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FERTIGATION DISTRIBUTION WITH LOW PRESSURE MULTIGATE IRRIGATION SYSTEMS IN A SUGARCANE AGROECOSYSTEM

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ABSTRACT

In the state of Veracruz, Mexico, low sugarcane yields are reported despite the high use of inputs. This results in economic losses and environmental pollution. A fertigation system designed at the Colegio de Postgraduados (COLPOS) Campus Veracruz was established to determine the uniformity and stability of fertilizer distribution in the sugarcane crop. This study was carried out in a sugarcane plot with a farmer participant. Three levels of valve openings at the injector inlet (1/3, 2/3, and 3/3) were tested to determine the homogeneity of fertigation at the outlet of the gates and the stability of the system over time. Samples of water-fertilizer mixture were taken at the outlet of the gates. They were analyzed in the laboratory with a UV-visible spectrophotometer at 202 nm for nitrogen. It was found that the 1/3 and 3/3 valve position openings caused instability in the system. For the 2/3 opening with $p = 0.359$, no statistical difference ($\alpha = 0.05$) was found during the time of emptying the container of the water-fertilizer mixture. Therefore, the fertigation system proved to be stable with a valve opening close to 2/3. Using the valve openings, the flow rate of water-fertilizer entering the system is uniformly mixed at the outlets of the multi-gate pipeline that pours into the crop furrows ($p = 0.474$ and $\alpha = 0.05$). It can be concluded that in fertilization using a low-pressure irrigation system, nitrogen fertilizer is uniformly distributed when a Venturi type injector is used in a sugarcane agroecosystem with a valve opening close to 2/3.

Keywords: *Saccharum* spp., urea, fertilization, low pressure irrigation, contamination.

INTRODUCTION

According to the National Water Commission (CONAGUA), 77 % of the water available in the Mexican Republic is used in agriculture (CONAGUA, 2019). In addition, sugarcane fertilization is usually applied "broadly", using granular fertilizers such as urea. This represents a potential problem in terms of water and environmental pollution. It is estimated that to produce 1 kg of refined sugar, 1782 L of water are required (Water Footprint Network, 2018a). Thus, proper water and

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fertilizer management are imperative to reduce the water footprint and environmental pollution.

Multi-gate irrigation systems have an efficiency rate between 70 and 85 % (Flores-Gallardo *et al*., 2014; Ramírez *et al*., 2014). This suggests that the current trend is to increase the efficiency of irrigation water used for food crops; i.e., to decrease the ecological footprint (Water Footprint Network, 2018b). A low-pressure irrigation system consists of a water piping system that takes advantage of the difference in levels - hydraulic pressure between the source and the field, to use the necessary hydraulic head pressure during irrigation (Vargas and Escobar, 2015).

The pipeline has some adjustable gates in front of each furrow or group of furrows; these gates allow adjusting the water flow for irrigation delivered in the furrows (Ferreyra, 1989) (Figure 1). The importance of using a low-pressure irrigation system with multi-gates lies in the fact that it allows a more efficient water management. At the same time, it prevents ground water contamination from percolation of solid nitrogen fertilizers and reduces production-labor costs of fertilization (Flores-Gallardo *et al*., 2014).

Low-pressure pipe irrigation systems with multi-gates are technological packages improved by the Mexican Institute of Water Technology (IMTA) in 1986. They use a main pipe, a hydrant or check valve, and pipes with multiple gates that control the flow of water discharged into the furrows (Figure 2). Sugarcane is used as raw material for granulated sugar production. Under the concept of climate-smart agriculture (Azadi

Figure 1. Multi-gates in a low-pressure irrigation system in sugarcane (*Saccharum* spp. hybrid) var. Mex 69-290.

Figure 2. Channelized low-pressure irrigation system with multiple gates in sugarcane cultivation (*Saccharum* spp. hybrid) var. Mex 69-290.

et al., 2021), fertigation represents a feasible approach for agroecosystems (AES) with sugarcane. In turn, fertigation is the application of fertilizer through irrigation water (Hedley, 2015; Qin *et al*., 2016). It is an agricultural practice designed to simplify fertilizer application and improve its distribution uniformity (Abbasi *et al*., 2012). Fertilizer distribution through fertigation allows the nutrients to reach the desired location of the root zone and, therefore, reduces the amount of fertilizer applied (Al-Qurashi *et al*., 2015). Consequently, efficient management and fertigation practices can mitigate the impact on air and ground water quality in the zone near the crops.

The application of nutrients to plants with irrigation water (fertigation) has proven to be a cost-effective and efficient method of fertilizer application to improve agricultural production and reduce potential environmental problems, as compared to conventional methods (Abbasi *et al*., 2012). Based on the above, better yields can be achieved in AES with sugarcane. The aim of this study was to assess the uniformity and stability in which the gates of a multi-gate pipeline of a low-pressure irrigation system distribute nitrogen fertilizer when a Venturi-type injector is used in an AES with sugarcane.

MATERIALS AND METHODS

Study area

The experiment was carried out in an AES plot with improved sugarcane variety Mex 69-290 and a surface area of one and a half hectares with multi-gate irrigation, located in the Ejido Arroyo de Piedra, municipality of Actopan, Veracruz, Mexico. The Arroyo de Piedra community is located at an altitude of 100 m, at coordinates 19° 40′ 86″ N and 96° 51′ 91″ W (Figure 3), and has a population of approximately 1207 inhabitants. Irrigation on these communal lands is provided by the Módulo de Riego II-1 Actopan, Distrito de Riego 035 La Antigua. The lands of the irrigation module range in altitude from 1 to 1000 m. The experimental plot is located in the same area as the irrigation module, at coordinates 19° 25′ 47.38″ N, 96° 30′ 8.79″ W. Its main tributaries are the Actopan and La Antigua rivers. The irrigation district has over 2827 km^2 of irrigated land.

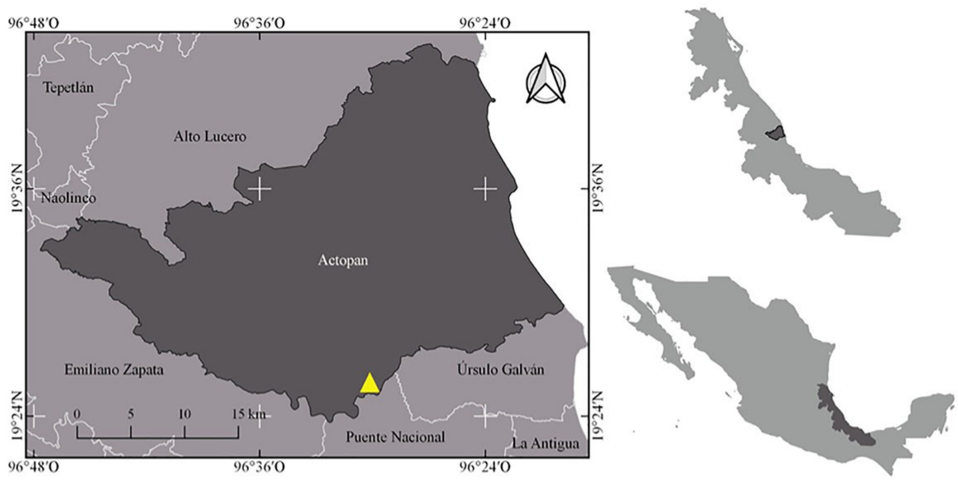

Figure 3. Geographical location of the experimental plot of sugarcane (*Saccharum* spp. hybrids) var. Mex 69-290 in Ejido Arroyo de Piedra, Actopan, Mexico.

For this study, a sugarcane crop (*Saccharum* spp. hybrid) var Mex 69-290, with annual cycle was used as the sampling unit. The outlets of a multi-gate system were used as experimental units (U_E), which were selected using a systematized sampling technique.

Experimental design

To carry out this study, the rationalist and functional-structural epistemological approach was used, where the operation of the multi-gate fertigation system and a Venturi type injector was validated. The maximum length for the multi-gate irrigation pipeline was 105 m. The distance between furrows was 1.2 m, and the gates at the same distance from each other. Consequently, the maximum number of gates in each sampling was N = 83. A representation of the fertigation system with low-pressure irrigation pipes with field- installed multi-gates (UE) is shown (Figure 4). The irrigation system had a flow rate of G ≈ 35 L s^{-1}.

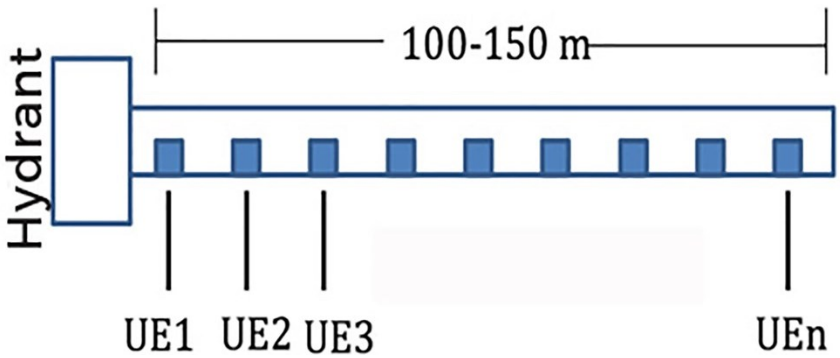

Figure 4. Layout of the multi-gate piping used for fertigation in an AES with sugarcane (*Saccharum* spp. hybrid) var. Mex 69-290. The experimental units (U_E) correspond to the gates of the fertigation system from which the samples were taken.

The population parameter was μ; therefore, the estimator was $\bar{x}$. To estimate the population ratio for the minimum sample size $\bar{x}(n)$, a 95 % confidence interval (IC) was used. The sample size n for each level of valve opening factor was 52 gates. The sampling method was systematic, with k = 1.6, i.e., water-fertilizer samples should have been taken at the outlet of every 1.6 gates. Since this cannot happen, the following was done to select the gates to be sampled: the gates were numbered and selected by multiples of 1.6 (1.6, 3.2, 4.8, 6.4, 8 ...). From the resulting list, they were rounded to the nearest number, either up or down (2, 3, 5, 6, 8...). Finally, 52 gates were randomly taken over the entire length of the multi-gate pipeline, representing the experimental units (U_E). The experimental design model for this study is shown (Figure 5).

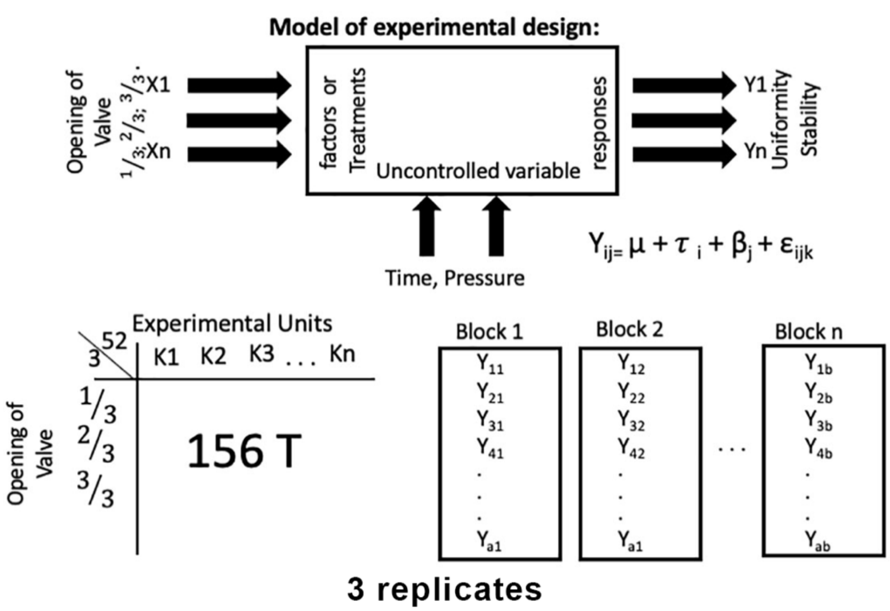

Figure 5. Model of the experimental design used in this research work.

In the experimental design, two variables were included: time variable, i.e., the time it takes for the water-fertilizer solution to travel from the container along the fertigation system to reach the multiple gate outlets, and the hydraulic pressure variable at the system inlet. However, the latter is not considered to be a blocking variable, since it is not easy to have control over it. Then, a complete randomized block design was used, taking a single factor a of the valve opening type with three levels, and the multigate outputs factor with 52 levels (U_E *b*), blocks (axb). That is, this design included 52 experimental units given by factor *k* (selected outlets of gates) and a factor called Valve opening (polycotomical variable) with three levels of position: 1/3, 2/3 and 3/3 (total opening), a total of 156 treatments by three samples of repetitions in each experiment. The statistical hypothesis was that all treatment measures were equal $H_0 = \mu_1 = \mu_2 . . . = \mu_n$, at least for one of the levels of the valve opening factor, showing homogeneity in fertilizer distribution. Non-parametric Kruskal-Wallis statistical tests were performed to analyze differences between means and determine fertilizer application homogeneity, as well as parametric tests to compare means through a one-factor analysis of variance to determine fertigation stability.

The experiment was conducted on three different days (three replicate samples) of the same week. Three replicates were performed in each replicate test per factor level. This is intended to avoid inducing an error in a change of valve level. Urea dissolved in water was used as the analyte for the injected nitrogen. The variables to be measured were: valve opening factor, with three levels of treatments: 1/3, 2/3 and 3/3, and fertigation homogeneity using urea concentration (water-urea mixture) as the analyte at the outlet of each multi-gate of the fertigation system, selected by the sampling technique. Although N loss is assumed when urea is dissolved in water, the experiment was designed as such because it is a fertigation system, i.e., a fertilizer application through the irrigation system.

The fertigation system consisted of a multi-gate irrigation system with a water source from a tributary of the Actopan River and a Venturi type fertilizer injector designed at the Colegio de Postgraduados (COLPOS) Campus Veracruz. The Venturi type injector was made of a 3/16” thick carbon steel plate. The hydraulic connectors used in the multi-gate irrigation system were flanged to the injector (Figure 6). In the second stage, the fertigation system was validated in the field by using water from the source for the visual tests with red dye in place of the fertilizer to follow the path from the reservoir to the furrows. The third stage consisted of fertigation with a water-urea solution to identify fertilizer application homogeneity. The urea concentration at the outlet of each gate of the selected system was measured for comparison. In the fourth stage, the water-fertilizer samples taken from the U_E were analyzed in the laboratory. Finally, in a fifth stage, the statistical analysis of the samples collected in the field was carried out.

Figure 6. Venturi injector used for fertigation in the low-pressure irrigation system with multi-gates in sugarcane cultivation (*Saccharum* spp. hybrid) var. Mex 69-290.

Fertigation with nitrogen fertilizer solution. Tests of homogeneity of fertilizer distribution along the entire length of the pipeline

In the third stage, a fertigation system with low-pressure pipes and multi-gates was installed in the field (Figure 7). Samples were collected at the outlets of the multi-gates. Prior to sampling, the outlets of the multi-gates were gauged to establish similar conditions in the gates to be sampled. A water-fertilizer mixture was prepared for

Figure 7. Field tests of the fertigation system on land cultivated with sugarcane (*Saccharum* spp. hybrid) var. Mex 69-290.

fertigation using water and granulated urea (Fertigolfo®), with 46 % N. This solution was used as a liquid fertilizer in the system. A total of 60 kg of urea was dissolved in 1000 L of water for each replicate of the experiment. Samples of the water-fertilizer solution were taken at the outlets of the multi-gates using the systematic sampling technique described previously. Three factors of the experimental design corresponding to different valve openings (1/3, 2/3 and 3/3) were tested by regulating the amount of fertilizer entering the injector to see their effects on the fertigation homogeneity at the outlet of the gates. Samples of the water-fertilizer mixture doses were taken at the outlet of the gates of the irrigation system, which were analyzed in the laboratory with a UV-visible spectrophotometer to compare them by means of an analysis of means in stage five.

Subsequently, the total nitrogen (N) content of the water-fertilizer samples was analyzed by spectrophotometry. For this purpose, five samples were prepared using solutions of urea reagent grade A.C. S. (Meyer) and distilled water at concentrations of 2, 4, 6, 8, and 10 g L^{-1}. A scan was performed in the UV-visible Spectrophotometer Thermo Scientific MOD. G10S UV-VIS in the wavelength range of 190 to 350 nm absorbance. From the sweep, a curve showing the peak of the measured spectrum was obtained, and it was determined that the urea-water solutions could be measured at the peak wavelength of 202 nm. In these same samples, the amount of total nitrogen was determined by the Kjeldahl method to elaborate a calibration curve that was used to estimate the nitrogen contained in the samples.

The calibration curve was constructed using the water-fertilizer solutions measured in the spectrophotometer at a wavelength of 202 nm (absorbance vs. urea concentration) (Equation 1), corresponding to the linear regression obtained by the least square method with a coefficient of determination $\mathbf{R^2 = 0.65476}$.

$$Y = 0.0887x + 1.5604 \tag{1}$$

Similarly, the amount of total nitrogen in these same water-urea samples was determined by the micro-Kjeldahl (NTK) method, in accordance with the NMX-AA-026-SCFI-2010 standard for determination using micro-Kjeldahl in a LABCONCO Rapidstill II equipment of the Soil and Water Laboratory of the COLPOS Campus Veracruz. NTK was determined using the water-urea calibration curve. With this calibration curve and the NTK measurement, a calibration curve (absorbance vs. NTK) was made to estimate the NTK in the samples collected, with a coefficient of determination $\mathbf{R^2 = 0.97885}$ **(**Equation 2).

$$Y = 8E - 0.5x + 2.3977 \tag{2}$$

Fertigation system stability testing

In addition to homogeneity, the stability of the fertigation system was tested for each level of valve opening, i.e., the behavior of the distribution with respect to time in the application of fertilizer. Similarly, the fertigation holding tank was filled with a solution of 60 kg of granulated urea dissolved in 1000 L of water. The 83 gates were numbered, corresponding to the 105 m of pipe section used for fertigation. Three gates were sampled from the 83 available outlets: numbers 12, 44, and 73, located at the beginning, middle, and end of the length of the pipe section, respectively. Samples were taken at the outlets of the three gates, with two replicates for each level at five different times of emptying the tank containing the fertilizer solution. The five levels sampled were at the remaining 900, 700, 500, 500, 300, and 100 L of the solution content of the container tank. Three replications of the experiment were carried out on different days. This was done to find out if the decrease in hydraulic pressure as the tank was emptied, influenced the suction of fertilizer from the injector, and to identify any variation in the concentrations at the outlet of the gates with respect to the time when the water-fertilizer solution was emptied from the container. With this, the valve opening that showed the greatest stability of the system was identified.

In stage four, the urea-water samples from the field experiment were analyzed in the UV-visible spectrophotometer at a wavelength of 202 nm for absorbance, using quartz cells. By using the NTK calibration curve, the amounts of total N in each sample were estimated. Kolmogorov-Smirnov normality tests were performed on the data set corresponding to nitrogen fertilizer for valve openings, with $\alpha = 0.05$. In addition, a Kruskal-Wallis H-test with $\alpha = 0.05$ was performed to compare U_E and a two-way Friedman analysis of variance by ranks for samples related to $\alpha = 0.05$ to find similarities.

Finally, in stage five, the data from the experiment were processed by means of a statistical analysis of means comparison in the IBM SPSS® V25 statistical software. The null statistical hypothesis H_0 was that all the means of the multi-gate outlets were equal for some level of the Valve Opening factor.

RESULTS AND DISCUSSION

Statistical differences were found between the uses of each valve opening. It was also identified that the wider the opening, the higher the concentration and vice versa (Table 1).

Table 1. Data set statistics of the experiment with nitrogen fertilizer.

Combinations for Nitrogen concentration	Mean	Variance	Median	S.D.	Dev. Error
Replicate 1 and valve opening at 1/3	3.960903	0.085272	3.879166	0.292014	0.040495
Replicate 2 and valve opening at 1/3	2.864293	0.157390	2.813777	0.396724	0.055016
Replicate 3 and valve opening at 1/3	2.179401	0.089137	2.086607	0.298557	0.041402
Replicate 1 and valve opening at 2/3	6.931807	0.135741	6.906224	0.368430	0.051092
Replicate 2 and valve opening at 2/3	6.481933	0.059828	6.460903	0.244597	0.033920
Replicate 3 and valve opening at 2/3	6.280736	0.084279	6.319978	0.290308	0.040258
Replicate 1 and valve opening at 3/3	6.931807	0.135741	6.906224	0.368430	0.051092
Replicate 2 and valve opening at 3/3	6.481933	0.059828	6.460903	0.244597	0.033920
Replicate 3 and valve opening at 3/3	6.280736	0.084279	6.319978	0.290308	0.040258

Water-urea concentrations (g L^{-1}). S.D.: standard deviation; Dev: deviation.

Homogeneity for the fertigation system of the fertilizer irrigation system

The homogeneity of the system was evaluated with water-fertilizer for the three levels of valve position opening factor: 1/3, 2/3 and 3/3. The main statistical results for each replicate and for each experimental opening are shown (Table 1). In the exploratory analysis of the data set, very little variance is observed, implying that the fertigation concentrations at the outlets in the multi-door pipes for the evaluated openings are similar.

A Kolmogorov-Smirnov normality test was performed on the data set corresponding to nitrogen fertilizer for valve openings, with α = 0.05. The results were below the defined α. Therefore, it was decided to perform an analysis of variances through nonparametric tests to compare significant differences between fertigation outputs at each level and between openings. In this case, a Kruskal-Wallis H-test with α = 0.05 and a two-way Friedman analysis of variance by ranks for related samples with α = 0.05 were performed. The results were the same for all three replicates, with p value = 0.474 (asymptotic significances); the distribution of urea concentrations (g L^{-1}) was the same. There were no differences in multi-gate pipe openings in any of the replicate samples for the 1/3 opening. This shows homogeneity in fertigation application. This same behavior was present at all three valve opening levels.

A two-way Friedman's rank analysis of variance for related samples showed that the nitrogen concentration distribution was the same across the 1/3 valve opening replicates. There were differences between replicates of the same level with α = 0.05 and a p value = 0.0001. This was due to unintentional errors induced in the experiments such as: at some time the fertilizer hose was disconnected from the tank at the end of some sampling, no attention was paid to the tank levels at the time of preparing the doses, the tank was filled with different water sources because in some days there was no drinking water, the urea dissolution was not properly completed in the storage tank because the solution was not stirred, it rained on the day of sampling and it is assumed that there was an extra nitrogen input in the irrigation water inlets, or once the tank was forgotten to be uncovered and the suction of the injector "sucked" the tank and the fertilizer injected in a repetition did not come out normally. These ~~details~~ failures were corrected. The data collected from this experiment were not taken into account for the final analysis; however, they were useful for the discussion. Subsequently, a Kruskal-Wallis test with α = 0.05 was performed to determine if there were differences in the distribution of nitrogen concentration (g L^{-1}) in the use of the three valve openings.

Differences were found between the uses of each valve opening for experiments conducted with nitrogen fertilizer with a value of p = 0.0001. It was also observed that the higher the valve opening, the higher the concentration and vice versa. These results support the ~~Ho~~ hypothesis, since there are differences in the concentrations of nitrogen fertilizer when using different valve openings to regulate the fertilizer to be injected (Figure 8).

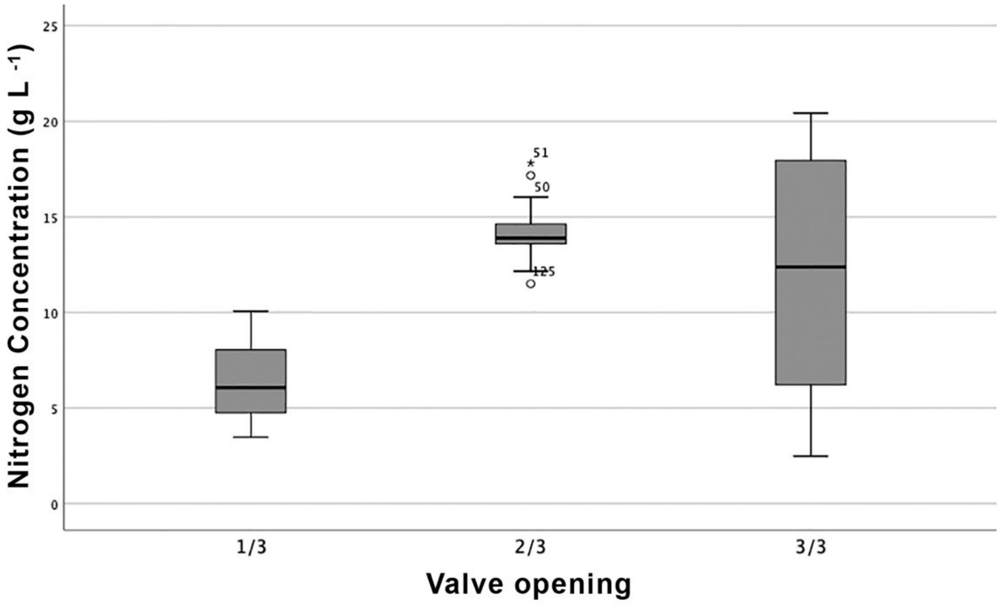

Figure 8. Differences in the concentration of nitrogen injected at the gate outlets due to valve openings.

Stability test results for the fertilizer irrigation system evaluated

This section presents the results of the experiment designed to compare the stability of the system using the three valve openings. The gate outlets 12, 44, and 73 were selected from U_E; with five times each. Only two repetitions were considered due to the resources, complexity, and logistics of the experiment. Initially, a normality test (Table 2) was performed on the data to determine the type of test to be performed for comparison of the means.

It was concluded that the data fit a normal distribution when values of $p > \alpha$ were obtained, as shown in the table above, so we proceeded with the parametric tests for

Table 2. Normality test: Shapiro-Wilk with Lilliefors significance correction, $\alpha = 0.05$ for the stability data set for the fertilizer irrigation system in sugarcane (*Saccharum* spp. hybrid) crop var. Mex-69-290.

Combinations for Nitrogen concentration	Test statistic (W)	f.d.	*p*-value
Replicate 1 and valve opening at 1/3	0.951943	15	0.555558
Replicate 2 and valve opening at 2/3	0.953043	15	0.573586
Replicate 1 and valve opening at 1/3	0.917183	15	0.174464
Replicate 2 and valve opening at 2/3	0.917357	15	0.175537
Replicate 1 and valve opening at 1/3	0.948530	15	0.501605
Replicate 2 and valve opening at 2/3	0.949487	15	0.516400

comparison of means. In this case, an analysis of variances (ANOVA) of one factor was used, with Tukey HDS test as Post-Hoc; both with an $\alpha = 0.05$.

For valve openings 1/3 and 3/3 there were differences in the concentrations at the outlets of the gates sampled for stability, so their analysis was not continued. The results for the three openings with their respective *p*-values are shown (Table 3).

With these results, Post Hoc tests were performed with the 2/3 opening to identify the grouping in the times, performing the Tukey HDS test (Table 4).

Table 3. Results of ANOVA to compare the stability at the three valve openings with respect to the time of emptying the liquid fertilizer container.

Valve Opening	Replicate 1 *p* value	Replicate 2 *p* value
1/3	**0.002733**	**0.034107**
2/3	0.114694	0.216066
3/3	**6.7384^{-10}**	**5.7959^{-7}**

Table 4. Tukey HDS test for 2/3 opening stability, $\alpha = 0.05$.

Times 2/3	N	Subset A replicate 1	Subset B replicate 2
5	3	6.094499	6.128321
4	3	6.267366	6.372590
3	3	7.120429	6.661955
2	3	7.289538	7.154251
1	3	7.518776	7.285780
p value		0.359955	0.342907

The results of nitrogen fertilizer concentration in five different types of tank emptying, using urea for each experiment replicate, belong to the same subsets, respectively (Table 4). With *p* value = 0.359955 and 0.342907, both sample replicates indicate that there were no significant differences with respect to the emptying time. Consequently, it is concluded that this system behaves in a stable manner as the tank empties the fertilizer content, at least for a valve opening close to 2/3.

Quaggio *et al*. (2014), Sedaghatdoost and Ebrahimian (2015), Qin *et al*. (2016), and Šimůnek *et al.* (2016) have conducted studies on the uniformity of fertilizer application using fertigation techniques. However, only a few of these studies have simultaneously evaluated the stability of fertigation systems, which is considered of vital importance in the quest for homogeneous fertilizer distribution in crops.

Rosano-Méndez *et al*. (2001) calibrated a fertigation model and compared it with a traditional method; in comparison, the present study demonstrated both homogeneity and stability of the system, mainly due to the Venturi injection device used. In further studies, it will be necessary to examine the distribution with fertigation according to soil types. Consequently, the uniformity of fertilization application (UAF) in a fertigation system depends on the fertigation system devices (DSF), the system stability (ES), and the fertigation strategy defined by the end user (EFUF) (Equation 3).

$$UAF = f\,(DSF + ES + EFUF) \qquad (3)$$

In the fertigation system evaluated at a fertilizer flow control 2/3 valve opening entering the system through the injector, uniformity was not affected when the system pressure in the fertilizer holding tank decreased.

Efficiency in the management of available hydraulic resources should improve for sugarcane production (Surendran *et al*., 2016). The above is achieved by adopting agronomic practices such as nutrient application using fertigation as a proposed system in low pressure pipes (dos Santos *et al*., 2016). Such benefits were demonstrated in this study through the homogeneous distribution of fertilizer in the fertigation practice.

The injection rate has a significant impact on the uniformity of fertilizer distribution. This idea is only accepted when evaluating a system in terms of time (stability). In this study, it was shown that if a cross-sectional test is performed, the injection rate is probably not significant. Consequently, when studying the uniformity of fertilizer application, the evaluation of the system stability should also be considered.

Technical factors such as fertigation strategy and input flow rate influence fertigation performance (Bai *et al*., 2013). The homogeneity of fertilizer application is determined by regulating the amount of fertilizer entering the injector, as found in this work. In that sense, the fertigation strategy induced errors that were observed and analyzed by the first-order observer. Therefore, when fertigation techniques are not applied correctly, the uniform distribution of fertilizer throughout the area to be fertilized cannot be guaranteed.

Fertigation should be used to control the amount of nitrogen applied and to avoid contamination by the leaching of excess fertilizer into the subsoil in sugarcane crops. Mismanagement of fertigation systems by end users can decrease the efficiency of such systems.

CONCLUSIONS

In the fertigation system evaluated at a 2/3 opening valve of fertilizer flow entering the system through the injector, uniformity was not affected when the system pressure in the fertilizer holding tank decreased.

The valve openings tested and the quantity of water-fertilizer entering the fertigation system obtained a uniform mixture at the outlet of the multi-gate pipe orifices in a low-pressure system that discharges the fertilizer into the crop furrows. The regulation of the quantity of fertilizer, by means of the different openings of the valve of the suction port of the nitrogen fertilizer injector, makes possible a homogeneous distribution in the system insofar as the flow rate in each of the orifices is the same. The fertigation system behaves in a stable way during the operation time in the whole path of the multi-gate pipeline only for valve openings that regulate the suction close to 2/3. At 1/3 and 3/3 openings, this fertigation system becomes unstable.

There are differences in the total amounts of nitrogen emitted from the orifices or gates of the fertigation system to the crop by varying the rate of the water-fertilizer mixture injected into the crop. The system responds linearly with respect to the fertilizer input regulated by the valve installed at the injector suction port and the output of the fertilizer mixture at the gate orifices.

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REFERENCES

Abbasi F, Rezaee HT, Jolaini M, Alizadeh HA. 2012. Evaluation of fertigation in different soils and furrow irrigation regimes. Irrigation and Drainage 61 (4): 533–541. https://doi.org/10.1002/ird.1646

Al-Qurashi AD, Awad MA, Ismail SM. 2015. Growth, yield, fruit quality and nutrient uptake of tissue culture-regenerated ‘barhee’ date palms grown in a newly established orchard as affected by npk fertigation. Scientia Horticulturae 184: 114–122. https://doi.org/10.1016/j.scienta.2014.12.034

Azadi H, Moghaddam SM, Burkart S, Mahmoudi H, Van Passel S, Kurban A, Lopez-Carr D. 2021. Rethinking resilient agriculture: From climate-smart agriculture to vulnerable-smart agriculture. Journal of Cleaner Production 319: 128602. https://doi.org/10.1016/j.jclepro.2021.128602

Bai M, Xu D, Zhang S, Li Y. 2013. Spatial–temporal distribution characteristics of water-nitrogen and performance evaluation for basin irrigation with conventional fertilization and fertigation methods. Agricultural Water Management 126: 75–84. https://doi.org/10.1016/j.agwat.2013.05.006

CONAGUA (Comisión Nacional del Agua). 2019. Estadisticas del agua en México, edición 2019. Secretaría de Medio Ambiente y Recursos Naturales: Ciudad de México, México. 276 p.

dos Santos LNS, Matsura EE, Gonçalves IZ, Barbosa EAA, Nazário AA, Tuta NF, Elaiuy MCL, Feitosa DRC, De Sousa ACM. 2016. Water storage in the soil profile under subsurface drip irrigation: Evaluating two installation depths of emitters and two water qualities. Agricultural Water Management 170: 91–98. https://doi.org/10.1016/j.agwat.2015.09.025

Ferreyra ER. 1989. Sistema móvil de distribución de agua. IPA La Platina 51: 47–52.

Flores-Gallardo H, Sifuentes-Ibarra E, Flores-Magdaleno H, Ojeda-Bustamante W, Ramos-García CR. 2014. Técnicas de conservación del agua en riego por gravedad a nivel parcelario. Revista Mexicana de Ciencias Agrícolas 5 (2): 241–252. https://doi.org/10.29312/remexca.v5i2.963

Hedley C. 2015. The role of precision agriculture for improved nutrient management on farms. Journal of the Science of Food and Agriculture 95 (1): 12–19. https://doi.org/10.1002/jsfa.6734

Qin W, Heinen M, Assinck FBT, Oenema O. 2016. Exploring optimal fertigation strategies for orange production, using soil–crop modelling. Agriculture, Ecosystems and Environment 223: 31–40. https://doi.org/10.1016/j.agee.2016.02.025

Quaggio JA, Souza TR, Bachiega Zambrosi FC, Marcelli Boaretto R, Mattos D. 2014. Nitrogen-fertilizer forms affect the nitrogen-use efficiency in fertigated citrus groves. Journal of Plant Nutrition and Soil Science 177 (3): 404–411. https://doi.org/10.1002/jpln.201300315

Ramírez GD, Ávalos JE, González MR, Valencia EAC, Arriaga GE. 2014. Evaluación y diseño del riego por melgas mediante un modelo de simulación. Agrofaz 14 (2): 45–51.

Rosano-Méndez L, Rendón-Pimentel L, Pacheco-Hernández P, Etchevers-Barra J, Chávez-Morales J, Vaquera-Huerta H. 2001. Calibración de un modelo hidrológico aplicado en el riego tecnificado por gravedad. Agrociencia 35 577–588.

Sedaghatdoost A, Ebrahimian H. 2015. Calibration of infiltration, roughness and longitudinal dispersivity coefficients in furrow fertigation using inverse modelling with a genetic algorithm. Biosystems Engineering 136: 129–139. https://doi.org/10.1016/j.biosystemseng.2015.05.011

Šimůnek J, Bristow KL, Helalia SA, Siyal AA. 2016. The effect of different fertigation strategies and furrow surface treatments on plant water and nitrogen use. Irrigation Science 34 (1): 53–69. https://doi.org/10.1007/s00271-015-0487-z

Surendran U, Jayakumar M, Marimuthu S. 2016. Low cost drip irrigation: Impact on sugarcane yield, water and energy saving in semiarid tropical agro ecosystem in india. Science of The Total Environment 573: 1430–1440. https://doi.org/10.1016/j.scitotenv.2016.07.144

Vargas JG, Escobar N. 2015. Consideraciones técnicas para el diseño de sistemas de riego por goteo de baja presión asistido por la aplicación "rilo" v-4.27. Revista Unellez de Ciencia y Tecnología 33: 100–107.

Water Footprint Network. 2018. Virtual water trade. Enschede, Netherlands. https://waterfootprint.org/en/water-footprint/national-water-footprint/virtual-water-trade/ (Retrieved: September 2018).

Water Footprint Network. 2018. Enschede, Netherlands. Product gallery. http://waterfootprint.org/en/resources/interactive-tools/product-gallery/ (Retrieved: July 2018).