

## Abstract

This study aimed to evaluate the uniformity of distribution and water depth applied with a center pivot irrigation systems according to the change in speed of rotation of set motor pump with a frequency inverter and the effect of the position of the lateral line in these parameters. Three positions of lines of collecting water were tested: incline of 3.45%, level and slope of 11.78%. The experimental design was completely randomized, with three replications made at each position tested. Analysis of variance was applied followed by Tukey test. The average value of the coefficient of uniformity of Heermann e Hein was 88.85%, describing the uniformity of water distribution as good. The mean weighed depth of irrigation applied was 5.71 mm, varying significantly within each test (5%) between the positions of slope versus incline and level. It was concluded that the position of the lateral line influenced significantly in the rotation the set motor pump, water depth applied and energy consumption. However, in the values of uniformity of water distribution there was no difference.

**Key words:** water application, irrigation control, rotation.

## Introduction

The main aim of an irrigation system is to provide conditions to produce economically what is achieved through production increase and cost reduction by unit produced. In this aspect, the parameters which express irrigation quality must be understood as decisive components of the planning process and irrigation system operations (FRIZZONE, 1992).

It is indispensable to know the equipment performance, mainly with regard to distribution uniformity of water and applied water depth, in order to find ways of saving water and energy. When only enough irrigation depth is applied to an area (when this depth corresponds to the average depth), because of the lack of uniformity, a fraction of this area is over irrigated, whereas in another fraction there is water deficit.

In the over irrigated fraction, one part is stored in the root zone for the use of plants and the other part is lost by deep percolation, transporting part of the nutrients from that layer as well.

In the deficit fraction, the infiltrated water is stored in the root zone, however, in a lower amount to the hydrical needs of the plants. On the other hand, if the average depth of applied irrigation is higher than necessary, the fraction with irrigation deficit can be even eliminated, however the irrigation cost rises to the point of being economically achievable,

# Use of the frequency inverter on center pivot irrigation system and its effects on water depth and water distribution uniformity

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besides aggravating nutrient leaching. Therefore, the distribution uniformity of water irrigation must be analyzed not only as simple dispersion data, but also as an important parameter in the economic irrigation assessment (ZOCOLER et al., 2004).

In order to increase productivity, it is necessary that the entrepreneur apply all the technology available and, in agriculture, it is essential to apply water correctly to the cultures, since its development is under this condition. Irrigation stands out as one of the main techniques to be implemented, however a great deal of the irrigated areas of the country works with electric energy from the interconnected system of generation and transmission, or with small local hydraulic generations (ARRUDA, 1988).

With the constant raises of energy bills, water pumping has become an important portion of production cost, forcing the irrigator to seek alternatives that may reduce costs. Electric engines consume most of the electric energy used in irrigation systems, and the incorrect measuring of this equipment may cause higher electric energy consumption (AZEVEDO, 2003). The use of frequency inverters, which enable the variation of motor-pump set rotation, allows adjusting electric energy consumption to charge needs.

Conzett and Robeck (1983) claim that one of the ways to operate a pumping system properly

in order to reduce outflow, is to change pump rotation until the necessary outflow is obtained, according to Rateaux relationships; that does not imply that introducing charge loss and operation timing is not changed. Tiago Filho (1996) claims that the frequency inverter is a piece of equipment capable to produce this effect fast and efficiently, and it works changing the frequency of tension applied to the engine, enabling it to control its rotation; still, according to this author, the use of the frequency inverter in pumping system industry is a very common experiment, because its economic applicability is justifiable by the reduction of energy consumption, compared to other procedures, specially valve closure.

In irrigation systems, the electric engines used to activate the pumps are usually dimensioned to supply the greatest outflow demand associated with maximum manometric height. The use of frequency inverters in these systems may result in substantial reduction of electric energy consumption. Henson et al. (1996), quoted by Carvalho et al. (2000), have applied the frequency inverter in some irrigation systems with these aims, in the U.S, obtaining satisfying results, once the reduction of the consumed power, caused by equipment use, had generated substantial energy saving.

In this context, this study aimed to evaluate the distribution uniformity and water depth applied in center pivot irrigation equipment according to rotation speed variation of the motor-pump set with the use of a frequency inverter and the effect of the side line position in these parameters.

## Material and methods

the experiments were carried out in the second term of 2008 on Nossa Senhora Aparecida farm in the municipality of Coronel Macedo, in São Paulo, whose coordinates are: latitude 23°41' south, longitude 49°11' West and 630 m elevation.

There are three pieces of Valley Center pivot irrigation system installed on the farm called PC-07, PC-08 and PC-09. This equipment is interconnected by a single adductor and works with the same pumping set interspersedly, where this set is controlled by a frequency inverter start key. The experiments were carried out in the PC-09

pivot, which is the closest equipment to rainwater catchment.

The main characteristics of the irrigation equipment evaluated are: circular irrigated area: 43.94 ha; time (100% relay): 6,87 h; total outflow: 338.59 m<sup>3</sup> h<sup>-1</sup>; side line length: 347.55 m; total irrigated range: 374.0 m; unevenness between the pump and the pivot Center: 51.0 m. Three positions have been tested for the experiment: 3.45% acclivity, level and 11,78% declivity. The experiments have been performed according to rule Project n° 04:015.08-008 of Brazilian Association of Technical rules (ABNT) of 1998, installing two radial lines of water traps, with a regular and constant 3 meter-space among traps, from the pivot center to the irrigated area extreme, perpendicular to the equipment side line topographic profiling with a crack angle of 3° between the lines. The percentage of the equipment relay was adjusted to 100% in order to perform the tests.

The climate data collected during the experiment were wind speed and evaporation. To check wind speed and evaporation during the experiment, an Instrutherm portable digital thermal-anemometer, model TAD-500, 0.3 to 45.0 m s<sup>-1</sup> speed reading and ± 3 % precision was used. Evaporation during each experiment was measured using control collectors installed in the surroundings of the pivot base, where the values obtained were added to the collected water depths, as ABNT determines for this kind of experiment, averaging out the total liquid depth applied by the equipment.

Pressures in the pumping set have been checked using a Bourdon manometer with 21.00 kgf cm<sup>-2</sup> reading and ± 1 % precision. At the pivot point (in the ascent pipe) and in the equipment end (before the pressure regulator) the pressures have also been measured with a Bourdon manometer according to ABNT rules to check out deviations with regard to the technical project.

To work out the recovery time of capital invested in the acquisition of the frequency inverter in order to reduce electric energy consumption, value of saved electric energy consumption (Vc) was simulated during the equipment use period. To do so, the energy saved was examined by the use of a single n° 9 pivot working 20 hours a day only during 1/3 of the

dry period of the year (from May to November), once during the other 2/3 of this period the inverter key would be connected to two other pivots (PC-07 and PC-09), which are positioned in more elevated areas.

The experimental design was a completely randomized with three replications (times in each tested position). Analysis of variance was applied followed by Tukey test.

## Results and discussion

The climate data record in the field, wind speed and evaporation of the collectors (rain gages), are shown in Table 1. In respect to wind speed during experiments, the values measured did not exceed the limit in the rule project, in which wind speeds above  $3,0 \text{ m s}^{-1}$  invalidate the tests. The values observed during experiments did not exceed  $2,6 \text{ m s}^{-1}$ .

In table 2, the values of rotation were statically significant among the three positions. In these experiments, the inverter programming established variable pressure in the pumping exit according to the side line position in the area, that is, 132,5, 122,5 and 82,5 mca for the positions of acclivity, level and declivity, respectively. Therefore, in order to cause such pressures, the rotation would have to be reduced when the side line moved from acclivity to declivity, according to Rateaux relationships. This programming is correct for this starter and operation device, because as the line goes from acclivity to declivity, the manometric height falls, however the part concerning the level variation is transformed into pressure that operates, above all, in the sprinklers subdued to this

level variation and, on account of that, the pump rotation can be reduced without reducing sprinkler operation pressure, therefore causing a consumption reduction and energy demand in the system.

Alves et al. (2002), tried to check the veracity between Rateaux relationships and the reduction of power consumption in the pumping, when the frequency inverter is used, which allows rotational variation in the motor-pump set. Through the use of the frequency inverter, the average reduction of power consumed was 40.7 and 75.0% by reducing the rotation from 1800 to 1500 rotations  $\text{min}^{-1}$  and from 1800 to 1100 rotations  $\text{min}^{-1}$ , respectively.

Table 3 shows the results of the uniformity distribution, where the motor-pump set rotation varied in the attempt to meet the manometric height demand according to the side line position in the area (acclivity, level or declivity). Though there was significant difference in rotation among the experiment positions (Table 2), there was not significance between uniformity and distribution values, proving that the pressure regulators set performed satisfyingly, irrespective of the position of operation, whether in acclivity or declivity, resulting in a good uniformity in three experiment positions, according to ABNT.

Zocoler, Cesar and Vanzela (2004) verified that, after evaluating central pivot irrigation equipment in three positions of operation (acclivity, level and declivity), the side line position did not influence water distribution uniformity of this very equipment.

**Table 1.** Wind speed and evaporation values during experiments.

Positions	Repetition	Evaporation of water traps (mm)	Wind speed ( $\text{m.s}^{-1}$ )
Acclivity	2	0.20	1.00
Level	2	0.23	0.00
Declivity	2	1.00	1.60

**Table 2.** Side line relative position effect in the motor-pump set rotation.

Positions	Motor-pump pressure set		Pump rotation	
	(mca)	(rpm)	Average	Tukey
Acclivity	132.5	1683	1682	C
Level	122.5	1626	1622	B
Declivity	82.5	1380	1375	A

*Analysis of variance not significant (1% probability).*

Table 4 shows catchment results of water depth. Unlike rotation, there was significant difference in the three positions (Table 2), there was difference of depth catchment only between declivity versus level position and declivity versus acclivity position. Considering that the inverter had been programmed to fulfill pressure needs adequate for each position, the depths were not supposed to differ statistically. However, even with the exit pressure adjusted to 82.5 mca in declivity, this value happened to be enough for the outflow to be greater than previous positions and, in this manner, it promoted elevation of the applied depth.

Zocoler et al. (2004), upon evaluating the effect of the side line position of center pivot irrigation equipment in the applied irrigation depth, concluded that although the center pivot end ranged 24.37 m, vertically, between acclivity and declivity, there was no significant effect of positions in this variable.

In Figure 1 the pressure-based operation points can be observed in the exit of the motor-pump set, outflow estimated through weighed average depth and motion of this position points in acclivity and from level to declivity.

As the operation condition determined rotation variation on account of manometric height demand, this is one of the main factors responsible for frequency inverter implantation in irrigation

systems. Table 5 shows energy consumption-related parameters of the motor-pump set. There was significant difference of consumption in the three experiment conditions (acclivity, level and declivity), as well as in rotation and booster pressure results. The results showed that average energy consumption between the ground ends had 40.13% reduction.

Mello et al. (1999) had an array power reduction of 35.87% and 28.02% by comparing the difference of power consumed by a frequency inverter in pumping setting aimed to control pressure in irrigation lines, through the reduction of motor-pump rotation, concerning usual handling procedures: charge loss insertion and irrigation time reduction of the line, respectively.

Due to local conditions, in which a single pumping system supplied three Center pivot irrigation systems, it would not be possible to use a starter command other than the inverter key, since the motor-pump rotation must vary according to center pivot in operation and its side line position. Therefore, the reduction of average electric energy consumption was estimated to PC-09 according to rotation reduction.

Considering that the consumer has the right to a discount on consumption bills between 9:30 p.m and 6:00 a.m of the next day, here are the application conditions to calculation:

**Table 3.** Distribution uniformity coefficient.

Positions	Pump rotation		Distribution uniformity		
	(rpm)	average	CUH (%)	average	ANOVA
Acclivity	1683	1682	88.26	89,37	ns*
Level	1626	1622	85.94	87,50	ns*
Declivity	1380	1375	89.47	89,69	ns*

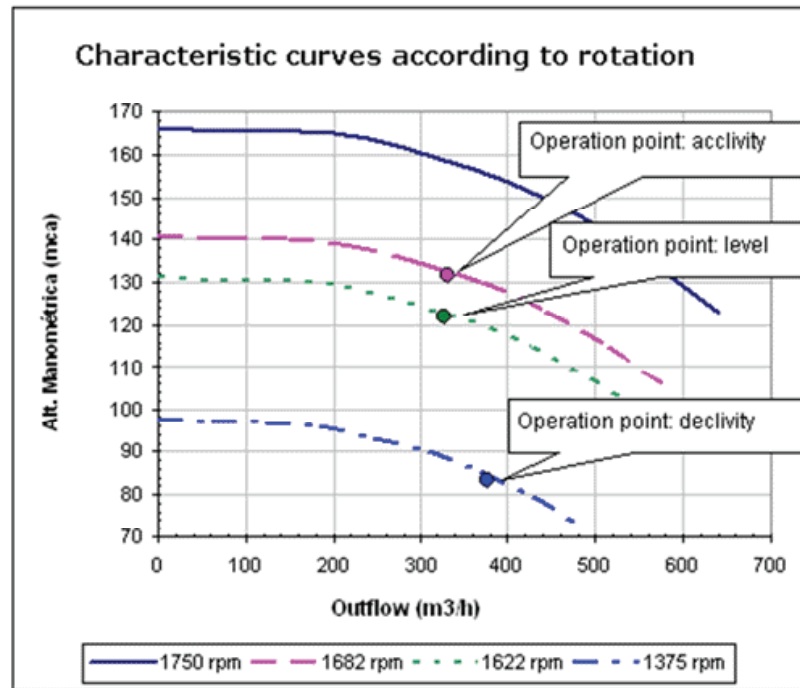
\*Analysis of variance not significant (5% probability).

**Table 4.** Rotation and irrigation depth values.

Positions	Pump rotation		Irrigation depth collected		
	(rpm)	Average	mm	Average	Tukey
Acclivity	1683	1682	5.39	5.54	B
Level	1626	1622	5.54	5.39	B
Declivity	1380	1375	6.13	6.19	A

\*Analysis of variance not significant (5% probability).

**Figure 1.** Operation points  $H_{man}$  (mca) x Outflow ( $m^3 h^{-1}$ ), according to pressures measured in the motor-pump set and outflows estimated from a weighed average depth.



- Consumer: Group A, subgroup A4, Class IV (Rural), Subclass a - farming and cattle raising item 2 – water pumping service destined to irrigation activity (Normative Resolution 156, from May from ANELL that changed Resolution 456, from November 29 2000 from ANEEL);

- Average power of operation: 148.16kW (maximum regarding the highest position 185.36 kW; and minimum regarding the lowest position 110.96 kW);

- Daily operating time: 20 h (turned on at 9h30 p.m and turned off at 5:30 p.m of the next day);

- Number of operating days in the dry season (May to November): 70;

- Daily operating hours for irrigators (according to benefits of Resolution 207, from January 9 2006, from National Electric Energy Agency - Agência Nacional de Energia Elétrica - ANEEL): 8.5 hours (maximum);

- Electric energy consumption bill from 6 a.m to 8 p.m (CPFL – Paulista for subgroup A4, according to Resolution 445/ANEEL – DOU (Brazil's Official Gazette) from 04/03/2007: R\$ 0.17647 kw h-1;

**Table 5.** Values of power of the Motor-pump set

Positions	Repetition	Pump rotation (rpm)	Booster pressure (mca)	Motor frequency (Hz)	Motor tension	Motor power		
						(kW)	Average	Tukey
Acclivity	2	1683	132,50	56,7	357,0	188,4	185,36	A
Level	2	1626	122,50	54,7	344,0	176,0	171,06	B
Declivity	2	1380	82,50	46,3	292,0	114,0	110,96	C

*Analysis of variance not significant (1% probability).*



- Discount factor over consumption bill from 6 a.m to 8 p.m for irrigation: 70% (Southwest region);  
 - Federal taxes: (PIS/PASEP and COFINS), that generally add up to 4%, were not included in the bills.

Therefore, electric energy consumption value (R\$) that was saved during equipment use is worked out as follows:

$$V_c = \frac{(185,36 - 110,96)}{2} \cdot 11,5.70.0,17647 + \frac{(185,36 - 110,96)}{2} \cdot 8,5.70.0,17647.0,30 = 6456,37$$

Knowing that the inverter key acquisition price is R\$ 65,200.00 (according to WEG representative on 10/24/2008) and that two soft starter keys should have been purchased instead (even with limitation of the case), whose acquisition price is R\$ 10,850.00 each, recovery time of invested capital between these two options, due to energy saving only, would be of 6.74 years, what seems a very interesting investment, as well as the fact that the inverter key dispenses with the use of capacitor bank for system power factor correction.

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## Conclusions

According to the conditions mentioned, here are the conclusions:

Rotation, pressure and values of power operated according to Râteaux relations. In this experiment the equipment position of operation determined the manometric height, optimizing the use of the motor-pump set through rotation speed control by the frequency inverter;

The position of the equipment influenced the rotation values and the water depth applied, though it did not influence water distribution uniformity that was classified as good, proving that in spite of lower rotation the distribution uniformity was kept;

Applied water depth values for the experiments were above the specified values in the technical form provided by the equipment manufacturer, showing the necessity of evaluating irrigation equipment after installation. In that way, it is possible to improve their performance not only in water application but energy consumption as well.

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