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Research Article

Effect of the Continuous and Intermittent Drip Irrigation in the Yield of the Beans Crop

Randon Ortiz Calle*

Central University of Ecuador, Faculty of Agricultural Sciences, Ecuador

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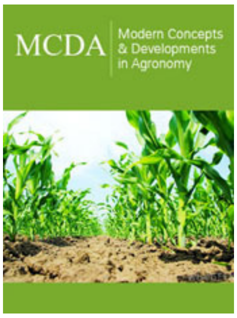

***Corresponding author:** Randon Ortiz Calle, Central University of Ecuador, Faculty of Agricultural Sciences, Quito, Ecuador

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Abstract

Intermittent drip water application is a water management technique that maximizes the supply of oxygen, water and nutrients in the soil to enhance the plant´s physiological activity. The research was conducted in the Tumbaco Valley, Ecuadorian Andeans, to study the effect of the continuous and intermittent drip irrigation on the soil-water-plant relationship. Two variables (water application methods and fertilizer doses) were evaluated in an experimental design of split plots: Drip is the continuous drip water management (100% fertilizer dose) and RPro is the intermittent water application (50% fertilizer dose). Result: i) crop yield: Drip, 3.11t ha^{-1} and RPro, 4.38t ha^{-1}; ii) gross water depth: Drip, 368.15mm and RPro, 236.40mm; iii) days to harvest: Drip, 120 days and RPro, 105 days. In conclusion, RPro in contrast to Drip provided for a 40.80% increase in crop production with 50% of the fertilizer dose, a 55.73% reduction in water use and a two-week reduction in the vegetative cycle.

Keywords: Conventional drip irrigation; Low volume drip irrigation; Fert irrigation; Beans var. “Rojo del Valle”

Introduction

The agricultural sector’s current challenge is to produce more food with less water and less fertilizers to satisfy the world’s growing food demand which is accompanied by a reduction of the agricultural lands caused by the urbanization works, including an uncertainty in the availability of fresh water for irrigation owing to the climate change. The agricultural sector in Ecuador uses about 81% of the available fresh water [1], and it is urgent to reduce this percentage by using efficient irrigation methods [2]. Nowadays, drip is one of the most efficient irrigation methods used to optimize the water usage with better yields [3].

According to the FAO-56 methodology [4], the crop water requirement for the Andean beans in the Tumbaco Valley is about 400mm [5], being the amount of water to be applied in the continuous drip irrigation about 440mm, in sprinkler nearly 620mm, in furrows almost 880mm and through the intermittent drip irrigation around 250mm; considering the later value as the new irrigation set point, the water savings accounts for 60% in contrast to drip, 148% for sprinklers and 252% with furrows, thus, the intermittent drip water management is one of the best alternatives to reduce the water use in most row crops [3].

The oxygen-water relationship in the soil solution is a physical parameter which enhances the physiological activity of the plant, and it is influenced by the irrigation method and the water application regime. It is poor in furrows and sprinkler because the weekly water depth applied between 30 and 70mm reduces the oxygen availability during irrigation. The continuous irrigation improves this relationship because of the daily water application with water depths ranging from 3 to 7mm, and the intermittent irrigation keeps an equilibrated oxygen-water relationship because the small water depths of 0.2mm avoids the reduction of the oxygen content in the soil solution [3].

The continuous water application produces a wetting bulb with higher dimensions vertically with water losses by deep percolation and nutrients leaching out from the root zone. The intermittent application maintains moisture levels above field capacity, higher hydraulic conductivities and higher water potentials, good soil aeration and avoids water losses by deep percolation [3,6-11]. The moisture content above field capacity reduces the adsorption of nutrients by the soil matrix, making it more efficient the fertilization [3].

Because of its high protein, starch, mineral and fiber content, the Andean bean crop is one of the most important agricultural products in the Ecuadorian diet. At national scale, about 18000.0 hectares are cultivated with an average yield of 0.62t ha^{-1} [12]. In Ecuador (Loja), with drip irrigation for 1 and 3 day frequencies, yields ranged from 3.2 to 2.4t ha^{-1} [13]. In Mexico (San Luis Potosi), fertigation resulted in a yield of 5.1 t ha^{-1} [14]. In Egypt, the fresh bean crop under drip irrigation yielded 11.0t ha^{-1} for four applications and 9.0 t ha^{-1} for one application [15]. These results show that pulse irrigation enhanced better yields of the beans crop.

A split plot experimental design was planned to answer the research question, with two factors in study: methods of water application (continuous and intermittent) and fertilizer dose (50% and 100%). The continuous application with 100% fertilizer dose is the conventional drip irrigation (Drip) and the intermittent application with 50% fertilizer dose (RPro) is the water management technique to be tested. The objective of the research was to evaluate the integral effect of the continuous and the intermittent drip water application in the Andean beans crop (var. “Rojo del Valle”).

Material and Methods

Location of the research area

The research was conducted in the Tumbaco Valley, province of Pichincha, at the “Centro Académico Docente Experimental la Tola (CADET)” of the Faculty of Agricultural Sciences of the Central University of Ecuador. Altitude: 2480 meters above sea level; south latitude: 0°13’46” and west longitude: 78°22’0”. The Tumbaco Valley is characterized by two climatic seasons, the rainy season from October to May and the summer season from June to September; the relative humidity varies between 65.70% and 79.20%; the maximum temperature varies between 25.4 °C and 26.6 °C; the minimum temperature between 4.7 °C and 7.2 °C; the wind speed between 0.70m s^{-1} and 1.70m s^{-1}; the daily shining hours between 4.3h and 7.4h.

Materials

Irrigation equipment and management: An automatic drip compensated irrigation system was used. The soil moisture tension was measured using analog tensiometers. Drippers with a discharge of 1.0 l h^{-1}, emitter spacing of 0.2m and lateral separation of 0.8m. Portable meters (accuracy: 1-5%) were used to record the temperature and relative humidity in the crop foliage and to measure the chemical variables in the soil solution. Continuous drip irrigation was controlled for a soil moisture between 10 and 15 centibars and the intermittent drip irrigation for a soil moisture between 8 and 10 centibars.

Crop variety, cycles, fertilizers dose and soil: The Andean beans crop INIAP-481 “Rojo del Valle” was evaluated with a density of 100 thousand plants per hectare. This crop has an average yield of 1.4t ha^{-1}, maximum plant height of 50cm, 12 number of pods per plant and 5 grains per pod [16]. The research was performed in two cycles: 2018 and 2019. Fertilizers (NPK) in kg ha^{-1}: dose 100%, 80-40-60; dose 50%, 40-20-30.

The soil type of the experimental area is Cangahua (Durustoll), a hard and sterile soil with a loam texture [17,18]. The soil had an effective depth of 0.2m, a pH of 6.67 units and an organic matter content of 3.5 percent.

Methods

Experimental Design: The experimental design was divided plots with two study factors (water application methods and fertilizer doses) with four repetitions; the experimental unit had an area of 80m^2 and the total testing area 1280m^2. Water was applied in two methods: a single application (continuous irrigation) and many applications (intermittent irrigation). The fertilization factor had two levels: F100, nutrients based on soil analysis and crop needs and F50 half of F100. Treatment 1 (T1) is known as Drip and refers to the traditional water management (continuous irrigation and 100% fertilizers); treatment 2 (T2) is known as continuous irrigation with 50% fertilizers; treatment 3 (T3) is known as intermittent drip irrigation with 100% fertilizers and treatment 4 (T4) is defined as RPro and it is the intermittent drip irrigation with 50% fertilizer dose.

Variables and statistical analysis: The variables evaluated were:

A. Climate: temperature (T, °C) and relative humidity (RH, %) were measured at 2.0 meters above the ground and in the foliage of the crop (20cm above the ground) in the maturation phase of the pods.

B. Soil physics: the soil moisture tension (millibars) was measured through analogic tensiometer´s with a reading frequency of 3 minutes. Dissolved oxygen content (O_2, ppm) was measured three times a week. The width (W, cm) and depth (D, cm) of the wetting bulb was measured along the vegetative cycle.

C. Soil chemistry: the electrical conductivity (CE, dS m^{-1}) and the nitrates content (NO_3, ppm) were measured three times a week.

D. Water: the water depth applied (L, mm) was determined in all treatments at the end of the cycle.

E. Plant: yield (R, t ha^{-1}, 12% of moisture) and time to harvest (Th, days).

The software R was used to perform the statistical analysis. The Shapiro-Wilks test for normality was used. A simple mean test was performed for T, HR, O_2, W, D and Th. An analysis of the variance was done for the yield, and the Tukey test for differences among them. The level of significance for all statistical analysis was 5%.

Result and Discussion

Although the effect of the “pulse irrigation” in the crop yield has been extensively described and discussed in some scientific articles [7-10], there is no information related to the integrated effect of the continuous and intermittent drip irrigation on the soil-water-plant relationship. The main differences between the intermittent drip irrigation (RPro) and "Pulse Irrigation" are: i) in RPro water is applied in low volumes during the day to cover about 0.2mm of the real evapotranspiration every time, and in "Pulse Irrigation" water is applied in many irrigations with intervals of 10 minutes between them to cover the crop daily water requirement.

Climate parameters

Table 1: Mean climatic parameters at "La Tola" station.

Cycles	Tmax	Tmin	HR	Sunshine	Eo
	°C	°C	%	h d^{-1}	mm d^{-1}
2018	22.47	9.58	69.34	6.09	4.34
2019	22.97	10.17	61.82	6.71	5.74

Table 1 summarizes the mean climatic data during the vegetative cycle at La Tola station INAMHI (2019). In the experimental area, the weather in 2019 was hottest, with higher rates of evaporation (32.2%), shining hours (10.2%) and temperature (Tmax, 2.2%; Tmin, 6.2%), which influenced in a higher water consumption by the crop.

Temperature and relative humidity in the foliage of the crop

Figure 1 shows the temperature and the relative humidity at the air and in the foliage of the crop. Between RPro and Drip, a significant difference according to the mean test was computed for the temperature at midday (p-value, 3.03E-5) and in the afternoon (p-value, 3.4E-3); the HR at midday (p-value, 6.6E-6) and in the afternoon (p-value, 2.7E-5). At midday (13:00), in RPro, the maximum temperature was 18.4 °C and HR about 88.0%; in Drip, the maximum temperature was 15.7 °C and HR about 83.0%. In the afternoon (19:00), in RPro, the maximum temperature was 34.4 °C and HR 68.8%; in Drip, the maximum temperature was 27.9 °C and HR about 77.2%. There is not a study in this area in the region to contrast our findings. Analyzing the data, in RPro, at midday, the combination of lower temperatures with higher relative humidity shows a good regulation of the transpiration by the plant while in the afternoon, the heat accumulated in the crop's foliage was dissipated at higher temperatures, indicating a better plant´s physiological activity.

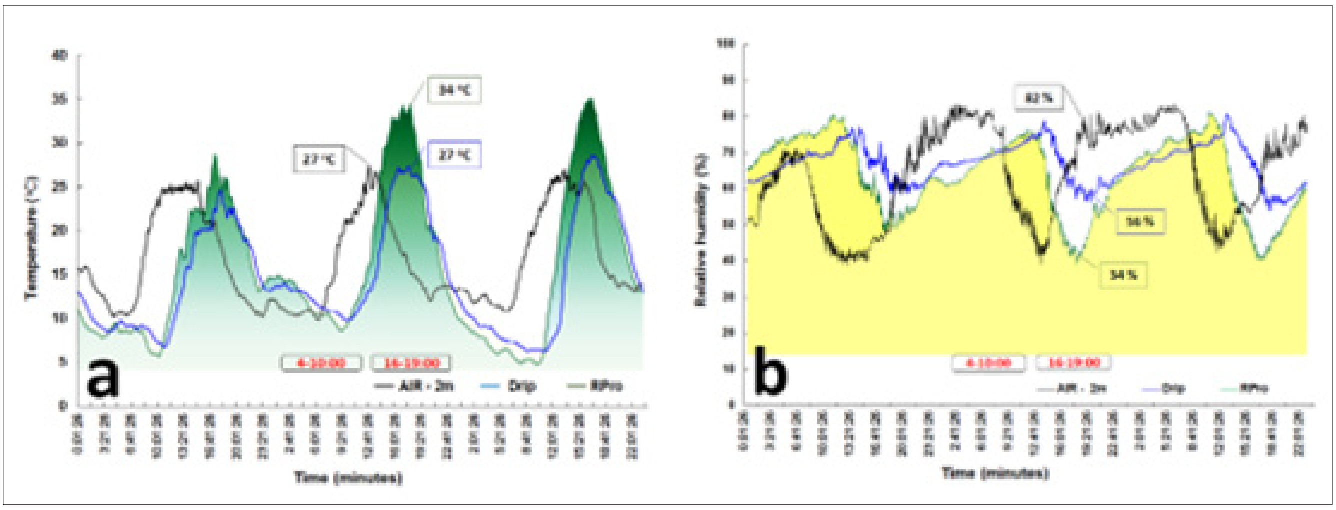

Figure 1: Microclimate in the foliage:
a) temperature (oC RPro in green color),
b) relative humidity (%, RPro in yellow color).

Oxygen concentration in the soil solution

Between RPro and Drip a significant difference according to the mean test was computed for the content of the oxygen (p-value, 1.29E-8). The maximum concentration of oxygen in RPro was 12.0ppm and in Drip about 8.99ppm. The minimum concentration of oxygen in RPro was 6.44 ppm and in Drip about 5.70ppm. In RPro, the average concentration of oxygen was 16.0% higher than Drip. The intermittent water application reduced the application rate of the drippers from 6.25mm h^{-1} to 0.21mm h^{-1}. Previous researchers found that pulse irrigation increases the aeration of the soil solution [3,19] and it reduces the application rate while using drippers with higher discharges [3,20]. The results are consistent with those findings, because the intermittent application avoids the air displacement from the soil porosity during irrigation due to the reduced rate of the drippers (0.21mmh^{-1}), which maximizes the oxygen availability for the root system and it improves the living conditions for beneficial fungi.

Soil moisture content

Figure 2 shows the variation of the moisture content for both water management techniques. In RPro, the mean moisture tension was 7.5 centibars and in Drip around 13.3 centibars. The intermittent water application raised the soil moisture content above field capacity despite the moisture tension objective. El-abedin [7], Skaggs et al. [8], Abdelraouf et al. [21], Eid et al. [9] and Zamora et al. [10] found that pulse irrigation increases the moisture content in the soil above field capacity and Segal et al. [6] reported that higher moisture contents increase the water potential and the hydraulic conductivity of the soil. In fact, moisture contents above field capacity reduces the osmotic potential produced by the salts and it improves the distribution of water and nutrients in the entire wetted zone owing to the higher hydraulic conductivities, improving the water use by the plants to match the maximum transpiration demand, ensuring higher yields [3].

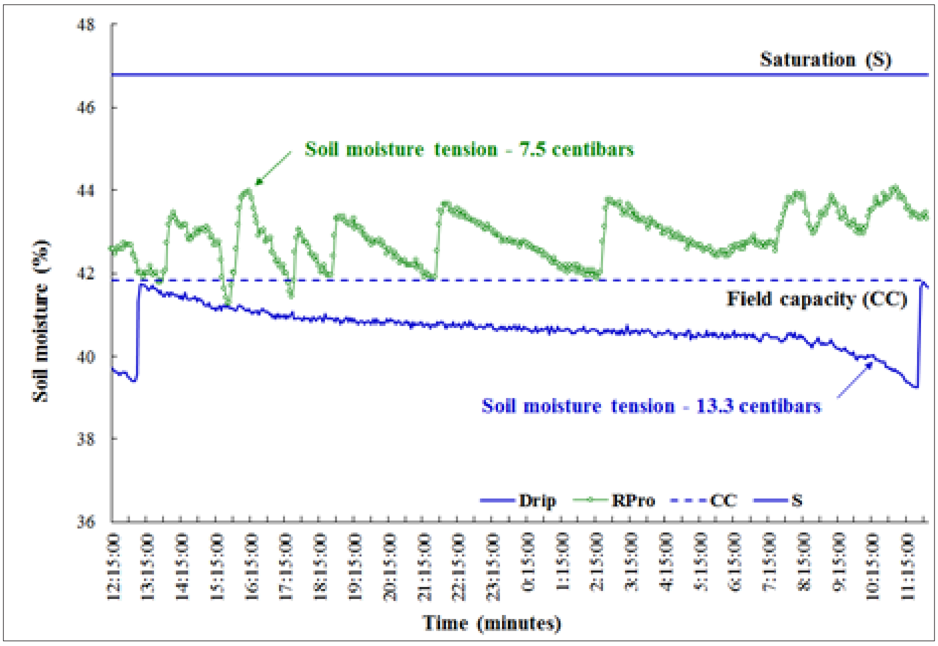

Figure 2: Soil moisture content in Drip and RPro.

Wetting bulb and wetting zone

Between RPro and Drip a significant difference according to the mean test was computed for the width of the wetted zone (p-value, 7.8E-4). In Drip, the width of the bulb was 34.06cm and the depth about 48.05cm; in RPro, the width of the zone was 51.07cm and the depth about 25.08cm. In RPro, the width of the wetting zone was greater than Drip by 49.94% and the depth was 47.80% shallower, considering that the soil is Cangahua (rock). Al-Naeem [22], Elmaloglou [23] and Ismail et al. [24] reported two advantages of the pulse against the continuous irrigation:

i) it reduces the water losses by deep percolation and

ii) it creates wider wetting zones. Al-Ogaidi et al. [25] and Kilic [11] developed and tested a numerical model to predict the wetting pattern (width and depth) in function of the number of pulses and as the number of pulses increases the wetting zone gets wider and shallower. These findings match fully the results described herein. Certainly, when the water supply is continued, the movement of water occurs downward by gravity with deeper wetting bulbs and water losses by deep percolation. Applying water in short times facilitates the water movement by capillary forces, resulting in a wider and shallower wetting zone, reducing the water infiltration to no more than 25cm depth and avoiding water losses by deep percolation. Moreover, in RPro, the secondary root system of the crop was distributed horizontally in the wetting zone, while in Drip, the roots were spread vertically into the wetting bulb.

Nutrients in the soil solution

Figure 3 shows the variation of the nitrates content and the electrical conductivity in the soil solution for T2 and RPro. In the first 45 days of the crop vegetative cycle, for the same fertilizer dose (50 %), NO_3 and CE were higher in the continuous irrigation than RPro. From days 45 to 70, NO_3 and CE were higher in RPro than T2. From day 70 to 105, NO_3 was almost the same and CE was lower in RPro. In previous investigations, it was found that moisture contents above field capacity under pulse irrigation improves the nutrients uptake by the crops [6,9,15,21,26]. As matter of fact, the intermittent water application was more efficient than the continuous regime based upon the nutrient´s uptake: in the first period, the rate of absorption of the nutrients in RPro was higher because the younger roots are distributed in the upper part of the soil profile were the nutrients are distributed uniformly due to the higher hydraulic conductivities; in the second period, the contents of NO_3 and CE were higher because of the larger period of activity of the plant, producing more pods per plant.

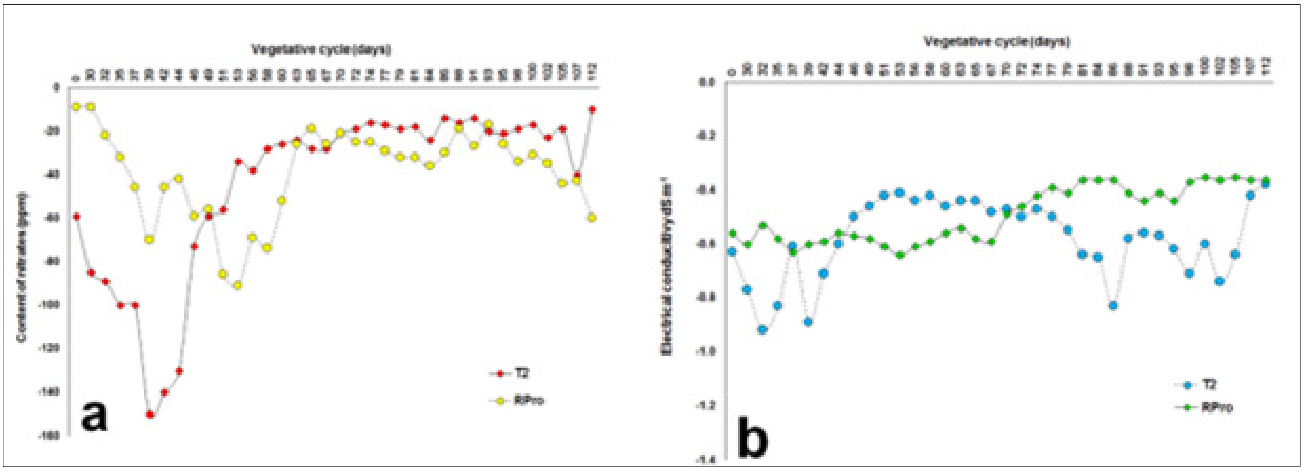

Figure 3: Soil solution chemistry in Drip and RPro:
a) content of nitrates,
b) Electrical conductivity.

Nutrients in the soil solution

Table 2: Average yield in the two cycles.

Treatments	R (t ha^{-1})	
	2018	**2019**
Drip	3.11 c	3.11 c
T2	3.05 c	3.04 c
T3	4.12 a	5.18 a
RPro	3.89 b	4.87 b
Irrigation	3.39 *	15.23 *
Fertilization	7.76 ns	0.14 *
Interaction	2.79 ns	0.05 *

*p<0.05; ns, not significant.
Similar letters are not different statistically.

Table 2 summarizes the crop yield and the statistical analysis of the variance for all treatments. In relation to the factor irrigation methods, there were significant differences and for the factor fertilization doses there was no significant differences. For the 100% fertilizer dose, the yield was higher in T3 than Drip by 49.40%; for the 50% fertilizer dose, the yield was higher in RPro than T2 by 43.9%. The results were consistent over the two cycles. Previous research's tested pulse and the continuous irrigation with the following results: El-Mogy et al. [15] in Egypt, the fresh bean crop under drip irrigation yielded 11.0t ha^{-1} for four applications and 9.0t ha^{-1} for one application. Sivisaca [13] in Ecuador, for irrigation frequencies of 1 and 3 days obtain 3.2 and 2.4t ha^{-1}, and Jasso [14] in Mexico, under fertigation, reported a yield of 5.1t ha^{-1}. Contrasting the later yields with RPro, it was higher than the reported in Ecuador and almost the same than the reported in Mexico, remembering the conditions of the experiment: 100 thousand plant density, crop cultivated on cangahua (rock), and the yield reported correspond to the marketable weight (moisture of 12%). The yield was higher in the intermittent drip irrigation due to the better plant's physiological activity, enhanced by the optimum oxygen availability, moisture contents above field capacity and nutrients distributed uniformly in the wetting zone.

In the intermittent water application, the days to harvest were 105 in T3 and RPro. In the continuous water application, the days to harvest were 120 in T1 and T2. The vegetative cycle of the beans crop was shorter in two weeks in the intermittent irrigation, this discovery can be addressed to the higher temperatures occurring in the afternoon during the dissipation of the energy absorbed by the crop (Figure 1).

Water depths

There was a significant difference between the water depths for both methods of water application (p-value, 0.04). The average of the water depths applied in the two cycles were: Drip, 368.15mm; T2, 370.30mm; T3, 250.50mm and RPro, 236.40mm. The intermittent irrigation presented water savings about 46.97% in relation to T1, and 56.64% contrasted with T2. The intermittent drip water management reduces the water use because it avoids the water losses by deep percolation.

Conclusion

RPro is a drip water management technique that takes the advantages of the nature (soil-water-climate-plant) to enhance more crop per drop, in a shorter time by using less water and less fertilizers. It:

A. creates wider and shallower wetting zones

B. increases the aeration of the soil porosity and the oxygen availability for the plants

C. improves the soil environmental conditions for beneficial fungi

D. increases the hydraulic conductivity to improve the water and nutrients distribution in the wetted zone

E. avoids water losses by deep percolation

F. reduces the conventional fertilizer dose because the moisture content above field capacity reduces the soil absorption, and

G. improves the plant´s physiological activity.

The Andean beans crop variety "Rojo del Valle" presented a higher yield of 40.80% when irrigation water is applied intermittently than the continuous supply, 212.9% higher than the mean yield reported by the Experimental Station [16] and 606.4% compared to the national average yield [12].

RPro allowed reducing the water usage by 55.73% in relation to the conventional drip water application, being the intermittent application of water in low volumes more efficient than the continuous irrigation, because it avoids water losses by deep percolation [27-30]. With RPro, 50% of the conventional dose of fertilizers is required to obtain higher yields than the conventional drip water application, because the movement of the nutrients by diffusion in the wetting zone makes more efficient the fertilization as well as avoids nutrients leaching [31-33]. In RPro, the vegetative cycle of the crop was reduced by two weeks, because the application of water in low volumes with high frequency improves the plant´s physiological activity due to the suited oxygen, moisture and nutrient availability in the soil solution.

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