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EFFECT OF DIFFERENT IRRIGATION DEPTH ADJUSTMENT METHODS ON MAIZE YIELD COMPONENTS, GRAIN YIELD AND WATER USE EFFICIENCY

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1 ABSTRACT

Since water stress is one of the main causes for low maize yield in Brazil, this study aimed to evaluate yield components, grain yield and water use efficiency of maize crop submitted to different methods of irrigation depth adjustment and validate the depth spreadsheet to recommend irrigation depth in this crop. The treatments applied were: non-use of irrigation (control); irrigation depth adjustment provided by the depth spreadsheet (depth); soil moisture equivalent to actual capacity of water in the soil at 55% of the total soil water capacity (55% RWC); and soil moisture equivalent to 100% of the field capacity (100% FC). The experimental design was a randomized block with four replications, each experimental unit consists of a 3 meters wide and 3 meters long plot. The variables analyzed were total water applied, dry matter, ears per plant, kernel rows per ear, kernels per row, kernels per ear, one thousand kernels weight, grain yield and water use efficiency. Grain yields were similar across irrigated treatments, showing significant differences when compared to control. Depth and 55% RWC showed the best results for water use efficiency and yield components. Depth treatment used the least amount of water, with high yields, contributing to rational water use in irrigated agricultural systems.

Keywords: soil moisture, water deficit, *Zea mays* L.

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2 RESUMO

Sendo a deficiência hídrica uma das principais causas para a baixa produtividade da cultura do milho no Brasil, o presente trabalho objetivou avaliar os componentes do rendimento, a produtividade e a eficiência do uso da água na cultura do milho submetido a diferentes formas de ajuste da lâmina de irrigação e validar a planilha “Lâmina” para recomendação de irrigação na cultura. Os tratamentos aplicados foram: não utilização de irrigação (controle); ajuste da lâmina de irrigação conforme valor fornecido pela planilha “Lâmina” (Lâmina); umidade do solo equivalente a capacidade real de água no solo em 55% da capacidade total de água do solo (55% CRA); e umidade do solo equivalente em 100% da umidade da capacidade de campo (100% CC). O delineamento experimental utilizado foi de blocos inteiramente casualizados com quatro repetições, sendo cada unidade experimental constituída de uma parcela com 3 m de largura e 3 m de comprimento. Analisou-se as variáveis água consumida, matéria seca, espigas por planta, fileiras por espigas, grãos por fileira, grãos por espiga, peso de mil grãos, produtividade e relação litros de água por quilograma de grãos produzidos. As produtividades foram similares entre os tratamentos irrigados, apresentando diferenças significativas para o tratamento controle. Para a eficiência do uso da água e os componentes do rendimento, os tratamentos Lâmina e 55% CRA apresentaram os melhores resultados. O tratamento Lâmina utilizou a menor quantidade de água aplicada, apresentando alta produtividade, contribuindo para o uso racional da água em sistemas agrícolas irrigados.

Palavras-chave: deficiência hídrica, umidade do solo, *Zea mays* L.

3 INTRODUCTION

Maize (*Zea mays* L.) is currently the most produced and consumed cereal in the world, being an important commodity for many agricultural sectors. Between the main maize uses are human food, animal feed and biofuels production. About 65% of maize global production is concentrated in three countries, United States, China and Brazil, being the North American country the largest world producer (USDA, 2015).

In Brazil, the maize crop has great importance in the agricultural supply chain, either in small or large farms as for the country economy. Although of crop importance, the average grain yield is of 4,934 kg.ha^{-1}, very low when compared to the major producer’s countries (CONAB, 2016). Between the main reasons to the low crop yield is the water deficit, which results in a negative impact on most of the plant physiological processes.

Low water availability in soil cause significantly changes in the amount of water inside the plant, reducing the osmotic potential and plants relative water content, resulting in low photosynthetic rate and low crop yield. In addition, in the tasseling stage, water deficit can cause irreparable impact on grain yield (ATTEYA, 2003).

The grain yield reduction is greater when the water deficit occurs during the R3 reproductive stage compared to V8 vegetative stage (MANSOURI-FAR; SANAVY; SABERALI, 2010). The critical period for irrigation in order to minimize water stress occurs during 12-14 weeks after seedling emergence, which coincides with the R3 (milky grain) and R4 (grain doughy) stages (PAYERO et al., 2009). Maize grain yield can be affect by the water conditions during the critical period, which goes from tasseling stage to early grain filling stage, and irrigation during this period allow high grain yield (BERGAMASCHI et al., 2004).

In this way, the use of an irrigation system can meet the crop water needs and avoid yield losses. However, in Brazil, irrigation systems are used in a low scale, where the maize irrigated area is about 3.5% of all national maize area planted (IBGE, 2006). In addition, in many cases the irrigation is done without any concern about water rational use, resulting in huge water waste and increasing operational costs. Currently, it is estimated that the water waste in irrigation systems is around 40% (ANA, 2013).

Given the issues above, the present study aimed to evaluate the yield components, water use efficiency and grain yield of maize by applying different methods to adjust the irrigation depth and to validate the "Lâmina" spreadsheet to recommend irrigation depth to this crop.

4 MATERIAL AND METHODS

The study was conducted in the Erechim - RS city, during the 2015/16 agricultural season. The soil in the study area is classified as Latossolo Vermelho Alumino Férrico Húmico (EMBRAPA, 2006). The local climate is classified as Cfa, where the temperature in hottest month is above 22 °C and below 18 °C in the cooler month. The rainfall presents to be well distributed throughout the year (KÖPPEN, 1931).

To reach the goals, it was used a randomized block experimental design with four replications. Each experimental unit was constituted of a plot 3 m wide and 3 m long (9 m²). The soil acidity correction was carried out using limestone filler, applied in soil surface. The limestone dose was determined by raising bases saturation to 70%, so, it was used 5,500 kg·ha^{-1} of limestone (100% RPTN).

The crop was sown in a no-till system on November 3rd, 2015, using the simple hybrid MG 300 PW (Morgan seeds). The planter was regulated to obtain a population of 8 plants·m^{-2} (80,000 plants·ha^{-1}) with 0.5 m between rows and 2 cm depth. The seed was previously treated with insecticide (tiametoxan) and fungicide (captan), in the doses of 250 ml and 200 g of product by 100 k of seeds, respectively. The fertilizer dose used was 500 kg·ha^{-1} of NPK (5-20-20), plus 200 kg·ha^{-1} of simple superphosphate (16% P_2O_5) at sowing and 140 kg·ha^{-1} of urea (45% N), divided into two applications, one in V4 and another in V8 vegetative stage. All the fertilizer doses were calculated according to SBCS (2004), based in the nutrients available in the soil, determined by soil chemical analysis.

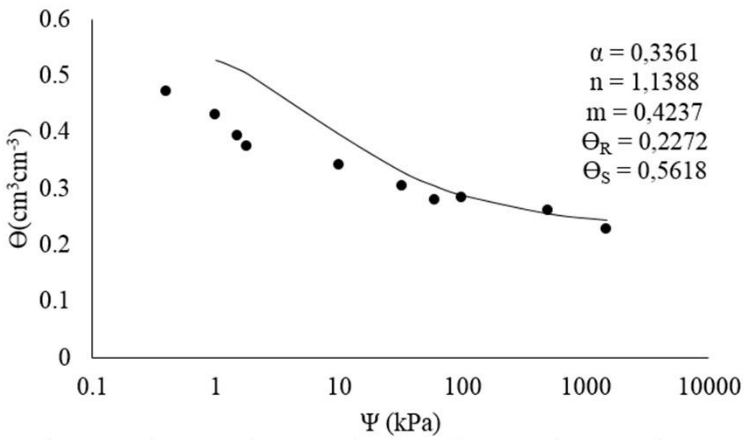
The weed plants were controlled applying a post-emergent herbicide, (glyphosate) with 3 L·ha^{-1} dose in pre-planting. After crop emergence, it was used atrazine (6 L·ha^{-1}) and glyphosate (3 L·ha^{-1}) herbicides when the first weeds emerged. Pests and diseases were controlled using fungicides and insecticides registered for the crop, always when the economic thresholds were reached, so the crop was constantly monitored.

The irrigation was realized manually, using a digital hygrometer to measure the water amount applied in the crop rows, with a 2-days interval. To evaluate the irrigation effect to the crop, it was applied four treatments: non-irrigation (control), irrigation depth determined by the "Lâmina" spreadsheet (Lâmina); soil moisture maintenance to actual capacity of water in the soil at 55% of the total capacity of the ground water (55% RWC); and maintenance of the soil moisture at 100% of field capacity (100% FC).

In order to determine the soil hydraulic properties, it was constructed the soil retention curve, using the Richards chambers methodology (RICHARDS; FIREMAN, 1943; EMBRAPA, 1997). To do so, it was collected four undisturbed soil sample with cylindrical rings of known volume, in 0 - 10 cm depth, using a manual auger type “Uhland”. To construct the retention curve, it was applied the following pressures: 0.4; 1.0; 1.5; 1.8; 10; 33; 60; 100; 500; and 1,500 kPa.

In the end of all pressures applied, the samples were dried in an oven with forced air circulation, at 105±2°C for 72 hours. Thus, the samples volumetric moisture was calculated to each pressure. Then, the water retention curve was constructed, adjusting the soil moisture values by Van Genuchten (1980) model (Figure 1).

Figure 1. Soil water retention curve on the study area.



Following the methodology described, the field capacity (θ_{CC}) was obtained at 33 kPa pressure (32.92%), and the wilting point (θ_{WP}) at 1500 kPa pressure (24.00%). Other soil physical properties calculated were macropores (13.10%), micropores (18.74%) and cryptopores (24.36%) totalizing 56.20% of solids present in the soil.

The different treatments were applied since the crop sowing to the harvest. In the non-irrigation treatment (control), water available to the plants were provided by the natural rainfall, and monitored with automatic weather station (Agrosystem brand, Vantage Pro 2 model), installed near the study area. For the treatment soil moisture equivalent to 100% of the field capacity (100% FC), the soil moisture was determined using a TDR probe (Time Domain Reflectometry - Soil Moisture Equipment brand, Mini-Trase Kit model), and it was applied the amount of water needed to recover field capacity moisture.

In the treatment soil moisture maintenance to actual capacity of water in the soil at 55% of the soil water total capacity (55% RWC), according to the soil depletion factor to the crop, established by Allen and Pereira (1998), it was calculated the soil water total capacity (WTC), according to Equation 1 and the real soil water capacity (RWC) Equation 2, both proposed by Bernardo (2005).

$$\mathrm{WTC} = \frac{(\theta_{CC} - \theta_{PMP})}{10} \mathrm{x\ z} \quad (1)$$

Where, WTC is the soil water total capacity (mm); θ_{CC} is the volumetric soil moisture at 100% field capacity (%); θ_{PMP} is the volumetric soil moisture at wilting point (%); and z is the actual root depth (0.6 m for maize).

$$\mathrm{RWC} = \mathrm{WTC\ X\ p} \quad (2)$$

Where, RWC is the real soil water capacity (mm) and p is the soil depletion factor to the crop.

$$WS = \theta \, X \, z \qquad (3)$$

Where, WS is the water storage in the soil (mm); ϴ is the soil volumetric moisture at the reading moment (%), and z the crop root depth (m). The difference between the RWC and WS was equal the amount of water to be applied in the crop.

In the "Lâmina" treatment, the irrigation depth was obtained using a spreadsheet designed by the authors, according to the Allen and Pereira (1998) methodology. The spreadsheet uses data of location, soil, irrigation system, crop, and weather conditions to calculate the soil water balance in relation to the grown crop and provide an irrigation depth to meet the crop needs.

In this way, global solar radiation ($MJ \cdot m^{-2} \cdot day^{-1}$), average air temperature (°C), average and minimum air relative humidity (%), wind speed ($m \cdot s^{-1}$) and precipitation ($mm \cdot day^{-1}$) data were collected every day. This data was collected with an automatic weather station installed near the study area. Putting into the spreadsheet the weather data, plus the location (latitude, longitude and altitude), the soil physical properties (θ_{CC} and θ_{PMP}) and crop (species and stage), the irrigation depth was obtained, using two days' interval.

In all treatments were determined the total water applied to the crop, allowing to relate the water amount and the crop yield. The crop harvest and the ear threshing were done manually in a 4 m^2 area each plot, on March, 6th, 2016. The grain moisture was around 18 to 22%. After collected, the ears were dried in an oven with forced air circulation for two days to allow the manual threshing process.

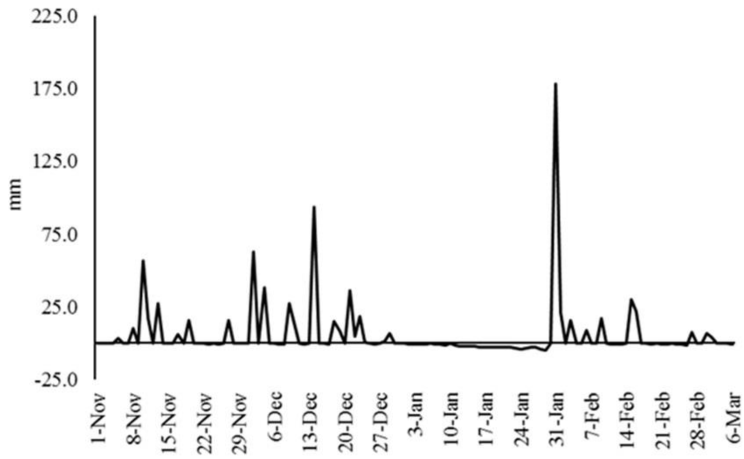
The yields components analyzed were: plant dry matter (DM); ears per plant; rows per ear, kernels per row, kernels per ear and a thousand kernels weight. The number of ear per plant was determined analyzing all the plants in each plot. The number of rows per ear, kernels per row and kernels per ear were determined in seven ears in each plot. The remaining parts of shoot plant was ground and dried in an oven with forced air circulation, at 60 °C until constant weight, to measure the plant dried matter, being not included the kernels weight. The thousand kernels weight was determined taking a weight of 8 samples of 100 kernels each in an analytical scale. The grain yield ($kg \cdot ha^{-1}$) was calculated, taking a weight of the grain harvested in each plot. Both the grain yield and the thousand kernels weight were adjusted for 13% moisture on a dry basis. The grain moisture was determined in oven methodology at 105±2 ºC for 24 hours. The water use efficiency was calculated dividing the amount of water provided to the plants by the kilograms of grain produced ($L \cdot kg^{-1}$).

The data were submitted to analysis of variance and treatment averages were compared by Tukey's HSD test ($p \leq 0.05$) using SPSS software v.22.0. For the relationship between the amount of water applied and grain yield, a regression analysis was performed, obtaining the adjusted equation, using Microsoft Excel.

5 RESULTS AND DISCUSSION

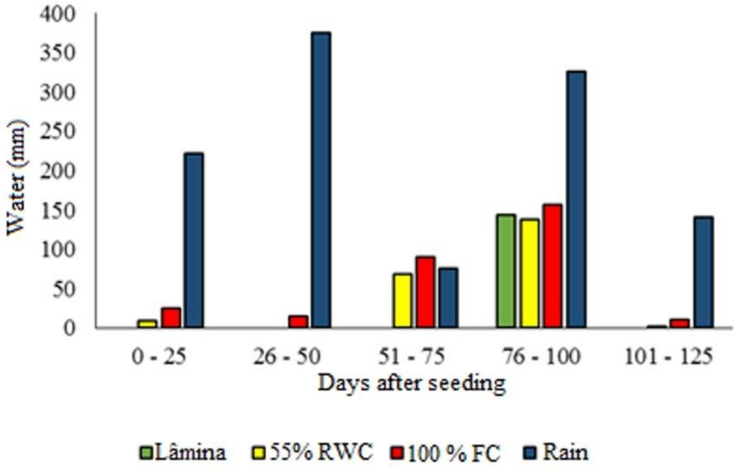
The 2015/16 agricultural season had registered rainfall above the average when compared to the normal rainfall for the Erechim city, where was registered 1,139.60 mm from the crop sowing to the harvest. According to Matzenauer, Radin and Almeida (2011), the normal rainfall to this period is about 615.40 mm. This high amount of rainfall occured can be explaind by the El Niño-Southern Oscillation phenomenon (ENSO) positive phase, that influenced the weather in the 2015/16 season. According to Berlato, Farenzena and Fontana (2005) in years under El Niño positive phase influence, there is 75% probability of rainfall to be above median of neutral years, and greater than 80% of years under the ENOS negative phase influence. However, analyzing the daily water balance (Figure 2), despite the large amounts of rainfall, there were periods of water deficit during the crop growth season, especially in the period of January 10^{th} to 30^{th}. During this time, the maize was in initial grain filling stage.

Figure 2. Daily water balance, from November 1^{st} 2015 to March 6^{th} 2016.



Following the methodology proposed, the irrigation depth and timing in different tretaments varied according to the available water to the plants. In this way, to better understand the irrigations applied, it is showed the irrigations distribution through time, during the crop growth (Figure 3), being the averages irrigation of the four replications, in 25 days period combined. In addition, it is presented the rainfall distribution in the same time.

Figure 3. Irrigations averages (mm) distribution and rainfall conbined in a 25 days period, during the maize growth.



It is observed that the Lâmina treatmant concentrated the irrigations in the period between 76 and 100 days after seeding, which was the longer deficit water period. In the treatmnets 55% RWC and 100% FC, it is observed a better distribution of the irrigations through the crop growth, however, as Lâmina, both used a greater amount of water in the 76 to 100-day period.

According to the total amount of water (rainfall + irrigation) provided to the crop (Table 1), the Lâmina treatment showed the greatest water saving, comparing to the others irrigated treatments, since the control treatment received only rainfall water.

Table 1. Water provided (mm) for maize, during crop growth.

Treatment*	**Water (mm)**
Control	1,139.60^{d}
Lâmina	1,284.05^{c}
55% RWC	1,345.62^{b}
100 % FC	1,416.89^{a}
CV (%)	1.26

*Averages followed by the same letter in the column do not differ according to the Tukey's HSD test ($p \leq 0.05$).

The 100% FC treatment used the greatest amount of water, followed by the 55% RWC, and all the treatments showed significant differences between each other. The less amount of water used in the Lâmina treatment can be explained because this treatment uses a greater number of factors to calculate the irrigation depth compared to the other treatments.

Analyzing the maize yield components (Table 2), treatment 55% RWC showed the best results to the plant dry matter (DM), showing significant differences from other treatments. Treatments 100% FC and Lâmina did not show significant differences between then. All irrigated treatments showed significant differences to the control treatment that obtained the least dry matter yield. These results can be explained by the water deficit periods during the crop growth.

Table 2. Maize yield components.

Treatment*	Dry matter (kg·ha^{-1})	Ears per plant	Rows per ear	Kernels per row	Kernels per ear	Thousand kernels weight (g)
Control	6,095.0^{c}	0.96^{b}	15.6^{a}	33.1^{a}	512.3^{b}	320.1^{c}
Lâmina	6,610.5^{b}	0.96^{b}	15.9^{a}	34.7^{a}	537.6^{a}	334.6^{ab}
55% RWC	7,162.3^{a}	1.02^{a}	16.0^{a}	30.8^{b}	517.9^{b}	338.1^{a}
100 % FC	6,788.9^{b}	0.95^{b}	16.0^{a}	32.9^{a}	509.1^{b}	326.6^{bc}
CV (%)	2.4	1.10	2.7	2.7	1.7	1.2

*Averages followed by the same letter in the column do not differ according to the Tukey's HSD test ($p \leq 0.05$).

The greatest dry matter yield in the 55% RWC treatment can be explained by the irrigations realized during vegetative growth stages, that were not applied in the Lâmina treatment. The 100% FC also received irrigations during vegetative growth stages, however, as it was aimed to keep the moisture at field capacity, and there was great amount of rainfall, the plants in this treatment may have been under saturated soil conditions. According to Floss (2011) under saturated soil conditions, the water excess decreases the air space in the soil, this way, the oxygen lack prevents the plant water metabolic absorption, resulting in energy unavailability (ATP), due to the low respiratory activity efficiency.

According to Magalhães and Durães (2006) all maize leaves and ears are formed in the V3 vegetative growth stage (approximately two weeks after sowing) and during this growth stage both water deficit or excess can result in crop damage because the plant growing point is still below ground. This fact can be the reason for both higher dry matter yield and ears per plant in the 55% RWC treatment.

Rows per ears did not showed sigficant differences between the treatments, with 15.89 rows per ear in average. On the other hand, for kernels per row, the 55% RWC treatment showed the least yield, which can be explained by the great number of rows per ear, although there was no significant difference, since for kernels per ear, only the Lâmina treatment showed greater yields. The 55% RWC treatment showed the second highest number of kernels per ear, however, the treatment did not showed significant differences from 100% FC and control treatments. The number of rows per ear is defined in the V12 vegetative growth stage while the number of kernels per row and the number of kernels per ear are defined in V17 vegetative growth stage, and both water deficit or excess can cause a decrising in the kernels number, yet, the greatest kernels number reduction can happened in the R1 reproductive growth stage, where the number of ovules fertilized are determined, so no fertilized ovules will not produce kernels (MAGALHÃES; DURÃES, 2006).

According to Floss (2011) plants under water deficit estress produces less number of pollen grains and ovules, due to reduced proteins synthesis and lower DNA replication rate. For maize, it can also be the result of non ovule fertilization, since the pollen tube formation and its insertion in the female style only occur if the style is fully hydrated. This fact makes the maize crop, one of the most sensitive to drought when it occurs 15 days before and after the flowering. In this way, the statistical differences found between treatments for this yield component can be explained by a lower water availability (control) or water excess (100% FC) during these stages.

Finally, in the thousand kernels weight conponent can be observed a higher weight in the 55% RWC, followed by Lâmina treatment, not showing significant differences between each other. The 100% FC treatment, showed a similar weight to the Lâmina treatment, however, did not showed differences from the control treatment, which obtained the least thousand kernels weight. Fancelli (2015) reports that the maize grain filling occurs essentially in two stages: the stage R2 reproductive growth stage, where it is observed an accumulation of suggars in the grain endosperm that contribute to increase its mass, which are provided by the suggar translocation from the leaves and stems; and R3 reproductive growth stage where it is observed a strong deposition of the starch in the grains, being a time almost exclusively designated for the grain weight gain. Low water availability in any of these phases, implies in a low translocation rate efficiency, resulting in grain weight loss, generating light and small grains. As the weight of grains is the result of suggar translocation contained in the leaves and stalks, there is a similarity of results between the dried matter yield and the thousand kernel weight, showing a greater thousand kernel weight for the treatment that showed higher dried matter yield (55% RWC). However, it should be noted that this treatment received satisfactory water during grain filling stage, reducing the negative effect of water stress on the suggar translocation efficiency rate.

For the average grain yield (Table 3), Lâmina, 55% RWC and 100% FC treatment obtained the highest grain yields, showing significant differences only to control treatment. These results are in agreement with those found by Soares et al. (2010), which studying the irrigation depth (156, 144 e 116 mm) effect in two maize hybrids (BM 1201 e BRS 3150) did not find differences in the grain yield, under irrigated treatments, and the hybrid BM 1201 showed the highest grain yield in the 144 mm irrigation depth while the hybrid BRS 3150 showed the highest yield with the least amount of water (116 mm).

Table 3. Maize grain yield and water use efficiency.

Treatment*	**Grain yield ($kg \cdot ha^{-1}$)**	**Water use efficiency ($L \cdot kg^{-1}$)**
Control	$1,0380.9^{b}$	$1,098.1^{ab}$
Lâmina	$1,3019.5^{a}$	986.3^{b}
55 % RWC	$1,3399.0^{a}$	$1,010.1^{b}$
100 % FC	$1,2235.7^{a}$	$1,158.3^{a}$
CV (%)	4.8	5.0

*Averages followed by the same letter in the column do not differ according to the Tukey's HSD test ($p \leq 0.05$).

According to Bergamaschi et al. (2004), the maize grain yield is a result from water conditions during the critical period, which begins at tasseling and goes to grain filling. Analysing the water balance (Figure 2), it is possible to identify an aproximately 20 days period under water deficit, between January 10th and 30th. In this time, the crop was at the inicial grain filling stage, which is one possible reason for least grain yield in the control treatment.

Furthermore, less soil water available influences negatively in most of the plant physiological processes, resulting in photosynthetic rate reduction, due to the decrease in leaf area index, stomatal closure, increasing in leaf canopy temperature, because of low crop evapotranspiration, loss of cell turgidity. In addition, it also can decrease the suggar translocation, resulting in a negative impact in the grain filling and increasing the leaf senescence. (FLOSS, 2011; KO; PICCININI, 2009; PEGORARE et al., 2009).

On the other hand, even with no significant difference, it is observed a decrease in grain yield in the 100% FC treatmnet, which was aimed to keep the soil moisture at field capacity, and how was said before, due the high rainfall amounts, the crop under this treatment may stood in saturated soil conditions, resulting negatively in the crop grain yield (FLOSS, 2011).

The present study obtained a grain yield gain of 29.07%, 25.42% and 17.87% for treatments 55% RWC, Lâmina and 100% FC, respectively, comparing to the control treatment. Silva et al. (2007) studying sunflower crop response to irrigation, found a grain yield gain of 9.17%, 33.26% e 48.79% applying an irrigation depth of 50.84 mm (75% Etc), 428.70 mm (100% Etc) and 522.14 mm (130% Etc), respectively comparing to an irrigation depth of 117.20 mm (non-irrigated).

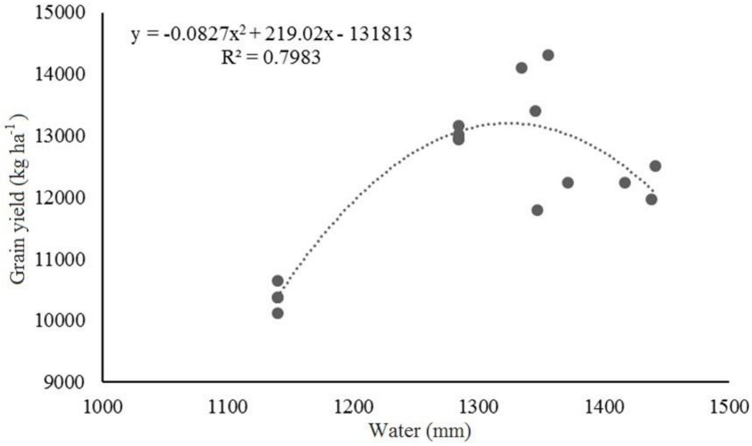
Lima, Custodio and Gomes (2008) applying different irrigation depths on coffee crop found significant results on crop yield, which between 2000/2001 and 2004/2005 agricultural season, the yield gain in response to irrigation reach 119% in the 60% Evaporation Pan irrigation depth, compared to non-irrigated. For dry beans, Santana et al. (2009) found a grain yield gain in response to the water replacement level, reaching the peak with 100% water replacement of the total water consumed, presenting a decline above this depth. For soybean, Sartori et al. (2015) observed an increase in crop yield in the use of supplemental irrigation on soil moisture conditions below 60% of field capacity.

Finally, in the water use efficiency (Table 3), Lâmina and 55% RWC treatments showed the best water use efficiency, being used in average 986.28 e 1010. 14 $L{\cdot}kg^{-1}$, respectively. However, 55% RWC treatment did not show significant differences from control. 100% FC treatment showed the least water use efficiency, which also did not show significant differences from control. The best water use efficiency in the Lâmina treatment can be explained by concentrated the irrigations on reproductive crop stages while treatment 55% RWC applied considerable amount of water during the vegetative crop stages, producing more dried matter and ears per plant, having a positive impact on crop yield.

These results are in agreement with Payero et al. (2009) theory, that studying the irrigation timing in maize, suggests that yield is reduced if the crop is stressed out at any stage. However, the effect is more severe when the stress happens during the reproductive stages, since the crop evapotranspiration is greater and the stress can further reduce evapotranspiration. During vegetative stages, stress reduces the total plant dry matter, that is linearly correlated with crop yield, limiting potential yield early in the crop development. Bergamaschi et al. (2004) suggests that the amount of water applied it is not the main factor to be analyzed for irrigation management. The adequate irrigation use should consider, especially, the time that the crop needs more water, in order to achieve greater efficiency.

To better understand the influence of water on crop yield is shown the relationship between the water applied (rainfall + irrigation) and grain yield (Figure 4). According the equation, it was possible to determine the point of maximum yield (1,3198.36 kg·ha^{-1}) with 1,324.18 mm of water applied.

Figure 4. Relationship between water (mm) and maize grain yield (kg ha^{-1}).



6 CONCLUSION

By using the “Lâmina” spreadsheet was possible to improve the yield components, crop yield and water use efficiency of maize. In this way, the Lâmina” spreadsheet can be used to recommend irrigation depth for maize crop. However, more studies are needed to test in different agricultural seasons.

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