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Effects of Land Use and Management on Soil Hydraulic Properties

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Abstract: Soil hydraulic properties are among the most important parameters that determine soil quality and its capability to serve the ecosystem. Land use can significantly influence soil properties, including its hydraulic conditions; however, additional factors, such as changes in climate (temperature and precipitation), can further influence the land use effects on soil hydraulic properties. In order to develop possible adaptation measures and mitigate any negative effects of land use and climatic changes, it is important to study the impact of land use and changes in land use on soil hydraulic properties. In this paper, we summarize recent studies examining the effect of land use/land cover and the associated changes in soil hydraulic properties, mainly focusing on agricultural scenarios of cultivated croplands and different tillage systems.

Keywords: Land management; Land cover change; Infiltration; Tillage; Agriculture

1 Introduction

Land use change is a complex process shaped by human activity affected by ecological, economic, and social drivers, and capable of influencing a wide range of environmental and economic conditions [1, 2]. When the selection of land use type involves economic considerations, especially for agricultural purposes, the applied management practice is commonly driven by agricultural needs such as crop farming for food supply and cultivation techniques for monetary gains. On the other hand, economic reasons can also drive land abandonment [3].

One of the main challenges related to the selection of applied land use is implementing sustainable and efficient use of natural resources such as soils and surface and subsurface waters. Due to intensified agricultural production, natural resources encounter increasing anthropogenic pressure. Consequently, the effects of land use and land cover change on soil properties have drawn much attention over the past several decades.

In general, two main soil types can be distinguished based on the degree of anthropogenic influence. The first type, genoforms, has minimal impact from human interaction such as forest soil series [4]. The other type, phenoforms, undergoes considerable changes by different land uses such as pasture and cropland [4]. Studies related to land use change effects on soil properties mainly concern phenoforms, as the changes in these soils occur much faster.

Soil formation is a slow process, while soil physical, chemical and biological degradation processes, such as soil compaction [5], erosion [6], acidification [7, 8], decline in organic matter content [9], *etc.*, can occur relatively fast, especially in areas of agricultural land use [10, 11]. The faster pedogenic processes reach steady state after tens to hundreds of years, while slow processes of soil formation evolve on a time scale of thousands to tens of thousands of years [12]. As a result of these faster degradation rates caused by human activities, soil is currently not a sustainable natural resource [10], and both short term and long term consequences need to be addressed to assess and decrease probable soil degradation processes and to preserve soil fertility and healthy soil functioning.

Water and nutrients are essential for plant production and soil functioning; accordingly, it is important to know the impact of various land use types and soil management systems on water and nutrient transport within the soil matrix. During the last century, strong correlations between plant available soil water content and type of cul-

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tivated crop were documented [13, 14]. Moreover, in agricultural systems, the plant available water in soil matrices can affect cultivation methods and economic considerations such as use of an irrigation system. Therefore, understanding the soil hydraulic properties and their changes over time may influence future decision making in both agricultural and environmental sectors.

Soil hydraulic properties, such as soil water retention curve (*SWRC*), soil water diffusivity (D), and soil hydraulic conductivity function (K), are key elements for determining water retention and water movement in soils and, consequently, its accessibility for plant uptake and growth. Soil and crop properties such as soil texture, porosity (n), bulk density (ρ), vegetation types, and root structures can strongly influence the soils' hydraulic properties [15]. Our knowledge of soil hydraulic and physical processes and the associated changes and interactions through soil matrices driven by environmental and/or ecological factors needs to be continuously improved to mitigate potential adverse impacts of future land modifications on soil functioning.

Vegetation is one of the particularly important elements affecting the rate of soil quality changes. Vegetation cover is often considered a major factor in controlling soil processes [15–18]. Vegetation density [19] and types play key role in modifying runoff and soil erosion [20, 21]. Changes in vegetation can occur due to anthropogenic activities, such as changes in agricultural cultivation practices or deforestation, or due to natural sources like wildfire. The interactions between ecological and hydrological processes are key factors for influencing erosion, runoff, and, ultimately, plant growth [22]. Soil degradation resulting from stormwater runoff and erosion, in many cases, can be exacerbated by removing vegetation, which affects soil water holding capacity [20, 23], bulk density, porosity, penetrability, and aggregate or particle size distribution [20, 24]. Wind erosion can also be an important factor in soil degradation processes, which can be altered significantly by changes in land vegetation cover [25].

Soil hydraulic properties can influence subsurface water and solute movement. Hydraulic properties can substantially be altered with land use or cover change and by the impact of environmental conditions such as precipitation or temperature changes [26, 27]. Land use change also indirectly affects climatic conditions on regional and global scales [28]. It has been noted by earlier studies that the average earth surface temperature is increasing, and this trend will most likely continue with a total increase of 1 to 4°C during the 21st century [29]. Temperature, precipitation, wind, and their correlations are very important environmental factors in soil forming processes [30]. To better understand and estimate the potential combined effects of land use change and climate change on soil properties and soil forming processes, we need to expand our knowledge in these areas.

When considering land use change, the most influential anthropogenic activity is connected to agriculture. Therefore, the main objectives of this study were to review recent studies in soil quality and hydrological property changes due to different land use systems, with special focus on agricultural land types, and to summarize the different effects of land use practices presently used in cultivation systems.

The study focuses primarily on short-term and long-term effects of agricultural cultivation methods and land use types on soil hydraulic properties, mainly regarding the combination of predicted land use changes and environmental changes. The study also focuses on changes in soil hydraulic properties caused by different tilling techniques used on agriculturally cultivated lands. In the context of this paper, "land use system" refers to the type of land cover determined or selected by human activity for a given area, and "land management" describes the applied agricultural management practice in reference to agricultural land use including different tillage systems, mulching, fertilization, *etc.* Hence, this review focuses on the effect of the following two factors on soil hydraulic properties: 1) land use types, which deal with cultivation types at a given location (*e.g.* pasture or forest, land use changes), and 2) soil management systems, especially different tillage practices (*e.g.* conventional and conservational tillage).

2 Overview of Soil Hydraulic Properties

Water movement through terrestrial subsurface mainly occurs by infiltration, evapotranspiration, percolation to groundwater, and capillary rise from the groundwater table [31, 32]. The physical and biochemical properties of soil [33] and its vegetation cover [34] greatly influence these processes. In general, the dynamics of the soil water budget comprise the main components of precipitation, infiltration, capillary rise, evapotranspiration, surface runoff, inter (or soil) flow and groundwater flow [35]. The interconnection between the water balance elements can have a strong impact on the plant available soil water content, consequently influencing the choice of crop farming and cultivation techniques.

The amount of water present in soil matrices can influence soil physical factors, including soil temperature and aeration; biotic factors, such as microbial accumulation; and several soil chemical factors [10]. Water flow in unsaturated soils is described with the Richards equation [36]:

$$C(h)\frac{\partial h}{\partial t} = \frac{\partial}{\partial z}\left[K(h)\left(\frac{\partial h}{\partial z} - 1\right)\right] + s$$

where t is time [T], z is spatial coordinate [L], h is the pressure head [L], $C(h)$ is the specific water capacity [L^{-1}] defined by the change of the volumetric water content θ [L^3 L^{-3}] [37]. $C = \partial\theta/\partial h$, $K(h)$ is the unsaturated hydraulic conductivity [L T^{-1}], and s is a source/sink term [T^{-1}] [37].

Water retention capacity of the soil is the soil's ability to absorb and retain water [10] and is characterized by the Soil Water Retention Curve (*SWRC*), which describes the relationship between the soil water content (Θ) and soil water potential (ψ). The *SWRC* is closely related to the soil hydraulic conductivity (K) function. Soil water retention capacity, including other soil parameters such as organic carbon content, dry bulk density, soil macroporosity, soil–matrix porosity, air capacity, plant available water capacity, and saturated hydraulic conductivity, is often used as an indicator of soil physical quality in agricultural soils [10, 38, 39].

The *SWRC* and the K are determined by soil textural, structural and chemical properties. The coarse textured soils, such as sand, retain less water compared to finer textured ones, containing high amounts of clay or silt [10, 40]. Structural changes in soil properties can be expressed by changes in soil bulk density, total porosity, macroporosity, pore-size distribution, *etc*.

Long–term, and even short–term changes in the soil forming factors or changes in soil bulk density, structure, texture, organic matter content and biological activity can influence soil water retention and, consequently, the soil hydraulic properties. Land use change and soil management influence most of the above described soil properties and can also modify infiltration conditions and groundwater recharge; therefore, local changes in soil properties can affect the hydrological conditions of larger areas.

3 Land Use and Its Effects on Soil Hydraulic Properties

The available information regarding changes in soil textural and structural properties induced by land use change and its effect on soil hydraulic properties has increased significantly in the last several decades. However, our knowledge in some areas, such as forest soils and mountainous areas, is still rather limited as most of the studies and monitoring efforts concern cultivated areas [41–43]. Moreover, sensitivity of soils to land use change is also affected by geographical factors, morphological factors and other site specific properties. For instance, a land use change from forest to grassland has a drastically different effect on soil erosion risk and, to a greater extent, on soil hydraulic properties for a hilly/mountainous area compared to an area located in a plain [19, 21]. Similarly, the effect of management practices involving agricultural land, *i.e.*, the sensitivity of the site for erosion caused by tillage, can also vary among sites depending on exposure to wind and water erosion [44].

Changes in soil properties attributed to land use change effects are difficult to estimate due to the time scale of the changes. It is also difficult to distinguish land use induced changes from changes caused by other effects such as changes in climate. However, the effect of climate manifests on a much longer time scale compared to that of land use change. This is especially true for land use change with anthropogenic origin, which typically occurs instantaneously and has an immediately dramatic effect on soil structure. Soil hydraulic properties are influenced by the type of the cultivated plants, the seasonal impact, and land use types such as altered agricultural systems. These particular types of land use demand further research to better understand the long term consequences of land use changes [4].

The evolution of different soil hydrological properties in natural ecosystems, such as forests, can be a relatively slow process; however, in agricultural land use systems, mechanical disturbances, like tillage systems, can rapidly change the soil physical, chemical, and hydrological properties [45]. Since the soil hydraulic functions can determine the soil water regime and the soil water balance elements, the peculiarities of the applied soil tillage systems and the effect of catch crops, undersown crops, *etc*. should be taken into account when investigating the soil water regime of soils under agricultural utilization.

It has been noted by numerous studies that different land use types with changes in land cover can influence the soil's hydraulic properties [4, 26, 46]. Findings of several studies on the effects of different tillage systems and land use types on soil properties are summarized in Tables 1 – 3 and explained in more detail below.

Table 1: Soil properties of *Alfosols*/grey forest soils, *Typic Hapludults*, and *Ultic Hapludalf* soils as influenced by land use. *BD* – dry soil bulk density; *Ksat* – saturated hydraulic conductivity of the soil matrix; K_{sat}_M – saturated hydraulic conductivity with the inclusion of macropores; *PAW* – plant available water, defined as the difference of volumetric water contents at –33 kPa (*FC*) and –1500 kPa (Wilting point – *WP*); *FC* – field capacity defined as the volumetric water content at –33 kPa; alpha – soil texture/structure parameter for macropores (with diameter > 0.03 m), larger for soils with well-developed structure. *CT* stands for conventional tillage.

Soil property	Soil type	Layer (cm)	Land use type and its peculiarity				Source
			forest	grass	arable	abandoned	
				for 7–12 years	*wheat + undersown grass for 5 years*	*for 5 years*	
BD (kg m^{-3})	*Alfosols/grey forest soils (RU)*	0–12		1.14	1.42–1.52		[99]
Water-stable aggregate content					1.5–2.4	8.9–9.4	
$K_{sat}M$ (10^{-6} m s^{-1})				833–1192	< 400	127	
FC (v%)				24.0	42.0		
			small anthropogenic influence	*grazing*	*2 years corn – 1 year alfalfa, CT*		
BD (kg m^{-3})	*Typic Hapludults* 1 (ST, 2009)		1.13	1.58	1.50		[4]
PAW (v%)			20.4	12.5	13.8		
Total C (%)			11.0	3.0	1.5		
alpha (m^{-1})			62 ± 30	69 ± 17	65 ± 28		
K_{sat} (10^{-6} m s^{-1})			17.1–20.2	13.6–18.8	9.7–23.1		
			small anthropogenic influence	*grazing*	*2 years corn – 1 year alfalfa, CT*		
BD (kg m^{-3})	*Typic Hapludults* 2	topsoil	1.64	1.55	1.60		[4]
PAW (v%)			7.2	16.7	15.3		
Total C (%)			11.0	2.1	1.3		
alpha (m^{-1})			83 ± 34	59 ± 19	73 ± 47		
K_{sat} (10^{-6} m s^{-1})			26.6–38.1	3.1–20.6	10,8–14.7		
BD (kg m^{-3})	*Typic Hapludalf*	topsoil	0.88	1.47	1.56		[4]
PAW (v%)			6.3	12.8	8.7		
Total C (%)			7.1	2.0	1.4		
alpha (m^{-1})			73 ± 24	79 ± 41	88 ± 30		
K_{sat} (10^{-6} m s^{-1})			16.2-18.0	6.4-23.9	10.7-31.2		
BD (kg m^{-3})	*Ultic Hapludalf*	topsoil	1.40	1.64	1.85		[4]
PAW (v%)			1.8	4.1	6.9		
Total C (%)			12.1	1.6	0.9		
alpha (m^{-1})			79 ± 38	66 ± 26	73 ± 43		
K_{sat} (10^{-6} m s^{-1})			19.9–30.6	17.7–18.4	10.4–20.1		

Table 2: Soil properties of *Cryrendoll*, Alpine Steppe, and *Haplic Cambisol Dystric* soils as influenced by land use. *BD* – dry soil bulk density; K_{sat}_M – saturated hydraulic conductivity with the inclusion of macropores; *WHC* – water holding capacity (or saturation water content), defined as the volumetric water content at 0 kPa; *PAW* – plant available water, defined as the difference of volumetric water contents at −33 kPa (*FC*) and −1500 kPa (*WP*); *PWC* – productive water content, calculated as the difference between the moisture levels at field capacity (*FC*) and at total retardation point of plant growth (−490 kPa water potential) *I* - infiltrability; *CT* stands for conventional tillage.

Soil property	Soil type	Layer (cm)	Land use types and its peculiarity					Source
			pasture	pasture	cultivated	meadow	abandoned	
			Native	*Perennial*	*Annually cultivated*			
BD (kg m^{-3})	*Cryrendoll*	0–10 cm	0.83	0.81	0.91			[49]
Total organic C (%)			8.0	6.6	5.2			
Porosity (%)	Alpine Steppe Soil		66	68	65			
WHC (v%)			49	43	38			
BD (kg m^{-3})	*Cryrendoll*	20–30 cm	0.96	0.85	1.08			[49]
Total organic C (%)			5.9	6.8	3.5			
Porosity (%)	Alpine Steppe Soil		62	67	59			
WHC (v%)			49	45	41			
			Sheep-grazed		*CT: potato, ryegrass, oat*	*Untreated but harvested*	*Abandoned meadow (10 years)*	
BD (kg m^{-3})	*Haplic Cambisol Dystric*	0–10 cm	1.20		0.93	1.04	1.1	[57]
Porosity (%)			53.0		63.7	59.4	58.4	
Macroporosity (%)			9.14		19.1	11.8	13.0	
K_{sat}_M (10^{-6} m s^{-1})			2763		1998	2862	2631	
PAW (v%)			25.6		20.3	25.1	24.8	
PWC (%)			21.1		16.9	20.8	20.7	
BD (kg m^{-3})	*Haplic Cambisol Dystric*	10–20 cm	1.29		1.27	1.37	1.42	[57]
Porosity (%)			49.8		50.4	46.5	44.4	
Macroporosity (%)			6.4		10.1	6.8	6.3	
K_{sat}_M (10^{-6} m s^{-1})			1051		1072	995	1011	
PAW (v%)			23.7		19.7	21.5	22.2	
PWC (%)			19.6		16.1	17.6	18.3	
			Forest	*Prepasture*	*Pasture*			
I (10^{-3} m s^{-1})	Kandiudults	topsoil	0.42	0.36	0.03			[48]
K_{sat} (10^{-3} m s^{-1})		12.5	206	276	26			
K_{sat} (10^{-3} m s^{-1})		20	36	57	9			
			Natural Forest	*Pasture*	*Forest*			
K_{sat} (10^{-3} m s^{-1})	*Inceptisols* and *Histosols*	12.5	135	14	738			[47]
		20	92	17	130			
		50	11	130	178			

Table 3: Soil properties of a *Haplic Luvisol*, a *Mollic Fluvisol* developed on loam and sandy clay loam soils with grass cover, abandonment time, and tillage types as influenced by land use. *BD* – dry soil bulk density; *Ksat* – saturated hydraulic conductivity of the soil matrix; *WHC* – water holding capacity (or saturation water content), defined as the volumetric water content at 0 kPa; *RWC* – residual water content, defined as the volumetric water content of the soil at -10^6 kPa; *SWRC* represents soil water retention constant. *CT* stands for conventional tillage; *NT* stands for no or zero tillage; and *MT* stands for minimum tillage.

Soil property	Soil type	Layer (cm)	Land use type and its peculiarity					Source
			Grass cover	Tillage type		Abandonment		
			30-year permanently	*CT*				
WHC (v%)	*Haplic Luvisol*	≈ 0–30	46.9–48.9	36.4–39.1				[50]
RWC (v%)			2.6–2.7	1.8–2.4				
K_{sat} (10^{-6} m s^{-1})				2.7				
WHC (v%)	*Haplic Luvisol*	≈ 30–100	41.6–45.3	39.2–41.3				
RWC (v%)			2.4–2.7	1.9–2.3				
K_{sat} (10^{-6} m s^{-1})			2.8–7.9	2.1–9.1				
			Wet meadow	*Arable*				
BD (kg m^{-3})	*Mollic Fluvisol*	0–5	1.26	1.46				[100]
K_{sat} (10^{-6} m s^{-1})			17.01	9.14				
				CT	*MT*	*ZT*		
BD (kg m^{-3})	Sandy clay loam	≈ 0–7.5		1.34	1.34	1.35		[85]
K_{sat} (10^{-6} m s^{-1})				3.98	4.28	4.55		
SWRC				4.2	4.5	4.6		
				Cultivation		*Short-time Abandonment*	*Long-time Abandonment*	
BD (kg m^{-3})	Slope gradient 25%			1.4		1.2	1.7	[21]
Porosity (%)				46		55	36	
Organic matter (%)				5.1		7.8	6.6	
				NT	*CT*			
BD (kg m^{-3})		0–5		1.20	1.38			[88]
Organic C (%)				24.6	13.5			
BD (kg m^{-3})		5–15		1.52	1.51			
Organic C (%)				10.5	11.1			

3.1 Effect of Land Use

Soil holds moisture mostly on the basis of texture, although plant available water can be modified by soil organic matter content because of the way soil particles aggregate.

Zimmermann and Elsenbeer [47] investigated several land cover types and landslides as soil forming processes and their influence on soil structural properties including soil hydraulic conductivity and soil bulk density. The authors found that natural forest conversion to pasture, associated with higher degree of soil disturbance, can decrease soil surface permeability by two orders of magnitude [47]. A study by Zhou *et al.* [4] showed that surface soil hydraulic properties were impacted by the differences in land use and soil types (Table 1), such as generally higher bulk densities and lower hydraulic conductivities for pasture and cropland compared to woodland. However, the authors also noted that in many cases the temporal variability of these properties appeared to be greater than their spatial variation caused by land use and soil series [4].

Zimmermann *et al.* [48] investigated soil hydraulic properties, including hydraulic conductivity at different depths under primary and cleared secondary forest, teak, pasture, and secondary forest after banana–cacao or pasture land types. The authors observed that soil K_{sat} decreases were proportional to the land use intensity; for example, areas with less intense land-use (secondary forest and banana) prior to reforestation had similar K_{sat} values [48]. Li *et al.* [49] investigated the effect of land disturbance, such as cultivation and overgrazing, in an alpine pastureland and found that even slight disturbance of alpine grassland (Table 2), *e.g.*, single cultivation prior to establishing perennial pasture, had a negative impact on soil structural properties and water retention capacity. Although in the present paper the primary focus is on soil hydraulic properties, it is important to point out that the authors discovered that these changes were closely related to losses of soil organic carbon [49]. The deterioration of soil structural properties accelerated soil erosion and decreased soil infiltration and water retention [49]. The authors concluded that the cultivated areas in alpine regions were likely to store less water and can experience higher erosion rates than non–cultivated areas. Kodesová *et al.* [50] observed larger saturated soil water content and larger retention ability of grassland compared to arable land, based on water retention curves of Haplic Luvisol (Table 3). The authors found that soil water retention was significantly higher under permanent grass cover compared to arable soil due to the capillary soil–pore system. The soil water retention curve shapes in the study indicated that the soil, which has not been periodically tilled, contained larger fractions of large capillary pores (pores corresponding to a matrix potential range of −0.2 and 7 kPa) [50]. These pores play key role in water retention [51], soil aeration [52], transport processes [53], plant nutrients distribution [54] and organism activity [40, 55, 56]. In general, land management has been shown to impact both macropores and matrix pores in the tilled layer, while the grassland soil indicated well reestablished stable soil structure with favorable soil hydraulic properties with higher porosity and soil water retention, higher fraction of large capillary pores, and lower fraction of gravitational pores [50, 57]. Changes in soil macropores and matrix pores can greatly influence the water flow [58] that consequently affects nutrient transport through the soil profile [59].

As suggested by some of the studies above, overuse of land and excessive soil disturbance can cause decreases in soil permeability and hydraulic conductivity, and increases in soil bulk density and water retention capacity primarily by modifying the soil structure. These modifications might accelerate soil erosion; therefore, changes in the intensity of land use or, in some cases, even land abandonment can present possible answers to mitigate some of these harmful effects. However, land abandonment can lead to either deterioration or improved conditions for plant cover depending on the type of the soil and regional climatic conditions [3]. Especially in cultivated mountainous areas, to avoid irreversible soil degradation and desertification [3], land abandonments need to occur prior to reaching a critical soil depth when the possibility of soil erosion is high, thus prohibiting natural vegetation recovery. Land use or land abandonment induced soil physical changes have an impact on the water balance at scales going beyond that of a given soil profile. Decrease of water retention in the soil–plant system can cause increases in surface runoff and erosion after intensive rainfall events. Studies, carried out in the Tatra Mountains in Slovakia [60] and in other mountainous areas, emphasize these conclusions [61, 62], indicating that the large–scale deforestation can result in temporary increases in runoff characteristics such as the flashiness index.

3.2 The Effect of Soil Management

The most intensive anthropogenic activity is related to crop production on arable lands. Considering the extent of arable land on the terrestrial surface and the high variety of agricultural management and tillage practices available, the effect of tillage on soil properties has been subject to scientific attention.

Tillage systems, in general, are important areas of conventional farming methods as an approach to enhance crop production. Depending upon the level of mechanical soil disturbance, tillage methods can be generally categorized into several distinct types such as no tillage, conventional tillage (usually intensive tillage such as ploughing or disking), and conservational or reduced tillage [70]. Soil structure can be improved by combining tillage methods with the application of catch crops, undersown crops, and mulching [63]. The selection of the soil tillage system influences soil water retention and infiltration properties as well as soil temperature [64]. However, it has been noted that the decision regarding the most appropriate soil management system for local conditions is based heavily on the prevailing conditions [65], such as soil type, rainfall amount, perennial weed type, or the main type of crop [66–68]. As some studies suggest, changes in soil physical properties and, consequently, soil hydraulic properties can be unfavorably impacted by the degree of disturbance associated with the applied land use or management [48, 69].

Several studies have investigated the effects of conventional and conservation tillage on soil physical and hydraulic properties [71–73]. Conservational tillage is one of the many tillage practices where at least 30% of the soil surface is covered by previous crop residue in order to conserve soil moisture and to reduce soil erosion [74]. In reduced tillage, the relative area covered by crop residue should be between 15 and 30%. The typical cultivation depth in reduced tillage is 5–20 cm. When conventional tillage is employed, minimal crop residue, *i.e.*, less than 15%, is left behind after harvest, and the tillage depth of approximately 20–35 cm [74] is produced by mechanical means such as plough. No–tillage or zero tillage is a technique where the soil cultivation is limited to the seedbed at the time of planting [75]. The type of the tillage system can influence long–term changes in soil properties [73, 76]; however, inter–annual changes can also cause significant alterations. Alletto and Coquet [77] found an increase in soil bulk densities during growing season, while Korsunskaia and Farkas [78] reported strong seasonal dynamic of soil hydraulic properties within different soil tillage systems.

Conservation tillage compared to conventional tillage can lead to soil aggregate stability and improved soil structure due to concentrated soil organic matter near the soil surface [74]. The decomposing crop residue can reduce soil compaction and improve surface soil structure [79], further implying that soil physical properties can be directly related to the amount of organic matter present. Lampurlanes and Cantero-Martinez [80] studied the effects of different tillage systems on soil hydraulic properties. The authors found larger water content and poorer water movement conditions employing no tillage compared to subsoil or minimum tillage. The different tillage types also influence the evaporation, water storage, and water storage efficiencies as found by Lampurlanes *et al.* [81]. The authors reported that no tillage can be a preferable system for fallow lands as it promotes greater root development and root length density due to higher soil water content [81].

Glab *et al.* [57] compared the effects of four land use systems of conventional and reduced tillage, with or without mulching, on soil hydraulic properties. The authors found that the impact of land management on soil physical and hydraulic properties was valuable in the upper 0–10 cm layer (Table 2). An increase in the bulk density was observed due to a decrease in macroporosity, especially in case of sheep–grazed pasture with intensive animal treading [57]. Slawinski *et al.* [82] investigated the soil moisture dynamics and some physicochemical properties of Haplic Cambisol and Eutric Fluvisol soils, *e.g.*, porosity, hydraulic conductivity, and water retention, under traditional or reduced tillage systems cultivated with winter wheat during more, than three years. The authors observed better overall moisture conditions under reduced tillage and significantly higher soil moisture contents during the second year of the investigated period in case of the Eutric Fluviol soil compared to Haplic Cambisol under reduced tillage system [81].

Not only management practices, but also the proper timing and execution of management events, can affect soil quality. Although the application of tillage methods originally intended to make soil more suitable for cultivation, harmful side effects, like subsoil compaction, often occur due to improper application of certain techniques. In order to prevent these damages, several national and international organizations have produced guidelines regarding the suggested best management practices for agriculture. Following published soil-specific guidelines, farmers can minimize the potentially harmful effects caused by poor soil management and maintain soil quality.

Soil properties can change in several ways. For instance, increased traffic in a particular area can result in compaction of soil and, consequently, in reduction of total soil porosity and increase of soil bulk density [83, 84]. Tillage, on the other hand, can loosen up the topsoil, which increases soil porosity [83]. As soil mechanical disturbance changes soil structure and increases soil porosity, it also results in increase of the thickness of the aerobic layer in the tilled depth. This leads to rapid changes in soil hydraulic conductivity. Bhattacharyya *et al.* [85] found that soil K_{sat} values were significantly greater in conventional tillage systems compared to no–tillage practices (Table 3).

The level of soil compaction and changes in soil hydraulic properties can lead to changes in soil erodibility. Surface soil erosion can be influenced by soil compaction parameters. For example, infiltration of water can decrease the degree of soil compaction, thus increasing soil surface erosion [86].

Besides its direct effects via mechanical disturbance, soil tillage has indirect effects on soil conditions by impacting root growth, biological processes, soil organic matter content, and pore–size distribution as well as soil structure. Consequently, besides its direct impacts, soil tillage affects soil water retention and infiltration properties [87] indirectly. Beare *et al.* [88], for example, found 18% higher organic carbon content in soils under no–tillage compared to conventional tillage practice, which impacted soil hydraulic properties (Table 3).

Maintenance of stable soil structure is an important issue from both agricultural and environmental aspects [89]. When soil structural degradation occurs, seedbed collapse can take place, which might result in an anaerobic environment that could become unsuitable for crop growth [90]. Pagliai *et al.* [91] stated that soil structural degradation, especially from an agricultural point of view, is highly related to intensively cultivated arable lands, which are more exposed to soil erosion and desertification. Analyzing different vertisol soils after 64 and 49 years of cultivation, Cook *et al.* [92] found that continuous cultivation can decrease the stability of both wet and dry aggregates. The study also found that long term cultivation decreased hydraulic conductivity of soils indicating surface sealing, consequently, influencing water infiltrability [92]. Along with soil physical degradation, the chemical degradation, such as salinization or acidification, and the biological degradation, such as decline in soil biodiversity or reduced humus quality, simultaneously produces soil structural changes [93].

As soil tillage systems have complex effects on soil physical, hydraulic and chemical properties, it is essential to develop, select and apply site-specific, soil-specific, and soil conserving tillage systems to ensure sustainable crop production.

4 Concluding Remarks

In soil science, the need for integrated methods to investigate soil hydro-physical properties that will enable us to comprehensively evaluate the results of different studies is becoming essential. The outcomes from various studies describing the effect of land use and land use changes on soil hydraulic properties can vary due to the following reasons: 1) the authors use different concepts or classification systems to describe the studied soil types; 2) there is no common soil sampling strategy and the sampled soil layers differ significantly; 3) the authors use different soil properties to represent the land use change effects on soils; 4) there is no common measurement methodology for determining soil properties; and 5) the methods, used for describing soil hydraulic properties are mostly indirect. The time factor is also considerable. When changing land use, the soil functions and, consequently, soil properties will tend to new equilibria corresponding to the changed situation. Therefore, it is challenging to compare the effects of long-term, established land use systems on soil properties with those freshly established. This calls attention to the importance of long-term field trials.

Besides all the constraints described above, the high spatio-temporal heterogeneity of soils also makes difficult to estimate how land use change and different soil management systems might impact the soil hydraulic properties. However, in order to mitigate the possible harmful effects of land use change on soils, to enhance future soil capacities, and to reduce soil degradation and erosion processes, estimation of possible effects of land use change coupled with climate change induced temperature and/or precipitation changes on soil properties and soil forming processes should be taken into account prior to consideration of land use change.

The authors agree that land use change can significantly alter soil hydraulic properties and, consequently, soil quality and vegetation growth. Natural forces such as temperature, precipitation, and wind are very significant environmental factors influencing soil forming processes and soil erosion/degradation processes on both long and short time scales.

Upon analyzing the studies reported by different authors, we can conclude that with intensification of soil disturbance, in general, we can expect a loss of soil organic carbon, an increase in soil bulk density, and a decrease in soil water retention as well as plant available water. In many studies, the most unfavorable soil conditions were found in the abandoned soils or conventionally cultivated soils. In the case of abandoned lands, soil conditions could be improved by re-cultivation of the land. For the majority of arable lands, sustainable soil management practices should be implemented to ensure soil and moisture conservation, improve soil quality, and increase adaptation to projected climate and soil physical changes.

Anthropogenic forcing, such as agricultural demand induced land use changes, *e.g.*, deforestation, can also considerably alter soil quality. Adverse soil quality changes, due to anthropogenic influences, can be significantly reduced if a potential land management system is carefully implemented, especially in cases where mechanical systems will be used. Several studies have found that conservational tillage systems, mainly no or reduced tillage practices, had promising results in terms of soil moisture conservation, which were beneficial for crop production, *e.g.* improved root growth. However, the possible benefits from these management systems often become visible only after several years of application, especially on soils with heavy texture. Even though there are several benefits of conservational tillage systems on soil hydro-physical properties, other aspects might influence land management choices, *e.g.*, additional weed control. Therefore, in the future, more harmonized studies on the effects of different land use types and management systems on soil properties would be necessary to widen our knowledge of the different factors influencing soil quality changes. Sensitivity of soils for degradation as an outcome of land use change can also be site-specific, driven by a combination of climate, topography and geography of the site. Considering their sensitivity as described above, future research should focus more on hilly regions and soils of non-arable sites.

Concerning methodological aspects, in the future it would also be beneficial to apply direct methods for describing the effects of land use and soil management on soil structure and hydraulic properties in addition to the conventional indirect approaches. Non-destructive computer tomography (CT) could be an alternative approach as it enables visualization and quantification of the pore structure of undisturbed soil in 3D [94]. So far, only a few studies have investigated how measures of pore geometry and topology are affected by basic soil properties and management practices [*e.g.* 95–97], and even fewer have investigated how soil pore structure quantified by X-CT scanning influences measured flow and transport processes [*e.g.* 98]. Indeed, X-CT scanning could be an advanced approach in the future for direct visualization and characterization of land and soil management induced changes in soil pore system and soil hydraulic properties.

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