GEOREFERENCED SOYBEAN YIELD AND NUTRITIONAL STATUS EVALUATION UNDER NO TILL SYSTEM IN SOUTHERN BRAZIL.

A.C.C. Bernardi, P.L.O.A. Machado, C.A.F.S. Carmo

Embrapa Solos
Rio de Janeiro, Brazil

C.A. Silva

Soil Science Department - UFLA
Lavras, Brazil

L.I. Ortiz Valencia, C. Bettini

Institute of Geosciences - UFRJ
Rio de Janeiro, Brazil

J.P. Molin

Rural Engineering Department – ESALQ/USP
Piracicaba, Brazil

M.S. Meirelles

Department System Engineering and Geomatics – UERJ/Embrapa Soils
Rio de Janeiro, Brazil

ABSTRACT

The use of soil test variability in precision agriculture studies is well known. However, little is known about the spatial variability of the plant nutrient concentration, specially in a no-tillage system. The nutrient concentrations in plants reflect its real availability in the soil. In a no-till farm in southern Brazil, two growing seasons of soybean were sampled to evaluate the spatial variability of plant nutrient concentrations; and to identify the constraints to soybean yield. Georeferenced soil and leaf samples were collected in a 13-ha area in a grid of 40 by 40 m; and sub-sampled in grids of 20 m by 20 m; 10 m by 10 m; and 5 m by 5 m. Semivariograms for all nutrients in plants were modeled, and the ranges indicated that a grid of 20 by 20 m was appropriate to indicate spatial variability of plant nutrients. At the second growing season a 6-ha area was sampled with a grid of 20 by 20 m. Concentrations of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, Mo and Zn were determined in soybean leaves. Two approaches of nutritional status evaluation were used and discussed: sufficient ranges (SR) and the Diagnosis and Recommendation Integrated System (DRIS). Grain yield was evaluated at the harvest time. Semivariograms for all nutrients in plants were modeled, and the ranges indicated that a grid of 20 by 20 m was appropriate to indicate spatial variability of plant nutrients. Both nutritional status methods were complementary on showing that K and P were the most limiting nutrients to soybean yield.

Keywords: spatial variability, plant analysis, sufficient range, DRIS.

INTRODUCTION

Soil tests provide information about soil ability to supply plant-available nutrients by indirect measurements. Plant analysis is a direct measurement since the results reflects the actual uptake of a nutrient element by the crop, and therefore not as clouded by soil uncertainties (Munson and Nelson, 1990). Plant analysis had been developed to provide information on the nutrient status of plants as a guide to nutrient management for optimal plant yield. Other use includes also the estimation of overall nutritional status of a region or site. The nutrient concentrations in the plants reflect its real availability in the soil, including all factor interactions on them, even the fertilization. In spite of these possibilities, currently use fits to diagnose suspected nutrient deficiencies (Hergert, 1998).

Nutritional status based on the plant analysis may be evaluated by two major approaches: the sufficiency range (SR); and the Diagnosis and Recommendation Integrated System (DRIS). SR is an extension of the critical level concept, which corresponds to the nutrient concentration related with 90 to 100% of maximum plant growth, yield or quality (Munson and Nelson, 1990). SR is between the critical level and a second point where the yield begins to decline. This approach provide discrete, easily computed and independent nutrient indices. Sfredo et al. (1986) presented the sufficient standards ranges for leaf nutrients status in soybean for Brazilian Southern growth conditions.

The DRIS method was introduced by Beaufils (1973) and Jones (1981) proposed three modification on original methodology for simplify its use and interpretation. The calculation is based on balance ratios of nutrient pairs, then comparing the samples ratios to normal ratios in high-yielding crops. A relative score for each ratio is calculated and averaged to get one nutrient index. This approach assumes that nutrient balance must be maintained within limits in order to produce maximum yields. Its use minimizes morphogenic and genotypic effects on the accuracy of deficiency diagnosis, and ranks which nutrient is most limiting to yield. Nevertheless, the DRIS index are continuous, difficult to calculate but easily interpreted, an offers an overall balance index and a ranking of the relative deficiencies (Walworth and Sumner, 1987; Baldock and Schulte, 1996).

There is not a concern on DRIS method use, since Beverly (1993) discussed the prescient diagnostic analysis method and modified nutrient efficiency ratings for DRIS; and concluded that current DRIS diagnostic results were unacceptable for some nutrients deficiency diagnoses in soyabeans. On the other hand, analysis by DRIS confirmed nutrient limiting, and established different rankings in the degree of deficiency for each nutrient (Bethlenfalvay et al., 1990).

The use of soil variability in precision agriculture studies is well known. However, There is little information concerning the use of plant analysis as a basis for precision agriculture, particularly in a no-tillage system. Franzen and Peck (1995a; 1995b; 1997) related calcium, magnesium, phosphorus, and potassium levels in maize leaves with the nutrients levels in soil. The authors concluded that plant analysis was useful in mapping areas for leaf nutrients where soil analysis was not descriptive of plant response to nutrient supply.

Management zone is an alternative for classifying the variability within a field. Sub-regions of an area can be delineated, which shows a relatively homogeneous combination of yield limiting factors (Doerge, 2000). The establishment of management zones requires knowledge of the spatial variability of the factors that affects crop yield. Based on this concept of management zone, Valencia et al. (2001) established zones with homogeneous physical soil properties in a field using cluster k-means. The authors used an indicator kriging for estimating the risk of deficient plant nutrients.

For mapping soil test and plant analysis spatial variability it is necessary to develop efficient sampling strategy based on geostatistcs. McBratney and Pringle (1999) showed that geostatistics was essential to describe and quantify the spatial variability of yield limiting factors. Probably the principal geostatistic parameter for decisions concerning the grid sampling is the semivariogram range. According to Flatman and Yfantis (1984), the sampling spacing is established from ¼ to ½ of the range.

The objective of this research was to evaluate the spatial variability of plant nutrient concentrations and to identify the constraints to soybean yield.

MATERIAL AND METHODS

The study area was located in a farm at Campos Gerais region, municipality of Carambeí, Paraná State, Brazil (24^{o}51'45" S and 50^{o}15'58"; and 615 to 870 m asl). The climate is subtropical, classified as Cfb, with 1,560 mm of mean annual rainfall; and mean annual temperature of 17.6^o C. The deep, well drained soil is as a clayey, kaolinitic Typic Hapludox (Latossolo Vermelho, Brazilian Classification).

Soybean was cultivated in rotation with wheat and black oat in winter, and after 2 summer growing seasons, with maize. No-tillage system has been used on this field since 1983. At the sowing time of the first evaluation term, the soil was fertilized with 62.5 kg K_2O ha^{-1}, and 62.5 kg P_2O_5 ha^{-1}. No nitrogen fertilizer was applied as soybean seeds were inoculated with N_2-fixing bacteria *Bradyrhizobium spp* ..

The grain yield was continuously evaluated using a combine equipped with a real-time global positioning system unit (GPS). Crop yield was measured for the whole field using the Massey Fergusson Fieldstar system. The yield at each grid node was based on average yield (after checking for artifacts) over an area of 2 m^2 around the node.

Georeferenced samples for both soil and plant chemical properties were taken in 2 crop seasons in a 13-ha area of soybean grown in a no-till system farm. At the first growing season, data were collected in a sampling grid of 40 X 40 m. Two of these 40 X 40 grid were sub-sampled in 20 by 20; 10 by 10; and 5 by 5 m grid. In the following growing season (2nd evaluation term), a 6-ha area was selected and a grid measuring 20 by 20 m was set up. The grid localization and sampling pattern is shown in Figure 1. Valencia et al. (2001) showed a difference in the sampled area based on soil texture: A area was clayey; and B area was less clayey (Figure 2).

Leaf diagnosis was done in the fully youngest expanded leaf, collected at the blossom time from the top of the soybean plant. Leaves of 30 plants in each sampling cell were collected. Plant material was washed in distilled water, dried in a forced air oven at 70^{o} C and ground to pass a 60-mesh screen. Nitrogen analysis was obtained by a micro-Kjeldahl method. After nitric-percloric acid digestion, P, S, and B were obtained by colorimetric method; K by flame-photometric method; and Ca, Mg, Cu, Fe, Mn, Mo and Zn by plasma emission spectroscopy. The sampling and laboratory analysis procedure were base on Silva et al. (1999).

Nutritional status evaluation was conducted using the sufficient ranges (SR) and Diagnostic Recommendation Integrated System (DRIS). The sufficient range method for soybean was developed by Sfredo et al. (1986). Nutrient concentrations are split into 5 diagnostic categories: deficient, low, sufficient, high and very high.

DRIS procedure was based on Jones (1983). DRIS norms were developed using a high-yield population of the 2-year data set. The selection of the nutrients ratios to the norms were done by the F test ($p< 0.05$). The high-yield population was arbitrarily selected using areas where yield was greater than 3,900 kg per ha. This corresponded to the average (3,486 kg per ha) plus standard deviation (491 kg per ha) of the data set. The selected high-yield population had 49 local references. The sample ratios were compared with ratios of the high-yield soybean and the standard scores for each nutrient were averaged to obtain one index per nutrient.

The data were analyzed using geostatistical methods of kriging and co-kriging (GSLIB, Stanford University, 2001). Maps of soil property levels and plant nutrient contents were produced using Surfer 6.1 for Windows (Golden Software Co., Golden, CO) using inverse distance squared interpolation to develop mapping contours.

RESULTS AND DISCUSSION

A summary statistics are given in Table 1 for soybean yield, N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn in soybean FYEL, in both evaluated year.

The data from each sampling was also subjected to geostatistical analysis to determine whether samplings were spatially variable. Variograms were computed for all of the nutrients concentrations in soybean FYEL. The spatial statistics from each set of plant analysis and the model parameters are given in Table 2. All variables fitted exponential models, just P fitted a spherical model, and these models were correlated to the variograms, indicating that each plant sampling is spatially variable. The larger percentage of nugget variance compared to sill for N, K, Ca, Mg, B, Cu, Fe and Mn FYEL concentrations, suggests that more of the spatial relationship is not represented by the variogram model than P, S, and Zn FYEL concentrations. It suggests that variability may be greater for N, K, Ca, Mg, B, Cu, Fe and Mn levels, and that more factors may influence their spatial variability than for the P, S, and Zn levels. The maps of the kriged estimates for soybean yield and N, P and K FYEL levels at the first evaluation season are shown in Figures 3 and 4, respectively.

The average between X and Y ranges were 67 and 41 meters, respectively. Based on Flatman and Yfantis (1984), the sampling spacing may be established as ½ of the range, so a grid of 20 X 20 meters may be adequate for access the spatial variability of soybean nutrients levels. This grid was used at the second growing season evaluation.

Since Valencia et al. (2001) showed two management zones in this study area (Figure 2), now the discussion will be based on the differences between these two areas at the same year, and between both more clay areas (A) through 2-year sample.

Five diagnostic categories were used based on Sfredo et al. (1986), with the objective of improving the interpretation of the results (Table 3). The results presented showed that diagnostic categories of SR system are easy to interpret and independent. The level of one nutrient does not affect the classification of another nutrient. But the SR method do not rank the nutrients within a category, so there is ambiguity regarding which is most limiting. The SR scale is not continuous, then when a sample is in low category it is not clear if it is slightly low or very low, which can make a great difference in yield response. The SR method indicated P, K, Mg, S, Cu and Zn were deficient at the first growing season. At the second just Cu and S may be deficient with lower percentage.

The continuos and easily interpreted DRIS scale, ranked the nutrient from most deficient to most excessive. Table 4 shows that within each area the decreasing order of limiting was: 1st year A area, K > P > N; 1st year B area, K > S > P > N; 2nd year A area, N > P > B. These finds are in agreement with Bethlenfalvay et al. (1990).

DRIS method was useful to identify N and P as limiting yield in both evaluated years, even though none of these nutrients were below their sufficient ranges (Table 3). Since DRIS indices are not independent, the level of one nutrient can have a marked effect on the other indices. Probably this suggested an imbalance since N is not recommended to be fertilized to soybean (Sfredo et al., 1986), since the seeds are efficient inoculate with N_2-fixing bacteria.

The Sufficiency Range (SR) system and the Diagnosis and Recommendation Integrated System (DRIS) represent two approaches to interpreting plant analyses. But, when both methods were jointly used they were complementary and useful to calculate the N, P and K as the most limiting factors to soybean yield at the study area. Figure 5 illustrates the relationships between N, P and K DRIS Indices and FYEL concentrations. Just for K, there was observed good correlation.

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Table 1: Summary statistics for soybean yield and plant analysis at the first evaluated year.

Statistical Parameters	Yield	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	kg ha^{-1}	g kg^{-1}						mg kg^{-1}				
1st year - A area												
Mean	3457.4	44.8	2.8	13.9	6.1	2.3	1.9	33.3	5.7	66.7	30.8	16.3
SD	618.2	2.3	0.4	3.2	0.4	0.2	0.3	4.3	0.7	17.4	3.9	1.9
Median	3295.0	45.0	2.7	14.0	6.2	2.4	1.9	33.8	5.7	62.0	29.9	16.0
Max	5436.0	49.2	3.8	20.8	7.2	2.8	2.9	42.9	8.8	154.0	44.2	21.3
Min	2142.0	36.1	1.9	7.3	5.0	2.0	1.5	22.1	4.7	48.8	24.5	12.9
CV	17.9	5.2	14.8	22.9	7.1	8.2	16.7	12.9	11.7	26.1	12.8	11.8
1st year - B area												
Mean	4120.5	44.5	2.9	15.4	6.4	2.3	1.8	33.1	5.7	59.6	28.6	15.3
SD	476.7	3.1	0.4	3.0	0.4	0.2	0.3	3.3	0.5	5.6	4.4	1.4
Median	4088.0	44.1	2.8	15.3	6.3	2.3	1.7	32.6	5.6	59.1	27.9	15.2
Max	5774.0	56.1	3.9	20.8	7.4	3.1	2.5	42.9	7.5	80.9	38.5	18.5
Min	2850.0	38.0	2.1	9.8	5.4	2.0	1.4	25.3	4.4	47.9	19.9	12.9
CV	11.6	7.0	14.4	19.4	7.0	9.2	17.1	9.9	9.4	9.4	15.4	9.4
2nd year - A area												
Mean	3299.2	46.5	3.5	23.8	8.3	3.5	2.8	32.0	9.5	75.9	38.6	27.2
SD	208.6	4.5	0.2	3.6	0.7	0.3	0.5	3.8	1.5	10.5	5.3	3.0
Median	3320.5	47.0	3.6	23.4	8.3	3.5	2.8	31.9	9.3	73.8	38.7	27.0
Max	3665.3	60.0	4.1	33.4	10.3	4.3	3.9	43.7	19.0	114.0	57.0	38.2
Min	2738.0	0.0	3.0	13.2	6.7	2.5	1.7	23.4	7.0	59.6	26.2	20.7
CV	6.3	9.7	6.5	14.9	7.9	8.7	17.8	12.0	15.8	13.8	13.8	10.9

Table 2: Variograms models and coefficients for soybean plant analysis at the first evaluated year.

Parameter	Model	A		C_0	C	Sill
		X	Y			
N	Exponential	60	20	0.40	0.80	1.20
P	Spherical	60	60	0.02	0.10	0.12
K	Exponential	60	60	0.40	0.50	0.90
Ca	Exponential	60	30	0.30	0.40	0.70
Mg	Exponential	80	80	0.30	0.45	0.75
S	Exponential	80	30	0.20	0.70	0.90
B	Exponential	70	25	0.35	0.60	0.95
Cu	Exponential	80	35	0.35	0.55	0.90
Fe	Exponential	60	60	0.20	0.35	0.55
Mn	Exponential	50	20	12.0	10.0	22.0
Zn	Exponential	80	35	0.20	0.50	0.70

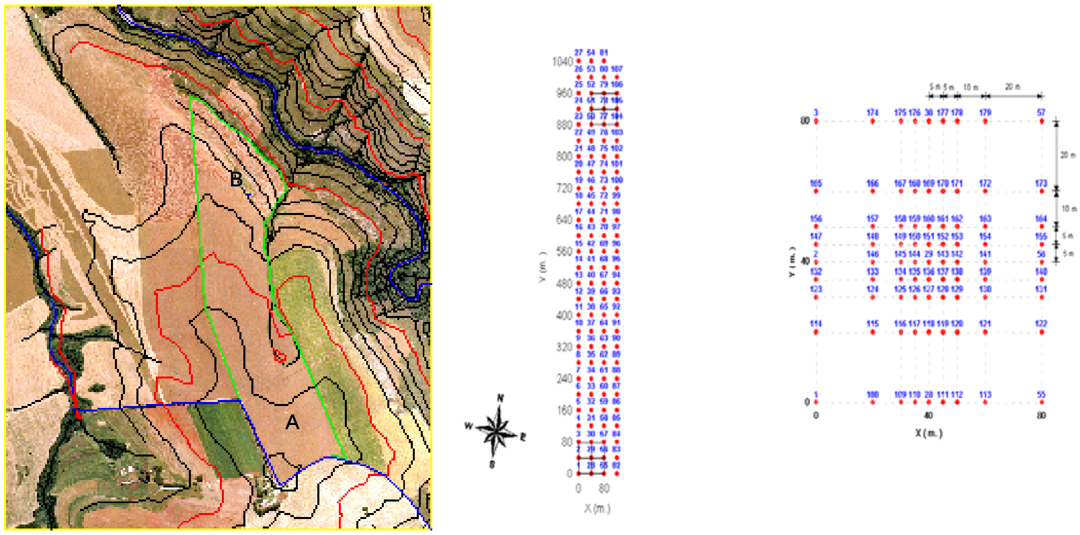

Figure 1: Imaging of the study area with the sampled areas localization and the coarse and fine sampling grids.

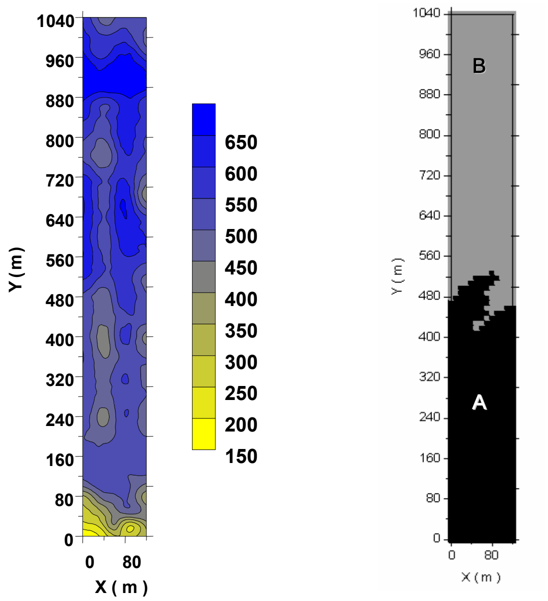

Figure 2: Clay area spatial variability and management zones established by Valencia et (2001).

Table 3: Occurrence (%) within sufficient. ranges of nutrients concentrations in soybean FYEL for sampled points.

Sufficient Range*	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	% of occurrence										
	1st year – A area										
Deficient	-	-	36.4	-	-	5.5	-	14.5	-	-	-
Low	3.6	30.9	45.5	-	81.8	65.5	-	85.5	3.6	-	94.5
Sufficient	96.4	69.1	18.2	-	18.2	29.1	100.0	-	96.4	100.0	5.5
High	-	-	-	-	-	-	-	-	-	-	-
Very high	-	-	-	100.0	-	-	-	-	-	-	-
	1st year – B area										
Deficient	-	-	23.1	-	-	11.5	-	7.7	-	-	-
Low	3.8	9.6	40.4	-	80.8	61.5	-	92.3	1.9	1.9	100.0
Sufficient	94.2	90.4	36.5	-	19.2	26.9	100.0	-	98.1	98.1	-
High	1.9	-	-	-	-	-	-	-	-	-	-
Very high	-	-	-	100.0	-	-	-	-	-	-	-
	2nd year – A area										
Deficient	-	-	-	-	-	-	-	-	-	-	-
Low	2.2	-	2.8	-	0.6	10.6	-	58.9	-	-	-
Sufficient	97.2	100.0	63.3	-	99.4	89.4	100.0	41.1	100.0	100.0	100.0
High	0.6	-	20.0	-	-	-	-	-	-	-	-
Very high	-	-	13.9	100.0	-	-	-	-	-	-	-

* Based on Sfredo et al. (1986).

Table 4: Mean, standard deviation and maximum and minimum values of DRIS indices for all nutrients in FYEL soybean evaluated years and areas.

Statistical Parameters	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	DRIS Indices										
	1st year –A area										
Mean	-0.38	-1.35	-1.95	-0.47	-0.15	-0.01	0.00	0.04	1.21	0.44	0.62
SD	1.13	2.23	3.18	0.56	0.55	1.16	1.23	0.90	3.40	0.67	1.80
Max	1.45	1.67	2.01	0.74	1.17	2.07	2.99	5.41	21.02	2.37	6.30
Min	-5.54	-8.80	-12.9	-1.79	-1.40	-3.07	-4.32	-0.83	-0.62	-0.56	-3.58
	1st year – B area										
Mean	-0.18	-0.20	-0.29	0.03	-0.09	-0.31	0.18	0.04	0.03	0.05	-0.05
SD	0.84	1.47	1.94	0.51	0.53	1.26	0.89	0.52	0.60	0.84	1.16
Max	1.55	2.03	1.88	1.03	1.30	1.65	2.33	1.86	2.76	2.03	2.72
Min	-2.88	-4.92	-6.65	-1.37	-1.10	-3.71	-2.69	-0.86	-0.75	-1.82	-2.27
	2nd year – A area										
Mean	-7.32	-3.14	1.84	-0.45	0.72	0.67	-5.20	3.66	-0.02	0.19	6.88
SD	3.48	1.57	1.26	0.52	0.47	1.50	2.08	3.09	0.70	0.66	2.76
Max	0.00	0.14	4.29	1.06	1.66	2.48	-0.34	27.36	4.21	2.04	18.01
Min	-18.8	-10.3	-5.33	-1.89	-0.57	-4.32	-12.4	0.41	-0.77	-1.20	2.02

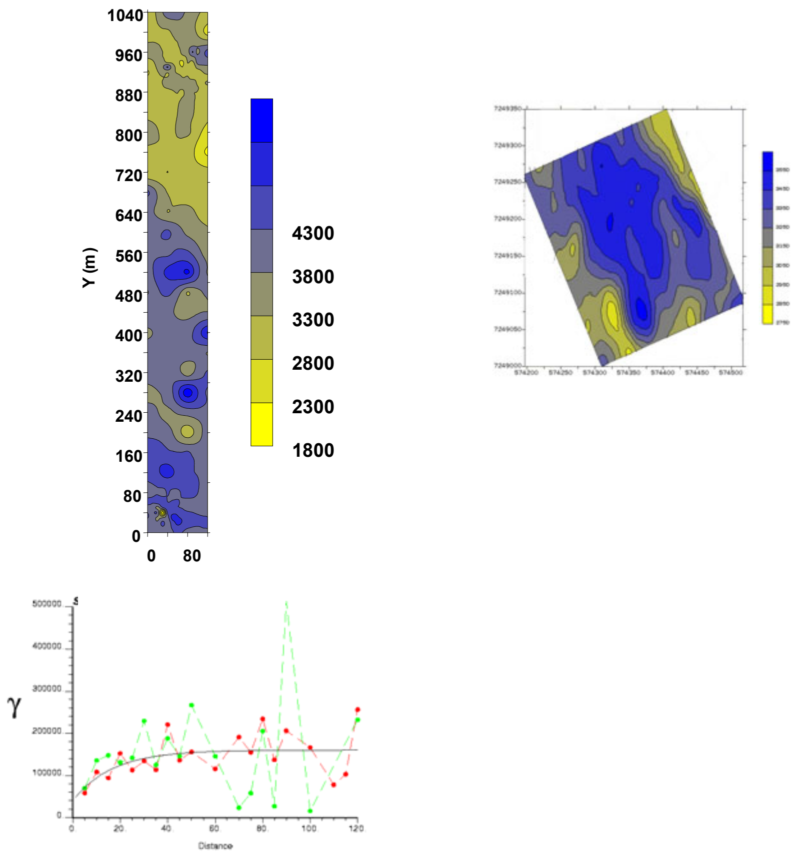

Figure 3: Experimental semivariograms with the fitted model and maps of the kriged stimated for soybean yield in both sampled growing seasons.

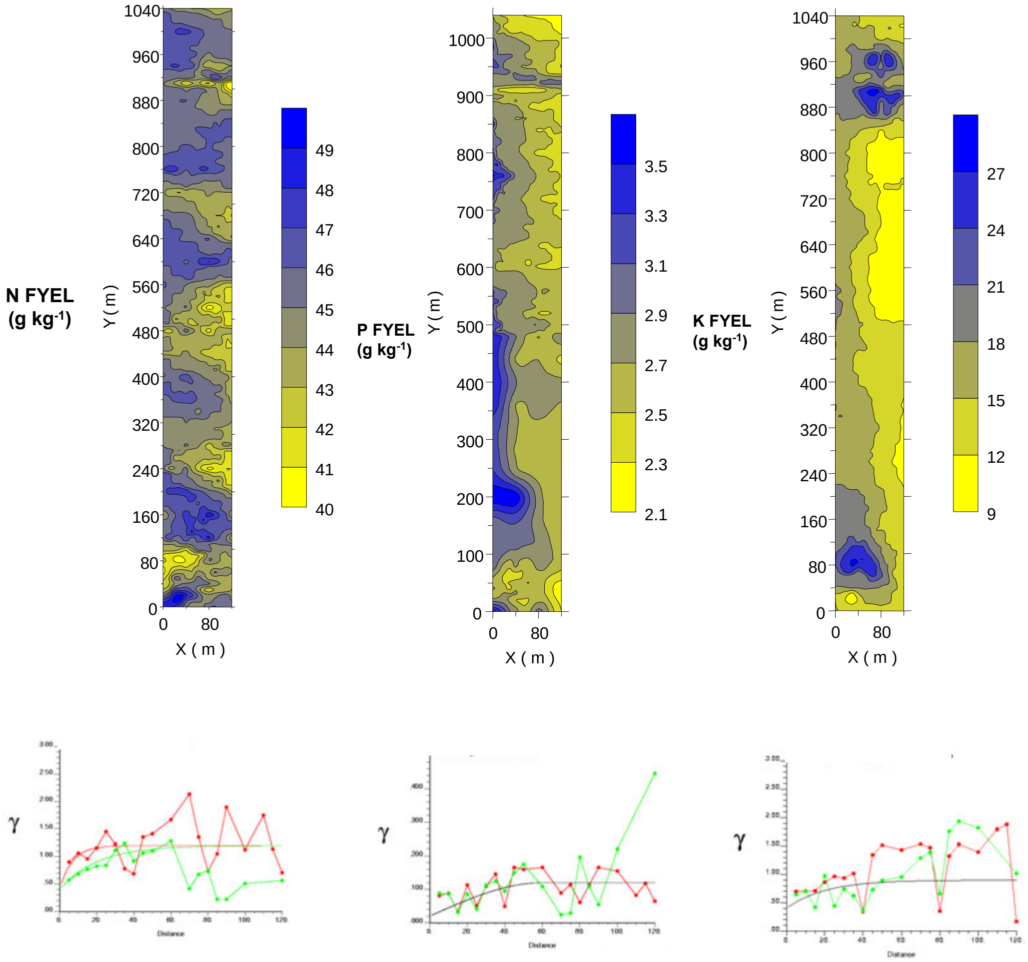

Figure 4: Experimental semivariograms with the fitted model and maps of the kriged stimates for nitrogen, phosphorus, and potassium concentration on soybean FYEL at the first year evaluation.

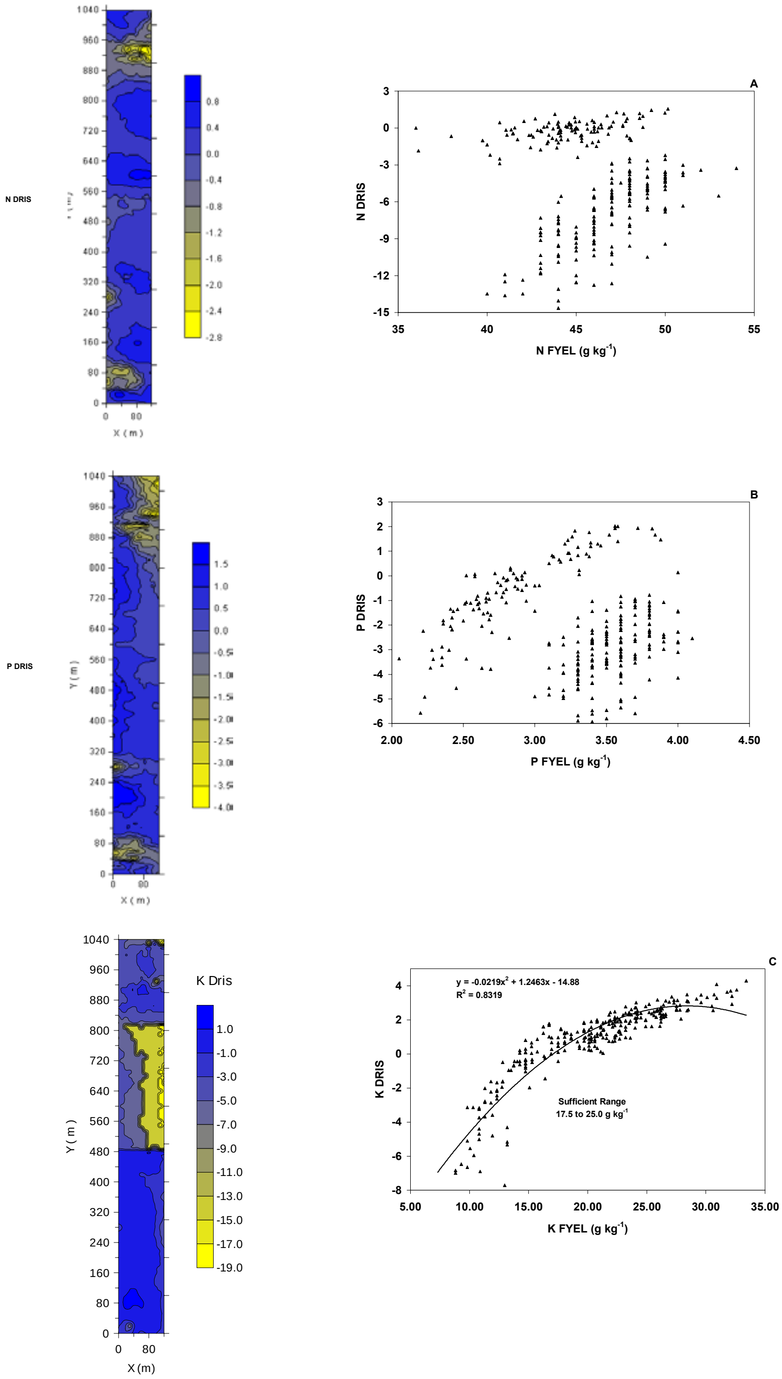

Figure 5: DRIS indices maps for N, P and K and the graphs with correlation between DRIS Indices and FYEL concentration of these nutrients.