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Fertigation quality with drip irrigation system in grape orchard by using the process capability index

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Abstract

The capability of the process is used to produce acceptable products or processes. Process-capability studies have large impact on many management decision problems that occur over the product cycle, including decisions and process improvements that reduce process variability. In order to study the quality of fertigation in grapes, a field experiment with drip irrigation system was conducted in a farm in the state of Parana, Brazil. The experiment was factorial 2 × 4, with two fertilizer concentrations, 200 and 400 mg L^{-1} of NPK (nitrogen, phosphorus and potassium) and four head pressures, 150, 200, 250 and 300 kPa. Analysis of variance was performed for the coefficients CUC (Christiansen's uniformity coefficient) and CVt (coefficient of total variation). The PC (process capability index) was calculated for all combinations of head pressure with fertilizer concentration. The head pressures of 150 and 200 kPa resulted in more water distribution uniformity. The relationships of CUC and CVt with CP resulted in R^2 equal to 91.84% and 93.76%, respectively. The process capability index showed that the head pressure of 300 kPa is inadequate since this index was less than 1. The process capability index showed to be able to diagnose whether the fertigation process maintains acceptable levels of water distribution uniformity. In all evaluations, CUC exceeded 90% and CVt was less than 10%, classifying the water distribution uniformity of the drip irrigation system as "Good" and "Excellent", respectively.

Key words: Head pressure, fertilizer concentration, water distribution uniformity, Christiansen's uniformity coefficient, coefficient of total variation, process capability index.

Introduction

The fertigation ensures the availability of water and nutrients around the amounts considered optimal for growth and crop productivity. This way, the quantity of nutrients, fractionated or not, must adjust to the needs of the crop during its development stages [5]. Recently, in countries like India, drip irrigation, using fertigation, is being seen as a benefit to farmers, because of the high efficiency of fertilizer application through this irrigation system [16].

The uniformity of fertigation has a direct influence on agricultural production. The irrigation quality reduces spending on water, energy and fertilizer. The importance of uniformity in fertigation is emphasized [12], since its absence implies to reduction of the quality of application, causing contamination, soil degradation and reduced productivity.

One of the important characteristics of irrigation is to be accomplished in a sustainable manner to ensure its economic viability, efficient use of water and energy. This is possible through the application of performance evaluation tools [6].

Agricultural products outside of specified standards are intended to represent a secondary market and lower profit because, besides having lower value, they have the same cost of production. Fertigation has a direct influence on the agricultural production, and its quality is of extreme importance.

The statistical quality control procedures started to be used in the industries of Japan after World War II. It is considered responsible for the triumph in the production of products, processes and services with high quality. Quality control is perfectly adaptable to agricultural production system, because with the correction and elimination of overeating and failures, reduced costs and increased productivity; many advantages have aggregated competitiveness in the field [17].

The capacity index in fertigation process means to determine how this process is appropriate in terms of quality. A high coefficient of uniformity and low variability distribution contribute to increase the value of this index, responsible for the adequacy of this irrigation by pre-establishing criteria of uniformity of distribution.

The process capability index showed to be a useful tool for the diagnosis of fertigation quality, allowing the evaluation of its ability to sustain tolerable levels of uniformity [10]. Therefore, this research aimed to evaluate the quality of fertigation in a drip irrigation system in grape orchard by using the process capability index. Several processes were evaluated at different combinations of head pressures and fertilizer concentrations.

Material and Methods

The experiment was conducted at a farm in the state of Parana, Brazil. The field was irrigated by drip irrigation in grape culture, maple and French varieties.

The irrigation system consisted of 17 drip laterals fixed to 1.8 m high on the wires supporting the vineyard. The drip laterals had 125 m in length and were spaced 2.5 m. The used emitters were pressure-compensating, from the Netafim manufacturer, model DRIPNET PC™; the emitter spacing was 0.6 m, totaling 210 emitters per lateral line, and the nominal discharge was 1.6 L h^{-1}. The experimental irrigated area was 0.53 ha.

The pressurization system was made by a 7.5 hp centrifugal pump and the water was pumped from a water course on the lower level of the farm. After the pumping, a fertilizer injection system was installed. At the beginning of the main line, a filter of 120 mesh was installed. For taking the variation of system pressure and to check the pressure stability 3 digital manometers, located at the beginning of the first lateral line, in the middle of the ninth lateral line and at the end of the last line were installed (Fig. 1). The model of manometers was INSTRUTEMP accurately scale between + 0.3% and + 700 kPa.

Each experiment was performed for the head pressures of 150, 200, 250 and 300 kPa. These head pressures were combined with two fertilizer concentrations of NPK (nitrogen, phosphorus and potassium), 200 and 400 mg L^{-1}. Thus, there were 8 treatments with 3 replicates, totaling 24 plots.

To vary the head pressure it was installed a return of water controlled by a register drawer. To apply the fertilizer concentration, a flowmeter was installed in the injection system (Fig. 1).

The methodology used for collecting the discharge was the one proposed by Deniculi *et al.* [8] with 32 points in the system. For the measurements of discharge, a mechanism with steel cables

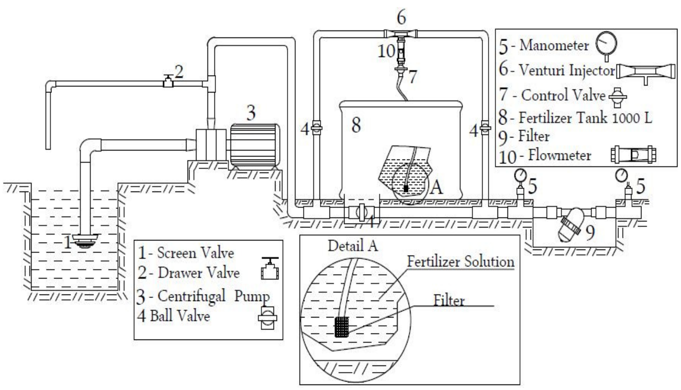


Figure 1. Schematic of arrangement of equipments.

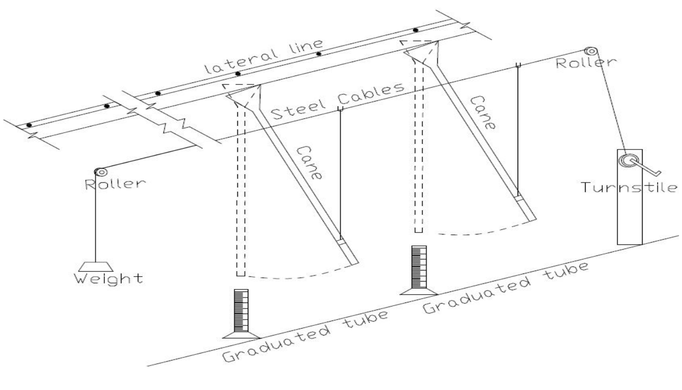


Figure 2. Collection mechanism.

and polyethylene canes was used (Fig. 2). Steel cables simultaneously moved the canes, directing water into the graduated tubes during the time of water collection and out of the graduated tubes at the end of the collection time.

Once the discharge data has been obtained, the CUC (Christiansen's uniformity coefficient) [7], CVt (coefficient of total variation) and Cp (process capability index) were determined. The Christiansen's uniformity coefficient (CUC) was found according to the equation 1:

$$CU\ (\%) = \left(1 - \left(\sum_{1=0}^{n} |q_i - q_m|\right).(n.q_m)^{-1}\right).100 \quad (1)$$

where CUC Christiansen's uniformity coefficient, %, q_i collected discharge L h^{-1}, q_m mean discharge - L h^{-1} and N number of measurements.

The coefficient of total variation (CVt) was found according to the equation 2:

$$CVt = s.q_m^{-1}.100 \quad (2)$$

where CVt coefficient of total variation %, s standard deviation and q_m mean discharge L h^{-1}.

For the calculation of the process capability index, the upper and lower specification limits were established. The limits were based on the function range of pressure-self-compensating pressure given by the manufacturer; this range is usually adopted as the scaling parameter. The range of self-compensating pressure of the emitters is from 50 to 400 kPa.

Using the equation of the characteristic curve (Eq. 3), determined at laboratory in accordance to ABNT NBR ISO 9261 [3] and the pressure limits values, the Lower Specific Limit (LSL) and the Upper Specific Limit (USL) for the discharges for fertigation processes were calculated:

$$q = 0.4807.h^{0.2478} \quad (3)$$

where q average discharge, - L h^{-1} and h head pressure, kPa.

Considering the head losses in the system, 100 kPa was used as the lower pressure specification and 400 kPa as the higher pressure specification. Thus, the LSL was 1.50 L h^{-1} and the USL was 2.12 L h^{-1}; with these values, the process capability index was calculated by Eq. 4:

$$Cp = (LSL\text{-}USL)\,6\sigma^{-1} \quad (4)$$

where Cp process capability index, LSL lower specific limit, USL Upper Specific Limit and σ population standard deviation.

With the values of the coefficients it was possible to classify the water distribution of the irrigation system and also to check the quality of fertigation processes. Linear regression between Cp and CV and Cp and CVt was obtained for verifying existing correlation between these coefficients. Subsequently, the parameters were compared to determine the statistical differences between treatments, and these factors were determinant in the performance of fertigation.

Results and Discussion

The average discharge and the coefficients CUC (Christiansen's uniformity coefficient), CVt (coefficient of total variation) and CP (process capability index) with their respective classifications are

Table 1. Average discharge and the coefficients CUC (Christiansen's uniformity coefficient), CVt (coefficient of total variation) and Cp (process capability index).

Fertilizer concentration (mg L^{-1})	Head pressure (kPa)	Mean discharge (L h^{-1})	CUC (%)	Rating	Cvt (%)	Rating	Cp	Status
		1.74	97.2	Good	3.5	Excellent	1.71	Green Light
200	150	1.73	97.5	Good	3.1	Excellent	1.89	Green Light
		1.70	97.8	Good	2.9	Excellent	2.05	Green Light
		1.74	98.0	Good	2.9	Excellent	2.06	Green Light
200	200	1.73	97.4	Good	3.5	Excellent	1.69	Green Light
		1.73	97.9	Good	2.6	Excellent	2.29	Green Light
		1.77	97.4	Good	3.6	Excellent	1.60	Green Light
200	250	1.73	96.8	Good	4.4	Excellent	1.36	Green Light
		1.77	97.2	Good	3.7	Excellent	1.57	Green Light
		1.83	95.6	Good	5.8	Excellent	0.97	Red Light
200	300	1.86	95.2	Good	6.0	Excellent	0.92	Red Light
		1.82	95.9	Good	5.4	Excellent	1.04	Yellow Light
		1.72	97.9	Good	2.7	Excellent	2.24	Green Light
400	150	1.71	98.3	Good	2.8	Excellent	2.14	Green Light
		1.70	98.2	Good	2.6	Excellent	2.36	Green Light
		1.77	96.9	Good	4.1	Excellent	1.43	Green Light
400	200	1.76	97.6	Good	2.9	Excellent	2.03	Green Light
		1.74	97.9	Good	2.8	Excellent	2.09	Green Light
		1.80	95.8	Good	5.5	Excellent	1.03	Yellow Light
400	250	1.79	95.8	Good	5.5	Excellent	1.04	Yellow Light
		1.78	95.4	Good	5.7	Excellent	1.01	Yellow Light
		1.81	96.7	Good	4.6	Excellent	1.23	Yellow Light
400	300	1.79	96.8	Good	4.7	Excellent	1.22	Yellow Light
		1.83	94.9	Good	7.1	Excellent	0.78	Red Light

summarized in Table 1. In all evaluations CUC exceeded 90%, classifying water distribution uniformity of the system as "Good"[2]. In other study evaluating the uniformity of irrigation and nitrogen fertigation of lettuce, the authors found a CU above 85% [1] and concluded that the own topography variations between emitters did not affect significantly the uniformity. In all evaluations CVt was less than 10%, classifying water distribution uniformity of the system as "Excellent" [15].

For $Cp < 1$, it corresponds to a red light, which means that the process capability is inadequate, being necessary to readjust the process in a way more appropriate to the specifications. If $1 \leq Cp \leq 1.33$, it means a yellow light, and so the process capability is around the difference between the specifications; in this case, it is often necessary to monitor the process. The green light indicates $Cp > 1.33$, and the process capability is adequate for required tolerance, and it can be considered as excellent [13].

The fertigation processes are less adequate with the head pressure of 300 kPa; there were three evaluations in which Cp was less than 1, "Red Light", everyone with 300 kPa of head pressure, two with fertilizer concentration of 200 mg L^{-1} and one with 400 mg L^{-1}. In these cases the average discharge was higher than in other fertigation processes with 1.83 and 1.86 L h^{-1}.

When the head pressure was 250 kPa and the fertilizer concentration of 400 mg L^{-1}, the fertigation processes stayed within specifications, $1 < CP < 1.33$, "Yellow Light". In this case it is necessary to monitor the process more frequently. The other fertigation processes were considered excellent, "Green Light".

Fig. 3 shows linear correlation between CUC and CP and CP and CVT, with coefficient of determination R^2 equal to 91.84% and 93.76%, respectively, showing a strong correlation with CP. This demonstrates that the CP can be used to determine the quality of fertigation processes. The process capability refers to uniformity of the process by measuring its variability, which can be instantaneous or over time [14].

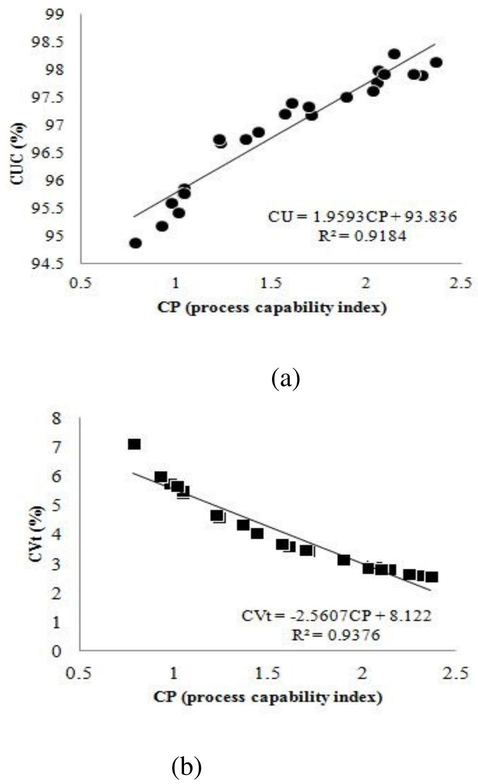


Figure 3. Relationships for CP versus CUC (a) and CP versus CVt (b).

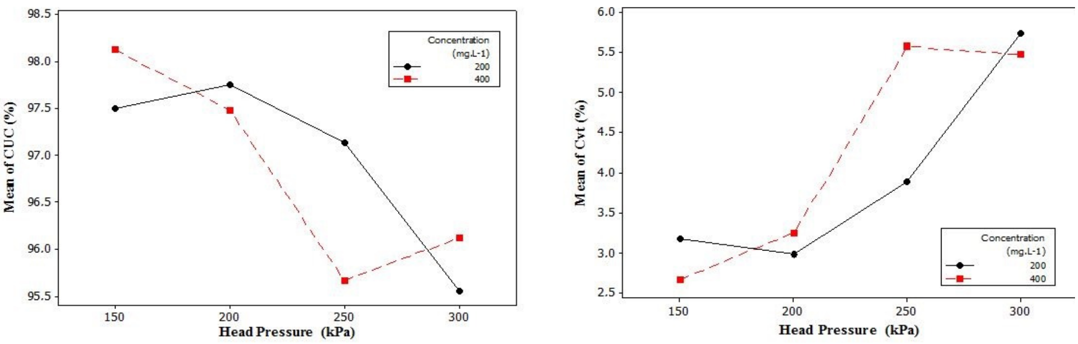
Justi *et al.* [9] in the evaluation of a sprinkler irrigation system, concluded that the increase in process capability index is directly proportional to the increase in water distribution uniformity. Another study used statistical techniques of control in a drip irrigation system the relationship is expressed by the equation $CU (\%) = 79.46 + 1.925CP$, with coefficient of determination $R^2 = 61\%$ [11].

Table 2 presents the analysis of variance for the CUC and CVt depending on the factors head pressure and fertilizer concentration. The results indicate with 95% of confidence that the head pressure affected the CU during fertirrigation and there was interaction between the factors analyzed. Teixeira *et al.* [18], testing unclogging in pressure-compensation drippers, including the model used in this experiment, concluded that the application of nitric acid at high concentration did not affect significantly the damage compensation membrane. The results for the CVt indicate the same condition found for the CUC.

Table 2. Analysis of variance for the CUC and CVt depending on fertilizer concentration and head pressure factors.

Source of variation	CUC		CVt	
	p-value	Decision rule	p-value	Decision rule
Head pressure (HP)	0.000	*	0.000	*
Fertilizer concentration (FC)	0.502	ns	0.257	ns
HP x FC	0.006	*	0.035	*

* indicates that p-value is significant and "ns" not significant at the 5% level of probability.



(a) (b)

Figure 4. Response of CUC (a) and (CVt) to the interaction between head pressure and fertilizer concentration.

The fertilizer concentration of 200 mg L^{-1} with 200 kPa of head pressure resulted in the most satisfactory values of CUC and CVt. The 300 kPa of head pressure, for the same fertilizer concentration, resulted in lower mean values of CUC and CVt (Fig. 4). The fertilizer concentration of 400 mg L^{-1} with 150 kPa of head pressure resulted in the most satisfactory values of CUC and CVt. The 250 kPa of head pressure for the same fertilizer concentration resulted in lower mean values of CUC and CVt (Fig. 4).

According to the Tukey test (Table 3), the mean values of CUC obtained for the head pressures of 150 and 200 kPa are statistically higher than the ones obtained for head pressures of 250 and 300 kPa.

Table 3. Mean values CU (%) for different pressure heads and Tukey test.

Head pressure kPa	Observation number	Mean CU (%)
150	6	97.81 a
200	6	97.62 a
250	6	96.40 b
300	6	95.84 b

The same letters in the column indicate non significant difference at the 5% level of probability.

According to Tukey test (Table 4), the mean values of CVt for the pressure heads of 250 and 300 kPa are statistically higher than the ones for the pressure heads of 150 and 200 kPa. Thus, the lower pressure heads resulted in discharge with less variability in fertigation process, which is consistent to the demonstrated ability of the process capability index. Borssoi *et al.* [4], evaluating a drip irrigation system in the field, subject to different pressures, concluded that the intermediate pressures resulted in more satisfactory values of CVt.

Table 4. Mean values of CVt (%) for different pressure heads and Tukey test.

Pressure head (kPa)	Observation Number	CVt (%)
300	6	5.61 a
250	6	4.73 a
200	6	3.11 b
150	6	2.32 b

The same letters in the column indicate non significant difference at the 5% level of probability.

Conclusions

In all evaluations, CUC exceeded 90% and CVt was less than 10%, classifying the water distribution uniformity of the drip irrigation system as "Good" and "Excellent", respectively. The fertilizer concentrations did not influence the water distribution uniformity of the drip irrigation system. The irrigation set was more uniform for the head pressures of 150 and 250 kPa. The process capability index is shown to be able to diagnose whether the fertigation process maintains acceptable levels of water uniformity.

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References

[1]Basso, C., Villafane, R. and Torres, S. 2008. Evaluation of uniformity effect of irrigation and nitrogen fertigation gardening in milky (*Carica papaya* L.). Bioagro, Barquisimeto **20**(2):105-110.

[2]Bernardo, M. M. P., Soares, A. A. and Mantovani, E. C. 2009. Irrigation Guide. 8th edn. UFV, Viçosa, 625 p.

[3]Brazilian Association of Technical Standards ABNT. NBR ISO 9261**.** 2006 Agricultural irrigation equipment - Emitters and emitting pipe - Specification and test methods. São Paulo, 17 p.

[4]Borssoi, A. L., Vilas Boas, M. A., Reisdörfer, M., Hernandez, H. R. and Follador, F. A.C. 2012. Water application uniformity and fertigation in a dripping irrigation set. Agricultural Engineering **32**(4):718-726.

[5]Cardoso, G. G. G. and Klar, A. E. 2010. Fractionation of fertigation and its effect on production of lettuce under protected cultivation. Irriga, Botucatu **16**(3):259-270.

[6]Córcoles, J. I., Juan, J. A., Ortega, J. F., Tarjuelo, J. M. F. and Moreno, M. A. 2012. Fertigation in furrows and level furrow systems. I: model description and numerical tests. Journal of Irrigation and Drainage Engineering **138**(3):225-234.

[7]Christiansen, J. E. 1942. Irrigation by Sprinkling. University of California, Experiment Station, Berkeley, 124 p.

[8]Deniculi, W., Bernardo, M. M. P. and Thiebaut, J. T. L.1980. Uniformity of distribution of water under field conditions in a drip irrigation system. Magazine Ceres, Viçosa, **27**(150):155-162.

[9]Justi, A. L.,Vilas Boas, M. A. and Sampaio, S. C. 2010. Process capacity index in the uniformity evaluation of sprinkler irrigation. Agricultural Engineering, Jaboticabal **30**:264-270.

[10]Hermes, E., Vilas Boas, M. A., Gris J. D., Frigo E. P., Berger J. S., Lins M. A. and Frigo J. F. 2014. Irrigation with wastewater from cassava processing with different concentrations of suspended solids. Journal of Food, Agriculture & Environment **12**(1):487-490.

[11]Hermes, E., Vilas Boas, M. A., Gomes, S. D., Gomes, B. M. and Reis, C. F. 2013. Quality control in irrigation and fertigation with cassava processing wastewater into drip system. Journal of Food, Agriculture & Environment **11**(2):841-845.

[12]Li, J., Meng, Y. and Li, B. 2006. Field evaluation of fertigation uniformity as affected by injector type and manufacturing variability of emitters. Irrigation Science **25**:117-125.
[13]Lopes, L. F. D. 2007. Statistical Process Control. Santa Maria, UFSM, 70 p.
[14]Montgomery, D. C. 2009. Introduction to Statistical Quality Control. 4th edn. Rio de Janeiro, LTC, 513 p.
[15]Peixoto, J. F. S., Chaves, L. H. G. and Guerra H. O. C. 2005. Distribution uniformity of fertigation irrigation district in Platô de Neopolis. Biology and Earth Science, Campina Grande **5**(2):1-8.
[16]Ravikumar, V., Vijayakumar, G., Simunek, J., Chellamuthu, S., Santhi, R. and Appavu, K. 2011. Evaluation of fertigation scheduling for sugarcane using a vadose zone flow and transport model. Agricultural Water Management, Amsterdam, **98**:1431-1440.
[17]Silva, R. P., Souza, F. G., Cortez, J. W., Furlani, C. E. A. and Vigna, G. P. 2007. Spatial variability and statistical control of the process losses in mechanical harvesting of cotton. Agricultural Engineering, Jaboticabal, **27**(3):742-752.
[18]Teixeira, M. B., Coelho, R. D., Melo, P. F. and Oliveira, S.A. 2009. Evaluation of chemical damage to membranes compensation drippers caused by static application of nitric acid. Irriga **14**(2):190-204.