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MODELS TO ESTIMATE POTASSIUM AND NITRATE IN CHANGES OF ION CONCENTRATION IN SOIL SOLUTION IN BANANA CULTIVATION

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ABSTRACT

The adequate use of fertigation is based on the application of nutrients by water according to crop needs throughout its cycle. The evaluation of nutrients in the soil solution may be faster if based upon soil electric conductivity and moisture by using parametric models. The objectives of the study were: (i) to evaluate models for estimating the concentration of nitrate and potassium in the soil solution as a function of moisture and apparent electrical conductivity; (ii) to define the need to adjust the models for possible potassium and nitrate concentration ranges in the soil solution throughout the banana crop cycle for the purpose of monitoring the concentrations of these ions. The Vogeler model was used, in which the concentration of ions is a function of moisture and electrical conductivity of the soil; the other model was the potential in which the concentration is a function of the electrical conductivity of the soil solution. The potential model presented a better performance compared to that of adapted from Vogeler, as for estimation of ion concentrations as for the sensitivity of this model to changes in concentration of this ion in the soil solution. The models showed greater sensitivity when fitted to data corresponding to all possible occurrences in the soil during the crop cycle. The results show that the variations in potassium concentration over time. The model must consider a range of concentrations with the possible values of the soil solution throughout the harvest cycle. The model presented an average of normalized errors (MEN) ranging from 0.01 to 0.02; square root of the mean of squares of errors (RMSE) from 0.01 to 0.03; and R^2 from 67.0% to 91.0%.The model should consider a range of concentrations with the possible values of the soil solution along crop cycle.

Palavras-chave:
fertirrigação
monitoramento de íons
irrigação localizada

MODELOS PARA ESTIMAR POTÁSSIO E NITRATO EM MUDANÇAS DE CONCENTRAÇÃO DE ÍONS EM SOLUÇÃO DO SOLO NO CULTIVO DE BANANA

RESUMO

O monitoramento da concentração de íons da solução do solo é essencial para aplicação correta de fertilizantes na fertirrigação. A determinação dos teores de nutrientes pode ser realizada rapidamente com base na condutividade elétrica do solo e na umidade por meio de modelos paramétricos. Objetivou-se: (i) avaliar modelos de estimativas da concentração de nitrato e de potássio na solução do solo em função da umidade e da condutividade elétrica aparente; (ii) definir a necessidade de ajustar os modelos para possíveis faixas de concentração de potássio e nitrato na solução do solo ao longo do ciclo da cultura da bananeira para fins de monitoramento das concentrações desses íons. Utilizou-se o modelo de Vogeler, o qual a concentração de íons é função da umidade e da condutividade elétrica do solo; o outro modelo foi o potencial no qual a concentração é função da condutividade elétrica da solução do solo. O ajuste do modelo potencial apresentou um melhor desempenho comparado ao de Vogeler, tanto na estimativa das concentrações dos íons, como na sensibilidade do modelo às variações das concentrações desses íons na solução do solo. A definição dos parâmetros do modelo potencial para estimativa de potássio na solução do solo durante o ciclo da cultura deve considerar uma faixa de concentração do íon que contemple os possíveis valores na solução do solo ao longo do ciclo.

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INTRODUCTION

In recent years, fertigation has been expanding in the productive areas, especially for fruits and vegetables (BORGES *et al.*, 2016), mainly due to labor reduction, improved management and efficiency of nutrient application (SOUSA *et al.*, 2011), which has contributed to increased crop productivity with other technologies (EDGERTON, 2009; FAN *et al.*, 2011). The proper fertigation management bases on nutrient application according to the need of the plants during their development and in the monitoring of nutrient concentration in the soil solution to rationalize fertilizer application. The low efficiency of monitoring process of ion concentration of soil solution makes it difficult to handle fertigation, which often occurs in shorter time intervals than those required to make the results of the analyses available. However, research has shown time domain reflectometry (TDR) in association with mathematical models based on soil moisture and bulk electrical conductivity, as a feasible alternative to evaluate electrical conductivity and ions available in soil solution (HEIMOVAARA *et al.*, 2004; RITTER *et al.*, 2005). The use of mathematical models for the representation and analysis of certain chemical, physical and biological processes, both in the laboratory and in the field, can be a very useful tool and still little known in the field of agronomic and agricultural engineering (NETO *et al.*, 2016).

However, in order to obtain reliable results for estimating the ion concentration in the soil solution using TDR, it is necessary to work with averages of the literature that increase the accuracy. Ponciano *et al.* (2016) verified that the average readings increase the accuracy of the potassium estimate with soil moisture readings and apparent electrical conductivity made with TDR.

Ion concentration in the soil solution can be estimated from the electrical conductivity of a solution (EC_w) with a potential model. The use of parametric models to estimate nitrate and potassium in the soil solution, from soil water content (θ) and bulk electric conductivity (ECa) or ECw has been evaluated by different authors (MMOLAWA; OR, 2000; NETO *et al.*, 2012). In this scenario, modeling becomes a good strategy for predicting concentration in the soil solution, providing a good alternative for a better understanding of the dynamics of water and solutes (FESSEHAZION *et al.*, 2015).

In recent years, the use of mathematical models has made it possible to work with experimental data to the point of obtaining information about the movement of ions in the soil solution and making long-term predictions. Mathematical modeling has been shown to be efficient in the study of problems such as crop production management, environmental impact assessment, among others. Models of water and solute flow in the soil and crop performance have been widely used to broaden and extend the conclusions of experimental results, since the results of field experiments are often relevant only for a climatic condition, management practice and type of specific soil (LIANG *et al.*, 2018; SHAHROKHNIA; SEPASKHAH, 2018; ŠIMŮNEK *et al.*, 2016).

These models have been analyzed under laboratory conditions in specific ranges of concentration (SANTANA *et al.*, 2007) or in field (NETO *et al.*, 2012). However, the dependence of the models, the ion concentration ranges on soil solution and validity conditions during the cycle of a crop need evaluation, since chemical processes in the soil are dynamic, mainly with the frequent application of fertilizers that occurs in fertigated crops.

Thus, this study aimed to (i) evaluate estimate models of nitrate and potassium concentration in the soil solution as a function of the soil water content and bulk electrical conductivity; (ii) to define the need to adjust the models for possible potassium and nitrate concentration ranges in the soil solution throughout the banana crop cycle for the purpose of monitoring the concentrations of these ions.

MATERIAL AND METHODS

The work took place at the EPAMIG Minas Gerais, North unit. The place has an Aw climate according to the Köppen classification and is located at 537 m altitude, on the geographical coordinates 15º 46’ 38,98” S and 43º 17’ 22,06”. The soil of the experimental area had a loam clay-silt classification, with 483 g kg^{-1} total sand; 234.0

g kg^{-1}silt and 283.0 g kg^{-1} clay and density of 1.71 kg dm^3. The chemical attributes of the soil at the time of planting at the depth of 0.20- 0.40 m were: pH 6.3; 11.1 mg dm^{-3} P; 0.9 cmolc dm^{-3} K; 2.5 cmolc dm^{-3} Ca; 0.9 cmolc dm^{-3} Mg; 3.4 cmolc Ca + Mg; 0.07 cmolc dm^{-3} Na; 2.1 cmolc dm^{-3} H+Al; CTC 6.2 cmolc dm^{-3} and V 67% (TEIXEIRA *et al.*, 2017).

Data collection of the soil solution occurred along the banana cv. Grand Naine cycle. Daily water needs were supplied by a micro sprinkler irrigation system. Fertigations occurred every seven days, with application of 0.6 kg potassium nitrate diluted in 15 dm^3 water. The soil solution was collected with Hidrosense Model HID35 porous capsule solution extractors installed at 0.20 and 0.40 m depth and 0.50 m between the plant and the microsprinkler. For that, a vacuum with a negative precession of 70 kpa was given, the vacuum was applied before each fertigation and the solution was collected six hours after application of the vacuum. We collected the soil solution three times (September 23rd, 2014, October 14th, 2014 and December 11th, 2014). TDR probes were installed horizontally at 0.05 m from the extractors. Suction was applied to water samplers and solution was extracted after four hours. Readings of θ were performed every half hour from the beginning of suction. We obtained average soil water content during time interval in which the suction occurred. ECa readings were corrected to 25°C (RICHARDS, 1954). Bulk dielectric constant (Ka) was obtained by applying the equation of Ledieu *et al*. (1986) to TDR readings of soil water content data and converted to soil moisture (θ) by using a third-degree polynomial model according to Silva and Coelho (2014). The bulk electrical conductivity (ECa) was obtained by the equation of Giese and Tiemann (1975).

Electrical conductivity of the soil solution (ECw) was obtained by using a tabletop conductivity meter. Nitrate ion concentrations were determined with a rapid analysis equipment (Card Horiba), where the equipment works with the principle of the selective electrode of the nitrate ion. The concentration of potassium ion was obtained with flame spectrophotometry (TEIXEIRA *et a.l*, 2017). The model of Vogeler *et al*. (1996), equation 1, allowed obtaining the estimate of ECw as function of ECa and soil water content in which:

$$EC_w = \frac{EC_a - (a\theta - b)}{c\theta - d} \tag{1}$$

ECw - electrical conductivity of soil solution (dS m^{-1}); ECa - apparent electrical conductivity of soil (dS m^{-1}); θ - soil water content (cm^3 cm^{-3}); and a, b, c and d - are parameters of the model.

Concentration data of potassium and nitrate of the soil solution were related to ECw of soil solution by a potential function using equations 2 and 3 (SANTANA *et al*., 2007, NETO *et al*., 2012).

$$ECw = \alpha I^{\mu} \tag{2}$$

$$I = \beta EC_w^{\lambda} \tag{3}$$

in which:

α, β, λ and μ are the parameters of the potential model and I is ion concentration (K^+ ou NO_3^-).

The substitution of Eq. 2 in Eq. 1 resulted in equation 4, which allows to estimate the concentration of the ion (I) in soil solution with soil water content and ECa obtained by TDR.

$$I = \left\{ \frac{1}{\alpha} \frac{[EC_a - (a\theta - b)]}{(c\theta - d)} \right\}^{\frac{1}{\mu}} \tag{4}$$

The model (Equation 4) derives from the model of Vogeler *et al*. (1996) and came to be referred to as adapted Vogeler. The parameters of the models were obtained by minimizing the sum of the square errors. The models were adjusted on each date individually, i.e., a model was generated by the adapted Vogeler model, and a potential with soil water content data, ECa and ECw collected in the respective time. The Vogeler model adapted and the evaluated with data of soil water content and ECa or ECw data, respectively, in addition to the nitrate and concentration of soil solution collected on September 23rd, 2014 and October 14th, 2014 together.

Model evaluation occurred at each date through the statistic indicators: square root of mean square error (RMSE), mean of errors normalized (MSE), concordance index (d) Willmott (1981) and the coefficient of determination - R^2.

The models were considered adjusted, when the values of "RMSE" and "MEN" were close to zero, meaning that the estimated values were equal or very close to the observed values. The agreement index "d" shows that the closer to one, it means that the values estimated by the models showed agreement with the observed values. The coefficient of determination R^2 shows the correlation between the values estimated by the adjusted models in relation to the real potassium and nitrate values of the solution samples. Thus, from these statistical coefficients it was possible to determine when the models were adjusted.

The Student's t test at 5% probability level compared the measured and estimated ion concentrations. The sensitivity of models to variations of its independent and dependent variables observed on those dates in field was evaluated by the square root of mean square error and by the Student's t test at 5% probability level.

RESULTS AND DISCUSSION

The model of Vogeler *et al.* (1996) of ECw estimation showed a reasonable adjustment satisfactory in all three dates, on which Table 1 was adjusted with the statistical indicators MSE ranging from 0.01 to 0.02; RMSE from 0.01 to 0.03; and R^2 of 67.0% to 91.0% indicating that the variations of ECw are explained by the variations of ECa and θ.

These indicators are in the same range as those obtained by Santana *et al.* (2007) that evaluated the model in two soils of sandy loam and loam texture. The potassium estimate presented in Table 1 for the three periods also showed satisfactory indicators of model Eq. 2 with RMSE of 1.96, 0.76 and 1.88, MSE of 1.46, 0.46 and 1.41 and R^2a of 68.0, 88.0% and 0.48% respectively.

The potential model for estimating nitrate and potassium in the soil solution from ECw has resulted in satisfactory performance, according to statistical indicators (Table 2).

These results are in line with those obtained by other authors (SOUZA *et al.*, 2006; SANTANA *et al.*, 2007; NETO *et al.*, 2014) and confirm an adjustment with higher precision specially for potassium compared to the adapted Vogeler model. This result occurs because ion concentration is a function only ECw, which eliminates data dispersions involving the ECa relation and soil water content, where ECa considers the resident charges fixed in the micelles and the charges of the exchange complex that supply the soil solution. ECa is sensitive to soil water content. Estimates of nitrate concentration in the soil solution by the adapted Vogeler model and of the potential type adjusted according to data of soil water content and ECa of the dates: September 09, 2014; October 14th, 2014 and December 11th, 2014 were compared by the t test to the nitrate concentrations observed on September 23rd, 2014 and October 10th, 2014 together (Table 3).

Table 1. Parameters and statistical coefficients of adjustment of the model derived from Vogeler *et al.* (1996) to estimate ECw and the nitrate and potassium concentration in soil solution as a function of the apparent electrical conductivity (ECa) and water content of soil

		Setting Parameters [1]						Coefficients [2]			
Date	Variable	A	A	a	D	μ	α	D	MEN	RMSE	R^2a
09/23/2014	CE_w	-2.51E+02	-1.72E+02	-1.07E+02	4.23E+02	-	-	0.99	0.01	0.01	0.75
	K^+	-2.51E+02	-1.72E+02	-1.07E+02	4.23E+02	1.15	7.86E-03	0.12	1.46	1.96	0.68
	NO_3^-	-2.51E+02	-1.72E+02	-1.07E+02	4.23E+02	0.26	3.98E-02	0.24	1.29	1.48	0.19
10/14/2014	CE_w	-3.48E+02	-2.09E+02	-1.09E+02	3.52E+02	-	-	0.99	0.01	0.01	0.91
	K^+	-3.48E+02	-2.09E+02	-1.09E+02	3.52E+02	1.13	8.29E-03	0.86	0.46	0.76	0.88
	NO_3^-	-3.48E+02	-2.09E+02	-1.09E+02	3.52E+02	6.46	1.97E-02	0.80	0.53	0.74	0.80
12/11/2014	CE_w	-2.67E+01	-2.38E+02	-2.34E+04	-6.35E+03	-	-	0.99	0.02	0.03	0.67
	K^+	-2.67E+01	-2.38E+02	-2.34E+04	-6.35E+03	1.26	1.06E-02	0.17	1.41	1.88	0.48
	NO_3^-	-2.67E+01	-2.38E+02	-2.34E+04	-6.17E+03	1.26	1.34E-03	0.71	2.80	3.21	0.97

[1]Adjustment parameters of Vogeler *et al.* (1996)

[2]D - Willmott's concordance index (1981); MEN - Mean of standard errors; RMSE - Square root of the mean of the squares of the errors; R^2a- coefficient of determination of the adjustment.

Table 2. Parameters and statistical coefficients of adjustment of the potential model to estimate nitrate and potassium concentration as a function of electrical conductivity of soil solution (ECw)

Date	Potential model (NO_3^-)	R²	RMSE	Potential model (K^+)	R²	RMSE
09/23/2014	$NO_3^- = 55.049\ CEw^{0.6555}$	0.90	0.48	$K^+ = 146.52\ CEw^{1.1846}$	0.83	1.17
10/14/2014	$NO_3^- = 54.563\ CEw^{0.7442}$	0.71	0.87	$K^+ = 86.495\ CEw^{0.8484}$	0.94	0.53

R² - Coefficient of determination; RMSE - Square root of the mean of the squares of the errors; EF- Efficiency of the model

Table 3. Average concentrations of nitrate (mg L^{-1}) in the soil solution estimated by model derived from the adapted Vogeler and the potential model, adjusted with data of each individual date: September 23rd, 2014; October 14th, 2014 and December 11th, 2014 and evaluated with the data of nitrate observed from the two dates September 23rd and October 14th, 2014 together

	Individual adjustment dates of the models								
	09/23/2014			10/14/2014			12/11/2014		
	Measure	Estimated	RMSE	Measure	Estimated	RMSE	Measure	Estimated	RMSE
Vogeler	19.07 A	18.31 A	1.12	19.07 A	19.18 A	0.82	19.07 B	124.56 A	120.49
Potential	19.07 B	20.90 A	2.38	19.07 A	18.18 A	1.76	19.07 B	122.07 A	103.48

Means followed by the same letter in the line do not differ statistically from each other by the T test at 5% probability

The nitrate concentration measured in the soil solution in which the models were verified showed a variation from 18 to 22 mg L^{-1} on September 23rd, 2014; from 17 to 22 mg L^{-1} on October 14th, 2014 and from 58 mg L^{-1} to 117 mg L^{-1} on December 11th, 2014. Concentration averages of nitrate observed together on September 23rd and October 14th, 2014 did not differ from estimated by the Vogeler model adapted on the individual dates September 09 and October 14th, 2014. The Potential Model only showed better performance when adjusted for the date December 11th, 2014, since, the potential model only performed better than the Vogeler model for estimating the nitrate concentration when adjusted for the date of December 11th, 2014. The evaluation of the Potential Model generated on either date, except on October 14th, 2014, when evaluated with ECw data for the two dates of September 23rd, 2014 and October 10th, 2014 together resulted in a significant difference between the estimated nitrate and observed concentrations. This result can be explained since the concentration data for both dates are in the model's adjustment range on October 14th, 2014 (17 to 22 mg L^{-1}).

Estimates of potassium concentration in the soil solution by the adapted Vogeler model and by the potential model adjusted according to data of soil water content and ECa and ECw of the dates: September 09th, 2014; October 14th, 2014 and December 11th, 2014 were compared by the t test to the potassium concentrations observed on September 23rd, 2014 and October 14th, 2014 (Table 4).

Table 4. Values of potassium concentrations (mg L^{-1}) estimated by the derived model of adapted Vogeler and by the potential model adjusted in the three individual dates September 23rd, 2014; October 14th, 2014 and December 11th, 2014 and evaluated with the potassium data of two dates September 23rd and October 14th, 2014

	Adjustment of the derived model of the adapted Vogeler								
	09/23/2020			10/14/2014			12/11/2014		
	Measure	Estimated	RMSE	Measure	Estimated	RMSE	Measure	Estimated	RMSE
Adapted Vogeler	24.66 A	21.56 B	4.01	24.66 B	26.20 B	3.1	24.66 A	15.75 B	11.08
Potential	24.66 B	25.58 B	1.57	24.66 B	24.73 B	0.86	24.66 A	14.49 B	10.35

The potassium concentration measured in the soil solution rang minimum maximum value of potassium readings from 18 to 25 mg L^{-1} in September 23rd, 2014; from 23.70 to 28 mg L^{-1} on October 14th, 2014 and from 8 to 16 mg L^{-1} on December 11th, 2014, values within the ranges also used by Santana *et al*. (2007), from 0 to 60 mg L^{-1} and from 0 to 120 mg L^{-1} for loam and sandy-loam texture soils, respectively. This result occurs because the ion concentrations at these dates are between 18 and 28 mg L^{-1}. This concentration range of the maximum minimum value of the potassium readings is also the reason for the low performance of the model on December 11th, 2014, whose concentration range was between 8 and 16 mg L^{-1}. The difference of averages of values observed from the first two dates and estimated by the adapted Vogeler model on September 23rd, 2014 is due to the low performance of the model with R^2 of 0.68 (Table 1). The low correlation between the models indicates that the calibration process for the dynamic N soil was not satisfactory in the evaluated model and additional analyses would be necessary (LIDIÓN *et al*., 2019).

In addition to the concentration ranges, Kaleita *et al.* (2012) verified that the models are sensitive to the volumetric content of water of the soil. In the nitrate ranges from 0 to 200 mg L^{-1} and θ from 0.25 to 0.30 m^3 m^{-3}, the R^2 was from 0.87 and 0.93 to RMSE from 25 and 19 mg L^{-1}.

The potential and the adapted Vogeler models in the individual dates September 23rd, 2014; October 10th, 2014 and December 11th, 2014 and applied to ECw data referring to the first two dates together generated averages of the estimates that did not differ from the potassium concentrations observed on the first two dates for the results of December 11th, 2014 (Table 4) due to the lowest potassium concentration range observed at that date. Potential models showed performance better than the Vogeler model adapted according to the accuracy indicators (Table 4), especially the RMSE, which has been verified by the authors from this line of study (PONCIANO *et al*., 2016).

The nitrate concentration in the soil solution observed and estimated by the Vogeler adapted and by the potential model throughout the crop cycle, considering the period of September 2014 is represented in Figure 1. The models were adjusted in September 23rd, 2014 or 193 days after planting (DAP), according to Figure 1A and on October 14th, 2014 or 214 DAP (Figura 1B). Potential models adjusted on the same dates applied to the measured data of ECw resulted in the measured and estimated nitrate concentrations in these respective periods (Figures 1C and 1D).

There was a good approximation of the potassium levels measured and estimated by both models; close observations were identified by Neto *et al*. (2012), which, working with different concentrations of 1.0; 2.5 and 4.0 g L^{-1} potassium chloride verified a good approximation of the measured potassium contents and those estimated by the same model, under micro sprinkler conditions throughout the cycle of the banana crop 'Grande Naine'. The best performance of the potential model with efficiencies above 0.80 and RMSE lower than 2.0 compared to the Vogeler adapted with RMSE values above 5.0 and negative efficiency of the model confirms the accuracy indices verified in Table 4.

Although the values obtained for RMSE are high, this range of values has also been reported in other studies in which the N content of the soil is simulated (SUN *et al*., 2013; SOTO *et al*., 2014). Both models underestimate the nitrate content in all simulation periods, which indicates that more field data is needed to improve the calibration of the nitrate cycle, as it is more complex than the water dynamics. In addition, a review of the nitrate dynamics models implemented in the codes would be needed to improve the prediction capabilities of the models for horticultural crops when organic changes are performed and crop residues are incorporated.

The adjustment coefficients are fundamental factors to observe the nitrate concentration between the estimated and measured in order to obtain nutrient values that limit the growth of crops and the nutrient absorption rates.

Calibration of the coefficient between the estimated and measured values of nitrate concentration in the soil solution has been shown to have a positive effect on the simulation of nitrate estimation as observed by Soto *et al*. (2018). Suárez-Rey *et al*. (2016) also found that the model tended to estimate nitrate uptake, almost 10% in percolation, if not calibrated as seen in pepper

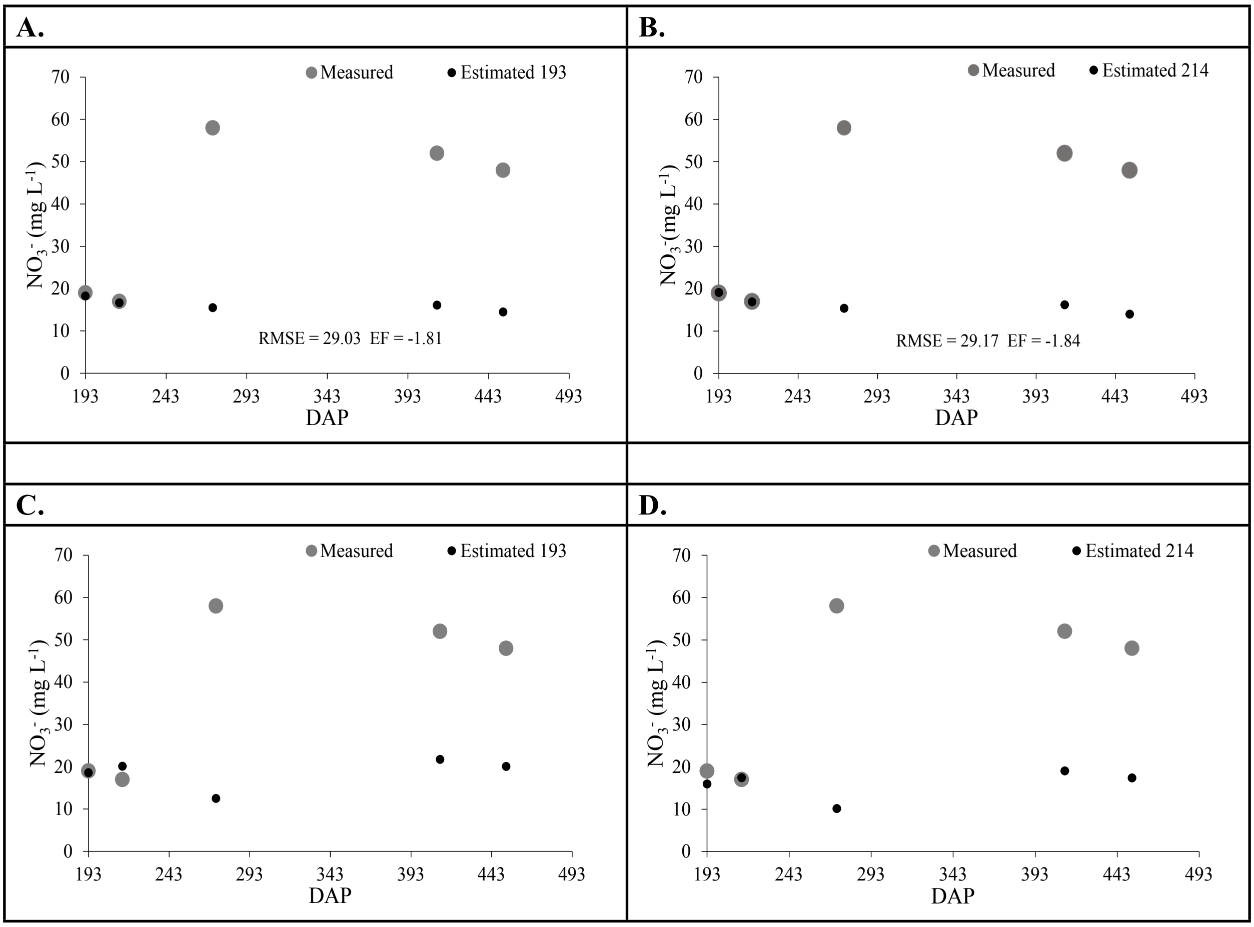

Figure 1. Measured and estimated values of the nitrate concentration in the soil solution from the Vogeler model adapted for 09/23/14 (A) and 10/14/2014 (B) and from the potential model on 09/23/14 (C) and 10/14/2014 (D)

(DOLTRA; MUÑOZ, 2010; SOTO *et al*., 2018). Therefore, the results in the literature regarding the sensitivity of nitrogen uptake to the critical coefficients of the curve are contradictory.

The satisfactory approximation of measured and estimated potassium levels (Figures 1C and 1D), according to RMSE values and efficiency of the model for the potential model adjusted at 193 and 214 DAP are consistent with those obtained by Neto *et al*. (2012) that observed lower RMSE values, but close to those obtained for three concentrations of fertilizers in irrigation water.

The results show that the use of the Vogeler model adapted despite the satisfactory performance in nitrate estimation (Table 3) or the potential model adjusted on September 23rd, 2014 and October 14th, 2014, which no longer performed well (Table 3) for this ion, are not reliable for field use in periods with range concentrations of nitrate from the soil solution different from those used in adjusting models, given the low accuracy (RMSE and efficiency) indicators of the model (Figure 1).

In the case of potassium estimation, only the potential model showed better performance with field data including the period in which the model was adjusted; Neto *et al*. (2016) had the same result, which enables the indication of the model for field use. The results show that the variations of potassium concentrations over time even with fertigations, can be considered in the adjustment of the potential model (Equation 3), provided that the adjustment is made with a range of concentrations that occur over the course of the crop.

These results, in general, illustrate the need for parameterization models so that the model can adapt to environmental variations or conditions - for the evaluated parameters; therefore, they must be carefully measured and characterized (SUÁREZ-REY *et al*., 2019; LIDIÓN *et al*., 2019).

In this study, the potential model adjusted for the individual dates September 23rd, 2014 and October 14th, 2014 had in its nitrate concentration data and the corresponding ECw, values present on both dates, which did not occur for the values that were adjusted on December 11th, 2014.

CONCLUSION

- The Potential Model is suitable for estimating the potassium concentration in the soil solution for knowledge purpose of this concentration in the field, based on the electrical conductivity reading of the soil solution.
- The adapted Vogeler model shows unsatisfactory performance in relation to the potential model in terms of accuracy for use in estimating the concentration of potassium or nitrate in the soil solution from the soil moisture readings and the apparent electrical conductivity with reflectometry in the field of considering the possibility of use in the field.
- The adjustment or definition of the parameters of a Potential Model for use in field, for potassium estimation in soil solution along a crop cycle should consider a range of ion concentration that considers possible values in the soil solution throughout the cycle.

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