Infiltration in three soil management for soybean growing under rainfed agriculture

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ABSTRACT
Objective: To study infiltration parameters (infiltration rate, cumulative infiltration, saturated hydraulic conductivity, and sorptivity), on the basis of three soil management treatments (subsoiling, ploughing, and harrowing), for soybean (*Glycine max*) growing, under rainfed agriculture, during three discontinuous years (2020, 2022, and 2023).
Design/Methodology/Approach: The experiment was carried out in the region of Tapachula, Chiapas, Mexico. Each treatment was established in 0.50 ha, with independent plots. Two infiltration tests were made per treatment in 2020 and 2023, using cylindrical infiltrometers for 450 minutes in average. During 2020, 2.0 m × 1.50 m soil profiles were made at a depth of 1.50 m to detect the plough layer. Based on this information, the subsoiling depth (0.70 m) was planned. Additionally, three soil samples were extracted at depths of 0-20 cm and 20-40 cm to analyze their physical and chemical properties.
Results: Based on their physical properties, texture, organic matter, and soil conditions, the initial moisture and infiltration parameters (2020) were calculated to compare them with the final results (2023).
Findings/Conclusions: The following infiltration parameters had a marked variability in the subsoiling, ploughing, and harrowing soil management systems, for soybean growing under rainfed agriculture: infiltration rate, cumulative infiltration, saturated hydraulic conductivity, and sorptivity. Infiltration parameters were higher with subsoiling than with the ploughing and harrowing systems.

Keywords: parameters, cumulative infiltration, ploughing layer.

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INTRODUCTION

Infiltration is the movement of water from the topsoil to the subsoil layer (Hillel, 2003; Brutsaert, 2005); therefore, physical infiltration (q_0) is the time-dependent i(t) downwards flow of water. Doubtlessly, infiltration is the only source of water for plants and aquifer recharge and is therefore one of the most important issues for agriculture and related sectors (Ahuja, 1974; Alley, 2009). Nevertheless, the soil compaction resulting from the intensive and prolonged use of agricultural machinery reduces water infiltration, increases resistance to root penetration, severely impacts water and nutrient absorption, and restricts plant growth, among other negative results (Bengough *et al.*, 2011; Whalley *et al.*, 2005; Whitmore and Whalley, 2009).

Subsoiling currently contributes to the sustainable improvement and minimizes the compaction of soils (Flower and Lal, 1998; Antille *et al.*, 2015; Shaheb *et al.*, 2021; Antille *et al.*, 2015). Additionally, subsoiling increases infiltration rate and cumulative infiltration, in comparison with traditional ploughing (Desale *et al.*, 2012). Therefore, this research analyzed infiltration in moist soils from the region of Tapachula, Chiapas, México used to grow soybean (*Glycine max*). Soil preparation in this region has caused soil compaction (Motavalli *et al.*, 2003; Botta *et al.*, 2004; Harper *et al.*, 2008; Botta *et al.*, 2016; Ewetola *et al.*, 2022). Soy has been grown under rainfed agriculture conditions for 45 continuous years and is currently grown in 14,000 ha. However, soil has always been prepared under high moisture conditions, resulting in high compaction levels for most of these soils (Alonso *et al.*, 2023). Therefore, the aim of this research was to analyze the infiltration parameters (basic infiltration, cumulative infiltration, and saturated hydraulic conductivity) in three soil management systems used to grow soybean under a rainfed agriculture.

MATERIALS AND METHODS

The experiment was established for three discontinuous years (2020, 2022, and 2023) in the San Antonio plot, Tapachula, Chiapas, Mexico (14° 45' N and 92° 23' W, at 16 m.a.s.l.). The climate is warm subhumid, has an average temperature of 28±1 °C, and a mean cumulative annual precipitation of 1,110 mm.

According to its texture, the soil is loamy, has a pH of 6.5, is slightly acid, and has as 2.5% organic matter content. The experiment consisted of three 1.5-ha treatments (each one measuring 0.5 ha) and was made up of independent plots: 1) subsoiling (SUB), plus one harrowing and mechanized sowing; 2) ploughing (PLO), plus one harrowing and mechanized sowing; and 3) harrowing (HAR), with two harrowings and mechanized sowing.

Soil preparation for soybeans was carried out every year, on the second fortnight of July, with variable sowing dates during this observation period (July 10-22). Based on previous studies, the subsoiling treatment was carried out during the dry season (April 2022-2023), in order to break the compaction recorded at a depth of ≈35 cm, before the rainy season. The purpose of such practice was to generate friability and to increase infiltration and to compare this system with the ploughing and harrowing treatments.

The plant material sown consisted of the Huasteca 100 soybean variety. The abovementioned preliminary studies consisted of three 1.5-m wide × 2.0-m long soil profiles at a depth of 1.5 m in April 2020 and April 2023. A ploughing layer was detected and used to define the subsoiling depth. Likewise, three soil samples were extracted at a depth of 0-20 cm and 20-40 cm and subsequently dried for eight days in the shade. The samples were then sieved with a 2-mm mesh. An 800-g portion of each sample was weighted and sent to the laboratory for its physical and chemical analysis.

The initial moisture parameters (2020) were calculated and later compared with the experiment period (2023). The following moisture parameters were calculated: volumetric moisture content to field capacity(θ_{CC}), permanent wilting point (θ_{PMP}) saturated moisture content (θ_s), infiltration rate (q_0), saturated hydraulic conductivity (Ks), and apparent density (Da).

A brief description of the physical-mathematical models that rule soil infiltration is shown below. *In situ* infiltration was measured using infiltrometers (Bouwer, 1986); two 8-hour long (≈480 min) infiltration tests were made for each treatment (SUB, PLO, and HAR). These tests were carried out in 2020 and 2023. Based on field studies, infiltration parameters were calculated with the following equations:

Infiltration rate: $q_0 = dI / dt$; cm min^{-1} (Equation 1), where the 0 subscript is the water inflow from the topsoil; $Z=0$. This magnitude approaches a constant value throughout time (q_0); $t=0$, $q_0 \rightarrow \infty$ (Equation 2), when $t \rightarrow \infty$, $q_0 = constant$; theoretically, $q_0 \approx Ks$, where Ks (cm min^{-1}) is the saturated hydraulic conductivity (Equation 3). For a prolonged time, the infiltration rate will have a cumulative infiltration connotation (cm), $I(t) = \int_0^t q_0(t)\,dt$ (Equation 4).

One of the objectives of the infiltration analysis was to deduce some parameters, including saturated hydraulic conductivity (Ks) (Chow *et al.*, 1988) —a key parameter for the appropriate design of irrigation systems. Other objectives included the description of hydraulic properties and the water balance on soil surface (Campbell, 1985; Hillel, 2003; Lal y Shukla, 2004; Morbidelli *et al.*, 2011; Van Looy *et al.*, 2017).

Cumulative infiltration $(I(t))$ was calculated with only the first three terms of the Philip infiltration equation (1957): $I(t) = C_1 t^{1/2} + C_2 t + C_3 t^{3/2} + \ldots$ (Equation 5), where C_1, C_2, C_3,... C_m; are the equation's parameters and t is time. Kutílek and Krejča (1987) suggested using Equation 5 to determine the adjustment coefficients and Equation 6 to estimate saturated hydraulic conductivity (Ks): $Ks = (3C_1 * C_3)^{1/2} + C_2$ (Equation 6), where C_1 estimates sorptivity (S) and C_3 and C_2 are the equation's parameters. Based on the analysis of field information through the abovementioned numeric process, the $q_0(t)$, $I(t)$, and Ks infiltration parameters were determined for each of the soil management systems under study. Numeric estimations and adjustments were carried out with the CurveExpert v. 2.6 software.

RESULTS AND DISCUSSION

Table 1 shows the initial moisture parameters of the soil and its physical and hydraulic characteristics before the research period (April 2020) and before the soil management systems were established in the experiment site.

The initial referential parameters (infiltration rate (q_0), available moisture $(HD = I(t))$, and saturated hydraulic conductivity (Ks)) were compared with the 2023 measurements (Table 2) for each of the soil management systems (SUB, PLO, and HAR) to determine the impact of the proposed treatments on the hydraulic parameters of infiltration. The results of the comparison of these parameters (q_0; cm min^{-1}, $I(t)$; cm, Ks; cm min^{-1}) (Table 1) were compared with the results for the same parameters after a two-year observation (Table 2) —with the exception of mean sorptivity (S), which was only measured in 2023—, revealing that the initial infiltration rate (q_0) was 380%, 312%, and 356% higher under the subsoiling, ploughing, and harrowing systems. Meanwhile, cumulative infiltration $[HD = I(t)]$ in subsoiling, ploughing, and harrowing exceeded the initial parameters by 277%, 190%, and 241%; however, the parameter was 80% lower for the ploughing and harrowing systems.

Table 1. Physical and hydraulic parameters of the loamy soil from the experimental site located in San Antonio, Tapachula, Chiapas (initial period: 2020).

Parameters	Dense compaction	Hard compaction	Average
θ_{PMP} (cm^3cm^{-3})	14.8	14.8	14.8
θ_{CC} (cm^3cm^{-3})	28	27	27.5
θs (cm^3cm^{-3})	40.6	35.2	37.9
Da (g cm^{-3})	1.57	1.72	1.64
HD (cm m^{-1})	13.25	12.17	12.71
q_0 (cm min^{-1})	0.016	0.016	0.016
Ks (cm min^{-1})	0.088	0.025	0.056

Based on these results, infiltration was positively impacted by the subsoiling system in relation to the conventional management systems (ploughing and harrowing) used to prepare the soil for the soybean cultivation, under a rainfed agriculture system in the study region.

In a similar experiment, Singh *et al.* (2019) evaluated three subsoiling treatments in Punjab, India, and reported that the reduction of the apparent density improved the physical and hydraulic properties of the soil —a situation that increased porosity and infiltration rate. Likewise, they concluded that implementing subsoiling practices at a depth of 1-1.5 m every three years strengthens crop yield. Similar research works have proved that the infiltration rate was 1.7 and 2.4 higher with a subsoiling treatment than in soils without subsoiling (Solhjou and Niazi, 2001; Heidari *et al.*, 2008).

After a 10-year comparative study in Brazil with a light use of chisel plough and subsoiling, Peixoto *et al.* (2012) recorded that the latter improved the physical properties of the soil and increased soil yield during the first five years of production. For their part, Singh and Hadda (2014) evaluated the effect of three subsoiling treatments (2012-2013) in the physical and hydraulic properties of soils with high compaction levels and determined that subsoiling resulted in an increase of the infiltration rate and cumulate infiltration.

After a 37-year research in western Tennessee (USA) with no-till farming and reduced tillage, Nouri *et al.* (2018) reported a remarkable increase in soil yield and infiltration. Regarding the physical properties of the soil quality indicators of static and dynamic spheres (soil hydraulic parameters), Lovino *et al.* (2013) and Lozano *et al.* (2016) reported

Table 2. Initial and final hydraulic parameters between soil management treatments after a two-year observation (2022-2023), in San Antonio, Tapachula, Chiapas, México.

Parameters	Initial average	Subsoiling	Ploughing	Harrowing
S (cm $min^{-1/2}$)		1.92	1.56	1.28
q_0 (cm min^{-1})	0.016	0.061	0.050	0.057
I(t) (cm)	12.71	33.69	24.17	30.58
Ks (cm min^{-1})	0.056	0.060	0.045	0.045

that, as a result of subsoiling, dynamic indicators predicted soil yield and infiltration with greater efficiency.

Likewise, Sivarajan *et al.* (2018) and Nouri *et al.* (2018) confirmed that subsoiling effectively eliminates the soil compaction caused by the conventional systems used to prepare agricultural land. Overall, subsoiling enhanced the physical and hydraulic properties of the soil —including the internal flow of water in the root area of crops, which is associated with a higher infiltration than with ploughing and harrowing (Desale *et al.*, 2012; Avila *et al.*, 2020; Zibilske y Bradford, 2007; Mohanty *et al.*, 2007 Undoubtedly, these results will help to achieve a sustainable agriculture (Shaheb *et al.*, 2021).

CONCLUSIONS

Soil cultivation under rainfed agriculture recorded highly variable infiltration parameters (infiltration rate, cumulative infiltration, saturated hydraulic conductivity, and sorptivity), regarding the soil management systems under evaluation. Infiltration parameters recorded better results with subsoiling than with the ploughing and harrowing systems.

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