

Soybean Yield and Chemical Attributes in Soil after Five-Year Surface Application of Slag, Aqueous Lime and Sewage Sludge

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ABSTRACT

The agricultural use of industrial residues and sewage sludge in order to provide essential nutrients to a plant and soil liming, will be one of the most promising alternative options of soil fertilization and liming management in a very near future, as far as these applications follow the prevailing technical norms to prevent eventual environmental contamination. The aim of this study was to evaluate the effect of slag, aqueous lime, sewage sludge and limestone, under surface application, on soil chemical attributes and soybean yield during a 5-year cultivation period. The experiment was carried out in dystrophic Clayey Rhodic Hapludox in no-till system from 2002 to 2007. The experiment had a 4x4+1 factorial random block design and 4 replications. The treatments consisted of centrifuged sewage sludge (CS), biodigestor sewage sludge (BS), aqueous lime (AL) and slag (SL) doses of zero (control), 2, 4 and 8 Mg ha⁻¹ and one additional treatment of dolomitic limestone of 2 Mg ha⁻¹. All treatments were applied on soil surface in 2002 and reapplied in 2005. CS, AL and SL wastes can be used as alternative materials of limestone in soil liming, presenting effects on pH and base saturation. Superficial application of wastes and limestone on soybean crop increased uptake of N and P in 2003, 2004 and 2005; K in 2003, 2004 and 2006; Ca in all studied years; Zn in 2003, 2004, 2005 and 2006, where applied the sewage BS. Superficial application of wastes increased soybean yield in 2003, 2004, 2005 and 2006; however, in 2007, this increase occurred only with the application of CS. Exchangeable heavy metals available in soil were insignificant and that contributed to the bioavailability absence of these toxic elements in soybean plants during all experimental years.

Keywords: urban wastes, industrial wastes, soil liming, *Glycine max*.

INTRODUCTION

One of the main causes of low crop productivity in Brazil, independently of the yield system, is the high acidity of most of its soils, mainly in the cerrado region (Quaggio, 2000). Therefore, the appropriate use of correctives in soil liming is extremely important to sustainable assure agricultural productivity.

The most discussed topic in no-tillage soil management is the non-incorporating of limestone, even though it is a low water soluble product and its reaction products (carbonates and bicarbonates) present limited mobility on the soil surface, making it relatively slow (Ramos et al., 2006). Superficial application of limestone on no-tillage soil increases soybean crop yield because this system allows a differentiated dynamics of acidity characteristics due to superficial organic matter and nutrient

accumulation, lower Al toxicity and higher water availability (Caires et al., 2003). However, there are other acidity correctives like slag, aqueous lime and centrifuged sewage sludge, which can have higher solubility and allow soil liming and superficial alkaline displacement in a shorter time interval when compared to limestone because of their dissociation reaction products that have higher mobility in the soil.

It is probable that the same favorable results occur to soybean crop development, but further studies on the application of liming materials like slag, aqueous lime and sewage sludge applied on no-tillage system soil surface are needed. Thus, the aim of this paper was to evaluate the effect of superficial application of sewage sludge, aqueous lime and slag on some chemical soil attributes and soybean productivity during 5 years.

MATERIAL and METHODS

The experiment was carried out under field conditions from 2002 to 2007 at Lageado Experimental Farm in the School of Agronomic Sciences (Faculdade de Ciências Agrômicas – FCA), UNESP, Botucatu, State of Sao Paulo, Brazil, latitude 22° 51'15''S, longitude 48° 26'30''W and altitude 740m with relief lower than 10%. The predominant weather is Cwb according to Köppen classification.

The experiment was planted in dystrophic Clayey Rhodic Hapludox (Embrapa, 1999), moderate A, medium texture, subtropical field phase, with wavy smooth relief, under no-tillage system. Sampling for chemical characterization of the soil was taken from layer at the depth of 0-20 cm, and presented the following attributes: pH (CaCl₂) 4.1; 43 mmol_c dm⁻³ of H+Al; 16 g kg⁻¹ of O.M.; 5.6 mg dm⁻³ of P (resin); 0.8, 15 and 6 mmol_c dm⁻³ of K, Ca and Mg, respectively, (Raij et al., 2001) and 34% of base saturation.

The treatments consisted of four wastes, centrifuged sewage sludge with addition of CaO – CS (type A), biodigestor sewage sludge with addition of polyelectrolyte – BS (type B), slag – SL (waste from production process of pig iron and steel) and aqueous lime – AL (waste from cellulose whitening process), applied on soil surface in doses of zero (control), 2, 4 and 8 Mg ha⁻¹ (dry base) and one additional control treatment of dolomitic limestone of 2 Mg ha⁻¹.

Before the experiment installation, the total heavy metal content present in the wastes was determined (Table 1) using nitric and hydrochloric acids because this method is similar to the one of EPA SW-846, but without peroxide. Readings were made using an argon plasma-induced emission spectrophotometer (ICP/AES). It is noteworthy to point out that the wastes presented heavy metal levels lower than the minimum ones allowed by the Brazilian Legislation.

The treatments were distributed in a random block design and had a 4x4+1 factorial scheme and four replications. In each block, the plots were 6 m wide and 7 m long.

The experiment started in 2002 when guandu beans (*Cajanus cajan* L.) were dried in order to produce straw on which the treatments were applied without incorporation. The initial application took

place three months before the soybean seeding in the 2002/2003 harvest, and the reapplication was done in May 2005, before the seeding of winter cultivation. In the experimental period, five soybean cultivations were carried out, using cultivar EMRAPA 48 (harvests of 2002/2003, 2003/2004, 2004/2005, 2005/2006 and 2006/2007), making result comparison within the same species possible. In the seeding, 300 kg ha⁻¹ of formulated chemical fertilizer (00-20-10) was applied in the first three years and 300 kg ha⁻¹ (08-28-16) in the last two years; the seeds were inoculated with *Bradyrhizobium japonicum* every year. In the winter, black oats were cultivated during four years (2003, 2004, 2005 and 2006) in order to produce straw; thus, 100 kg ha⁻¹ of urea was used for nitrogen fertilization to improve the crop initial development. No-tillage system was used during all cultivation years.

Soil sampling for chemical characterization was done after 5 years of cultivation, from the layers at the depths of 0-5, 5-10, 10-20 and 20-40 cm, using a probe auger to collect four samples per plot for the composed sample. Levels of pH, base saturation, phosphorus and zinc were determined according to Raij et al. (2001). For heavy metal availability in the soil, extraction with DTPA was used. Leaf content of N, P, K, Zn macronutrients was determined using Malavolta et al. (1997) methodology, by sampling the third leaflet+petiole from the apex of 30 soybean plants. Two central rows were harvested in each plot, using a plot harvesting machine and then the grain weight was determined and moisture was corrected at 13% to obtain productivity results.

The results were analyzed as to their variance (Sisvar 4.2 program) and posterior regression, by adjusting equations through the F Test, significant at 1 and 5%, and also through the magnitude of determination coefficients (Sigmaplot 10.1 program). All treatments were contrasted with limestone using t Test (MSD) at 1 to 5% (Sisvar 4.2 program).

RESULTS and DISCUSSION

After five years of cultivation in no-tillage system, when two superficial applications with increasing doses of CS, BS, AL and SL and limestone control treatment were done, chemical analysis of pH, base saturation, P and Zn in soil show that there is still a contribution to the improvement of soil fertility conditions (Figure 1) and that it allowed good culture development.

There was an increase of pH and base saturation values because of the increasing dose application of CS, AL and SL and the limestone treatment. For CS, AL and SL, soil reaction happens in the 10-20cm deep layer whereas acidity neutralization for limestone occurs in the 5-10 cm layer. These results corroborate the ones by Melo et al. (2001) and Oliveira et al. (2002) for incorporated sewage sludge, and the ones by Prado & Fernandes (2003) and Carvalho-Pupatto et al. (2004) for incorporated slag. BS did not cause pH variation and base saturation in the soil (Figure 1), because of its polyelectrolyte content like DTPA and EDTA, which cause a very strict effect to soil liming and do not present desirable characteristics as acidity correctives.

Application and reapplication of CS, AL and SL wastes (Figure 1) increased pH and base saturation values because of the higher concentration of resulting products from liming reaction (CaO,

NaO, CaSiO₃ and CaCO₃), allowing a higher availability and possibility of displacement of these products due to a lower concentration of acid cations in the dissolution zone of the corrective when compared to other cations, specially K⁺, Ca²⁺ and Mg²⁺. The continuous action of deep soil liming using CS, AL and SL wastes, mainly in higher doses and limestone dose of 2 Mg ha⁻¹, is related to the increase of soil base saturation (Figure 1). The displacement of resulting products from CS, AL and SL waste reactions, keeps on occurring until they reach the next acid layer and react again to acid cations, specially Al³⁺, that will replace Ca and Mg due to its higher electrostatic strength, and then start the liming process in deeper layers (Fidalski & Tormena, 2005).

After five years of no-tillage cultivation there are still contributions of increasing doses of waste applications on the P content in the soil, observed for CS and SL up to the depth of 10 cm and for BS up to the depth of 5 cm (Figure 1). This increase of P availability is caused by the soil pH increase, presence of P in the chemical composition of CS, BS and SL wastes (4.9, 2.0 and 1.4% of dry matter mass) and the addition of P in the seeding of soybean crop.

Application of increasing doses of BS increased Zn content in the soil up to the depth of 20 cm (Figure 1), where the dose of 8 Mg ha⁻¹ resulted in higher values of this micronutrient in the soil. This increase is a consequence of this element presence in its composition (Table 1), and also because this waste does not have any effect on the soil liming, making Zn available in the soil solution and, therefore, more likely to be absorbed by crops while, according to Raij (1991), pH increase in the soil reduces the contents of most cationic micronutrients, including Zn.

Application of wastes and limestone increased soybean N leaf content in 2003, 2004 and 2005 (Table 2). This increment results from the improvement of chemical attributes in the soil, as pH and base saturation, which allows a better interaction between *Rhizobium* bacteria and the root and, consequently, improving nitrogen biological fixation. Another probable cause for the N increase in soybean leaves is that wastes as sewage sludge are a direct source of this nutrient in the soil, where CS has 25 g kg⁻¹ of N, and BS has 40 g kg⁻¹ of N (Table 1). However, after the reapplication of wastes, significant effects of N were not observed, probably because of no-tillage system stability, that allows greater soil nutrient recycling and also a higher onset of microorganisms, especially for *Rhizobium*. According to Malavolta et al. (1999), the appropriate N leaf level to obtain a reasonable productivity of 2700 kg of soybean ha⁻¹ is 36 g kg⁻¹. In 2003 and 2004, the obtained results were higher than the ones considered ideal to obtain reasonable productivity, and, in 2005, the dose zero and the treatments with 2 and 4 Mg ha⁻¹ of BS were lower than those values.

P content in soybean increased due to the application of wastes and limestone, except for the AL treatment in 2004 and 2005 and the SL in 2005 (Table 2), because CS, BS, SL and AL provided a total P₂O₅ amount of 160, 392, 112 and 16 kg ha⁻¹, respectively, in the highest doses, and also caused increased values of soil pH for the treatments with CS, SL, AL and limestone, leading to greater P availability for plant absorption. In 2006 and 2007, there was no significant effect for P content in soybean, except for SL in 2006. This happened because there is more organic P in soil in no-tillage

systems and due to the application of this nutrient in the soybean seeding, increasing P content availability in the soil and consequently its absorption by the plant. The P content in the soybean leaf of 2.6 g kg^{-1} is considered appropriate to obtain a productivity of 3000 kg ha^{-1} (Malavolta et al., 1999), thus, all treatments presented higher P values, except for the dose zero in the first year of the cultivation.

K leaf content in soybean increased with SL and AL wastes in 2003, but in 2004 all wastes improved the absorption of this nutrient, and linear behaviors were obtained for CS and SL, and quadratic ones for BS and AL. However, in 2006, after the reapplication of wastes, there was a decreasing quadratic behavior for CS, BS and AL (Table 2). In 2005 and 2007, there were no significant differences for K content in soybean because the treatment dose zero contained 3.2 and $2.0 \text{ mmol}_c \text{ dm}^{-3}$ of K, which are considered appropriate values for soil fertility (Raij et al., 1996), in the 0-20 cm layer, allowing the increase of mass flow transportation through diffusion (Rosolem et al., 2003) as K presents high mobility in soil (Oliveira et al., 2002). Besides these factors in soil, plants present a double mechanism for K absorption, in an active way, through transporting proteins; and, in a passive way, through channel proteins when there are low or high concentration K contents in the soil (Malavolta, 2004). Thus, in 2005 and 2007, there was abundant K for the soybean crop to absorb, because of its high concentration in the soil, even for the treatments where there was no superficial applications of wastes and limestone.

There was a higher Ca concentration in soybean leaves because of the increase of waste doses and soil liming in 2003 and 2004, except for BS in 2004. The increase of soybean Ca content occurred because the wastes of CS, SL and AL directly provided this nutrient to the soil. In 2005, only AL increased Ca content in soybean. A possible reason for just one waste be the responsible for Ca absorption by the plant is that the no-tillage system stability provides better soil fertility conditions, guaranteeing the balance among Ca, Mg and K, and allowing better availability of this nutrient to soybean; this can be confirmed by the high Ca content on the leaf (11 g kg^{-1}) in dose zero. After the reapplication of wastes there was an increase in Ca content in soybean for the treatment with CS in 2006, and CS and SL in 2007. According to Malavolta et al. (1999), the appropriate Ca content to obtain appropriate soybean productivity is 10.8 g kg^{-1} ; approximate or higher values to this one were obtained with application of wastes and limestone.

In 2003 and 2004, Zn leaf content in cultivated soybean was influenced only by BS application, and increased when the dose was increased; in 2005, there was a significant effect to all wastes with linear and decreasing responses in function of the increased doses of CS, AL and SL, due to soil pH increase while BS showed opposite behavior, an increasing response. In 2006, when BS was applied, the highest Zn leaf content occurred with the dose of 4 Mg ha^{-1} .

Superficial application of SL, BS, CS and AL and limestone increased soybean productivity in 2003, 2004 and 2006. In 2005, there was an increment for CS, AL, SL and limestone, and in 2007, just for CS and limestone (Table 3). This productivity result may be caused by the improvement of the soil

chemical properties, increase of pH level and base saturation, which provided a higher absorption of N, P, Ca and K nutrients in soybean for some treatments. Thus, the use of these wastes, as well as liming in no-tillage system soil surface, is an alternative option to obtain good soybean productivity.

Considering the presence of available heavy metal content in the soil after 5 years of cultivation, the superficial application of CS, BS, AL and SL wastes did not cause environmental pollution because the average content found for the 0-20 cm layer were: n.d. (not detected) to 0.360 mg dm⁻³ for As; n.d to 0.045 mg dm⁻³ for Cd; 0.081 to 0.355 mg dm⁻³ for Ni; 0.370 to 1.225 mg dm⁻³ for Pb; n.d. to 0.418 mg dm⁻³ for V and n.d. for Hg. Because of the low availability of heavy metals present in the soil, there was not phitoavailability of those toxic elements to the soybean crop; only low leaf content was detected. Considering the last two crops, after two applications, average soybean leaf contents were: 0.00 – 6.02 mg kg⁻¹ for As, 0.35 - 1.15 mg kg⁻¹ for Cd; 2.25 – 5.00 mg kg⁻¹ for Cr; 4.54 - 30.52 mg kg⁻¹ for Ni; 5.21 – 35.55 mg kg⁻¹ for Pb; 1.00 – 33.95 mg kg⁻¹ for V; these values were lower than the critical level of phitotoxicity according to Kabata-Pendias and Pendias (1992). According to these results, it can be inferred that doses up to 8 Mg ha⁻¹ of centrifuged and biodigestor sewage sludge and industrial wastes of aqueous lime and slag may be applied and reapplied after three years, in a no-tillage system without environmental contamination on a dystrophic Clayey Rhodic Hapludox with Cwb type weather, under soil management, mainly organic matter one. However, in the long run, the increase of heavy metal concentration in the soil, due to successive application of sewage sludge may become a concern because it may threaten the trophic chain if it is not appropriately controlled (Hue, 1995).

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Table 1. Chemical composition (total contents, d.m.) of wastes used in the experiment and maximum permitted concentration (MPC) values of metals in sewage sludge and wastes.

Parameter	Unity	CS	BS	AL	SL	MPC ^(1 a)	MPC ^(1 b)
Moistness	%	5	29	19	2		
Organic Matter	%	26	50	3	1		
Organic Carbon	%	14.4	27.8	1.7	0.3		
C/N Relation	%	6/1	7/1	7/1	1/1		
pH	CaCl ₂	12.0	7.0	12.0	12.0		
Nitrogen	g kg ⁻¹	25	40	4	3		
Phosphorus	g kg ⁻¹	20	49	2	14		
Potassium	g kg ⁻¹	3.0	2.0	1.0	1.0		
Calcium	g kg ⁻¹	280	20	370	230		
Magnesium	g kg ⁻¹	4	4	6	21		
Sulphur	mg kg ⁻¹	0.5	1.6	0.3			
Sodium	mg kg ⁻¹	640	500	20400	600		
Copper	mg kg ⁻¹	72	760	90	16	1500	
Iron	mg kg ⁻¹	1600	36750	1096	22900		
Manganese	mg kg ⁻¹	104	218	158	34300		
Zinc	mg kg ⁻¹	660	2950	86	24	2800	
Arsenium	mg kg ⁻¹	14	27	1.4	5	41	1000
Cadmium	mg kg ⁻¹	n.d.	0.1	n.d.	n.d.	39	n.a.
Chromium	mg kg ⁻¹	4	19	13	61	1000	n.a.
Lead	mg kg ⁻¹	17	107	60	308	300	1000
Mercurium	mg kg ⁻¹	n.d.	n.d.	n.d.	n.d.	17	100
Nickel	mg kg ⁻¹	7	180	96	19	420	n.a.

CS= centrifuged sewage sludge; BS= biodigester sewage sludge; AL= aqueous lime; SL= slag.

(1) Brazilian Legislation: (a) CONAMA (2006), (b) NBR 10004 (ABNT, 1987), n.d. (non-detected) and n.a. (non-applicable at the NBR 10004/1987).

Table 3. Soybean crop productivity during five years, due to superficial application of wastes and limestone on no-tillage soil.

Treatments		Productivity				
		2002/2003	2003/2004	2004/2005	2005/2006	2006/2007
		----- kg ha ⁻¹ -----				
CS	2	4179	3495	3072	2403	3684
CS	4	4377	3598	3578	2500	4620
CS	8	4611	3958	3502	2941	4950
Regression		L**	L**	L**	L*	L**
BS	2	4257	3636	2768	2752	3716
BS	4	4344	3624	2745	2879	4175
BS	8	4391	3748	3033	2408	3047
Regression		L**	L**	n.s.	Q*	n.s.
AL	2	4049	3585	3223	3337	3653
AL	4	4113	3831	3478	3372	4070
AL	8	4291	3996	3407	2828	3645
Regression		L**	L**	Q**	Q**	n.s.
SL	2	4290	3734	3245	2918	3903
SL	4	4457	3885	3272	3729	3796
SL	8	4735	3942	3559	2957	3451
Regression		L**	Q**	L**	Q**	n.s.
Control	0	3786	2997	2626	2312	3530
Limestone	2	4100	3600	3100	3116	4117
V.C. (%)		7	10	12	14	21

CS= centrifuged sewage sludge; BS= biodigester sewage sludge; AL= aqueous lime; SL=slag. * significant at 5%, ** significant at 1% and n.s.= non-significant, L= linear and Q= quadratic.

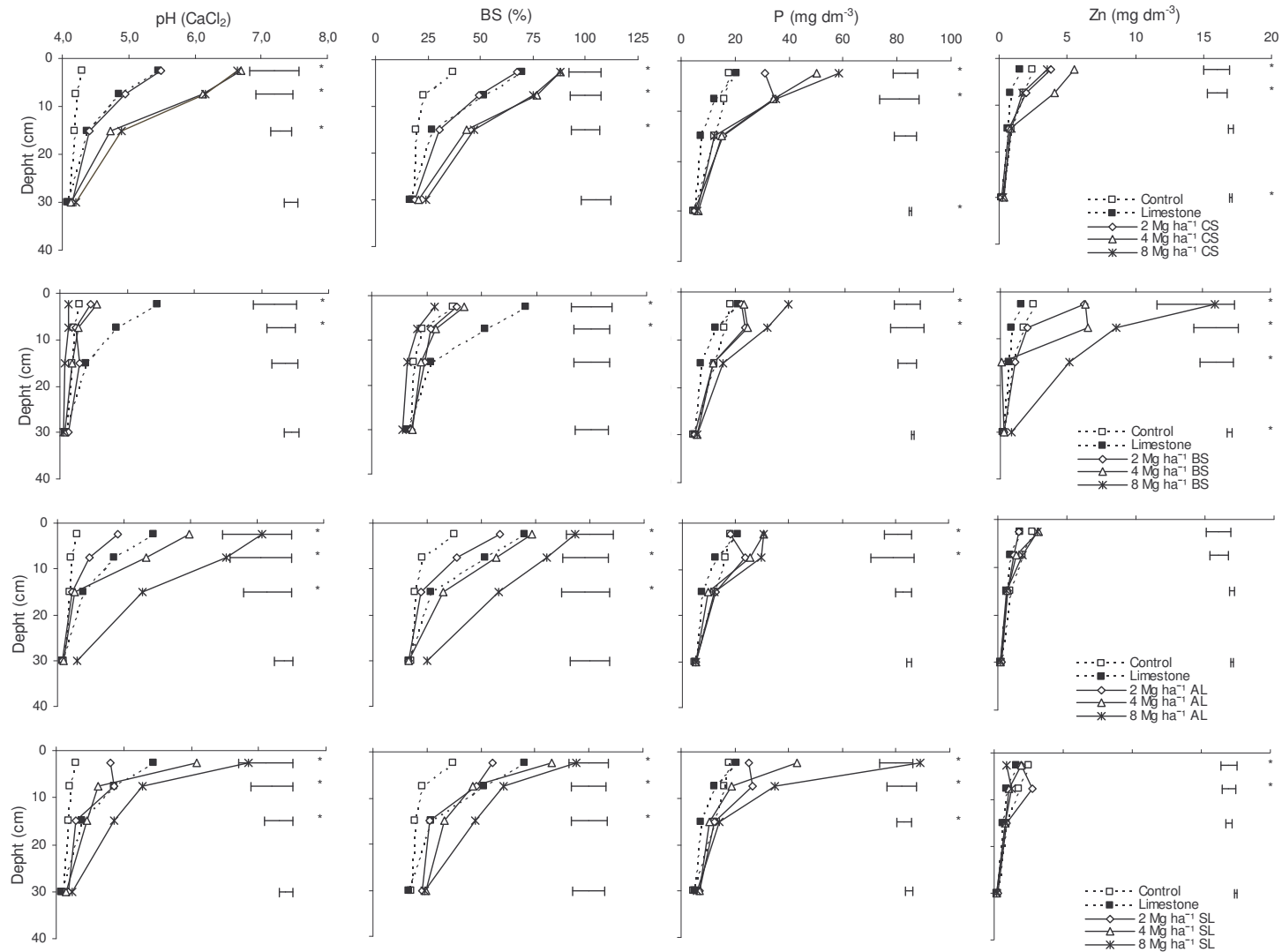


Figure 1. Dynamics of pH, base saturation (BS%), P and Zn after five years of soybean cultivation, in function of application of wastes and limestone under no-tillage system soil surface. * minimum significant difference (MSD) among averages by t Test at 5%.

Table 2. Leaf Content of N, P, K, Ca and Zn in soybean during 5 years of cultivation, due to superficial application of wastes and limestone under no-tillage system soil surface.

Treatments	2003					2004					2005					2006					2007					
	N	P	K	Ca	Zn	N	P	K	Ca	Zn	N	P	K	Ca	Zn	N	P	K	Ca	Zn	N	P	K	Ca	Zn	
	----- g kg ⁻¹ ---				mg	----- g kg ⁻¹ ---				mg	----- g kg ⁻¹ ---				mg	----- g kg ⁻¹ ---				mg	----- g kg ⁻¹ ---				mg	
	-----				kg ⁻¹	-----				kg ⁻¹	-----				kg ⁻¹	-----				kg ⁻¹	-----				kg ⁻¹	
CS	2	47	2.8	15	12	81	43	3.0	24	11	44	36	3.0	25	13	46	38	3.2	15	16	62	52	3.3	18	12	62
CS	4	49	2.9	15	12	85	45	3.5	27	11	43	39	3.2	22	12	43	37	3.2	13	18	61	53	3.2	18	11	85
CS	8	51	3.1	16	13	77	46	3.5	28	13	42	42	3.2	24	13	40	41	3.5	16	19	60	52	3.4	18	13	49
Regression		L**	Q**	n.s.	L**	n.s.	L**	L*	L**	L**	n.s.	L**	L**	n.s.	n.s.	L**	n.s.	n.s.	Q*	L**	n.s.	n.s.	n.s.	n.s.	L*	n.s.
BS	2	47	2.7	16	10	92	41	3.0	24	10	80	32	2.6	22	12	60	38	3.2	15	15	81	50	3.0	18	9	91
BS	4	49	2.8	14	13	130	46	3.5	23	11	128	35	3.0	20	12	118	41	3.4	14	16	136	50	3.2	17	11	94
BS	8	50	3	15	13	155	45	4.0	26	10	128	40	3.2	20	12	128	36	3.3	17	16	78	51	3.2	18	10	142
Regression		L**	L**	n.s.	L**	L**	Q**	L**	Q**	n.s.	Q**	L**	L**	n.s.	n.s.	Q**	n.s.	n.s.	Q*	n.s.	Q**	n.s.	n.s.	n.s.	n.s.	n.s.
AL	2	47	2.7	17	10	81	44	3.2	27	10	45	41	3.1	24	11	46	39	3.3	16	18	62	54	3.4	18	12	67
AL	4	49	2.7	15	11	71	44	3.1	27	12	40	42	3.1	22	13	41	40	3.2	13	17	72	51	3.1	17	11	87
AL	8	48	2.9	17	13	77	44	3.2	26	14	38	42	3.1	20	15	34	39	3.3	16	17	76	50	3.1	22	11	106
Regression		L**	L**	L**	L**	n.s.	Q**	n.s.	Q**	L**	n.s.	Q**	n.s.	n.s.	L**	L**	n.s.	n.s.	Q*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
SL	2	48	2.9	16	11	81	44	3.2	24	12	44	41	3.3	27	11	42	38	3.1	15	16	58	52	3.2	18	10	67
SL	4	50	3.1	17	11	74	44	3.2	26	12	43	37	3.2	24	13	38	39	3.1	15	18	64	55	3.3	18	11	87
SL	8	50	3.1	19	12	81	46	3.7	28	14	40	42	3.3	22	12	35	40	3.4	15	17	59	51	3.5	18	12	106
Regression		L**	Q**	L**	L**	n.s.	L**	L**	L**	L**	n.s.	Q**	n.s.	n.s.	n.s.	L**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	L*	n.s.
Control	0	44	2.5	15	9	78	39	3.0	24	9	46	29	2.9	22	11	59	38	3.2	18	13	75	53	3.2	20	9	68
Limestone	2	48	2.8	15	10	85	42	3.2	25	11	48	37	3.1	24	12	50	41	3.4	17	15	73	55	3.3	21	9	67
V.C.%		5	6	9	15	9	6	12	7	14	14	6	8	15	16	17	9	5	17	16	13	5	9	20	22	60

CS= centrifuged sewage sludge; BS= biodigester sewage sludge; AL= aqueous lime; SL=slag. * significant at 5%, ** significant at 1% and n.s. non-significant, L= linear and Q= quadratic.