academicJournals

Vol. 9(44), pp. 3267-3275, 30 October, 2014
DOI: 10.5897/AJAR2014.8597
Article Number: FF9018648305
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Full Length Research Paper*

# Impact of an agricultural chronosequence in recharge areas of aquifers in the Brazilian savannah

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Received 7 February, 2014; Accepted 10 October, 2014

**Current study was conducted, in 2010, on the Boa Vista Farm at the Rio Claro watershed of the southwestern region of Goiás, state, Brazil. The region features micro-reliefs with marshy fields and predominantly Haplic Plinthosols. Most areas were incorporated into the agricultural production systems without evaluating the impact on their hydro-physical characteristics. Current analysis evaluates the transformation impact of marshy lands into agricultural areas through an investigation of empirical methods of water infiltration into the soil. Three chronosequenced areas for agricultural use and a preservation area were selected. Water infiltration in the soil was analyzed by field data and by calculations following Kostiakov, Horton and Lewis-Kostiakov. Models overestimated infiltration rates at the beginning of the process and compared to those from field data. The model proposed by Horton was highly similar to rate of basic infiltration speed harvested from field data. Structural quality was reduced through infiltration velocity in the area with human interference with grown under no-tillage system.**

**Key words:** Haplic plinthosol, mounds, hillocks, cylinder infiltrometers, no-tillage system.

## INTRODUCTION

Micro-reliefs in marshy fields (murundus, covais, cocorutos and monchões, in Portuguese) of the savannah plateau of Goiás state, Brazil, form extensive areas predominantly featured as Haplic Plinthosols soil. The soil is highly relevant due to its role as a water recharge and supply for underground water and the maintenance of water levels in streams and rivers of one of the most important Brazilian hydraulic sources, or rather, the river Paranaíba basin.

During the last decades the above mentioned areas in the Goiás state, Brazil, were incorporated to cash crop production systems. Landscape transformation in an agriculture-occupied process went beyond the loss of biodiversity and climate changes, with the modification of soil structure. The consequences, comprising soil compaction and erosion, accumulation of silt in waterways and liability in water resources, are perceptible, even though their evolution and economical and environmental consequences are still largely unknown. Impact caused by structural changes in the soil´s physical and hydraulic features has been reported by Alves et al. (2007) and Bonini and Alves (2012). According to Mota and Valladares (2011), human activities have produced environmental degradation, erosion, soil contamination and silt in the water courses. In fact, the impact model currently threatens the sustainability of the productive systems.

The incorporation of marshy areas, essential for the recharge of the region´s aquifers and characterized by soil saturation during most of the year, brought about the building of a great network of soil drainage. In other words, the underground water of the earth mound fields was lowered by a network of drainage canals in several municipalities of the region. The municipality of Jataí in the southwestern region of the Goiás state may be highlighted. Results quite often caused an excessive dryness of the soil and consequently the hardening of the plinthic ground surface by barring infiltration, hindering the natural drain of water, discharge decrease of streams with lower water flow towards the rivers of the watershed in which they lie.

Due to the region´s characteristics (high rates of organic materials and clay, land relief and possibility of mechanization), high productivity rates abounded throughout the last decades. Consequently, year by year producers have incorporated other areas to the production system without evaluating the effect of such incorporation on soil quality and environment. This is especially grave due to the importance of the region for the Brazilian hydrological system (Gomes Filho et al., 2011). According to Silva et al. (2012), the soil´s physical and hydraulic properties affect the hydrological processes which comprise infiltration, erosion, wetness redistribution and the transport of solved materials.

Models of water infiltration in the soil such as Kostiakov´s, Kostiakov-Lewis´s, Horton´s, among others, link the model´s parameters to soil characteristics without necessarily having any physical significance. In fact, they include some factors in the determination of their constants, such as soil heterogeneity, which are difficult to be assessed in theoretical models.

Infiltration velocity is affected by surface conditions, profile and soil´s initial water contents (Panachuki et al., 2006). Water erosion processes are greatly affected by surface materials, topography, rain seasonality and vegetation (Silva and Kato, 1998) which may be compounded by changes in texture, structure, porosity and organic matter caused by land usage and its respective management (Pereira and Teixeira Filho, 2009).

The objective of this work was current analysis evaluates the agricultural chronosequence impact on Haplic Plinthosol soil on the phytophysionomy of earth mounds in the savannah region close to the town of Jataí GO Brazil, by empiric models of water infiltration in the soil.

## MATERIALS AND METHODS

Current assay was conducted on the Boa Vista Farm, in the micro-basin of the river Claro in the municipality of Jataí, GO, Brazil, in 2010. The region has been characterized by micro-reliefs of earth mounds (murundus, covais, cocorutos and monchões, in Portuguese) with a predominance of Haplic Plinthosol soils (Figure 1). The region´s climate is Aw, or rather, a savannah tropical mesothermal climate with well-defined dry and rainy seasons, according to Köppen´s classification. Mean annual temperature varies between 18 and 32°C. The rainy period ranges between November and May, with more than 80% of yearly rainfall. Mean annual rainfall varies between 1600 and 1700 mm (with gradual spatial variation without any differentiated rainy nucleus in the region under analysis).

Current analysis compared the areas during the period with agricultural usage (5, 10 and 15 years) and two areas without any agricultural usage, of which one was on the upper section of the mound and the other on the lower section (Figure 2). Since all areas were close to one another, with the same Haplic Plinthosol soil type, the environmental conditions were homogeneous. Five areas, which represent the different classes of soil use, were chosen (Figure 3).

Through the layout of chronosequence of human usage, the impact on soil infiltration speed was evaluated, according to the treatments below:

1. Treatment 1 (MURUNDUINF): Natural conditions exist in the lower section of the earth mound, with no human intervention in the area. The area lies on the lower section of the mounds, flooded most of the year, with no termite activity and covered by crawling graminoid vegetation.
2. Treatment 2 (MURUNDUSUP): Natural conditions on the higher section of the earth mound, approximately 2 m high, without human intervention, which remains dry most of the year, formed by termites. It has typically savannah vegetation, with a great diversity of shrubs and graminoids (Figure 2);
3. Treatment 3 (SPD5): Area occupied for 5 years by no-tillage system. Cash crops consisted of soybean in the harvest; maize (or millet or sorghum) in the winter harvest; fallow state in the interim harvest.
4. Treatment 4 (SPD10): Area occupied for 10 years by no-tillage system. Successive cash crops consisted of soybean in the harvest period; maize in the winter harvest; fallow land.
5. Treatment 5 (SPD15): Area occupied for 15 years by no-tillage system. Successive cash crops consisted of soybean in the harvest

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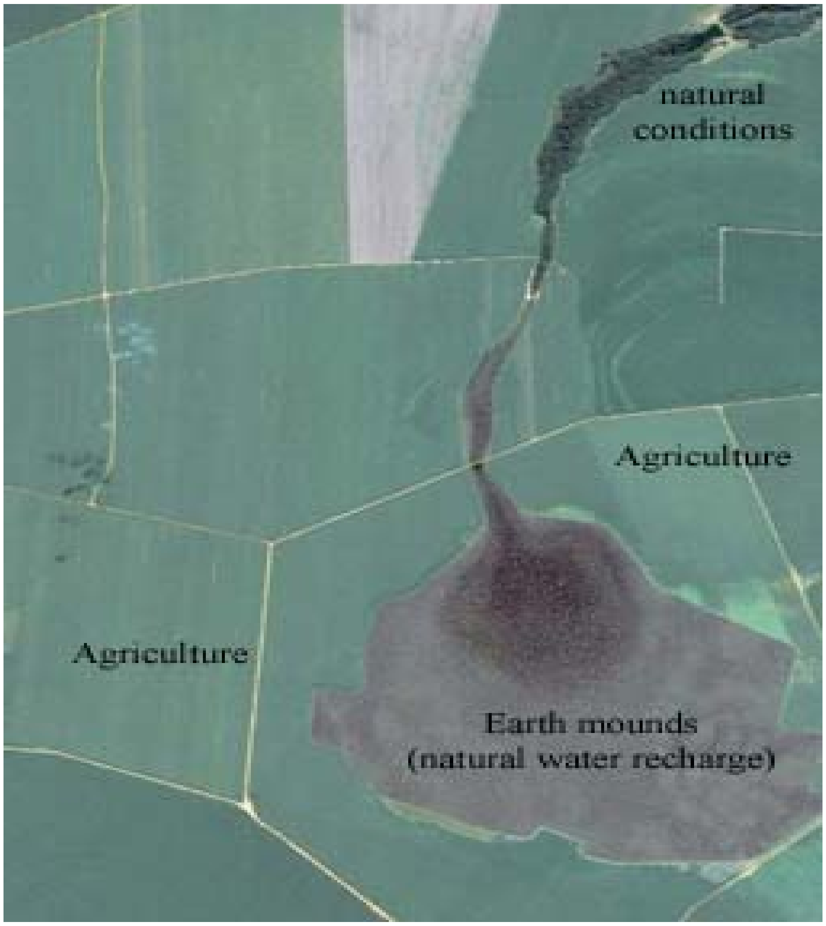

**Figure 1.** Satellite photo showing the natural composition of the micro-relief of earth mounds on the Boa Vista Farm under analysis.

**Figure 2.** Composition of preserved micro-relief of earth mounds, normally a flooded area. Black and white arrows show respectively the upper and lower section of the earth mounds.

period and maize in the winter harvest.

The process of the area´s incorporation to the agricultural production system required a systematization of areas which disturbed the approximately 2 m-high earth mounds. Systematization consisted of cuts and distribution of earth to the lower parts which were leveled. Since the area was plowed and harrowed, changes in the area occurred. It was formerly a rolling landscape and was transformed into a totally flat area with no traces of its natural form (Figure 4).

When the areas were incorporated to the production system, they

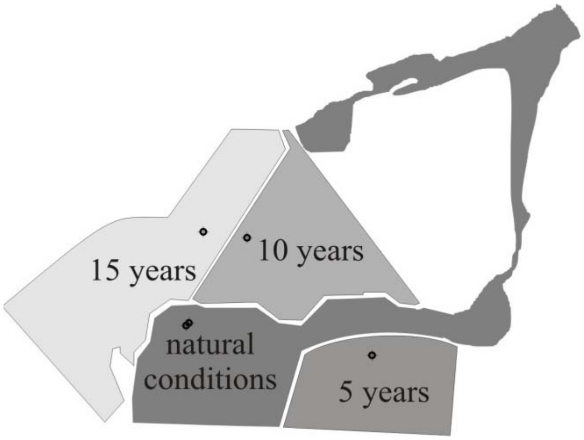

**Figure 3.** Site of the experiment following the chronsequence of human usage.

**Figure 4.** Agricultural area where formerly earth mounds abounded.

were first treated with limestone during the systemization process without any further treatment. This fact differentiates the treatments with regard to the management of each area under analysis.

Table 1 characterizes the clayey texture of the areas; the upper part of the earth mound, 5-, 10- and 15-year periods of incorporation to the no-tillage system (NTS) and the clayey-sandy texture of the lower part of the earth mound.

Infiltration tests were performed on each site under analysis by a double-ring cylinder infiltrometer, measuring 60 cm high and 10 and 20 cm diameter, respectively, for the inner and outer rings (Figure 5).

The two cylinders were placed at a depth of 30 cm and a constant water volume of approximately 19 cm to the soil surface was maintained during tests. Water flow was manually controlled by a register duly adjusted to a pipe linked to the inner cylinder, whilst the outer one was manually supplied. Reading was done at 0, 1, 2, 5, 10 15 and 30 min, starting from 0 min, with replications at every 30 min, up to total time limit of 210 min for each test.

Tests were performed till the infiltration rate, registered on the inner ring, became approximately constant with time. The criterion for constant infiltration rate was the repetition of the reading of the water flow in the inner ring for at least three times.

Water infiltrated into the soil was determined in situ by the ring infiltrometer method and empirically by methods proposed by Horton (1940), Kostiakov (1932) and Kostiakov-Lewis (1945), according to Equations (1), (2) and (3), respectively.

Horton´s model: $V = V_0 + \left(V_0 - V_f\right)\exp\left(-k_f.t\right)$ (1)

Kostiakov´s model: $V = V_0.t^b$ (2)

Kostiakov-Lewis´s model: $V = V_0.\mathrm{t}^b + V_f.t$ (3)

Where: $V$ (cm $h^{-1}$) is the velocity of water infiltration into the soil at a certain time (t) (h) after the formation of a water pool on the soil surface; $V_0$ and $V_f$ are respectively the velocities of initial and final infiltration (cm.$h^1$); $b$ and $K_f$ are proportional constants which depend on the type of soil and rain intensity. $K_f$, $V_0$ and $V_f$ may be obtained experimentally: $V_f$ is the asymptote of graph $V$ versus infiltration time; $K_f$ is the slope of the straight line of the graph ($V_0$ - $V_f$ ) versus $t$; and $V_0$ - $V_f$ is the intercept of the ordinate´s intercept when $t = 0$ (Dantas et al., 2011; Gomes Filho et al., 2011; Paixão et al., 2009; Alves et al., 2007; Alves Sobrinho et al., 2003; Castro and Souza, 1999; Silva and Kato, 1998).

Performance between infiltration field rates and the rates calculated by Kostiakov´s, Horton´s and Kostiakov-Lewis´s empirical methods for infiltration was evaluated by statistically comparative analysis of results by coefficient of determination $R^2$. After data collection, they were used in the laboratory to trace the curves according to the model used. The models´ adjustment

**Table 1.** Soil´s texture characteristics of the areas under analysis.

| **Usage** | **Treatment** | **Clay** | **Silt** | **Sand** |
|---|---|---|---|---|
| | | | **(g kg$^{-1}$)** | |
| Natural features of the earth mound | MURUNDUINF | 434 | 110 | 456 |
| | MURUNDUSUP | 576 | 139 | 285 |
| Chronosequence of agricultural usage | SPD (5 years) | 482 | 193 | 325 |
| | SPD (10 years) | 501 | 185 | 314 |
| | SPD (15 years) | 398 | 213 | 389 |

**Figure 5.** Installation of the double-ring infiltrometer.

quality was evaluated by non-linear regressions between the estimated rates and mean rates registered in each treatment, coupled to the respective coefficients of determination. The following statistic indexes were in the evaluation: coefficient of residual mass (CRM), adjustment coefficient (AC) and efficiency (EF) (Alves Sobrinho et al., 2003), given by Equations (4), (5) and (6) respectively.

$$CRM = \frac{\left(\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} P_i\right)}{\sum_{i=1}^{n} O_i} \tag{4}$$

$$AC = \frac{\sum_{i=1}^{n}\left(O_i - \overline{O_i}\right)^2}{\sum_{i=1}^{n}\left(P_i - \overline{O_i}\right)^2} \tag{5}$$

$$EF = \frac{\left[\dfrac{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2}{\sum_{i=1}^{n}\left(O_i - \overline{P}\right)}\right]}{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2} \tag{6}$$

Where: $O_i$ represents reported rates; $P_i$ is the estimated rates; $n$ is the number of observations; $\overline{O}$ is the arithmetical average of observations; and $\overline{P}$ is the arithmetical average of the estimated rates.

## RESULTS AND DISCUSSION

Table 2 shows rates for Basic Infiltration Velocity (BIV) for each treatment in the area under analysis and the respective classification suggested by Bernardo et al. (2006). Further, BIV rates in soils without human interference were higher than those in soil with no-tillage system. Infiltration velocity was very high.

BIV´s low rates in cultivated areas may be due to changes in the soil structure caused by the destruction of the earth mounds for the preparation of the area for planting and by harvesting machines throughout the years. Sales et al. (1999) evaluated the association between BIV and the physical traits of surface and sub-surface layers of Dark Red Latosol and Red-Yellow Podzolic soils and reported that rates were extremely contrasting. Results may be associated to the distinct morphological characteristics related to the soils´ surface structure. The same authors registered 12.1 mm h$^{-1}$ for BIV in the Red-Yellow Podzolic soil, with 422 g kg$^{-1}$ clay and a 7.8% macropore volume; in the case of Dark Red Latisol they reported 653 g kg$^{-1}$ and 16.8% macropores, with BIV at 56.6 mm h$^{-1}$.

Alves Sobrinho et al. (2003) studied water infiltration in soil cultivated under different management systems, crop rotation and acceptable analyses of equations by Horton and Kostiakov-Lewis to calculate water infiltration rate in the soil by aspersion infiltrometer. They reported the

**Table 2.** Rates of Basic Infiltration Velocity (BIV) of the areas under analysis, equations of infiltration velocity; coefficients of determination ($R^2$) of empirical models and statistic indexes for areas with or without human interference.

| Treatment | BIV (mm.h$^{-1}$) | Classification | Models | Equation | R² | CRM | AC | EF |
|---|---|---|---|---|---|---|---|---|
| MURUNDUINF | 170.0 | Very high | Kostiakov | $VI = 298.5t^{-0.06}$ | 0.978 | -0.087 | 2.109 | 0.000002 |
| | | | Kostiakov-Lewis | $VI = 467.43t^{-0.036}$ | 0.979 | -0.840 | 0.055 | 0.000002 |
| | | | Horton | $VI = 234.35t^{-0.072}$ | 0.835 | 0.180 | 0.881 | 0.000013 |
| MURUNDUSUP | 242.0 | Very high | Kostiakov | $VI = 451.86t^{-0.074}$ | 0.978 | -0.097 | 1.958 | 0.000001 |
| | | | Kostiakov-Lewis | $VI = 691.44t^{-0.044}$ | 0.979 | -0.844 | 0.072 | 0.000001 |
| | | | Horton | $VI = 369.02t^{-0.095}$ | 0.839 | 0.411 | 1.080 | 0.000006 |
| SPD5 | 2.0 | Low | Kostiakov | $VI = 37.1t^{-0.318}$ | 0.978 | -0.123 | 2.770 | 0.000270 |
| | | | Kostiakov-Lewis | $VI = 38.105t^{-0.279}$ | 0.979 | -0.277 | 2.418 | 0.000364 |
| | | | Horton | $VI = 32.675t^{-0.606}$ | 0.899 | 0.411 | 1.726 | 0.000318 |
| SPD10 | 2.0 | Low | Kostiakov | $VI = 23.992t^{-0.278}$ | 0.978 | -0.117 | 3.163 | 0.000603 |
| | | | Kostiakov-Lewis | $VI = 25.345t^{-0.233}$ | 0.979 | -0.331 | 2.427 | 0.000799 |
| | | | Horton | $VI = 19.202t^{-0.495}$ | 0.890 | 0.418 | 1.848 | 0.000699 |
| SPD15 | 2.0 | Low | Kostiakov | $VI = 27.999t^{-0.319}$ | 0.978 | -0.123 | 2.885 | 0.000495 |
| | | | Kostiakov-Lewis | $VI = 29.054t^{-0.269}$ | 0.979 | -0.327 | 2.372 | 0.000597 |
| | | | Horton | $VI = 28.013t^{-0.574}$ | 0.896 | 0.293 | 1.603 | 0.000574 |

CRM, Coefficient of Residual Mass; AC, adjustment coefficient; EF, efficiency.

interference of some soil traits or BIV factors, mainly macro-porosity, management type and soil surface sealing. Further, the latter was the main factor for water infiltration overrate reported by Zonta et al. (2012) and Ali et al. (2010).

When the coefficient of residual mass (CRM) was investigated (Table 2), Horton´s equation used in the five treatments underestimated infiltration rate, whereas equations by Kostiakov and Kostiakov-Lewis overrated it. Behavior has been registered by positive rates of CRM index of Horton´s equations and by the negative ones of Kostiakov and Kostiakov-Lewis´s equation. Results corroborate rates by Alves Sobrinho et al. (2003) and Panachuki et al. (2006) in their studies on water filtration in the soil cultivated under different management systems and culture rotations by Horton´s and Kostiakov-Lewis´s models. Statistical index also confirmed the best adjustment for Horton´s equation with deviations close to zero. Adjustment coefficient and efficiency were also better for the five treatments by Horton´s equation. Indexes´ rates, close to one, confirmed the equation as the most adequate to estimate the infiltration rate in the type of soil under analysis.

Similar to results by Alves Sobrinho et al. (2003) and Panachuki et al. (2006), the Adjustment Coefficient (AC) was, as a rule, better in Horton´s equation since the mathematical model provided rates close to one for the five treatments analyzed. Since efficiency index (EF) was the same in the three equations with differences in treatments, it showed that infiltration models positively indicated the process of water infiltration in the soil and those treatments under natural conditions provided responses which were similar to agricultural chronosequence treatments.

Figure 6 shows the velocity curves of water infiltration and their respective adjustment equations in each soil of the areas under analysis. Equations showed coefficient of determination rates $R^2 = 0.896$ and $R^2 = 0.872$, respectively, in the area without human interference in the lower and upper sections of the earth mounds. Rates $R^2 = 0.935$, $R^2 = 0.923$ and $R^2 = 0.976$ were lower than those in areas, respectively, with 5, 10 and 15 years of human interference.

Figure 6 shows infiltration velocity rates related to time. Infiltration velocity rates in areas without human interference were higher than those in areas with no-tillage agricultural system. According to Silva et al. (2012), infiltration volume was greater when water infiltration rate in the soil at the basin´s bottom was smaller.

Figure 7 demonstrates comparative rates of infiltration velocities by cylinder infiltrometer and rates calculated by Kostiakov´s, Kostiakov-Lewis´s and Horton´s equations for areas without human interference in the upper and lower sections of the earth mound and for areas with 5, 10 and 15 years human interference by agricultural systems.

Figure 7 demonstrates that empirical models in all areas behaved similarly, or rather, Kostiakov-Lewis´s model had the highest velocity rates of water infiltration in the soil and Horton´s model provided velocity rates of water infiltration in the soil close to those from the

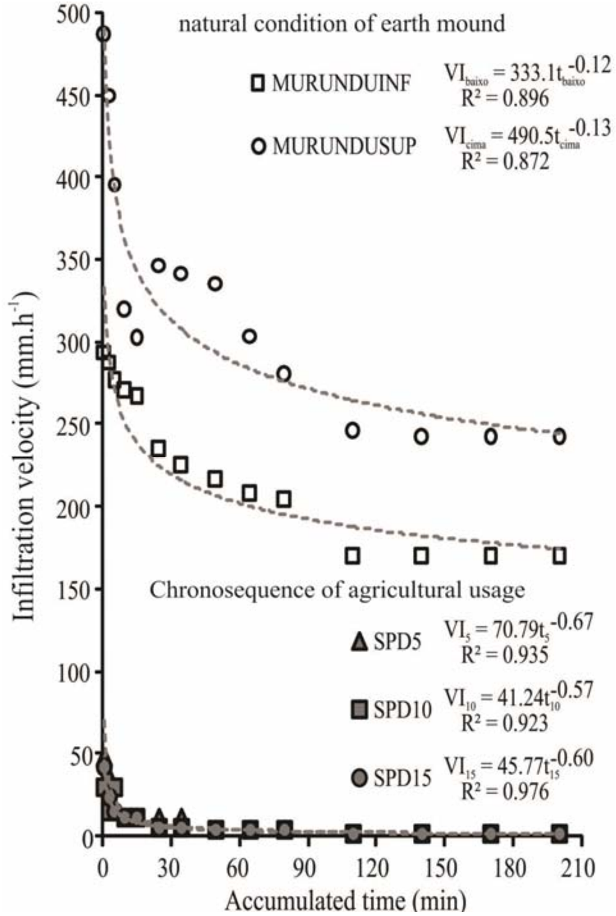

**Figure 6.** Velocity of water infiltration in soil of the areas under natural conditions and those with human interference, as a function of time.

cylinder infiltrometer field model. Rates by Kostiakov´s empirical model overrated rates by Horton´s model and those retrieved from the field model.

The behavior of empirical models in current analysis provided results similar to those reported by Paixão et al. (2009) who estimated water infiltration in soil through adjustments of non-linear functions and of empirical models proposed by Horton, Kostiokov and Kostiokov-Lewis and compared results with data retrieved from field ring infiltrometer in sandy texture soils in Lagoa Seca PB Brazil.

Table 2 shows the rates of empirical equations of models proposed by Kostiakov, Kostiakov-Lewis and Horton for all areas with and without human interference. Horton´s model presented basic infiltration velocity similar to rate from double-ring cylinder infiltrometer (Figure 7) (Montenegro and Montenegro, 2006). Horton´s process was predominant in some regions with a semi-arid climate. It was the main source for the production of discharge peaks in watersheds especially in areas with compacted soils or soils lacking any vegetal covering (Dalri et al., 2010; Tomasini et al., 2010; Thomaz, 2009). The model demonstrated better infiltration in soils with high infiltration capacity.

When compared with field data, the evaluation of empirical models revealed the model that better applied to local conditions which involved physical and water attributes and different phytophysionomies. According to Cavalcante et al. (2011), usage and management methods led, within a rising order, no-tillage system, conventional preparation and pastureland towards the deterioration of the soil´s physical attributes within the savannah context.

Water flow behavior in areas without any human interference evidenced the natural runoff conditions of rain through the soil. Due to the high velocity of basic infiltration, these areas naturally had a great capacity in draining rain water. Contrastingly, areas which underwent human interference but which formerly had the same infiltration velocity lost such a capacity and after the first five years revealed the low velocity of basic infiltration. The above characteristic is a great concern in events of

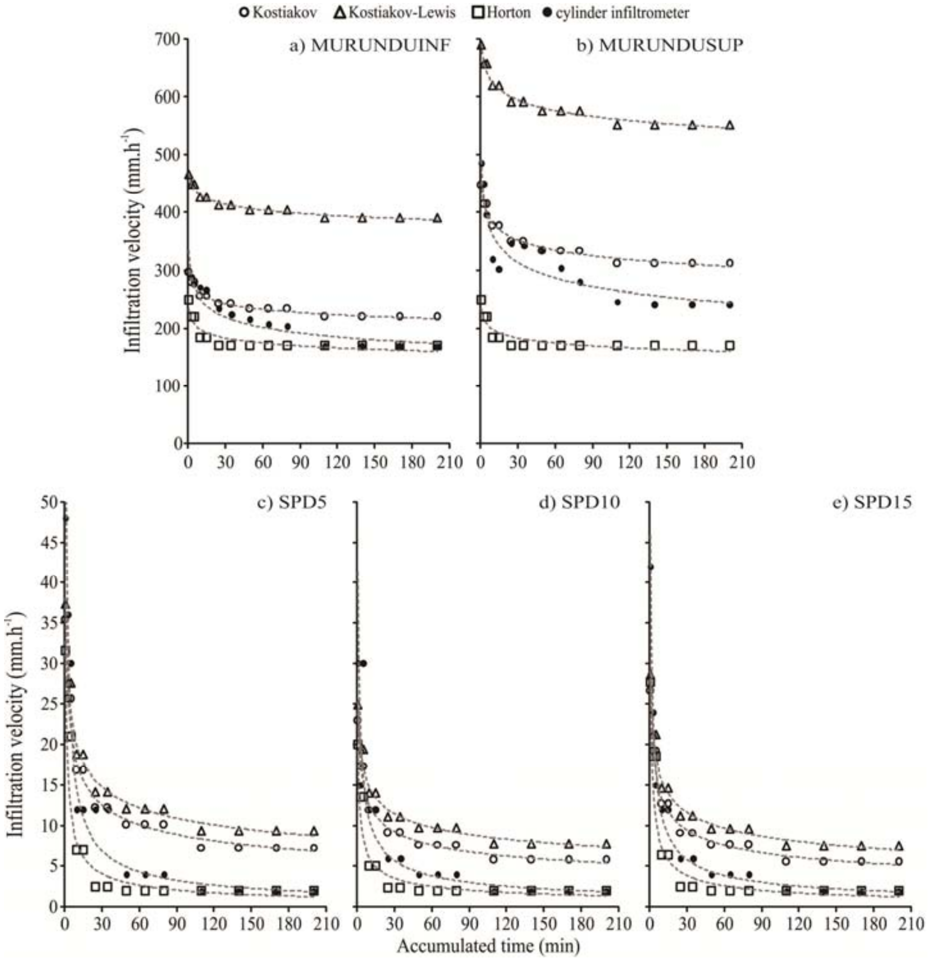

**Figure 7.** Field test of infiltration velocity of water in soil by the cylinder infiltrometer method and data by Kostiakov´s, Kostiakov-Lewis´s and Horton´s equations for the lower section of the earth mound.

prolonged or concentrated rains which will certainly cause surface runoff and erosion.

## Conclusions

Basic Infiltration Velocity (BIV) rates in soils without any human interference were higher to those found in soils with no-tillage system. BIV was classified as very high. Areas with 5, 10 and 15 years under no-tillage production process had very low BIV rates. On average, empirical models overrated infiltration rates at the beginning of the process when compared to field data. Rates by Horton´s model were very close to those obtained from basic infiltration velocity in field data.

## Conflict of Interest

The author(s) have not declared any conflict of interest.

## ACKNOWLEDGEMENTS

The authors would like to thank the Ministry of Science and Technology (MCT), The Brazilian Council for Scientific and Technical Development (CNPq), the Coordination for the Upgrading of Higher Education Personnel (CAPES), the Foundation for Research of the State of Goiás (FAPEG) and the Studies and Projects Funding Foundation (FINEP), for funding the research project and for the scholarship grant to the postgraduate student.

**Abbreviations: AC,** adjustment coefficient; **BIV,** Basic Infiltration Velocity (mm.h$^{-1}$); **CRM,** coefficient of residual mass; **EF,** efficiency; **MURUNDUINF,** natural conditions exist in the lower section of the earth mound; **MURUNDUSUP,** natural conditions on the higher section of the; earth mound; **SPD10,** Area occupied for 10 years by no-tillage system; **SPD15,** Area occupied for 15 years by no-tillage system; **SPD5,** Area occupied for 5 years by no-tillage system.

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