ISSN: 2073-9524
eISSN: 2310-8746

Study of Agricultural Soil Infiltration under the Movement of Machinery

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Article history:

Received: 13 March 2024
Accepted: 21 June 2024
Published: 30 December 2024

Keywords: *Soil infiltration, Soil compaction, Agricultural soil, Tire tractor.*

Abstract

A key problem for horticulture is compaction of the soil during the work, the aim of this article is to assess the state of water infiltration, under different water conditions at different depths of sandy soil. This experimental test showed that the decrease of the infiltration according to the increase the mass of the machine and the tractors number pass. In this case, the soil is more compressible and the infiltration of water in the plot studied decreases during the passage of tractors. However, the number of passes (2 successive passes) reduces the infiltration rate between 70% and 75% compared to the infiltration of tilled soils. Also, the results showed that the infiltration rate was directly linked to the depth, the number of passes, time and indirectly to the work of the soil and the weight of the machine. The findings indicate that tilled soils have the capacity to absorb water at a quicker pace than non-tilled soils. As a result, a significant evaluation of soil infiltration (R2=0.92) showed the observable reduction in infiltration following a number of passes and as a function of depth.

https://dx.doi.org/10.52951/dasj.24160201

Introduction

Soil compaction is one of the major problems of vegetable crops. Soil settlement by wheeled agricultural vehicles has a negative impact on the structure of arable soils and in a severe way, it will affect crop production in both the short term and long term. Compaction represents one of the problems that affect the state of agricultural soils. The multiple passages of wheeled agricultural machinery cause the destruction of the structure of arable soils and negatively influence the development of crops and production (Soane and Van Ouwerkerk, 1994). Thus, Vitlox and Loyen (2002), declare that the expansion of machinery has an indirect or direct connection to the primary causes of soil compaction. Mismanagement of machines and tools causes settlement. Also, these tractor passages generate variations in density, permeability, and resistance to penetration (Elaoud *et al.*, 2017; Ben Hassen *et al.*, 2020; Elaoud *et al.*, 2021).

Test soil condition monitoring studies at the wheel track level of the engine utilized to carry out cultivation operations illustrated that the force applied by the wheels manifests itself in depth by an increase in density (Elaoud and Chehaibi, 2011; Elaoud *et al.*, 2017).

The intensity of agricultural soil compaction is present in the form of the stresses implemented by the machine and its soil resistance. Constraints engaged on soil depend on the mass of the machine, its speed, the contact pressure, the number of passages, etc. (Larson and Pierce, 1994). Several types of research have been carried out experimentally and also in terms of simulation of the settlement of agricultural soils in Tunisia (Elaoud and Chehaibi, 2011; Elaoud *et al.*, 2014; Ben Hassen *et al.*, 2020; Jalel *et al.*, 2021; Elaoud *et al.*, 2021; Elaoud *et al.*, 2023).

Many factors have conditioned the degree of compaction, some of them being connected to the engine (tire pressure, number of passes, speed, mass ...) decreasing porosity, and infiltration which affects water movement, mineral availability, aeration and crop yield. From where, the settlement reduces soil aeration and water infiltration. It penalizes root development and biological functioning. Thus, infiltration is essential for the sustainable functioning of terrestrial ecosystems, the protection of water resources, agricultural production and the prevention of water-related risks such as erosion and flooding. Appropriate water management and soil protection practices are essential to promote effective infiltration and maintain optimal hydrological balance. Estimation of the importance of the infiltration process allows to determine what fraction of the rain will be used to feed underground flows and thus also to fill groundwater (Nadjib and Abdenour, 2019).

According to Silva (2008), the infiltration rate in soil can also be used to monitor the soil in the compaction state. The infiltration capacity is an indicator of the productivity of soil.

There is usually a considerable positive effect on infiltration when carrying out tillage. A decrease in infiltration can lead to soil degradation, as water cannot infiltrate and move to the surface, eroding the soil and especially its fertility.

Experimentally, a minority of the study of this field was performed in Tunisia, specifically in the area of Morneg-Ben Arous. The question that arises is how to evaluate compaction based on the measurement of water infiltration into the soil. Hence, the objective of this work is to assess the state of water infiltration, under different water conditions, at different depths of sandy soil.

Materials and Methods

Site of test

The study was conducted at parcel in Ben Arous, Morneg Region, Tunisia (36°38'47.2"N 10°14'50.8"E). The tests were carried out on sandy soil texture (0% clay, 6.83 loam and 95.66% sand). In order to conduct this research, we chose to install a gadget that split parcels into 3 blocks.

Engine and experimental device

Experimental tests were carried out in three successive repetitions on the sandy texture plot, at varying depths from 0 to 40 cm (each 10 cm). The measurements were carried out of the following parameters:

1-The grain size test: to determine the soil texture,

2-The humidity test: to determine the water content,

3-The density test: to deduce the state of soil compaction.

Three replications were carried out to study the evaluation of the density as a function of depth for three treatments carried out (initial state, after a first pass and after soil work). The tractor moving in the field resulted in a compaction.

4-An infiltration test: to determine the water content of the soil depth for three treatments carried out (initial state, after one pass, after two passes and after soil work).

The work was finished with a LANDINI 5860 tractor weighing 1.250 tons. The diesel engine motor is 47 hp (35.0 kW), the front tire: is 7.50-16 and the 2 drive rear wheels tire: is 12.4 R32.

Soil physical parameters

One of many important variables when assessing the tillage response is soil density. The cylinder sample methodology represented one of the techniques utilized during the examination to determine this variable. The dirt and hammer are used to introduce this sampling densimeter, Figure 1 shows the method of taking soil samples to measure density and water content A-cylinder; B-Hammer (Black, 1965).

A B

Figure 1. Method of taking soil samples to measure density and water content A-cylinder; B-Hammer

The cylinder gets pushed under the soil at each of the three depths (10, 20, and 30 cm) and samples are obtained at every level.

According to (Black, 1965), the soil samples dry in an oven at 105ºC for 24 h, when an exact weight is achieved, matching its dry mass (Figure 2).

Figure 2. Dry soil samples in the oven

The equation 1 that follows is used to calculate the soil's density (Elaoud and Chehaibi, 2011):

$$W_v = W_s / V \quad \text{-------} (1)$$

Where: Ws is the dry mass (g); V is the volume of the cylinder (cm^3) and Wv is the soil bulk density (g/cm^3).

The volume of the cylinder is calculated by using equation 2 (Elaoud and Chehaibi, 2011):

$$V = l \times \pi \times r^2 \quad \text{-------} (2)$$

With l is the length of the cylinder and is equal to 5 cm, r is the radius of the cylinder base and is equal to 2.5 cm, π is the Pi and is equal to 3.14 and V is the volume of the cylinder and is equal to 98.17 cm^3

Water content

Soil samples were taken weighed and then put in the oven at 105º C for 24 hours, then the dry soil was weighed and soil moisture was calculated by following the equation:

-Measure the sample and record its dry weight.

The equation 3 is used to determine the water content of the soil (Elaoud and Chehaibi, 2011):

$$W = ((Mh - Ms)/M_s) * 100 \quad \text{-------} (3)$$

With W denoting the water content (%), *Mh* the wet mass of the soil sample, and *Ms* the dry mass of the soil sample.

Infiltration measurement (Single Ring Infiltrometer by Dingman Method)

The rate of infiltration relying on the moisture and the factors that influences it. The infiltration rate has a certain classification which has been determined according to Lee (1988), (Table 1).

Table 1. Soil infiltration classification

Description	Infiltration(mm/h)
Very slow	<1
slow	1-5
Being-Slow	5-20
Being	20-65
Medium Fast	65-125
Fast	125-250
Very fast	>250

A simple infiltrator ring allows direct measurements of the infiltration soil capacity. An impermeable boundary, usually consisting of a plastic ring, delimits the space. The ring is inserted into the ground at a depth of 5 to 10 cm, the test begins in a water accumulation situation, where a constant load is applied and maintained throughout the test. The objective is to saturate the soil with water to standardize the measurements and compare them. Figure 3 shows schematically the progress of the wetting front during a test with a single ring infiltrometer for periods. With this infiltration technique, rising water to the surface is a risk. Water infiltrates vertically and laterally into the soil in a single-ring infiltration test under gravity and capillary forces (Dingman, 1994). To reduce the impact of horizontal flows in the soil around the ring, it is generally recommended to use a larger diameter ring (Nadjib and Abdenour, 2019).

The experiment consists of hammering a PVC ring 10 cm in diameter and 30 cm in height to a depth of 5 cm, 10 cm, 15 cm and 20 cm into the ground and using a ruler or a meter, the height of the water is measured for a period measured by a stopwatch. Then an amount of water is poured into the ring using a plastic bottle. This first operation aims to saturate the soil with water in order to standardize the measurements and to be able to compare them. If the first bottle has fully infiltrated before 15 min, then a second bottle of the same amount is poured and the water infiltration is measured directly. To measure infiltration, the height of water in the ring after pouring the second water bottle (t=0) and after 5 min (t=5 min) is measured with one meter. If there is still plenty of water from the first bottle in the ring after 15 min, then the infiltration measurement is directly measured for 5 min (from t= 15 min to t= 20 min) and continues until the infiltration rate becomes stable. These tests are conducted in the normal soil state, during a first pass, a second pass, and in the plowing state of the soil (Figure 3).

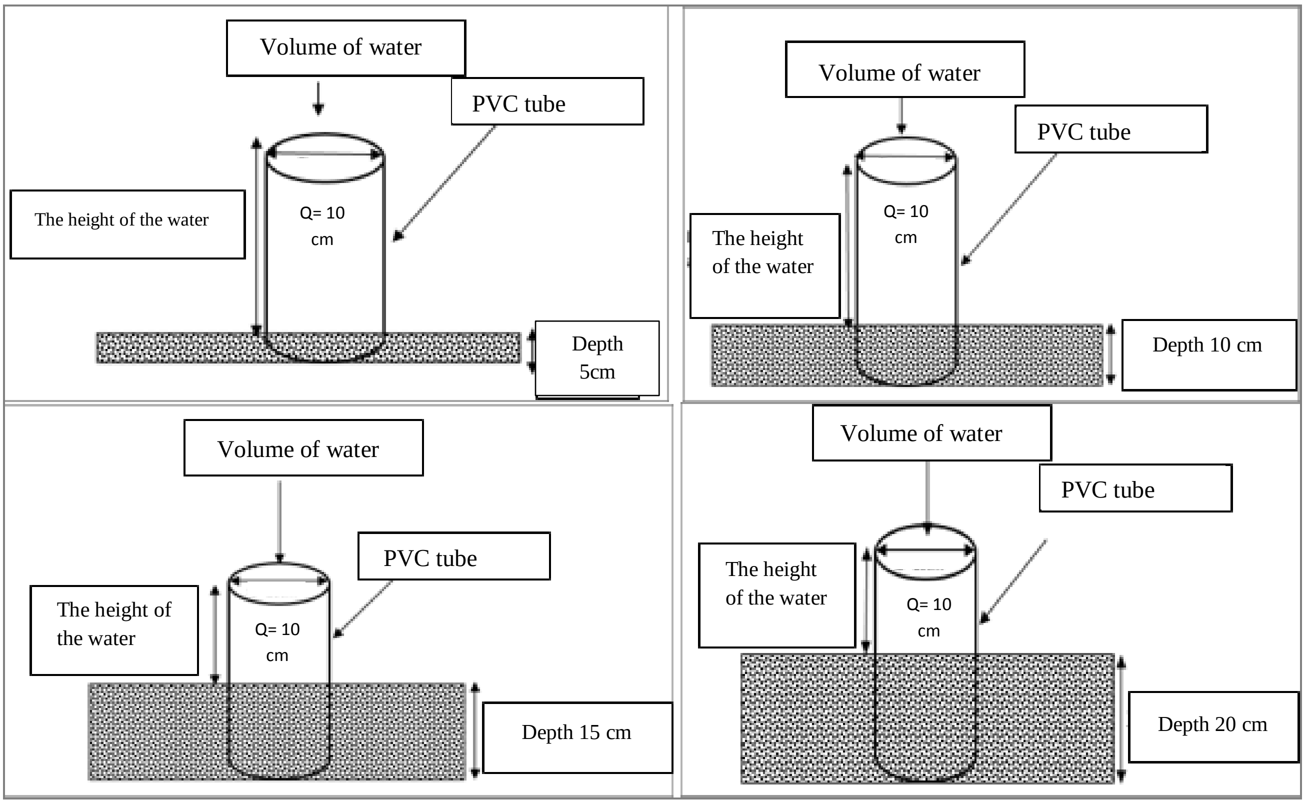

Figure 3. Test with single ring infiltrometer depending on the depth

The experimental work is classified into four measurement campaigns where the infiltration is carried out at 4 depths: 5cm, 10cm, 15cm and 20cm.

The first campaign illustrates the infiltration measurements on a control soil, where no passage was made (Figure 4).

The second campaign (Figure 5A), is carried out on the ground following the first passage of the tractor (type Landini 5860) coupled with a semi-trailer of 980 kg of weight.

The third campaign was carried out following a second run (Landini 5860 tractor weighing 2250kg) (Figure 5B).

And the fourth partner generates infiltration measurements following a control tillage (with Landini 5860 tractor; Canadian farmer of 165kg weight), (Figure 6).

Figure 4. Measurement of infiltration in the normal soil state

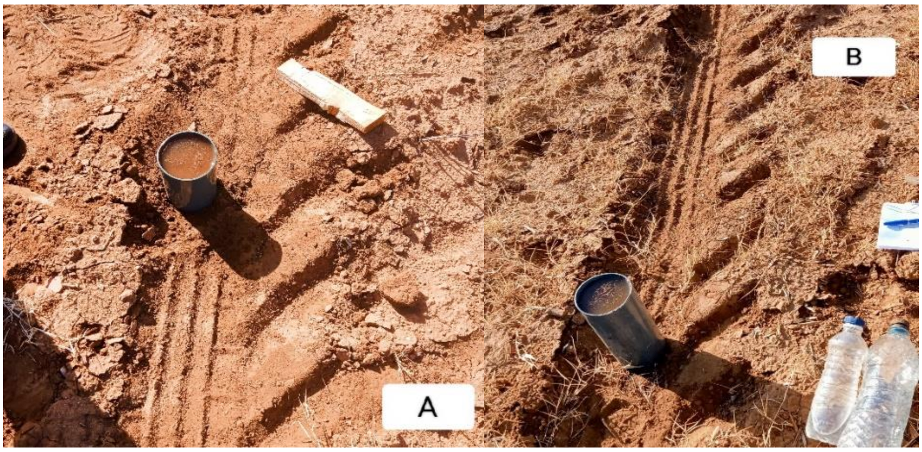

Figure 5. Measurement of the infiltration at the level of the track of the wheels: a-following the first passage; b-following the second passage of the tractor cultivator spring type Canadian

Figure 6. Infiltration at the furrow tilled by plow

Results and Discussion

1.1. Evaluation of density as a function of depth

This study is based on three campaigns of measurements: soil control (D0), following a passage of a tractor (Dp) and after a tillage by a plough (Dt).

After each treatment, the density was measured and quantified. Moreover, the results of these measurements are illustrated in Figure 7, so the density D0 of the soil control of the plot (without passage) shows a difference between the densities of a soil tilled (tractor passage with plough) and D from soil following the first passage with trailer.

At 30 cm depth, the first pass shows a bulk density of 1.57 g/cm^3, while the control soil and the worked soil recorded a low density of 1.46 g/cm^3 and 1.38 g/cm^3, respectively at the same depth. However, the change in the density of the soil after the tractor was used resulted in a 13% increase in the density of the soil.

Density measurements illustrate the phenomenon of settlement before the first pass, after a pass and after ploughing. Thus, all measured density values do not exceed 1.6g/cm^3, which implies that the recorded settlement is not intense and does not affect agricultural production (Houskova, 2004).

A risk of settlement can be detected at 30 cm, after the passage of the engine, where a density of approximately 1.6g/cm^3 illustrates. To prevent the problems of this compaction, it is necessary to plan tillage of the soil for depths beyond 30 cm.

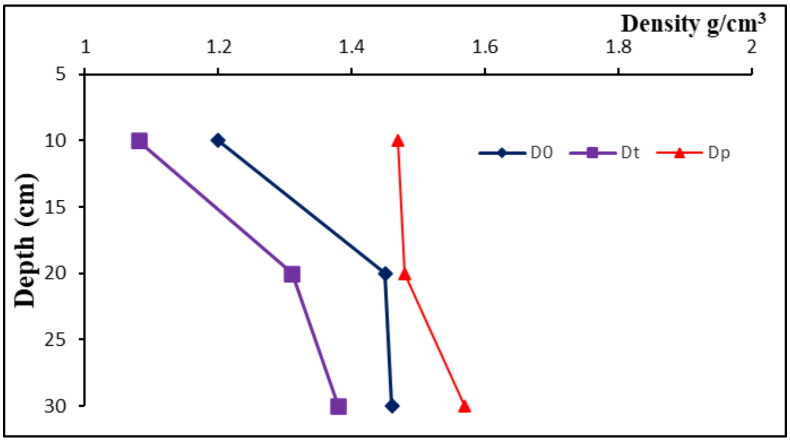

Figure 7. Density variation for the three soil states (D0: control soil; Dt: tillage state; Dp: After passage of tractor)

1.1 Evaluation of infiltration as a function of depth

This part shows four measurement campaigns: Control soil; after one passage; after two passages and after a tilled soil. Following each action, the infiltration rate was measured and calculated. The results of these measurements shown in Figure 8 show the evolution of the water infiltration rate (mm/h) as a function of time (min) for the different soil conditions (soil not tilled, after first tractor passage, second tractor passage and after tilled soil).

On the other hand, we note that the rate of infiltration under the Canadian plough was higher than that without plowing; and the other which undergoes at the passages of the tractor of 1187.5 mm/h and 300mm/h at 10 minutes and 301.2mm/h and 75 mm/h at 50 minutes on a depth 5 cm and 10 cm the water infiltrates for 50 minutes but also we notice that at the depth of 20 cm the rate of infiltration under plough being the same higher than that without ploughing and the other which undergoes at the passages of the tractor of 312.5 mm/h and

93.75 mm/h at 10 minutes up to 42.91 mm/h and 42.27 mm/h at 140 minutes. After 145 minutes of measurements, there was no difference in the infiltration rate between plowing, no plowing and tractor runs. However, the number of passages (2 successive passages) reduces the infiltration rate between 19% and 25% compared to infiltration at the level of tilled soils.

Studies have suggested that no-till management can reduce water infiltration (Stone and Schlegel, 2010). Taking this into account, the findings indicate that tilled soils have the capacity to absorb water at a quicker pace than non-tilled soils, in addition the rate of infiltration at depth 15 cm and 20 cm indicated that the number of passages has a significant effect on the topsoil and it is slowly influenced on the sub-soil and compress that could diminish the ability of infiltration into the soil a similar trend has been reported in other research (Mileusnić *et al.*, 2022). These results are consistent with previous studies (Schwartz *et al.*, 2010).

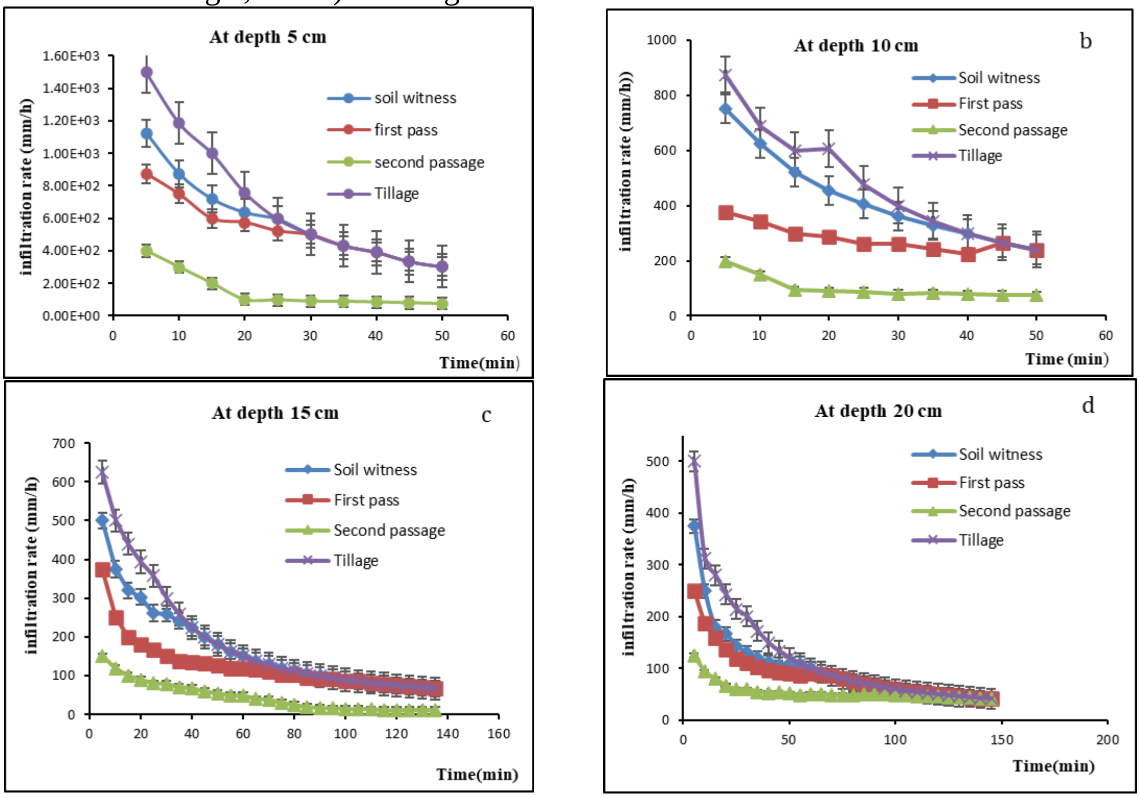

Figure 8. Infiltration rate as a function of time at different depths: a-At depth 5 cm; b-At depth 10 cm; c-At depth 15 cm; d-At depth 20 cm

These results (Figure 9) show that the water regime was influenced by the passage of the tractor with the trailer, which caused an increase in the time of water penetration (60 minutes) at a depth of 5 to 10 cm. On the other hand, one notices that on a tilled soil, water takes a short time to seep in (15 minutes). It is the same case at a depth of 15 to 20 cm, when water infiltrates at 30 minutes on tilled soil.

Thus, soil compacted by the number of passages takes 140 minutes for water to infiltrate. Mileusnić *et al.* (2022) showed results similar to those illustrated in this work.

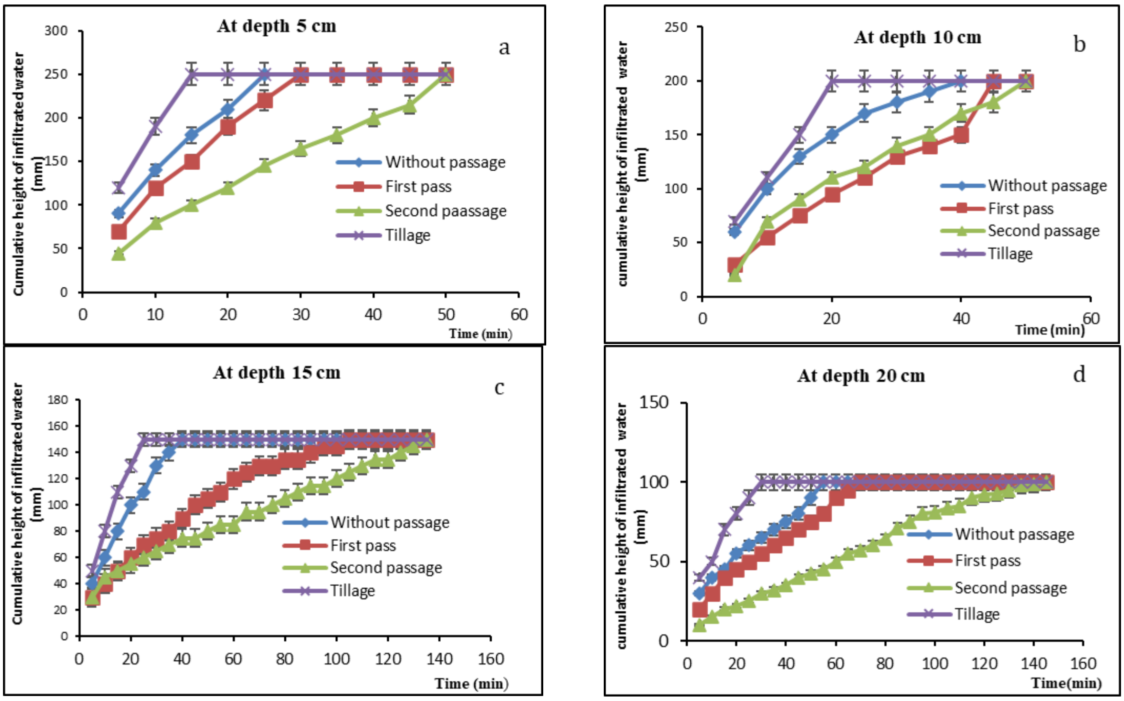

Figure 9. Cumulative height function of time at different depths: a-At depth 5cm; b-At depth 10 cm; c-At depth 15 cm; d-At depth 20 cm

Conclusions

The soil compaction problems have been reported following the overuse of machinery. In this context, this work was introduced to illustrate the state of soil following the measurement of its infiltration. Experimental tests on a plot located in Morneg were carried out with 4 campaigns (control soil, first tractor pass, second pass and plowed soil). Interesting results showed that the number of passages (2 passes) reduced the water infiltration from 19% to 25% depending on the time following each pass of the machine. Also, the results showed that the infiltration rate was directly linked to the depth, the number of passes, time and indirectly to the work of the soil and the weight of the machine. Studies have suggested that no-till management can reduce water infiltration. Taking this into account, the findings indicate that tilled soils have the capacity to absorb water at a quicker pace than non-tilled soils.

Conflict of interest

Regarding the publication of this manuscript, the authors declare that there are no conflicts of interest.

Acknowledgments

We acknowledge the Ministry of Agriculture, Water Resources and Fisheries, Tunisia and the Ministry of Higher Education and Scientific Research of Tunisia for their continuous encouragement by the project of Young Research 21JPEC D1-03.

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