INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
22–0153/2022/28–4–201–209
DOI: 10.17957/IJAB/15.1971
http://www.fspublishers.org

Review Article

Conventional and No-Tillage Impacts on Soil Water Infiltration: A Full Review

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Received 07 April 2022; Accepted 25 August 2022; Published 16 October 2022

Abstract

In this review, the effect of tillage on soil infiltration is discussed on the basis of the latest studies available in specialized global journals. Understanding of changes in soil infiltration is vital in soil water management and crop production. This review focused on studies that investigated changes in soil infiltration under different tillage practices including conventional and no-tillage. Studies that resulted in a significant increase in water infiltration were focused. The reason for increased soil infiltration in the two types of tillage, although they are different practices, might be the different soil types in which the experiments were conducted and the factors that affected each experiment were also different. The formation of soil macropores, fractures and voids, effective water transport channels and paths, alteration of soil structure and the different land-use types may account for the increase in the soil infiltration rates in conventional tillage. In no-tillage the presence of vegetation cover, absence of soil slaking, increase in the biological activity of the soil, abundance of soil macrofauna, increased aggregation, and permanent pore development may account for the increase in the soil infiltration. Studies conducted under conventional tillage demonstrate that the factors with the highest influence on soil infiltration are plowing depth, time and depth of measurement, type of implement used, years of management, and season. It was found that the moldboard plow affects the soil infiltration more favorably than other implements and deep tillage is better than shallow tillage for increasing soil infiltration. Moreover, vegetation cover, soil type, crop planted, and measurement depth were the most influential on soil infiltration under no-till conditions. The traditional method of soil infiltration measurement, by double-ring infiltrometer, and recent updates to it has also been thoroughly discussed in this review.

Keywords*:* Vegetation cover; Plow; Soil infiltration; Double-ring; Infiltrometer; Land-use

Introduction

Conventional tillage is one of the oldest and most common agricultural practices worldwide; in many countries, the practice involves the use of moldboard, chisel and disk plows (Mamkagh 2019). Conventional tillage can increase crop productivity by regulating soil temperature, reducing soil resistance to plant root penetration (O'Brien and Daigh 2019) and enhancing soil infiltration (Conyers *et al.* 2019) by improving the characteristics of the macropore system and the soil's physical properties (Frede *et al.* 1994; Tebrügge and During 1999; Shipitalo *et al.* 2000). The selection of the tillage system is extremely crucial in rain-fed semi-arid regions, where precipitation is the primary source of soil moisture, which, in turn, directly affects all crops' productivity (Vita *et al.* 2007; Mamkagh 2009, 2018); hence, it can be derived that conventional tillage would likely be more beneficial for rain-fed semi-arid regions (Zhao *et al.* 2018). Conventional tillage can also manage the properties of the soil and leads to the roughness that affects the rainwater partitioning (Römkens *et al.* 2002; Novara *et al.* 2011; Balota *et al.* 2016).

For many farmers globally, the increased costs of agricultural production due to high fuel prices, and concern about soil degradation have led to a shift from conventional tillage to no-tillage (Verhulst *et al.* 2010; Zarea 2010). By slowing down the water runoff due to the increased soil cover, no-tillage can reduce the erosion of the soil, increase water infiltration and the soil's ability to hold more water (Wahl *et al.* 2004; Stone and Schlegel 2010; Page *et al.* 2013). Most importantly, it can reduce costs of agricultural production (Blanco-Canqui and Ruis 2018). Accordingly, such practices may be more beneficial to farmers in regions where soil water is the main constraint to crop yield (Page *et*

To cite this paper: Mamkagh AM, FA Al-Zyoud, RM Al-Atiyat (2022). Conventional and no-tillage impacts on soil water infiltration: A full review. *Intl J Agric Biol* 28:201–209

al. 2019). Nevertheless, some researchers believe that the important obstacles that determine the use of no-tillage are soil compaction (Hussain *et al.* 1998; Ferreras *et al.* 2000; Hamza and Anderson 2005; Sun *et al.* 2018), the spread of weeds (Crawford *et al.* 2015; Liu *et al.* 2016) and excessive application of pesticides (Reicosky *et al.* 2011).

Previous studies indicated that different tillage practices have affected the soil's ability to absorb water in different ways, comparison of soil infiltration in different tillage practices has reported some inconsistent results (Strudley *et al.* 2008). For instance, according to some scholars, no-tillage practice can reduce (Unger 1992; Baumhardt *et al.* 1993) or not impact soil infiltration (Pikul and Aase 1995) but is still considered the leading tillage system in terms of production costs and soil erosion reduction (Quincke *et al.* 2007). It must be considered that the infiltration rate can be influenced by different tillage practices, to various degrees (Strudley *et al.* 2008). Soil infiltration can be enhanced when compacted layers are disrupted or can be reduced by reducing aggregate soil stability and macro-porosity (Unger 1992). Soil surface roughness and vegetation cover can also affect the soil infiltration (Almeida *et al.* 2018), as well as soil porous system and pore size distribution (Pagliai and Vignozzi 2002; Kodešová *et al.* 2011), which in turn are significantly affected by tillage practices (Schjønning and Rasmussen 2000; Kay and VandenBygaart 2002; Peth *et al.* 2008; Kravchenko *et al.* 2011).

Herein, it is very important to choose the right tillage system because it can increase soil infiltration and moisture. This is vital to plant development, soil micro-organisms and to avoid environmental problems caused by improper tillage (Zhao *et al.* 2018). The high capacity of the soil to store more rainwater depends on water infiltration, which is the most critical property in terms of capturing rainwater. Soils with such characteristics are more suitable for rain-fed semi-arid and arid regions, as they retain water under drought conditions and climate fluctuations (Blanco-Canqui *et al.* 2017).

Understanding the impact of different tillage methods, conventional and conservation (Ren *et al.* 2019; Rahmati *et al.* 2020) on soil and the hydraulic properties in different regions of the world is essential for conserving and managing soil water in a changing climate. Hence, focusing on studies related to this topic is essential, because their results have a direct impact on soil water movement and retention and thus crop yields. The specific goals of this review paper is to discuss results from research that studied changes in soil infiltration under different tillage practices, and to understand how some factors like season, management duration, precipitation, location, soil texture, crop grown, plowing depth and implements, vegetation cover and time of measurement can influence the soil infiltration. Further, this review is also aimed to define which changes inside or on the surface of the soil can increase the infiltration; review soil infiltration measurement by double-ring infiltrometer and some of its improvements as the most common method used in most scientific studies.

Double-ring infiltrometer and the latest updates thereto

The soil infiltration rate can be defined as the speed at which water from the outer surface enters the soil vertically and is usually measured in meters day^{-1} or millimeters hour^{-1} (Mao *et al.* 2016). The traditional method of soil infiltration rate measurement in the field includes the use of a double or single-ring infiltrometers. The double-ring infiltrometer is a well-recognized and documented device and is commonly used to measure soil infiltration in a field. It consists of two steel rings; the small ring is placed inside a large one during the test (Fatehnia *et al.* 2016). Usually, the diameter of the outer ring reaches 30 cm and the inner reaches 20 cm, with heights from 10 to 20 cm. The edges of the rings should be sharp to enable easy insertion into to a depth of 5 cm at least. The outer ring is necessary to prevent lateral water flow and maintain a correct vertical infiltration rate from the inner ring. During the experiments, water can be manually or automatically added to both rings to an equal level, which should remain constant, then the soil infiltration can be measured only in the inner ring (Bouwer 1986). Eventually, soil infiltration can be calculated from the amount of water added to the smaller ring by the Horton model, which can be expressed as $f_p = f_c + (f_o + f_c)\ e^{-kT}$, where; fp = soil infiltration capacity at the time (mm h^{-1}); f_c - final soil infiltration capacity (mm h^{-1}); f_o = initial soil infiltration capacity (mm h^{-1}); T = the length of time; and k = the infiltration capacity decay coefficient (h^{-1}) (Guo and Guo 2018).

However, the double-ring infiltrometer has some disadvantages. For instance, it is unable to measure the initial infiltration rate accurately if the water supply is insufficient (Mao *et al.* 2016) and disturbs the surface conditions when placed in the soil, forming a crust at the soil surface due to fast wetting after the addition of the water (Levy *et al.* 1997; Mamedov *et al.* 2001) and can be inaccurate, difficult to use, and take a long time to complete the measurements (Zhang and Li 2020). To address this, many researchers have made several attempts to develop this method of measurement, including Arriaga *et al*. (2010), who automated the process of measuring soil infiltration under conditions of the falling head when a traditional infiltrometer was used. When they used aluminum rings, an inner of about 15 cm in height and 14 cm in diameter and an outer ring of the same height and about 33 cm in diameter. To keep the inner ring at the center of the outer ring and to serve as a handle, they welded an aluminum pipe with a length of 55.0 cm and a diameter of 2.5 cm to the top of the inner ring and bolted it to the outer ring with brackets.

Thereafter, they added a pressure transducer to the device and a data logger to record the transducer output. The performance of the modified device was later compared with the constant head method under different soil textures. Finally, it was concluded that the new design could reduce operator errors and allows multiple measurements to be taken by one operator easily. Fatehnia *et al*. (2016) also developed the traditional double-ring infiltrometer when they used an Arduino micro-controller, water level sensors, a float valve, and a peristaltic pump. To facilitate the measurement process, this new design stores the data on a memory card.

The modifications made the new device more accurate, especially when measuring low infiltration rates, this system is more sensitive when infiltration rate reaches the steady-state.

Ruggenthaler *et al*. (2016) suggested a new design for a double-ring infiltrometer to take multiple measurements of soil infiltration at the same location. A small plastic ring with a 20 cm diameter and 4 mm thickness was placed in a steel ring with a 40 cm diameter and 25 cm height. The inner ring was divided into upper and lower parts. At the beginning of the experiment, the lower part was permanently placed inside the soil; directly before the measurement process, the upper part was mounted on the lower part. Finally, it was confirmed that the modified double-ring infiltrometer is capable of studying soil infiltration behavior at different initial soil moistures and over long periods.

Tillage effects on soil infiltration

Conventional tillage effect: To investigate the impact of 4 and 7 years old zero and conventional tillage on some physical properties of the soil and the root length density, Martínez *et al*. (2008) conducted a field study in two separate sites in Chile, where the mean annual precipitation was 330 mm. Both sites were cultivated with wheat and maize. Under two tillage practices, the infiltration of the soil was measured at planting and harvesting stages using a cylinder infiltrometer at a depth of 15 cm. For conventional tillage, a moldboard plow was used at 20 cm depth to break up the soil, chop, and bury the residues, before planting followed by the use of a disk harrow. Under no-tillage the remains of the crops were cut up and left in the field.

The results of their study showed a faster water infiltration rate in conventional tillage than in no-tillage at anthesis periods, which was attributed to the macropores created by conventional tillage that facilitated water infiltration. While in 2004 the effect of no-tillage on soil infiltration was similar to that of conventional tillage.

Blanco-Canqui *et al*. (2017) evaluated the hydraulic properties of soil under conventional and no-tillage in silty clay loam soil in rain-fed continuous maize in eastern Nebraska, where the mean annual precipitation was 693 mm. The maize harvest tillage was performed from 1980 to 2014. In the fall of 2014, all treatments were converted from conventional tillage to no-tillage, during which infiltration of the soil was measured using a tension infiltrometer. The measurement was based on the study of Perroux and White (1988), then a double-ring infiltrometer was used under ponded conditions as shown by Reynolds *et al*. (2002).

Herein the superiority of the moldboard plow over no-tillage is clearly evident when the infiltration measured under ponded conditions. The moldboard plowing also increased the soil infiltration in general more than disking and chiseling. The superiority of the moldboard plow, by deep and intensive plowing, over no-tillage, disk and chisel plows might be attributed to the voids and fractures created in the soil. Under the two techniques, less infiltration was found under tension conditions than under ponded. In 2017 and 2018, Kuang *et al*. (2020) tried to determine the impact of sub-soiling on yield of summer maize and water consumption characteristics and in loam soil in China. One of their goals was to define the soil infiltration rate under rotary plowing at 40 cm and subsoiling at 35 cm. Sub-soiling and rotary tillage were applied before winter wheat planting. To measure the soil infiltration rate at the maturity stage of summer maize, a single-ring soil water infiltrometer was used in 2017 and 2018.

The results showed that the soil infiltration under rotary tillage was significantly lower than under sub-soiling. This was attributed to the effective water transport channels and paths in the soil layers created by deep tillage that facilitated the infiltration into deeper layers of the soil and increased water use in the later growth stage of maize.

Seasonal soil mechanical and physicochemical properties and sugarcane production were evaluated under different tillage practices by Awe *et al*. (2020) in a sandy loam soil for three growing seasons in Brazil. Soil treatments consisted of no-till, no-till with compaction, conventional tillage with a disk plow and harrow at 20 cm depth and minimum tillage of chiseling with a chisel plow at 20 cm depth. Soil infiltration, as one of the studied soil properties, was measured by a double ring infiltrometer.

At the initial stages of their experiment, results showed the highest initial soil infiltration rate under the effect of chiseling and the lowest when the soil was not tilled at all. The results were the same for accumulated and final infiltrations but at the end of the experiment. To justify such results, the increase in soil infiltration might be attributed to the volume of macropores in the soil, resulting from conventional tillage.

Additionally, Liu *et al*. (2018) investigated the impact of tillage on infiltration of the soil in a typical agricultural region in North China, where the soil texture was sandy loam, using a disc infiltrometer to take 132 measurements in forest land, shrub land and crop land. The authors used cropland under conventional tillage and no-tillage established 5 years prior to the experiment, where a wheat-maize rotation was the predominant crop system. Their results showed a more significant effect of conventional tillage practice on soil infiltration than no-tillage, as the mean value of the cumulative infiltration in conventional tillage was thrice more than in no-tillage. From the results related to soil infiltration, they concluded that conventional tillage plays a more critical role than no-tillage in increasing soil water infiltration and decreasing the spatial variability of infiltration in crop lands.

Table 1: Cumulative infiltration for no-tillage and stubble-mulch tillage management in Bushland, Texas, Schwartz *et al*. (2019)

Year	Phase	Cumulative infiltration (mm)	
		No-tillage	Stubble mulch tillage
2007	Sorghum Fallow	42.4	38,2
2007	Sorghum	56.4	56.1
2008	Sorghum Fallow	156.6	151.7
2008–2009	Wheat	150.5	152.8

Table 2: Increased soil infiltration under conventional tillage

Title	Location	Precipitation (mm)	Texture	Implement used	Plowing depth, mm	Crop or land use	Management duration (Y).	Infiltration rate ($cm.h^{-1}$)	The possible reason for the increase in infiltration	Reference
Soil physical properties and wheat root growth as affected by no-tillage and conventional tillage systems in a Mediterranean environment of Chile.	Chile	330	Sandy clay	Moldboard Disk harrow	200	Wheat–maize rotation	4 and 7	Conventional tillage Aver. 5.86 No-tillage Aver. 2.63	The macropores creation	Martínez *et al*. (2008)
Long-term tillage impact on soil hydraulic properties	Nebraska	693	Silty clay loam	Moldboard Disk Chisel	250	Maize-soybean	35	26.9 cm (When the moldboard was used)	Fractures and voids creation	Blanco-Canqui *et al*. (2017)
Effects of subsoiling before winter wheat on water consumption characteristics and yield of summer maize on the North China Plain	China	389 (2017) 447 (2018)	Loam	Subsoiler Rotary tiller	35 and 40 15	Winter wheat and summermaize	13	24 (max) Subsoiling at 40 cm	Creation of effective water transport channels and paths in the soil layers	Kuang *et al*. (2020)
Sugarcane production in the subtropics: Seasonal changes in soil properties and crop yield in no-tillage, inverting and minimum tillage	Brazil	1300 to 1800	Sandy loam	Disk plow and harrow. Chisel	20	Sugar cane	3	(cumulative infiltration) 35.4 mm under no-tillage 42.4 mm under no-tillage + compaction	Macropores formation in the soil	Awe *et al*. (2020)
Land use dependent variation of soil water infiltration characteristics and their scale-specific controls	China	615	Sandy loam	Tine cultivator	---	wheat-maize	5	Cumulative 180 mm - under cropland 130 mm under shrub land 120 mm under forest land	The change of soil structure under different land-use types	Liu *et al*. (2018)

Table 2 summarizes the most recent studies that investigated the impact of conventional tillage on soil infiltration conducted in different regions under different conditions such as precipitation, soil texture, type of crop, implement used, depth of plowing, and study duration. According to these studies, conventional tillage significantly increased water infiltration, compared to no-tillage. They attributed this to the formation of soil macropores, fractures and voids, effective water transport channels and paths, and alteration of soil structure under different land-use types.

No-tillage effect

To reduce groundwater depletion, Anderson *et al*. (2020) evaluated the impact of land use and soil property on the soil infiltration into Alfisols in the Lower Mississippi River Valley in six major land uses: deciduous and coniferous forests, prairie and grassland and conventional and no-tillage agriculture. Between 7th November 2015 and 6th July 2016, to measure soil infiltration six times they used the procedure described in the study of Desrochers *et al*. (2019). Regarding the relationship between plowing and infiltration, their results showed that the overall infiltration in no-tillage did not differ from that in conventional tillage. Notwithstanding this finding, several studies have reported an increase in the rate of soil infiltration if only no-tillage is applied (Azooz and Arshad 1996; Bhattacharyya *et al.* 2008; Stone and Schlegel 2010). For instance, in their study Almeida *et al.* (2018) assumed that field surface vegetation can, in association with tillage practices, alter soil infiltration in agricultural systems; hence they investigated the impact of vegetation cover and different tillage practices on soil infiltration in pastures and in soybean fields during a wet season in Brazil in a sandy clay soil. In their study, a mobile rain simulator with a constant water rate was used as an alternative to precipitation. Sampling time and infiltration depth were used to find the soil infiltration rate. The soil infiltration rate was obtained when the surface runoff remained constant. The findings showed a higher infiltration under the soybean system in no-tillage than the other treatments after 80 days of soybean sowing.

To find the impact of zero tillage and stubble-mulch

Table 3: Increased soil infiltration under no-tillage

Title	Location	Precipitation, mm	Texture	Crop or land use	Management duration (Y)	The year of measurements	Infiltration rate ($cm.h^{-1}$)	The possible reason for the increase in infiltration	Reference
Effect of soil tillage and vegetal cover on soil water infiltration	Brazil	rainfall simulator 60 mm h^{-1}	Sandy clay	Bare soil, soybean and pasture	2	2013–2014	(infiltration rate) 26.7 in the bare soil 23.4 in soybeans cultivated in conventional tillage, 53.7 in the pasture.	The vegetation cover intercepted and stored rainfall, and changed the soil properties	Almeida *et al*. (2018)
Contrasting tillage effects on stored soil water, infiltration and evapotranspiration fluxes in a dryland rotation at two locations	In Bushland, Texas	455	Silt loam	Sorghum Sorghum Wheat Wheat	13	2007 2008 2009 2010	53.6 173.2 126.5 60.3	The increased residue levels under no-tillage	Schwartz *et al*. (2019)
	In Tribune, Kansas, USA	475	Clay loam	Wheat Sorghum Sorghum		2006 2006 2007	89.6 60.3 72.7		
Cover cropping and no-tillage improve soil health in an arid irrigated cropping system in California's San Joaquin Valley, USA.	USA	200 (Long term average)	Clay loam	tomato-cotton	15	2012–2014	400 ml/min Standard tillage 7.33 No-tillage 5.38	Due to the absence of slaking associated with no-tillage that could clogged soil pores.	Mitchell *et al*. (2017)
Long-term impact of no-till conservation agriculture and N-fertilizer on soil aggregate stability, infiltration and distribution of C in different size fractions.	South Africa	645 (Long term average)	Clay loam	Maize-soybean	13	2015/2016		The abundance of soil macro fauna, particularly termites and millipedes, and to higher large and smaller macro aggregates.	Sithole *et al*. (2019)
Tillage and crop rotation phase effects on soil physical properties in the west-central Great Plains.	USA	425	Silt loam	winter wheat sorghum	4	2008/2009		Enhancement of the ability of the soil for water intake under no-tillage.	Stone and Schlegel (2010)
Effects of no-tillage systems on soil physical properties and carbon sequestration under long-term wheat-maize double cropping system.	China	600	Silty loam	Winter wheat-maize	9	2012	Max. cumulative 152.8	Increased aggregation and permanent pore development as a result of increased soil biological activity.	Huang *et al*. (2015)
Soil physical quality on tillage and cropping systems after two decades in the subtropical region of Brazil.	Brazil	1651	Clay	Diverse rotation	24	2012-2013		Presence of high pore frequency and volume at size classes > 100 mm in all soil layers	Moraes *et al*. (2016)

tillage on the stored water in the soil, infiltration, and evapotranspiration during phases of dry land wheat-sorghum-fallow rotation, Schwartz *et al*. (2019) initiated their field studies in 2006 in Bushland, Texas, where the mean annual precipitation was 475 mm, in a clay loam soil and simultaneously in Tribune, KS where the mean annual precipitation was 455 mm in a silt loam soil. Based on hourly changes in soil water, water balance approach and a drainage model were used to estimate the cumulative infiltration. In Bushland the results indicated no significant effect on the cumulative infiltration under stubble mulching and no-till from after harvesting of sorghum in 2007 until the wheat phase in 2009 (Table 1), while in Tribune, a greater effect on soil infiltration was found in no-tillage during the sorghum growing season, the fallow period after sorghum in 2005 and during the fallow period after wheat in 2006. The authors attributed the increase in the soil infiltration in Tribune to the increased residue levels due to no-tillage practice.

To improve soil health a study was conducted at the University of California in a dry irrigated cropping system where the soil was clay loam. The total precipitation during the study period was about 344 mm (Mitchell *et al.* 2017). They investigated the impact of tillage and covered cropping practices on some properties of soil during a 15-year experimental period. For conventional tillage, a sub-soiling shank was used for deep soil treatment up to 45 cm. In order to break up the soil clods, a disk was used at a 20 cm depth. To measure soil infiltration, a single ring infiltrometer was used and 400 mL of water was added to the soil within the ring twice and then the time required for all the water to be absorbed in the first and second time was recorded.

The results of this study showed faster infiltration of water into the soil under no-tillage compared to conventional tillage, when water was added both the first and second time to the ring, which might be due to the increased slaking associated with conventional tillage that could clog soil pores and contribute to a slower infiltration rate. To ascertain the impact of tillage on soil infiltration, Sithole *et al*. (2019) conducted a long-term experiment in Bergville, Winterton, KwaZulu-Natal Province, South Africa in an existing trial in a clay loam soil, where the mean annual precipitation was 645 mm. The treatments were no-tillage and conventional tillage. No-tillage included a direct seeding into the undisturbed soil and rotational tillage after every four years. Conventional tillage included moldboard plowing to a depth of 30 cm followed by disking to a depth of 10 cm. The cumulative infiltration in no-tillage plots was found to be significantly higher than in other treatments. The increase in soil infiltration in no-tillage practice was attributed to the abundance of soil macrofauna, particularly termites and millipedes and to the increase in macro-aggregates resulting from this practice. A similar finding was reported by Mando *et al*. (1996), highlighting the important effect of termites on soil infiltration.

To estimate the impact of conventional, reduced, no-tillage and the phase of the winter wheat-grain sorghum-fallow rotation on physical properties of soil, Stone and Schlegel (2010) conducted a study in the semiarid region near Tribune, Kansas in a silt loam soil where the mean annual precipitation was 425 mm and the mean annual air temperature was 11.2°C. To control weeds during fallow, plots in conventional tillage were treated by sweep plow as needed, while weeds in plots under no-tillage were controlled by herbicides. In this study, the steady-state infiltration rate was measured and calculated as described by Reynolds *et al*. (2002).

The study showed soil infiltration in no-tillage to be significantly higher than in conventional and reduced tillage because it enhanced the water intake ability of the soil. The infiltration rate in the no-tillage practice was 99 and 167% higher than in reduced and conventional tillage, respectively.

Huang *et al*. (2015) started a 9-year experiment in the Yellow River Delta, China with an average annual regional precipitation of 600 mm, to find the impact of tillage and fertilizers on carbon sequestration and other physical properties of a silt loam soil under winter wheat-maize double cropping system. Three tillage systems were used, *viz*., conventional tillage and conventional tillage with urea nitrogen, straw cover and urea nitrogen without tillage, with urea nitrogen and manure without tillage The results showed a significant increase in the initial, steady-state, and cumulative infiltration with residue cover without tillage and with manure without tillage. Without tillage, cumulative infiltration of the soil increased by up to 69.4 and 62.5% with residue cover and residue manure respectively, 84.9 and 69.8% higher than in conventional tillage.

These results are consistent with findings from previous studies conducted in the field (Franzluebbers 2002; Shukla *et al.* 2003; Alvarez and Steinbach 2009) that attributed the increase in infiltration to the biological activity in the soil in no-tillage.

A significant impact on the soil infiltration under tillage and cropping systems was found when Moraes *et al.* (2016) studied the physical quality of the soil under long-term management. The experiment was established in 1988 in Londrina, State of Parana, Brazil, in clay soil with an average annual regional precipitation of 1651 mm. Under two cropping systems (wheat in winter and soybean in summer) treatments were consisted of no-till farming for 11 years and 24 years, chiseling at shallow depth every year, chiseling shallow depth every three years, heavy disk harrowing at a depth of 15 cm for 24 years followed by light disk harrowing at a depth of 8 cm. In the experimental site, a three-dimensional constant infiltration rate was evaluated at 10 and 20 cm depth using a constant head well permeameter as described by Vieira *et al*. (2011). The highest soil infiltration rate was found when the field was planted without tillage for 24 years at 10 cm depth and the lowest in conventional tillage at 20 cm. It was noted that the soil infiltration rate at 10 cm depth was significantly high when the field was planted without tillage at all. A higher pore frequency and volume were found at size classes > 100 mm in all soil layers under no-tillage for 24 years, which in turn increased soil infiltration, in their opinion.

Table 3 summarizes the most recent studies that investigated the impact of no-tillage on soil infiltration conducted in different regions worldwide under different conditions such as precipitation, soil texture, type of crop grown and duration of the study. The results indicate that no-tillage can significantly increase water infiltration, compared to conventional tillage. According to these studies, the greater soil infiltration rate in no-till may be due to increased residues, interception, and storage of precipitation by vegetation cover, absence of slaking that can clog the soil pores, enhanced soil water absorption capacity, increased aggregation and permanent pore development due to increased soil biological activity, presence of high pore frequency and volume at size classes > 100 mm in all soil layers and the abundance of soil macrofauna, particularly termites and millipedes.

Factors affecting soil infiltration in conventional and no-tillage

In this work, the reviewed studies were conducted under the influence of various factors such as duration of management (Martínez *et al.* 2008; Blanco-Canqui *et al.* 2017), measurement time (Strudley *et al.* 2008), soil texture (Arriaga *et al.* 2010), location of the experiment (Schwartz *et al.* 2019), precipitation (Vita *et al.* 2007), crop grown (Stone and Schlegel 2010), number of residues in no-tillage (Unger 1992; Almeida *et al.* 2018), plowing depth (Sithole *et al.* 2019) and implement type in conventional tillage (Moraes *et al.* 2016). Most of these factors may affect the physical properties of the soil, including infiltration.

The current review of the available studies related to the effect of different tillage practices on soil infiltration indicates the following: (1) Soil infiltration can be affected by the number of years of management. From 2007 to 2009 the cumulative infiltration increased from 38 to 152 mm (Schwartz *et al.* 2019); (2) The type of plow also affects soil infiltration. It has been found that the moldboard plow may increase cumulative infiltration more than others. When the moldboard plow was used the cumulative infiltration was more than the disk plow by 26.9 cm and more than the chisel plow by 39.0 cm at the end of the 3 h of measurement (Blanco-Canqui *et al.* 2017); (3) Deep tillage positively affects soil infiltration rates, as it can create fractures and voids in the soil, the infiltration rate was 10 mm h^{-1} at a depth of 20 cm and 60 mm h^{-1} at a depth of 10 cm (Moraes *et al.* 2016); (4) Tillage has a greater impact on soil infiltration than other land uses such as shrub land or forest land. The cumulative infiltrations were 18, 13 and 12 mm under cropland tillage, shrub land, and forest land respectively (Liu *et al.* 2018); (5) Conventional tillage impact on the rate of soil infiltration can change with the measurement time within the same year; (6) With different soil types, no-tillage practices affect soil infiltration differently. It was found that cumulative infiltrations in the soil of the sugarcane field were 35.4 and 42.4 mm under no-tillage, and no-tillage + compaction (Awe *et al.* 2020).; (7) In no-tillage, the rate of soil infiltration can be influenced by the type of crop grown and the year in which the measurements were taken; (8) Soil infiltration can be affected by the depth of measurement also in no-tillage practices and (9) The vegetation cover under no-tillage leads to higher infiltration rates. For instance, Almeida *et al.* (2018) found that the stable infiltration rate (mm h^{-1}) was 26.7 in the bare soil, 23.4 in soybeans cultivated in conventional tillage and 53.7 in the pasture.

Conclusion

This review indicates that tillage practice, whether conventional or no-tillage, can have positive effects on soil infiltration, and thus on crop yields particularly in dry lands around the world. These effects may depend on several factors such as duration of management, time of infiltration measurement, soil texture, location of the experiment, precipitation, crop grown, number of residues in no-tillage, plowing depth and type of implement used in conventional tillage. These benefits in conventional tillage may be due to the formation of soil macropores, fractures and voids, effective water transport channels and paths and alteration of the soil structure under different land uses. As for no-tillage, they may be due to the presence of vegetation cover, absence of soil slaking, the increased biological activity of the soil, abundance of soil macrofauna, increased aggregation and development of permanent pore. Accordingly, additional studies on conventional and no-tillage across different management durations, soil textures, times of measurement, crops grown, plowing depths, implement types and a number of residues are required, to fully understand the effect of tillage practices on soil infiltration. More studies are required in other regions of the world to afford a better understanding of how tillage practices affect soil infiltration and thus crop yields worldwide. This review also indicates that a double-ring infiltrometer is the most common instrument used for *in situ* measurement of soil infiltration rate. Several attempts have been made to develop this traditional method and have succeeded in facilitating the measurement process and making it faster and more accurate. The double-ring infiltrometer modification also proved effective in performing multiple soil infiltration measurements at the same experiment simultaneously.

Acknowledgments

None to declare.

Author Contributions

All authors (Mamkagh A, FA Al-Zyoud, R Al-Atiyat) searched in the literature, wrote, reviewed and approved the final version of the manuscript equally.

Conflicts of Interest

The authors declare no conflict of interest.

Funding Source

This review paper received no external funding.

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