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Division – Soil Use and Management | Commission – Soil Fertility and Plant Nutrition

Boundary Line Model to Estimate the Nutrient Sufficiency Range in Muskmelon Leaves

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ABSTRACT: The boundary line is a method frequently used to assess the nutritional status of plants when the relationship between the variables under analysis is influenced by other interacting factors. The objective of this study was to propose and test the boundary line model to estimate the nutrient sufficiency range and nutritional status of irrigated muskmelon. The lower and upper limits of the sufficiency range were calculated as a basis for assessment of the nutritional status of muskmelon. Leaf material was collected from 70 muskmelon crop areas in northern Brazil. The nutrient (N, P, K, Ca, Mg, S, Fe, Zn, Mn, B, and Cu) concentrations in the leaf tissue and the respective fruit yield of each area were measured. The proposed model to estimate the boundary line allowed estimation of the sufficiency range of nutrients for irrigated muskmelon. The main growth-limiting factors of muskmelon due to nutritional deficiency were P > N = K, and those caused by nutrient excess were N > Zn = Cu.

Keywords: modeling, nutritional evaluation, leaf analysis.

INTRODUCTION

Growth-limiting critical leaf concentrations, in the field of agronomy, are usually determined by regression in response to the variation of only one factor, although the results are site-specific. In practice, however, a number of factors affect plant growth and development, and, in different years, the adjusted equations can differ from those fitted in previous years, mainly due to interactions with other factors (Walworth et al., 1986).

There are various methods of interpretation of leaf nutritional analysis; those based on the critical level or sufficiency ranges are most widely used. However, Camacho et al. (2012) claimed that the methods that determine reference values for region-specific nutritional diagnoses can provide more accurate results than those that diagnose plant nutritional status. Another advantage is that the former provide promising results without requiring calibration tests. The method of the boundary line suggested by Webb (1972) consists of plotting yield as a function of the characteristics evaluated, removing some points and leaving only the points of the border line, adjusting a polynomial model to obtain the optimum value or optimum range of the nutrient in the leaf (above which no further increase in yield could be expected), which is used to assess the nutritional status of plants and determine the critical level or sufficiency range in plant leaves.

This method was suggested in biological experiments, of which Webb (1972) stated that relationships between variables are usually confused with other interacting factors, i.e., data dispersion is not only a result of measurement errors and biological variability, but also of interactions with other factors. The method has been used in different areas, e.g., in a study of Imhoff et al. (2010) to evaluate soil physical properties, and by Schmidt et al. (2000) and Topp et al. (2013) to evaluate N_2O emission from agricultural soils. Widiatmaka et al. (2014) used this method to establish sustainability criteria in cashew growing areas in Indonesia, while Shatar and McBratney (2004) used a third-grade polynomial model to identify yield response to soil chemical properties.

The boundary line method is also widely used to assess the nutritional status of the plant, mainly to determine the critical level or sufficiency range in leaves. According to Walworth et al. (1986), this method can be used to determine the optimum level and the relationships between nutrients in maize plants. To evaluate nutritional standards in rubber trees, Suchartgul et al. (2012) determined standard pH values, base saturation and exchangeable acidity, nutrient availability in the soil and leaf nutrient concentrations, the sufficiency range of CEC, and soil Mg and leaf Mn and Zn. Optimum concentrations of N, P, K, Ca, and Mg in soil and plants and the sufficiency range for rubber tree cultivation were determined by Njukeng et al. (2013). Evaluating the optimum concentration of N, P, K, Ca, and Mn in coniferous trees in Canada, Quesnel et al. (2006) concluded that the method is considered appropriate for this purpose, similar to CND (compositional nutrient diagnosis). Similarly, Lafond (2009) obtained an optimum concentration and sufficiency range for N, P, K, Ca, and Mg of *Vaccinium angustifolium*, while Lenwandowski and Schmidt (2006) evaluated N efficiency of *Tritico secale Wittmack,* and Rafique et al. (2008) used the method to assess the nutritional status of zinc in onion.

Similarly to the method proposed by Maia et al. (2001) to calculate critical leaf concentrations and the method that uses the mean and standard deviation of the nutrient in a high-yielding population to establish the sufficient range (Gott et al., 2014), the boundary line is an alternative to compute the critical level and leaf sufficiency range without requiring field trials, but only nutritional status data.

Nutritional status data through the boundary line method allows an estimation of the sufficiency range of leaf nutrients. Thus, the purpose of this study was to propose and evaluate the boundary line model to estimate the sufficiency range in leaves, with a view to assessing the nutritional status of irrigated muskmelon.

MATERIALS AND METHODS

The model proposed for estimating the sufficiency range is based on yield estimated by the boundary line of nutrient i (P_i) according to the leaf nutrient concentrations (Equation 1):

$$P_i = \frac{4.P_{max}.\beta}{(1 + \beta)^2}$$

Eq. 1

where P_{max} is the maximum yield in the database and $\beta = \exp\left[\frac{f*1.7145}{Max\text{--}Min}(\bar{x} - x)\right]$, where f is the adjustment factor (here 2); x, $\bar{x}$, Max, and Min correspond to the leaf nutrient concentration of the sample and the mean, maximum, and minimum nutrient concentration in the database, respectively.

The concentrations corresponding to the lower limit (L_i) and upper limit (L_u) of the sufficiency range were calculated by equations 2 and 3, respectively, β_i and and β_s by equations 4 and 5, respectively:

$$L_i = \bar{x} - \left[\frac{Max\text{--}Min}{f*1.7145}\ln(\beta_i)\right]$$

Eq. 2

$$L_s = \bar{x} - \left[\frac{Max\text{--}Min}{f*1.7145}\ln(\beta_s)\right]$$

Eq. 3

$$\beta_i = \left[\frac{2}{P_r}(1 + \sqrt{1 - P_r})\right] - 1$$

Eq. 4

$$\beta_s = \left[\frac{2}{P_r}(1 - \sqrt{1 - P_r})\right] - 1$$

Eq. 5

where P_r is the desired relative yield in relation to P_{max} for which 0.9 was used, referring to 90 % of P_{max} of muskmelon.

The nutritional index (NI) of each sample was calculated by equation 6:

$$NI = \frac{\Sigma(P\text{--}P_i)}{n.P_{max}}$$

Eq. 6

where n is the number of analyzed nutrients, and the more negative the index, the more severe the nutritional deficiency.

The proposed boundary line model was evaluated with leaf data from 70 plots of commercial production of irrigated muskmelon in the western region of Rio Grande do Norte, a region with predominantly limestone soil of the region of the Chapada do Apodi. Leaves were collected in the flowering period; the fifth leaf from the plant apex was sampled and, at the end of the cycle, the respective fruit yield of each area was measured. After drying the plant material in a convection oven at 70 °C to constant weight, the material was ground, and the concentrations of N, P, K, Ca, Mg, S, Fe, Zn, Mn, B, and Cu were determined by the methods described by Silva (2009).

RESULTS AND DISCUSSION

The boundary line for all evaluated nutrients was defined by the mathematical model (Figure 1), where even without outlier removal, a good fit of the contour was observed (boundary yield as a function of leaf concentrations). One of the main advantages of the proposed method is that the (frequently manual) removal of the non-border data is not required to then adjust the polynomial model in order to obtain the optimum concentration and sufficiency range, as observed by Lafond (2009) for N, P, K, Ca, and Mg.
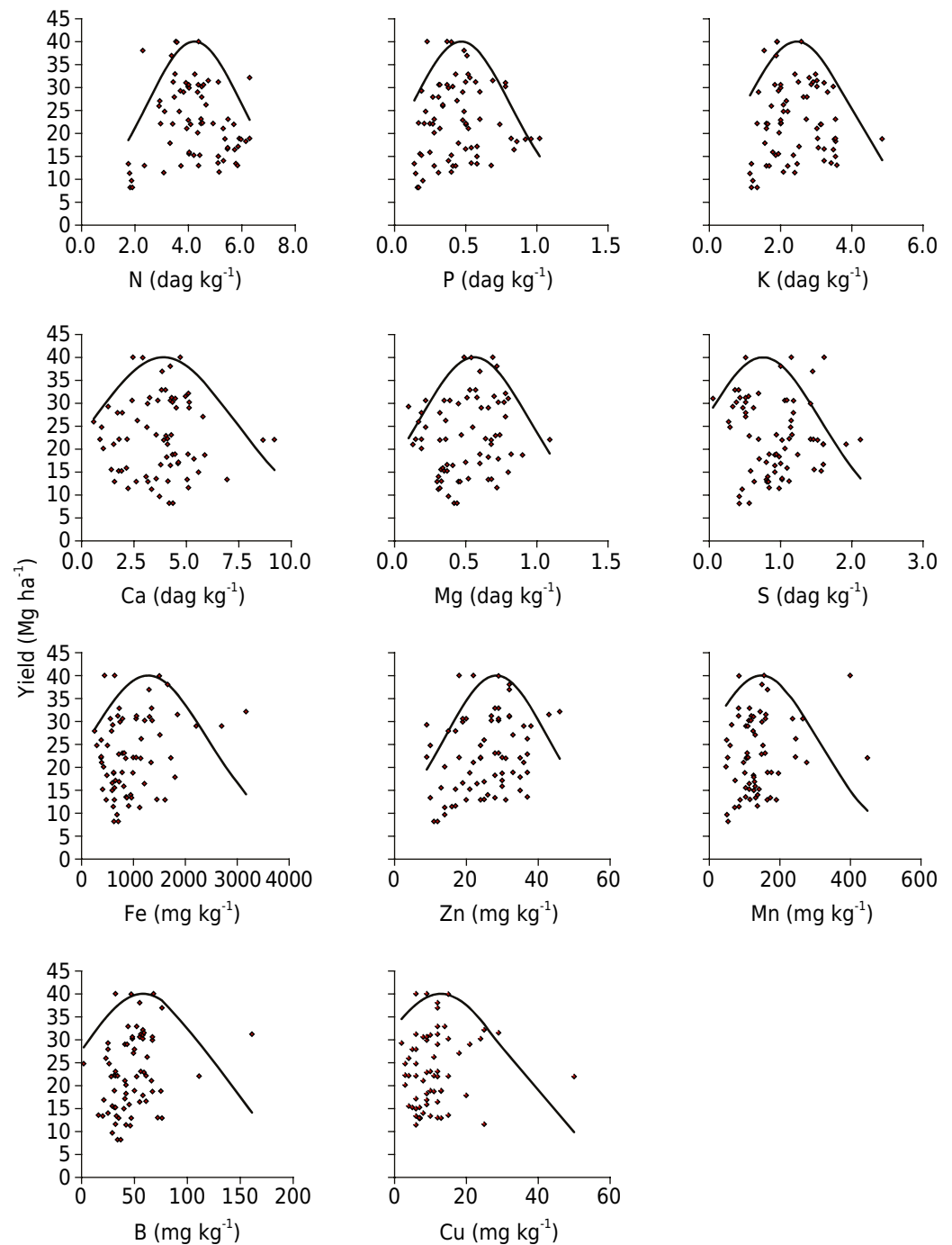
Figure 1. Yield observed and estimated by the boundary line as a function of leaf nutrients of irrigated muskmelon.

The optimum concentration is calculated for $\beta = 1$, when the leaf concentration is equal to the nutrient mean. The critical level was set at 90 % of the maximum yield (Maia et al., 2001) using the same criterion. The sufficiency range was estimated for a yield of 36.05 Mg ha^{-1}, with a maximum of 40.05 Mg ha^{-1}. In comparison to the standards published by Jones Jr. et al. (1991) (Table 1), the ranges were relatively consistent, except for Fe, for which the lower and upper concentrations of the calculated range were higher than the values in the literature. However, in high-yielding areas (>28 Mg ha^{-1}), the mean leaf Fe exceeded the upper limit of the range proposed by 1.283 mg kg^{-1}.

The boundary line describes the direct effect of a nutrient on crop yield, and nonlinearity reveals the critical value of each nutrient, be it at the optimal concentration or in the sufficiency range for a given yield, as stated by Haneklaus et al. (2007). These same

effects were also observed for the relationship between nutrients, and the relationships between them are calculated in a way similar to the sufficiency range for nutrients. The sufficiency ranges for the ratios N/P, P/K, Ca/Mg, and Mg/K were 6.69-15.08, 0.13-0.24, 5.83-9.40, and 0.11-0.34, respectively (Figure 2).

After establishing the sufficiency ranges, the nutritional status of muskmelon was assessed in low yield areas (Table 2). The major limitations by deficiency were for P, N, and K in 29, 24, and 24 % of the areas, respectively, and by excess for N, Zn, and Cu in 37, 20, and 20 %, respectively. Magnesium, Fe, and Mn were within the sufficiency range, with 82, 80, and 80 % of the areas considered normal, respectively. It is however noteworthy that only in 38.78 % of the areas was the N concentration within the sufficiency range. In the areas with lowest yield (<12 Mg ha^{-1}), the major

Table 1. Lower limit (L_l) and upper limit (L_u) of the sufficiency range for irrigated muskmelon in the region of the *Chapada do Apodi*, RN, Brazil, estimated by the boundary line method and reference values

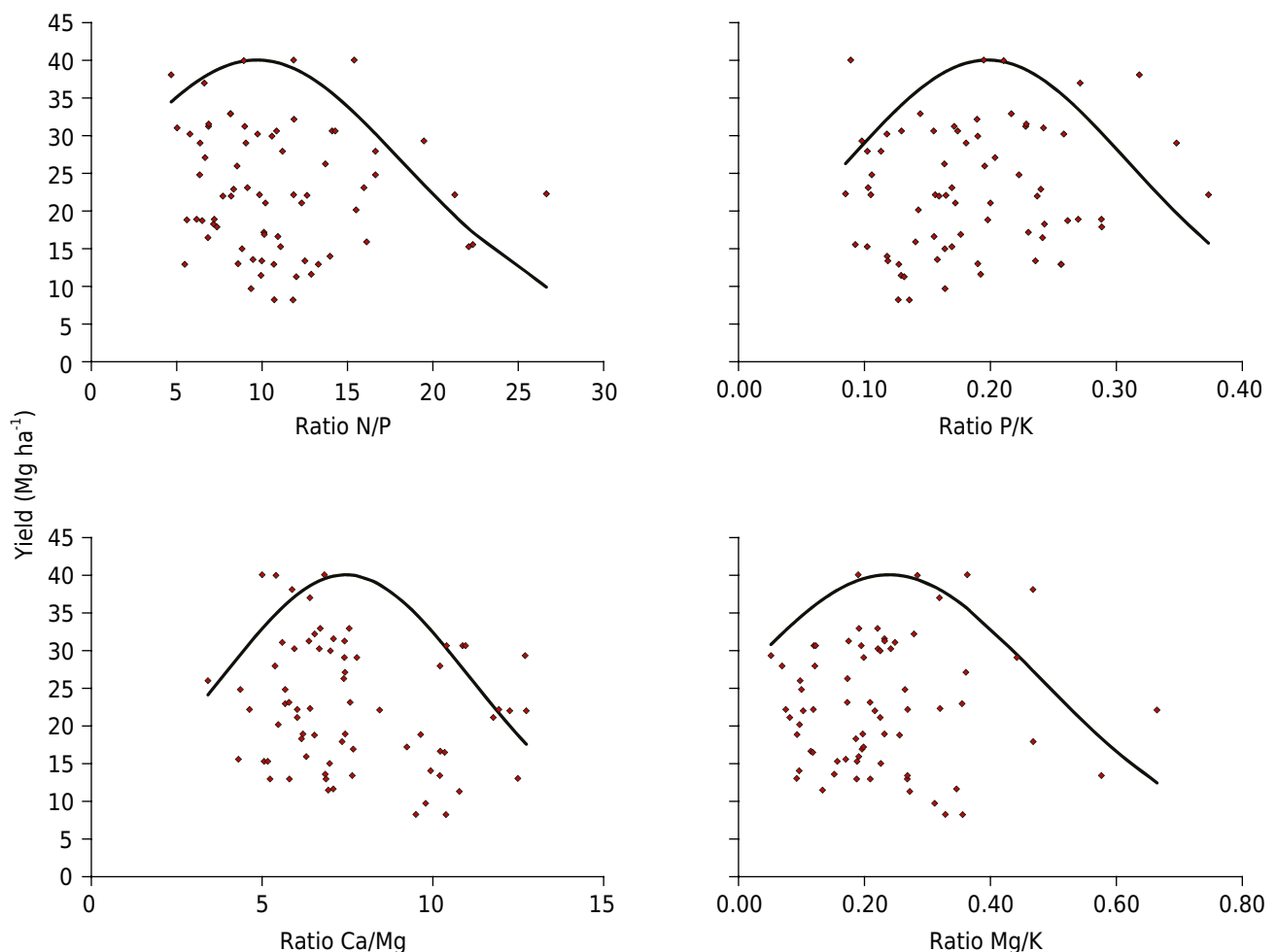|	N	P	K	Ca	Mg	S	Fe	Zn	Mn	B	Cu
	dag kg^{-1}						mg kg^{-1}				
L_i	3.36	0.28	1.71	2.07	0.31	0.51	391.46	18.30	58.78	25.21	5.32
L_s	5.09	0.62	3.13	5.36	0.69	1.31	1505.31	32.44	211.96	66.85	15.63
	Reference (Jones Jr. et al.. 1991)										
L_i	4.09	0.25	3.59	2.59	0.35	0.23	50	20	50	25	7
L_s	5.00	0.60	4.50	3.20	0.80	1.20	300	200	250	60	30

Figure 2. Yield observed and estimated by the Boundary Line based on the ratios of N/P, P/K, Ca/Mg, and Mg/K of leaf concentrations in irrigated muskmelon.

deficiencies were N = Zn > P = K > S. In the areas with a yield of 15-20 Mg ha^{-1}, excessive concentrations of N were observed in 60 % of the areas, and excessive concentrations of Mg, S, and Zn in 20 % of the areas.

The P, N, and K deficiencies observed were due to the calcareous origin of the soils of the region, poor in N and P. Even when these nutrients are added through fertilizers, uptake efficiency is decreased by the high Ca concentrations and pH values, causing partial binding of P to Ca (Novais and Smyth, 1999), while part of the N can be volatilized in the form of ammonia, reducing availability to plants. In irrigated muskmelon crop areas, Maia (2013) found that application of irrigation and heavy P fertilization over 10 crop cycles increased the pH from 5.04 in original native forest to values of > 7.0 in the cultivated areas, and available P concentrations increased from 0.60 mg dm^{-3} to more than 60 mg dm^{-3}. In contrast, K deficiency was mainly due to high Ca and Mg soil concentrations. The antagonistic effect of these three nutrients decreases K uptake, making the application of high amounts of K to this type of soil a common practice among farmers in the region.

In the case of excess N, Zn, and Cu, due to low levels of organic matter and N in the soils of the region, farmers apply high amounts of fertilizer based on subjective observations, exceeding plant requirements. In many areas, Cu is found at excessively high levels, probably due to leaf applications of Cu-based fungicide.

Although Mg concentrations were within the calculated sufficiency range in 82 % of the evaluated low-yield areas, deficiency of the nutrient was not observed in any area. This was probably due to lower requirement for Mg than for Ca, and because, even in high Mg soils, a certain additional amount is applied through irrigation water, which is mostly water from the aquifer of the Jandaira limestone formation. In 24 % of the low-yield areas, Ca deficiency was detected, which is probably not due to a lack of the element but to the decreased soil availability of the element because of its lower solubility, even when the soil concentrations of the element are high and despite its application through irrigation water. Over several crop cycles, increasing Ca and Mg concentrations in soil with irrigated muskmelon were observed by Maia (2013), who assumed that this increase was due to the quality of the irrigation water.

The relation between the nutritional index (*NI*) and yield was satisfactory, with a coefficient of determination of 0.9327 (Figure 3). The more negative the *NI*, the greater the nutritional deficiency; for *NI* = 0, calculated yield was 36.61 Mg ha^{-1}, approximately the yield for 0.9 P_{max} used to calculate the sufficiency range, which was 36.05 Mg ha^{-1}.

Although the model proposed here (Equation 1) can be used in most cases, it may be modified, especially under conditions where the coefficient of variation (CV) for yield is higher than that for the nutrient (CV$_{prod}$ > CV$_n$). In this case, the following expression can be used:

$$\beta = \exp\left[\frac{1.7145}{s}(\bar{x}-x)\right], \text{ with } L_i = \bar{x} - \left[\frac{s}{1.7145}\ln(\beta_i)\right] \text{ and } L_s = \bar{x} - \left[\frac{s}{1.7145}\ln(\beta_s)\right],$$

where *s* is the standard deviation of the nutrient.

Table 2. Percentage of low-yield areas of irrigated muskmelon without nutritional restriction and with limitation by deficiency and excess for the nutrients assessed by the boundary line method

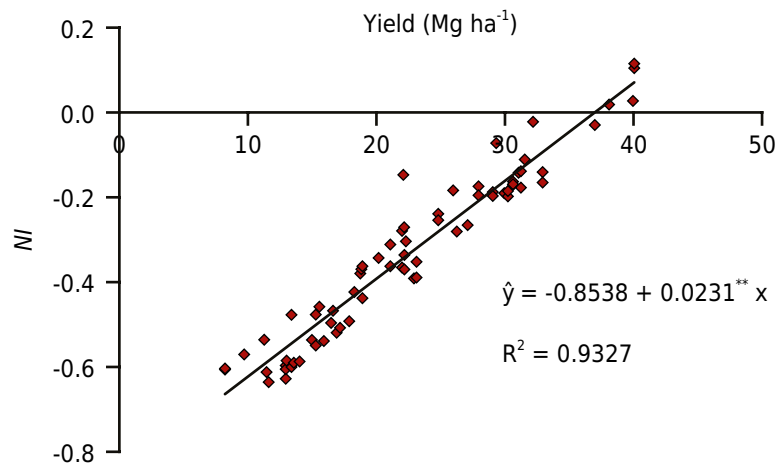|	N	P	K	Ca	Mg	S	Fe	Zn	Mn	B	Cu
						%					
No limitation	38.78	71.43	75.51	63.27	81.63	67.35	79.59	48.98	79.59	75.51	63.27
Deficiency	24.49	28.57	24.49	24.49	0.00	14.29	12.24	30.61	12.24	14.29	16.33
Excess	36.73	0.00	0.00	12.24	18.37	18.37	8.16	20.41	8.16	10.20	20.41

For a yield of < 28 Mg ha^{-1}.

Figure 3. Nutritional Index (*NI*) as a function of yield in irrigated muskmelon.

CONCLUSIONS

The sufficiency range of nutrients for irrigated muskmelon was able to be estimated by the proposed boundary-line model.

For muskmelon, the main nutritional limitations were P > N = K for nutrient deficiency, and N > Zn = Cu for excess nutrient concentrations.

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