USING BEERKAN INFILTRATION EXPERIMENT TO ASSESS THE INFILTRATION CAPACITY OF TERRACED SOILS IN SEMI-ARID REGION IN TURKEY

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ABSTRACT

The central and eastern part of Turkey is a semi-arid mountainous region. Global warming has a detrimental effect on precipitation with more extreme episodes. As a result, during heavy rainfall the erosion of sloping soils is accentuated by surface runoff. The transport of sediments in watercourses and dams has the effect of reducing the life of hydraulic structures. One of the methods of controlling the erosion of sloping soils is the creation of terrace surfaces to promote the infiltration of rainwater. This technique is often accompanied by the revegetation of terraces. Monitoring the infiltration capacities of terraced soils over time and space is essential to understand the effect of terraces on the hydrology of the watershed and its effect against soil erosion. On the last decade, Beerkan infiltration experiments became very popular due to ease of implementation in the field and very low cost in comparison to other techniques. Beerkan infiltration experiments were performed on terrace soil of Munzur University campus in Turkey. Approach without soil sampling procedure was used and compared with robust Beerkan Estimation of Soil Transfer parameters (BEST) method. Infiltration data treatment without soil sampling procedure conducted to similar estimation of saturated soil hydraulic conductivity (Ks) when compared to robust BEST methods with relative difference less than 30%. Considering the soil Ks variability, these results show that simplified method allows an easy, economical, rapid estimation of Ks and encourage the monitoring of the infiltration capacities of the terraces to alert on maintenance requirement operations.

Keywords: Terrace soil, Ks, SSBI, BEST method

1. INTRODUCTION

The global warming and its effect on precipitations were reported by increase of heavy precipitations events (Alexander, 2016). This harmful effect on soil erosion in Turkey semi-arid region was observed on several studies (Berberoglu and al., 2020; Ozsoy et al., 2012; Yüksel et al., 2008). The terrace techniques on slope soils have for effect to cuts the runoff speed of the rainwater and promote the infiltration into the soil (Kalkan et al., 2017) and therefore reduce the soil erosion. Greening of terraces help to restore the soils properties. The terrace practice performances are mainly monitored by soil quality observations and plants growing (Pekal, 2009; Taysun et al., 2000) but the infiltration capacity is very rarely measured and only a few studies investigated this point (Posthumus and Stroosnijder, 2010; Nie et al., 2017). In Turkey, the infiltration capacity is almost never measured. The main reason is that the transport in situ of equipment, time requirements and costs are break on use of infiltration methods on terrace monitoring. But on the last decade, the development of infiltration methods such as Beerkan infiltration experiments allows economical, rapid way to perform infiltration. Beerkan Estimation of Soil Transfer parameter (BEST) method was developed for the treatment of beerkan infiltration data. The BEST-slope "BS" method (Lassabatere et al., 2006) was the first to propose a methodology based on soil physical properties and beerkan infiltration experiment. In this method, the knowledge of particle size distribution, dry bulk density and specific density of the studied soil are required. The proposed method estimates the completes hydraulics properties of the soil such as water retention curve $h(\theta)$ and hydraulic conductivity curve $K(\theta)$. Then BEST-intercept "BI" (Yilmaz et al., 2010) and BEST-Steady "Bstd" (Bagarello et al., 2014a) methods were proposed to improve the estimation of the soil hydraulic functions. For the case of rapid Ks estimation on the field without any sampling procedure, simple approach of Beerkan infiltration (SBI) were introduced. Firstly, Bagarello et al. (2013, 2014b) proposed the transient simplified beerkan (TSBI) method. And alternative based on the steady state infiltration equation was proposed and referred as SSBI for steady SBI method (Bagarello et al.,2017). For both methods, α* scale parameter was chosen according to structural and textural aspect of soils (Reynolds and Elrick, 1990). Recently α* parameter estimated from Beerkan infiltration curve shape without any sampling procedure (Yilmaz, 2021) was proposed.

This paper proposes assessment of infiltration capacity of terrace soil of Munzur University campus using SSBI method without any sampling procedure and robust BEST-steady method. For that a total of 8 beerkan infiltrations and soils sampling were performed in situ.

2. MATERIAL AND METHOD

2.1. Theory

The BEST algorithm uses the van Genuchten (1980) relation (Equation 1a -1b) for the water retention curve h(θ), and the Brooks & Corey (1964) relation (Equation 2a-2b) for hydraulic conductivity, K(θ):

$$\frac{\theta-\theta_r}{\theta_s-\theta_r} = [1+|\alpha h|^n]^{-m} \qquad \text{Equation 1a}$$

$$m = 1-\frac{k_m}{n} \qquad \text{Equation 1b}$$

$$K(\theta) = K_S\left[\frac{\theta-\theta_r}{\theta_s-\theta_r}\right]^\eta \qquad \text{Equation 2a}$$

$$\eta = \frac{2}{mn}+3 \qquad \text{Equation 2b}$$

where θ (L^3 L^{-3}) is the volumetric soil water content, h (L) is the water pressure head, K (L T-^{1}, where L and T represent length and time in the international unit system (SI)) is the soil hydraulic conductivity, n, m and η are shape parameters, and α (L^{-1}, representing the inflection point of the water retention curve), θ_s (L^3 L^{-3}, field-saturated soil water content), θ_r (L^3 L^{-3}, residual soil water content) and K_s (L T^{-1}, field-saturated soil hydraulic conductivity) are scale parameters. The BEST methods derive the whole set of hydraulic parameters using two sets of data (particle-size distribution (PSD) with bulk density, and the cumulative infiltration curve I(t) with the initial and final soil water contents). The BEST methods make the following assumptions: θ_r is assumed to be zero and the saturated water content θ_s is equal to soil porosity. The shape parameter n was estimated from pedotransfer functions that use particle-size distribution of the fraction < 2 mm (Lassabatere et al., 2006). The scale parameters K_s and h_g were then derived from the analysis of cumulative infiltrations.

The three-dimensional cumulative infiltration, I(L) can be approached by the following explicit transient two-term expressions (Equation 3a) and steady-state expansions (Equation 3b) (Haverkamp et al., 1994; Lassabatère et al., 2006):

$$I(t) = S\sqrt{t}+(AS^2+BK_S).t \qquad \text{Equation 3a}$$

$$I_{+\infty}(t) = (AS^2+K_S).t+C\frac{S^2}{K_S} \qquad \text{Equation 3b}$$

where t (T) is the time and S the soil sorptivity (L $T^{-0.5}$) is the steady-state infiltration rate. The A (L^{-1}), B and C constants are defined for the specific case of a Brooks and Corey (1964) relationship as:

$$A = \frac{\gamma}{r(\theta_S-\theta_0)} \qquad \text{Equation 4a}$$

$$B \approx \frac{2-\beta}{3} = 0.4667$$ Equation 4b

$$C \approx \frac{1}{2(1-\beta)} \ln\left(\frac{1}{\beta}\right) = 0.6385$$ Equation 4c

where β and γ are coefficients that are commonly set at 0.6 and 0.75, respectively, for $\theta_0 < 0.25\ \theta_S$ (Smettem et al., 1994; Haverkamp et al., 1994). The Ks is estimated according to BEST-steady method (Bagarello et al., 2014a) as follow:

$$K_s = \frac{s_{std}}{\frac{A}{C} i_{std} + 1}$$ Equation 5

Where s_{std} and i_{std} are respectively the slope and the intercept of the steady state asymptote (Equation 3b). The SSBI method calculates Ks as follow:

$$K_S = \frac{s_{std}}{\left(\frac{\gamma \cdot \gamma_W}{r\alpha^*} + 1\right)}$$ Equation 6a

where γw is the sully constant known as 1/b with b=0.55 (Sully and White, 1987), α* parameter was commonly set to 0.001, 0.004, 0.012 or 0.036 mm-1 according to visual aspect of the texture of the soil (Reynolds and Elrick, 1990). Recently, Yilmaz (2021) proposed α* parameter function of empirical and steady state shape curve,:

$$K_S = \frac{s_{std}}{\frac{3,5594}{r} i_{std} + 1}$$ Equation 6b

In the SSBI approach, no sampling is needed where for BEST-steady structural value is expected.

2.2. Material

2.2.1. Munzur University Campus soil

The studied site is a terrace soil located at the campus of Munzur University in Turkey (Figure 1). For struggle erosion, pine trees were planted on the terrace. Long term goal aims to monitor hydraulics properties of the terrace section and effect of tree growth on soil structural properties. The studied soil is a rectangle surface of 15 meters longer and 3 meters width. The textural class of the soil is loamy sand. A campaign of Beerkan infiltration, sampling for soil water content profile and soil bulk density were performed on 25-26 November 2019 (Figure 2). The soil specific density was measured with the pycnometer method to 2.50 g.cm^{-3}. The gravimetric water content was measured at three points (Figure 2) and mean value of 5.96 % of dry mass was considered. For each Beerkan run soil sampling was collected to determine the soil bulk density. The physical properties of studied soil are presented in table 1.

Fig. 1. Studied site google map picture and terrace with pine trees

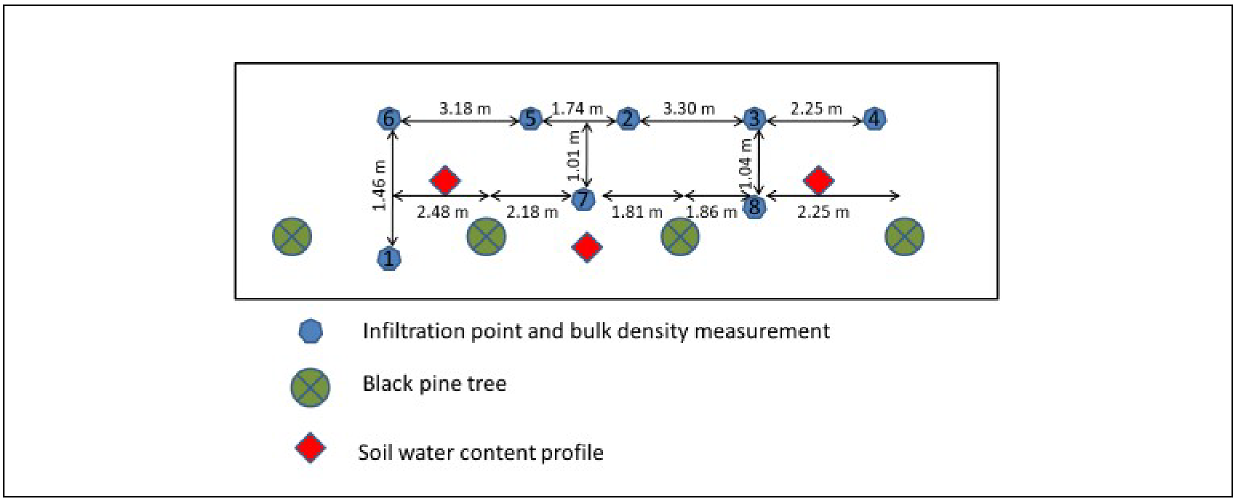

Fig. 2. Soil sampling and Beerkan runs

Table 1. Specific and dry bulk density, USDA soil textural classification

water profil	soil depth	ωi [%]	Beerkan	Bulk density	θs
Point 1	0-5 cm	0,0420	Point ID	[g/cm3]	[m3/m3]
	5-10 cm	0,0667	1	1,379	0,451
	10-15 cm	0,0727	2	1,556	0,380
Point 2	0-5 cm	0,0560	3	1,455	0,420
	5-10 cm	0,0695	4	1,336	0,468
	10-15 cm	0,0891	5	1,271	0,493
Point 3	0-5 cm	0,0339	6	1,262	0,497
	5-10 cm	0,0420	7	1,605	0,361
	10-15 cm	0,0647	8	1,476	0,412

2.3. Beerkan infiltration

At total of 8 Beerkan experiments were done with an infiltration ring devise of 50.85 mm in radius. The cylinder ring was positioned at the soil surface and inserted to a depth of 1 cm to avoid a lateral loss of ponded water. Several doses of water of same volume were prepared. The first dose was poured into the cylinder at time zero and the elapsed time required to complete infiltration was recorded. Then, the second dose was poured into the cylinder, and the time required to infiltrate was measured (in cumulative terms). This procedure was repeated for a series of between 8 and 20 known volumes to reach steady state, meaning the stabilization of the times required to infiltrate the dose of similar volumes. At the end of the experiment, the volumes were divided by the ring surface to compute the cumulative height of infiltrated water, this last being reported as a function of time to build the cumulative infiltration curves.

3. RESULTS AND DISCUSSION

Cumulated Beerkan infiltration curves from terrace soil of Munzur university campus are illustrated in figure 3. All infiltration curves present a concave part at the beginning and the steady state was reached for each experiment. The shorter experiment duration was 0.35 hour and the longest duration was 0.55 hour.

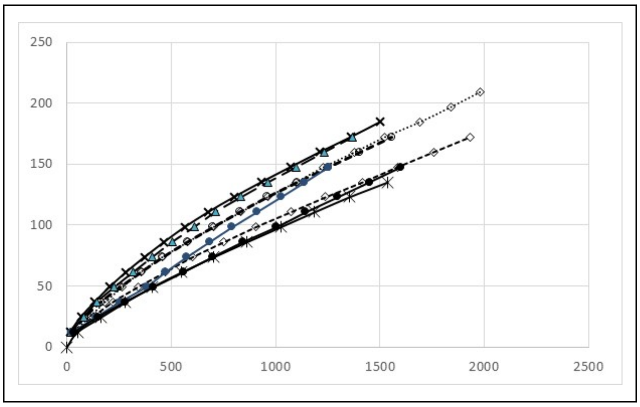

Fig. 3. Cumulated Beerkan infiltration curves, horizontal axe belongs to time [s] and vertical axe belongs the cumulated infiltrated water [mm]

Table 2 summarizes the estimates of Ks for each method. The mean value of Ks of the studied section were 0.0280 mm/s for BEST-steady and 0.0236 mm/s for SSBI methods. The maximum relative difference of 30.36% in Ks estimates between both methods was observed for Beerkan ID5. The minimum difference of 0.57% was for Beerkan ID5. Considering the soil variability in situ, the mean relative difference between both methods of 15.67% is not significant. Therefore, if we consider Ks as an indicator of the infiltration capacity of the terrace soil, the use of SBBI method with α* parameter defined by Yilmaz (2021) give satisfactory results.

The studied area presented some variability between infiltration experiments, this was mainly due to machine compaction for transportation of tree in situ. Especially point 2 and 7 presented high compaction in comparison to the others. However, the more compacted point 7 conducted to the highest Ks value. This indicates the presence of macropore inside of the soil matrix and has positive effect for promoting rainwater into the soil. Concerning the black tree pin effect, no conclusion can be done at this stage since a long-time monitoring is necessary. In fact, as the trees were planted one month before the experiment, no effect of the roots in the soil matrix is expected. The next campaign infiltration will be conducted for 2021 autumn season and then every two years the site will be monitored to check Ks variability in time.

Table 2. Ks estimates [mm/s]

Beerkan ID	θi	θs	s_std	i_std	Steady	SSBI
1	0,082	0,451	0,0698	28,16	0,0252	0,0199
2	0,093	0,380	0,0817	45,42	0,0174	0,0162
3	0,087	0,420	0,0854	56,43	0,0173	0,0142
4	0,080	0,468	0,0855	39,93	0,0252	0,0188
5	0,076	0,493	0,0912	47,43	0,0251	0,0175
6	0,075	0,497	0,0705	36,04	0,0237	0,0168
7	0,096	0,361	0,1088	11,51	0,0541	0,0538
8	0,088	0,412	0,0815	17,41	0,0362	0,0320

4. CONCLUSION

In this study, infiltration capacity of terrace soil of campus of Munzur university were investigated using SSBI and BEST-steady approaches. Both methods gave consistent results showing that the pseudo empirical value for α* was sufficient and sampling was not necessary. If the monitoring of the terrace soil infiltration is enough then the SBBI method can be considered as very inexpensive and rapid soil characterization method. However, the use of BEST methods with soils sampling allows measurement of structural and textural parameter of the soils and permit a complete characterization of the soil characteristic such as soil water retention curve and hydraulic conductivity curve. The effect of black pine tree was not investigated and will be the subject of further research.

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