s \times 0.3 \times M]}{Wt}, \quad (3)$$

$$\text{Total Organic Carbon (\%)} = 1.334 \times \text{Oxidizable Carbon}, \quad (4)$$

$$\text{Organic Matter (\%)} = 1.724 \times \text{Total Organic Carbon}, \quad (5)$$

where V_b and V_s are the volume of blank sample and volume of soil sample, 0.5 M is the molarity of $(NH_4)_2SO_4$ and $FeSO_4.6H_2O$, used titration of V_b and V_s, and Wt is the soil sample weight.

2.2.1 | Sampling procedure for root image analysis

Intact soil core sample was collected using steel ring of 10 cm in diameter of length and height at six different soil layers 0–10, 10–20, 20–30, 30–40, 40–50, and 50–60 cm in depth. Carefully, plant roots were separated from attached soil particles. Roots were washed and surface dried with blotting paper. Finally, root images were taken by using the Epson Perfection V700 Photo Scanner (Seiko Epson Corporation, Nagano, Japan) preceded by the computer software Win-Rhizo, 2009, to measure the root diameter (root length density, root surface area, and average root diameter; Himmelbauer et al., 2004).

2.2.2 | Measurement of infiltration rate from different land use

On each site triplicate infiltration, experiments were carried by using the DP (Figure 2). Before the experiment, soil surface was cleaned and covered with fine sand; standing plants were trimmed with scissors, and then infiltration was tested using different pressure
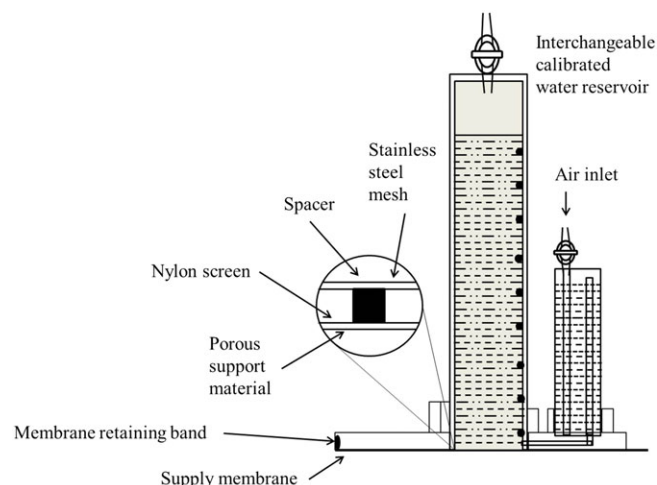
FIGURE 2 Flow diagram of disc permeameter [Colour figure can be viewed at wileyonlinelibrary.com]

heads of 0.53, 0.63, 0.82 1.12, and 1.17 kpa, and the flow of water was recorded in the time intervals of 10, 20, 30, 40, 50, 60, 70, 80, 90, 120, and 150 s and then intervals of 3, 4, 6, 9, 12, 15, 18, 21, 24, and 27 min under stable conditions and calculated in the following formula after the observation of three continual tests in similar infiltrated flow in soil (Huang et al., 2016).

$$f_s = \frac{\Delta h D_2^2 \times 10^{-4}}{\Delta t D_1^2 \left(0.7 + 0.03T\right)}, \tag{6}$$

where f_s = 10°C standard water temperature infiltrations rate (m s^{-1}), D_1 is the effective diameter of infiltrated disc (cm), D_2 is the water storage pipe diameter (cm), Δh is the difference between the readings of water, Δt is time period (min), and T is the average water temperature (°C) for a given period of time.

2.2.3 | Soil water characteristic curve

The Hitachi CR21G, a high-speed centrifuge, was used to analyze SWCC with pressure heads ranged from 10.2 to 10,200 cm. Hitachi CR21G automatic maintained the air temperature at 20°C. The high-speed centrifugal force was applied to the saturated sample. The pressure head consecutively increased with rotation speed. The pressure head (cm), rotation speed (r s^{-1}), and time period (min) were measured and recorded at the same time. Furthermore, Table 1 showed the tested pressure heads, with equilibrium to rotation speed and time period.

2.3 | Data analysis

Analysis of variance was used to estimate the effect of the different land uses on infiltration rate, SWCC, root biomass, and related soil properties, with mean and standard errors. The significant difference between the data was calculated at $p \leq 0.05$ probability using STAT 8.1 version.

TABLE 1 Pressure head of centrifuge, speed with equilibrium time period, and rotation speed

Pressure head (cm)	Rotation speed (r s^{-1})	Time period (min)
10.2	18.6	10
102	58.8	26
204	82.8	36
408	117.6	45
612	144	51
816	166.2	55
1,020	186	58
2,040	262.8	68
4,080	372	77
6,120	456	83
8,160	526.2	87
10,200	588	90

3 | RESULTS

3.1 | Characteristics of basic soil properties

Triplicate data of the soil particle size (sand, silt, and clay) distribution for different land uses are presented in Table 2. The observation results show that soil textures were silty-loam at the different depth of layer through the whole soil profile of 0–60 cm for different land uses (Table 2). The BD of surface soil is lower than that of subsurface soil layers, with an average of 1.2 Mg m^{-3} across all study sites and throughout the whole soil profile of 0–60 cm but except for Flw 1.48 ± 0.18 at 20–30 cm of soil depth (Table 2). The RB of NGL at depth of 0–10 cm is higher than in other study sites, whereas RB is higher in Flw than Flm (Table 2), and the lowest RB was recorded in AO with comparison of all other sites (NGL, SGL, AAO, Flw, Flm, and AO) in a decreasing order (Table 2). The result is different in soil layers, although this is statistically nonsignificant ($p \leq 0.05$). STP was ranging from 42% to 65% and decreased with soil depth (Table 2). Mostly, the maximum STP was observed in AAO at 0–10 cm of the soil layer. Overall, the ascending order of STP under different land uses was Flm, AO, Flw, SGL, NGL, and AAO respectively at 0–10 cm of soil layer (Table 2). BD and SOM are the most important soil physicochemical properties and have an effect on soil hydraulic properties, mainly on soil permeability and SWCC. The maximum SOM was recorded in NGL, about 3.2 ± 0.09% at 0–10 cm of soil. The SOM content of Flw was higher than that of Flm, and AAO was higher than that of AO in every layer of soil (Table 2); the results were different and varied with soil layers (0–60 cm), though this was not found statistically significant ($p \leq 0.05$).

3.2 | Infiltration rate in different land uses

The infiltration rate for different land uses showed that it was significantly different among land uses (Figure 3). Increasing pressure caused a decrease in the infiltration rate with the lowest infiltration rate recorded in AO at 1.71 kpa and the maximum infiltration rate in NGL and AAO at 0.53 kpa among all applied pressures, that is, 0.53, 0.63, 0.82, 1.12, and 1.71 kpa and in all study sites (Figure 3). The

TABLE 2 Soil basic properties under different land use systems

Soil layers (cm)	Land use	Porosity (%)	Root biomass (g kg^{-1})	Bulk density (Mg m^{-3})	Soil organic matter (%)	Soil particle distribution		
						Sand%	Silt%	Clay%
0–10	NGL	65.85 ± 1.79a	1.95 ± 0.12a	1.23 ± 0.08ab	3.20 ± 0.09a	11.84 ± 3.69a	69.13 ± 1.43a	19.02 ± 2.37a
	AO	59.10 ± 1.91ab	0.06 ± 0.03c	1.32 ± 0.06b	2.51 ± 0.14a	9.641 ± 3.85a	69.87 ± 1.45a	20.48 ± 2.42a
	AAO	66.09 ± 10.14a	0.73 ± 0.24b	1.28 ± 0.05a	2.86 ± 0.05a	15.67 ± 8.52a	64.60 ± 3.30a	19.72 ± 5.30a
	FLm	44.73 ± 2.46b	0.58 ± 0.17BC	1.24 ± 0.10b	2.32 ± 0.43a	12.16 ± 5.90a	69.45 ± 1.55a	18.37 ± 4.56a
	FLw	60.63 ± 2.49ab	0.65 ± 0.25b	1.21 ± 0.00ab	2.58 ± 0.39a	13.63 ± 1.29a	67.58 ± 1.64a	18.77 ± 1.15a
	SGL	64.19 ± 8.99a	0.70 ± 0.08b	1.30 ± 0.07ab	0.87 ± 0.42b	10.64 ± 0.61a	70.22 ± 0.74a	19.13 ± 1.13a
10–20	NGL	64.06 ± 0.00a	0.22 ± 0.12ab	1.30 ± 0.04a	2.32 ± 0.29a	5.54 ± 0.80a	71.08 ± 0.81a	23.37 ± 0.13a
	AO	61.73 ± 0.31a	0.10 ± 0.06b	1.37 ± 0.01b	1.77 ± 0.19ab	21.25 ± 8.23a	59.94 ± 3.83b	18.79 ± 4.94a
	AAO	65.24 ± 3.85a	0.43 ± 0.14a	1.22 ± 0.09a	2.53 ± 0.26a	10.75 ± 5.58a	68.61 ± 0.83a	20.62 ± 4.77a
	FLm	63.06 ± 2.76a	0.15 ± 0.02b	1.24 ± 0.18ab	1.96 ± 0.16ab	9.8365 ± 0.67a	71.47 ± 0.63a	18.69 ± 1.29a
	FLw	60.80 ± 3.19a	0.16 ± 0.06b	1.24 ± 0.02a	2.09 ± 0.56ab	7.94 ± 1.59a	70.71 ± 0.58a	21.33 ± 1.78a
	SGL	66.84 ± 3.29a	0.19 ± 0.02ab	1.28 ± 0.05a	1.20 ± 0.28b	8.27 ± 0.87a	71.68 ± 0.12a	20.04 ± 0.79a
20–30	NGL	63.33 ± 0.36ab	0.35 ± 0.22a	1.19 ± 0.04ab	1.69 ± 0.18ab	12.27 ± 5.29a	68.79 ± 0.53ab	18.92 ± 5.00a
	AO	58.85 ± 3.02b	0.28 ± 0.07a	1.33 ± 0.24b	1.65 ± 0.11ab	4.42 ± 0.71a	70.26 ± 1.69ab	25.31 ± 2.40a
	AAO	58.93 ± 0.06b	0.42 ± 0.21a	1.34 ± 0.03ab	2.19 ± 0.38a	16.68 ± 5.01a	68.34 ± 0.93ab	14.97 ± 4.08a
	FLm	66.17 ± 3.24a	0.13 ± 0.04a	1.32 ± 0.26ab	1.63 ± 0.06ab	21.24 ± 6.92a	65.72 ± 2.23b	13.03 ± 5.21a
	FLw	58.46 ± 1.85b	0.38 ± 0.33a	1.33 ± 0.03a	2.37 ± 0.69a	9.11 ± 1.86a	71.20 ± 0.73ab	19.67 ± 1.24a
	SGL	60.59 ± 0.49ab	0.17 ± 0.05a	1.31 ± 0.01a	0.97 ± 0.16b	7.83 ± 0.32a	72.10 ± 0.74a	20.05 ± 0.88a
30–40	NGL	61.61 ± 0.64ab	0.21 ± 0.09a	1.37 ± 0.04a	1.67 ± 0.15a	4.41 ± 0.23a	70.02 ± 0.18a	25.55 ± 0.23a
	AO	59.40 ± 1.72ab	0.09 ± 0.01a	1.48 ± 0.18b	1.70 ± 0.15a	11.25 ± 6.54a	69.93 ± 1.97a	18.80 ± 4.63a
	AAO	79.73 ± 17.10a	0.28 ± 0.19a	1.47 ± 0.04ab	1.08 ± 0.16b	14.18 ± 3.64a	70.20 ± 0.52a	15.60 ± 3.71a
	FLm	44.81 ± 5.01b	0.03 ± 0.01a	1.30 ± 0.12ab	1.45 ± 0.06ab	8.70 ± 0.28a	71.05 ± 0.26a	20.23 ± 0.54a
	FLw	62.01 ± 0.56ab	0.08 ± 0.04a	1.22 ± 0.11b	1.24 ± 0.17ab	9.27 ± 1.10a	72.25 ± 0.23a	18.46 ± 1.12a
	SGL	59.93 ± 0.28ab	0.14 ± 0.01a	1.37 ± 0.05ab	1.42 ± 0.27ab	7.25 ± 0.8a	72.57 ± 0.21a	20.17 ± 0.74a
40–50	NGL	57.99 ± 1.01a	0.20 ± 0.09a	1.43 ± 0.13a	1.59 ± 0.02a	14.64 ± 5.7a	69.27 ± 0.96a	16.07 ± 5.08a
	AO	57.46 ± 1.49a	0.04 ± 0.03a	1.43 ± 0.14a	1.24 ± 0.01ab	11.82 ± 8.37a	67.81 ± 3.03a	20.35 ± 5.60a
	AAO	56.40 ± 1.52a	0.18 ± 0.11a	1.40 ± 0.04a	1.54 ± 0.04a	5.20 ± 0.16a	71.90 ± 0.69a	22.89 ± 0.69a
	FLm	54.89 ± 2.72a	0.38 ± 0.30a	1.33 ± 0.03a	0.78 ± 0.12c	10.37 ± 0.45a	70.73 ± 0.43a	18.88 ± 0.89a
	FLw	52.25 ± 3.93ab	0.15 ± 0.13a	1.26 ± 0.10a	1.11 ± 0.26BC	8.15 ± 1.27a	72.93 ± 0.35a	18.90 ± 1.09a
	SGL	46.97 ± 0.67b	0.27 ± 0.21a	1.23 ± 0.10a	1.03 ± 0.12BC	7.51 ± 0.09a	73.97 ± 0.42a	18.51 ± 0.50a
50–60	NGL	57.40 ± 0.67BC	0.36 ± 0.22a	1.24 ± 0.10a	1.48 ± 0.14ab	29.71 ± 12.15a	58.80 ± 6.88a	11.41 ± 5.29a
	AO	60.14 ± 0.28ab	0.11 ± 0.01ab	1.33 ± 0.13a	1.38 ± 0.12b	3.37 ± 0.47a	70.62 ± 0.66a	25.99 ± 1.13ab
	AAO	50.79 ± 5.18c	0.12 ± 0.04ab	1.45 ± 0.14a	2.11 ± 0.35a	18.71 ± 6.81a	67.42 ± 2.64a	13.80 ± 4.23ab
	FLm	57.38 ± 2.30BC	0.04 ± 0.02b	1.31 ± 0.08a	0.66 ± 0.13c	9.14 ± 1.13a	70.92 ± 0.71a	19.92 ± 1.67ab
	FLw	55.09 ± 0.12bc	0.03 ± 0.02b	1.37 ± 0.03a	1.08 ± 0.35BC	8.46 ± 0.86a	72.86 ± 0.26a	18.67 ± 0.80ab
	SGL	66.82 ± 3.97a	0.05 ± 0.02b	1.37 ± 0.09a	0.90 ± 0.06BC	6.63 ± 1.06a	73.24 ± 0.49a	20.11 ± 0.59b

Note. Soil basic properties under different land use systems, NGL, AO, AAO, Flm, Flw, and SGL, the mean of triplicates with standard errors, the values with a similar lowercase letter within the column of different land uses and soil layers are not significantly different ($p \leq 0.05$). AAO: abandoned apple orchard; AO: apple orchard; Flm: farmland maize; Flw: farmland wheat; NGL: natural grassland; SGL: scrub grassland.

infiltration rates recorded in NGL, AAO, and SGL were more noticeable than all others whereas an ascending order was recorded as AAO, SGL, NGL, Flm, Flw, and AO (Figure 3).

3.3 | Root image analysis

The analysis result of root images is presented in Figure 4 with the root images categorized as root length density cm cm^{-3} (RLD), root surface area cm^2 cm^{-3} (RSA), and average root diameter mm (ARD; Stokes, Atger, Bengough, Fourcaud, & Sidle, 2009). The maximum root RLD, RSA, and ARD were recorded in NGL 6.97 ± 0.344 cm cm^{-3}, 1.56 ± 0.24 cm^2 cm^{-3}, and 0.814 ± 0.24 mm in comparison with other land use at 0–10 cm depth in the soil profile (Figure 4). The minimum results were recorded in AO 0.51 ± 0.03 cm cm^{-3}, 0.49 ± 0.12 cm^2 cm^{-3}, and 1.88 ± 0.24 mm among Flm, Flw, SGL, and AAO at 0–10 cm depth in the soil profile. The results of root parameters were decreased with increase in the depth of soil layers. So different land uses and the depth of soil layers may have different root characters (Figure 4), though not statistically significant ($p \leq 0.05$).

3.4 | Soil water characteristic curve

The result of SWCC is presented in Figure 5 and showed that the maximum soil water content (θ_r) at 0–10 cm of soil depth were recorded in SGL 0.45 ± 0.01 (at 0 pressure head and 240 min for saturation period), and at the same soil depth, the minimum of soil water content was recorded in Flm (0.04 ± 0.001) with the time interval of 90 min under the pressure head of 10,200 cm (Figure 5). Furthermore, the water content (θ_r) decreases with an increase of pressure head and time period. In comparing Flm and Flw, Flw has greater water content under the same pressure head (Figure 5). The results also indicated that SWCC at different depths of layers 0–10, 10–20, 20–30, 30–40, 40–50, and 50–60 cm are impartially similar. The results are also different in soil layers under different land uses (Figure 5).

4 | DISCUSSION

The degradation of soil leads to the loss of vegetation, which in turn worsens the soil erosion (wind and water). The change in land use
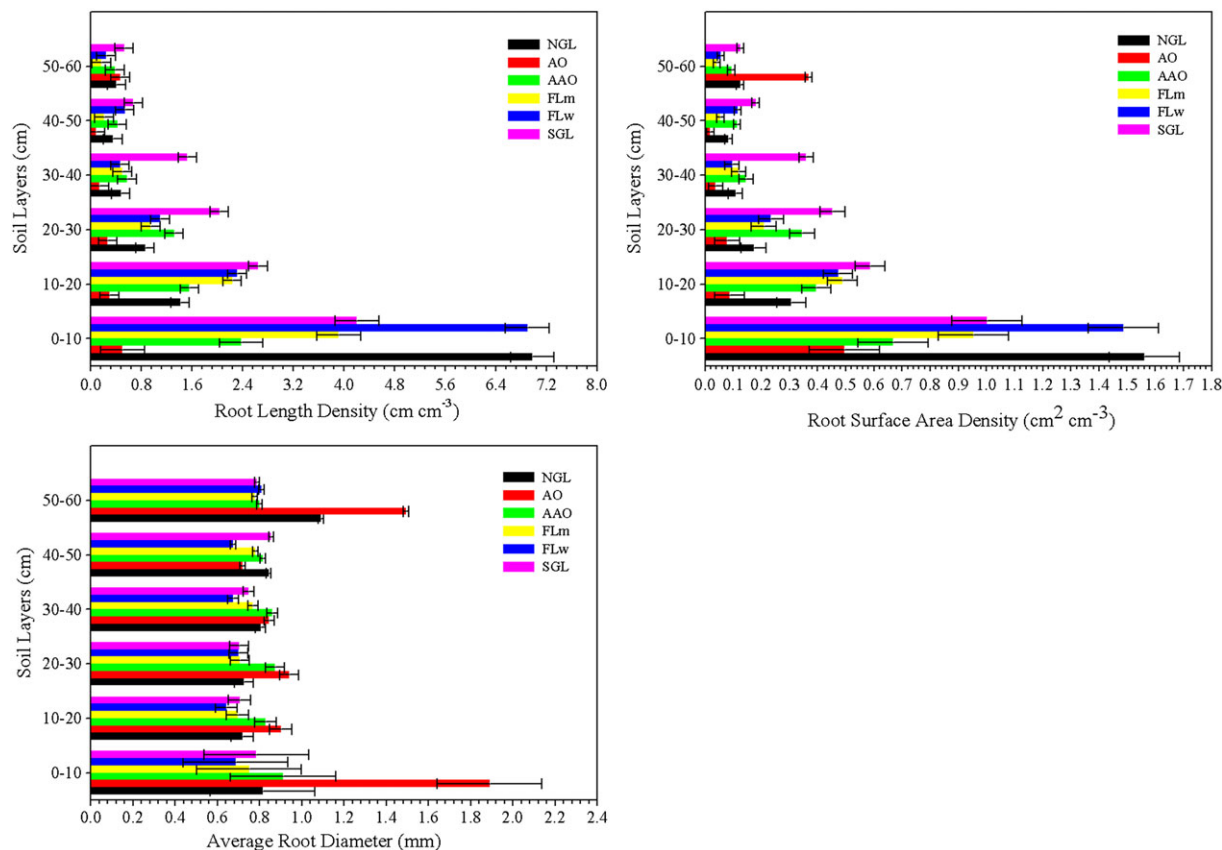
FIGURE 3 Root image analysis (root length density, root surface area, and average root diameter), under different land uses of NGL, AO, AAO, Flm, Flw, and SGL, the mean results in triplicate with standard errors. AAO: abandoned apple orchard; AO: apple orchard; Flm: farmland maize; Flw: farmland wheat; NGL: natural grassland; SGL: scrub grassland [Colour figure can be viewed at wileyonlinelibrary.com]

systems, primarily through conversion of natural vegetation, may employ a great influence on various natural environmental processes, and unsuitable agriculture practices may result in the degradation of the naturally restored plant ecosystems. The study showed that soil hydraulic properties were considerably improved on slopes in NGL, SGL, and AAO after the land was abandoned for 15–18 years. This has also been realized in many studies (Kalhoro et al., 2017; Y. Zhao et al., 2013). The changes of the infiltration rate are directly correlated with vegetation feature and soil property (Neris, Jimenez, Fuentes, Morillas, & Tejedor, 2012). The changes could increase the percentage of SOM in the soil, which develop soil structure and soil porosity. The same type of experiments have been conducted and revealed that grassland had a higher infiltration rate than cropland (Huang et al., 2016). Similar findings were observed in NGL, AAO, and SGL that the higher amounts of SOM play a major role in improving infiltration status (Yuksek & Yuksek, 2011). Furthermore, the formation of macropores, root channels, and preferential flow paths could reduce the runoff water and water erosion (Bargues et al., 2014). Such kind of changes was also observed in some studies (King & Bjorneberg, 2012) partially in line with our findings (Liu, Fu, Lu, Wang, & Gao, 2012) that the BD is slightly higher in farmland as compared with NGL, AAO, and SGL (Table 2). We assume that soil hydraulic conductivity and mainly soil infiltration rate play a major role in the soil physicochemical properties, due to much variations of vegetation cover for different land uses with more vegetation in NGL, AAO, and SGL and less in AO, Flm, and Flw.

SWCC shows the connection between water suction and water content of an unsaturated field. It is an important factor for analysis and soil behavior (Gens, 2010; Nuth & Laloui, 2008). The observation of this study shows that water retention curves of different land uses are fairly similar in terms of soil depths. The results are slightly significant with regard to different land uses, that is, NGL, SGL, AO, AAO, Flm, and Flw at the high-pressure head (Figure 5). The similarity may be due to the similar weather and environmental conditions (at least in the present study period) for different land uses, but the main cause might be that soil structure and texture are the leading aspects of the water suction controlling the water retention (Manoli et al., 2014). Many researchers have observed that NGL, SGL, and abandoned lands had more macropores than cultivated land (Tarantino, 2010), which is consistent with our findings that the NGL and SGL is in favor of the formation of macropores and root channels by the activity of soil fauna and decayed plant roots (Moore, Burch, & Wallbrink, 1986) and that they had more air capacity whereas farmland had less macropore (Schwarzel et al., 2011), mainly due to tillage operations that possibly destroyed the root channels and mainly caused the formation of macropores (Cai et al., 2015; Y. Wang, Fan, Cao, & Liang, 2015).

Root image analysis is an important and commonly used method for examining roots. Computerized root image analysis provides more data such as RLD, RSA, and ARD at different angles and compared with other methodologies. The diameter of roots is important for agricultural ecosystems (Sadeghi, Vangah, & Safaeeian, 2007). The growth
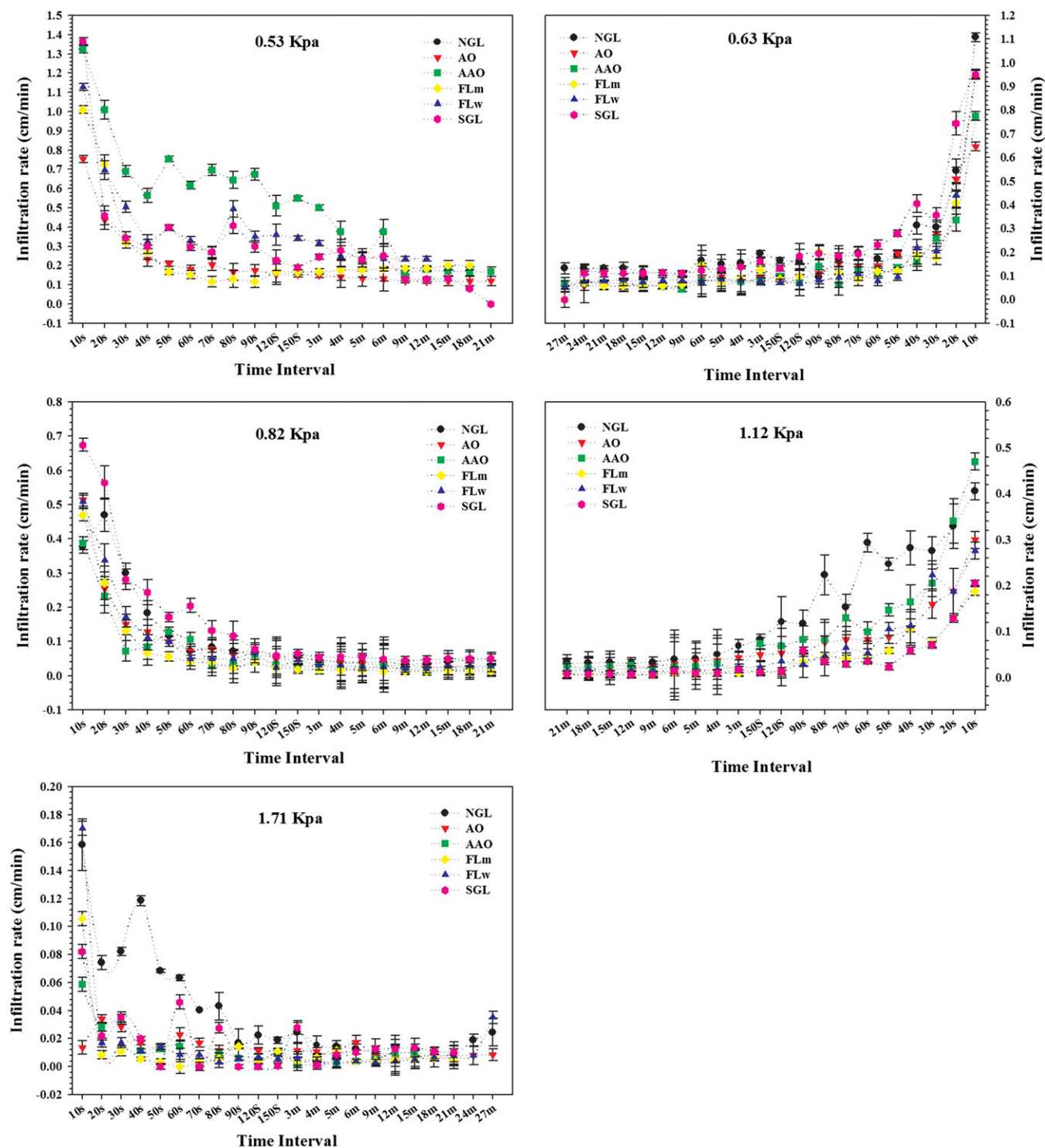
FIGURE 4 Infiltration rate of different land uses of NGL, AO, AAO, Flm, Flw, and SGL, the mean results in triplicate with standard errors and with applied different pressures (0.53, 0.63, 0.82, and 1.12 kpa). AAO: abandoned apple orchard; AO: apple orchard; Flm: farmland maize; Flw: farmland wheat; NGL: natural grassland; SGL: scrub grassland [Colour figure can be viewed at wileyonlinelibrary.com]

of roots is important for soil porosity (Banger, Kukal, Toor, Sudhir, & Hanumanthraju, 2009). Being used for soil microorganisms and their populations (Loranger, Ponge, Blanchart, & Lavelle, 1998), the root growth and its distribution play a key role for enhancement of soil physicochemical properties (Goss, 1991). The results of RLD, RSA, and ARD were recorded in a descending order as NGL, AAO, Flw, Flm, SGL, and AO. The decayed and growing roots are the primary pool for SOM in the soil. The diameters of roots and SOM are taken

as the primary supporting factors playing a major role in the soil hydraulic properties, particularly for soil infiltration rate and SWCC (Poeplau et al., 2011). Better infiltration rate and SWCC recorded in NGL and SGL compared with other land uses (Figures 4 and 5) were associated with more SOM and root biomass (Table 2) as revealed by other researchers (Huang et al., 2016; Mamedov, Huang, Aliev, & Levy, 2017; Poeplau et al., 2011; Y. Wang et al., 2015; Yu et al., 2015). There are limited RLD, RSA, and ARD in AO compared with
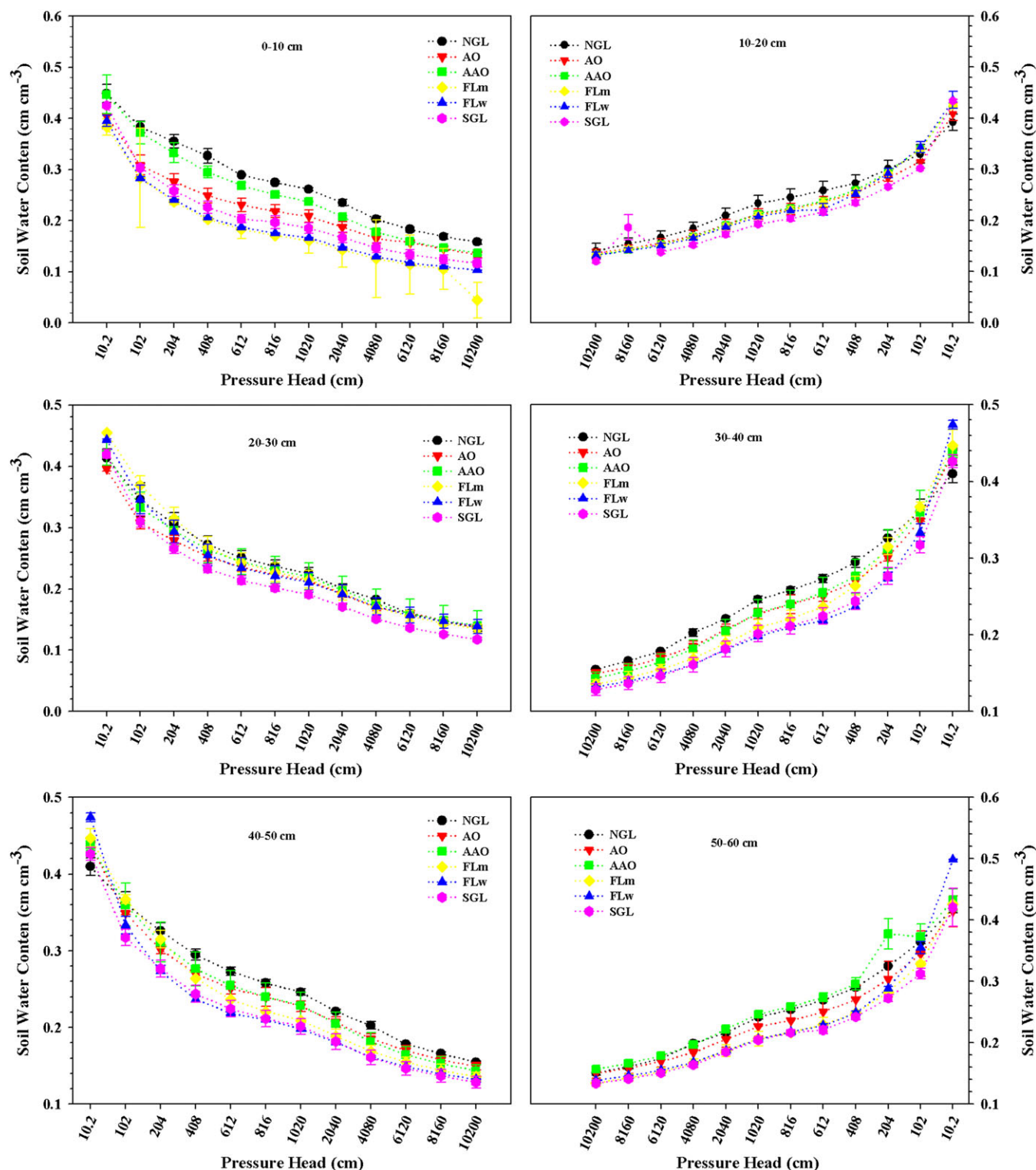
FIGURE 5 Soil water characteristic curve (cm cm^{-3}) under different land uses and in soil layers of NGL, AO, AAO, Flm, Flw, and SGL, the mean results in triplicate with standard errors and with applied different pressures. AAO: abandoned apple orchard; AO: apple orchard; Flm: farmland maize; Flw: farmland wheat; NGL: natural grassland; SGL: scrub grassland [Colour figure can be viewed at wileyonlinelibrary.com]

NGL, AAO, SGL, FLm, and Flw, which we assumed is due to farmers practice during crop growth as all types of vegetation have been removed from the soil surface to maintain a clean field. All land use system showed different correlate relationships with root parameters. Generally, SOM has significantly ($p \leq 0.05$) positive correlation with root parameters such as RB, RLD, RSA, and ARD in all land use systems except in scrub grassland land followed by apple orchard.

Similarly, STP has a positive correlation with root parameters in apple orchard, abandoned apple orchard, and scrub grassland. However, it has a nonsignificant and negative impact on root parameters in farmland maize and farmland wheat, respectively. Likewise, soil texture (silt, clay, and sand) has no any significant correlation with natural grassland and apple orchard land use. But in case of an abandoned apple orchard, farmland wheat, and scrub grassland, silt showed a

negative correlation with root parameters. The changes in the correlation among the soil properties (SOM, STP, BD, RB, and related soil properties) indicated that soil factors have a significant effect on soil hydraulic properties.

5 | CONCLUSION

Usually, vegetation restoration is a promising approach to control soil losses, especially in area such as Chinese Loess Plateau. The observation of this study showed that plant roots of different communities could be effective factors in improving soil hydraulic properties and controlling soil losses. The dense root growth system is highly effective for favorable soil infiltration rate and many other related soil properties (such as SOM, root biomass, soil moisture content, and flow of water). The positive effect of different plant communities on surface and subsurface soil layers were observed in natural grassland, abandoned apple orchard, and scrub grassland compared with farmland wheat and maize. The considerably improved soil infiltration was mainly attributed to the perfection of soil particle distributions, soil porosity, and root mass density.

Root image analysis shows that the root system (root biomass, root length density, root surface area, and average root diameter) of natural grassland, abandoned apple orchard, and farmland wheat occupied more space than apple orchard and farmland maize. In conclusion, this study suggests that the transformation of different land uses is important for improving soil hydraulic conductivity and mitigating soil and water losses in the Chinese Loess Plateau, particularly for cultivated cropland.

CONFLICT OF INTEREST

All authors have declared that no competing of interest exists.

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REFERENCES

Banger, K., Kukal, S., Toor, G., Sudhir, K., & Hanumanthraju, T. (2009). Impact of long-term additions of chemical fertilizers and farm yard manure on carbon and nitrogen sequestration under rice-cow pea cropping system in semi-arid tropics. *Plant and Soil*, 318, 27–35. https://doi.org/10.1007/s11104-008-9813-z

Bargues, A., Tobella Reese, H., Almaw, A., Bayala, J., Malmer, A., Laudon, H., & Ilstedt, U. (2014). Effects of trees on infiltrability and preferential flow in two contrasting agro-ecosystems in Central America. *Water Resource Research*, 50, 3342–3354. https://doi.org/10.1016/j.agee.2013.10.027

Cai, J., Zeng, Z., Connor, J. N., Huang, C. Y., Melino, V., Kumar, P., & Miklavcic, S. J. (2015). Root graph: A graphic optimization tool for automated image analysis of plant roots. *Journal of Experimental Botany*, 66, 6551–6562. https://doi.org/10.1093/jxb/erv359

Chartier, M. P., Rostagno, C. M., & Pazos, G. E. (2011). Effects of soil degradation on infiltration rates in grazed semiarid rangelands of northeastern Patagonia, Argentina. *Journal of Arid Environments*, 75, 656–661. https://doi.org/10.1016/j.jaridenv.2011.02.007

Chen, L. D., Wang, J. P., Wei, W., Fu, B., & Wu, D. (2010). Effects of landscape restoration on soil water storage and water use in the Loess Plateau Region, China. *Forest Ecology and Management*, 259, 1291–1298. https://doi.org/10.1016/j.foreco.2009.10.025

Fisher, R. F., & Binkley, D. (2013). *Ecology and management of forest soils* (4th ed.). Chichester: Wiley-Blackwell.

Gens, A. (2010). Soil-environment interactions in geotechnical engineering. *Geotechnique*, 60, 3–74. https://doi.org/10.1680/geot.9.P.109

George, E., Rolf, S., & John, R. (2013). *Methods of soil, plant and water analysis: A manual for the West Asia and North Africa region* (3rd ed.). Beirut, Lebanon: ICARDA.

Gonzalez-Sosa, E., Braud, I., Dehotin, J., Lassabatere, L., Angulo-Jaramillo, R., Lagouy, M., ... Michel, K. (2010). Impact of land use on the hydraulic properties of the topsoil in a small French catchment. *Hydrological Processes*, 24, 2382–2399. https://doi.org/10.1002/hyp.7640

Goossens, D., & Buck, B. (2009). Dust emission by off-road driving: Experiments on 17 arid soil types, Nevada, USA. *Geomorphology*, 107(3–4), 118–138. https://doi.org/10.1016/j.geomorph.2008.12.001

Goss, M. J. (1991). Consequences of the activity of roots on soil. In D. Atkinson (Ed.), *Plant root growth an ecological perspective. Special Publication Number 10 British Ecological Society*. London: Blackwell Scientific Publications.

Himmelbauer, M. L., Loiskandl, W., & Kastanek, F. (2004). Estimating length, average diameter and surface area of roots using two different image analyses systems. *Plant and Soil*, 260, 111–120. https://doi.org/10.1023/B:PLSO.0000030171.28821.55

Huang, Z., Tian, F. P., Wu, G. L., Liu, Y., & Dang, Q. (2016). Legume grasslands are in favour of promoting precipitation infiltration than Gramineous grasslands in the arid regions. *Land Degradation & Development*, 28, 309–316. https://doi.org/10.1002/ldr.2635

Jarvis, N. J., & Messing, I. (1995). Near-saturated hydraulic conductivity in soils of contrasting texture measured by tension infiltrometer. *Soil Science Society of American Journal*, 59, 27–34. https://doi.org/10.2136/sssaj1995.03615995005900010004x

Jegou, D., Schrader, S., Diestel, H., & Cluzeau, D. (2001). Morphological, physical and biochemical characteristics of burrow walls formed by earthworms. *Applied Soil Ecology*, 17, 165–174. https://doi.org/10.1016/S0929-1393(00)00136-0

Jiao, F., Wen, Z. M., & An, S. S. (2011). Changes in soil properties across a chronosequence of vegetation restoration on the Loess Plateau of China. *Catena*, 86, 110–116. https://doi.org/10.1016/j.catena.2011.03.001

Kalhoro, S. A., Xu, X., Chen, W., Hua, R., Raza, S., & Ding, K. (2017). Effects of different land-use systems on soil aggregates: A case study of the Loess Plateau (Northern China). *Sustainability*, 9, 1349. https://doi.org/10.3390/su9081349

King, B. A., & Bjorneberg, D. L. (2012). Transient soil surface sealing and infiltration model for bare soil under droplet impact. *American Society of Agricultural and Biological Engineers*, 55, 937–945. https://doi.org/10.13031/2013.41525

Kodesova, R., Jirk, U., Kodes, V., Muhlhanselova, M. A., & Zigova, A. (2011). Soil structure and soil hydraulic properties of Haplic Luvisol used as arable land and grassland. *Soil and Tillage Research*, 111, 154–161. https://doi.org/10.1016/j.still.2010.09.007

Kumar, P., Huang, C. Y., Cai, J. H., & Miklavcic, S. J. (2014). Root phenotyping by root tip detection and classification through statistical learning. *Plant and Soil*, 380, 193–209. https://doi.org/10.1007/s11104-014-2071-3

Lavelle, P., Rouland, C., Binet, F., Diouf, M., & Kersante, A. (2004). *Regulation of microbial activities in functional domains of roots and invertebrates*. Berlin: Springer Verlag.

Leung, A. K., Garg, A., Coo, J. L., Ng, C. W. W., & Hau, B. C. H. (2015). Effects of the roots of *Cynodon dactylon* and *Schefflera heptaphylla* on water infiltration rate and soil hydraulic conductivity. *Hydrological Processes*, *29*, 3342–3354. https://doi.org/10.1002/hyp.10452

Li, X. Y., Contreras, S., Sole-Benet, A., Canton, Y., Domingo, F., Lazaro, R., … Puigdefabregas, J. (2011). Controls of infiltration–runoff processes in Mediterranean karst rangelands in SE Spain. *Catena*, *86*, 98–109. https://doi.org/10.1016/j.catena.2011.03.003

Li, Y., Jiao, J., Wang, Z., Cao, B., Wei, Y., & Hu, S. (2016). Effects of revegetation on soil organic carbon storage and erosion-induced carbon loss under extreme rainstorms in the hill and gully region of the Loess Plateau. *International Journal of Environmental Research and Public Health*, *13*, 456. https://doi.org/10.3390/ijerph13050456

Li, Y. Y., & Shao, M. A. (2006). Change of soil physical properties under long-term natural vegetation restoration in the Loess Plateau of China. *Journal of Arid Environments*, *64*, 77–96. https://doi.org/10.1016/j.jaridenv.2005.04.005

Liu, Y., Fu, B., Lu, Y. H., Wang, Z., & Gao, G. Y. (2012). Hydrological responses and soil erosion potential of abandoned cropland in the Loess Plateau, China. *Geomorphology*, *138*, 404–414. https://doi.org/10.1016/j.geomorph.2011.10.009

Loranger, G., Ponge, J. F., Blanchart, E., & Lavelle, P. (1998). Impact of earthworms on the diversity of microarthropods in a vertisol (Martinique). *Biology and Fertility of Soils*, *27*, 21–26. https://doi.org/10.1007/s003740050394

Mamedov, A. I., Huang, C., Aliev, F. A., & Levy, G. J. (2017). Aggregate stability and water retention near saturation characteristics as affected by soil texture, aggregate size and polyacrylamide application. *Land Degradation & Development*, *8*, 543–552. https://doi.org/10.1002/ldr.2509

Manoli, G., Bonetti, S., Domec, J. C., Putti, M., Katul, G., & Marani, M. (2014). Tree root systems competing for soil moisture in a 3D soil–plant model. *Advances in Water Resources*, *66*(2), 32–42. https://doi.org/10.1016/j.advwatres.2014.01.006

Mchunu, C. N., & Chaplot, V. (2012). Land degradation impact on soil carbon losses through water erosion and CO_2 emissions. *Geoderma*, *177*, 72–79. https://doi.org/10.1016/j.geoderma.2012.01.038

Michaelides, K., Lister, D., Wainwright, J., & Parsons, A. J. (2009). Vegetation controls on small-scale runoff and erosion dynamics in a degrading dry land environment. *Hydrological Processes*, *23*, 1617–1630. https://doi.org/10.1002/hyp.7293

Moore, I. D., Burch, G. J., & Wallbrink, P. J. (1986). Preferential flow and hydraulic conductivity of forest soils. *Soil Science Society of American Journal*, *50*, 876–881. https://doi.org/10.2136/sssaj1986.03615995005000040009x

Neris, J., Jimenez, C., Fuentes, J., Morillas, G., & Tejedor, M. (2012). Vegetation and land-use effects on soil properties and water infiltration of Andisols in Tenerife (Canary Islands, Spain). *Catena*, *98*, 55–62. https://doi.org/10.1016/j.catena.2012.06.006

Nuth, M., & Laloui, L. (2008). Advances in modeling hysteretic water retention curve in deformable soils. *Computers and Geotechnics*, *35*, 835–844. https://doi.org/10.1016/j.compgeo.2008.08.001

Poeplau, C., Don, A., Vesterdal, L., Leifeld, J., Van, W. B., Schumacher, J., & Gensior, A. (2011). Temporal dynamics of soil organic carbon after land-use change in the temperate zone carbon response functions as a model approach. *Global Change Biology*, *17*, 2415–2427. https://doi.org/10.1111/j.1365-2486.2011.02408.x

Ren, Z. P., Zhu, L. J., Wang, B., & Cheng, S. D. (2016). Soil hydraulic conductivity as affected by vegetation restoration age on the Loess Plateau, China. *Journal of Arid Land*, *8*, 546–555. https://doi.org/10.1007/s40333-016-0010-2

Sadeghi, S. H. R., Vangah, G. B., & Safaeeian, N. A. (2007). Comparison between effects of open grazing and manual harvesting of cultivated summer rangelands of northern Iran on infiltration, runoff and sediment yield. *Land Degradation & Development*, *18*, 608–620. https://doi.org/10.1002/ldr.799

Scholl, P., Leitner, D., Kammerer, G., Loiskandl, W., Kaul, H. P., & Bodner, G. (2014). Root induced changes of effective 1D hydraulic properties in soil column. *Plant and Soil*, *38*, 193–213. https://doi.org/10.1007/s11104-014-2121-x

Schwarzel, K., Carrick, S., Wahren, A., Feger, K. H., Bodner, G., & Buchan, G. (2011). Soil hydraulic properties of recently tilled soil under cropping rotation compared with 2-years-pasture: Measurement and modeling the soil structure dynamics. *Vadose Zone Journal*, *11*, 354–366. https://doi.org/10.2136/vzj2010.0035

Shwetha, P., & Varija, K. (2015). Soil water retention curve from saturated hydraulic conductivity for sandy loam and loamy sand textured soils. *Aquatic Procedia*, *4*, 1142–1149. https://doi.org/10.1016/j.aqpro.2015.02.145

Stokes, A., Atger, C., Bengough, A. G., Fourcaud, T., & Sidle, R. C. (2009). Desirable plant roots traits for protection natural and engineered slopes against landslides. *Plant and Soil*, *324*, 1–30. https://doi.org/10.1007/s11104-009-0159-y

Tarantino, A. (2010). Unsaturated soils: Compaction versus reconstituted states. In *5th International Conference on unsaturated Soils*, Alonso & Gens (eds). Taylor & Francis Group, London.

Wahl, N. A., Bens, O., Schafer, B., & Huttl, R. F. (2003). Impact of changes in land-use management on soil hydraulic properties: Hydraulic conductivity, water repellency and water retention. *Physics and Chemistry of the Earth*, *28*, 1377–1387. https://doi.org/10.1016/j.pce.2003.09.012

Wang, B., Liu, G. B., Xue, S., & Zhu, B. B. (2010). Changes in soil physico-chemical and microbiological properties during natural succession on abandoned farmland in the Loess Plateau. *Environmental Earth Sciences*, *62*, 915–925. https://doi.org/10.1007/s12665-010-0577-4

Wang, Y., Fan, J., Cao, L., & Liang, Y. (2015). Infiltration and runoff generation under various cropping patterns in the red soil region of China. *Land Degradation & Development*, *27*, 83–91. https://doi.org/10.1002/ldr.2460

Yu, M. Z., Zhang, L. L., X, X., Feger, K. H., Wang, Y. H., Liu, W. Z., & Schwarzel, K. (2015). Impact of land-use changes on soil hydraulic properties of caloric regosols on the Loess Plateau, NW China. *Journal of Plant Nutrition and Soil Science*, *178*, 486–498. https://doi.org/10.1002/jpln.201400090

Yuksek, T., & Yuksek, F. (2011). The effects of restoration on soil properties in degraded land in the semi-arid region of Turkey. *Catena*, *84*, 47–53. https://doi.org/10.1016/j.catena.2010.09.002

Zhao, X., Wu, P., Gao, X., Tian, L., & Li, H. (2014). Changes of soil hydraulic properties under early-stage natural vegetation recovering on the Loess Plateau of China. *Catena*, *113*, 386–391. https://doi.org/10.1016/j.catena.2013.08.023

Zhao, Y., Wu, P., Zhao, S., & Feng, H. (2013). Variation of soil infiltrability across a 79-year chronosequence of naturally restored grassland on the Loess Plateau, China. *Journal of Hydrology*, *504*, 94–103. https://doi.org/10.1016/j.jhydrol.2013.09.039

Zhi, L., Liu, W., Zhang, X., & Zhang, L. (2009). Impacts of land use change and climate variability on hydrology in an agricultural catchment on the Loess Plateau of China. *Journal of Hydrology*, *377*, 35–32. https://doi.org/10.1016/j.jhydrol.2009.08.007

Zhou, D. C., Zhao, S. Q., & Zhu, C. (2012). The grain for green project induced land cover change in the Loess Plateau: A case study with Ansai County, Shaanxi, China. *Ecological Indicators*, *23*, 88–94. https://doi.org/10.1016/j.ecolind.2012.03.021