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Effect of soil tillage and vegetal cover on soil water infiltration

Wilk Sampaio de Almeida[a,*], Elói Panachuki[b], Paulo Tarso Sanches de Oliveira[c], Roniedison da Silva Menezes[b], Teodorico Alves Sobrinho[c], Daniel Fonseca de Carvalho[d]

[a] *Federal Institute of Education, Science and Technology of Rondônia, Campus Colorado do Oeste, BR 435, Km 63, Colorado do Oeste, RO, 76993-000, Brazil*
[b] *State University of Mato Grosso do Sul, Agronomy Department, CEP 79200-000 Aquidauana, MS, Brazil*
[c] *Federal University of Mato Grosso do Sul, CxP. 549, Campo Grande, MS, 79070-900, Brazil*
[d] *Federal Rural University of Rio de Janeiro, Engineering Department, BR 465, Km 7, CEP 23897-000 Seropédica, RJ, Brazil*

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ABSTRACT

Land cover and land use change have altered hydrologic processes. However, there are still some uncertainties on the magnitudes of these effects in tropical regions. Here, we evaluate the effect of soil tillage and land cover on soil water infiltration, through measurement of this parameter in areas under bare soil, soybeans (conventional tillage and no-tillage) and pasture. We use a portable rainfall simulator with a constant intensity rain (60 ± 1.715 mm h^{-1}) in plots of 0.7 m^2 in size. In total, 96 rains were applied, 24 in each treatment, after soil preparation and in five stages after soybean sowing (every 20 days). We use the observed data to fit three infiltration models, Kostiakov-Lewis, Horton and Philip, whose the quality of adjustment, was verified by correlation coefficient (R), root mean square error (RMSE) and the Nash-Sutcliffe efficiency (NSE). Our results show that the stable infiltration rate (SIR) in the no-tillage soybean system is greater than in the other systems by 40 days. Furthermore, SIR values in bare soil (BS) and soybean under conventional tillage (SCT) systems do not differ ($p < 0.05$), except at 80 days after soybean sowing (SIR BS = 14.28 mm h^{-1} and SIR SCT = 24.00 mm h^{-1}). We find that Horton's model adjusts the best to the different systems, with an R = 0.88, 0.86, 0.47 and 0.63, RMSE = 4.46, 4.87, 5.76 and 8.12, and NSE = 0.78, 0.74, 0.23 and 0.45, for the BS, SCT, SNT and PA systems, respectively. However, the Kostiakov-Lewis and Philip models adjust is very close, independent of the presence of vegetal cover and soil tillage. We conclude that soil water infiltration is more influenced by vegetal cover, depending on the type of land use, than by the soil tillage system.

1. Introduction

Increasing global demand for food, fiber, and energy has favored the conversion of native vegetation areas into agricultural lands, mainly in Brazil for soybeans production (Gardi et al., 2014; Merten et al., 2015) and pasture (Gibbs et al., 2010). Areas under native vegetation in the Cerrado (Brazilian Savannah) that have been transformed for agriculture use are approximately 50% of the original extension of this biome (Klink and Machado, 2005; Gibbs et al., 2015). Currently, large areas under pasture have been replaced by mechanized soybean and sugarcane monocultures because pasture areas in the Cerrado can be easily converted to cultivated fields to accommodate soybean expansion (Barona et al., 2010; Merten and Minella, 2013).

In these areas, conventional soil tillage predominates to increase soil porosity and water infiltration and as a traditional practice of many farmers. However, surface sealing tends to occur in just a few days after tillage, due to the direct impact of raindrops on the soil. Because the limited vegetation cover on soil surface, porosity and infiltration decrease, causing intensification of the soil erosion process (Carvalho et al., 2015). Didone et al. (2014) also report problems of erosion in many areas under no tillage cultivation in southern Brazil because of the limited presence of crop residues, removal of structures for surface runoff control (terraces), down-slope cultivation, and soil compaction.

Soil water infiltration is influenced by several factors, such as tillage and vegetal cover, surface roughness, soil porosity and density, amount of organic carbon, size and stability level of the aggregates, and soil water content. These factors that influence infiltration, consequently interfere on runoff. According Carlesso et al. (2011) land use and land cover greatly affects infiltration, and has an important influence on raindrop interception. Increasing the percentage of plant canopy, residue cover, soil surface roughness, and the crop evapotranspiration, will increase infiltration rate at the beginning of the rainfall event, thus reducing runoff.

Cover crop residues are important to increase water infiltration into

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* Corresponding author.
E-mail addresses: wilk.almeida@ifro.edu.br, wilksalmeida@gmail.com (W.S. de Almeida), eloip@uems.br (E. Panachuki), paulotarsoms@gmail.com (P.T.S. de Oliveira), roniedison1@hotmail.com (R. da Silva Menezes), teodorico.alves@ufms.br (T.A. Sobrinho), carvalho@ufrrj.br (D.F. de Carvalho).

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soil and reduce surface runoff and erosion, and serve as a primary form of organic matter input that enhances soil biological activity, conserves moisture and moderates soil temperature (Derpsch et al., 2014). Despite these benefits, the high profitability of soybeans and favorable production prospects over the last decade in Brazil have led farmers to adopt a poorly diversified crop sequence (in which cover crops are rarely included in the system) that does not produce enough residue to allow for permanent cover throughout the cropping season (Merten et al., 2015). As in southern Brazil (Didone et al., 2014), the size of agricultural machinery has increased in the Cerrado region to reduce operations time in the farms.

Besides that, in Brazil, areas with conservational soil systems, such as no-tillage and adequate management pastures have increased (Panachuki et al., 2010). However, water infiltration under different land uses is still poorly studied (Oliveira et al., 2015). Furthermore, it is still necessary to better understand the influence of vegetal cover on soil water infiltration and the fitness of infiltration models from measurements data (Carvalho et al., 2015).

Our hypothesis is that the vegetal cover on soil surface in association with cultivation practices changes distinctly the soil water infiltration on agricultural systems. Therefore, the objective of this study is to evaluate the effect of soil tillage and vegetal cover on the infiltration processes in areas under bare soil, soybean (conventional tillage and no-tillage), and pasture. We also assess the performance of three infiltration models (Kostiakov-Lewis, Horton and Philip) to fit the observed data of 96 rain events in plots of 0.7 m^2 in size.

2. Materials and methods

2.1. Characterization of the study area

The study was carried out during the wet season (November 2013 through May 2014) in the municipality of Aquidauana, MS, Brazil (20°27′ S, 55°40′ W; altitude of 191 m). According to the Brazilian System of Soil Classification (Santos et al., 2013), the soil is a Argissolo Vermelho Distrófico típico (Red Dystrophic Ultisol, USA) with a soil texture (sand, silt and clay) of: 770 g kg^{-1}, 110 g kg^{-1} and 120 g kg^{-1} (0–24 cm) and 610 g kg^{1}, 140 g kg^{-1} and 250 g kg^{-1} (50–65 cm) (Schiavo et al., 2010). According to the Köppen climate classification, the climate is Aw (Tropical wet-dry climate), with annual temperatures and precipitation ranging from 24 to 26 °C, and 1300 to 1600 mm, respectively (Alvares et al., 2013). The slope steepness of the experimental area is approximately 0.03 m m^{-1} (Santos et al., 2014).

2.2. Treatments, experimental design and soil analysis

We studied the following soil covers and managements: bare soil (BS) after conventional tillage (in the direction of slope); soybeans (*Glycine max* L.) cultivated in conventional tillage (SCT) also in the direction of slope; soybeans (*Glycine max* L.) cultivated in no-tillage (SNT); and pasture (*Brachiaria ruziziensis*) (PA). The experimental design was completely randomized, arranged in subdivided plots (in time), with four repetitions for treatment. In each of the plots, the system of culture was evaluated (BS, SCT, SNT and PA) and in the subplots, the six levels of soil vegetal cover were measured after 0, 20, 40, 60, 80 and 100 days after soybean sowing (DAS).

Characterization of soil bulk density, porosity (macroporosity and microporosity) and aggregateś stability (mean geometric diameter – MGD and pondered mean diameter – PMD) in each experimental plot were performed in samples collected in the layers 0–10, 10–20 and 20–40 cm in depth (Donagema et al., 2011). Soil resistance to penetration was measured by three readings in un-deformed samples using a digital penetrometer (Serafim et al., 2008).

We use a portable rainfall simulator (Alves Sobrinho et al., 2008) (Fig. 1) calibrated with a constant rain intensity of 60 ± 1.715 mm h^{-1} (considering the height of the sprinkler beak, 2.30 m in relation to the soil surface), mean drop diameter of 2.0 mm and pressure of 32 kPa. Galvanized steel rectangular sheets (runoff collector) of 1.0 × 0.7 m (0.7 m^2) that were kept fixed in the field until the end of the study surrounded the experimental plots, which received precipitation. Alves Sobrinho et al. (2008) report a detailed information of design, construction and operation of this rainfall simulator, which can produce kinetic energy > 90% the kinetic energy of corresponding natural rain.

Fig. 1. The portable rainfall simulator *InfiAsper* during a rainfall application in bare soil system: 1 – motor, 2 – water application, 3 – blocking device, 4 – upper frame, 5 – runoff collector, 6 – water pump, 7 – tank, 8 – excess water collector and 9 – electric panel control.

Before rains simulations, soil wetting was performed, with which standardization of all the treatment soil humidity was guaranteed (Cogo et al., 1984). To obtain soil moisture before of rain simulations, we sampled soil in different soil profile: 0–10, 10–20 and 20–40 cm.

The depth of water infiltration (DWI) was estimated by the difference between the artificial rain and the surface runoff (SR). The SR was calculated each minute through the relation between the volume of water and the experimental plot area. The infiltration rate was calculated by the relation between the DWI and the considered sampling time. The stable infiltration rate (SIR) of water in the soil was obtained when the SR remained constant. Time for the surface runoff was considered as that passed from the start of the applied precipitation until the moment at which the superficial water runoff began.

2.3. Infiltration rate estimation models

The infiltration values observed in the field were adjusted to the models of Kostiakov-Lewis (Kostiakov, 1932; Lewis, 1937) (Eq. (1)), Horton (Horton, 1933, 1939) (Eq. (2)) and Philip (Philip, 1957, 1969) (Eq. (3)) as a function of the corresponding time, as described by Assouline (2013). In the equations, i is the estimated instant infiltration rate (mm h^{-1}), i_o and i_f are the observed initial and the stable infiltration rate (mm h^{-1}) and t is the infiltration time (min).