Australian Journal of Crop Science AJCS

AJCS 12(02):274-280 (2018) ISSN:1835-2707
doi: 10.21475/ajcs.18.12.02.pne766

# DRIS standards for nutritional evaluation of *Phaseolus vulgaris* in Cerrado, Goiás state, Brazil

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**Abstract**

The knowledge of nutritional requirements of beans, the efficiency of soil acidity correction and the fertilization programs are essential to increase productivity. The Integrated Recommendation and Diagnosis System (DRIS) assists with nutritional diagnosis of cultivated plants based on existing interactions between nutrients and the hierarchizing of limitations. This study aimed at establishing standards using the DRIS method for areas of production of irrigated common beans and at determining the most limiting nutritional factors to production using leaf analyses interpreted by concentration ranges and DRIS. Eighteen different bean-producing areas were selected in a central pivot irrigation system, from which 82 sampling points were established to collect leaves of crop and determine their nutritional contents. The reference population had productivity of over 3,000 kg $ha^{-1}$. Using DRIS, we determined that phosphorus is the most limiting nutrient regarding its deficiency, with great sensitivity to diagnose nutritional problems of plants, especially micronutrients. Phosphorus (68.3%), molybdenum (65.9%), iron (64.6 %) and sodium (63.4%) and are nutrients with highest percentage of samples presenting levels below adequate according to sufficiency ranges for plants. Using DRIS, we can evaluate interactions among nutrients and determine of the magnitude of crop nutritional limitation whether due to deficiency or excess. These results may indicate which nutrients are limiting the crop productive capacity, allowing greater efficiency in its correction in soil.

**Keywords:** Integrated Recommendation and Diagnosis System; macronutrients; micronutrients; fertilization; plant nutrition.
**Abbreviations:** CL_critical levels; CR_concentration ranges; DRIS_Integrated Recommendation and Diagnosis System; NBI_nutritional balance index; RSL_regional sufficiency level; SF_ sufficiency range; SD_standard deviation; CR_concentration ranges; N_ nitrogen; P_ phosphorus; K_potassium; Ca_calcium; Mg_magnesium; S_sulfur; Na_sodium; B_boron; Cu_copper; Fe_iron; Mn_manganese; Zn_zinc; Co_cobalt; Mo_molybdenum; $BaCl_2$_barium chloride; $HNO_3$_nitric acid.

## Introduction

Brazil ranks first as producer of common beans (*Phaseolus vulgaris* L.). Production reached 3.112 million tons in the 2014/15 crop. The state of Goiás accounts for approximately 12.11% of beans produced in Brazil (Conab, 2016). In eastern Goiás, the municipality of Cristalina has expressive area irrigated by central pivots, approximately 44,700 ha, where a large plot has been cultivated with common beans (mainly third harvest crop). In the Cerrado conditions, there are reports of decrease in bean productivity during harvest. This is mainly attributed to inherent management issues, especially nutritional imbalance of plants (Paula Júnior et al., 2006). Thus, farmers try to minimize such effects using high doses of fertilizers and successive applications of chemical inputs. However, results are not always satisfactory: production cost and environmental pollution increase. Knowledge of nutritional requirements of common beans, efficiency of programs to correct soil acidity and fertilization are essential for plants to express their full productive potential. Leaf analysis is a useful tool that allows us to monitor, evaluate and adjust agricultural fertilization (Tomio et al., 2015). It is highly important to fertilization programs (Menesatti et al., 2010). Interpretation of results of leaf analysis has been made using critical levels (CL) or concentration ranges (CR) based on isolate evaluation of nutrients (univariate analyses), disregarding interactions between them, especially specificities of nutrients in different varieties and stages of plant development. Hence, the need for methods to evaluate the relation between nutrients since one may interfere with the availability of the other. The Integrated Recommendation and Diagnosis System (DRIS) is based on the balance of nutrient contents in soil and plant (Beaufils, 1971; Baldock and Schulte, 1996). It takes into account binary relations between concentrations of all nutrients (bivariate analyses), resulting in greater accuracy in diagnoses when compared to individual interpretations of nutrients (Leandro, 2016). The nutritional balance has direct relation with plant productivity levels (Fageria et al., 2009). Adequate plant nutrition allows us to determine practices involving the use of nutritional balance instead of management of fertilization using homogeneous technological packages (Leandro, 2016). Using DRIS, we can evaluate interactions among nutrients and score their limitations aiming at establishing "sufficiency ranges" for tissues, crop stages and crop varieties based on a database of nutrient concentrations to high-productivity plant populations. It differs from univariate methods which lack calibration curves for each case. DRIS does not indicate whether a particular nutrient is at a toxic or deficient concentration, it rather indicates the most limiting nutrient either by excess or deficiency. Despite this, DRIS is still a promising technique for agricultural fertilization programs (Leandro, 2016). Nutritional reference values obtained by DRIS vary from region to region, suggesting local refinement aiming at method better accuracy (Rocha et al., 2007; Partelli et al., 2014). Edaphoclimatic characteristics, culture management, sampling time, among other variables, are relevant issues to improve diagnosis accuracy by DRIS (Beaufils, 1973; Partelli et al., 2006; Partelli et al., 2014).

DRIS can promote greater efficiency of nutritional evaluations of common beans in the Cerrado of Goiás state. The use of this technique can potentiate the productivity of irrigated crops in detriment of a better nutritional balance. This study aimed at establishing DRIS standards by creating a leaf analysis database and determining the productivity of irrigated common bean crops. We aimed at a nutritional diagnosis in areas of the eastern Cerrado of Goiás state, municipality of Cristalina, Brazil, the major producer of this legume and the second largest producer in the country.

## Results and Discussion

### *Nutrient levels when using DRIS*

Supplementary Table 1 shows the DRIS standards and their respective means, standard deviations and coefficients of variation of nutrients and binary nutrient content relations for the most productive populations or the reference population. Means of leaf nutrient between most productive subgroup and the reference population were compared with concentration ranges (CR). The levels of N and P were considered high, unlike Ca, S and Cu. The levels of K, Mg, B, Fe, Mn, Zn and Mo were adequate.

Mean values of Ca, S and Cu did not differ significantly according to F test ($p>0.05$). This also occurred with means of the ratios N/P, N/Ca, Mg/N, P/Ca, Ca/P, Mg/P, S/P, K/Ca, S/K, Ca/Mg, Ca/Mg, Ca/S, S/Ca, S/Mg, Mn/B, Fe/Cu, Cu/Zn and Zn/Cu.

Mean values of N, P, K, Mg and Zn and the mean values of ratios K/N, N/Mg, N/S, K/P, P/Mg, P/S, K/Mg, K/S, Mg/Ca, Mg/S, B/Cu, Fe/B, B/Mn, Zn/B, Cu/Fe, Cu/Mn, Fe/Mn, Zn/Fe and Zn/Mn were higher than those observed by Paiva Júnior (2011). The average values for B, Fe and Mn and means of ratios P/N, N/K, Ca/N, S/N, P/K, Ca/K, Mg/K, Cu/B, B/Zn, Mn/Cu, Mn/Fe, Fe/Zn and Mn/Zn were low.

Among the 61 possible comparisons of means of nutrient contents and their ratios, 33% did not differ significantly even though they were standards for two distinct regions of the state of Goiás using similar production systems and during similar seasons (third harvest). The approximate values of standards are related to the characteristics of reference populations, which present little differences.

Despite the low contrast between standards, DRIS still must be used in a location-specific way to make interpretations more efficient. Escano et al. (1981), Walworth and Sumner (1987) and Rocha et al. (2007) evaluating corn crops, and Leandro (1998) and Cunha (2002) evaluating soybeans, reported different responses to different conditions. This suggests that standards should be used in a location-specific way to obtain better accuracy in the diagnosis. This corroborates with the observations by Partelli et al. (2006) and Partelli et al. (2014) using nutrient integrated recommendation and diagnosis system.

Critical levels or concentration ranges, methods for interpretation of leaf analyses, should also be used in a specific way for cultivars and edaphoclimatic conditions. However, they have been widely and largely used disregarding several factors involving plant development. Their implementation depends on calibration experiments performed in different regions and cultures to obtain reference values. It spends longer and higher costs. Thus, DRIS has several advantages in relation to critical levels, since it requires less time and practicality to obtain reference values (Leandro, 2016). It is an auxiliary tool to agricultural fertilization programs (Menesatti et al., 2010; Tomio et al., 2015).

Regarding the standards obtained (Supplementary Table 1), coefficients of variation of leaf contents and nutrient ratios were low considering that a coefficient of variation of 50% is satisfactory and all nutrient contents and ratios were below this value.

The reduced functions used for calculation of DRIS indices are consistent to coefficients of variation of reference population. High coefficient of variation has low weight to the index calculation. Therefore, this reduces the possibility of misinterpretation. Walworth and Sumner (1987) stated the coefficient of variation ponders the variability of a high-productivity subgroup.

### *Interpretation of DRIS indices*

Supplementary Table 2 shows DRIS indices for each nutrient at each sampling point. The decreasing order of limitation from deficient to excess, and the nutritional balance index (NBI) were also determined for each sampling point.

DRIS provides the nutritional balance index (NBI), which is the sum of absolute values of DRIS indices of each nutrient, indicating the nutritional status of each crop. The lower the NBI, the better the crop nutritional status (Bataglia and Santos, 1990; Leite, 1993).

All sampled points had high NBI which did not interfere with obtaining high productivity. The NBIs ranged from 38 to 302. However, populations with highest productivities had NBIs from 38 to 174.

After ordering DRIS indices at each sampling point, we obtained the distribution of frequency, which could be determined for the first, second and third order, followed by means among all three orders (Table 1). This frequency, opposite to that obtained for sampling points interpreted by concentration ranges, does not allow interpretation categorized in classes: it allows interpretation of the most limiting nutrients regarding deficiency and excess.

**Table 1.** Percentage of occurrence of most limiting nutrients determined by DRIS indexes obtained by leaf analyses for irrigated common beans cultivated in the city of Cristalina, Goiás state, during the 2009/10 harvest.

Limiting Nutrients for deficiency

| Variable | Percentage of Occurrence[1] | | | |
|---|---|---|---|---|
| | 1st Order | 2ndOrder | 3rd Order | Average |
| N (g kg $^{-1}$) | 1.22 | 2.44 | 4.88 | 2.85 |
| P (g kg $^{-1}$) | 14.63 | 13.41 | 7.32 | 11.79 |
| K (g kg $^{-1}$) | 2.44 | 10.98 | 10.98 | 8.13 |
| Ca (g kg $^{-1}$) | 7.32 | 4.88 | 6.10 | 6.10 |
| Mg (g kg $^{-1}$) | 6.10 | 3.66 | 6.10 | 5.28 |
| S (g kg $^{-1}$) | 1.22 | 2.44 | 10.98 | 4.88 |
| Na (mg kg $^{-1}$) | 10.98 | 2.44 | 2.44 | 5.28 |
| B (mg kg $^{-1}$) | 3.66 | 6.10 | 3.66 | 4.47 |
| Cu (mg kg $^{-1}$) | 8.54 | 14.63 | 4.88 | 9.35 |
| Fe (mg kg $^{-1}$) | 15.85 | 6.10 | 6.10 | 9.35 |
| Mn (mg kg $^{-1}$) | 13.41 | 7.32 | 6.10 | 8.94 |
| Zn (mg kg $^{-1}$) | 3.66 | 6.10 | 7.32 | 5.69 |
| Co (mg kg $^{-1}$) | 7.32 | 9.76 | 9.76 | 8.94 |
| Mo (mg kg $^{-1}$) | 3.66 | 9.76 | 13.41 | 8.94 |

Limiting nutrients by excess

| Variable | Percentage of Occurrence [1] | | | |
|---|---|---|---|---|
| | 1rd Order | 2rd Order | 3rd Order | Average |
| N (g kg $^{-1}$) | 1.22 | 2.44 | 2.44 | 2.03 |
| P (g kg $^{-1}$) | 1.22 | 6.10 | 7.32 | 4.88 |
| K (g kg $^{-1}$) | 9.76 | 4.88 | 4.88 | 6.50 |
| Ca (g kg $^{-1}$) | 3.66 | 8.54 | 10.98 | 7.72 |
| Mg (g kg $^{-1}$) | 8.54 | 8.54 | 14.63 | 10.57 |
| S (g kg $^{-1}$) | 9.76 | 8.54 | 7.32 | 8.54 |
| Na (mg kg $^{-1}$) | 2.44 | 8.54 | 2.44 | 4.47 |
| B (mg kg $^{-1}$) | 14.63 | 15.85 | 9.76 | 13.41 |
| Cu (mg kg $^{-1}$) | 6.10 | 3.66 | 6.10 | 5.28 |
| Fe (mg kg $^{-1}$) | 6.10 | 7.32 | 3.66 | 5.69 |
| Mn (mg kg $^{-1}$) | 21.95 | 7.32 | 3.66 | 10.98 |
| Zn (mg kg $^{-1}$) | 10.98 | 9.76 | 10.98 | 10.57 |
| Co (mg kg $^{-1}$) | 3.66 | 6.10 | 8.54 | 6.10 |
| Mo (mg kg $^{-1}$) | 0.00 | 2.44 | 7.32 | 3.25 |

[1] In the 1st, 2nd and 3rd order occurrence percentages, the first, second and third most positive indices of each sampling point are considered respectively and the average refers to the average of the three% occurrence.

**Table 2.** Polynomial regression equations between the concentration of the variable (Y) and its DRIS index (X) obtained by leaf analyses, regression coefficient ($r^2$), Regional Sufficiency Level (RSL), standard deviation of the high-productivity population (SD) and F test for irrigated common beans cultivated in Cristalina, Goiás state.

| Variable | RSL | SP | | | coefficient of equation $Y = a + bx + cx^2 + dx^3$ | | | | | | | | $r^2$/ test F[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | a | | B | | | C | | d | |
| N (g kg $^{-1}$) | 58.63 | 3.69 | y | = | 58.63478 | + | 0.22665 | x | | | | | 0.17** |
| P (g kg $^{-1}$) | 4.93 | 0.59 | y | = | 4.93355 | + | 0.06533 | x | + | 0.00076 | $x^2$ | | 0.79** |
| K (g kg $^{-1}$) | 24.80 | 3.25 | y | = | 24.79820 | + | 0.29428 | x | | | | | 0.73** |
| Ca (g kg $^{-1}$) | 13.07 | 1.28 | y | = | 13.07393 | + | 0.16419 | x | + | 0.00298 | $x^2$ | | 0.79** |
| Mg (g kg $^{-1}$) | 4.67 | 0.64 | y | = | 4.66888 | + | 0.06648 | x | + | 0.00090 | $x^2$ | | 0.86** |
| S (g kg $^{-1}$) | 1.85 | 0.29 | y | = | 1.84649 | + | 0.03219 | x | | | | | 0.86** |
| Na (mg kg $^{-1}$) | 133.23 | 17.73 | y | = | 133.28756 | + | 1.71905 | x | | | | | 0.72** |
| B (mg kg $^{-1}$) | 46.00 | 9.78 | y | = | 45.99546 | + | 1.02269 | x | + | 0.00292 | $x^2$ | | 0.93** |
| Cu (mg kg $^{-1}$) | 7.45 | 1.65 | y | = | 7.44725 | + | 0.15264 | x | + | 0.00204 | $x^2$ | | 0.92** |
| Fe (mg kg $^{-1}$) | 197.78 | 55.44 | y | = | 197.77583 | + | 4.78796 | x | + | 0.04550 | $x^2$ | | 0.93** |
| Mn (mg kg $^{-1}$) | 57.02 | 16.71 | y | = | 57.02298 | + | 1.37984 | x | + | 0.00821 | $x^2$ | | 0.98** |
| Zn (mg kg $^{-1}$) | 47.08 | 8.95 | y | = | 47.08079 | + | 0.84394 | x | + | 0.00279 | $x^2$ | | 0.94** |
| Co (mg kg $^{-1}$) | 0.26 | 0.03 | y | = | 0.26362 | + | 0.00322 | x | | | | | 0.84** |
| Mo (mg kg $^{-1}$) | 0.85 | 0.06 | y | = | 0.84966 | + | 0.00574 | x | | | | | 0.53** |

[1] Significance level of the F test: ** significant at the 1% probability level

**Table 3.** Distribution of frequency of the variables N, P, K, Ca, Mg, S, Na, B, Cu, Fe, Mn, Zn, Co and Mo obtained by leaf analyses at 82 sampling points in irrigated common beans cultivated in the municipality of Cristalina, Goiás state.

| Variable of leaf analysis | FS irrigated bean[1] | Concentration ranges |
|---|---|---|
| N ($g\ kg^{-1}$) | 58.63 – 62.32 | 30.00-50.00 [2] |
| P ($g\ kg^{-1}$) | 4.93 – 5.52 | 2.00-3.00 [2] |
| K ($g\ kg^{-1}$) | 24.80 – 28.05 | 20.00-25.00 [2] |
| Ca ($g\ kg^{-1}$) | 13.07 – 14.35 | 15.00-20.00 [2] |
| Mg ($g\ kg^{-1}$) | 4.67 – 5.31 | 4.00-7.00 [2] |
| S ($g\ kg^{-1}$) | 1.85 – 2.14 | 5.00-10.00 [2] |
| Na ($mg\ kg^{-1}$) | 133.23 – 150.96 | - |
| B ($mg\ kg^{-1}$) | 46.00 – 55.78 | 30.00-60.00 [2] |
| Cu ($mg\ kg^{-1}$) | 7.45 – 9.10 | 10.00-20.00 [2] |
| Fe ($mg\ kg^{-1}$) | 197.78 – 253.22 | 100.00-450.00 [2] |
| Mn ($mg\ kg^{-1}$) | 57.02 – 73.73 | 30.00-300.00 [2] |
| Zn ($mg\ kg^{-1}$) | 47.08 – 56.03 | 20.00-100.00 [2] |
| Co ($mg\ kg^{-1}$) | 0.26 – 0.29 | - |
| Mo ($mg\ kg^{-1}$) | 0.85 – 0.91 | 0.50-1.50 [3] |

[1] Obtained through the sum of the Regional Sufficiency Level (RSL) with the standard deviation (SD) of the reference population, the RSL being the lower limit and the upper limit being the sum with the SD; 2 Malavolta, et al. (1997), and Ambrosano et al. (1996).

**Table 4.** Distribution of frequency of the variables N, P, K, Ca, Mg, S, Na, B, Cu, Fe, Mn, Zn, Co and Mo obtained by leaf analyses at 82 sampling points in irrigated common beans cultivated in the municipality of Cristalina, Goiás state.

| Variable | Classes of interpretation | | |
|---|---|---|---|
| | Low | Suitable | High |
| | -------------------------------------- % ---------------------------------- | | |
| N[1] | 57.3 | 37.8 | 4.9 |
| P[1] | 68.3 | 19.5 | 12.2 |
| K[1] | 42.7 | 45.1 | 12.2 |
| Ca[1] | 40.2 | 36.6 | 23.2 |
| Mg[1] | 36.6 | 39.0 | 24.4 |
| S[1] | 54.9 | 23.2 | 21.9 |
| Na[1] | 63.4 | 25.6 | 11.0 |
| B[1] | 45.1 | 22.0 | 32.9 |
| Cu[1] | 36.6 | 47.6 | 15.8 |
| Fe[1] | 64.6 | 18.3 | 17.1 |
| Mn[1] | 57.3 | 13.4 | 29.3 |
| Zn[1] | 40.2 | 33.0 | 26.8 |
| Co[1] | 39.0 | 46.3 | 14.7 |
| Mo[1] | 65.9 | 30.5 | 3.6 |

[1] Based on the sufficiency ranges obtained in this work by the DRIS method for irrigated common bean.

The order of limitation by nutrient deficiency of the most negative DRIS indices related to the occurrence of first order nutrient contents was Fe>P>Mn>Na>Cu>Ca=Co>Mg>B=Zn=Mo>K>N=S. Thus, to increase the reliability of DRIS method, the order of deficiency was interpreted by the average among the three most limiting orders resulting in the sequence P>Cu=Fe>Mn=Co=Mo>K>Ca>Zn>Mg=Na>S>B>N.

Matos et al. (2007), using DRIS to evaluate the limitation of mineral nutrition of Palma (*Elaeis guineensis* Jacq.) in the state of Pará, Brazil, reported that the most limiting nutrient was calcium, while the least limiting nutrient was phosphorus. Results are different from those obtained in this study. Behera et al. (2016) observed phosphorus and potassium among the most limiting nutrients for the same crop (*Elaeis guineensis* Jacq.) in soils of Karnataka, India. We also determined the ordering of limitation by nutrient excess of the most positive DRIS indices regarding the occurrence of first-order nutrient contents. The following sequence was determined:Mn>B>Zn>K=S>Mg>Cu=Fe>Ca=Co>Na>N=P>Mo. Meanwhile, the ordering of limitation by nutrient excess interpreted by the mean among the three most limiting orders was B>Mn>Mg=Zn>S>Ca>K>Co>Fe>Cu>P>Na>Mo>N.

In reviewing the DRIS methodology, Sumner (1990) stated indices classify nutrients in a relative order. Based on this, no nutrient can be considered deficient. It can only be stated a nutrient is insufficient compared to other nutrients. However, even if an index is more negative, a productivity response may not necessarily be obtained, as there may be other more limiting factor. According to the author, when correctly used, both the traditional method and DRIS can be efficient and useful in providing information to perform a nutritional diagnosis of a culture.

Table 2 shows adjustments of polynomial regression equations between nutrient content (independent variable) and DRIS index (dependent variable) for leaf analyses of common beans. Equations were significant ($p>0.01$) for all variables according to the F test. Regression coefficients were high for all nutrients, except for N (0.17). The high regression coefficients increased reliability of regional sufficiency ranges regarding these variables. The standard deviation of high-productivity populations (reference population for establishing DRIS indices) and the standard deviation of the entire sampled population were used as criterion to establish sufficiency ranges. The use of standard deviation of total sampled population aims at obtaining a sufficiency range with greater amplitude. When comparing SR obtained by DRIS with concentration ranges as proposed by Malavolta et al. (1997) and Ambrosano et al. (1996), N and P showed SR with increased upper and lower limits (Table 3). Values were higher than those proposed by Malavolta et al. (1997). However, the lower limit for K was close to the upper limit of SR. Contents of Ca, S and Cu had SR with upper limits below CR lower limits. Meanwhile, as for contents of Mg, B, Fe, Mn, Zn and Mo, the SRs were between the lower and the upper limits of CRs. Therefore, SRs are more restrictive and have lower amplitude than CRs. In general, SRs estimated in this study were lower than ranges for a same nutrient content recommended by other authors, especially micronutrients. This small amplitude of estimated range is due to low standard deviation of nutrient contents of the reference population. Some authors reported lower amplitude of SRs estimated by the DRIS method compared to the values found in the literature (Wadt et al., 1998; Urano et al., 2007; Dias et al., 2013).

The nutritional diagnosis by DRIS along with the use of generic standards does not always present the same results after evaluating the nutritional state of plants when compared to the nutritional standards found in the literature (Dias et al., 2013).

The mean values of standards, when compared to the SRs in this study, were classified mostly as low, close to the lower limit of "adequate" range, with the exception of Mo, which was classified as "adequate" at the low limit of range.
Considering an interpretation based on DRIS sufficiency ranges for irrigated common bean crops, the nutrients presenting the highest percentages (Table 5) in samples with levels below adequate were P (68.3%), Mo (65.9%), Fe (64.6%) and Na (63.4%). Meanwhile, the ordering of limitation by nutrient deficiency was P>Mo>Fe>Na>N= Mn>S>B >K >Ca=Zn>Co>Mg=Cu.

## Materials and Methods

### *Study Area*

We conducted the study in irrigated commercial areas cultivated with common beans (*Phaseolus vulgaris* L.), cultivar "Pérola", in the municipality of Cristalina, eastern region of Goiás, Brazil, under coordinates 16°45' S and 47°36' W. The average altitude is 850 m. The regional climate is Cwa, humid mesothermic, according to the Köppen classification (Köppen, 1948). Rainfalls are abundant in the summer. The winter is dry and the summer is hot.

Means for climate indicators are 1,600 mm of annual rainfall, average temperature of 22ºC and 73% of relative humidity. This characterizes this region as subtropical, in which the average temperature during the coldest months (June and July) is approximately 16ºC.

The predominant soils are *Latossolo Vermelho Eutrófico* (Oxisol) and *Nitossolo Vermelho Eutrófico* (Ultisol), with predominant clayey texture in a flat to wavy relief.

We selected 18 areas along the municipality. All of them were in a pivotal center, in which 82 plots were established to collect leaves of bean plants to determine nutrient contents. Selected areas were cultivated using a no-tillage system during 1-5 years. To define the planting areas, we determined the homogeneity of the area based on crop development stage, existence and intensity of straw, presence and intensity of concretions, relief and soil color. Each plot was marked with a stake. Geographical coordinates and altitude were determined for later localization and the obtaining of average productivity results.

### *Sampling and laboratory analysis*

We performed sampling of bean leaves from May to August during the 2009/10 harvest. In each plot, we collected the leaf sample at random. There were 20 subsamples following a zigzag route in approximate 1-hectare area. We collected leaf samples at the beginning of crop flowering at the R5 phenological stage (Fernandes et al., 1986). We collected the first ripened leaf with a petiole from the branch tip, placed it in a paper bag, labeled it, kept it in shade and sent it to the laboratory. Subsequently, leaves were washed in deionized water and dried in a forced-air ventilation oven at approximately 65ºC until constant mass. The dehydrated material was ground using a Willey mill and sent to the laboratory to determine nutrient contents.

We determined the levels of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), sodium (Na), boron (B), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), cobalt (Co) and molybdenum (Mo). Methods applied for samples digestion and for nutrient doses were those recommended by Embrapa (1999). To determine N, samples underwent a sulfuric solubilization and the element was determined by digestion-titration (Kjeldahl). To determine the content of P, K, Ca, Mg, S, Na, Cu, Fe, Mn and Zn, the samples initially underwent a nitroperchloric digestion. We determined P by colorimetry using ammonium molybdate, K and Na by flame photometry, and S by turbidimetry using $BaCl_2$. We determined Ca, Mg, Cu, Fe, Mn and Zn by atomic absorption. As for B, Co and Mo, samples were incinerated in muffle and ash dissolution in $HNO_3$ at 0.1mol $L^{-1}$. Co and Mo were determined by atomic absorption and B by azimethine colorimetry.

We obtained the average yield of common beans on the eve of harvest by sampling. We considered 5 m samples, consisting of five 1 m subsamples in planting lines in each plot. Plants were ripped and individualized in bags, dried, trodden and weighed to estimate productivity at 13% moisture.

### *Statistical analysis*

In order to use the Integrated Recommendation and Diagnosis System (DRIS), we used the results obtained by leaf analyses and their respective productivities to compile a database. We divided the results into two subgroups according to productivity criteria (Beaufils, 1973; Malavolta et al., 1989). One subgroup corresponded to areas with a productivity of bean grains above 3,000 kg $ha^{-1}$ (reference population) and the other subgroup corresponded to areas with productivity of bean grains below 3,000 kg $ha^{-1}$. Values were approximately 2,800 kg $ha^{-1}$ based on average productivity of third-crop bean in GO during the 2011/12 harvest, (Conab, 2016). Productivity of 3,000 kg $ha^{-1}$ is desired. From the reference population of 34 samples, DRIS standards were obtained by calculating means, standard deviations and coefficients of variation of leaf nutrients based on leaf analyses and possible binary relations (Beaufils, 1971, 1973). Mean values of nutrient concentrations and their relations with their respective variances represent the nutritional conditions of crops (Beaufils, 1971, 1973; Walworth and Sumner, 1987; Malavolta et al., 1989; Raij, 1991). Binary ratios between N, P, K, Ca, Mg, S, Na, B, Cu, Fe, Mn, Zn, Co and Mo contents were calculated based on leaf analyses to calculate DRIS indices. These indices were calculated based on the reference population. The process used to calculate the indices takes into account mineral nutrition criteria for DRIS. The procedure was proposed by Alvarez and Leite (1999). Indices were calculated by the mean between direct and inverse ratios of nutrients according to equation 1.

$$\text{index A} = \frac{Z\left(\frac{A}{B}\right) + Z\left(\frac{A}{C}\right) + \cdots + Z\left(\frac{A}{N}\right) - Z\left(\frac{B}{A}\right) - Z\left(\frac{C}{A}\right) - \cdots - Z\left(\frac{N}{A}\right)}{2(n-1)}$$

(Equation 1)

Where:

• Z (A/B) to Z (N/A) is direct and inverse normal ratios between contents of all nutrients in relation to the nutrient A;

• n - 1 is the number of possible ratios.

Before comparing ratios among variables (sample vs. standard), ratio data were transformed using reduced functions, calculated according to equations 2 and 3 (Beaufils, 1971, Beaufils, 1973; Oliveira, 1998).

$$Z\left(\frac{A}{B}\right) = \left(\frac{A/B}{a/b} - 1\right)\frac{Kt}{CVa/b} \quad \text{se} \ \frac{A}{B} > \frac{a}{b}$$

(Equation 2)

$$Z\left(\frac{A}{B}\right) = \left(1 - \frac{a/b}{A/B}\right)\frac{Kt}{CVa/b}\,\text{se}\,\frac{a}{b} > \frac{A}{B}$$

(Equation 3)

Where:

• A/B is the quotient of nutrient contents A and B of sample under study;

• a/b is the mean between the ratio of nutrients A and B of the reference population;

• CVa/b is the coefficient of variation of the ratio between nutrients A and B of the reference population which satisfies a minimum level of productivity;

• Kt is the sensitivity coefficient; it has an arbitrary value. The value used was 100.

We interpreted DRIS indices using a standard procedure (Beaufils, 1971). Negative values mean deficiency of nutrient in relation to the others, positive values indicate excess. If indices are close to zero, they will be closer to the plant nutritional balance (Beaufils, 1973; Walworth and Sumner, 1987). We obtained the percentage of occurrence in the first, second and third orders, corresponding to the first, second and third most negative and positive indicesat each sampling point. Then, the mean of the three orders was calculated, more negative and more positive. The nutritional balance index (NBI) was calculated by the adding DRIS indices to each leaf analysis variable at each sampling point. We calculated the adjusted values for polynomial equations between nutrient contents (independent variable - Y) and DRIS indices (dependent variable - X) in leaf analyses. Then, we obtained the regional sufficiency level (RSL) for each variable (Oliveira and Souza, 1988). Sufficiency ranges (SR) were calculated based on the RSL and the standard deviation (SD). The SRs were compared with concentration ranges (CR) for common beans (Malavolta et al., 1997; Ambrosano et al., 1996). The classes of interpretation of nutrients were as follows: N: 30-50 g $kg^{-1}$, P: 2.0-3.0 g $kg^{-1}$, K: 20-25 g $kg^{-1}$, Ca: 15-20 g $kg^{-1}$, Mg: 4.0-7.0 g $kg^{-1}$, S: 5.0-10 g $kg^{-1}$, Cu: 10-20 mg $kg^{-1}$, Fe: 100-450 mg $kg^{-1}$, Mn: 30-300 mg $kg^{-1}$, Zn: 20-100 mg $kg^{-1}$, B: 30-60 mg $kg^{-1}$ (ranges established by Malavolta et al., 1997), and Mo: 0.5-1.5 mg $kg^{-1}$ (range established by Ambrosano et al., 1996). Thus, the mean nutrient contents of the reference population were compared with both SR and CR. The DRIS standards established by this study were compared with those obtained by Paiva Júnior (2011). The author developed them for irrigated beans using a pivotal center system, cultivar "Pérola", in the region of Rio dos Bois, GO, Brazil, with a reference population comprising 29 sampling points and productivity above 2,700 kg $ha^{-1}$. Macronutrient contents presented by Paiva Júnior (2011) had different scale from this study. As a consequence, the ratios between macronutrients and micronutrients could not be determined. The comparison of standards was performed using the F test and the software *Statistical Analysis System - SAS* (Freund and Littell, 1981).

**Conclusion**

The contents of nitrogen (N) and phosphorus (P) were classified as high, the contents of calcium (Ca), sulfur (S) and copper (Cu) were classified as low, and the contents of potassium (K), magnesium (Mg), Boron (B), iron (Fe), manganese (Mn), zinc (Zn) and molybdenum (Mo) were classified as adequate for means of DRIS standards compared with the concentration ranges reported in the literature. N, P, K, Ca, Mg, S, Na, B, Cu, Fe, Mn, Zn and Co contents were classified as low and the content of Mo was classified as adequate for DRIS standards compared to the sufficiency ranges obtained in this study. The contents of Ca, S and Cu did not differ significantly compared to mean nutrient values of DRIS standards. The ordering of limitation by deficiency, interpreted by the mean among the three most limiting orders, was P>Cu=Fe>Mn=Co=Mo>K> Ca>Zn>Mg=Na>S>B>N. The ordering of limitation by excess, interpreted by the mean among the three most limiting orders, was B>Mn>Mg=Zn>S>Ca>K>Co>Fe>Cu>P>Na>Mo>N. P (68.3%), Mo (65.9%), Fe (64.6%) and Na (63.4%) are nutrients with the highest percentage of samples presenting levels below adequate interpreted by sufficiency ranges.

**Acknowledgements**

Our acknowledgments are to the Brazilian company of Agricultural Research (EMBRAPA – rice and beans) and the Universidade Federal de Goiás (UFG - School of Agronomy).

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