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Accuracy of nutritional diagnostics for phosphorus considering five standards by the method of diagnosing nutritional composition in sugarcane

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ABSTRACT

The accuracy of nutritional diagnoses can enable the definition of the best set of standards by the method of nutritional composition diagnosis (CND) in sugarcane. In this sense, the purpose of this study was to perform the accuracy of the nutritional diagnosis for phosphorus and to determine the best set of CND standards in sugarcane. A database of 720 samples was created, using the productivity and foliar concentrations of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn. The criteria used to establish the norms populations were average productivity; average productivity + 0.5 standard deviation; average productivity + 1.0 standard deviation; average productivity + 1.5 standard deviations; and average productivity + 2.0 standard deviations. Variables studied included mean nutritional balance index (NBIm); CND index and productivity; and the degree of agreement between the standards and accuracies of the nutritional diagnoses for phosphorus by the method of Beverly and Hallmark. The lowest productivity loss was registered with the use of standard P1 and the largest losses with the use of standard P5 when compared to the other standards. Accuracy analysis of the nutritional diagnosis of phosphorus identified poor performance for all sets of CND standards, but better performance was obtained from reference populations of greater productivity.

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CND; reference population; *Saccharum* spp; validation

Introduction

Sugarcane is one of the most cultivated crops in the world, present in more than 109 countries (Choudhary et al. 2017).

Brazil is the largest sugarcane producer in the world, with an average yield of 72 t ha^{-1} and a total production of 633 million tons in the 2017/2018 harvest. São Paulo State is responsible for over 50% of the country's production (Conab – Companhia Nacional de Abastecimento 2019). Thus, the sugarcane crop, installed in a large area, is among the main crops that consume the most fertilizer in Brazil, representing 15% of the total fertilizer marketed in the country (ANDA – Associação Nacional para Difusão de Adubos 2018).

Despite the economic importance and the high demand for fertilizers by the crop, fertilizer management is still based almost exclusively on soil analysis. The future scenario, where fertilizer shortages are expected to increase, with increasing unit costs, could compromise a significant

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fraction of the sector's profitability in the medium or long term, if the implementation and maintenance of these systems are not followed by nutritional monitoring practices. Improve soil fertility and maintain nutritionally balanced crops.

Use of leaf nutritional patterns may represent an alternative for crop evaluation and specific management of systems (Oliveira et al. 2019).

The nutritional status of sugarcane can be known by interpreting nutrient contents in leaves using univariate methods (critical level or ranges of sufficiency) with defined standard values (Camacho et al. 2012) or by bi or multivariate methods, such as the nutritional composition diagnosis (CND) method in which interactions are considered (Calheiros et al. 2018). However, the efficiency of the CND method in nutritional diagnosis depends on the criteria used to define the reference values and, therefore, on the set of crops used to obtain these values, since these standards directly determine the nutritional diagnosis (Serra et al. 2013).

Several criteria are used to define the reference population, according to Beaufils (1973) in the group of average productivity there is better representation of the variability of the relationships between nutrients. Malavolta (2006) recommends that the reference population be a maximum of 80% of the observations. Morais et al. (2019) recommend separation of plots with productivity above the average of the sampled crop population.

Besides defining the criteria for obtaining the reference population, it is necessary to evaluate the quality of the nutritional diagnoses formed. In this context, Píperas, Creste, and Echer (2009) evaluated the diagnoses of the populations, choosing the best relationship between the mean nutritional balance index (NBIm) and productivity. Other studies evaluate the performance of the diagnoses, using other parameters such as CND index and productivity (Barłóg 2016; Queiroz et al. 2014), or degree of agreement (Serra et al. 2013).

These nutritional status parameters are most often based on linear regression models with the highest coefficient of determination (R^2) and when the level of agreement between nutritional diagnoses is used as a criterion, set of rules with greater degree of agreement.

However, these cited criteria for assessing the quality of nutritional diagnoses may not result in the possibility of defining the best set of standards, since they do not objectively evaluate the plant's response to nutrient application.

Thus, accuracy measures were proposed by Beverly and Hallmark (1992) who used the plant's response to the nutrient under analysis and evaluated the quality of nutritional diagnosis. The ideal is that standards developed, regardless of method, are validated and proven to be accurate (Teixeira et al. 2015).

Thus, the purpose of this study was to perform the accuracy of the nutritional diagnosis for phosphorus and to determine the best set of CND standards in sugarcane.

Materials and methods

Data were collected from five experimental areas cultivated with sugarcane, located in three municipalities in the Brazilian state of São Paulo. Two areas were located in Catanduva (21°05′07″S, 48°54′22″W), two were in Santa Adélia (21°16′49″S, 48°49′38″W), and one in Santa Albertina (20°02′44″S, 50°37′55″W) (Moda et al. 2015; Caione et al. 2015).

According to the Köppen classification, the region has a type of Aw climate (tropical rainy with dry winter). The soils of the experimental areas were classified as eutrophic Red Argisol and dystrophic Red-Yellow Argisol (Catanduva), dystrophic Red Latosol and eutrophic Red-Yellow Argisol (Santa Adélia), and dystrophic Red-Yellow Latosol (Santa Albertina) (Santos et al. 2013).

The sugarcane varieties cultivated were CTC 15, of average/late cycle (Catanduva and Santa Adélia), and RB 855 453, early cycle (Santa Adélia and Santa Albertina).

In all areas, planting was performed conventionally, adopting the yearly sugarcane system. Experimental plots were composed of five sugarcane rows measuring 15 m long, spaced 1.5 m apart. The three central rows were used for sampling, discarding 1.0 m from each end.

To generate the database, a $3 \times 4 \times 2 \times 2$ factorial design was used, consisting of three phosphorus sources (triple superphosphate, Araxá rock phosphate, and Bayovar reactive or Gafsa reactive phosphate), four doses of P_2O_5 (0, 90, 180, and 360 kg ha^{-1} of P_2O_5 soluble in 2% citric acid), two conditions of decomposed filter cake at a dose of 7.5 t ha^{-1} dry weight (equivalent to 15 t ha^{-1} wet weight) (absence or presence), and two leaf sampling times (four and eight months after sprouting), with three replicates per treatment.

Basic fertilization of 100 kg ha^{-1} K_2O (Catanduva and Santa Adélia) and 80 kg ha^{-1} K_2O (Santa Albertina) was applied at the time of planting following Raij and Cantarella (1997). At 40 days after sprouting, topdressing was performed at approximately 10 cm from the end of the row, applying 50 kg ha^{-1} N (Raij and Cantarella 1997). Ammonium sulfate was used as a nitrogen source, and potassium chloride was used as a source of potassium.

Leaf samples for a total of 720 plants were collected at four and eight months after sprouting in the sugarcane cycle. In the first leaf sampling at four months, 15 leaves were collected (middle third of leaf + three, excluding the midrib) per plot to assess the nutritional status of the culture, following Malavolta (1992). The second sampling was performed at full culture development (eight months), collecting 15 leaves (middle third of leaf + one, excluding the midrib) per plot (Raij and Cantarella 1997).

Leaves were washed and dried in an oven at 65 °C until they reached constant weight, before being ground in a mill, and chemically analyzed for N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn, following methodology described by Bataglia et al. (1983).

Productivity data were recorded at the point of sugarcane harvest, 12 months after sprouting, when 3 m^2 were harvested manually from each plot without burning (1 m from each useful row). Stalks were weighed and valued in t ha^{-1} of stalks (Moda et al. 2015; Caione et al. 2015).

CND standards

The database was compiled from information on the chemical analysis of foliar concentrations and productivity of sugarcane plantations, composed of five reference populations with productivities greater than 172, 193, 214, 235, and 256 t ha^{-1}, denominated by P_1, P_2, P_3, P_4, and P_5, respectively. Productivity values were selected as they represented the average productivity, average productivity + 0.5 standard deviation, average productivity + 1.0 standard deviation, average productivity + 1.5 standard deviations, and average productivity + 2.0 standard deviations, respectively, for each of the five references populations: P_1, P_2, P_3, P_4, and P_5.

The CND standards were produced by transforming the original data to g kg^{-1} to compare between nutrients of different units. Nutrient level values that were considered extreme, i.e., smaller or larger than the average content ± 2.55 × standard deviations, were excluded. Remaining values were used to obtain the CND standards and determine the CND indices.

For each leaf sample, the value of R was determined, which corresponds to the balance of the dry matter per 1 kg, using the equation:

$$R = 1000 \ - (vN + vP + vK + vCa + vMg + vS + vB + vCu + vFe + vMn + vZn),$$

where R = the balance of dry matter for 1 kg; 1000 = 100% dry matter; vX = content of each nutrient in g kg^{-1}, and X represents each of the nutrients evaluated (N, P, K, … Zn) (Parent and Dafir 1992).

We then determined the geometric mean (mGeo) of the nutritional content in each sample, using the formula:

$$\mathrm{mGeo} = (\mathrm{vN} \times \mathrm{vP} \times \mathrm{vK} \times \mathrm{vCa} \times \mathrm{vMg} \times \mathrm{vS} \times \mathrm{vB} \times \mathrm{vCu} \times \mathrm{vFe} \times \mathrm{vMn} \times \mathrm{vZn}\ \ x\ \ \mathrm{R})^{(1/n)},$$

where mGeo = root order "n" of the product of the nutritional content and the R value; and "n" = number of factors used in calculating the geometric mean (Parent and Dafir 1992).

The multivariate relationship (zX) was calculated from the natural logarithm of the ratio of the N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn contents and the geometric mean of the nutritional composition in the leaf samples, using the expression:

$$\mathrm{zX} = \ln(\mathrm{vX}/\mathrm{mGeo}),$$

where vX = levels of each nutrient expressed in (g kg^{-1}); and mGeo is the geometric average of nutrients in the sample (Parent and Dafir 1992).

Finally, for each reference population, the averages and standard deviations of the multivariate relationships were calculated for the evaluated nutrients, which constitute the five sets of CND standards.

CND and NBIm indices

The CND index (I_X) was calculated for each set of the standards, using the following expression:

$$I_X = (\mathrm{zX} - \mathrm{mX})/\mathrm{sX},$$

where I_X = CND index of any nutrient (X); zX = multivariate relationship for the same nutrient; and mX and sX = the standard average and standard deviation, respectively, of the multivariate relationships for nutrient X (Parent and Dafir 1992).

The NBIm was calculated using the expression:

$$\mathrm{NBIm} = (|I_N| + |I_P| + |I_K| + |I_{Ca}| + |I_{Mg}| + |I_S| + |I_B| + |I_{Cu}| + |I_{Fe}| + |I_{Mn}| + |I_{Zn}|)/n,$$

where NBIm = mean nutritional balance index; |I_X| = module of the CND nutritional indices for each nutrient in which X represents each of the evaluated nutrients (N, P, K, … Zn); n = number of nutrients evaluated in a given plant or leaf sample (Sumner 1977).

Interpretation of the nutritional state

Interpretation of nutritional status was performed via the CND index in three interpretation classes: balanced, deficient, and excess. The nutrient was considered nutritionally balanced when the CND index module was less than, or equal to, the NBIm, deficient when its CND index module was negative and also greater than the NBIm, and in nutritional excess when its CND index was positive and also greater than the NBIm (Wadt 2005).

Interpretation was grouped into one of two classes, deficient or adequate, where the adequate class represented groups of instances considered, for each nutrient, as balanced and in excess.

Degree of agreement between nutritional diagnoses

The degree of concordance between the diagnoses of nutritional status for phosphorus was determined in three interpretational classes – balanced, deficient, and excess – comparing the diagnoses obtained for each CND standard. Therefore, for each combination of different standards, the number of concordant diagnoses within each pair (balanced and balanced, deficient and deficient, or excess and excess) was calculated. All other combinations of diagnoses were considered discordant. Results were expressed as a percentage of concordant diagnoses.

Table 1. Adequacy distribution of the nutritional diagnoses.

Nutritional diagnosis	Nutritional state defined by the response to fertilization	
	Insufficient	Sufficient
Deficient	True deficiency (TD)	False deficiency (FD)
Adequate	False adequacy (FA)	True adequacy (TA)

Accuracy of the nutritional diagnoses

Accuracy of the nutritional status for phosphorus diagnoses was determined by defining two interpretation classes, deficient or adequate, using each of the five sets of CND standards generated.

Accuracy was determined from the nutritional diagnosis (obtained by the procedure for the nutritional state) that corresponded to the plant response, in terms of productivity variation, to the added nutrient.

Therefore, the nutritional diagnosis of each standard was combined with the response of the plant to applications of phosphorus, comparing cases of phosphorus absence (control situation) with cases where only phosphorus was added (response situation), or comparing cases with a lower (control situation) or higher dose of phosphorus (response situation).

Comparisons were always conducted between treatments without filter cake and those that used triple superphosphate as a phosphorus source. Subset pairs of plots from the same experimental block and treatment, except for variation in phosphate fertilizer, were compared.

The Fertilization Response Potential method diagnosed the control treatment as deficient or adequate, as described above, in the interpretation criterion of the CND indices.

Diagnoses of the response situation were also classified as insufficient when the addition of phosphorus resulted in an increase in production of more than 10% above the control. All other cases were classified as sufficient.

There were four possible outcomes from comparing the diagnosis with the response of the crops: true deficiency (TD), there was a response to phosphorus supply and the crop was diagnosed as deficient; false deficiency (FD), there was no response to phosphorus supply and the crop was diagnosed as deficient; true adequacy (TA), there was no response to phosphorus supply and the crop was diagnosed as adequate; and false adequacy (FA), there was no response to phosphorus supply, and the crop was diagnosed as deficient (Table 1).

Three measures of accuracy, proposed by Beverly and Hallmark (1992), were used to evaluate the performance of nutritional diagnostics for phosphorus: efficiency, deficiency ratio, and yield.

Efficiency of the nutritional diagnosis was estimated by the sum of the true diagnosis percentages (%TD + %TA). The deficiency ratio was calculated by dividing the diagnosis of TD by the FD (%TD/%FD) (Table 2).

Finally, yield was calculated by the diagnostic contribution to increased productivity, where increases in yield are considered the variations in productivity resulting from diagnoses of TD and TA, and decreases in yield the diagnoses of FD and FA. For each set of standards, the yield was then obtained from the average of the individual yields of the cases assessed (Table 2).

Statistical analysis

Values of the NBIm index, CND index for phosphorus, and productivity were evaluated using scatter plots, with the NBIm or CND index as the independent variable, and productivity as the dependent variable. In each case, a linear regression was also adjusted between productivity and each of the independent variables measured. Adjusted models were obtained for each set of CND

Table 2. Measures of accuracy, expected range, and acceptable values in performance evaluation of the nutritional diagnoses (adopted from Beverly and Hallmark 1992).

Criteria	Calculation	Range	Acceptable values
Efficiency	(%TD) + (%TA)	0 to 100	>50
T ÷ F	(%TD) ÷ (%FD)	0 to 100 (undefined as % FD = 0)	>1
$\sum$d (Y)	[d (Y) TD] − [d (Y) TA] − [d (Y) FA] + [d (Y) FD]	$-\infty$ to $+\infty$	>0

TD: true deficiency; TA: true adequacy; FD: false deficiency; FA: false adequacy; [d(Y)TD], [d(Y)TA], [d(Y)FA], and [d(Y)FD]: responses to fertilizer application associated with the diagnoses of TD, TA, FA, and FD, respectively.

standards generated, using Excel 2003 spreadsheets (Microsoft Office) and Calc (Openoffice.org version 4.1).

Results and discussion

There was no linear fit between NBIm and productivity from the dispersion analysis of the different CND standards (Figure 1), as the productivity values ranged from low to high in the range of low NBIm values. Similar results were reported for oranges in the municipality of Bebedouro – SP, Brazil (Hernandes et al. 2014), and for potatoes in the municipalities of São Gotardo and Itajubá, in Minas Gerais, Brazil (Queiroz et al. 2014).

This result is consistent with the theoretical model suggested by Beaufils (1973) that predicts no significant relationship between productivity and NBI, since non-nutritional factors can result in low productivity, but with high nutritional balance (low NBI).

Nevertheless, the relationship between the NBI and productivity has been used as a criterion for defining standards or selecting calculation procedures, and is considered the most appropriate model to generate a linear fit, i.e., the highest coefficient of determination (R^2). Examples of studies that used the relationship between the NBI and productivity to define standards include: Serra et al. (2013, 2014), based on commercial cotton fields in southern Mato Grosso Píperas, Creste, and Echer (2009), based on sugarcane cultivation in São Paulo; and Guindani, Anghinoni, and Nachtigall (2009), based on irrigated rice in Rio Grande do Sul.

When adopting similar procedures, including using data selected from commercial sugarcane stands to verify the dispersion model between NBIm and productivity, we observed that a smaller number of data better defined the relationship, reflected by higher values of R^2 (Figure 2), than when all of the sample data were used (Figure 1).

When evaluating the data for the relationship between the NBI and productivity in specific conditions (fewer data), we concluded that standards performance was better when plants of greater productivity were used for the reference population (Figure 2). However, when comparing the performance between specific (fewer) data and that from the total number of samples, we observed that the best correlation between productivity and the NBI arose from a lower number of sampling data, resulting in lower variability of the non-nutritional factors, but not necessarily better model performance.

Similarly, graphical evaluation of the dispersion between productivity and the CND index of a nutrient can also be used to evaluate the model or the standards. When a large amount of data is evaluated, one should expect a wider range of nutrient index values at low productivity, and as productivity increases, the amplitude of the nutrient CND index values is reduced, tending toward values close to zero. This model was reproduced using the data from this study (Figure 3), independent of the reference population size used for production of the CND standards.

Although some authors have used this criterion to select calculation procedures or select standards (Queiroz et al. 2014; Barłóg 2016), usually with a reduced number of data, the model becomes inaccurate when using a large volume of data. This is particularly acute when assessed

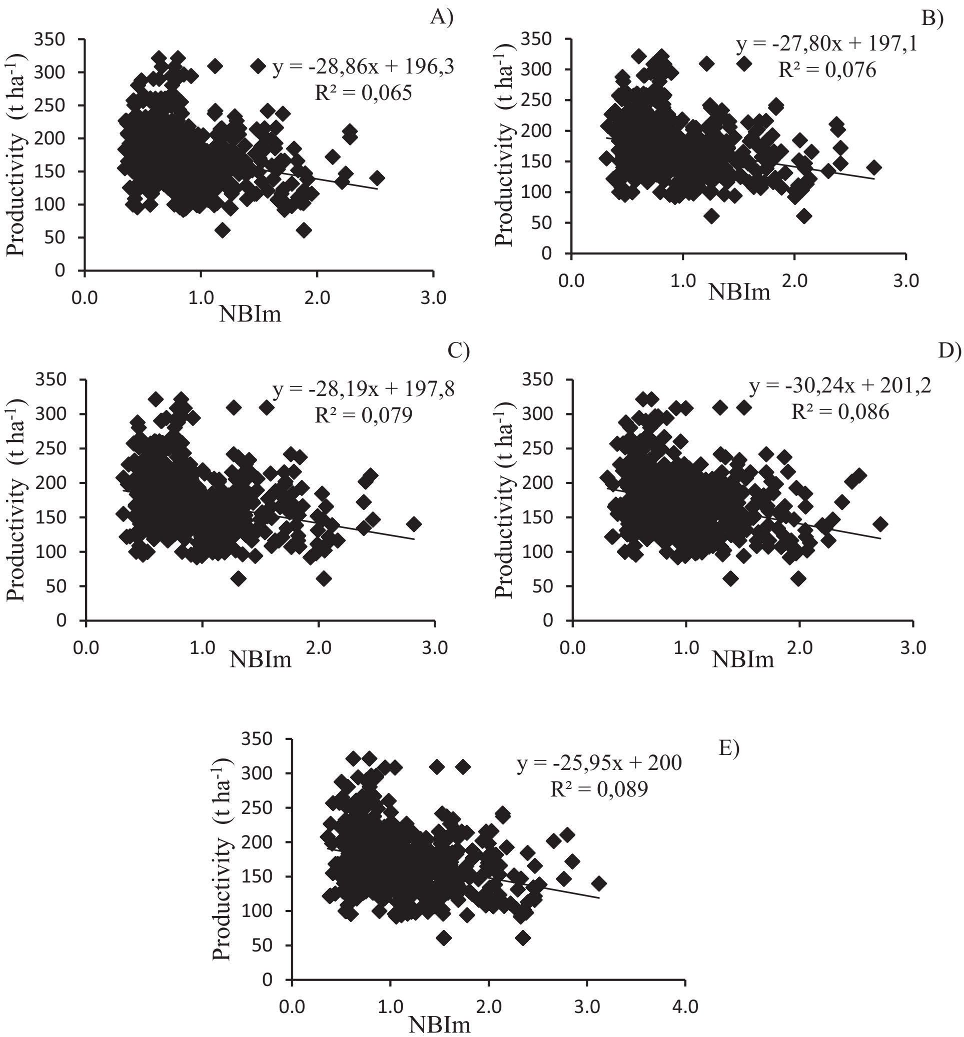

Figure 1. Dispersion of NBIm and productivity values for sugarcane in relation to the five reference populations: P_1 (A): average productivity; P_2 (B): average productivity + 0.5 standard deviation; P_3 (C): average productivity + 1.0 standard deviation; P_4 (D): average productivity + 1.5 standard deviations; and P_5 (E): average productivity + 2.0 standard deviations.

cases are more similar, for example, the five reference populations defined in the present Barłóg (2016) observed a trend toward closer agreement of empirical and theoretical models of productivity and the CND index, when using a smaller number of leaf samples to evaluate the nutritional state. However, this may be misleading if the true cause is reduced sampling variability.

The criteria for selecting standards have previously been based on the degree of agreement between diagnoses obtained from the same set of crops. For example, Serra et al. (2013) found that the maximum correlation in cotton occurred with criteria three and four (89.1%), corresponding to fields with productivity greater than the mean + SD ($n = 18$) and fields with productivity higher than the mean + four-thirds SD ($n = 8$), respectively.

When assessing the degree of agreement between diagnoses of different reference populations, we observed that the greatest disparity occurred between the standards produced by P1 and P5, which had the greatest difference in the number of samples (Table 3). Conversely, reference populations with larger sample sizes and that were closely matched in the number of samples had a greater degree of agreement between diagnoses, as observed for P1 × P2, P2 × P3, and P4 × P5 (Table 3).

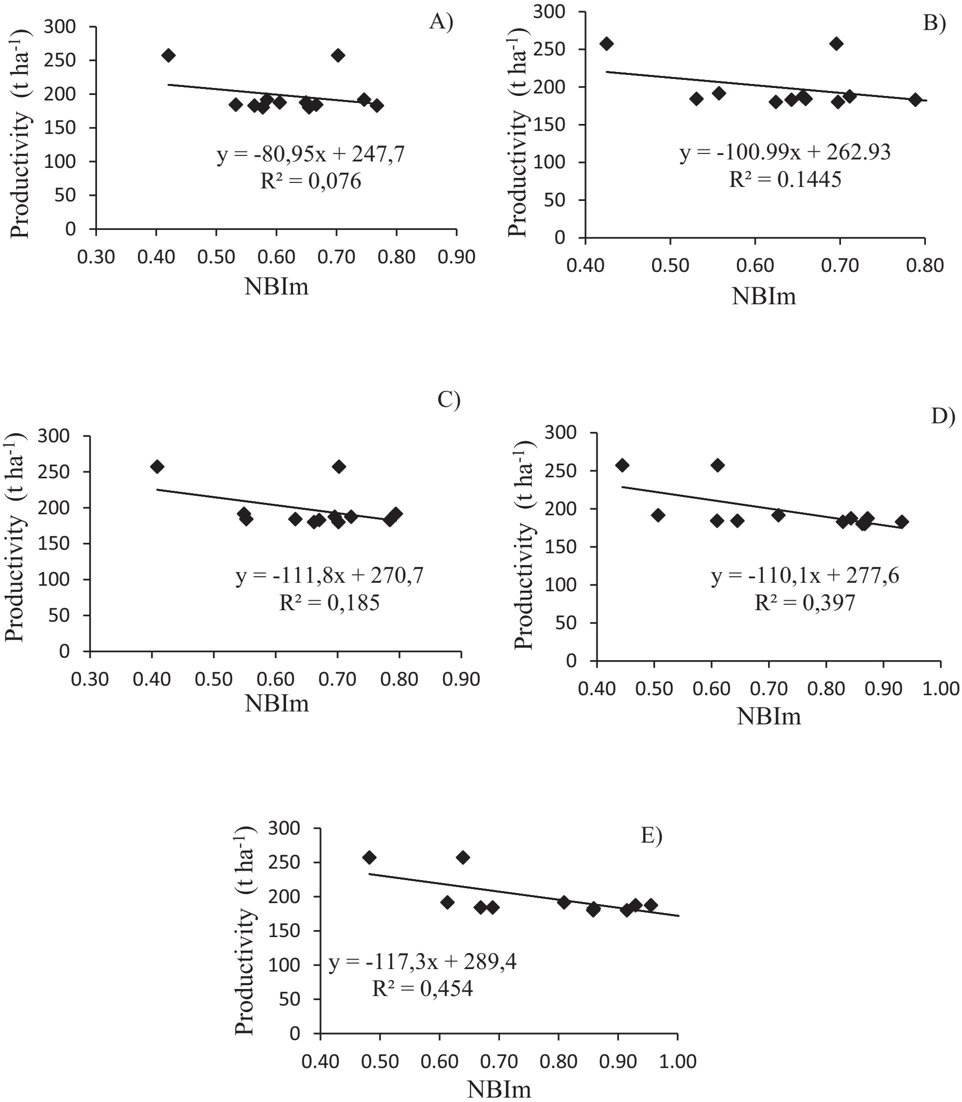

Figure 2. Dispersion of NBIm and productivity values for specific conditions (fewer data) of sugarcane in relation to the five reference populations: P_1 (A): average productivity; P_2 (B): average productivity + 0.5 standard deviation; P_3 (C): average productivity + 1.0 standard deviation; P_4 (D): average productivity + 1.5 standard deviations; and P_5 (E): average productivity + 2.0 standard deviations.

Using the degree of agreement as a criterion for selecting standards does not necessarily imply that the diagnoses are true, only that the standards are concordant with each other, since the nutritional diagnoses for each standard were not evaluated for accuracy, i.e., they did not include plant responses to applications of phosphorous.

Therefore, using the degree of agreement is an arbitrary decision. The alternative, proposed by Beverly and Hallmark (1992), is to evaluate the diagnosis of a control treatment with nutrient application and validate the diagnosis produced in the control treatment.

When we applied this criterion to this data, it was possible to compare 900 cases for the five CND standards. For the sake of illustration, only 30 cases are presented (Table 4).

We exemplify case one for a better understanding: the nutritional diagnosis of the control treatment (0 kg ha^{-1} P_2O_5) by the CND indicated sufficient state (S), with of 116.67 t ha^{-1}. The

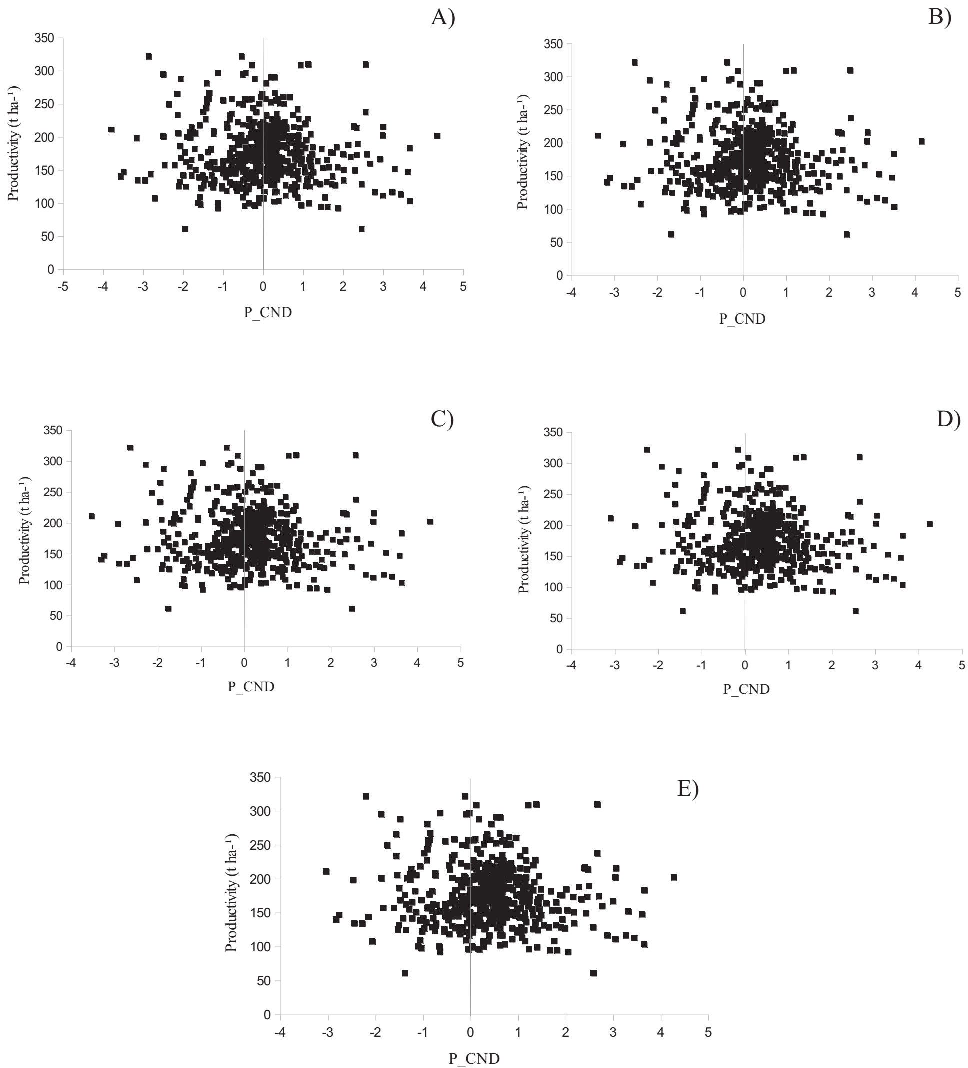

Figure 3. Dispersion of the CND index values for phosphorus (P_CND) and sugarcane productivity in relation to the five reference populations: P_1 (A): average productivity; P_2 (B): average productivity + 0.5 standard deviation; P_3 (C): average productivity + 1.0 standard deviation; P_4 (D): average productivity + 1.5 standard deviations; and P_5 (E): average productivity + 2.0 standard deviations.

Table 3. Degree of agreement among the five reference populations for diagnosis of the phosphorus nutritional status, in 694 valid cases.

Combinations of standards	Degree of agreement %
$P_1 \times P_2$	92.4
$P_1 \times P_3$	92.7
$P_1 \times P_4$	84.6
$P_1 \times P_5$	81.8
$P_2 \times P_3$	98.8
$P_2 \times P_4$	90.8
$P_2 \times P_5$	89.2
$P_3 \times P_4$	90.8
$P_3 \times P_5$	89.2
$P_4 \times P_5$	95.0

P_1: average productivity; P_2: average productivity + 0.5 standard deviation; P_3: average productivity + 1.0 standard deviation; P_4: average productivity + 1.5 standard deviations; P_5: average productivity + 2.0 standard deviations.

Table 4. Accuracy of nutritional diagnosis for the nutrient phosphorus for five CND standards in sugarcane.

Case	Standard	Location	Soil	Sampling Months	Comparison kg ha^{-1} P_2O_5	Diagnose control	Prod. control t ha^{-1}	Prod. manured t ha^{-1}	Increase of Prod. %	State P real	Gain of Prod. t ha^{-1}
1	P_1	1	eRYA	04	0 × 90	S	116.67	136.00	17	D	−19.33
2	P_1	1	eRYA	04	0 × 180	S	116.67	155.33	33	D	−38.67
3	P_1	1	eRYA	04	0 × 360	S	116.67	186.00	59	D	−69.33
4	P_1	1	eRYA	04	90 × 180	S	136.00	155.33	14	D	−19.33
5	P_1	1	eRYA	04	90 × 360	S	136.00	186.00	37	D	−50.00
6	P_1	1	eRYA	04	180 × 360	S	155.33	186.00	20	D	−30.67
7	P_2	3	eRA	08	0 × 90	S	143.67	191.67	33	D	−48.00
8	P_2	3	eRA	08	0 × 180	S	143.67	258.00	80	D	−114.33
9	P_2	3	eRA	08	0 × 360	S	143.67	296.67	106	D	−153.00
10	P_2	3	eRA	08	90 × 180	S	191.67	258.00	35	D	−66.33
11	P_2	3	eRA	08	90 × 360	S	191.67	296.67	55	D	−105.00
12	P_2	3	eRA	08	180 × 360	S	258.00	296.67	15	D	−38.67
13	P_3	1	dRL	04	0 × 90	D	168.67	95.67	−43	S	−73.00
14	P_3	1	dRL	04	0 × 180	D	168.67	193.33	15	D	24.67
15	P_3	1	dRL	04	0 × 360	D	168.67	155.00	−8	S	−13.67
16	P_3	1	dRL	04	90 × 180	S	95.67	193.33	102	D	−97.67
17	P_3	1	dRL	04	90 × 360	S	95.67	155.00	62	D	−59.33
18	P_3	1	dRL	04	180 × 360	S	193.63	155.00	−20	S	38.33
19	P_4	2	dRYL	04	0 × 90	D	61.00	120.67	98	D	59.67
20	P_4	2	dRYL	04	0 × 180	D	61.00	134.33	120	D	73.33
21	P_4	2	dRYL	04	0 × 360	D	61.00	140.00	130	D	79.00
22	P_4	2	dRYL	04	90 × 180	S	120.67	134.33	11	D	−13.67
23	P_4	2	dRYL	04	90 × 360	S	120.67	140.00	16	D	−19.33
24	P_4	2	dRYL	04	180 × 360	D	134.33	140.00	4	D	5.67
25	P_5	3	dRYA	08	0 × 90	S	170.00	180.20	6	D	−10.20
26	P_5	3	dRYA	08	0 × 180	S	170.00	173.10	2	D	−3.10
27	P_5	3	dRYA	08	0 × 360	S	170.00	199.00	17	D	−29.00
28	P_5	3	dRYA	08	90 × 180	S	180.00	173.10	−4	S	7.10
29	P_5	3	dRYA	08	90 × 360	S	180.00	199.00	10	D	−18.80
30	P_5	3	dRYA	08	180 × 360	S	173.10	199.00	15	D	−25.90

P_1: average productivity; P_2: average productivity + 0.5 standard deviation; P_3: average productivity + 1.0 standard deviation; P_4: average productivity + 1.5 standard deviations; P_5: average productivity + 2.0 standard deviations; Location 1: Santa Adélia; Location 2: Santa Albertina; Location 3: Catanduva; eRYA: Eutrophic Red-Yellow Argisol; eRA: Eutrophic Red Argisol; dRL: Dystrophic Red Latosol; dRYL: Dystrophic Red-Yellow Latosol; dRYA: Dystrophic Red-Yellow Argisol; S: sufficient state; D: deficient; Prod: productivity.

Table 5. Performance of nutritional diagnoses for the nutrient phosphorus associated with true and false diagnoses in sugarcane, assuming a 10% increase in productivity.

Standard	Gain Prod. average t ha^{-1}	Diagnoses T (D)	T (A)	F(D)	F(A)	Efficiency %	T/F ratio
P_1	−10.29	33	37	9	97	40	3.7
P_2	−13.79	23	40	6	107	36	3.8
P_3	−12.78	25	40	6	105	37	4.2
P_4	−14.94	19	44	3	110	36	6.3
P_5	−17.40	13	42	1	120	31	13.0
Average	−13.84	23	41	5	108	36	6.2

P_1: average productivity; P_2: average productivity + 0.5 standard deviation; P_3: average productivity + 1.0 standard deviation; P_4: average productivity + 1.5 standard deviations; P_5: average productivity + 2.0 standard deviations; Prod: productivity; T(D): true deficiency; T(A): true adequacy; F(D): false deficiency; F(A): false adequacy.

selected comparison treatment was the application of 90 kg ha^{-1} P_2O_5, with a productivity of 136.00 t ha^{-1}, representing a 17% increase in productivity from the application of fertilizer. Increased productivity from the application of phosphorous indicated that the plant would be deficient in the control treatment (D), rendering the S diagnosis false with a calculated 19.33 t ha^{-1} loss in productivity (Table 4).

When assessing the accuracy of diagnoses for phosphorus, we noted that all reference populations resulted in a loss of productivity when the nutritional status of the treatments was evaluated with the CND (Table 5). However, the lowest productivity loss was recorded with the P_1 standard and the highest with the P_5 standard when compared to the others (Table 5). A similar result was observed by Martins (2015) when evaluating the accuracies of nutritional diagnoses for potassium in cowpea, with a loss of 32 kg ha^{-1} in function of the diagnoses produced by the CND method. However, for P they found productivity gains of 129 kg ha^{-1} for diagnoses made by the CND method.

When using the set of plots with greater productivity as the reference population, there was a significant improvement in the T/F ratio (Table 5), i.e., the proportion of true diagnoses for deficiency increased, which was due to a nine-fold reduction in the number of false deficiencies and a reduction of two-and-a-half times the number of TD diagnoses. This suggests that higher average productivity standards are those most indicated.

Wadt and Lemos (2010) argued, however, that the greatest loss in the decision on fertilization management might be the lack of TD indicators, preventing a responsive increase in fertilizer dose and thereby reducing productivity gains. This problem became evident when comparing the P1 and P5 standards, which resulted in 33 and 13 true diagnoses for deficiency, respectively, i.e., the P5 standard did not indicate 20 cases of TD (Table 5).

Furthermore, the cases of TA were relatively unaffected, ranging from 42 cases for standard P5 to 37 cases for standard P1. Although the use of reference populations with higher productivity improves the ratio of TD and FD cases, there is also a considerable loss in the total number of indications of TD, resulting in an increase in cases of FA, from 97 to 120 cases for standards P1 and P5, respectively.

The difference in performances was reflected in the greater efficiency of the diagnosis produced from the reference population with the highest number of cases of low productivity (P1 = 40%), compared with the standard obtained from the plots of greater productivity (mean 31%) (Table 5). This result is not surprising, since the us Beaufils (1973) for defining the reference population for the integrated diagnosis and recommendation system method, although it is not used by most authors who work with this methodology.

Based on the productivity (gain or loss) and diagnosis efficiency, we recommend applying standards to further datasets, including those representing lower productivity. However, we caution that applying standards to populations with higher productivity tends to reduce the number of false diagnoses for deficiency, which results in a higher T/F ratio.

Any reference population that achieves a maximum performance efficiency less than 50% represents an unacceptable value for all diagnostic methods (Teixeira, Santos, and Bataglia 2002). Poor performance indicates that more than half of the diagnoses were not confirmed by plant responses to fertilizer application (Beverly and Hallmark 1992).

Thus, there is a clear need for improved diagnostic procedures produced by the CND method before it can be recommended for fertilizer management, without prejudice to the fact that broader reference populations show important improvement in performance of the obtained diagnoses.

Conclusions

Reference populations showed that it was possible to define the best set of standards from the degree of agreement criteria, or by analyzing the dispersion between productivity and the NBIm and CND indices.

Accuracy analysis of nutritional diagnosis for phosphorus identified low performance of all sets of CND standards, but better performance for standards was derived from reference populations of greater productivity.

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