WATER INFILTRATION IN TWO CULTIVATED SOILS IN SOUTHERN BRAZIL

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ABSTRACT

Infiltration is the passage of water through the soil surface, influenced by the soil type and cultivation and by the soil roughness, surface cover and water content. Infiltration absorbs most of the rainwater and is therefore crucial for planning mechanical conservation practices to manage runoff. This study determined water infiltration in two soil types under different types of management and cultivation, with simulated rainfall of varying intensity and duration applied at different times, and to adjust the empirical model of Horton to the infiltration data. The study was conducted in southern Brazil, on Dystric Nitisol (Nitossolo Bruno aluminoférrico húmico) and Humic Cambisol (Cambissolo Húmico alumínico léptico) soils to assess the following situations: simulated rains on the Nitisol from 2001 to 2012 in 31 treatments, differing in crop type, sowing direction, type of soil opener on the seeder, amount and type of crop residue and amount of liquid swine manure applied; on the Cambisol, rains were simlated from 2006 to 2012 and 18 treatments were evaluated, differing in crop, seeding direction and crop residue type. The constant of the water infiltration rate into the soil varies significantly with the soil type (30.2 mm h^{-1} in the Nitisol and 6.6 mm h^{-1} in the Cambisol), regardless of the management system, application time and rain intensity and duration. At the end of rainfalls, soil-water infiltration varies significantly with the management system, with the timing of application and rain intensity and duration, with values ranging from 13 to 59 mm h^{-1}, in the two studied soils. The characteristics of the sowing operation in terms of relief, crop type and amount and type of crop residue influenced soil water infiltration: in the Nitisol, the values of contour and downhill seeding vary between

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27 and 43 mm h^{-1}, respectively, with crop residues of corn, wheat and soybean while in the Cambisol, the variation is between 2 and 36 mm h^{-1}, respectively, in soybean and corn crops. The Horton model fits the values of water infiltration rate into the soil, resulting in the equation $i = 30.2 + (68.2 - 30.2)\ e^{-0.0371t}$ ($R^2 = 0.94^{**}$) for the Nitisol and $i = 6.6 + (64.5 - 6.6)\ e^{-0.0537t}$ ($R^2 = 0.99^{**}$) for the Cambisol.

Keywords: constant infiltration, basic infiltration, infiltration modeling, simulated rainfall.

RESUMO: *INFILTRAÇÃO DE ÁGUA EM DOIS SOLOS CULTIVADOS NO SUL DO BRASIL*

A infiltração é a passagem da água por meio da superfície do solo, influenciada pelo tipo de solo e cultivo, pela rugosidade e cobertura superficial e pelo teor de água no solo; ela consome a maior parte da água da chuva e, por isso, é fundamental para o planejamento de práticas conservacionistas de caráter mecânico com o fim de manejar o escoamento superficial. Os objetivos deste trabalho foram determinar a infiltração de água em dois tipos de solo cultivados por meio de diversos tipos de manejo e cultivo, mediante chuvas simuladas com intensidade e duração variadas aplicadas em diferentes épocas, e ajustar o modelo empírico de Horton aos dados de infiltração. Realizou-se este estudo no sul do Brasil, sobre os solos Nitossolo Bruno aluminoférrico húmico e Cambissolo Húmico alumínico léptico, para avaliar as seguintes situações: no Nitossolo, foram realizadas chuvas simuladas entre 2001 e 2012 e avaliados 31 tratamentos, diferentes em termos de tipo de cultura, direção da semeadura, tipo de haste na máquina semeadora, quantidade e tipo de resíduo cultural e quantidade de dejeto líquido de suínos aplicado; no Cambissolo, foram efetuadas chuvas simuladas entre 2006 e 2012 e avaliados 18 tratamentos, diferentes em termos de tipo de cultura, direção da semeadura e tipo resíduo cultural. O valor constante da taxa de infiltração de água no solo variou expressivamente com o tipo de solo, sendo 30,2 mm h^{-1} no Nitossolo e 6,6 mm h^{-1} no Cambissolo, independentemente do sistema de manejo, da época de aplicação e da intensidade e duração da chuva. A infiltração de água no solo ao final da chuva modificou expressivamente com o sistema de manejo, com a época de aplicação e com a intensidade e duração da chuva, cujos valores variaram entre 13 e 59 mm h^{-1}, incluindo os dois solos estudados. A orientação da operação de semeadura em relação ao relevo, o tipo de cultura e a quantidade e o tipo de resíduo cultural influenciou a infiltração de água no solo, pois, no Nitossolo, os valores variaram entre 27 e 43 mm h^{-1} na semeadura em contorno e na direção do declive, respectivamente, com resíduos culturais de milho, trigo e soja, enquanto, no Cambissolo, a variação foi respectivamente entre 2 e 36 mm h^{-1} nos cultivos de soja e milho. O modelo de Horton ajustou-se aos valores de taxa de infiltração de água no solo, resultando na equação $i = 30{,}2 + (68{,}2 - 30{,}2)\ e^{-0{,}0371t}$ ($R^2 = 0{,}94^{**}$), para o Nitossolo; e $i = 6{,}6 + (64{,}5 - 6{,}6)\ e^{-0{,}0537t}$ ($R^2 = 0{,}99^{**}$), para o Cambissolo.

Palavras-chave: infiltração constante, infiltração básica, modelagem da infiltração, chuva simulada.

INTRODUCTION

Data of water infiltration into soil under no-tillage, under continuous management or truncated by some operation of mechanical tillage, in long-term field experimentation, are unprecedented in Brazil. On the other hand, the duration of experiments of this nature is critical for the scientific importance to the data, regardless of statistical analysis. Water infiltration into the soil is characterized by the water passage through the surface and can be expressed as rate and capacity (Philip, 1957; Silveira et al., 1993; Libardi, 1995). The infiltration rate is the amount of water passing through the unit area of soil surface per unit of time, while the infiltration capacity refers to the constant final value of the water input rate into the soil (Libardi, 1995). This hydrological process is of paramount importance in planning hydraulic structures for runoff management to control water erosion. Based on data of a constant water infiltration rate into the soil it is possible to estimate the (maximum) constant rate of runoff and plan hydraulic and drainage structures, while with data of leakage volume we can estimate the runoff volume and dimension the size of structures for surface water storage, for example. The main hydraulic structure for management of surface water in agricultural areas is the agricultural terrace.

Water infiltration is influenced by the soil type (Horton, 1940; Philip, 1957; Schwab et al., 1981), tillage and management (Leite et al., 2004; Bertol et al., 2006, 2008; Panachuki et al., 2011), crop type (Leite et al., 2004; Luciano et al., 2009; Bertol et al., 2013), surface roughness and cover by crop residues (Burwell and Larson, 1969; Panachuki et al., 2006; Zoldan Junior et al., 2008; Ramos et al., 2014), and soil water content prior to rain (Luciano et al., 2009; Marioti et al., 2013).

In deep soil, it takes longer to stabilize water infiltration than in shallow soil, as is the case when a well-drained is compared with a poorly drained soil, while infiltration is faster and stabilizes sooner in sandy than in clayey soils (Horton, 1940; Philip, 1957). Soil tillage with a chisel plow increases water infiltration and the rate may take longer to become constant than in soil without tillage for a long time (Prando et al., 2010; Panachuki et al., 2011; Ramos et al., 2014). On the other hand, the absence of vegetation cover after tillage exposes the soil to particle disintegration by rain energy. There may be surface sealing and reduction of water infiltration, which stabilizes sooner than in covered and untilled soil (Panachuki et al., 2011). The occurrence of more frequent rains maintains the water content of the soil higher, and thus, infiltration decreases and stabilizes sooner than where rainfalls occur less often (Zonta et al., 2012).

Analyzing a Cambisol, Luciano (2008) determined the soil water infiltration rate ranging from 10 to 49 mm h^{-1} after rainfalls with intensity ranging from 58 to 87 mm h^{-1}, under several cultivation systems in two modes of no-tillage, evaluated at various times during the crop cycles. In the same soil, Mariotti (2012) observed values between 2 and 36 mm h^{-1} for this variable after rains between 63 and 75 mm h^{-1}, also under different no-tillage cultivation systems, evaluated at different times during the crop cycles. In a Nitisol, Barbosa (2011) observed water infiltration rates between 27 and 43 mm h^{-1} after rainfalls with an intensity between 67 and 71 mm h^{-1}, applied on residues of diverse crops in two forms of no-tillage. In these studies, the rains were applied with a rainfall simulator with rotating arms (Swanson, 1965). Panachuki et al. (2011), studying a Latosol in no-tillage, conventional tillage and reduced tillage, obtained infiltration rates between 24 and 52 mm h^{-1} after rains with intensity between 59 and 62 mm h^{-1}, applied with a micro simulator on three doses of soybean residues. These differences in infiltration rates demonstrate the influence of the intrinsic characteristics of each soil type.

The water infiltration rate into the soil can also vary with cropping systems and management, which influence the characteristics of soil surface and subsurface (Portela et al., 2011; Amaral et al., 2013). Variations in water infiltration rate after rains were stated at different times during the cycle of corn and beans cultivated in sequence, with values between 49 and 63 mm h^{-1} (Leite, 2003), and soybean between 36 and 54 mm h^{-1} (Engel, 2005). These studies were carried out on a Nitisol in southern Brazil.

This study aimed to estimate the water infiltration rate into the soil after rains, in two soil types and cultivation methods in a no-tillage system, applying simulated rainfalls with different intensity and duration at different times. Additionally, the goal was to adjust the empirical model of Horton to the data of water infiltration in the two soil types.

MATERIAL AND METHODS

Location of the experiments and soil characterization

One of the experiments was carried out on a clayey Dystric Nitisol (Nitossolo Bruno aluminoférrico húmico), between November 2001

Table 1. Physical properties of the Nitisol and the Cambisol in horizons/layers of the soil profiles described respectively in 2000 and 2006, at the sites of the experiments

Horizon	Layer	Bd	Ma	Mi	Pt	MWD	TOC	Clay	Silt	Sand
	cm	kg dm^{-3}	cm^3 cm^{-3}			mm	g kg^{-1}	%		
					Nitisol					
A1	0-12	1.05	0.13	0.44	0.57	5.63	34	64	24	12
A2	12-26	1.07	0.26	0.33	0.59	5.00	30	69	21	10
AB	26-46	1.09	0.24	0.32	0.56	4.25	28	72	18	10
Bt1	46-74	1.03	0.13	0.46	0.59	2.17	18	78	14	8
Bt2	74-126	1.11	0.12	0.46	0.57	1.96	12	63	29	8
BC/Cr	123-137+	0.97	0.16	0.45	0.61	1.43	9	51	38	11
					Cambisol					
A1	0-12	1.30	0.09	0.38	0.47	6.04	27	24	47	29
A2	12-28	1.35	0.06	0.42	0.48	6.01	23	26	46	28
AB	28-50	1.33	0.06	0.40	0.46	4.86	12	26	43	31
Bi	50-66	1.28	0.04	0.42	0.46	2.08	18	29	42	29
C1	66-80/85	1.27	0.03	0.48	0.51	1.45	13	33	43	24
Cr	80 -85+	1.19	0.01	0.49	0.50	1.19	1	29	67	4

Bd: bulk density; Ma: macropore volume; Mi: micropore volume; Pt: total pore volume; MWD: mean weight diameter of water-stable aggregates; TOC: total organic carbon.

and August 2012 (27° 43' S; 50° 31' W; 846 m asl). The other experiment was conducted on a silty clay loam Humic Cambisol (Cambissolo Húmico alumínico léptico), between August 2006 and April 2011 (27º 46 'S; 50º 18' W; 900 m asl). The soil properties are listed in table 1, classified according to IUSS/WRB (2006).

History of the experimental area on Nitisol, from 2000 to 2013

In March 2000, the soil was limed (11 t ha^{-1} limestone) and fertilized (300 kg ha^{-1} of 5-30-15 of N-P_2O_5-K_2O). The inputs were incorporated into the soil by plowing twice and harrowing thrice. From then on the soil was cultivated under no-tillage, with the exception of 2006, when the soil was chiseled in January. In April, Mello (2002) sowed black oats (*Avena strigosa*), which were cut in September and in November, soybean (*Glycine max*) was sown. Three simulated rain tests were applied during the cycle and the crop was harvested in April, 2001.

Before soybean harvest, Leite (2003) sowed common vetch (*Vicia sativa*), which was cut in October 2001, and on the residue, corn (*Zea mays*) was sown in November of the same year. During the corn cycle, three simulated rainfall tests were applied, and in June 2002, oats were sown before corn harvest. In November of that year, oats were cut and immediately black beans (*Phaseolus vulgaris*) were sown. During the bean cycle, three simulated rainfall tests were applied, and in April 2003 the crop was harvested.

Engel (2005) sowed forage radish (*Raphanus raphanistrum*) immediately before the black bean harvest in April 2003. Forage radish was cut in October of the same year, and in November soybean was sown. During the soybean cycle, five simulated rainfall tests were applied, and in March 2004 the crop was harvested.

Before soybean harvest, vetch was sown in March 2004, which was cut in October, and in November of that year corn was sown. Before harvest, oats were sown in May 2005 and then corn was harvested. The oats were cut in November and, in January 2006, the crop residues were removed from the soil surface. Immediately after that, the soil was chiseled and then five tests of simulated rainfall were applied between January and February. In March, tillage was performed with one plowing and two diskings and 5 t ha^{-1} of lime was applied and, in April, black oats were sown, which were cut in October. Then, corn was sown and harvested in May 2007.

In June 2007, Amaral (2010) sowed wheat that was cut in December when, again, corn was sown which was harvested in May 2008. Immediately before harvesting corn, black oats were sown and cut in November and, on the residue, in December, a test of simulated rain was applied. Later that month, corn was sown, which was harvested in April 2009, and a test of simulated rain was applied on the residue.

In May 2009, Barbosa (2011) sowed black oats intercropped with common vetch, in October of the same year he sowed corn and applied a test of simulated rainfall on the residues, in June 2010. In July of the same year wheat was sown. In November, the crop was harvested and on the residue, the author applied a simulated rain test in December 2010. Later that month the author sowed soybean, which was harvested in April 2011 and in May, a rainfall test was simulated.

In May 2011, Mecabô Junior (2013) sowed forage radish, which was cut in November of the same year, and then planted red beans, which were harvested in February 2012. Then corn was cultivated and during the cycle four simulated rain tests were applied. In April 2013, black oats were sown and then corn was harvested.

History of the experimental area on Cambisol, from 2006 and 2012

In March 2006, the area was limed (15 t ha^{-1} limestone), incorporated by plowing twice and harrowing twice. Thereafter, the soil was cultivated in no-tillage, with exception of 2008 when, in April, the soil was plowed once and harrowed twice. In July 2006, Barbosa (2008) and Luciano (2008) sowed black oats and common vetch, which were cut in November 2006 by hand. During these crop cycles, five tests of simulated rainfall were applied.

In December 2006, black beans were sown, harvested in April 2007 and then vetch was sown and cut in November of the same year. Subsequently, black beans were planted again and harvested in April 2008 and after that, the soil was prepared by plowing once and harrowing twice. Then vetch was sown, which was managed in November of the same year and, subsequently, black beans were sown and harvested in April 2009. In that month, a mixture of vetch and black oats was sown, which was cut in October 2009.

In December 2009, Bertol et al. (2013) sowed corn, soybean and black beans and a corn - bean intercropping system and during the cycle they applied four simulated rain tests. After harvest, between March and May 2010, wheat was sown in June and harvested it in November.

In November 2010, Marioti (2012) sowed corn and soybean and applied four tests of simulated rainfall during the cycle and, between April and May 2011, the crops were harvested.

In May 2011, Ramos (2012) sowed annual ryegrass (*Lolium multiflorum*) and common vetch, cut by hand in November of that year and, thereafter, between December 2011 and December 2012, the author applied eight tests of simulated rainfall to the treatments.

Treatments on the Nitisol

The treatments, in two replications, were subjected to simulated rainfalls with variable intensity and intervals in between, and constant intensity throughout the rainfalls: T1: corn (CC); T2: black beans (CB); T3: soybean (CS); T4: 8 t ha^{-1} corn residue, furrows opened with a disc seeder (CR-8D); T5: corn residue (4 t ha^{-1}) in furrows opened with a disc seeder (CR-4D); T6: corn residue (2 t ha^{-1}), in furrows opened with a disc seeder (CR-2D); T7: corn residue (8 t ha^{-1}), in furrows opened with a disc-drill seeder (CR-8D/H); T8: corn residue (4 t ha^{-1}), in furrows opened with a disc-drill seeder (CR-4D/H); T9: corn residue (2 t ha^{-1}), in furrows opened with a disc-drill seeder (CR-2D/H); T10: black oat residue (5.3 t ha^{-1}), in furrows opened with a disc seeder (RO-5.3D); T11: black oat residue (2.6 t ha^{-1}), in furrows opened with a disc seeder (RO-2.6D); T12: black oat residue (1.3 t ha^{-1}), in furrows opened with a disc seeder (RO-1.3D); T13: black oat residue (5.3 t ha^{-1}), in furrows opened with a disc-drill seeder (RO-5.3D/H); T14: black oat residue (2.6 t ha^{-1}), in furrows opened with a disc-drill seeder (RO-2.6D/H); T15: black oat residue (1.3 t ha^{-1}), in furrows opened with a disc-drill seeder (RO-1.3D/H); T16: corn residue (9.6 t ha^{-1}), in furrows along the contour line with a by disc seeder (CR9.6D/C); T17: corn residue (4.8 t ha^{-1}), in furrows along the contour lines with a disc seeder (CR4.8D/C); T18: corn residue, 9.6 t ha^{-1}, downslope furrows opened with a disc seeder (CR9.6D/P); T19: corn residue, 4.8 t ha^{-1}, downslope furrows opened with a disc seeder (CR4.8D/P); T20: wheat residue, 3.6 t ha^{-1}, furrows along the contour lines with a disc-drill seeder (WR3.6DH/C); T21: wheat residue, 1.8 t ha^{-1}, furrows along the contour lines with a disc-drill seeder (WR1.8DH/C); T22: wheat residue, 3.6 t ha^{-1}, downslope furrows opened with a disc-drill seeder (WR3.6DH/P); T23: wheat residue, 1.8 t ha^{-1}, downslope furrows opened with a disc-drill seeder (WR1.8DH/P); T24: soybean residue, 3.6 t ha^{-1}, furrows along the contour lines with a disc seeder (SR3.6D/C); T25: soybean residue, 1.8 t ha^{-1}, furrows along the contour lines with a disc seeder (SR1.8D/C); T26: soybean residue, 3.6 t ha^{-1}, downslope furrows opened with a disc seeder (SR3.6D/P); T27: soybean residue, 1.8 t ha^{-1}, downslope furrows opened with a disc seeder (SR1.8D/P); oat cultivation in no-tillage system with a single application of liquid swine manure: T28: 0 m^3 ha^{-1}; T29: 50 m^3 h^{-1}; T30: 100 m^3 h^{-1}; T31: 200 m^3 ha^{-1}.

Operational scheme of treatments on the Nitisol

In the treatments T1, T2 and T3, the crops were sown with a "saraquá" or "matraca" (rattle seeder), according to the recommended plant density for each one, without prior tillage. Throughout the crop cycles, three simulated rainfall tests were applied in T1 and T2 and five tests in T3. In the treatments T4 to T27, the residues were chopped and evenly distributed on the soil surface. The surface was furrowed with a no-tillage machine, without seeds and fertilizers, operating downhill in T4 to T15, while in treatments T16 to T27, the operation was performed as specified for the treatments. Sowing was always performed immediately before rain application. In these treatments a single simulated rainfall test was applied. In treatments T28 to T31, oat seed was broadcast immediately before corn harvest, without soil tillage, so the corn residues remained on the soil during the oat cycle. Throughout the crop cycle, four simulated rainfall tests were applied.

Treatments on the Cambisol

The treatments, with two replications, were subjected to simulated rainfall, with varied intensity and intervals and with constant intensity during rainfall. T1: oat sown along the contour lines (OC); T2: oat cultivation downhill (OD); T3: oat sown by broadcasting (OT); T4: vetch cultivation along the contour lines (VC); T5: vetch cultivation downhill (VD); T6: vetch sown by broadcasting (VT); T7: corn cultivation along the contour lines (CC7); T8: soybean cultivation along the contour lines (SC8); T9: bean cultivation along the contour lines (BC); T10: cultivation of corn and beans intercropped along the contour lines (C/BIC); T11: soybean cultivation downhill (SD); T12: soybean cultivation along the contour lines (SC12); T13: corn cultivation downhill (CD): T14: corn cultivation along the contour lines (CC14); T15 ryegrass residue (RR); T16: vetch residue (VR); T17: chiseled soil with ryegrass roots (SRR); T18: chiseled soil with vetch roots (SRV).

Operational scheme of the treatments on the Cambisol

In treatments T1 to T6, the oat and vetch sown downhill and along the contour lines, were sown with a no-tillage machine, with seeds and fertilizers, while by broadcasting, sowing and fertilization were done manually with lightweight incorporation through harrow. Throughout the crop cycle, five simulated rainfall tests were applied. In the treatments T7 to T14, seeding was done manually, with a "matraca" (rattle seeder) in furrows opened with a no-tillage seeder. The operation was carried out along the contour lines in T7 to T10 and, according to the treatments in T11 to T14. Throughout the crop cycle, four simulated rainfall tests were applied. In treatments T15 and T16, the crops were cut at the end of the cycle and the residues left distributed regularly over the soil surface without tillage. In treatments T17 and T18, the crops were cut at the end of the cycle, the shoot residues removed from the surface and the soil was chiseled along the contour lines. In these treatments, eight simulated rainfall tests were applied.

Experimental plots and rainfall simulators

The 3.5 × 11 m plots were delimited on the sides and upper end by galvanized sheets and at the lower end by a runoff gutter, which was connected to a PVC pipeline, channeling the flow to a trench located 6 m below the bottom end of the plot. To simulate rain, a simulator with rotating arms was used, which was installed between two plots, 3.5 m apart from each other, covering both. In the experiments on the Nitisol we used the Swanson type simulator (Swanson, 1965), while on the Cambisol, a pressurized rainfall simulator (Bertol et al., 2012).

Measurements before, during and after rainfall application

Before simulating rainfall, soil samples were collected with a Dutch auger from the 0-10 and 10-20 cm layers to determine the water content, and the results were obtained on a gravimetric basis, according to Forsythe (1975). After initiation of runoff and throughout its duration, runoff samples were taken every 5 min over a certain period of time, measured by a stopwatch, using a measuring cylinder or a measuring bucket, as needed. With these data, the instantaneous runoff rate was calculated and extrapolated to the time of 1 min. At the end of the rain, the water volume collected in 20 rain gauges placed on the soil in the area covered by the rain around the experimental plots was used to calculate the rain rate. The water infiltration rate into the soil at the end of the rain was calculated as the difference between the precipitation rate and runoff rate at the end of the rain. Coefficient values of water infiltration into the soil at the end of the rain were calculated by dividing the infiltration rate at the end of the rain by the rain rate.

Data treatment

The study was conducted with one field replication (two experimental units per treatment). Despite the field replication, the authors decided not to conduct conventional statistical analysis for comparison of means. Statistical analysis for some basic parameters was carried out, to support the discussion of the results.

The data used had been obtained since 2001 on the Nitisol and since 2006 on the Cambisol, published in dissertations and theses (Leite, 2003; Engel, 2005; Barbosa, 2008; Luciano, 2008; Amaral, 2010; Barbosa, 2011; Marioti, 2012; Ramos, 2012; Mecabô Junior, 2013) and by Bertol et al. (2013). The data of water infiltration into the soil (unpublished) were calculated as the difference between the data of the applied rainfall rate and the constant runoff rate (published), and are included in the database of the Department of Management and Conservation of the Soil - CAV/UDESC, under the leadership of Professor Ildegardis Bertol.

The data of water infiltration rate into the soil, obtained in 12 simulated rainfall events on Nitisol and in 16 rainfall events on Cambisol, were fit to the model of Horton (Horton, 1940):

$$i = i_f + (i_i - i_f)\, e^{-C\,t} \qquad \text{Eq. 1}$$

where i = estimated infiltration rate, mm h^{-1}; i_i = infiltration rate observed at the beginning of the rain, mm h^{-1}; i_f = infiltration rate observed at the end of the rain, mm h^{-1}; t = rain duration, min; and C = adjustment parameter.

The rains were selected for the following criteria: equal duration (90 min); little variation in intensity; little variation in soil water content prior to rainfall; and reaching a value of water infiltration into the soil at the end of the rain that can be considered as basic infiltration rate for each of the studied soils. The Horton model (Horton, 1940) was chosen from among the other empirical models as the best-fitting to the point data of water infiltration into the soil and for producing the best estimate of values of this variable, according to Paixão et al. (2009).

RESULTS AND DISCUSSION

Data obtained on the Nitisol

The data in table 2 indicate that the water content in the soil prior to rainfall simulation (WSB) varied little (0.24-0.31 kg kg^{-1} in the 0-10 cm layer and 0.22-0 30 kg kg^{-1} in the 10-20 cm layer), i.e., a variation of 41 % in the average of both layers. This possibly had little influence on water infiltration into the soil at the end of the rain (WIE). The WIE varied between 36 and 69 mm h^{-1}, equivalent to 92 %, indicating that other variables such as crop type and growth stage had more influence on WIE than on WSB. In the experiment on soybean, the infiltration coefficient was 0.67, while the average of experiments with corn and beans was 0.86, in the mean of the rainfalls throughout the crop cycle. The lowest coefficient of infiltration in soybean can be explained: the crop was the third to be assessed in the experiments, when the soil had become more compacted than in the previous years, as stated by Leite (2003) and Engel (2005). The variation in intensity and duration between one rain test and another also influenced WIE. Furthermore, the interception of water by plant shoots influenced the time the rainwater reached at the soil surface and the plant roots influenced the time until water infiltration decreased, as argued by Leite (2003) and Engel (2005) in the same experiment.

The WIE was 21 and 23 % lower in soybean than in beans and corn, respectively, while the rain intensity was almost equal in all three crops, in the mean of the rainfall tests (Table 2). This can be explained:

Table 2. Water content in two soil layers before simulated rainfall, water infiltration rate at the end of the rain and rainfall intensity of varying duration during the corn and bean cycles and of 60 min in soybean, in a Nitisol (average of two replications)

Rainfall	**Soil water content**		
	0-10 cm	**10-20 cm**	**Average**
Date		kg kg^{-1}	
		Corn cultivation(1)	
1 (11/27/2001)	0.30	0.30	0.30
2 (01/11/2002)	0.30	0.29	0.30
3 (03/09/2002)	0.30	0.22	0.21
		Bean cultivation(1)	
1 (11/20/2002)	0.31	0.30	0.31
2 (12/19/2002)	0.26	0.26	0.26
3 (01/22/2003)	0.22	0.23	0.23
		Soybean cultivation(2)	
1 (11/12/2003)	0.26	0.26	0.26
2 (12/13/2003)	0.26	0.26	0.26
3 (01/12/2004)	0.24	0.26	0.25
4 (02/13/2004)	0.24	0.26	0.25
5 (03/14/2004)	0.24	0.26	0.25

Infiltration rate, intensity and duration of the rain

Rain	Inf. C(3)		Rain	Inf. B(4)		Rain	Inf. S(5)	Rain(6)
N°	mm h^{-1}		min	mm h^{-1}		min	mm h^{-1}	
1	52	57	90	50	67	60	45	66
2	49	59	70	54	67	90	36	68
3	69	71	135	63	72	90	38	63
4	-	-	-	-	-	-	46	65
5	-	-	-	-	-	-	54	67
Mean	57	62	98	56	69	80	44	66
SD(7)	9	6	27	5	2	14	6	2

(1) Data from Leite (2003); (2) Data from Engel (2005); (3) Inf C: water infiltration into soil in corn; (4) Inf B: water infiltration into soil in beans; (5) Inf S: water infiltration into soil in soybean; (6) Rain applied 24 h after a moistening rain to standardize the soil water content; (7) SD: Standard Deviation. (-): Not evaluated.

in soybean, a moistening simulated rain had been applied 24 h before the rainfall test, which was not sufficient to increase the water content in the soil before the rains in this crop in relation to the others. As a result, the average WIE values in the first four tests of rain in soybean (41 mm h^{-1}) approached the basic water infiltration rate in the Nitisol, which would certainly not have been achieved in the rainfall tests applied to corn and beans.

The data in table 3 indicate that some WSB values varied little in the experiments carried out on Nitisol (0.31-0.43 kg kg^{-1} in the 0-10 cm layer and 0.32-0.47 kg kg^{-1} in the 10-20 cm layer), equivalent to 52 % for both layers. The WIE, on the other hand, varied between 24 and 62 mm h^{-1}, i.e., equivalent to an increase of 2.6 times for the different conditions studied. The coefficient of water infiltration into the soil was 0.37 in the treatment using a disc seeder on oat residue and 0.59 with a disc-drill seeder on the same residue, while, on corn residue, the coefficient was 0.45 without drilling and 0.77 with the disc-drill seeder. It was found that the duration of the simulated rains, the time of the experiments, and especially the amount and type of crop residues and soil plowing mechanism of the seeder influenced WIE more than WSB. Moreover, two important properties of the soil surface, i.e., surface roughness and soil cover by crop residues, influenced this variable, as argued by Amaral (2010) in the same experiment.

The sowing performed with disc-drill soil-openers increased WIE, in oat as much as in corn residues (Table 3). Under oat, the increase reached 59 % and under corn 73 %, in the mean of the residues, although the rainfall intensity on each sowing form and residue type was equal. The WIE

Table 3. Water content in two soil layers before simulated rainfall, water infiltration rate at the end of the rain and rainfall intensity of varying duration, on oat and corn residue, in a Nitisol (average of two replications)

Furrow opener type/crop residue rate	Soil water content		
	0-10 cm	**10-20 cm**	**Average**
Type/t ha^{-1}	kg kg^{-1}		
	Rain on oat residue(1) (12/17/2008)		
Without drill/5.3	0.40	0.42	0.41
Without drill/2.6	0.40	0.43	0.42
Without drill/1.3	0.35	0.36	0.36
Without drill/5.3	0.43	0.47	0.45
With drill/2.6	0.36	0.42	0.39
With drill/1.3	0.36	0.38	0.37
	Rain on corn residue(1) (06/04-05/2009)		
Without drill/8	0.32	0.38	0.35
Without drill/4	0.38	0.40	0.39
Without drill/2	0.31	0.32	0.32
With drill/8	0.39	0.40	0.40
With drill/4	0.36	0.38	0.37
With drill/2	0.34	0.35	0.35

Infiltration rate and rain duration

Type	Inf. Res. O(2)		Rain	Inf. Res. C(3)		Rain
t ha^{-1}	mm h^{-1}		min	mm h^{-1}		min
Without drill/5.3(O)/8(C)	24	71	75	27	77	120
Without drill /2.6(O)/4(C)	24	73	75	40	70	120
Without drill /1.3(O)/2(C)	33	75	110	33	75	120
Average	27	73	87	33	74	120
SD(4)	3	2	17	5	3	0
With drill/5.3(O)/8(C)	36	71	75	62	77	120
With drill/2.6(O)/4(C)	36	73	75	48	70	120
With drill/1.3(O)/2(C)	58	75	110	60	75	120
Average	43	73	87	57	74	120
SD	10	2	17	6	3	0

(1) Data from Amaral (2010); (2) Inf. Res. O: water infiltration into soil with oat residues; (3) Inf Res C: Water infiltration into soil with corn residue; (4) SD: Standard Deviation. O: oat residues; C: corn residues.

resulting from the average of oat and corn residue in the treatments with a disc seeder (30 mm h^{-1}) can reach the basic water infiltration rate in the Nitisol, while the values obtained with rainfall applied to the treatments with a disc-drill seeder both in oats (43 mm h^{-1}) and in corn (57 mm h^{-1}) did not reach the basic infiltration rate.

Table 4 shows less variation in WSB and greater variation in WIE data (0.26-0.31 kg kg^{-1} in the 0-10 cm layer and 0.28-0.30 kg kg^{-1} in the 10-20 cm layer), equivalent to 19 % for both layers in WSB, while WIE ranged between 27 and 49 mm h^{-1}, equivalent to 81 %. The water infiltration rate into the soil varied little (from 0.47 in corn residue with contour sowing to 0.44 on the same residue sown downhill). This value was 0.57 for wheat residue with contour sowing and 0.51 for the same residue sown downhill, but 0.49 for soybean residue with contour sowing and 0.49 for the same residue sown downhill. In this study, the type and amount of waste, sowing direction, and timing of rainfall application influenced this variable. The soil physical properties had no influence, while the soil cover by crop residues had little influence, as argued by Barbosa (2011) in the same experiment.

Contour sowing increased IAF by 7, 15 and 3 %, compared to downhill sowing, on corn, wheat and soybean residues, respectively, in the mean of the residue rates, where the rain intensity was practically the same (Table 4). In all cases, WIE was low, except in the contour sowing treatment with application of 9.6 t ha^{-1} wheat residue (43 mm h^{-1}),

Table 4. Water content in two soil layers before simulated rainfall, water infiltration into soil at the end of the rain and rainfall intensity lasting 90 min, over residue of corn, wheat and soybean, in a Nitisol (average of two replications)

Direction of seeding/crop residue rate	Soil water content		
	0-10 cm	10-20 cm	Average
Direction/t ha^{-1}	kg kg^{-1}		
	Rain on corn residue(1) (06/28/29/2010)		
Contour/9.6	0.29	0.30	0.30
Contour/4.8	0.27	0.29	0.28
Downhill/9.6	0.31	0.30	0.31
Downhill/4.8	0.26	0.29	0.28
	Rain on wheat residue (12/02/03/2010)		
Contour/3.6	0.28	0.29	0.29
Contour/1.8	0.28	0.29	0.29
Downhill/3.6	0.29	0.29	0.29
Downhill/1.8	0.28	0.29	0.29
	Rain on soybean residue (05/06/07/2011)		
Contour/3.6	0.27	0.30	0.29
Contour/1.8	0.26	0.28	0.27
Downhill/3.6	0.26	0.28	0.27
Downhill/1.8	0.26	0.27	0.27

Infiltration rate and intensity of rain

Direction	Inf. Res. C(2)	Rain	Inf. Res. W(3)	Rain	Inf. Res. S(4)	Rain
t ha^{-1}	mm h^{-1}					
Contour/9.6(C)/3.6(WS)	30	69	43	71	35	70
Contour/4.8(C)/1.8(WS)	33	67	35	67	33	69
Average	32	68	39	69	34	70
SD(5)	2	1	4	2	1	1
Downhill/9.6(C)/3.6(WS)	27	69	37	69	33	68
Downhill/4.8(C)/1.8(WS)	32	67	31	65	32	67
Average	30	68	34	67	33	68
SD	3	1	3	2	1	1

(1) Data from Barbosa (2011); (2) Inf Res C: Water infiltration into soil with corn residue; (3) Res Inf W: water infiltration into soil with wheat residue; (4) Res Inf S: water infiltration into soil with soybean residue; (5) SD: Standard Deviation. C: Corn residue; W: Wheat residue; S: soybean residue.

resulting in an average of 34 mm h^{-1}, which can be considered equivalent to the basic water infiltration rate for the Nitisol.

The data in table 5 show that WSB and WIE varied widely (0.18-0.31 kg kg^{-1} in the 0-10 cm layer, and 0.19-0.29 kg kg^{-1} in the 10-20 cm layer), equivalent to 72 % for both layers for WSB and between 13 and 53 mm h^{-1}, equivalent to 4.1 times for WIE. The water infiltration rate into the soil also varied widely between treatments and between the evaluation times during the crop cycle. The value ranged from 0.44 to 0.67 in the rain test applied on May 5, 2012, from 0.31 to 0.69 in the test applied on May 26, from 0.18 to 0.34 in the test applied on June 20 and from 0.46 to 0.84 in the rainfall test of August 25 of that same year. Thus, the time of application of the rains influenced this variable as well as the rainfall intensity and pig slurry rate, as argued by Mecabô Junior (2013), in a study carried out in the same experimental area.

The WIE value in rainfall test 1 (27 mm h^{-1}), test 2 (19 mm h^{-1}) and test 4 (29 mm h^{-1}) was lowest at a pig slurry rate of 100 m^{3} h^{-1}, while in test 3, the value was lowest (31 mm h^{-1}) when no pig slurry was applied (Table 5). According to the IAF data calculated from the studies of Leite (2003), Engel (2005), Amaral (2010), and Barbosa (2011) for this same soil, these values as well as some others in the rain tests 2 and 3, calculated based on Mecabô Junior (2013), can be equivalent to the basic water infiltration rate for the Nitisol.

Table 5. Water content in two soil layers before simulated rainfall, water infiltration into the soil at the end of the rain and rainfall intensity lasting 75 min in oat cultivation under four rates of pig slurry, in a Nitisol (average of two replications)

Rate of slurry	Soil water content[1] 0-10 cm	10-20 cm	Average
m^3 ha^{-1}	kg kg^{-1}		
	Rainfall test 1 (05/05/2012)		
200	0.27	0.26	0.27
100	0.27	0.28	0.28
50	0.27	0.27	0.27
0	0.25	0.26	0.26
	Rainfall test 2 (05/26/2012)		
200	0.27	0.27	0.27
100	0.28	0.28	0.28
50	0.31	0.25	0.28
0	0.26	0.26	0.26
	Rainfall test 3 (06/20/2012)		
200	0.27	0.28	0.28
100	0.29	0.29	0.29
50	0.28	0.27	0.28
0	0.29	0.27	0.28
	Rainfall test 4 (08/25/2012)		
200	0.18	0.19	0.19
100	0.20	0.21	0.21
50	0.20	0.21	0.21
0	0.21	0.20	0.21

Infiltration rate and intensity of rain

Rate	Inf. T1[2]	Rain	Inf. T2	Rain	Inf. T3	Rain	Inf. T4	Rain
m^3 ha^{-1}	mm h^{-1}							
200	43	64	42	61	21	72	52	63
100	27	61	19	62	16	71	29	63
50	41	61	28	62	24	71	53	63
0	35	64	23	61	13	72	48	63
Average	37	63	28	62	19	72	46	63
SD[3]	6	2	9	1	4	1	10	0

(1) Data from Mecabô Júnior (2013); (2) Inf. T: water infiltration into the soil in the rainfall test; (3) SD: Standard Deviation.

Data obtained on the Cambisol

The data of table 6 show that the water content of the soil prior to the applied rains (WSB) varied little (0.27-0.36 kg kg^{-1} in the 0-10 cm layer and 0.29-0.39 kg kg^{-1} in the 10-20 cm layer), 44 % for both layers. This exerted little influence on water infiltration into the soil at the end of the rain (WIE). The WIE ranged between 10 and 49 mm h^{-1}, increasing 4.9-fold, indicating that other variables such as crop type and growth stage and the form of sowing influenced WIE more than WSB. In oat sown downhill, the coefficient of infiltration was 0.31, 0.40 along the contour and 0.54 by manual broadcasting; for vetch sown downhill, the coefficient was 0.35, along the contour 0.54 and by manual broadcasting 0.49, in the mean of applied rains. The lower coefficient of infiltration in downhill sowing compared to contour sowing can be explained as follows: the marks of the seeder, along the contour, stored more water and for a longer time, decreasing the flow, as shown by Barbosa (2008) and Luciano (2008). The lower coefficient of infiltration observed in vetch was due to a lower production of biomass, which influenced mainly the interception of water by the shoots.

Contour sowing increased WIE by 35 and 65 %, compared to downhill sowing for oat and vetch, respectively, in the mean of the simulated rainfall

Table 6. Water content in two soil layers before simulated rainfall, water infiltration into soil at the end of the rain and rainfall intensity lasting 60 min for the oat and vetch cycles, in a Cambisol (average of two replications)

Rain	Soil water content(1)								
	0-10 cm	10-20 cm	Average	0-10 cm	10-20 cm	Average	0-10 cm	10-20 cm	Average
Date	kg kg^{-1}								
	Oat downhill			Oat contour			Oat broadcast by hand		
1 (08/04/2006)	0.31	0.32	0.32	0.30	0.31	0.31	0.27	0.30	0.29
2 (09/13/2006)	0.31	0.35	0.33	0.32	0.31	0.32	0.28	0.29	0.29
3 (10/17/2006)	0.33	0.32	0.33	0.32	0.31	0.32	0.34	0.29	0.32
4 (10/21/2006)	0.32	0.31	0.32	0.36	0.39	0.38	0.32	0.30	0.31
5 (11/24/2006)	0.34	0.35	0.35	0.33	0.36	0.35	0.31	0.30	0.31
	Vetch downhill			Vetch contou			Vetch broadcast by hand		
1 (08/04/2006)	0.35	0.35	0.35	0.33	0.36	0.35	0.31	0.30	0.31
2 (09/13/2006)	0.34	0.36	0.35	0.32	0.35	0.34	0.32	0.36	0.34
3 (10/17/2006)	0.32	0.37	0.35	0.29	0.30	0.30	0.32	0.32	0.32
4 (10/21/2006)	0.35	0.38	0.37	0.35	0.37	0.36	0.36	0.34	0.35
5 (11/24/2006)	0.32	0.34	0.33	0.33	0.36	0.35	0.31	0.33	0.32

Infiltration rate and intensity of rain

Rain	Inf.(2)	Rain	Inf.	Rain	Inf.	Rain
N°	mm h^{-1}					
	Oat downhill		Oat contour		Oat broadcast by hand	
1	19	63	29	58	46	69
2	15	67	30	77	32	68
3	35	63	40	70	49	70
4	19	63	23	66	32	66
5	10	68	12	67	25	72
Average	20	65	27	68	37	69
SD(3)	8	2	9	6	9	2
	Vetch downhill		Vetch contour		Vetch broadcast by hand	
1	29	67	46	76	33	68
2	30	76	46	84	40	87
3	27	76	46	79	41	80
4	21	72	38	76	38	75
5	22	78	41	81	36	81
Average	26	74	43	79	38	78
SD	4	4	3	3	3	6

(1) Data from Barbosa (2008) and Luciano (2008); (2) Inf.: water infiltration into soil; (3) SD: Standard Deviation.

tests, while the variation of rainfall intensity between tests was virtually zero (Table 6). In the case of broadcast seeding by hand, WIE was 37 % higher in oat and 12 % lower in vetch, compared to the contour, with no variation in rain intensity either. In most cases, WIE was high, except for some values in oat downhill and in the contour that can be considered close to the basic water infiltration rate for the studied Cambisol.

The values in table 7 showed that WSB varied (0.27-0.38 kg kg^{-1} in the 0-10 cm layer and 0.22-0.37 kg kg^{-1} in the 10-20 cm layer) 41 % in the surface layer and 68 % in the lower layer, which can be considered a small variation. Thus, this variation probably influenced WIE little. The WIE ranged between 2 and 43 mm h^{-1}, equivalent to 21.5 times, showing that other variables such as crop type and growth stage influenced WIE more than WSB. In corn, the coefficient of infiltration was 0.38, in soybean 0.34, in common bean 0.27 and in the corn/bean intercrop, the coefficient was 0.29, in the mean of the rains applied. The lower infiltration rate in common bean can be explained: the morphological characteristics of the roots of this crop, especially,

Table 7. Water content in two soil layers before simulated rainfall, water infiltration into soil at the end of the rain and rainfall intensity lasting 90 min for the cycles of corn, soybean, beans and corn/beans, in a Cambisol (average of two replications)

Rain	Soil water content(1)											
	0-10	10-20	Average	0-10	10-20	Average	0-10	10-20	Average	0-10	10-20	Average
	cm			cm			cm			cm		
	Corn			Soybean			Black beans			Corn/black beans		
Date	kg kg^{-1}											
1 (12/18/2009)	0.27	0.30	0.29	0.28	0.30	0.29	0.27	0.28	0.28	0.28	0.32	0.30
2 (01/26/2010)	0.31	0.31	0.31	0.38	0.37	0.38	0.30	0.31	0.31	0.33	0.35	0.34
3 (03/03/2010)	0.20	0.22	0.21	0.27	0.31	0.29	0.28	0.29	0.29	0.27	0.28	0.28
4 (05/14/2010)	0.32	0.32	0.32	0.35	0.37	0.36	0.31	0.33	0.33	0.36	0.36	0.36

Infiltration rate and intensity of rain

Rain	Corn		Soybean		Black beans		Corn/black beans	
	Inf.(2)	Rain	Inf.	Rain	Inf.	Rain	Inf.	Rain
N°	mm h^{-1}							
1	28	64	16	62	26	64	21	62
2	19	62	15	59	20	62	15	59
3	35	65	43	72	18	65	28	72
4	12	63	14	66	2	63	11	66
Average	24	64	22	65	17	64	19	65
SD(3)	9	1	12	5	9	1	6	5

(1) Data from Bertol et al. (2013); (2) Inf.: water infiltration into soil; (3) SD: Standard Deviation.

contributed little to form soil galleries, making infiltration more difficult than in the other crops, as shown by data presented by Bertol et al. (2013). The smaller shoot mass production of common bean, which mainly influenced rainwater interception, contributed to this.

Corn increased WIE by 9 and 41 %, compared to soybean and common bean, respectively, in the mean of the rainfall tests, while the variation in rainfall intensity between tests was practically zero (Table 7). In the corn/bean intercrop, the increase in WIE in corn was 26 %, with no variation in rain intensity either. In most cases, IAF was high, except for one value recorded for beans (2 mm h^{-1}), which was lower than the water infiltration rate considered as basic for the studied Cambisol.

The data in table 8 showed that WSB varied little (0.23-0.40 kg kg^{-1} in the 0-10 cm layer and 0.26-0.39 kg kg^{-1} in the 10-20 cm layer), representing a variation of 74 % in the surface layer and 50 % in the lower layer, in other words, WSB had little influence on WIE. The IAF ranged between 2 and 36 mm h^{-1}, equivalent to an 18-fold increase, demonstrating that other variables such as type and growth stage of the crop and sowing direction influenced WIE more than WSB. In soybean sown downhill, the infiltration coefficient was 0.06, while in the contour, it was 0.15; in corn sown downhill, the coefficient was 0.06, while in the contour it was 0.30, in the mean of the applied rains. The highest coefficient of infiltration observed in corn sown in the contour can be explained: the furrows of the seeder, along the contour lines, stored a larger volume of water and for a longer time compared to the other studied conditions, as observed by Luciano (2008), Marioti (2012) and Marioti et al. (2013), in studies carried out in the same experimental area. The lower biomass production in common bean shoots, which mainly influenced rainwater interception, contributed to this.

The corn planted in the contour increased WIE 5 times while soybean in the contour increased it by 2.5 times, compared to soybean downhill, in the mean of the simulated rainfall tests, while the variation in rainfall intensity between tests was zero (Table 8). The furrows of the seeder, along the contour lines, stored a larger volume of water and for a long time, facilitating infiltration in comparison to the downslope furrows which increased surface runoff, as observed by Luciano (2008) and Marioti (2012). The greater effect of corn than soybean was due to the morphological characteristics of the plants. Corn, with greater shoot mass, intercepted more rainwater and, with more root mass, enhanced the infiltration, compared to soybean.

Table 9 showed that WSB varied (0.18-0.34 kg kg^{-1} in the 0-10 cm layer and 0.22-0.35 kg kg^{-1} in the

Table 8. Water content in two soil layers before simulated rainfall, water infiltration into soil at the end of the rain and rainfall intensity lasting 90 min, during the cycles of soybean and corn, using two seeding directions, in a Cambisol (average of two replications)

Rain	Soil water content(1)											
	0-10	10-20	Average	0-10	10-20	Average	0-10	10-20	Average	0-10	10-20	Average
	cm			cm			cm			cm		
	Soybean downhill			Soybean contour			Corn downhill			Corn contour		
Date	kg kg^{-1}											
1 (01/20/2011)	0.33	0.34	0.34	0.28	0.30	0.29	0.29	0.32	0.31	0.30	0.30	0.30
2 (02/26/2011)	0.40	0.39	0.40	0.37	0.35	0.36	0.34	0.32	0.33	0.33	0.32	0.33
3 (03/19/2011)	0.25	0.30	0.28	0.23	0.26	0.25	0.25	0.28	0.27	0.27	0.29	0.28
4 (04/16/2011)	0.31	0.36	0.34	0.32	0.34	0.33	0.30	0.30	0.30	0.31	0.32	0.32

Infiltration rate and intensity of rain

Rain	Soybean downhill		Soybean contour		Corn downhill		Corn contour	
	Inf.(2)	Rain	Inf.	Rain	Inf.	Rain	Inf.	Rain
N°	mm h^{-1}							
1	4	74	12	70	5	75	14	69
2	3	64	4	66	3	64	8	66
3	6	64	15	67	3	64	21	67
4	2	65	8	63	3	63	36	66
Average	4	67	10	67	4	67	20	67
SD(3)	2	4	4	3	1	5	10	1

(1) Data from Marioti (2012); (2) Inf.: water infiltration into soil; (3) SD: Standard Deviation.

10-20 cm layer) equivalent to 94 %, for both layers. This had a great influence on WIE. The WIE varied between 8 and 21 mm h^{-1}, equivalent to a 2.6-fold increase, showing that other variables such as the type of crop residues, soil surface roughness and waste decomposition stage influenced WIE more than WSB. For ryegrass residue on the soil surface, the coefficient of infiltration was 0.25, while for vetch residue it was 0.19; in the soil chiseled with maintenance of only the roots of ryegrass the coefficient was 0.17, whereas in the scarification with vetch roots only it was 0.15, in the mean of the applied rains. The higher coefficient of infiltration for ryegrass residue can be explained by the water storage capacity of this residue and its ability to slow down the flow, over the course of most of the experiment, because of its high resistance to decomposition compared to vetch. To this effect, the roots of this crop contributed with the formation of soil galleries, which increased water infiltration, due to the fact that the soil had not been turned over, as shown by the soil property data obtained in the same experiment and presented by Ramos (2012).

The WIE for ryegrass residue on the soil surface increased by 45 %, compared to the chiseled soil maintaining only the roots of the crop, while the rain rate was virtually the same in both treatments (Table 8). In the case of vetch residue, WSB was 20 % higher when left on the surface compared to scarification maintaining only the roots, while the rain rate was equal. Thus, regarding the ability to decrease runoff, the ryegrass residue left on the soil surface performed better than vetch under the same management, as well as when compared to scarification carried out in the presence of the roots of both crops, as shown by Ramos (2012) and Ramos et al. (2014), working in the same experiment.

Adjustment of the Horton model to the data obtained in both soils

The Horton model (1940) significantly adjusted to the data of water infiltration for both soils (Figure 1). For the Nitisol, the model predicted 94 % of infiltration based on the mean of the data of 12 simulated rainfall events, while for the Cambisol, the prediction was 99 %, based on 16 events. The infiltration rate observed in the field at the beginning of the rain (time zero) was 68.2 mm h^{-1} in the Nitisol and 64.5 mm h^{-1} in the Cambisol, while at the end of 90 min of rain, the value was 30.2 mm h^{-1} in the Nitisol and 6.6 mm h^{-1} in the Cambisol. On the other hand, the infiltration rate at the end of the rain estimated by the model was 32.5 mm h^{-1} in the Nitisol and 7.1 mm h^{-1} in the Cambisol, overestimating the value observed by 8 % in both soils. In the case of the Nitisol, the lack of agreement between the values estimated by the model and the ones observed in the field, in the

Table 9. Water content in two soil layers before simulated rainfall, water infiltration into soil at the end of the rain and rainfall intensity lasting 90 min, in different treatments, in a Cambisol (average of two replications)

Rain	Soil water content(1)											
	0-10	10-20	Average	0-10	10-20	Average	0-10	10-20	Average	0-10	10-20	Average
	cm			cm			cm			cm		
	Ryegrass residue			Vetch residue			Ryegrass roots - C			Vetch roots - C		
Date	kg kg^{-1}											
1(12/17/2011)	0.32	0.31	0.32	0.30	0.28	0.29	0.32	0.35	0.34	0.20	0.22	0.21
2(01/10/2012)	0.25	0.29	0.27	0.18	0.27	0.23	0.23	0.27	0.25	0.20	0.25	0.23
3(02/07/2012)	0.34	0.33	0.34	0.34	0.35	0.35	0.31	0.31	0.31	0.28	0.27	0.28
4(03/10/2012)	0.24	0.29	0.27	0.27	0.31	0.29	0.23	0.33	0.28	0.22	0.30	0.26
5(05/11/2012)	0.26	0.30	0.28	0.23	0.31	0.28	0.19	0.29	0.24	0.20	0.28	0.24
6(08/18/2012)	0.27	0.31	0.29	0.24	0.30	0.27	0.22	0.32	0.27	0.21	0,32	0.27
7(11/02/2012)	0.24	0.31	0.28	0.28	0.32	0.30	0.23	0.30	0.27	0.19	0.27	0.23
8(12/18/2012)	0.24	0.31	0.28	0.24	0.32	0.28	0.22	0.29	0.26	0.21	0.25	0.23

Infiltration rate and intensity of rain

Rain	Ryegrass residue		Vetch Residue		Ryegrass roots - C		Vetch roots - C	
	Inf.(2)	Rain	Inf.	Rain	Inf.	Rain	Inf.	Rain
N°	mm h^{-1}							
1	15	64	13	60	10	58	9	61
2	20	72	13	73	10	74	11	74
3	15	59	11	62	13	64	11	66
4	21	65	12	61	14	60	12	62
5	17	59	10	60	9	60	10	61
6	15	61	12	64	12	65	9	65
7	12	63	11	66	10	68	8	66
8	15	61	10	65	10	67	11	65
Average	16	63	12	64	11	65	10	65
SD(3)	3	4	1	4	2	5	1	4

(1) Data from Ramos (2012); (2) Inf.: water infiltration into soil; (3) SD: Standard Deviation. C: chiseled soil.

beginning of the rain, is explained by the fact that the water infiltration capacity of the soil in those moments was far superior to the rate of rain applied, while in the Cambisol, the higher agreement between the estimated and the observed data was because the infiltration capacity was similar to the rainfall rate. This behavior is explained mainly by the difference in macropore volume, due to the difference, especially in clay content, between both soils (Table 1). The over- estimated infiltration rate at the end of the rain in both soils was due to the hydraulic variables, not controlled experimentally, especially those depending on soil physical properties. Thus, it is possible to conclude that the constant rate for water infiltration for the Nitisol was 30.2 mm h^{-1} and 6.6 mm h^{-1} in the Cambisol, under the experimental conditions.

CONCLUSIONS

Water infiltration into soil varies significantly with the soil type, with a constant value of 30.2 mm h^{-1} in the Nitisol and 6.6 mm h^{-1} in the Cambisol, regardless of the management system, time of application and rain intensity and duration.

Water infiltration into soil varies significantly with the management system, with the time of application and rain intensity and duration, with a constant value between 13 and 59 mm h^{-1}, for the two soils.

The direction of seeding in relation to the relief, crop type and amount and type of crop residue on the soil influences water infiltration into the soil: in Nitisol, the values vary between 27 and 43 mm h^{-1} in contour and downhill sowing, respectively, on

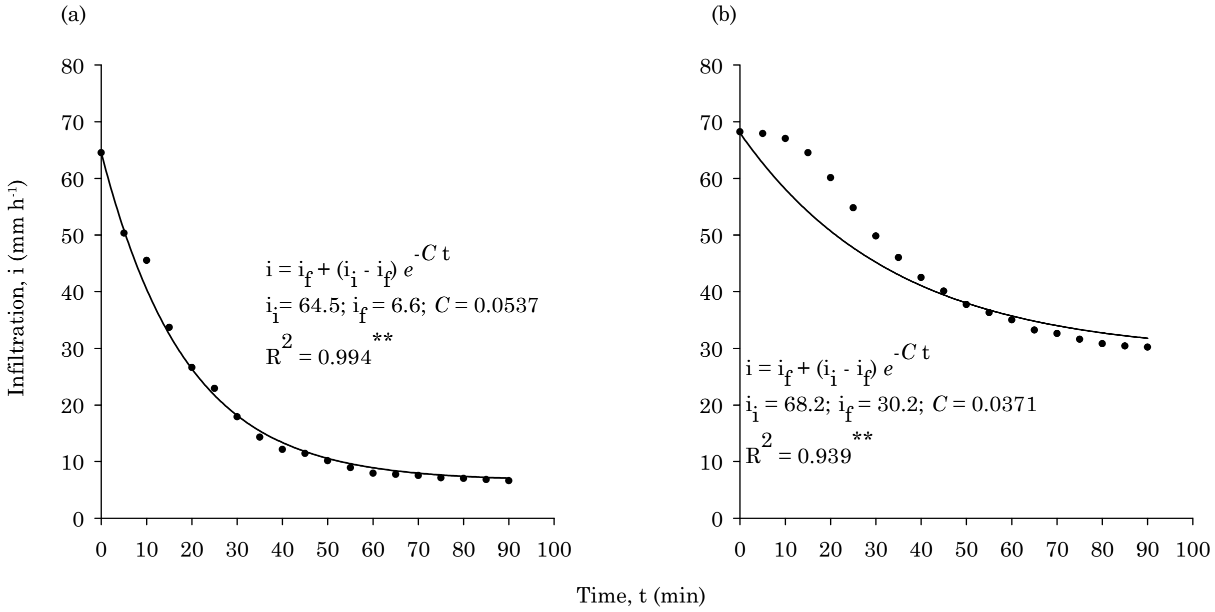

Figure 1. Model of Horton (1940) adjusted to the data of water infiltration into the soil, for 12 simulated rainfall events in a Nitisol (a) and 16 events in a Cambisol (b) (average of replications and events).

residues of corn, wheat and soybean, while in Cambisol, the variation is respectively between 2 and 36 mm h^{-1}, in soybean and corn.

The Horton model adjusts to the water infiltration rates in the Nitisol and Cambisol, resulting in the respective equations $i = 30.2 + (68.2 - 30.2)\ e^{-0.0371t}$ ($R^2 = 0.94^{**}$) and $I = 6.6 + (64.5 - 6.6)\ e^{-0.0537t}$ ($R^2 = 0.99^{**}$).

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