ISSN: 2228-6322© International Academic Journals

Differential expression in soybean leaf during water deficit in Brazil management system

Lucieta Guerreiro Martorano[1], Homero Bergamaschi[2], Carlos Tadeu dos Santos Dias[3], Genei Antônio Dalmago[4], Rogério Teixeira de Faria[5], Bruna M. Heckler[6]

[1]*Agrometeorology /Modelling, Embrapa Eastern Amazon. Enéas Pinheiro s/n Avenue, current postal, 48 CEP. 66095-100 - Belem, Para, Brazil. Author for corespondence (email: martorano.lucietta@gmail.com)*
[2] *Faculty of Agronomy, UFRGS and CNPq - Porto Alegre, RS, Brazil.*
[3] *Escola Superior de Agricultura "Luiz de Queiroz" - ESALQ/USP, SP, Brazil.*
[4] *Embrapa Trigo - Passo Fundo, RS, Brazil.*
[5] *Extension Service of the Federal District, EMATER, Brasília, DF, Brazil.*
[6] *Department of Rural Engineering, FCAV-UNESP and CNPq – Jaboticabal, SP, Brazil.*

Received November; accepted in revised form December 2013

ABSTRACT

It is considered that management system effects can express differences within soil water conditions and be reflected upon crop's responses. In order to assess these effects and responses, a field experiment was installed during 2003/2004 cropping period, in a Typical Dystrophic Red Argissoil (Brazilian Soil Classification System). The experimental design, adopted in a 0.5 hectare area was in strips, with four treatments and four repetitions for each one. No-tillage system (NT) was used in half of the experimental area, while the other half was tilled in conventional system (CT), both areas had irrigated (I) and non-irrigated (NI). The experiment used soybean crop (Fepagro RS10, a long cycle cultivar), grown at the Agronomic Experimental Station in Eldorado do Sul, Brazil. The row spacing was 0.40 m and the average population was around 300 thousand plants ha^{-1} in the establishment stage. Meteorological variables were monitored using an automatic station and the matric soil-water potential was monitored through daily registers with tensiometer sets. Crop growth and development were assessed weekly as well as yield components to the end of the crop cycle. The results showed that under water stress, the minimum water potential was lower (more negative) for short dry periods and the foliar stomatal conductance was higher in the non-irrigated no-tillage system, which was associated to the leaves maintenance, expressed as leaf area index (LAI), dry matter and yields showed statistically significant differences between treatments with and without irrigation. Those information may help decisions in water critical periods and providing improvements in social, economic and environmental in management of soybeans systems in Brazil.

Keywords: Brazil, management system soybean, water deficit

1. INTRODUCTION

Soybean [*Glycine max* (L.) Merrill] is a *commodity* influenced by international supply and demand, attracting interest of national and international market and is an important source of food, oil, and protein. Brazil has been the important producer of soybeans and the climate conditions represent to soybean farmers a high correlation of rainfall with grain yield. The soybean crop is predominantly rainfed in Rio Grande do Sul State and the water deficit is the major factor responsible for the yield of economic interest crops (Matzenauer et al., 2003; Bergamaschi et al., 2004). The water stress in crop plants can reduce productivity by 50% in various parts of the world. Under stress conditions, the plants present a series of changes in their morphology, physiology and biochemistry, negatively affecting their growth and productivity (Lisar et al., 2012).

In short dry periods, there was higher soil water availability under no-tillage compared to conventional system (Dalmago, 2004; Martorano et al., 2009). Increased soil water availability was attributed to higher water-holding capacity, resulted from larger micropores compared with conventional system (Santos, 2008). The soil structure was similar to those in forest areas, after the ninth year of implementation of no-tillage (Pereira Neto et al., 2007). Soil water deficit can cause physiological and biochemical effects on plants, such as increased resistance to diffusion of water vapor, caused by stomatal closure. In addition, it decreases leaf water potential, leaf area and the absorption of CO_2 compromising the efficiency of the photosynthetic apparatus (Taiz and Zeiger, 2004). This agrees with the results of Liberato et al. (2006), after thirty-five days, non-irrigated plants exhibited a leaf water potential 70 % lower compared to control plants (irrigated daily) and the stomatal conductance reached values close to zero, inducing a severe decrease in gas exchange (photosynthesis and transpiration). Lawlor and Cornice (2002) found in soybean that the real stress occurs when the relative water content is below 75%, which decreases leaf water potential and reduces ATP synthase and, consequently, the Rubisco enzyme (RuBP).

Studies by Liu et al. (2003) showed that decrease in stomatal conductance coincided with an increased concentration of xylem abscisic acid (ABA), which occurred before any significant change in leaf turgor was detected, indicating that chemical signals (due to ABA, originated at the root of plants) control the behavior of the stomata during periods of moderate water deficits. The hydraulic and chemical signals regulate leaf expansion in prolonged periods of low soil moisture. Liu et al. (2004) observed that, in periods of water deficit, linear increased in ABA caused linear decrease of water potential in soybean leaves. These authors observed that increased root ABA affected the stomatal conductance during periods of severe water deficit (14 days). Flexas and Medrano (2002) emphasized that limited assimilation of CO_2 by stomatal closure causes metabolic damage in C_3 plants such as soybean. In addition, they concluded that stomatal conductance is an indicator of plant responses to water stress. As consequence, a negative impact on grain yield is expected due to an impairment of whole plant metabolism (Desclaux et al., 2000).

Thus, the results expressed in terms of water potential and stomatal conductance in leaf, can be important to reinforce the significant evidence obtained in terms of forward and drying time in no-tillage system compared to conventional tillage (Martorano et al., 2009). Also, to expresses the relative difference between the observed data and estimations by CROPGRO-Soybean, as described by Martorano et al (2012) in this management system. In large crop system is possible to support decision making with adoption of practices instrumental monitoring in no-tillage system that has been expanding in Brazil (Casão Junior et al., 2012)

The objective of this study was to identify evidences of soybean water status, as expressed by means of leaf water potential and stomatal conductance responses, taken as indicators of differences in soil water conditions under no-tillage and conventional systems.

2. MATERIALS AND METHODS

An example of research on soil water status is presented based on a field experiment. To evaluate soil-plant-atmosphere processes associated with soil management on the express condition of water, an experiment was conducted in the cropping season of 2003/04 with soybeans (cv. Fepagro RS10, long cycle), at the Experimental Station of the Federal University of Rio Grande do Sul State (EEA/UFRGS), in Eldorado do Sul, Brazil (30^o 05'27"S; 51^o 40'18" W, altitude 46m). The experiment was sown on Nov. 20.2003 in a typical dystrophic red clay soil, with plots conducted under no-tillage (NT) and conventional tillage (CT), irrigated (I) and not irrigated (NI).

Soybean seeds were inoculated with *Bradyrhizobium japonicum* amid peat, derived from the *Rhizobium* germplasm bank of the State Agricultural Research Foundation (FEPAGRO, RS). The soil in the area is a Typical Red dystrophic Argisoil (Santos et al., 2006) with textural B horizon (Leguizamón Rojas, 1998). Before the installation of the experiment soil samples were collected and analyzed at the Embrapa Solos Laboratory, Rio de Janeiro, Brazil. The results showed 53% sand, 29% silt and 18% clay, in accordance to Latosoil Red soil textural class. Previous cropping in the experimental area were maize, in summer, and a mixture of *Avena strigosa* and *Vicia sativa*, in winter. On Oct. 22.2003, before soybean sowing, the green biomass on the basis of 4 to 6 t ha^{-1} of dry biomass was incorporated at a depth of 0.20 m in the plots under conventional system, using a disc plow farm machine.

Crop was sown 0.40 m between rows, with an average population of 300,000 plants ha^{-1}. An automatic meteorological station recorded weather variables and tensiometers (mercury-Hg column) measured daily soil water matric potential. Soybean leaf area index (LAI) and dry matter (DM) were determined weekly, beginning at eight days after the plant emergence. Plant samples were taken at random from a segment of 0.5 m planting row. Irrigation was applied when soil matric potential reached -60 kPa, as measured by tensiometers installed in irrigated no-tillage plots (NIT). The crop water use was monitored by a weighing lysimeter cultivated with soybean under conventional tillage. Each management system contained two batteries with tensiometers placed at depths (m) of 0.075, 0.15, 0.30, 0.45, 0.60, 0.75, 0.90 and 1.05 m and one with the same depths in addition to a tensiometer at 1.20m. Readings were made every day, around 9 p.m. (local time). Two harrowing were applied, with a disc harrow machine, one right after the plowing and the other just before soybean sowing. Tensiometers were installed at 30 and 45 cm depths in a weighing lysimeter to measure the soil water potential, and then indicating irrigation need to maintain soil moisture near field capacity.

With matric potential values, the corresponding soil moisture was calculated using the soil retention curves obtained experimentally by Dalmago (2004) for no-tillage and conventional tillage plots. The program of Dourado Neto et al. (2000) was used to calculate the volumetric water content (Soil Water Retention Curve-SWRC), using Equation 1, Van Genuchten (1980):

$$\theta v = \theta r + \frac{(\theta s - \theta r)}{\left[(1+\alpha \Psi m)^n\right]^m} \quad (1)$$

where the volumetric water content (cm^3 cm^{-3}) is represented by the θv and humidity and residual saturation θr and θs, respectively. The matric potential of soil water (kPa) is represented by Ψm and the letters α (kPa^{-1})

is related to the inverse of the air entry suction (α>0), n and m (m = 1 − 1/n) are empirical (dimensionless) parameters (Ghanbarian-Alavijeh et al, 2010).

Weeds, mainly to control *Brachiaria plantaginea*, were controlled by a systemic herbicide, plus adjuvant, diluted with water in post-emergence. Weed species such as grasses and dicotyledons were eliminated. The fertilization and cultural practices followed methodological guidelines set in the Reunion of the Soybean Research in the Southern Meeting (Reunião, 2003).

The experimental area was equipped with a conventional and automatic meteorological station (Campbell Scientific). Eldorado do Sul climate is classified as a subtropical (Cfa), according to Köeppen classification, with an annual average temperature of 19.2°C and rainfall of 1,446 mm, with water deficit from November to March (Bergamaschi et al., 2003).

The information about soybean phenology (cv. Fepagro RS-10), according to Fehr and Caviness (1977). The stomatal conductance (gf) was measured on adaxial and abaxial leaves by porometer ("Steady State"-LI-1600), according to von Caemmerer and Farquhar (1981). Chosen randomly, four replicates per treatment of the last fully expanded trefoil were taken immediately after cut to the pressure chamber measurements. Considering the parallelism of the leaf surfaces, the conductance was obtained according to the analogy of Ohm's Law, by the sum of stomatal conductance in parallel from both sides of each leaf examined. A Schollander chamber (*Soil Moisture, model 3000*) was used to measure the soybean leaf water potential during water deficit periods. The measurements of leaf water potential were made at around 13h (local time), on clear days, using a pressure chamber type Schollander. In each treatment, four separate samples of 100 seeds were collected randomly to determine the grain weight, also corrected to 13% humidity.

2.1. Statistical analysis

Possible causes o variation in the experiment were evaluated by applying analysis of variance, considering sources of variation three blocks with four plots, to control the variation between samples, inherent in the experimental block design, soil management system (conventional system and no-tillage), irrigation (with and without) and days after emergence (for growth analyses, too), together with interactions among soil management system, irrigation and days after emergence. Differences between means were compared by Tukey test at 5% level of significance. A regression analysis and correlation were also carried out, by applying an analysis of variance by F test to the data. It was made an exploratory analysis of data to verify the statistical model assumptions, which were verified outiliers, constant variance, influential observations, sample size and response scaling by Box-Cox (1964) transformation. The computer system was used SAS (2008).

3. RESULTS AND DISCUSSIONS

Soybean emergence occurred on Nov. 27.2003, corresponding to the seventh day after sowing, indicating favorable conditions for germination in terms of seed vigor and soil moisture. Evaluating the meteorological information during the soybean cycle (cv. Fepagro RS-10) showed that solar radiation ranged between 8.8 and 27.9 MJ $m^{-2}day^{-1}$ and the average of 20.7 MJ $m^{-2}day^{-1}$, corroborate with the climate average for the period in the region which is about 20 MJ $m^{-2}day^{-1}$ (Bergamaschi et al., 2003). There were two solar radiation peaks; one in January, the first ten-day period of (J1), the order of 27 MJ $m^{-2}day^{-1}$, and another in March, the second ten-day period (M2) close to 25 MJ $m^{-2}day^{-1}$. Regarding the total rainfall, 663.4 mm were computed during the soybean cycle, with two moments of rain shortage of supply. In the three first ten-day periods, the total amount of water in the 2003/04 agricultural year was above the climatology (Figure 1). In November, the third ten-day period, and in December the first ten-day period, rainfall amounted around 60 mm and the second ten-day period in December was close to 140 mm, exceeding the normal rainfall value (100 mm) observed in time series. In December the third ten-day period and in January the first ten-day period showed less rain supply, making it the first moment of water scarcity (Martorano et al., 2012).

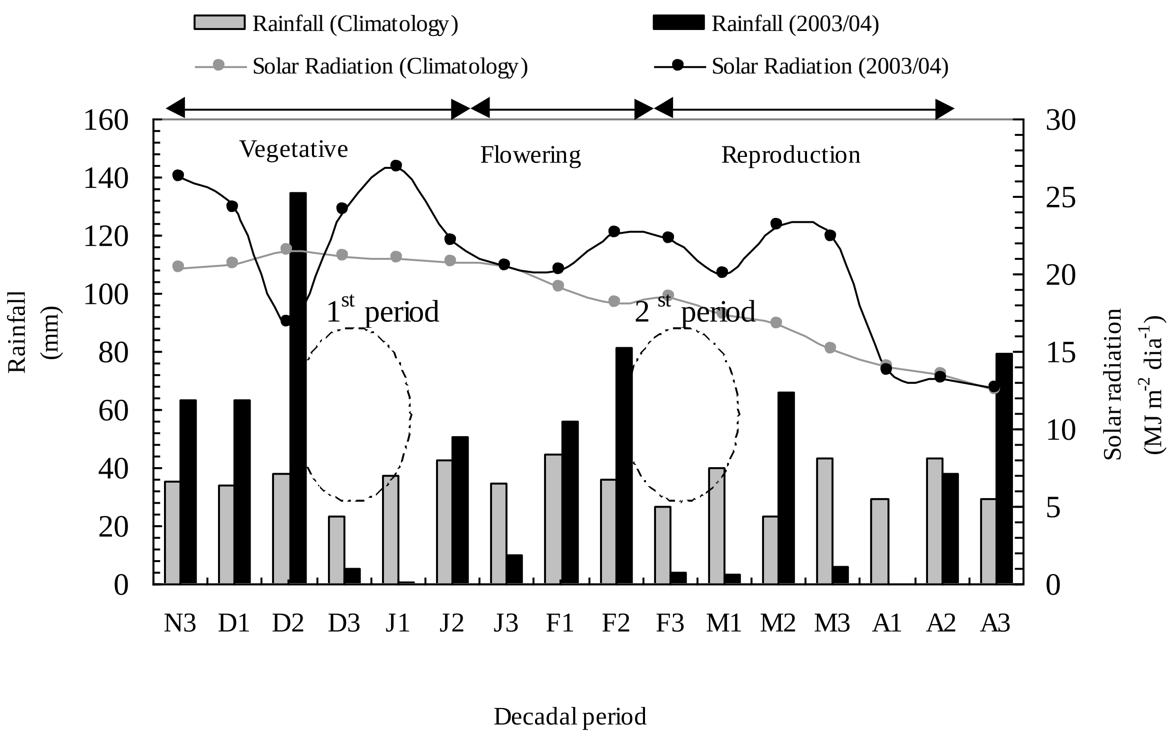

Fig. 1. Rainfall and solar radiation for ten-day periods during the soybeans cycle in 2003/04 crop year and Climatic conditions in Eldorado do Sul, RS, Brazil.

Soil moisture at the superficial layer (0.075 m) in the non-irrigated treatment under conventional tillage systems (CTNI) was 0.236 cm^3 cm^{-3} on Dec.23.2003, indicating the beginning of drying. That moisture level was only observed in the irrigated no-tillage treatment (NTI) on Dec.25.2003, when soil water content was 0.270 cm^3cm^{-3}. Those results indicate a faster soil drying under conventional system, as compared to no-tillage system. On Dec.25.2003, as the soil was 0.185 cm^3cm-^{3} in CTI, there was a disruption of the mercury tensiometers on Dec.26.2003, at the most superficial layer (0.075 m). This was only observed in no-tillage on Dec.29.2003, reinforcing the evidence of higher water storage in the upper layers in the no-tilled plots. In the subsequent depth of 0.15 m, the tensiometers mercury column crashed in plots under conventional system on Dec.28.2003, while in no-tillage it only occurred on Jan.3.2004, highlighting anticipation in the drying front of the soil under conventional system compared to no tilled plots. Diaz-Zorita et al. (2004) reported that the proportion of meso-pores occurring in the upper 10 cm of soil was 23% higher in continuous no-till operations compared to soils tilled every two years for winter wheat planting (0.189 cm^3cm^{-3} to 0.154 cm^3cm^{-3}). The authors conclude that greater water storage in no-till soils can be attributed to the larger percentages of meso-pores and macropore continuity.

The same drying pattern was found for measurements at 0.30 m depth, indicating a faster advance of the drying front in the conventional system. The second drying period started at the 3rd decendial in February and lasted until the 1st decendial in March. In the region, between January and March, water deficits can affect soybean yields because that period matches flowering and grain filling (R_1 to R_5), which is the most critical stages for water (Berlato, 1987; Berlato and Fontana, 1999).

3.1 Minimum leaf water potential ($\psi_{mín}$)

The following results refer to the responses of soybean to soil water deficit. Leaf water potential was more negative in the non-irrigated effects on Dec.2.2004 and 77 days after emergence (DAE), when the crop was in full and in blooming. However, there was no statistical difference between treatments, indicating that the irrigated treatments had also limited water availability. Martorano et al. (2009) affirms that the matrix potential ($\psi_{mín}$) was at the operating limit of the tensiometer. In conventional system on Nov.28.2004 (74 DAE), with values of -0.06 MPa, the roots were extracting water at 0.30 m depth. This fact only occurred under no-tillage on Dec.2.2004 (77 DAE), indicating that the soil moisture was kept for a period of three additional days with the no-tillage system (Figure 2).

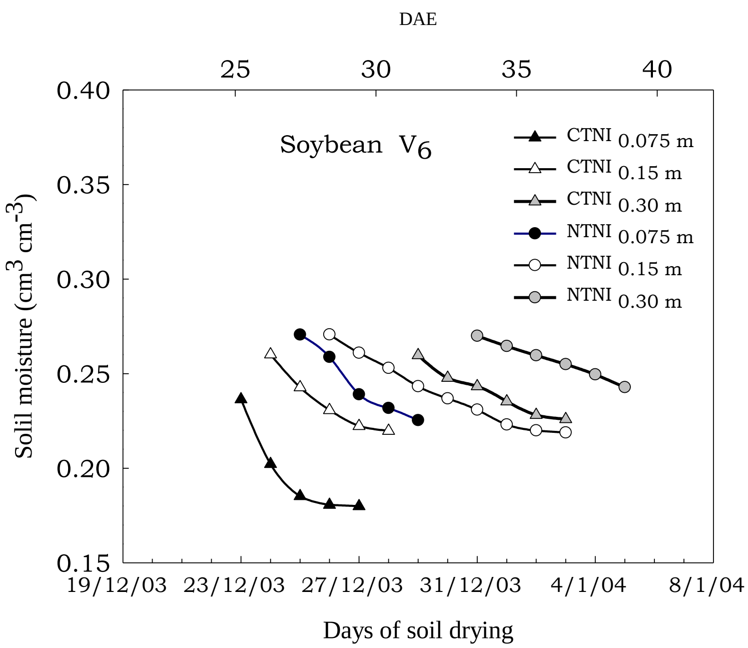

Fig. 2. Soil moisture in functions of days of soil drying and days after soybean plants emergence (DAE) under non-irrigated conventional tillage (CTNI) and no-tillage system (NTNI), in depths between 0.075 m and 0.30 m. in Eldorado do Sul, RS, Brazil, in 2003/04.

It was observed in Martorano et al. (2012) that on Dec.23.2003, the soil under conventional tillage systems without irrigation (CTI) contained 0.236 cm^3cm^{-3} of moisture in the superficial layer (0.075 m), indicating the beginning of drying, which was only observed in no-tillage irrigated (NTI) on Dec.25.2003, when soil water content was 0.270 cm^3cm^{-3}. These data indicated the anticipation of the soil drying under conventional system compared to no-tillage. On Dec.26.2003, the soil was 0.185 cm^3cm^{-3} in CTI and there was disruption of mercury columns of tensiometers on the most superficial layer (0.075 m), which was only observed in no-tillage on Dec.29.2003, reinforcing the evidence of higher water storage in the upper layers in no-tillage systems.

The crop responses in terms of minimum leaf water potential in fluid replacement treatments showed a considerable difference in values (-1.0 MPa and -1.1 MPa, respectively in the no-tillage and the conventional system), but with no statistical differences between tillage systems. In plots without water replacement values were already close to -1.5 MPa (Figure 3).

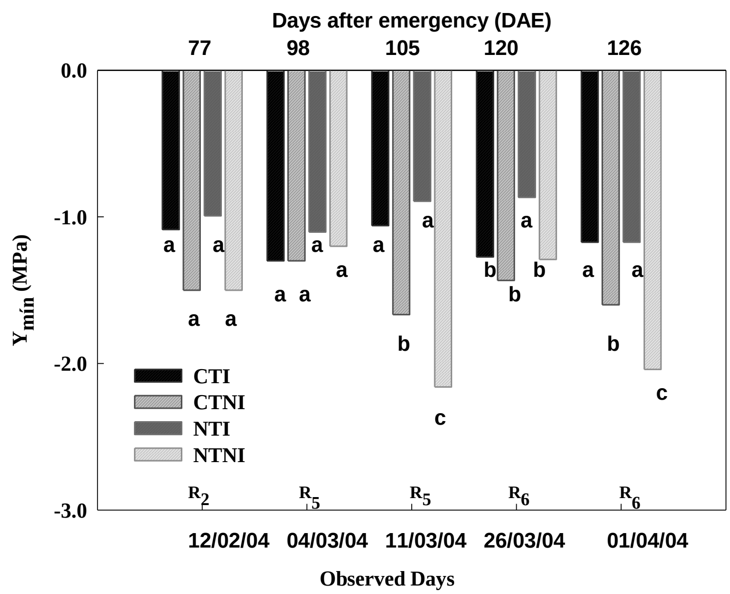

Fig.3. Minimum soybean (cv. Fepagro RS-10) leaf water potential under no-tillage (NT) and conventional (CT) systems, with (I) and without irrigation (NI), in Eldorado do Sul, RS, Brazil, in 2004. (Means with the same letter are not significantly different by Tukey test for 5% level of significance).

The analysis of variance showed statistical differences for soil management system and irrigation in three of the five monitored days. Even for the results with no significant differences, leaf water potential was more negative in no-tillage compared to conventional system. Leaf water potential in the irrigated treatments was statistically similar on Mar.3. 2004, but different for the non-irrigated treatments. Therefore, leaf water potential was -2.1 MPa in no-tillage and -1.7 MPa in conventional system. At that time the crop was in R_5, at the grain filling period, considered highly critical for water.

Although the difference was not significant in two of the monitored days, the values of $\psi_{mín}$ confirm the higher water availability in the no-tilled soil then in the conventional tillage system (Table 1). Since soil-plant-atmosphere system in an integrated way, despite the lower leaf water potential in non-irrigated no-tillage system at 105 DAE, it does not mean lower soil available water than the conventional tillage, or even that plants in no-tillage had lower water supply. Those results can be attributed to higher water retention of leaves in no-tillage, indicating higher rates of evapotranspiration than in conventional system, expressing the most negative $\psi_{mín}$. This statement will be supported by following results and discussion in this work. At 105 DAE, it was not possible to explain the water status of plants by the variation of soil water potential, because the tensiometers were out of their measurement limit, since the soil was dry in both the management systems. In the irrigated treatments, leaf water potential was always higher under no-tillage (-0.86 to -1.17 MPa), as compared to conventional tillage (-1.06 to -1.3 MPa). Since irrigation schedule was based on measurements of soil water potential in the no-tilled soil, it may have penalized the conventional tilled plots. Comparing leaf water potentials in the measuring period, measurements were low over time, reaching the lowest potential of -2.2 MPa for the no-tillage system without irrigation. This trend can be attributed to the prolonged drought that crop was subjected to ten-day period. Bianchi et al. (2005) also found higher values in the minimum leaf water potential of maize (*Zea mays* L.) in no-tillage, in the same experimental area, in an experiment conducted in the 2002/03 cropping season. In the same experimental area, Bergonci et al. (2000) found values between -1.2 and -1.5 MPa, which were identified as critical indicators of drought for the maize crop, as Bianchi et al. (2005) confirmed them later on.

Table 1. Minimum leaf water potential (MPa) in soybean (cv. Fepagro RS-10) under no-tillage (NT) and conventional (CT) systems, with (I) and without irrigation (NI), in Eldorado do Sul, RS, Brazil, in 2004. (Means with the same letter are not significantly different by Tukey test for 5% level of significance).

Days	Simple effect				Interaction (System x Irrigation)			
	Systems		Irrigation		Irrigation		Without irrigation	
	NT	CT	I	NI	NT	CT	NT	CT
12/2	-1,1a	-1,3a	-1,0a	-1,4b	-	-	-	-
04/3	-1,2a	-1,3a	-1,2a	-1,3a	-	-	-	-
11/3	-	-	-	-	-0,9a	-1,1b	-2,2b	-1,7a
26/3	-	-	-	-	-0,9a	-1,3b	-1,3a	-1,4a
01/4	-	-	-	-	-1,3a	-1,4a	-2,1b	-1,8a
Average	-1,2	-1,3	-1,1	-1,4	-1,0	-1,3	-1,9	-1,6

In soybean leaves, the Confalone and Dujmovich (1999a) and Confalone and Navarro (1999b) studies found values of leaf water potential of -1.85 MPa and order of -1.77 MPa, showing that the values in water deficit treatments are below -1.50 MPa, indicative of water stress. This may help the decision-making in areas where the economic and environmental conditions guarantee water replacement in critical periods such as the developmental stage of grain filling of the crop.

3.2. Stomatal conductance (g_f)

Following the evaluation of plant responses expressed in terms of stomatal conductance, it was observed a significant effect of irrigation. On Feb.12.2004 (77DAE), gf values in the irrigated treatments were 785 mmol $m^{-2}s^{-1}$ for no-tillage and 677 mmol $m^{-2}s^{-1}$ for conventional system, with no statistical difference. In the non-irrigated treatments gf was 221 mmol $m^{-2}s^{-1}$ in no-tillage and 148 mmol $m^{-2}s^{-1}$ in conventional system, with also no statistical differences. However, the difference (73 mmol $m^{-2}s^{-1}$) between measurements indicates slower stomatal closure for the no-tillage system, compared to the conventional one. Comparing treatments with and without irrigation, it was noted that plants without water stress had significantly different conductance compared to plants that rely on atmospheric supply rainwater. It is known that when the stomata open, to allow assimilation of carbon dioxide and close to conserve water, reducing the dehydration of the plant, it indicates that flow regulation in leaf transpiration through the stomatal conductance enhances the expression of leaf water potential in water shortage in the soil.

For soybean, Olioso et al. (1996) found that the soil drying promoted increases in transpiration rate, causing reductions in leaf water potential, stomatal conductance and photosynthesis. Flexas and Medrano (2002) observed that content of ribulose bisphosphate (RuBP) and adenosine triphosphate (ATP) decreased at the beginning of the period of soil drying and when the stomatal conductance reached values close to 150 mmol H_20 $m^{-2}s^{-1}$, causing damage in RuBP regeneration and ATP synthesis. The reductions in photochemical activity and Rubisco were observed when the conductance fell below 100 mmol H_20 $m^{-2}s^{-1}$, and a permanent photoinhibition occurred when the conductance values were below 50 mmol H_20 $m^{-2}s^{-1}$. Therefore, in plots without irrigation the stomatal conductance in soybean, presented in this work, may indirectly indicate effects of abscisic acid (ABA), more evident in plants with the conventional system. As the second period of soil water deficit occurred, when the crop started grain filling period (R5), the average conductance in no-tillage treatment was 42 mmol $m^{-2}s^{-1}$ and in conventional tillage it was 176 mmol $m^{-2}s^{-1}$. Although those values were significantly different, it is possible that the photosynthetic apparatus of non-irrigated plants had already compromised its efficiency. Comparing the irrigated treatments, gf was 660 mmol $m^{-2}s^{-1}$ in no-tillage and 497 mmol $m^{-2}s^{-1}$ in conventional tillage, which are statistically different, indicating higher rates of evapotranspiration for the first management system (Figure 4).

The lower conductance and lower leaf water potential, associated with several factors such as water deficits, high temperatures and high levels of solar radiation can be explained by the lower leaf drop in no-tillage due to higher soil water storage, when compared to conventional system. Following the period of drying soil at 120 DAE, the conductance in treatments without replacement were statistically similar, with values around to 200 mmol $m^{-2}s^{-1}$, reinforcing the effects of crop water deficit. In the irrigated treatments, the highest conductance measured at 126 DAE was observed in the conventional system (417 mmol $m^{-2}s^{-1}$) which was statistically different of no-tillage (269 mmol $m^{-2}s^{-1}$). On the other hand, the non-irrigated treatments, depending on the rainwater supply, had stomatal conductance of 98 mmol $m^{-2}s^{-1}$ and 80 mmol $m^{-2}s^{-1}$ for no-tillage and conventional, respectively, with no statistical difference. Those results support the evidence of higher maintenance of leaves in no-tillage system, that is confirmed by the higher leaf area index, height, higher dry matter production (Martorano, 2007) and prolongation of the drying of the no-tillage system in comparison to conventional system (Martorano et al., 2009). Those findings show that soybean responds to water deficit by stomatal closure, which can be used as an indicator of water condition in soil. The effects of water stress were presented by Martorano et al. (2004), who detected higher levels of chlorophyll (*a* and *b*) in no-tillage compared to conventional system, being an indicator of soybean response to higher water availability to tillage system, expressing higher inputs of nitrogen in the plant canopy. Also higher soil water storage in no-tillage compared to conventional system was found by Dalmago et al. (2003) and lower soil temperature variations was associated to no-tillage, as compared to conventional system by Martorano et al. (2009). Periods of water deficit in soil reduced leaf area index, plant height, shoot dry matter, specific leaf area, rate of plant growth and grain yield of soybean (Martorano, 2007). The evidence of soybean response to water conditions was also presented by Almeida et al. (2005), with data obtained in the same field experiment. The irrigated plants in no-tillage system showed lower reflectance in the visible region when compared to plots without water replacement. The reflectance in the visible region was less than 8%, regardless of water conditions, corroborating the literature data, which indicate high absorption of solar radiation by pigments in the mesophyll, reflecting less than 10% of incident radiation. In the near infrared region, mainly in the range between 800 to 1000 nm, reflectance was higher than 55% in irrigated plots and 45% in the plots under water deficit, thereby enhancing remote data in the soybean responses to the water conditions, and reducing logistics and operational costs for field research (Almeida et al., 2004).

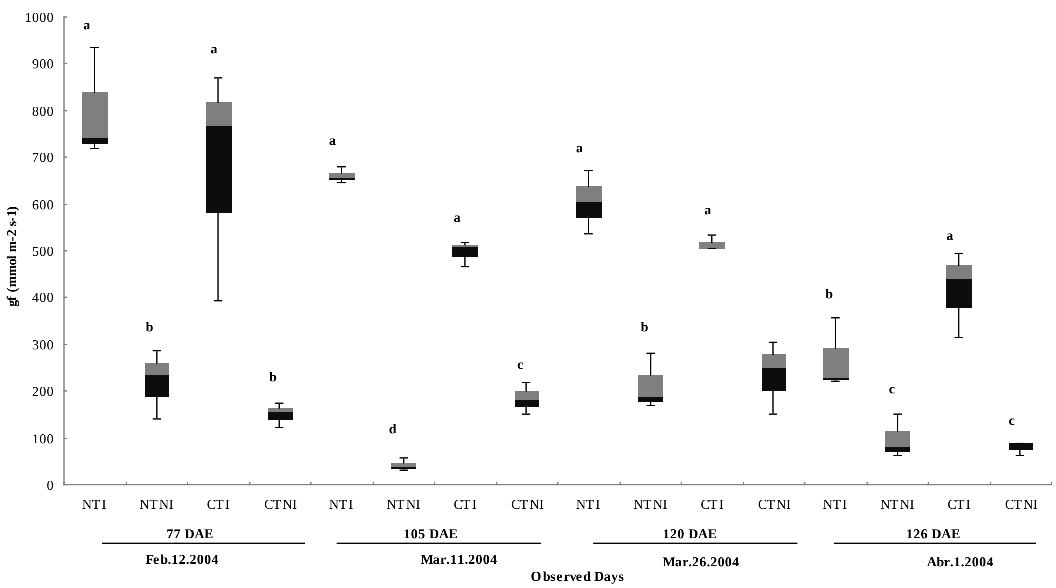

Fig.4. Soybean (cv. Fepagro RS10) leaf stomatal conductance for no-tillage with and without irrigation (NTI and NTNI) and conventional tillage with and without irrigation (CTI and CTNI), in Eldorado do Sul, RS, Brazil, in 2004 (Means with the same letter are not significantly different by Tukey test for 5% level of significance).

Water deficit associated with periods of prolonged drought during the rainy season are a major cause of failed crops of grain in Brazil. Martorano et al. (2009) shown that the soil water potential in conventional system was more negative than in no-tillage system. In a depth from 0.45 to 0.9 m in no-tilled plots and from 0.3 to 1.05 m in conventional system the soil remained drier than in the rest of the profile, probably due to a higher concentration of roots in this layer, if compared to the surface layer, resulting from the tap root system of soybeans. At a depth of 0.30 m the no-tillage system showed a higher potential (-0.03 MPa) than the conventional system, which had values around -0.05 MPa, in other words, at more negative potentials soil. Those indicators showed higher soil water storage in no-tillage treatment, which can be attributed to the higher soil water storage capacity due to the increment of biopores (Costa et al., 2003) and mesopores (Dalmago, 2004). The severity of water stress has often been assessed by its effect on relative water content (RWC), leaf water potential ($\psi_{mín}$) and gs, but Flexas et al. (2004) demonstrated that gs would be a more sensitive indicator of the severity of water stress in leaves, at least for comparative purposes in studies of photosynthesis. In the plant's overall biochemistry, under water-stress situations, this is very important.

The photosynthesis decreased by about 70%, while the respiration rate was not significantly affected under severe water deficit (Ribas Carbo et al., 2005), and the response of ATP synthesis to severe water stress agrees with a similar response of the ATP concentration in leaves, as it was presented by Flexas et al. (2004), using data compiled from the literature and suggests an additional interpretation: Reduced leaf ATP concentrations in leaves under severe water deficit may, at least partially, reflect changes in the partitioning of electrons between the cytochrome and the alternative pathways in the mitochondria. The levels of water stress were characterized by a light-saturated stomatal conductance (gf): well irrigated (gf > 0.2 mol H_2O $m^{-2}s^{-1}$), mildly water stressed (gf between 0.1 and 0.2 mol H_2O $m^{-2}s^{-1}$), and severely water stressed (gf < 0.1 mol H_2O $m^{-2}s^{-1}$). Short water deficiency significantly decreased leaf relative water content and total soluble proteins (Lobato et al., 2009). This differential behavior could lead to an imbalance between hydical supply and transpiration demand under extreme environmental conditions likely to become more common as global climate change. During drought conditions, soybean crops suffer significant losses in productivity. Understanding the responses of the soybean under this stress is an effective way of targeting crop improvement techniques.

Crop yield is affected by water deficit stress, particularly when it occurs during flowering and early pod expansion (Pedersen et al., 2005). Thus, in our experiment, the data showed the soybean yields statistically significant differences between treatments with and without irrigation. In irrigated conventional tillage was 3,597 kg ha^{-1} and no-tillage irrigated was 3,816 kg ha^{-1}. In non-irrigated conventional tillage was 1,559 kg ha^{-1} and no-tillage non-irrigated was 1,894 kg ha^{-1} (Figure 5).

4. CONCLUSIONS

This study demonstrated different water responses in soybean, promoters advantages of no-tillage system over conventional tillage. The allowing crop residues to act conserving soil moisture, reducing soil temperature fluctuation and improve the soil organic matter. Leaf water potential and stomatal conductance can be used as indicators of higher water storage found in non-irrigated no-tilled as compared to the conventional tillage system, also expressed in leaf areas index, dry matter, soil water potential and soybean grain production. This information may help decisions in water critical periods and providing improvements in social, economic and environmental in management of soybeans systems in Brazil. Further research is needed to determine the influence of tillage-induced changes on water responses in new centers of production, for example, in areas where grain crops are being used to recover degraded pastures in integrated farming systems in the Amazon.

ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to Embrapa, the Federal University of Rio Grande do Sul, FEPAGRO,

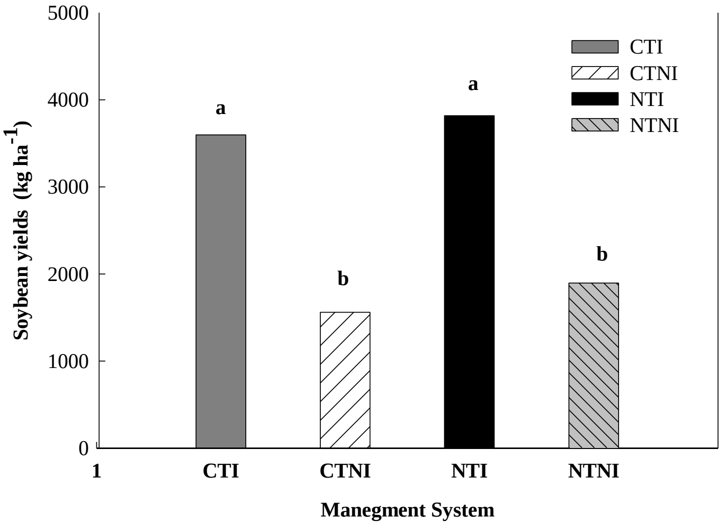

Fig.5. Soybean (cv. Fepagro RS10) yield for no-tillage with and without irrigation (NTI and NTNI) and conventional tillage with and without irrigation (CTI and CTNI), in Eldorado do Sul, RS, Brazil, in 2003/04 (Means with the same letter are not significantly different by Tukey test for 5% level of significance).

Embrapa Solos and the National Council for Scientific and Technological Development (CNPq) for supporting scientific, financial and technological developments in this research and all the agrometeorology team from UFRGS for their help in field collections.

REFERENCES

Almeida TS, Fontana DS, Martorano LG, Bergamaschi H (2004) Influência do sistema de manejo na reflectância da cultura da soja. In: XI Simposio Percepción Remota y Sistemas de Información Espacial, Santiago. XI Simposio Percepción Remota y Sistemas de Información Espacial. Santiago, Chile.

Almeida TS, Fontana DC, Martorano LG, Bergamaschi H (2005) Índices de vegetação para a cultura da soja em diferentes condições hídricas e de sistema de manejo do solo. In: XII Simpósio Brasileiro de Sensoriamento Remoto, Goiânia. XII Simpósio Brasileiro de Sensoriamento Remoto. Goiânia, Goiás.

Bergamaschi H, Guadagnin MR, Cardoso LS, Silva MIG (2003) da. Clima da Estação Experimental da UFRGS (e Região de Abrangência). Porto Alegre: UFRGS, 78p.

Bergamaschi H, Dalmago GA, Bergonci JI, Bianchi CAM, Müller AG, Comiran F, Heckler BMM (2004) Distribuição hídrica no período crítico do milho e produção de grãos. Pesquisa Agropecuária Brasileira, 39:831-9.

Bergonci JI, Bergamaschi H, Berlato MA, Santos AO (2000) Potencial da água na folha como um indicador de déficit hídrico em milho. Pesq. Agropec. Bras.35:1531-40.

Berlato MA (1987) Modelo de relação entre o rendimento de grãos de soja e o déficit hídrico para o Estado do Rio Grande do Sul. São José dos Campos: INPE. 93p. Tese Doutorado.

Berlato MA, Fontana DC, Gonçalves HM (1992) Relação entre o rendimento de grãos de soja e variáveis meteorológicas. 1992. Pesquisa Agropecuária Brasileira, Brasília. 27: 695-702.

Berlato MA, Fontana DC (1999) Variabilidade interanual da precipitação pluvial e rendimento da soja no Estado do

Rio Grande do Sul. Revista Brasileira de Agrometeorologia.7:119-25.
Bianchi CAM, Bergonci JI, Bergamaschi H, Dalmago GA (2005) Ajuste osmótico em milho cultivado em diferentes sistemas de manejo de solo e disponibilidade hídrica, Pesquisa Agropecuária Agropecuária Brasileira. 40:645-51.
Box George EP, Cox DR (1964) An analysis of transformation. Journal of the Royal Statistical Society, Series B 26(2):211-252.
Casão Junior R, Araújo AG, Llanillo RF (2012) No-till agriculture in southern brazil: factors that facilitated the evolution on of the system and the development of the mechanization on of conservative on farming. ISBN 978-92-5-107102-1. FAO and IAPAR, 2012. 83p.
Costa FS, Albuquerque JÁ, Bayer C, Fontoura SMV, Wobeto C (2003) Propriedades físicas de um Latossolo Bruno afetadas pelos sistemas plantio direto e preparo convencional. Revista Brasileira de Ciência do Solo. 27: 527-35.
Confalone AE, Dujmovich MN (1999a) Influência do déficit hídrico sobre o desenvolvimento e rendimento da soja. Revista Brasileira de Agrometeorologia, Santa Maria 6:165-9
Confalone AE, Navarro MD (1999b) Influencia do Déficit hídrico sobre a eficiência da radiação solar em soja. 1999. Revista Brasileira de Agrociência, Pelotas, 5: 195-8
von Caemmerer S, Farquhar GD (1981) Some relationships between the biochemistry of photosynthesis and the gas exchange of leaves. Planta 153: 376–387.
Diaz-Zorita M, Grove JH, Murdock L, Herbeck J, Perfect E (2004) Soil structural disturbance effects on crop yields and soil properties in a no-till production system. Agron J 96:1651–1659.
Dalmago GA, Bergamaschi H, Bianchi CAM (2003) Diferenças na disponibilidade de água no solo entre os sistemas de semeadura direta e convencional de milho. In: XIII Congresso Brasileiro Agrometeorologia. Anais Santa Maria, Soc. Bras. Agromet/UFSM/UNIFRA 1: 293-4
Dalmago GA, Dinâmica da água no solo em cultivos de milho sob plantio direto e preparo convencional (2004) 244 p. Tese (Doutorado) – Programa de Pós-Graduação em Fitotecnia, Faculdade de Agronomia, Universidade Federal do Rio Grande do Sul, Porto Alegre.
Desclaux D, Huynh T, Roumet P (2000) Identification of soybean plant characteristics that indicate the timing of drought stress. Crop Science, Madison, 40:722- 2000
Dourado Neto D, Nielsen DR, Hopmans JW, Reichardt K, Bacchi OOS (2000) Software to model soil water retention curves (SWRC, version 2.00). Scientia Agricola, Piracicaba. 57:191-2.
Farias JRB, Assad ED, Almeida IR, Evangelista BA, Lazzarotto C, Neumaier N, Nepomuceno AL (2001) Caracterização de risco de déficit hídrico nas regiões produtoras de soja no Brasil. Revista Brasileira de Agrometeorologia, Santa Maria. 9: 415-21.
Farias JRB (2005) Disponibilidade hídrica em solos arenosos: Estabelecimento de Déficit Hídrico em Culturas Dinâmica da água em regiões arenosas. In: Reunião de Pesquisa da Região Central do Brasil, 27, 2005. Cornélio Procópio, PR. ATA. Londrina: Embrapa Soja (Documentos / Embrapa Soja no. 265).
Fehr WR, Caviness CE (1977) Stages of soybean development. Ames, Lowa State University of Science and Technology, 11p.
Flexas J, Medrano H (2002) Energy dissipation in C3 plants under drought. Funct Plant Biol 29: 1209–15.
Flexas J, Bota J, Loreto F, Cornic G, Sharkey TD (2004) Diffusive and metabolic

limitations to photosynthesis under drought and salinity in C_3 plants. Plant Biol 6: 269–79.

Ghanbarian-Alavijeh B, LIAGHAT A, Guan-Hua H, VAN GENUCHTEN MTh (2010) Estimation of the van Genuchten Soil Water Retention Properties from Soil Textural Data. Pedosphere 20(4): 456–465, (ISSN 1002-0160/CN 32-1315) Soil Science Society of China.

Lawlor DW, Cornice G (2002) Photosynthetic carbon assimilation and associated metabolism in relation to water deficits in higher plants. Plant Cell Environ. 25(2):275-94.

Leguizamón Rojas CA (1998) Alterações físico-hídricas de um podzólico em função do manejo do solo. Porto Alegre, UFRGS, Dissertação (Mestrado em Ciência do Solo). Programa de pós-graduação em Agronomia. Universidade Federal do Rio Grande do Sul (UFRGS).

Liberato MAR, Goncalves JFC, Chevrenil LR, Nina JAR, Fernandez AV, Santos JUMD (2006) Leaf water potential, gas exchange and chlorophyll a fluorescence in acariquara seedlings (Minquartia guianensis Aubl.) under water stress and recovery. – Braz J Plant Physiol 18: 315-323

Lisar SYS, Motafakkerazad R, Hossain M M , Rahman IMM (2012) Water Stress in Plants: Causes, Effects and Responses. In:Rahman, I. M. M. & Hasegawa, H. Water Stress, InTech, Croatia, 01-14.

Liu F, Jensen CR, Andersen MN (2003) Hydraulic and chemical signals in the control of leaf expansion and stomatal conductance in soybean exposed to drought stress. Functional Plant Biology. 30: 65–73.

Liu F, Jensen CR, Andersen MN (2004) Pod Set Related to Photosynthetic Rate and Endogenous ABA in Soybeans Subjected to Different Water Regimes and Exogenous ABA and BA at Early Reproductive Stages. Annals of Botany. 94: 405-11

Lobato AKS, Neto MAM, Meirelles ACS, Silva LI, Marochio CA, Monteiro ER, Zeni Neto H, Maleia MP, Moiana LD, Bronzato AR, Cruz FJR (2009) Relationship Between Leaf Relative Water Content and Total Soluble Proteins in Soybean Exposed to Short Water Deficit. Research Journal of Biological Sciences: 4:1061-7

Martorano LG, Faria RT, Bergamaschi H, Dalmago GA (2008) Evaluation of the CROPGROW/DSSAT model performance for simulating plant growth and grain yield of soybeans subjected and no-tillage and conventional systems in the Subtropiccal Southern Brazil. Italian Journal of Agronomy 3:795-796

Martorano LG (2007) Padrões de resposta da soja a condições hídricas do sistema solo-planta-atmosfera, observados no campo e simulados no sistema de suporte à decisão DSSAT. Porto Alegre: UFRGS, 151p. (Tese Doutorado).

Martorano LG, Bergamaschi H, Dalmago GA, Faria RT, de Mielniczuk J, Comiran F (2009) Indicadores da condição hídrica do solo com soja em plantio direto e preparo convencional. Revista Brasileira de Engenharia Ambiental 13: 397-405.

Martorano LG, Bergamaschi H, Faria RT, de Dalmago GA (2012) Decision Strategies for Soil Water Estimations in Soybean Crops Subjected to No-Tillage and Conventional Systems, in Brazil. In: Manish Kumar (Org.). Problems, Perspectives and Challenges of Agricultural Water Management. Croácia: InTech 439-456.

Matzenauer R, Barni NA, Maluf JRT (2003) Estimativa do consumo relativo de água para a cultura da soja no Estado do Rio Grande do Sul. Ciência Rural 33:1013-19.

Olioso A, Carlson TN, Brisson N (1996) Simulation of diurnal transpiration and

photosynthesis of a water stressed soybean crop, Agricult For Meteorol 81:41–59.
Pedersen P, Lauer JG (2004) Cropping Systems: Soybean Growth and Development Response to Rotation Sequence and Tillage System. Agronomy Journal 9: 32-38
Pedersen P, Kumudini S, Board J, Conley S (2005) Soybean growth and development. In: Dorrance AE, Draper MA, Hershman DE, editors. Using Foliar Fungicides to Manage Soybean Rust. Ohio State University; Columbus: 2005, 41–47.
Pereira Neto OC, Guimarães MdeF, Ralisch R, Fonseca ICB (2007) Análise do tempo de consolidação do sistema de plantio direto. Revista Brasileira de Engenharia Agrícola e Ambiental. 11:489–96.
Reunião de Pesquisa, de Soja da Região Sul, Porto Alegre (2003) Indicações técnicas para culturas da soja no Rio Grande do Sul e em Santa Catarina. Porto Alegre: UFRGS, 2003. 137 p.
Ribas Carbo M, Taylor NL, Giles L, Busquets S, Finnegan PM, Day DA, Lambers H, Medrano H, Berry JA, Flexas J (2005) Effects of Water Stress on Respiration in Soybean Leaves. Plant Physiol 139(1): 466–73.
SAS - Statistical Analysis System (2008) v.9.2 Copyright © 2008 by SAS Institute Inc., Cary, NC, USA.
Santos HG dos, Jacomine PKT, Anjos LHC dos, Oliveira VA de, Oliveira JB de, Coelho MR, Lumbreras JF, Cunha TJF (ed.) (2006) Sistema brasileiro de classificação de solos. 2.ed. Rio de Janeiro: Embrapa Solos. 306p.
Santos R (2008) dos Propriedades de retenção e condução de água em solos, sob condições de campo e em forma de agregados, submetidos aos plantios convencional e direto. Dissertação (Mestrado em ciência do solo). Universidade Estadual de Ponta Grossa, PR–2008.
Taiz L, Zeiger E, Fisiologia vegetal (2004) Porto Alegre: ARTMED, 449-84.
Van Genuchten MTh (1980) A closed-from equation for predicting the conductivity of unsaturated soils. Soil Science Society of American Journal, Madison, 44:892-898.
Von Caemmerer S, Farquhar GD (1981) Some relationships between the biochemistry of photosynthesis and the gas exchange of leaves. Planta 153: 376-387