Arab J Geosci (2012) 5:1039–1046
DOI 10.1007/s12517-011-0497-y

ORIGINAL PAPER

Study on infiltration rate based on primary particle size distribution data in arid and semiarid region soils

Mahmoud Reza Mazaheri · Majid Mahmoodabadi

Received: 10 October 2011 / Accepted: 25 November 2011 / Published online: 6 January 2012

Abstract Soil particle size distribution (PSD) is used to estimate some soil processes, soil moisture characteristics, and infiltration rate (IR). Prediction of infiltration rate from soil texture data requires an accurate characterization of PSD. The objective of this study was to determine more important primary particle diameters that control IR. The experiments were conducted using double-ring method with constant head of 5 cm in 15 different soils and three replications. The range of measured IR for studied soils varied from 1.6 to 30.66 cm h^{-1}. The results indicated that the primary PSD had a significant influence on IR. In other words, most D_n fractions had significant positive effect on the final IR. Among different fractions, D_{30}, D_{40}, and D_{60} showed higher relationships with IR than the others. These diameters are attributed to particles with diameter of 0.05, 0.08, and 0.16 mm, respectively. The results also showed that increasing the percent of sand have intensified influence on increasing the final IR. Reversely, clay and silt contents showed negative effects on final IR. Furthermore, the $CaCO_3$ had a meaningful effect on the IR that showed the importance of lime in arid and semiarid regions. Finally, it is revealed that the role of texture was important, especially in behavior of infiltration, runoff, and production capability.

Keywords Permeability · Double ring · Primary particle size distribution

Introduction

Hydraulic properties of soil are one of the most important agents controlling infiltration, runoff rate, pesticides leaching in agricultural lands, and migration of pollutants from contaminated sites to groundwater. Therefore, there is a need for good water management practices in order to solve water-related problems such as irrigation and erosion issues. In this regards, it is essential to predict water infiltration rate into soil, to model water and solute transport processes, and to evaluate soil physical quality (Hillel 1998; Bagarello and Iovino 2004; Kutılek 2004; Machiwal et al. 2006).

Infiltration is the term applied to the process of water entry into the soil. This process is the movement of water into the soil from the surface by downward or gravitational flow. The rate at which it occurs is known as the infiltration rate, which continues to decrease and asymptotically approaches the saturated hydraulic conductivity. This rate of infiltration is termed the steady state infiltrability. It is approximately the same as the field saturated hydraulic conductivity of the surface soil. Infiltration rate mainly depends on soil properties, such as; initial moisture content, hydraulic conductivity, soil texture, porosity, swelling degree of soil colloids, organic matter content, and chemical properties, as well (Saxton et al. 1986; Bagarello and Iovino 2004; Chowdary et al. 2006).

Soil comprises water, air, and solid particles with varied directions and shapes (Prieksat et al. 1994). Connectivity

M. R. Mazaheri · M. Mahmoodabadi (✉)
Department of Soil Sci., Agriculture Faculty,
Shahid Bahonar University of Kerman,
Kerman, Iran
e-mail: mahmoodabadai@mail.uk.ac.ir

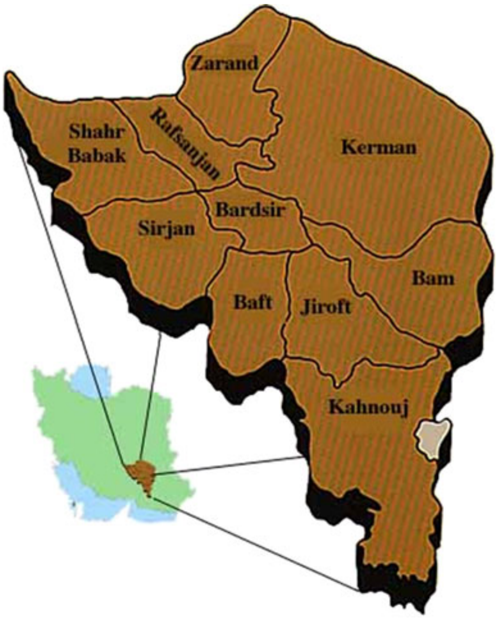

Fig. 1 Location of 15 sites on Kerman province map

has a great impact on liquid and its movement characteristics in solid particles. The array forms, sizes, and shapes of solid ingredients and interstices constitute soil structure and determine the series of characteristics and diversification of soil physical properties (Lin et al. 1999). Therefore, the infiltration process is closely associated with soil particle size distribution as well as soil pore size distribution (Boix 1997; Hwang 2004).

Soil particle size distribution (PSD) is the most widely used characteristic for soil processes modeling (Le Bissonnais and Arrouays 1997; Diaz-Zorita et al. 2007). In such models, PSD data afford a means of computing the water reserve that is usable by plants, determining fertility groups and estimating the soil's vulnerability to compaction, subsurface drain clogging, and ditch and watercourse bank instability, and also its vulnerability to the upward migration of coarse fragments as a result of human action (Dominguez et al. 2001; Hwang and Powers 2003). The PSD data can help users locate filling materials and estimate a soil's ability to tolerate the passage of vehicles, its frost susceptibility, or its tendency to settle (Bittelli et al. 1999; Hwang et al. 2002). However, soil samples have ably different PSD and therefore all kind of soils demonstrate different infiltration rates (Campbell and Shiozawa 1992; Bittelli et al. 1999).

In general, soil PSD is defined as primary (PPSD) and secondary (SPSD) which the former is related to soil texture and the later is attributed to aggregates. The main particle fractions of clay, silt, and sand do not provide complete information on soil PPSD. A more accurate description of texture is obtained by defining a PPSD function (Bittelli et al. 1999). In spite of such aspects, using this factor is partially beneficial and applicable. Determination of the soil PPSD by sieving (Kemper and Rosenau 1986), hydrometer and pipette (Gee and Bauder 1986) methods, or by laser diffraction (Hernadi et al. 2008; Bah et al. 2009) is mainly due to extraction of the size of irregularly shaped particles (Eshel et al. 2004). The soil PSD is useful for quantifying soil properties because it is related to soil pore space and water movement. Pore size distribution of soil depends on its PSD therefore, soils including larger particles have greater pores indicating higher infiltration rates. In other word, estimating hydraulic properties from particle size data is preferred when studying soil infiltration of different particle sizes.

Textures of various weight proportions of the primary separates particles of soil produce different PPSD. Particle size distributions are often rendered as cumulative functions, either as number of particles larger than a certain diameter, or as mass smaller than a certain diameter and are often showed by the geometric mean particle-size diameter (d_g; Bittelli et al. 1999; Shirazi et al. 2001). The D_g parameter changes a sample description from a conventional texture triangle and separate limits to a new system (Shirazi et al. 2001). The transformation has two distinct steps, the first defines the PPSD and the second mathematically integrates the PPSD to calculate the statistics d_g (Shirazi et al. 2001).

In these cases, a detailed characterization of infiltrate properties based on limit size of soil particles (passed

Table 1 Some physical properties of the studied soils

Parameter Unit	Clay %	Silt	Sand	OC.	Initial moisture	Saturated moisture	Bulk density g cm^{-3}
Min	6	4.6	10.7	0.05	2.5	25.4	1.1
Max	36.2	67.7	86	2.3	21	58	1.6
Average	15.1	32	52	1.3	7.9	37.1	1.4
CV%	59.3	64.6	50.3	85.7	63.2	27.5	12.8

Table 2 Some chemical properties of the studied soils

Parameter Unit	pH	EC (dS m^{-1})	Ca^{+2} (meq L^{-1})	Mg^{+2}	K^+	Na^+	SAR (meq $L^{-1})^{05}$	$CaCO_3$ %
Min	7	0.4	2.4	0.4	0.2	2.9	1	6.8
Max	8.1	38.1	89.6	145.6	8.5	213.8	16.6	24.3
Average	7.7	7.6	20	18.8	1.9	28.3	3.8	15.9
CV%	3.2	144.4	86.7	175.3	124.0	169.8	89.6	24.5

percentage of particle of soil from sieves) are very important for better understanding of their behavior towards PPSD and d_g. For example, in the International Soil Science Society system the boundary for sand fraction is different to the United States Department of Agriculture system. Because relationships between texture and other hydraulic properties are affected by these differences, the size definitions of the three main particle fractions of clay, silt, and sand, used as diagnostic characteristics in most classification schemes, are rather arbitrary, and they do not provide complete information on the soil PPSD and hydraulic properties (Bittelli et al. 1999; Shirazi et al. 2001). Infiltration in soil is a quite complex issue; therefore, in the present study, we wish to investigate the PPSD to show the most effective size on infiltration rate and also to determine the degree of relationship between infiltration rates and selected soil properties.

Material and methods

Soil sampling and preparation

Because infiltration rate is controlled by soil properties especially particle size distribution, soil samples were collected from different soils. Totally, 15 sites were selected near the city of Kerman and Jiroft, in south eastern Iran in arid and semiarid regions (Fig. 1). The mean annual temperature in the regions is 15–25°C and the mean annual precipitation is 140–180 mm, respectively. The soils have aridic moisture and thermic temperature regimes, dominantly. The main dominant plant species are four major vegetation types: evergreen broad leaved, warm coniferous plants, tropical shrubs, and hassock.

Measurement of infiltration rates and soil properties

At each site, three points were selected as replications to determine mean infiltration rate. Infiltration rate was measured using double-ring method with constant water head of 5 cm (Bouwer 1986). This method is useful that offers a simple, fast, and convenient means of determining soil hydraulic properties based on in situ infiltration measurements at the soil surface. Double ring has also been widely used for estimation of field-saturated hydraulic conductivity under pounded conditions without much disturbance to the soil surface at the measurement site (Bouwer 1986). Three double-ring tests were carried out at each site and duration of each experiment was based on the time to reach the steady state.

Beside each point, a soil sample was collected to analyze soil physical and chemical properties. Collected soil samples, after determination of primary moisture and bulk density, were air-dried, gently crushed, and passed through a 2-mm mesh. Sieved samples were stored in unused polythene bags, were labeled appropriately, and were prepared to laboratory analysis of selected physical and chemical properties. Bulk density was determined using core samplers (Grossman and Reinsch 2002). Saturation paste of the soils

Table 3 Initial and saturated moisture content in relation with hydraulic conductivity for 15 sites

Site	Antecedent moisture (%)	Saturated moisture (%)	Hydraulic conductivity (cm h^{-1})
1	2.8	46.5	21.4
2	15.9	54.7	16.3
3	18.5	55.6	14.3
4	4.5	28.3	15.3
5	7.0	29.3	7.5
6	8.8	41.4	7.0
7	2.1	26.9	9.6
8	15.0	33.5	20.4
9	7.8	50.6	9.4
10	4.4	35.2	1.8
11	5.8	29.7	22.4
12	10.7	33.4	6.5
13	2.3	35.6	2.6
14	6.8	26.4	13.0
15	6.2	29.1	10.7

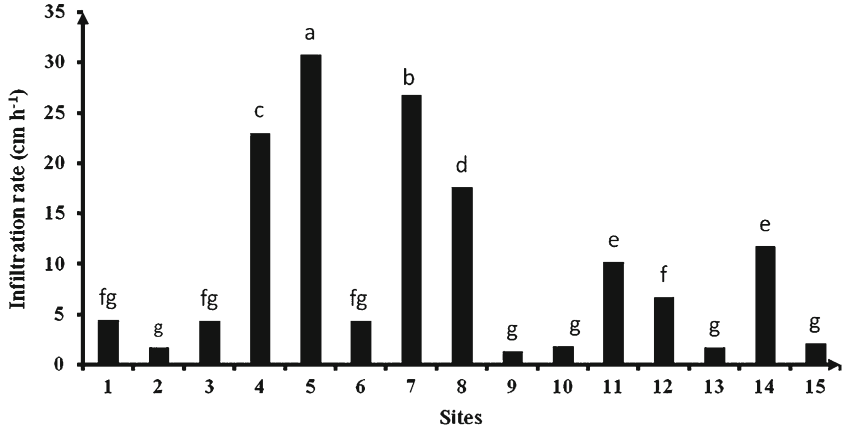

Fig. 2 Comparison of means of final infiltration rates for 15 sites (alpha=0.05)

was prepared and the pH and EC were measured. Organic carbon was determined using Nelson and Sommers (1982) method. Soluble Ca^{+2} and Mg^{+2} were measured by titration method. Soluble Na^{+} and K^{+} were obtained by a flame photometer. Gypsum content of the soils was calculated using the method of Berigari and Al-Any (1994).

Prior to particle size analysis, all soil samples were dispersed in sodium hexametaphosphate solution and shaken for 24 h to disperse aggregates. Sedimentation techniques based on Stoke's law were used to obtain particles finer than 2 mm diameters (Bittelli et al. 1999). The distribution of particles was determined by hydrometer method (Gee and Bauder 1986). To obtain other size classes finer than 2 mm, not obtained from hydrometer method, sieve analysis was done consequently. Sieve analysis consists of shaking the soil sample through a set of sieves that have progressively smaller openings (4.76, 2, 1, 0.5, 0.25, and 0.149 mm). The data of sieve analysis were expressed in terms of the percentage of the total weight of soil that passed through different sieves. The results of mechanical analyses (sieve and hydrometer analyses) were generally presented by semi-logarithmic plots known as particle size distribution curves. The diameter in the particle size distribution curve corresponding to % finer particles was defined as the effective size or D_n. The obtained data were analyzed using correlation and regression analysis in order to estimate the relationship between infiltration rates and PPSD using SPSS software.

Results and discussion

The measured values of some physical properties of studied soils from 15 sites are shown in Table 1. Because the soils were selected mainly based on diverse properties, the coefficient of variations (CV%) is relatively high that is satisfactory. As it is clear from the results of the physical properties (Table 1), the primary particles including clay, silt, and sand have the CV% higher than 50%, indicating adequate diversity in the soils texture. It was also found that the soils had a proper distribution regarding the organic matter. Table 2 shows some chemical properties of the soils. High quantities of CV percent for soluble cations, as well as EC reveal diverse conditions of salinity and electrolyte concentrations. In addition, the amount of gypsum in the soils was negligible, while the quantity of $CaCO_3$ was higher in comparison. In addition to the final IR, initial and saturated moisture contents and hydraulic conductivity were measured (Table 3). The range of initial moisture percentage varied from 2.1% to 18.5%, while the content of saturated moisture changed between 26.4% and 55.6%. As shown in Table 3, the range of hydraulic conductivity

Table 4 Simple correlation analysis of final infiltration rates with all of D_n values

Primary fractions		D_{10}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{70}	D_{80}	D_{90}
Mean value		0.003	0.028	0.049	0.082	0.142	0.162	0.235	0.340	0.668
IR	Correlation	0.374	0.559	0.701	0.749	0.520	0.711	0.642	0.563	0.565
	Probability >*F*	0.079	0.079	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

values varied from 1.8 to 22.4 cm h^{-1}, indicating the importance of particle size distribution effect on hydraulic properties. This is due to the fact that both pore size distribution and hydraulic conductivity are influenced by PSD.

Figure 2 shows the average infiltration rates for the 15 sites. The range of IR for studied soils was varied from 1.6 to 30.66 cm h^{-1}. Accordingly, the least IR was observed in sites 2, 9, 10, 13, and 15, while sites 5, 7, 4, and 8 found to have the highest rates of infiltration. The comparison of means for final infiltration rates was done. A high significant difference ($p<0.05$) was observed among the sites, indicating that the final infiltration rates vary in different sites. To determine if these differences can be attributed to PPSD, the analysis of simple correlation was carried out on data.

Table 4 shows simple correlation results between all of D_n and final infiltration rates. Significant correlation ($p<0.05$) was found between most of the D_n values and infiltration rates. The results indicated that the final infiltration rates vary because of the differences in D_n (Table 4) in the studied soils. In other words, D_n has significant positive effect on the final infiltration rate. Among all fractions, D_{30}, D_{40}, and D_{60} showed higher relationships with IR than the others. These diameters are attributed to the average of particle sizes, which (for D_{30}, D_{40}, and D_{60}) are about 0.05, 0.08, and 0.16 mm, respectively. This finding implies that the highest primary particles which control the final IR are placed in sand fraction.

To investigate the influence of D_n values on final IR, some representative sites were compared. Based on Fig. 2, sites 2 and 5 showed the least and the highest final infiltration rates, respectively. The differences between sites 2 and 5 in their IR may be partly assigned to the differences in their D_n. Therefore, D_{30}, D_{40}, and D_{60} values as well as soil textures for the sites is presented in Table 5. As shown in Fig. 3, site 5 has a higher IR compared to site 2, which is due to higher D_n values. This means that the PPSD has meaningful influence on infiltration rate which has been found by some other researchers (Romkens et al. 1995; Dominguez et al. 2001; Hwang et al. 2002; Barthes et al. 2008). The results indicated that the percent of sand for site 5 is 5.8 times higher than site 2, which caused to 31 times increase in final IR. Reversely, clay and silt contents showed negative effects on final IR. The relationship between measured IR and D_n indicated that high average of IR was usually observed under the maximum D_n. These results may be attributed to such factors as high total porosity and unclosed effective void (Kutılek 2004; Lipiec et al. 2006). The variation of IR in these sites is apparently due to variation in soils properties (Katsvairo et al. 2002).

Table 5 Comparison between sites 2 and 5 in respect of D_n and soil textures

D_n	Site 2	Site 5
D_{30}	0.0010	0.0860
D_{40}	0.0037	0.1415
D_{60}	0.0090	0.2540
Clay (%)	33.38	12.69
Silt (%)	53.09	9.44
Sand (%)	13.53	77.87

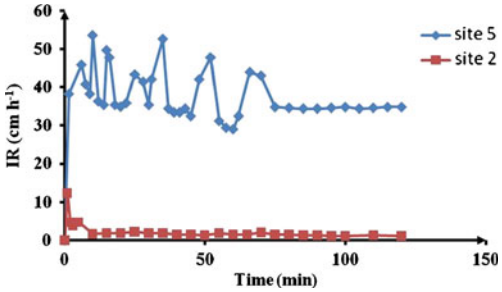

Fig. 3 Changes in infiltration rates with time for sites 2 and 5

Each fractions of soils texture showed a different behavior with regard to IR. Table 6 shows simple correlation results of final infiltration rates with selected soil properties. The correlations of IR with clay, silt, and sand contents were −0.551, −0.705, and 0.706, respectively. The negative role of clay and silt fractions is probably due to their small sizes, which caused blocking in the effective pores (Oster and Shainberg 2001; Bronick and Lal 2005; Carpenter and Chong 2010) especially the particles stay apart from aggregating (Curtin et al. 1994; Halliwell et al. 2001; Lado et al. 2004; Ruize-Vera and Wu 2006). Also, another fraction of texture, sand particles, probably because of their big sizes, caused to high IR (Romkens et al. 1995; Hwang and Powers 2003).

Simple correlation values of final infiltration rates with initial moisture and also saturated moisture contents are shown in Table 6. The initial moisture had no meaningful influence on final IR, however saturated moisture showed a negative significant effect ($R^2=-0.563$). In other word, those soils with higher saturated moisture contents have lower infiltration rates. This is probably attributed to clay effect that is to say increasing clay content, total porosity would be increased, while the frequency of macropores reduces. In addition, the results show that there is no significant relationship between final IR and hydraulic conductivity (Table 6). This is partly due to the fact that

Table 6 Simple correlation analysis of final infiltration rates with selected soil properties

Soil property		Clay	Silt	Sand	Antecedent moisture	Saturated moisture	Hydraulic conductivity	OM	$CaCO_3$
IR	Correlation	−0.551	−0.705	0.706	−0.174	−0.563	0.107	−0.265	−0.610
	Probability >*F*	0.0001	0.0001	0.0001	0.253	0.0001	0.484	0.078	0.0001

measurement of hydraulic conductivity was carried out in laboratory condition using disturbed soil samples. In other word, pore size distribution and subsequent hydraulic behaviors are highly affected by soil disturbance.

Relationship between measured IR and other soil properties (Table 6) indicated that organic matter and equivalent calcium carbonates have statistically significant negative effects on IR. This result is similar to those obtained by Nejadhashemi et al. (2000), Lado et al. (2004), Garcia-Orenes et al. (2005). The negative roles of the aforementioned properties might be because of their separate presence in the pores, as well as their small amounts and newly formed accumulations in these soils. These were effective on infiltration; there is no need to mention that they separate, because of the presence of some dispersing factors, such as high soluble Na^+ and SAR (Ruize-Vera and Wu 2006; Carpenter and Chong 2010).

To quantify the influence of different soil properties on final IR, simple regression using stepwise method was applied. Equation 1 shows the negative effect of saturated moisture as one of the moisture characteristics on IR. Moreover, Eq. 2 presents the effect of soil texture on final IR, implying obstruction influence of silt particles on permeability that discussed above. The effect of studied fractions on final infiltration rate indicated that among different D_n values, D_{40} have highest influence which was confirmed in Table 4. These equations prove that PSD is the most important agent controlling final IR. This is logical as the soils had low amounts of organic carbon due to low plant cover, so particle size distribution is affected by the primary agents.

$$IR = 30.012 - 0.544\mathrm{SP\%} \quad R^2 = 0.317 \tag{1}$$

$$IR = 20.42 - 0.33\mathrm{Silt\%} \quad R^2 = 0.48 \tag{2}$$

$$IR = 1.741 + 97.953D_{40} \quad R^2 = 0.56 \tag{3}$$

To have a better view on the effect of major primary fractions of clay, silt, and sand, those sites had the highest and least amounts of mentioned fractions were plotted against. As shown in Figs. 4, 5, and 6 changes in infiltration rates with time regarding to clay, silt, and sand is deeply affected. The differences between infiltration rates in two contrasted cases (maximum and minimum values of primary fractions) demonstrated clearly the effect of clay, silt, and sand contents. In general, for all soils similar results were obtained on the effect of PPSD on final IR. However, some exceptions were observed that showed a reverse influence of primary particles. Saxton et al. (1986) stated that the influence of texture on infiltration rates dominates other factors. This is, however, not consistent completely with the

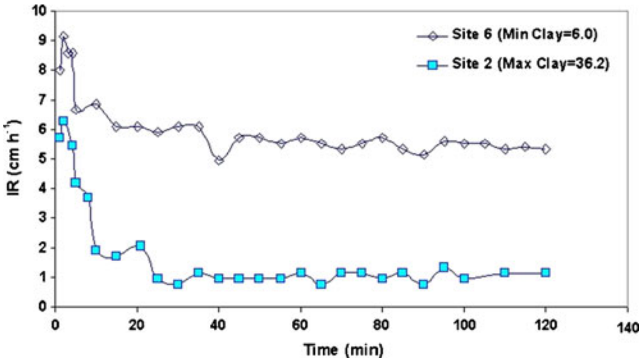

Fig. 4 Changes in infiltration rates with time regarding to clay content for sites 2 and 6

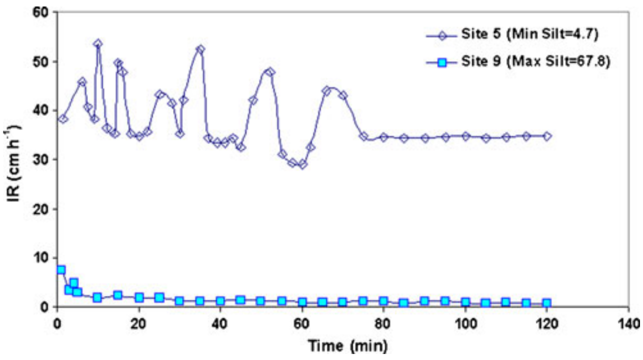

Fig. 5 Changes in infiltration rates with time regarding to silt content for sites 5 and 9

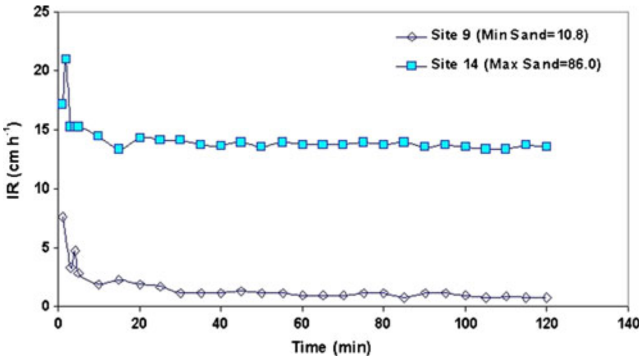

Fig. 6 Changes in infiltration rates with time regarding to sand content for sites 9 and 14

findings of this study, for example site 6 had higher D_n values than that of site 13, but the former had a lower IR (Figs. 7 and 8). This study revealed that even with the coarser primary particles of a given soil, other factors may interplay to cause a significant difference in infiltration rates. The same result was found by Osuji et al. (2010). However, in the studied soils which are all located in arid and semiarid regions, primary PSD plays an important role in permeability.

Conclusion

PPSD affects the infiltration rate of studied soils. However, the correlation analysis of sand, silt, clay, and some D_n revealed that the PPSD is considered as the most important factor which results in significant differences in the infiltration rates. The range of IR for studied soils was varied from 1.6 to 30.66 cm h^{-1}. A high significant difference ($p<0.05$) was observed among the sites, indicating that the final infiltration rates vary in different sites. Significant correlation ($p<0.05$) was found between most of the D_n values and infiltration rates. Among all fractions, D_{30}, D_{40}, and D_{60} showed higher relationships with IR than the others. These diameters are attributed to the average of particle sizes, which (for D_{30}, D_{40}0 and D_{60}) are about 0.05, 0.08, and 0.16 mm, respectively. The results indicated that increasing the percent of sand have intensified influence on increasing the final IR. Reversely, clay and silt contents showed negative effects on final IR. The correlations of IR with clay, silt, and sand contents were −0.553, −0.705, and 0.706, respectively. In general, for all soils, similar results were obtained on the effect of PPSD on final IR. However, some exceptions were observed that showed a reverse influence of primary particles. Finally, it is revealed that the role of texture was important, especially in behavior of infiltration, runoff, and production capability.

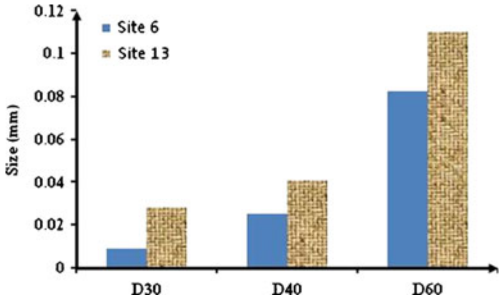

Fig. 7 Comparison between sites 6 and 13 in respect of D_n values

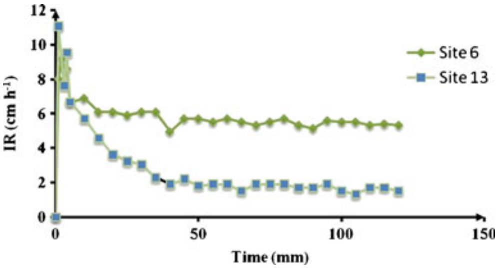

Fig. 8 Comparison between sites 6 and 13 in respect of time changes of infiltration rate

References

Bagarello V, Iovino M (2004) A simplified falling head technique for rapid determination of field-saturated hydraulic conductivity. Soil Sci Soc Am J 68:66–73

Bah AR, Kravchuk O, Kirchhof G (2009) Fitting performance of particle-size distribution models on data derived by conventional and laser diffraction techniques. Soil Sci Soc Am J 73:1101–1107

Barthes BG, Kouoakouoa E, Larre-Larrouy MC, Razafimbelo TM, de Luca EF, Azontonde A, Neves CS, de Freitas PL, Feller CL (2008) Texture and sesquioxide effects on water stable aggregates and organic matter in some tropical soils. Geoderma 143:14–25

Berigari MS, Al-Any FMS (1994) Gypsum determination in soils by conversion to water-soluble sodium sulfate. Soil Sci Soc Am J 58:1624–1627

Bittelli M, Campbell GS, Flury M (1999) Characterization of particle-size distribution in soils with a fragmentation model. Soil Sci Soc Am J 63:782–788

Boix EC (1997) The role of texture and structure in the water retention capacity of burnt Mediterranean soils with varying rainfall. Catena 31(3):219–236

Bouwer H (1986) Intake rate: cylinder infiltrometer. In: Klute A (ed) Methods of soil analysis. Part I, Agronomy Monograph 9, 2nd edn. ASA and SSSA, Madison, pp 825–844

Bronick CJ, Lal R (2005) Manuring and rotation effects on soil organic carbon concentration for different aggregate size fractions on two soils in Northeastern Ohio. USA Soil Till Res 81:239–252

Campbell GS, Shiozawa S (1992) Prediction of hydraulic properties of soils using particle size distribution and bulk density data. In: Van Genuchten MT, Leij FJ, Lund LJ (eds) Indirect methods for estimating the hydraulic properties of unsaturated soils. University of California, pp 317–328

Carpenter DR, Chong GW (2010) Patterns in the aggregate stability of Mancos shale derived soils. Catena 80:65–73

Chowdary VM, Damodhara Rao M, Jaiswal CS (2006) Study of infiltration process under different experimental conditions. Agri Water Manage 83:69–78

Curtin D, Campbell CA, Zentner RP (1994) Long-term management and clay dispersibility in two Hoploborolls in Saskatchewan. Soil Sci Soc Am J 58:962–967

Diaz-Zorita M, Grove JH, Perfect E (2007) Sieving duration and sieve loading impacts on dry soil fragment size distributions. Soil Till Res 94:15–20

Dominguez J, Negrin MA, Rodriguez CM (2001) Aggregate water stability, particle size and soil solution properties in conducive and suppressive soils to *Fusarium* wilt of banana from Canary island (Spain). Soil Bio Bioch 33:449–455

Eshel G, Levy GJ, Mingelgrin U, Singer MJ (2004) Critical evaluation of the use of laser diffraction for particle-size distribution analysis. Soil Sci Soc Am J 68:736–743

Garcia-Orenes F, Guerrero C, Mataix-Solera J, Navarro-Pedreno J, Gomez I, Mataix-Beneyto J (2005) Factors controlling the aggregate stability and bulk density in two different degraded soils amended with biosolids. Soil Till Res 82:65–76

Gee GW, Bauder JW (1986) Particle size analysis. In: Klute A (ed) Methods of soil analysis. Part I, Agronomy Monograph 9, 2nd edn. ASA and SSSA, Madison, pp 383–411

Grossman RB, Reinsch TG (2002) Bulk density and linear extensibility. In: Dane JH, Topp GC (eds) Methods of soil analysis. Part IV, vol 5, Soil Sci Soc Am Book Series. ASA and SSSA, Madison, pp 201–228

Halliwell DJ, Barlow KM, Nash DM (2001) A review of the effects of wastewater sodium on soil physical properties and their implications for irrigation systems. Aust J Soil Res 39:1259–1267

Hernadi H, Mako A, Kucsera S, Szabone Kele G, Sisak I (2008) Determination of soil mechanical distribution with different method (in Hungarian with English abstract). Talajvédelem (Soil Protection), Special Issue. 105–114

Hillel D (1998) Environmental soil physics. Academic, San Diego

Hwang S (2004) Effect of texture on the performance of soil particle size distribution models. Geoderma 123:363–371

Hwang SI, Powers SE (2003) Using particle-size distribution models to estimate soil hydraulic properties. Soil Sci Soc Am J 67:1103–1112

Hwang S, Lee KP, Lee DS, Powers SE (2002) Models for estimating soil particle-size distributions. Soil Sci Soc Am J 66:1143–1150

Katsvairo T, Cox WJ, Van Es H (2002) Tillage and rotation effects on soil physical characteristics. Agron J 94:299–304

Kemper WD, Rosenau RC (1986) Aggregate stability and size distribution. In: Klute A (ed) Methods of soil analysis. ASA and SSSA, Madison, pp 425–442

Kutılek M (2004) Soil hydraulic properties as related to soil structure. Soil Till Res 79:175–184

Lado M, Ben-Hur M, Shainberg I (2004) Soil wetting and texture effects on aggregate stability, seal formation and erosion. Soil Sci Soc Am J 68:1992–1999

Le Bissonnais Y, Arrouays D (1997) Aggregate stability and assessment of soil crustibility and erodibility. II. Application to humic loamy soils with various organic carbon contents. Eur J Soil Sci 48:39–48

Lin HS, McInnes KJ, Wilding LP, Hallmark CT (1999) Effects of soil morphology on hydraulic properties I. Quantification of soil morphology. Soil Sci Soc Am J 63:948–954

Lipiec J, Kus J, Słowinska-Jurkiewicz A, Nosalewicz A (2006) Soil porosity and water infiltration as influenced by tillage methods. Soil Till Res 89:210–220

Machiwal D, Jha M, Mal BC (2006) Modelling infiltration and quantifying spatial soil variability in a wasteland of Kharagpur, India. Biosyst Eng 95(4):569–582

Nejadhashemi AP, Mahmoodi S, Rahimi H (2000) Investigation of permeability of gypsiferous soils during leaching process. Iranian J Agric Sci 31(2):241–254

Nelson DW, Sommers LE (1982) Total carbon, organic carbon and organic matter. In: Page AL (ed) Methods of soil analysis. Part II, Agronomy Monograph 9, 2nd edn. ASA and SSSA, Madison, pp 539–579

Oster JD, Shainberg I (2001) Soil responses to sodicity and salinity: challenges and opportunities. Aust J Soil Res 39:1219–1224

Osuji GE, Okon MA, Chukwuma MC, Nwarie II (2010) Infiltration characteristics of soils under selected land use practices in owerri, southeastern Nigeria. World J Agri Sci 6(3):322–326

Prieksat MA, Kaspar TC, Ankeny MD (1994) Positional and temporal changes in ponded infiltration in a corn field. Soil Sci Soc Am J 58:181–184

Romkens MJ, Luk MSH, Poesen JWA, Mermut AR (1995) Rainfall infiltration into loess soils from different geographic regions. Catena 25:21–32

Ruize-Vera M, Wu L (2006) Influence of sodicity, clay mineralogy, prewetting rate and their interaction on aggregate stability. Soil Sci Soc Am J 70:1825–1833

Saxton KE, Rawls WL, Rosenberger JS, Papendick RI (1986) Estimating generalized soil water characteristics from texture. Soil Sci Soc Am J 50:1031–1036

Shirazi MA, Boersma L, Burch Johnson C (2001) Particle-size distributions: comparing texture systems, adding rock, and predicting soil properties. Soil Sci Soc Am J 65:300–310