SAVING ELECTRICITY FOR DIFFERENT OPERATING CONDITIONS ON CENTER PIVOT SYSTEMS PLANTING

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Abstract: In this analysis were simulated potential of electricity consumption in center pivot system operating in different conditions of uniformity of water application and climatic conditions for the cultivation of beans in winter no-tillage and conventional. To this end, we developed a spreadsheet for analysis in various operating conditions, whose input information were the hydraulic characteristics of the center pivot system, owned by the Brazilian Agricultural Research Corporation (Embrapa); climatic data; coefficient of uniformity of water application and; crop coefficient of beans grown under conventional and no-tillage. To this end, they employed the time series of climate variables with 24 years of daily observations collected at the weather station of Embrapa. Based on the simulations it was found that the increase in energy consumption by center pivot was more sensitive to variations in power spray jet with climatic conditions and that on average there was a reduction in energy consumption by 17.2%, when replacing the conventional tillage system by no- tillage.

Keywords: Application uniformity; irrigation efficiency; energy consumption.

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INTRODUCTION

Electricity is an important input for the development of modern civilizations, being present in almost all process activities. Among the energy consuming sectors, agriculture stands out as highly dependent to increase production and achieve meet the needs of the market, which is increasingly demanding and competitive (Moraes et al., 2011).

As irrigation systems are water users, it is necessary that the research aimed to design projects, use and management of these systems are contextualized and updated so that the studies have not only scientific but also practical and technical ensuring return advancement of knowledge to society. So the paradox of increasing water demand in the agricultural sector, which is its biggest user, the need to save it and the demand for new techniques involving the use of water in rural areas, fosters that new analytical methods and technologies are research targets in various areas of knowledge. Therefore, irrigation can find great future challenges, since the availability of water for irrigation will be reduced due to increased demand for other sectors as priorities (Santos et al, 2010; Vieira et al., 2011; Carvalho & Oliveira, 2012, Moraes et al., 2014, Vicente et al., 2015).

Due to operational ease, the high adaptability to different soil conditions and topography and the small demand for hand labor, the center pivot irrigation system has been widely used in the Midwest region of Brazil (Sano et al., 2005). The electricity consumed in center pivot irrigation systems is associated with pumping and drive the electric motors installed in the system towers, responsible for the displacement of the equipment on the irrigated area.

Jiménez-Bello et al. (2011) state that the electricity consumed in pumping depends on the volume of water to be raised from the source to the irrigated area and the overall efficiency of the pumping system. According to Moreno et al. (2010), the excess water use increases spending on electricity, which can reach 25% of production costs, reducing the income of the producer.

Like any other irrigation system, the objective of the center pivot is evenly distribute water and controlled in irrigated area and is considered one of the most important factors in their operation, interfering with power consumption, the unfavorable effects on productivity per unit water applied and the environment (Mendoza & Frizzone, 2012; Sandri & Cortezm (2009). Factors affecting the uniformity of water distribution are climate, such as evaporation, air temperature, relative humidity and wind local conditions and non-climatic factors, which are related to irrigation equipment, as the operating pressure of the emitter, speed and alignment of the transmitter side line height (Heinemann et al., 1998).

According Mantovani et al. (2000) the methods of low efficiency irrigation lead to consumption of electricity and water, higher than the required by crops and may emphasize that the expansion of irrigated areas is possible due to investment in equipment and technology that allowed greater mobility and control water use, increasing productivity and reducing operating and maintenance costs. Thus, it increases the competitiveness of irrigated agriculture with reduced consumption of energy and water losses (Mariotoni & Pain, 2004).

Knowledge of equipment performance, especially regarding the distribution uniformity of water and applied water depth, it is essential to take measures to save water and energy. When only applies to a necessary water depth area due to lack of uniformity, a fraction of this area is irrigated with excess, whereas in other fraction is water deficit. In excess with fraction part is stored in the root zone of plants for use and the other part is lost by deep percolation. In the fraction of a deficit, all infiltrated water is considered stored in the root zone, but in much lower to the water requirements of plants (Lima & Zocoler, 2010).

Another important aspect relates to the use of cropping systems, such as tillage, which allow a reduction in the volume of water used in irrigation. The permanence of straw on the soil surface is important also for the protection of soil-plant system benefiting the maintenance of moisture by reducing evaporation providing increased interval between irrigations (Calvo et al., 2010, Kaefer et al., 2012). Thus, it is expected that with the increase of soil coverage level, there are significant savings in the irrigation system operating costs (Stone & Moreira, 2000). These authors observed greater efficiency of water use in tillage with mulch, compared to other tillage systems.

With the objective of evaluating the potential of electricity consumption in a central pivot system, different operational situations were simulated due to the uniformity of water application and climatic conditions of the Brazilian savannah for the cultivation of beans in winter and conventional no-tillage.

MATERIAL AND METHODS

In the optimization study of the irrigation system we used the center pivot installed at Brazilian Agricultural Research Corporation, located in the municipality of Santo Antônio de Goiás-GO, Brazil. The equipment used in the case study consists of ten towers with average bids of 38.6 m with balance of 24 m, with irrigated radius of 411.2 m and irrigated area of 53.12 ha. The center pivot system has a height of 2.7 m, and pipe lateral line is made of galvanized steel with a diameter of 168.28 mm. The adductor, galvanized steel, is 1038 m in length and 159 mm diameter and suction is 2 m in length and 250 mm diameter. The pumping station is composed of a pump installed model TK 150-50, with power of 96.7 hp at shaft and yield of 70% and the electric motor WEG model of 100 hp, with 82% yield.

This analysis simulated the potential of electricity consumption in the center pivot system operating in different uniformity of conditions (80, 85, 90 and 95%) and weather conditions (extreme and average), irrigating winter beans, for systems no-tillage and conventional. To this end, a spreadsheet was developed to analyze the various operating conditions, whose input information was the climatic data, values of coefficients of uniformity and the bean crop coefficients, grown in no-tillage and conventional systems.

The climate data used in this analysis were: relative humidity, wind speed and evaporation of the Class A pan, extracted from a historical series of 24 years of daily observation (1983-2007), collected in the climatological station of Brazilian Agricultural Research Corporation (Embrapa). Initially, there was an analysis of the frequency of data considering the period from May to October, when growing winter bean in the State of Goiás. The power consumption was evaluated for the average values of weather data and also to the conditions of major events that occur in frequency analysis.

In simulation application efficiency, using Equeition 1, we considered the average and extreme weather conditions.

$$Ea = CUC\ Eap \qquad (1)$$

where: Ea - system application efficiency; Eap - potential application efficiency; CUC - Christiansen's uniformity coefficient of water application.

In determining the Eap (Equation 2), we used the methodology proposed by Keller (1984), due to the evapotranspiration of the reference culture, wind speed and spray rate of the spray jet (CI). In this study we used the values of IC 7 (low dispersion) and 17 (high dispersion).

$$Eap = 0.976 + 0.005ET - 0.00017ET^2 + 0.0012V - CI\,[0.00043ET + 0.00018V + 0.000016ET.V] \qquad (2)$$

where: Eap - potential application efficiency; Vv - wind speed (km d^{-1}); ET_0 - reference evapotranspiration (mm d^{-1}). Reference evapotranspiration was estimated using the method of the Class A pan installed in EMBRAPA, which surround radius grassed around the tank is 5.0 m. ET0 was obtained by the product of evaporation of Class A pan by the pan coefficient (Kt). In the determination of the tank coefficient (Eq. 3), the evaporation values of Class A tank, wind velocity measured at 2 m height and relative humidity were taken from the historical series collected at the EMBRAPA station, where the tank Class A is surrounded by grass (Allen et al., 1998).

$$Kt = 0.108 - 0.0286Vv + 0.0422Ln\ (Rt) + 0.1434\ Ln\ (UR) - 0.000631\ [Ln(Rt)]^2\ Ln\ (UR) \qquad (3)$$

where: Kt - Class A pan coefficient; Vv - wind speed measured at 2.0 m height (m s^{-1}); Rt - radius around the tank grassy (m); RH - relative humidity (%).

Based on the water demand of the area to be irrigated, corrected by the maximum number of hours that the equipment can operate every day, water losses that occur prior to their infiltration into the soil and the area fraction of receiving the water deficit, was calculated according Colombo (2003) the rate of daily pivot replacement (Equation 4):

$$TRD = \left(\frac{ET_c}{E_a}\right)\left(\frac{24}{JT}\right)\left(\frac{1}{L_{ad}}\right)\left(\frac{1}{1-P_e}\right) \qquad (4)$$

where: TRD - daily replacement rate of pivot (mm); ETc - bean crop evapotranspiration (mm d^{-1}); JT - number of hours worked on; Lad - water depth applied associated with different levels of poorly irrigated area; Pe - water loss by runoff.

The bean evapotranspiration was obtained by the ET_0 product by the crop coefficient (Kc), considering the no-tillage and conventional systems in the period of maximum demand of water culture, that is the flowering period and grain filling of 1.06 obtained Moreira et al. (1999) and by 1.28 Steinmetz (1983), respectively.

The consumption of electricity was obtained with respect to the fraction of the deficit area, which is the fraction of the irrigated area that receives less water depth that the necessary (Bernardo et al., 2006). The dimensionless value of applied water depth is associated with different levels of poorly irrigated area, for different levels of cumulative probability, based on normal statistical distribution is calculated by Equation 5.

$$Lad = 1 + CV\ Zad \quad (5)$$

where: Zad - reduced normal distribution corresponding variable application water depth (LAD) which has a probability of occurrence equal to cumulative fraction poorly irrigated area; CV - coefficient of variation of the distribution of irrigation water depths.

In the calculation of DAI fractions were considered poorly irrigated area (ZAD) ranging from 5 to 50%, and the estimate of the CV (Equation 6) was considered as equivalent to the Christiansen's uniformity coefficient (CUC).

$$CV = (1 - CUC)/\sqrt{2/\pi} \quad (6)$$

In the calculations of the daily pivot replacement rate for all analysis conditions, water losses by runoff were considered 5% of the total applied amount considered reasonable by Colombo (2003). Having the values of daily pivot replacement rates for all simulations, the flow rate is calculated thus possible to analyze the energy consumption (Equation 7).

$$Q = 10\left(A\ TRD\right)/JT \quad (7)$$

where: Q - flow rate ($m^3\ h^{-1}$); A - irrigated area (ha).

The energy consumed power was obtained according to the flow being applied to the different conditions of evaluation considering the structure of the lifting system and adduction of irrigation water.

RESULTS AND DISCUSSION

For the analysis of climate data, relative humidity values, wind speed and evaporation that showed a higher frequency of occurrence were 60%, 1.0 m s^{-1} and 6.0 mm d^{-1}, and found extreme values for water consumption were 25%, 2.2 m s^{-1} and 12.0 mm d^{-1}, respectively. Based on these values, they were estimated ET_0 and ETc, considered the period of greatest demand for water of winter bean crop, which according to Moreira et al. (1999) coincides with the phases of flowering and grain filling (Table 1) with durations between 35 to 60 days 60 to 80 days, respectively. The values of ETc show that the bean is more demanding in water consumption in flowering compared to the grain filling, and there is a reduction in the consumption when using the no-tillage system, for both the occurrence of conditions of climate values evaluated (extreme and mean). From Table 1, there is an average percentage reduction of ETc of 17.2 and 14.4%, for the stages of flowering and grain filling, when replacing the conventional tillage (PC) by no-tillage (PD), respectively.

Table 2 shows the values of Ea and Eap obtained for different values of CUC and CI for the two climatic conditions evaluated in this study (extreme and average). The Ea values obtained for C = 7 were higher than those obtained for the highest degree of pulverization, to the evaluated climatic conditions. To the same degree of water jet spray, it appears in the results the influence

Table 1: Reference evapotranspiration and culture for conventional and no-tillage systems.

ECA (mm d-1)	UR (%)	Vv (m s-1)	Kt	ET0 (mm d-1)	Phase	Kc		ETc (mm d-1)	
						PC	PD	PC	PD
Extreme climatic values									
12.0	25.0	2.2	0.58	6.90	Flowering	1.28	1.06	8.83	7.31
					Grain filling	1.04	0.89	7.18	6.14
Average climatic values									
6.0	60.0	1.0	0.73	4.37	Flowering	1.28	1.06	5.59	4.63
					Grain filling	1.04	0.89	4.54	3.89

of climatic conditions, and in the extreme conditions of evaporation, wind and humidity, there is a reduction in Ea valuesespecially when it increases the CI, corroborating with the statement of the Evangelista; Oliveira & Silva (2009) that the variables, wind speed, relative humidity and air temperature significantly influence the estimate to estimate application efficiency.

Regarding the uniformity of water distribution at rated system, it appears that there is a direct correlation between the values of the CUC and Ea, and that the increase in CI for the same weather conditions, provides a reduction in the range of the jet and its instead uniformity of water distribution by the sprinkler. Therefore, it can be inferred that for the climatic conditions of the state of Goiás, to have application efficiency within the recommended range in 80% literature, one should always work with irrigation system with low spray (CI 7) and to the extreme climatic conditions with CUC ≥ 95% and the average conditions CUC ≥ 85%. For conditions outside these limits is in a reduction of Ea, which will provide for increased water depth and in turn the power consumption, as according to Bernardo et al. (2006), a very sprayed jet is subject drifting by the wind, reducing the efficiency of application, requiring thus a higher water depth which is reflected in an increase in energy consumption (Mantovani et al., 2000).

For different values of uniformity of water distribution, weather, jet spray and percentage of poorly irrigated area, energy consumption was on average 17.2% lower when it adopts no-tillage compared with conventional system. Analyzing the effect of the spray jet, the consumption of energy to maintain the uniformity coefficients and percentages of poorly irrigated areas, energy consumption has averaged 25.1 and 64.0% higher than for the average climatic conditions and extreme when the IC varied from 7 to 17, respectively. On average increase in energy consumption was 3.4% when reduced the percentage of water deficit area, and on average there was a reduction in power consumption when uniform water application ranged from 80 to 95%, keeping the remaining variables.

The Figure 1 shows the variation in energy consumption depending on the percentage of poorly irrigated fields, for CUC 80% by varying the spray rate of the jet and the planting system.

Table 2: Efficiency of water application center pivot irrigation system

CUC (%)	CI = 7				CI = 17			
	Extreme		Average		Extreme		Average	
	Eap	Ea	Eap	Ea	Eap	Ea	Eap	Ea
	(%)							
0.80	84	67	93	75	31	24	70	56
0.85	84	71	93	79	31	26	70	59
0.90	84	75	93	84	31	28	70	63
0.95	84	80	93	89	31	29	70	66

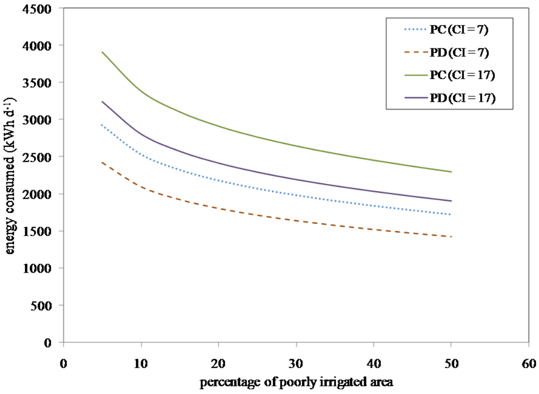

Figure 1: Power consumption due to the poorly irrigated areas, for different CI values, planting systems and CUC = 80%.

It is noted that to maintain the same uniformity of application, an increase in power consumption with the CI to the same planting system for the application of the water depth. The same behavior is observed when for the same CI, the conventional system of planting is replaced by no-tillage.

CONCLUSIONS

The results obtained in the simulations, it can be concluded energy consumption in center pivot system was more sensitive to the changes introduced by water jet spray emitted by sprinklers, especially for the most severe climatic conditions (64.0% on average), and that adoption of no-tillage system direct represents a reduction of alternative in water consumption for the winter bean crop in the Brazilian savannah (17.2% on average)

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