Yuzuncu Yil University Journal of Agricultural Sciences, Volume: 32, Issue: 3, 30.09.2022

Yuzuncu Yil University
Journal of Agricultural Sciences
(Yüzüncü Yıl Üniversitesi Tarım Bilimleri Dergisi)
https://dergipark.org.tr/en/pub/yyutbd

ISSN: 1308-7576 e-ISSN: 1308-7584

Research Article

Evaluation of the Relationship Between Infiltration Rate and Some Soil Properties under Different Land-Use

Gülay KARAHAN*[1], Yavuz Şuayip YALIM[2]

[1]Çankırı Karatekin University, Forest Faculty, Landscape and Architecture Department, 18200, Çankırı, Türkiye
[2]Çankırı Karatekin University, Institute of Science, 18200, Çankırı, Türkiye

[1]https://orcid.org/0000-0003-1285-6546, [2]https://orcid.org/ 0000-0003-2726-7429

*Corresponding author e-mail:gkarahan03@gmail.com

Article Info

Received: 13.06.2022
Accepted: 12.09.2022
Online published: 13.09.2022
DOI: 10.29133/yyutbd.1130123

Keywords

Infiltration rate,
Land conditions,
Morphology,
Factor analysis

Abstract: Soil infiltration rate (IR) is an important parameter and a good indicator of soil quality and fertility. The most influential factors for all conditions where the best performance in infiltration surveys is achieved are soil properties and land-use type. Therefore, a detailed understanding of infiltration is required for different land-use complexes. In this study, the effects of soil properties on IR in soils under different land-uses (pasture, fallow, and orchard) were investigated. Soil samples were taken from 30 points determined by GPS from 3 land-uses within the border of the Çubuk district of Ankara Province, Turkey. IR (with Minidisc infiltrometer, MDI), bulk density, and penetration resistance were measured in undisturbed soil samples. Saturated hydraulic conductivity (K_s) and sorptivity were obtained from infiltration measurements. Soil parametric analyses and morphological descriptions were made in disturbed soil samples. In order to digitize the morphological properties, the coding system was created with the help of soil identification cards. The average IR value was found to be the highest in the orchard and the lowest in pasture samples. Correlation analysis, one-way ANOVA, and factor analyses were used to evaluate the relationships between soil variables and IR. IR showed the highest correlation with sorptivity (0.72), sand (0.69), and K_s (0.86) in the pasture, fallow, and orchard, respectively. IR in different land-uses was loaded on the same factors with different soil variables. Due to different land management practices, such additional measurements need to be made to accurately assess the potential impact of land-use and management changes on agricultural activities.

To Cite: Karahan, G, Yalım, Y Ş, 2022. Evaluation of the Relationship Between Infiltration Rate and Some Soil Properties under Different Land-Use. *Yuzuncu Yil University Journal of Agricultural Sciences*, 32(3): 623-634. DOI: https://doi.org/10.29133/yyutbd.1130123

Foodnote: This study is derived from second author' master thesis and presented as an oral presentation at the 1st International Karatekin Science and Technology Conference (IKSTC1st) on 1-3 September. 2022.

1. Introduction

Infiltration is one of the main processes controlling water flow from surface to groundwater and is a complex dynamic process dependent on many factors (Jakab et al., 2019). Knowledge about the infiltration process, which has a fundamental role in agriculture and water research, is essential to be able to evaluate research results well (Pedretti et al., 2012). Therefore infiltration process continues to attract attention from researchers (Vand et al., 2018). Infiltration is, by definition, the initial stage of water flow into a relatively dry soil profile in which gravity plays only a minor role (Philip, 1957) (Equation 1). Infiltration can be measured in many ways as cumulative infiltration and IR. Cumulative infiltration is defined as the total of water flowing from the soil surface into the profile throughout a certain time (Chu, 1978).

$$I = St^{0.5} + At \tag{1}$$

Where I: cumulative infiltration (cm s^{-1}), S: sorptivity (cm $s^{-1/2}$), t: time (min), for one-dimensional vertical infiltration, A is proportional to the K_s of the soil.

The IR of soil depends on various factors such as initial conditions, structure, and mechanical behavior of soils (Angelaki et al., 2013). Another factor that has remarkable effects on infiltration due to the dynamics of soil properties is land-use (Biro et al., 2013).

In different land use, soil tillage tools, methods, and technological processes can affect soil's physical, chemical, and biological properties differently (Yankov and Drumeva, 2021). Due to the loss of land that can be used for agricultural purposes, different land uses, landuse planning (Şatır and Berberoğlu, 2021) and their effects have gained importance today. One of the soil processes affected by land use is soil infiltration capacity. It has been noted in many previous studies that soil infiltration capacity is controlled by the land-use type caused a significant change in the physical properties of the soil, and thus affected soil IR (Horel et al., 2015; Sun et al., 2018; Dionizio and Heil, 2019; Dionizio and Costa, 2019). However, in previous studies, general conclusions about land-use change effects on infiltration capacity could not be fully drawn due to the complexity of the plant and soil system. Although the land-use pattern is considered as one of the main factors affecting infiltration, the differences in the infiltration capacity of the soil are not very clear (Sun et al., 2018). Therefore, it is more important to reach the necessary information about soil management after the land is transformed into different land-use. Adequate knowledge of a soil's IR is essential for reliable prediction and control of soil and water-related environmental hazards (Patle et al., 2019). The aim of this study is to evaluate the relationships between IR of soils under different land-use (pasture, fallow, and orchard) and some physical, chemical, and morphological soil properties.

2. Material and Methods

2.1. Materials and soil sampling

This study was carried out in soils under 3 different land-uses in the Çubuk district in Ankara Province, Turkey (Figure 1). Pasture has less calcareous, high organic matter, neutral pH, unsalted, and generally clayey soils. Fallow soils are slightly alkaline and calcareous, with medium organic matter, unsalted and clayey. Orchard soils are slightly calcareous and alkaline, generally with weak organic matter, unsalted and clayey (Sarıdemir, 2010). For sampling, a total of 30 sample points were determined by GPS (Global Positioning System), 10 randomly from each land-use (Figure 1). Undisturbed soil samples were taken with a sampling cylinder (100 cm^3) after the topsoil was cleaned for infiltration measurements and bulk density. Disturbed soil samples were taken from the same points at a depth of 0-10 cm for basic soil analyses.

2.2. Methods

Infiltration measurements were made at a suction ratio of 2 cm (Decagon Devices, Inc. 2014). MDI is a useful device like a classical tension infiltrometer for predicting hydrodynamic properties of soils (Alagna et al. 2016). The soil surface isn't disturbed when using MDI (White and Perroux 1987). MDI prevents the water flow through the macropores because a negative potential was applied during measurement (Minasny and George 1999). Before measurements, ground vegetation was trimmed and surface litter carefully removed, and a very small amount of fine-grained sand was used to fully contact the infiltrometer with the soil. For the calculation of infiltration values, the simple method commonly used in dry soils suggested by Zhang (1997) was used (Equations 2 and 3).

$$I = C_1 t + C_2\sqrt{t} \tag{2}$$

$$k = \frac{C_1}{A} \tag{3}$$

Where C1 (m min^{-1}, relates to k) and C2 (m min$^{-1/2}$, corresponds to the soil sorptivity value) are the parameters. k is hydraulic conductivity (K_s) and C1 is the slope of the cumulative infiltration curve versus the square root of time. A is a value that relates van Genuchten parameters to the suction velocity and radius of the infiltrometer disc for a given soil type. Ks values were calculated by Equation 3. C1 was obtained from infiltration graphs. For A, values were taken corresponding to 4.5 cm disc diameter and -2 cm suction value (6.36 for silty clay and 4.30 for clay classes) (Decagon Devices Inc. 2014).

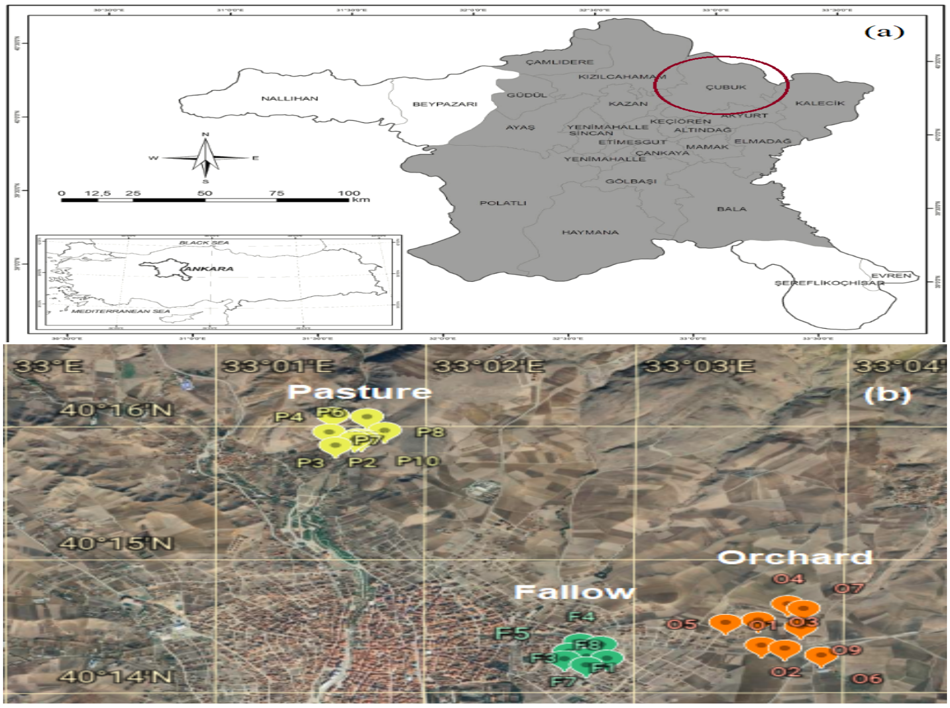

Figure 1. (a) Study areas (Orkun et al., 2014) and (b) soil sampling points (P: Pasture, F: Fallow, O: Orchard) (The map was downloaded from Google earth, sampling points and coordinates were edited).

The cumulative infiltration (I) was plotted as a function of the square root of time according to the Philip (1957) equation. The sorptivity values were obtained from the slope of the regression equations of these graphs for each sample (Baranian Kabir et al., 2020). Soil bulk density (Black and Hartge, 1986), soil texture (Gee and Bauder, 1986), field capacity (FC) and wilting point (Klute and Dirksen, 1986), aggregate stability index (Kemper and Rosenau, 1986), pH, organic matter and $CaCO_3$ content (Page et al., 1982), and electrical conductivity (Rhoades, 1982) were measured. Soil description charts were used for digitizing the morphological properties such as soil structure, pores, color, consistency, stickiness, plasticity, roots (Schoeneberger et al., 2012), and coefficient of linear extensibility (COLE) (Schafer and Singer, 1976) (Karahan and Erşahin, 2017). Correlation analysis was performed to evaluate the relationships between IR and soil properties. In order to create more meaningful and independent factors by reducing the number of variables, factor analysis (principal components) (SPSS Inc., 2015) was used. Factors with an eigenvalue of ≥1 were selected according to the factor analysis line graph of soil variables, and the critical factor load was taken as 0.5 for soil variables (Kalaycı, 2010). For reducing the number of variables loaded on more than 1 factor, varimax rotation was applied in the analysis.

3. Results

Descriptive statistics for some soil samples were given in Table 1. IR, K_s, soil structure type, and root properties were included in very variable classes in all land-use (Mulla and Mc Bratney, 2001). The highest average infiltration value is in an orchard, and the smallest is in pasture soil samples. IR classes are in very low class in all land-use (Kohnke, 1968). Infiltration values have positive kurtosis in all applications, but it showed high kurtosis (5.6) in fallow soils (Webster, 2001).

Table 1. Descriptive statistics of some soil variables for each land-uses

Soil variables	Max.	Min.	AM	SD	CV%	Skewness	Kurtosis
Pasture							
Infiltration rate (cm s^{-1})	0.011	0.001	0.005	0.003	66.780	1.0882	0.200
Clay (%)	61.200	46.200	55.275	5.138	9.300	-0.910	-0.475
K_s (cm s^{-1})	0.003	3x10^{-5}	43x10^{-5}	91x10^{-5}	213.900	2.963	8.932
Bulk density (gr cm^{-3})	1.298	1.025	1.118	0.082	7.300	1.108	1.551
Organic matter (%)	10.013	4.627	6.825	1.477	21.600	0.968	1.783
EC (dS m^{-1})	0,476	0,290	0,347	0,054	15,50	1,582	3,392
pH	7.435	6.555	7.079	0.299	4.200	-0.903	-0.319
PR (KPa)	783,333	446,667	560,667	110,630	19,70	0,937	0,230
Structure type	5.000	4.000	4.400	2.348	53.400	0.609	-3.33
Pore size	4.000	2.000	2.700	0.675	25.000	0.434	-0283
Stickiness	2.900	2.500	2.790	0.145	5.200	-1.156	0.201
Root quantity	2.000	1.000	1.000	0.966	60.400	0.111	-0.623
Fallow							
Infiltration rate (cm s^{-1})	0.045	0.004	0.014	0.012	90.440	2.2461	5.648
Clay (%)	64.150	60.400	62.100	1.092	1.800	0.429	-0.002
K_s (cm s^{-1})	85x10^{-5}	5 x10^{-5}	44 x10^{-5}	26 x10^{-5}	59.091	-0.024	-0.989
Bulk density (gr cm^{-3})	1.313	1.142	1.235	0.059	4.700	-0.398	-1.310
Organic matter (%)	2.435	1.773	2.157	0.202	9.400	-0.636	-0.005
EC (dS m^{-1})	0.214	0.168	0.191	0.014	7.100	0.101	0.041
pH	8.050	7.505	7.731	0.161	2.100	0.487	0.558
PR (KPa)	377.500	220.000	289.250	53.826	18.600	0.459	-1.224
Structure type	5.000	4.000	4.800	2.547	53.100	-2.236	5.000
Pore quantity	3.000	3.000	3.000	0.000	0.000	0.000	0.000
Stickiness	2.600	2.300	2.410	0.120	5.000	0.738	-0.878
Root quantity	3.000	1.000	1.400	0.843	60.200	1.779	1.406
Orchard							
Infiltration rate (cm s^{-1})	0.073	0.006	0.032	0.0192	59.430	1.028	1.299
Clay (%)	66.200	60.700	64.525	1.882	2.900	-0.981	0.271
K_s (cm s^{-1})	0.001	0,5x10^{-5}	72.7x10^{-5}	34.1 x10^{-5}	46.900	-0.979	1.021
Bulk density (gr cm^{-3})	1.199	1.007	1.107	0.056	5.000	-0.197	0.021
Organic matter (%)	2.842	1.406	1.920	0.381	19.900	1.579	3.946
EC (dS m^{-1})	0.209	0.167	0.191	0.015	7.90	-0.481	-1.515
pH	7.915	7.810	7.850	0.035	0.400	0.620	-0.488
PR (KPa)	212.500	112.500	172.250	32.112	18.60	-0.733	0.047
Structure type	5.000	4.000	4.667	2.547	54.600	-0.968	-1.875
Stickiness	2.800	2.600	2.720	0.120	4.400	-0.407	-1.734
Root quantity	1.000	0.000	0.100	0.316	316.200	3.162	10.000

IR: Infiltration rate, K_s: Saturated hydraulic conductivity, EC: Electrical conductivity, PR: Penetration resistance, pH: Soil reaction.

3.1. Infiltration rates of soil samples

IR graphs were created using cumulative infiltration values versus time (Zhang, 1997) (Figure 2). One-way analysis of variance was performed for the significance of the differences between the average IR and average sorptivity values in land-use (Table 2). The method indicated the soil IR and sorptivity properties among the land-use were statistically significant at 0.05 level ($p \leq 0.05$).

Table 2. One-way analysis of variance of average IR and sorptivity for land-use

Land-use	Average infiltration rate	Average sorptivity
Pasture	0.0045±0,00096^{a}	0.035±0,0025^{a}
Fallow	0.0136±0,0039^{b}	0.127±0,0073^{b}
Orchard	0.0323±0,0061^{c}	0.096±0,012^{c}

Means indicated with different letters in the same column are different at the level of 0.05.

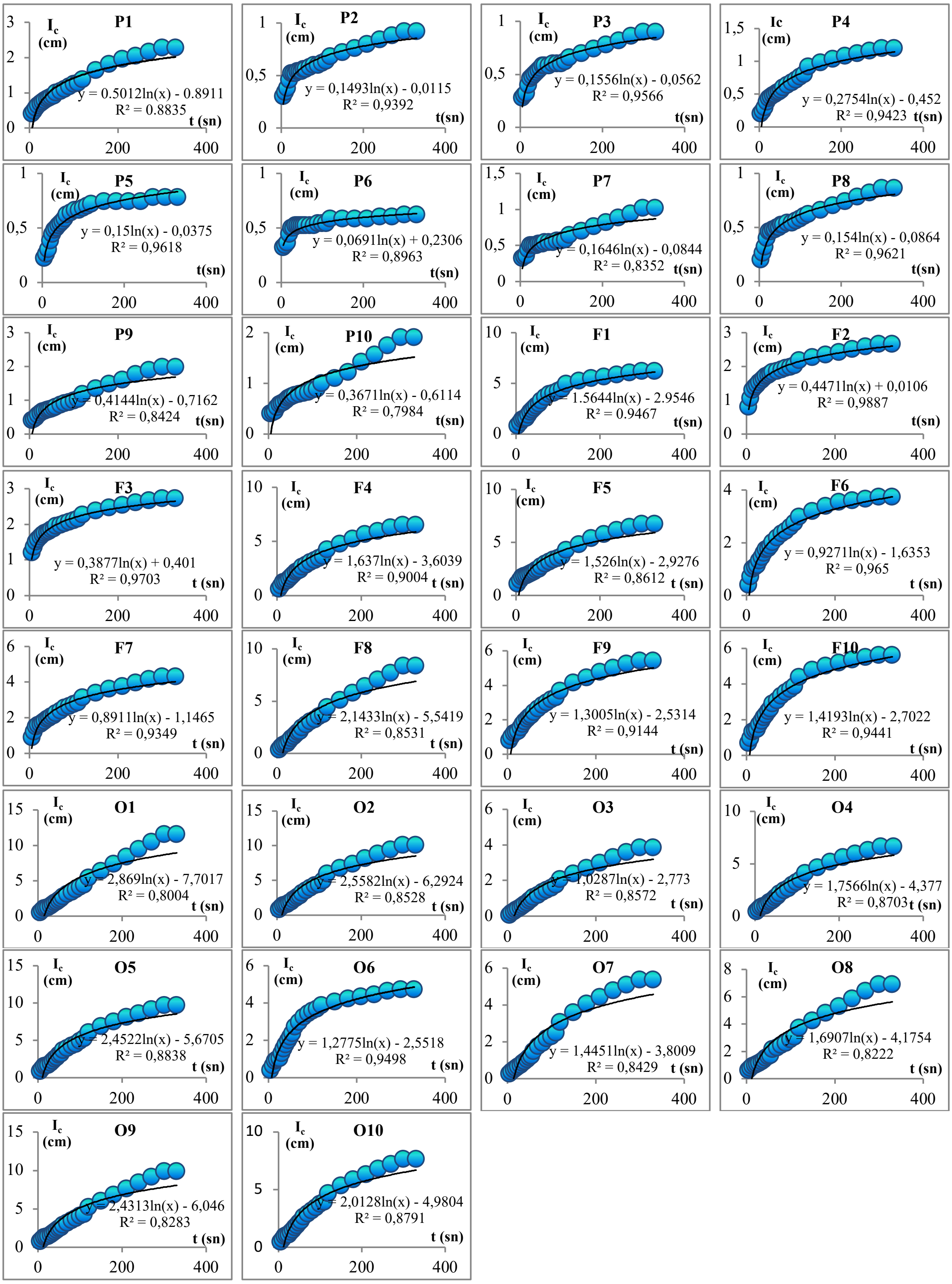

Figure 2. IR graphs of pasture (P), fallow (F) and orchard (O) samples.

3.2 Factor analysis of soil variables

Seven factors for pasture (the highest value is structure class and type, and the lowest value is wilting point), 8 factors for fallow (the highest value is structure size, the lowest is COLE), and 8 factors for the orchard (the highest value is color, the lowest is EC) were selected (Tables 3, 4, 5).

Table 3. Factor analysis of soil parametric and morphological variables for pasture soils

PASTURE	**Factors**				**Factors**			
Soil variables	**1**	**2**	**3**	**Soil variables**	**4**	**5**	**6**	**7**
Structure class	0.989			**pH**	0.814			
Structure size	0.989			**ASI (%)**	0.778			
EC (dS m^{-1})	-0.822			**$CaCO_3$ (%)**	0.696			
Root size	0.746			**Silt (%)**	0.657			
Sand (%)		-0.943		**Soil moisture (%)**	-0.651			
Stickiness		0.846		**IR (cm s^{-1})**	0.618			
Clay (%)		0.735		**Plasticity**	0.603			
COLE		0.658		**PR (KPa)**		0.930		
Bulk density (gcm^{-1})			0.932	**Organic matter (%)**		0.807		
K_S (cm s^{-1})			0.893	**Field capacity (%)**		0.626		
Pore size			0.850	**Wilting point (%)**		0.559		
Sorptivity (cm s$^{-1/2}$)			0.599	**Structure type**			0.926	
				Color			0.782	
				Consistency			0.719	
				Root quantity				0.899
Variation, %	20.880	15.100	14.470		14.130	12.150	11.090	7.230
Total variation, %								95.07

EC: Electrical conductivity, COLE: Coefficient of linear extensibility, K_s: Saturated hydraulic conductivity, pH: Soil reaction, IR: Infiltration rate, PR: Penetration resistance, ASI: Agregatte stability index, $CaCO_3$: Calcium carbonate.

Table 4. Factor analysis of soil parametric and morphological variables for fallow soils

FALLOW	**Factor**				**Factor**				
Soil variables	**1**	**2**	**3**	**Soil variables**	**4**	**5**	**6**	**7**	**8**
Structure size	0.929			**Stickiness**	0.901				
Color	0.811			**Pore quantity**	0.892				
$CaCO_3$ (%)	0.776			**Pore size**	-0.615				
Wilting point (%)	0.761			**COLE**	0.543				
EC (dS m^{-1})	-0.748			**PR(KPa)**		-0.911			
Structure class	0.729			**FC (%)**		0.787			
Structure type	-0.581			**IR (cm s^{-1})**			0.961		
Clay (%)		-0.954		**K_s (cm s^{-1})**			0.671		
Sand (%)		0.894		**Plasticity**				0.949	
Sorptivity (cm s$^{-1/2}$)		-0.842		**OM (%)**				-0.641	
Soil moisture (%)		0.609		**Consistency**				0.583	
pH			-0.898	**ASI (%)**					-0.920
Bulk density (cm g^{-1})			0.806						
Silt (%)			-0.632						
Variation, %	19.34	13.54	13.00		11.75	11.49	10.65	9.54	8.170
Total variation, %									97.51

$CaCO_3$: Calcium carbonate, EC: Electrical conductivity, pH: Soil reaction, COLE: Coefficient of linear extensibility, PR: Penetration resistance, FC: Fcapacity, IR: Infiltration rate, K_s: Saturated hydraulic conductivity, OM; Organic matter, ASI: Agregatte stability index.

Table 5. Factor analysis of soil parametric and morphological variables for orchard soils

ORCHARD	**Factors**				**Factors**				
Soil variables	**1**	**2**	**3**	**Soil variables**	**4**	**5**	**6**	**7**	**8**
Color	0.982			**Root quantity**	0.971				
Wilting point (%)	0.962			**Consistency**	0.971				
Field capacity (%)	0.932			**Structure class**	0.753				
$CaCO_3$ (%)	-0.804			**Structure type**		-0.951			
Soil moisture (%)	0.794			**Pore quantity**		-0.605			
Clay (%)	0.711			**OM (%)**			0.960		
IR (cm s^{-1})		0.947		**Silt (%)**				0.791	
K_s (cm s^{-1})		0.840		**pH**				0.706	
Sorptivity (cm s$^{-1/2}$)		-0.744		**Pore size**				0.657	
Sand (%)		0.670		**ASI (%)**					0.762
EC (dS m^{-1})		0.554		**Structure size**					-0.679
COLE			-0.840						
Bulk density (gr cm^{-3})			0.838						
Stickiness			0.824						
PR (KPa)			0.614						
Plasticity			0.594						
Variation, %	21.800	16.890	13.470		11.520	10.570	8.790	8.220	7.470
Total variation, %									98.750

$CaCO_3$: Calcium carbonate, Ks: Saturated hydraulic conductivity, EC: Electrical conductivity, COLE: Coefficient of linear extensibility, PR: Penetration resistance, IR: Infiltration rate, OM; Organic matter, pH: Soil reaction, ASI: Agregatte stability index

Table 6. The number of factors and definitions of the study area soil variables

PASTURE		FALLOW		ORCHARD	
FN	**Factor definition**	**FN**	**Factor definition**	**FN**	**Factor definition**
1	Morphology and EC	1	Morphology and chemistry	1	Soil physics
2	Texture and morphology	2	Texture and soil water	2	Soil water and EC
3	Soil water	3	Bulk density and pH	3	Bulk density and soil mechanics
4	Parametric ve plasticity	4	Morphology	4	Root and structure
5	Soil water and OM	5	Resistance and saturation	5	Structure and pore
6	Color and consistency	6	Conductivity	6	Organic matter
7	Pores	7	Consistency and organic matter	7	Pore and pH
		8	Stability	8	Stability and structure

FN: Factor number, OM; Organic matter, EC: Electrical conductivity.

According to the results of the factor analysis, the total 27 soil variables defined 95.07% of the total variability in the pasture, 97.51% in fallow, and 98.75% in orchards. In the pasture, the variables soil structure, EC, and root size were loaded on factor 1, and this factor explained 20.8% of the variance of the data set. Therefore, Factor 1 was named 'Morphology and EC'. In fallow, the variables structure size, color, $CaCO_3$, WP, EC, structure class and type were loaded on factor 1, and this factor explained 19.34% of the variance of the data set. Therefore, factor 1 was named ' Morphology and chemistry '. In the orchard, the variables color, WP, FC, $CaCO_3$, soil moisture, and clay were loaded on factor 1, and this factor explained 20.8% of the variance of the data set. Therefore, factor 1 was named ' Soil physics ' (Table 6). Similarly, factors were named according to the dominant soil characteristics loaded on each factor in pasture, fallow, and orchard (Table 3-6).

Soil variables loaded on the first factors show that morphological features are more dominant. It is seen that soil structural properties such as structure and pore, mechanical properties such as COLE, and root properties are positively related to infiltration in pasture land soil properties. However, EC, sand content and soil moisture content were negatively correlated with infiltration rate (Table 3). There were many previous studies that found soil infiltration was affected by soil properties (Tejedor et al., 2013; Sajjadi et al., 2016; Patle et al., 2019; Saputra et al., 2021). Saputra et al. (2021) reported that different land use shows variations in processes like infiltration due to they have different vegetation covers. Each type of vegetation has a different root system and therefore has different amounts of soil organic matter. These are important factors that affect the infiltration rate due to improvements in soil physical properties such as structure and soil porosity.

4. Discussion

It was noted that the soil infiltration process was generally affected by vegetation and soil characteristics (Leung et al., 2015). Therefore, many studies were performed on soil infiltration capacity using different soil variables such as water content, organic matter, and porosity under different land-use (Huang et al., 2017; Wu et al., 2016). In this study, we evaluated the relations between infiltration rate and some soil properties under 3 different land-use (pasture, fallow, and orchard) using One-way analysis of variance and factor analysis. The results showed that, contrary to expectations, the infiltration rate value was found to be the lowest in the pasture. For example, Fischer et al. (2015) stated that in the pasture, infiltration capacity increased due to water flow through macropores. However, our study showed the opposite result. Pasture samples have higher organic matter and penetration resistance and lower average IR, pore size, and clay and sand content than fallow and orchard samples (Table 1). Although the lowest clay and the highest organic matter content, the lowest average IR value was found in pasture samples. However, although clay content in the pasture is lower than in fallow and orchard samples, stickiness and plasticity were measured higher. Generally, these properties represent the clay fraction in soil, and their values increase as the clay ratio (Hardjowigeno 2016). Despite the low clay content, the effect of higher values of stickiness and plasticity may have resulted in a low measurement of IR in the pasture. This difference can be attributed to the different effects of clay content, stickiness, and plasticity, as stated in Karahan and Erşahin (2017). They reported that although soil stickiness and plasticity are tidily correlated with soil clay content, they may affect macropore flow in a different way to clay content, depending on the amount of 2:1-type active clays. This result also supports the effect of soil morphological features on water flow. Ferreira et al. (2015) studied hydrological properties including infiltration capacity in different land-use in central Portugal. They noted that infiltration capacity increased with sand content in both surfacesoil (r = 0.228) and subsurfacesoil (r = 0.201) soil, but decreased with clay fractions (r = -0.140). Therefore, we also attributed the lowest IR finding in the pasture to soil compaction. We can say that soil compaction suppresses the low moisture (5.81, 8.04 %, 8.33 % in pasture, fallow, and orchard, respectively) and high organic matter content, therefore causing low IR. Zhao et al. (2013) found the soil infiltration rate for five grasslands greater than that of cropland, and they attributed the reduction in IR of cropland to the effect of soil compaction. According to our results, the lower IR in pasture than in fallow and orchard could be attributed to the effect of soil compaction caused by more vehicle and human traffic and grazing. Similarly, as reported in Sun et al. (2018) and Alaoui et al. (2011), Radke and Berry (1993) noted that soil compaction might decrease the infiltration rate of soils by affecting soil structure. Saputra et al. (2021) associated the clogging of the soil pores t with human activity above the soil surface.

On the other hand, besides the low clay and sand content, therefore the number of macropores is also low in the pasture. These macropores that are few may have been destructed by soil compaction. This might be because the pasture area is used as a promenade and for overgrazing purposes. It has been reported in previous studies that land use due to soil compaction has an effect on infiltration capacity. Haghnazari et al. (2015) studied the infiltration rates of agricultural soils and reported that the movement of heavy machines and excessive grazing reduced the infiltration rate. Soil compaction causes a decrease in soil macropores and an increase in soil dry bulk weight and penetration resistance, and thus has the effect of reducing the rate of water infiltration. Alaoui (2015) investigated the hydrological parameters of four representative grassland soils on the Swiss plateau and found that the interaction between bulk density and macroporosity could facilitate water infiltration. This interaction is related to the soil sand content. The average sand content value in the pasture soils was found to be lower (10.62) than the fallow (19.6) and orchard (17.2). Contrary to Alaoui (2015), low sand content may also have resulted in low IR value in the pasture. Colloff et al. (2010) expected that the infiltration rate would increase when the vegetation cover produces macropores by altering soil structure in the pasture. This result is in line with ours that the infiltration rate decreases due to the destruction of macropores by soil compaction. In this study, it confirms that the highest bulk density and penetration resistance values are measured in the pasture confirms this result (Table 1). Benevenute et al. (2020) evaluated PR as an indicator of soil compaction and noted that animal trampling increased soil compaction and soil degradation in pastures. As a matter of fact, measuring the average penetration resistance (PR) value in the pasture area (560 kPa) is about twice as much as in fallow (289 kPa) and orchard (172 kPa) can be considered an indicator of compaction. Keller and Dexter (2012) and Bayat et al. (2017) emphasized the impact of animal trampling, especially after rainy weather, and indicated that increasing the plasticity and susceptibility to compaction can significantly increase soil PR in wet soils.

In addition, Wu et al. (2016) reported that root systems abundant in grasslands improved the infiltration capacity of the soils. Huang et al. (2017) also emphasized the importance of roots in the infiltration process in relation to belowground biomass. However, the results of these studies are not in line with the result of the lowest IR, although the total plant roots are higher in the pasture. Because the fact that there are mostly small diameter roots (Table 1) that have the effect of increasing the water flow in the soil may be due to overgrazing in the studied pasture area, moreover, roots in pasture may have clogged the pores in soil due to the compaction effect, and thus they may have decreased the soil infiltration rate. Cui et al. (2019) reported that there is a relative effect of roots that is not fully understood with different diameters in the infiltration stages. Considering that small roots can also block the pores, this may explain the lower infiltration rate in the weak roots pasture samples compared to the other land-use. In fallow, sand content, bulk density, root quantity, and size were found to be the highest compared to other land-use soil samples (Table 1). The fact that the fallow area has higher IR values due to having a higher sand content than the pasture is consistent with the result of Mazaheri and Mahmoodabadi (2012) and Mousavi (2015). Santra et al. (2021) measured soil infiltration of 15 sites in Jaisalmer, India, and reported that higher sand content results in higher steady-state IR in contrast to the clay content. Higher IR measurement in the fallow compared to pasture samples was attributed to higher sand content and bulk density values and lower clay content. In addition, the lowest organic matter content was measured in fallow samples.

In the orchard, clay and water content and pore size were found to be the highest, and bulk density, organic matter, PR were found to be the lowest compared to other land-use (Table 1). According to these measurements, only the high clay content and the low bulk density complement each other.

Contrary to expectation, although low organic matter and PR, and high clay content were measured, the IR value was found to be the highest in orchard samples in all land-use. The contrasts determined in relation to IR and soil properties in the pasture were also seen in the orchard. Therefore, different factors, such as plant roots and soil living organisms that lead to higher IR in the orchard, were evaluated. Saputra et al. (2021) reported that a low bulk density might indicate more development of roots and water in the soil. Dwiratna and Suryadi (2017) found that high total porosity is inversely proportional to its bulk density. Fischer et al. (2014) noted that roots increase the organic matter content of soil and help to form soil pores, therefore changing the earthworms' burrowing activity and biomass and affecting the infiltration capacity of soils. However, since the trees in the orchard (including the trees of apples, pears, plums, cherries, sour cherries, apricots, and peaches) have deeper roots and there is no graze cover among these trees, roots were not found in soil samples. However, we can say that tree roots contribute to the water flow in the lower part of the soil. Ow and Ghosh (2017) noted that tree roots could also increase IR by facilitating water flow in subsoils where the soil is more compacted. In addition, we can say that IR increases due to the gaps created by the activities of soil creatures that live in orchards. Observed earthworms in the orchard have contributed in this way to the increase in infiltration. These findings are consistent with studies (Fischer et al., 2014; van Schaik et al., 2014) which reported that burrowing activity and biomass of earthworms effects IR. In addition, Zadeh (2015) reported that soil organisms could lead to loosening in the soil with their activities, thus facilitating infiltration.

In pasture soils, soil water content was found to be negatively associated with infiltration rate (Table 3). According to Alaoui (2015), the lower initial soil water content may increase the infiltration. The negative correlation between soil moisture content and IR in pasture soils seems to be in agreement with this study. In addition, previous studies reported that there were significant negative correlations between soil infiltration and saturated and initial moisture contents (Neumann ve Cardon, 2012; Lun ve Liang, 2014). In fallow soils, negative relations were found between IR and clay content and penetration resistance (Table 4). In general, increased clay content reduces the formation of macropores (Karahan and Erşahin, 2017), which results in the IR decreasing. In orchard soils, negative relations were found between IR and COLE and pore quantity (Table 5). COLE and PQ are properties that are positively related to the clay content. The total amount of pores is higher in clay soils and small pores slow down the infiltration rate. Therefore, the water holding capacity of clay soils can be very high, but their water transmission capacity is quite low. Since PQ will increase with the amount of clay, it is negatively related to IR. Patle et al. (2018) estimated the infiltration rate using texture fractions, and they reported that an increase in clay would decrease IR significantly.

Conclusion

In this study, IR of soils under different land-use (pasture, fallow, and orchard) within the boundaries of the Çubuk district of Ankara, Türkiye were compared. Correlation analysis was performed for the IR of the variables belonging to the soil samples and the direction and degree of their relations with each other. It was seen that in the pasture, sorptivity had an effect (r=0.72) on IR while K_s was seen to be effective in fallow (r=0.69) and orchard (r=0.86) soils. It was found that the average IR and average sorptivity values in all land-uses were different at the 5% significance level according to the ANOVA test results. In pasture samples, although the organic matter content is 3 times more (6.8%) than fallow (2.2%) and orchard (1.9%) and mean clay content is the lowest, the IR value was found to be the lowest. Similarly, in the orchard, the clay content and bulk density were found to the lower according to pasture and fallow, but the highest IR was measured in the orchard. These are contradictory results contrary to expectations. Therefore, these obtained results show that there can be more dominant factors than clay or organic matter content in pasture and orchard that affect the infiltration rate of soils. These results were attributed to soil compaction for the pasture. It can be said the reason for soil compaction is the use of the pasture area for grazing and recreation. The measured maximum PR value in the pasture area confirms this soil compaction.

Soil compaction due to machine, animal, and human traffics destroys macropores which are the soil's structural properties, and the possibility of roots clogging the pores that provide water transmission can be said to be the reason for low IR in the pasture. Since there are trees with deeper and larger roots such as apple, pear, plum, cherry, sour cherry, apricot, and peach in the orchard and there is no weed cover among these trees, roots were not found in soil samples. In addition, due to the soil surface being cleaned during the sampling, it can be said that the litter consisting of tree leaves doesn't contribute to the organic matter content; therefore, it can be said that organic matter was measured as low. Therefore, we can attribute that it increases the IR due to the gaps created by the activities of soil creatures that live in orchards. Contrary to expectations, high IR in the orchard and low IR measurement in pasture show that land use rather than dominant soil characteristics may be more effective in the relationships between soil properties and infiltration rate. Obtained results in the study will provide useful information to researchers in modeling soil water relations and to farmers in making important application decisions. In addition, we used soil morphological variables as a different factor that affects IR, as well as using soil physical and chemical variables. The loading of morphological variables with high values on the factors shows that soil morphologic variables such as stickiness, plasticity, structure, pores, and roots are effective on IR. Therefore, especially an increase in studies that investigate the relationships between soil infiltration and structural properties under different field conditions will be beneficial in terms of obtaining more accurate results.

Acknowledgements

The authors thank the Çankırı Karatekin University for the financial support given under the grant of BAP (OF210621L18).

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