**Evaluation of the Relationship Between Infiltration Rate and Some Soil Properties in Different Land Use**

***Gülay KARAHAN1\*[C:\Users\Abdullah\AppData\Local\Microsoft\Windows\INetCache\Content.Word\ORCID-iD_icon-16x16.gif](https://orcid.org/0000-xxxx-xxxx-xxxx), Yavuz Şuayip YALIM2[C:\Users\Abdullah\AppData\Local\Microsoft\Windows\INetCache\Content.Word\ORCID-iD_icon-16x16.gif](https://orcid.org/0000-xxxx-xxxx-xxxx)***

*1* *Landcape Architecture Department*, *Faculty of Forestry, Çankırı Karatekin University, Çankırı, Turkey*

*2 Institute of Natural and Applied Science, Çankırı Karatekin University, Çankırı, Turkey*

|  |
| --- |
| **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 are 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 effect of soil properties under different land uses on infiltration was investigated. Soil samples were taken from 30 points determined by GPS from 3 different regions (grassland, fallow and orchard) within the border of Çubuk district of Ankara province in Turkey. IR (with Minidisc infiltrometer) and bulk density were measured in undisturbed soil samples and hydraulic conductivity and sorptivity values were obtained from infiltration measurements. Basic parametric soil analyses and morphological descriptions were made in disturbed soil samples. In order to digitize the morphological properties, the coding system created with the help of soil identification cards. The highest IR values were recorded from orchard and the lowest were recorded from grassland 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 hydraulic conductivity (0.86) in grassland, fallow and orchard, respectively. IR in different land uses were loaded on the same factors with different soil variables. Due to different land management practices, such additional measurements need to be made for accurately assess the potential impact of land use and management changes on agricultural activities. |
| Keywords: Infiltration rate, Land conditions, Morphology, Factor analysis |

1. **Introduction**

Infiltration is by definition the initial stages of infiltration into a relatively dry soil profile in which gravity plays only a minor role [1] (Equation 1). Infiltration can be measured in many ways, including cumulative infiltration and infiltration rate. Cumulative infiltration is the total amount of water that infiltrates into the soil over a period of time [2].

*I=St0.5+At*  (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 saturated hydraulic conductivity (Ks) of the soil.

The infiltration rate of a soil depends on various factors such as the initial conditions of the soil surface, the structure and mechanical behavior of the soil, the type of soil, its density, texture, and temperature [3]. In short, soil properties are one of the important parameters governing the infiltration rate [4]. Another factor that has remarkable effects on soil infiltration due to the dynamics of soil properties is land use [5]. It has been noted in many previous studies that soil infiltration capacity is controlled by vegetation and soil physical properties [6] and the land use type caused a significant change in the physical properties of the soil and thus affected the soil infiltration rate [7]. 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 [8]. However, it is important to reach the necessary information about soil management after the land is transformed into different land uses. Adequate knowledge of a soil's infiltration rate is essential for reliable prediction and control of soil and water-related environmental hazards [4]. The aim of this study is to evaluate the relationships between the infiltration rates of soils under different land uses (grassland, fallow, and orchard) and some physical, chemical, and morphological soil properties.

1. **Materials and Methods**

This study was carried out under 3 different land use soils in the Çubuk district in Ankara province, Turkey (Figure 1). Grassland soils are less calcareous, have high organic matter, neutral pH, unsalted, and generally clayey. Fallow soils are slightly alkaline and calcareous, medium organic matter, unsalted and clayey. Orchard soils are slightly calcareous and alkaline, generally weak organic matter, unsalted and clayey. Traditional methods have been applied for soil tillage. For soil samples, a total of 30 sample points were determined by GPS (Global Positioning System), 10 randomly from each area (Figure 1). Undisturbed soil samples were taken with a sampling cylinder (100 cm3) after the topsoil was cleaned for infiltration measurements and bulk density from grassland, fallow, and orchard areas. Disturbed soil samples were taken from the same points at a depth of 0-10 cm for basic soil analysis.

Infiltration measurement of soil samples was made on samples taken with sampling cylinders (100 cm3) and using a minidisc infiltrometer (MDI) at an emmer ratio of 2 cm [9]. MDI has proven to be a practical alternative to the classical tension infiltrometer for estimating hydrodynamic properties in some studies [10]. MDI does not disturb the soil surface [11] and prevents macropore flow due to the negative potential applied during infiltration measurements [12]. Fine-grained sand was used to fully contact the infiltrometer with the soil prior to measurement. For the calculation of infiltration values, the simple method commonly used in dry soils suggested by [13] was used (Equation 2 and 3).

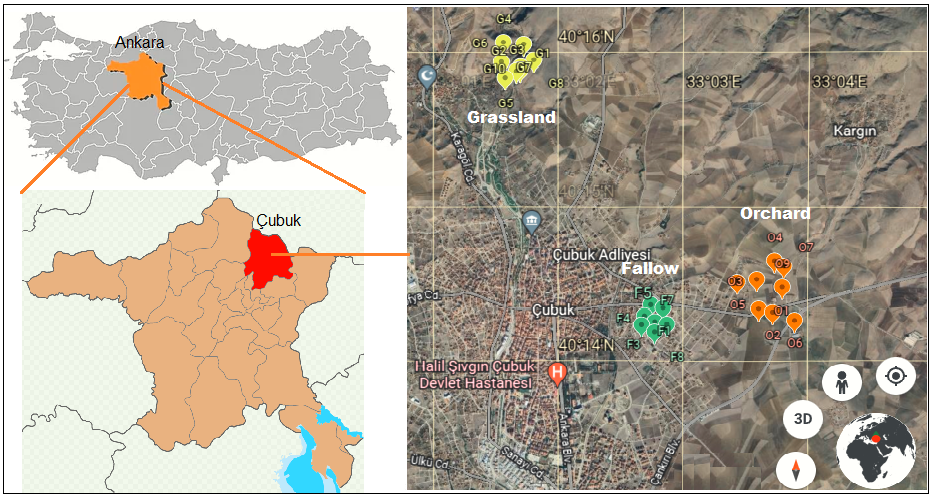
I=C1 t+C2√t (2)

Where C1 (m min-1) and C2 (m min-1/2) are the parameters. C1 relates to the hydraulic conductivity (k) and C2 corresponds to the soil sorptivity value.

k=C1/A (3)

Where k is hydraulic conductivity, 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 [9].

The cumulative infiltration (I) was plotted as a function of the square root of time according to the [1] equation. The sorptivity values were obtained from the slope of the regression equations of these graphs for each sample [14]. In order to create more meaningful and independent factors by reducing the number of variables, factor analysis (principal components) [15] was used. For reducing the number of variables loaded on more than 1 factor varimax rotation was applied in the analysis.



**Figure 1.** Study areas and soil sampling points (G: Grassland, F: Fallow, O: Orchard)

**3. Results and Discussion**

According to descriptive statistics for soil samples, IR, Ks, soil structure type, and root properties were included in very variable classes in all land-use [16]. The highest average infiltration value is in orchard and the smallest is in pasture soil samples. IR classes are in very low class in all land-use [17]. Infiltration values have positive kurtosis in all applications but it showed high kurtosis (5.6) in fallow soils [18].

**3.1. Infiltration rates of soil samples**

IR graphs were created using cumulative infiltration values versus time [13] (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 1). Method indicated the soil IR and sorptivity properties among the land-use were statistically significant at 0.05 level (p ≤ 0.05).

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

**Table 1.** One-way analysis of variance of average IR and sorptivity for land-use

|  |  |  |
| --- | --- | --- |
| Land-use | Average infiltration rate | Average sorptivity |
| Pasture | 0.0045a | 0.035a |
| Fallow | 0.0136b | 0.127b |
| Orchard | 0.0323c | 0.096c |

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

**3.2 Factor analysis of soil variables**

The definitions of factors for the soil variables are given based on the dominant soil properties in each factor (Table 2).

**Table 2.** 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 and 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

[19] studied on 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). [19] 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. Although the lowest clay and the highest organic matter content, the lowest average IR value was found in pasture samples. This result is also inconsistent with the finding of the lowest average sand content in the pasture samples. Therefore, we 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.

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. Human activity and machines have had an effect on compacting the pasture soils. This result is consistent with previous findings regarding the effects of soil compaction on infiltration capacity. [20] 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.

In addition, [21] reported that root systems abundant in grasslands improved the infiltration capacity of the soils. However, the fact that there are mostly small diameter roots 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. [22] 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.

[23] 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. [27] and [25] 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 general, it can consider that the reason for low IR in pasture soils is the compaction effect by animals, vehicles, and people.

In fallow, sand content, bulk density, root quantity, and size were found to be the highest compared to other land-use samples. The fact that fallow area has higher IR values due to having a higher sand content than the pasture s is consistent with the result of [26] and [27]. [28] 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 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. 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 pasture were also seen in the orchard. Therefore, different factors that lead to higher IR in the orchard were evaluated. [29] noted that roots increase 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. Therefore, we can say that it increases the IR due to the gaps created by the activities of soil creatures that live in orchard. Observed earthworms in the orchard have contributed in this way to the increase in infiltration. These findings are consistent with studies [29] which reported that burrowing activity and biomass of earthworms effects IR.

In this study, 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 on the first 3 factors of pasture and fallow shows that soil morphologic variables such as structure, pores, and roots are effective on IR. Therefore, especially increase in studies that investigate the relationships between soil infiltration and structural properties under different landuse will be beneficial in terms of obtaining more accurate results.

**Acknowledgements**

In this study, the financial support was provided by Çankırı Karatekin University, Project No. BAP, OF210621L18. All experimental works were conducted in Agriculture Faculty Laboratory of Ankara University. The authors would like to thanks to all supporters due to their precious contributions.

**References**

[1] Philip, J.R. (1957). The theory of infiltration: 1. The infiltration equation and its solution. *Soil Science,* *83*(5), 345–358. doi: 10.1097/00010694-195705000-00002.

[2] Chu, S.T. (1978). Infiltration during unsteady rain. *Water Resour. Research*, *14*(3), 461-466.

[3] Angelaki, A., Sakellariou-Makrantonaki, M., & Tzimopoulos, C. (2013). Theoretical and experimental research of cumulative infiltration. *Transport in Porous Media, 100* (2), 247-257.

[4] Patle, G.T., Sikar, T.T., Rawat, K.S., & Singh, S.K. (2019). Estimation of infiltration rate from soil properties usingregression model for cultivated land. *Geology, Ecology, and Landscapes,* *3*(1), 1-13.

[5] Biro, K., Pradhan, B., Muchroithner, M., & Makeschin, F. (2013). Land use/land cover change analysis and its impact on soil properties in the northern part of Gadarif region, Sudan. *Land Degradation and Development*, *24*, 90–102. doi:10.1002/ldr.1116.

[6] 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. *Hydrol. Process*, *29*, 3342–3354.

[7] Yimer, F., Messing, I., Ledin, S., & Abdelkadir, A. (2008). Effects of different land use types on infiltration capacity in a catchment in the highlands of Ethiopia. *Soil Use Manag*., *24*, 344–349.

[8] Sun, D., Yang, H., Guan, D., Yang, M., Wu, J., Yuan, F., Jin, C., Wang, A., & Zhang, Y. (2018). The effects of land use change on soil infiltration capacity in China. *Science of the Total Environment*, *626*, 1394–1401.

[9] Decagon Devices, Inc. (2014). *Infiltrometer, Mini Disk User’s Manual Version* 10.

[10] Alagna, V., Bagarello, V., Di Prima, S., & Iovino, M.V. (2016). Determining hydraulic properties of a loam soil by alternative infiltrometer techniques. *Hydrological Processes,* *30*(2): 263–275.

[11] White, I., & Perroux, K. M. (1987). The use of sorptivity to determine field soil hydraulic properties. *Soil Science Society of America Journal,* *51*(1093-1101).

[12] Minasny, B., & George, B. H. (1999). The measurement of soil hydraulic properties in the field. In B. H. Cattle, S.R., George (Eds.), *Describing, Analysing and Managing Our Soil,* 1st ed., 185-204.

[13] Zhang, R. (1997). Determination of soil sorptivity and hydraulic conductivity from the disk infiltrometer. S*oil Science Society of America Journal,* *61*, 1024-1030.

[14] Baranian Kabir, E., Bashari, H., Bassiri, M., & Mosaddeghi, M. R. (2020). Effects of land-use/cover change on soil hydraulic properties and pore characteristics in a semi-arid region of central Iran. *Soil and Tillage Research,* 197. doi: 10.1016/j.still.2019.104478.

[15] SPSS Inc. (2015). *Statistics for windows.* Version 23.

[16] Mulla, D.J., & Mc Bratney, A. B. (2001). Soil spatial variability. In A. W. Warrick (Ed.), Handbook of Soil Science (pp. 368-400). *Soil Physics Companion*. CRS Pres. doi:10.1201/9781420041651.

[17] Kohnke, H. (1968). *Soil physics*. Tata Mcgraw-Hill Publishing Company Limited, New Dilhi.

[18] Webster, R. (2001). Statistics to support soil research and their presentation. *European Journal of Soil Science,* 52, 330-340. doi:10.1046/j.1365-2389.2001.00383.x.

[19] Ferreira, C.S.S., Walsh, R.P.D., Steenhuis, T.S., Shakesby, R.A., Nunes, J.P.N., Coelho, C.O.A., & Ferreira, A.J.D. (2015). Spatiotemporal variability of hydrologic soil properties and the implications for overland flow and land management in a peri-urban Mediterranean catchment. *J Hydrol,* *525*, 249-263.

[20] Haghnazari, F., Shahgholi, H., & Feizi, M. (2015). Factors affecting the infiltration of agricultural soils: Review. *International Journal of Agronomy and Agricultural Research*, *6*(5), 21–35.

[21] Wu, G.L., Yang, Z., Cui, Z., Liu, Y., Fang, N.F., & Shi, Z.H. (2016). Mixed artificial grasslands with more roots improved mine soil infiltration capacity. *J. Hydrol.* *535*, 54–60.

[22] Cui, Z., Wu, G.L., Huang, Z., & Liu, Y. (2019). Fine roots determine soil infiltration potential than soil water content in semi-arid grassland soils. *Journal of Hydrology*, 578.

[23] Benevenute, P. A., de Morais, E. G., Souza, A. A., Vasques, I. C., Cardoso, D. P., Sales, F. R., & Silva, B. M. (2020). Penetration resistance: An effective indicator for monitoring soil compaction in pastures. *Ecological Indicators*, *117*, 106647.

[24] Keller, T. & Dexter, A.R. (2012). Plastic limits of agricultural soils as functions of soil texture and organic matter content. *Soil Research*, *50*(1), 7-17.

[25] Bayat, H., Sheklabadi, M., Moradhaseli, M., & Ebrahimi, E. (2017). Effects of slope aspect, grazing, and sampling position on the soil penetration resistance curve. *Geoderma*, *303,*150-164.

[26] Mazaheri, M.R., & Mahmoodabadi, M. (2012) .Study on infiltration rate based on primary particle size distribution data in arid and semiarid region soils. *Arab J Geosci*, *5*, 1039–1046.

[27] Mousavi, S. B. (2015). Employment of Pedo-transfer functions for predicting initial and final infiltration rates using Horton model and soil readily available characteristics. *Indian Journal of Agricultural Research*, *49* (4), 433-437.

[28] Santra, P., Kumar, M., & Kumawat, R.N. (2021). Characterization and modeling of infiltration characteristics of soils under major land use systems in Hot Arid Region of India. *Agricultural Research,10*(3), 417-433.

[29] Fischer, C., Roscher, C., Jensen, B., & Eisenhauer, N. (2014). How do earthworms, soil texture and plant composition affect infiltration along an experimental plant diversity gradient in grassland. *PLoS One*, 9.