SOIL NUTRITIONAL SURVEY FOR SOYBEAN PRODUCTION IN URUGUAY

Bordoli1 J.M. , Barbazán[1], M.M. , Rocha,[1] L.

[1]*Dpto. de Suelos y Aguas, Facultad de Agronomía. Universidad de la República Oriental del Uruguay. Garzón 780. CP 12900. Montevideo, Uruguay.*
jbordoli@fagro.edu.uy

Abstract

The recent changes in the agriculture in Uruguay, by the adoption of no-tillage planting systems, have included the use of marginal soils for crop production, being the soybean the main crop that allowed those changes. Several questions have arisen about the sustainability of the intensive soil use of these new production systems. The objective of this work was to detect situations with greater probability of nutrient deficiencies, using soybean as indicator crop. During crop seasons 2009/10 and 2010/11 a nutritional soil survey of soybean crops was conducted, collecting soil and leaf samples of 178 commercial fields widely distributed around the country, at the R1-R2 soybean growth stage. In half of the sites soybean was the main crop, and in the other half soybean was planted following winter crops. Soybean yield ranged from 511 to 5435 kg ha^{-1}. In 34% of the fields pH was below 5.3, even in the traditional agricultural zone. In 54% of fields available P was below 12 mg kg^{-1} of P Bray-1, and 23% of the cases were below 0.30 cmol$_c$ kg^{-1} of exchangeable K. The concentrations of macronutrients in leaves for all the samples were: 3.88 (±0.66) % N; 0.26 (± 0.08) % P; 2.03 (±0.53) % K; 1.14 (±0.23) % Ca; 0.36 (±0.10) % Mg; and 0.29 (±0.07) % S. The micronutrient concentration means were 9, 77, 61, and 30 mg kg^{-1} of Cu, Fe, Mn, and Zn, respectively. The more frequently deficient nutrients were P, K, and N, with 42, 39, and 13% of the fields with concentrations in leaves below the critical concentrations. The results show that the actual soybean productivity could be partially affected by nutrient deficiencies, suggesting that soil pH, and P or K corrections need to be considered in the nutritional management program for each crop production system.
INDEX WORDS: concentration, critical level, plant nutrient, requirements

Introduction

The present scenario of the agriculture in Uruguay includes the generalized adoption of no-tillage systems, which have allowed the incorporation of marginal soils, and an intensive use of the soil, with 1.5 crops per year (1) (DIEA, 2010), being the soybean the dominant crop. Thus, the continuous removal of nutrients could cause nutritional deficiencies that would limit a sustainable production in different zones of the country.
The objective of this study was to identify situations (areas, soil types, management practices) where nutritional imbalances are most likely to occur, using the soybean crop as an indicator.

Materials and methods

During the summer of 2009/10 and 2010/11, a nutritional soil survey with soybean crop was conducted, collecting soil and leaf samples of 178 commercial fields, widely distributed around the country. Of a uniform area of 0.2 ha samples were taken at various points. Composite samples of the most recently and completely developed leaf with petiole (25 - 30 leaves with petiole) were collected at the R1-R2 soybean stage. The samples were dried at 60 °C for 48 hs and ground to a size less than 1 mm. Total N was determined by the Kjeldahl method and total P according to Murphy and Riley (2). The Ca, Cu, Fe, Mg, Mn and Zn were determined by atomic absorption and emission as total K and Na (3) (Isaac and Kerber, 1971). The total S was determined by LECO combustion.
Soil samples (15 to 20 cores from 0 - 15 cm deep) were taken simultaneously with the leaves and from the same sampling area. The samples were dried at 40 °C for 48 hs and ground to determine pH in water and 1 M KCl by potentiometry, soil organic matter (SOM) by the Walkley and Black method, available P by the Bray-1 method (4) Bray and Kurzt, 1945), and exchangeable

bases extracted with 1 M ammonium acetate by atomic absorption (Ca and Mg) and emission (K and Na) (3) Isaac and Kerber, 1971).

Soil chemical values in samples were compared with reference values. For the plant samples we used the lowest critical concentration reported by Robinson and Reuter (5) for soybean crop.

Results and discussion

Table 1 shows the mean and range values for the soil and plant properties analyzed.

Soil chemical properties

Soil organic matter

The SOM content varied from 1.1 to 6.2 % (Table 1). In general, the soils located on the traditional agriculture zones (NW and SW) showed the highest values of SOM, and the more sandy soils or those located in the East zone presented the lowest, which is consistent with the values reported by Durán (6) 1991).

Soil acidity

Soil pH ranged from 4.4 to 7.6. The 34% of the soil samples showed values below 5.3, which suggests that could exist exchangeable Al^{+3}, that is toxic for some crops (Fig. 1a). Most of the sites with pH less than 5.3 corresponded to light texture soils, in the East, Centre, and in the SW of the country. These values agree with the natural values cited (6) (1991) for this type of soils. However, it is possible that nutrient management practices such as frequent ammonium application or extraction of cations by crops could have decreased the soil pH. In this sense, Morón and Quincke (7) 2010) reported that soil pH in soils under agriculture in the southwestern area was 50 and 31% lower at the 0-7.5 and 7.5-15 cm depth respect to the same soils without agriculture history.

On the other side, several soils with pH greater than 7.3 corresponded to those of Zones NW and SW, developed from quaternary materials with Ca carbonates (6). High soil pH values are associated to the deficiency symptoms of Fe and Zn in young leaves, frequently observed in several crops. Table 3 shows the Fe and Zn concentration in soybean leaves by the soil pH.

Exchangeable acidity mean in soils with pH lower than 5.3 was 0.28 $cmol_c\ kg^{-1}$, but the range was from 0.04 to 1.7.

Table 1. Soil survey of sites with soybean (n= 178) for the summer of 2009/10 and 2010/11.

Soil chemical properties (0-15 cm depth)	SOM	pH (H_2O)	Exch. Acidity	K	Na	Ca	Mg	P
	%		-------------------- $cmol_c\ kg^{-1}$				--------------------	mg kg^{-1}
Total of samples								
Mean	3.9	5.7	0.09	0.56	0.46	15.64	2.22	14
min	1.1	4.4	0.00	0.08	0.26	2.31	0.56	2
máx.	6.2	7.6	1.07	2.50	1.35	46.40	9.80	84
Soybean as first crop								
Mean	4.0	5.6	0.08	0.54	0.47	15.85	2.19	14
min	1.7	4.4	0.04	0.08	0.26	2.40	0.58	2
máx.	6.2	7.6	0.65	1.55	1.03	46.40	6.19	84
Soybean following a winter crop								
Mean	3.8	5.7	0.10	0.60	0.45	15.97	2.26	13
min	1.1	4.5	0.00	0.10	0.26	2.31	0.56	3
máx.	6.2	7.6	1.07	2.50	1.35	45.59	9.80	36

Leaf and petiole analysis at R1-R2 soybean stage	N	P	K	S	Ca	Mg	Cu	Fe	Mn	Zn	Yield
	--------------------------------		%			----------------------------------	----------------	mg kg^{-1}		--------------	kg ha^{-1}
Total of samples											
Mean	3.9	0.26	2.03	0.29	1.14	0.36	9	77	61	30	2752
min	2.8	0.09	0.35	0.17	0.67	0.19	2	43	22	8	511
máx.	6.2	0.48	3.30	0.51	2.00	0.84	18	226	278	53	5435
Soybean as first crop											
Mean	3.8	0.25	1.99	0.29	1.15	0.36	9	77	56	29	3073
min	2.8	0.09	0.35	0.21	0.67	0.19	2	45	22	8	523
máx.	5.9	0.48	3.22	0.51	2.05	1.12	17	307	228	47	5435
Soybean following a winter crop											
Mean	4.0	0.27	2.04	0.30	1.14	0.36	8	80	72	32	2300
min	2.8	0.12	0.66	0.19	0.69	0.22	3	43	23	21	511
máx.	6.2	0.48	3.30	0.48	1.59	0.59	18	226	278	53	4498

Phosphorus in soil

The mean of available P (Bray 1) was 14 mg kg^{-1}, ranging from 2 to 84. For the total of soil samples, the 48% to 54% showed values lower than the range of 10 to 12 mg kg^{-1} (Bray-1) suggested for soybean by the Oudri et al. (8) and Morón (9) in Uruguay (Fig. 1b). The low values were located in all zones and in both soybean crop types, but are more frequents at the new agricultural zones (Centre, East, and NE) with lower P fertilization history. Many studies have reported the low natural P content in most of the soils in Uruguay for many crops. This result suggests that there is need of a better P fertilization management.

Table 2. Soil survey of sites with soybean (n= 178) for the summer of 2009/10 and 2010/11, by zone and soybean type.

	Centre			East			NE			NW			SW		
	mean	mín	máx	mean	mín	máx	mean	mín	máx	mean	mín	máx	mean	mín	máx
Soybean as main crop															
P Bray1	11	6	24	7	3	18	8	2	18	15	4	34	18	4	84
SOM	3.7	2.5	4.8	2.9	1.1	6.0	4.6	3.5	5.2	4.4	2.6	5.7	3.8	1.7	6.2
pH(H_2O)	5.6	2.3	7.6	5.2	4.4	6.3	5.4	5.2	5.8	5.8	5.1	7.6	5.6	4.6	7.3
Ex. Ac.	0.14	0.08	0.20	0.36	0.18	0.65	0.35	0.24	0.54	0.06	0.04	0.10	0.15	0.08	0.23
K	0.39	0.09	0.70	0.27	0.08	0.49	0.65	0.24	1.20	0.55	0.26	1.01	0.63	0.13	1.55
Na	0.4	0.2	0.5	0.6	0.3	1.4	0.4	0.3	0.6	0.4	0.3	0.8	0.5	0.3	1.0
Ca	17.2	2.4	39.2	6.3	2.4	16.0	12.4	4.9	22.6	19.8	4.2	46.4	16.7	2.4	45.5
Mg	2.0	0.7	3.3	2.1	0.7	5.0	3.2	1.6	6.2	1.9	0.6	2.9	2.3	0.6	5.2
Soybean following a winter crop															
P Bray1	10	5	19	5	3	9	10	3	19	14	5	36	16	5	31
MO	3.6	2.3	5.2	2.5	1.1	3.9	4.4	2.9	6.2	4.6	1.8	5.6	3.5	1.6	5.9
pH(H_2O)	5.4	4.8	5.8	5.4	5.2	6.3	5.1	4.7	5.6	6.0	4.9	7.6	5.9	4.5	7.5
Ex. Ac	0.49	0.05	1.07	0.37	0.21	0.53	0.33	0.13	0.58	0.06	0.06	0.06	0.22	0.10	0.34
K	0.27	0.14	0.45	0.29	0.16	0.49	0.53	0.25	1.13	0.68	0.10	1.23	0.70	0.12	2.50
Na	0.4	0.30	0.6	0.7	0.4	1.4	0.4	0.3	0.5	0.3	0.3	0.6	0.5	0.3	0.8
Ca	10.5	3.3	22.1	6.7	3.0	16.0	9.1	2.3	17.9	19.5	2.4	45.6	18.5	2.5	44.0
Mg	2.5	1.0	4.4	2.6	1.2	5.0	3.3	0.7	9.8	1.5	0.8	2.0	2.2	0.6	5.2

†P Bray 1: mg kg^{-1}; SOM: %; K, Ca, Mg, Na, and Exchangeable acidity: $cmol_c$ kg^{-1}. Exchangeable acidity only for soil with pH (H_2O) lower than 5.3.

Exchangeable potassium

Soil K mean was 0.56 $cmol_c$ kg^{-1}, with a wide range from 0.08 to 2.5 (Fig. 1c). This variability agrees with the values reported by Hernández et al. (10). The 23% of the samples presented values below 0.30 $cmol_c$ kg^{-1} (8) and 0.34 $cmol_c$ kg^{-1} reported by Barbazán et al. (11). Most of the sites with low K values are light texture soils, located in the Centre, East, and SW zones.

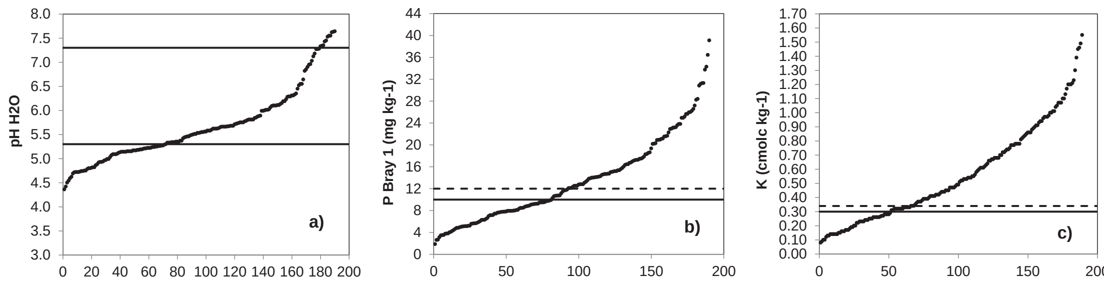

Figure 1. Soil pH (a), available P Bray 1 (b), and exchangeable K of 178 samples at 0-15 cm depth. Lines in a) indicate pH values of 5.3 and 7.3; in b) indicate critical values of 10-12 mg kg^{-1} for soybean, in c) indicate critical values of 0.30 and 0.34 $cmol_c$ kg^{-1} for many crops. In b) a site with 84 mg kg^{-1} of P Bray 1 was not included. In c) a site with 2.5 $cmol_c$ kg^{-1} was not included.

Exchangeable Calcium and Magnesium

Exchangeable Ca ranged from 2.3 to 46.4 $cmol_c$ kg^{-1}, and Mg from 0.56 to 9.8 $cmol_c$ kg^{-1} (Table 1 and Fig. 2a and b). Absolute Ca values were above the suggested critical values of 0.38 $cmol_c$ kg^{-1}. Only in two cases Mg in soil was below the suggested critical value of 0.62 cmolc kg^{-1}, in soils developed on Cretacic materials.

Although some authors recommend checking the ratios between cations, as indicator of potential deficiency problems, there is uncertainty about the guide from these relationships. The most common ratios between Ca+Mg/K, Ca/Mg, Ca/K, and Mg/K cited by the bibliography are 15, 7, 13, and 2, respectively.

Figure 3 shows the relationship between cations for all the soil samples. The sites with more probably deficiencies of Mg were those of the units Fray Bentos, Bequeló, and Cañada Nieto, of the SW zone, due to the natural Mg in the parent material. However, in plant this is not translated in plant deficiency.

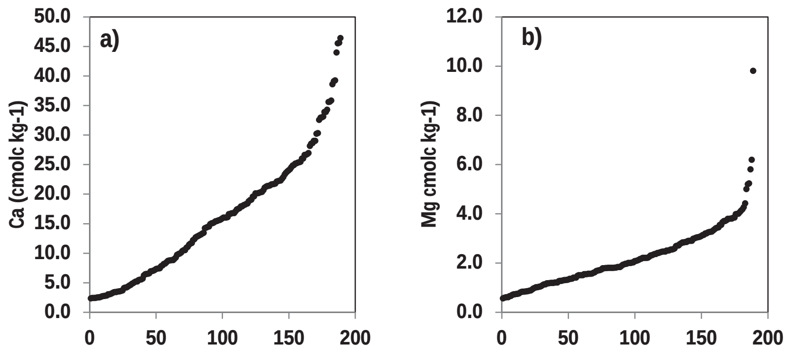

Figure 2. Exchangeable Ca (a) and exchangeable Mg (b) of 178 samples at 0-15 cm depth.

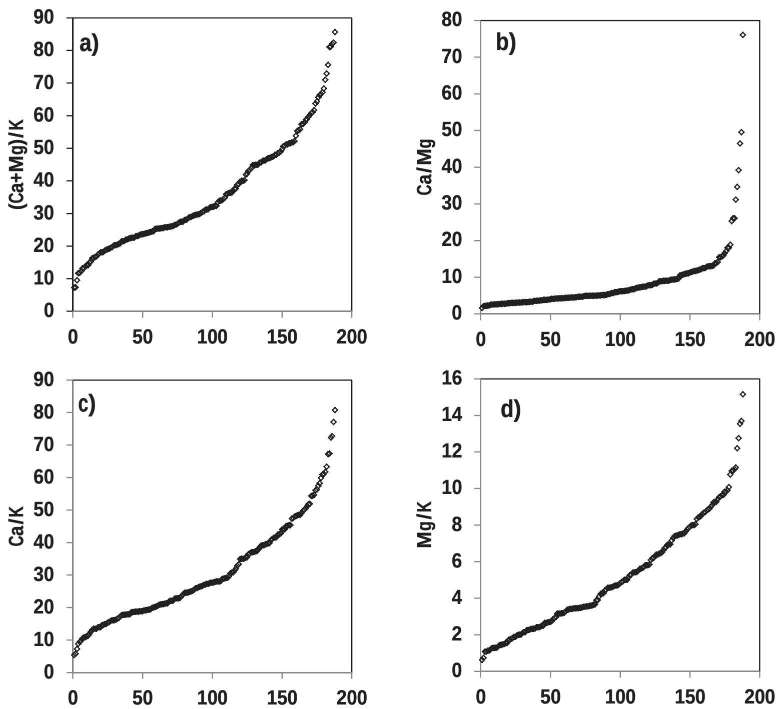

Figure 3. Relationship between cations: exchangeable (Ca+Mg)/K (a), exchangeable Ca/Mg (b), exchangeable Ca/K (c), and exchangeable Mg/K (d) of 178 samples at 0-15 cm depth, expressed in $cmol_c$ kg^{-1}.

Grain yield and nutrient concentration in leaves

The mean yield of soybean as first crop was 3073 kg ha^{-1}, 34% more than the mean yield for soybean as a second crop (2300 kg ha^{-1}). Both values were higher than the average yield for the country, 2000 kg ha^{-1} (1), and the ranges were very wide for both crops: from 523 to 5435 kg ha^{-1} for the first crop, and from 511 to 4498 kg ha^{-1}, for soybean following a winter crop (Table 1). The highest yield values were observed in the soils with the higher values of pH, soil organic matter, available P, and exchangeable bases, especially K (Fig. 5). However, the correlation among the variable measured were poor, indicating that other factors affected the yield.

Nitrogen concentration

The N concentrations in leaf with petiole ranged from 2.8 a 6.2% (Table 1). Figure 4a shows that the N concentration means for each zone, for samples of soybean as first crop, were higher than the critical concentration of 3.5%. Comparing to this value, the 13% of the samples tested lower than this critical concentration. The variability in N concentration could be explained by genetic differences and nutrient management practices, relating to soil pH and available P, which could limit the nitrogen fixation. Through all the samples, the correlation between N concentration and soil chemical properties was poor, indicating the complexity of this process. However, there was a clear relationship between N and P concentration in leaf (Fig. 5f). It is need to note that we used the most conservative reference value, in spite of higher critical concentration suggested by others.

Phosphorus concentration

The P concentration mean was 0.26%, ranging from 0.09 to 0.48%. Many samples (42%) tested lower than the critical concentration of 0.24%, and it was irrespective the zone (Fig. 1c). However, the new agricultural zones (E and NE) showed the lower values at Bray 1 soil test and the lower concentrations of P in leaves.

Potassium concentration

The K concentration mean was 2.03%, ranging from 0.35 to 3.30% (Table 1). The 39% of the total samples presented values in leaf less than 1.76%, the critical concentration. The East zone showed the lowest exchangeable and K concentration mean in leaves. However, low K values in leaves were observed even in soils testing medium or high in K, and at different zones, in both soybean types: first or second crop. In no-till systems, K absorption problems by plants have been frequently observed (12).

Other nutrients

Nutrients such as S, Mg, Ca, and micronutrients (Cu, Fe, Mn, and Zn) were at or higher the critical concentration (Table 1). Then, no nutrient deficiencies of these nutrients were evident from leaf analysis.

Table 3. Concentration of Iron and Zinc in leaf and petiole by the soil pH (H2O).

	Fe		Zn	
	Mean	Range	Mean	Range
Soil pH	mg kg^{-1}			
< 5.3	80	43 - 307	83	29 - 278
5.3 - 7.3	76	45 - 170	29	8 - 53
> 7.3	64	49 - 83	23	12 - 29

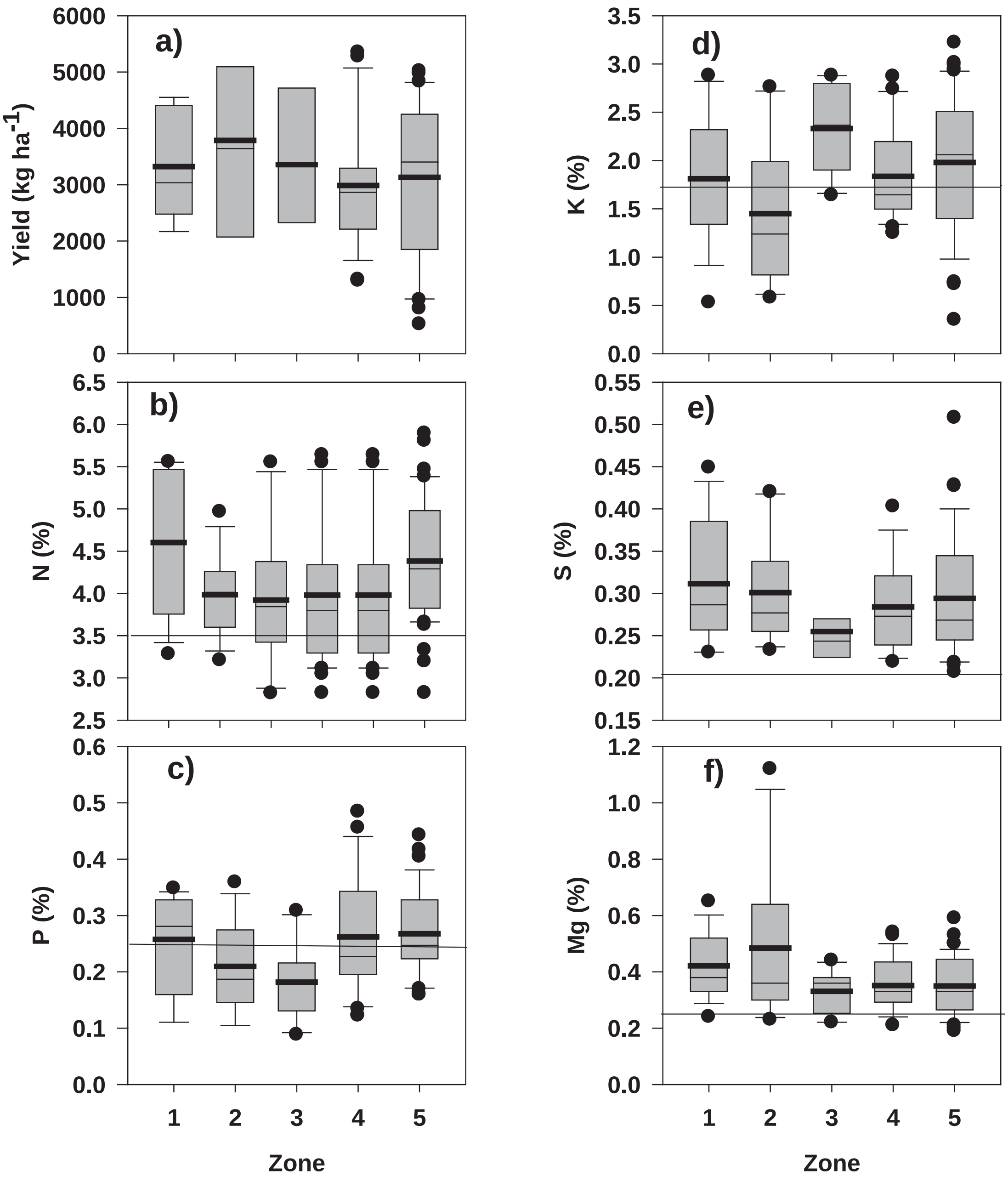

Figure 4. Mean (thick line), median (thin line), and percentiles (10, 25, 75 y 90 for yield (a), nitrogen (b), phosphorus (c), potassium (e), sulfur (f), magnesium (g) in leaf with petiole of soybean as first crop collected during 2009/10 and 2010/11 in different zones: 1: Centre; 2: East; 3: North East; 4: North West; 5: South West. Horizontal line means the critical concentration taken from Reuter and Robinson (1997): N: 3.50%; P: 0.24%; K: 1.76%; S: 0.20%, Mg: 0.20%.

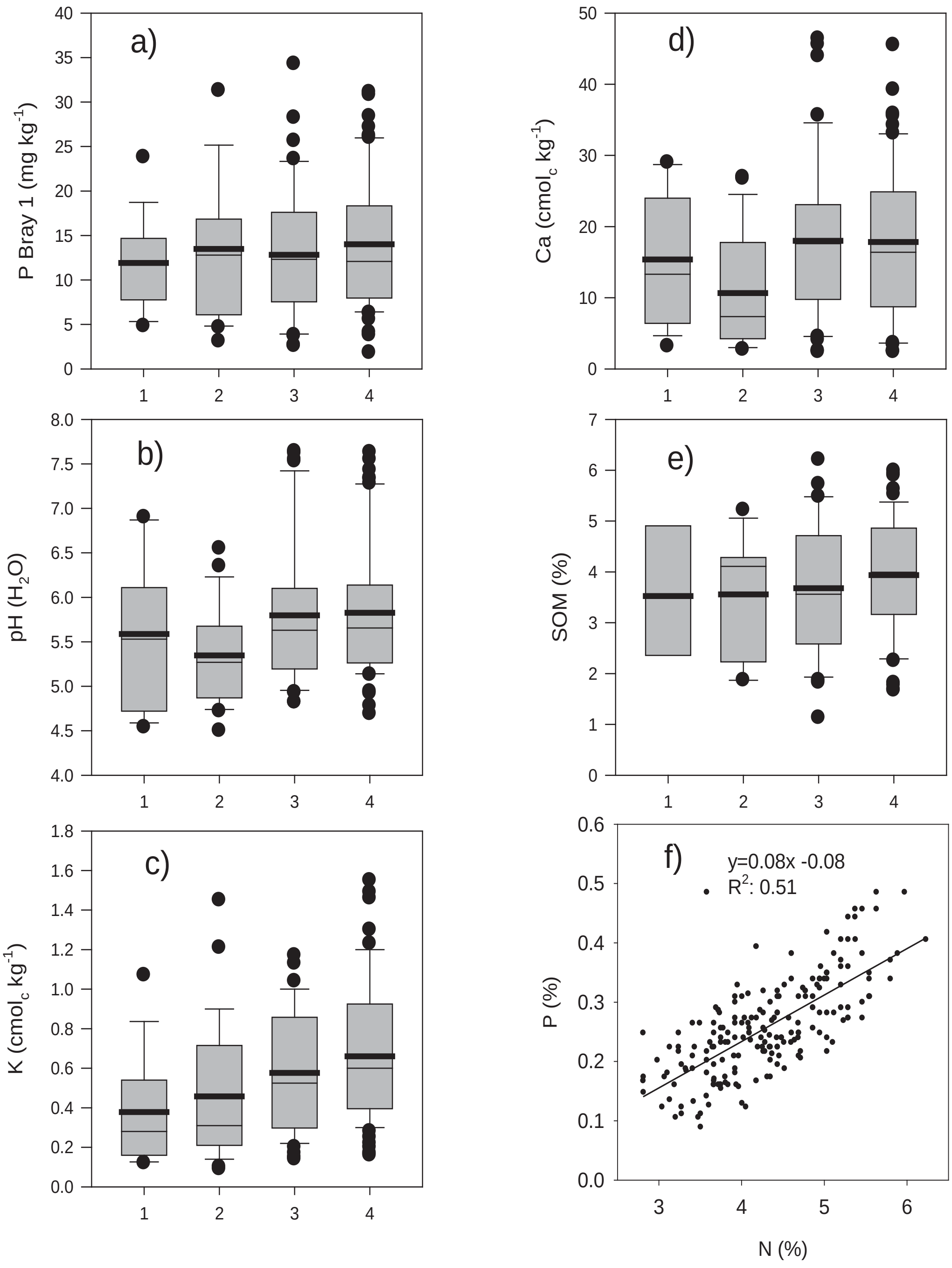

Figure 5. Mean (thick line), median (thin line), and percentiles (10, 25, 75 y 90 for available P (a), soil pH (b), exchangeable K (c), exchangeable Ca (d), and soil organic matter (e) for soybean yield lower than 1000 kg ha^{-1} (1), from 1000 to 2000 kg ha^{-1} (2), from 2000 to 3000 kg ha^{-1} (3), and for more than 3000 kg ha^{-1} for 178 samples. Relationship between P and N in leaf for the 178 leaf samples (f).

References

1) DIEA – MGAP. 2010. Anuario estadístico agropecuario 2010.
2) Murphy, J. and Riley, J. P. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta 27:31-36.
3) Isaac, R.A. and Kerber, J.D. 1971 Atomic Absorption and flame photometry: techniques and uses in soil, plant and water analysis. In Instrumental Methods for Analysis of Soil and Plant Tissues. pp. 17-37. Soil. Sci. Soc. Amer. Madison, Wisconsin, USA.
4) Bray R. H.and Kurtz L.T. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci.59:39-45.
5) Plant analysis: an interpretation manual. Second edition.
6) Durán, A. 1991. Los suelos del Uruguay. Editorial Hemisferio Sur. 398p.
7) Morón A. y A. Quincke. 2010. Avances de resultados en el estudio de la calidad de los suelos en agricultura en el Departamento de Soriano. Serie Actividades de Difusión N°605. Pp. 5-8.
8) Oudri N.; J. L. Castro; R. Doti y A. Sedondi de Carbonell. 1976. Guía para fertilización de cultivos. Ministerio de Agricultra y Pesca, Centro de Investigaciones Agrícolas “alberto Boerger”. Dirección de Suelos y Fertilizantes.
9) Morón A. 2005. Informe de resultados de la red de ensayos de fertilización de soja. Jornada Técnica de Cultivos de Verano. Serie Actividades de Difusión N°417. INIA. Uruguay.
10) Hernández, J.; Casanova, O. y Zamalvide, J. P. 1988. Capacidad de suministro de potasio en suelos del Uruguay. Facultad de Agronomía, Montevideo, Uruguay. Boletín de Investigación No. 19. Facultad de Agronomía. Montevideo, Uruguay. 20p.
11) Barbazán, M.M., Bautes, C., Beux, L., Bordoli, Cano, J., J., Ernst, O., García, A., García, F., Quincke, A. 2011. Fertilización potásica en cultivos de secano sin laboreo en Uruguay: rendimiento según análisis de suelos. Agrociencia Uruguay Vol. 15-2: 93-99.
12) Bordoli J.M. 2001. Dinámica de nutrientes y Fertilización en siembra directa. Pp. 289-297 In Siembra Directa en el Cono Sur. Coordinador Roberto Díaz Rossello. Serie Documentos, PROCISUR, Montevideo, Uruguay.