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Chapter 12

Use of Pasteurised and N-Organic-Enriched Sewage Sludge (Biosolid) as Organic Fertiliser for Maize Crops: Grain Production and Soil Modification Evaluation

Emilio Carral, Adolfo López-Fabal, Socorro Seoane,
Teresa Rodríguez, Carlos Caaveiro and
Elvira López-Mosquera

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Abstract

Trough plot-field essay, the effects of two pasteurised-N-enriched sludge loading (3000, 7000 kg ha^{-1}) on *Zea mays* L. crop were studied for grain production and soil modifications evaluation. The results of pasteurised sewage sludge application (Plateau-ASP–Active Sludge Pasteurization-ActiSolids©) showed a more grain production by the two biosolid doses in comparison with mineral fertilization (NPK: 15:15:15, 1270 kg ha^{-1}). The organic fertilization produced 11 tons ha^{-1} (grain dry matter) by 9 tons ha^{-1} (grain dry matter) for mineral application. No relationships were found between N and P application and grain production. The bisolid application (just for the large dose) derived in a low pH [with a low-aluminium saturation (%)], and low C: N, C: P and N: P soil ratios too, with a P soil content increment. By other hand, the heavy metal soil contents (Cd, Cr, Cu, Pb, Zn, Hi, Hg) are below Galiza-Spanish legislation levels (DOG 107/2012).

Keywords: pasteurized sewage sludge, *Zea mays* L. crop yield, soil modifications, heavy metals, grain production

1. Introduction

The adequate management of sludge from urban wastewater treatment plants is a critical global environmental concern due to population growth in urban centres, which increases the production of industrial and household waste and the amount of wastewater that must be processed by treatment plants. This issue is especially relevant, as more than 50% of the global population lived in urban centres in 2008 for the first time in the history of humankind [1]. The treatment of wastewater generates a semi-solid residue; the final disposal of this residue requires permanent technical and science-based solutions to prevent contamination of the natural environment. The most economical options that are available for the elimination of sludge entail its use as a fertiliser in agriculture or its disposal in landfills. The National Registry of Sewage Sludge in Spain [2] indicates that 1200 × 10^3 Mkg m.s. of sludge was generated in 2013, which represents an increase of 62% since 1997. The use of sludge in agricultural soils has increased in recent years: it was applied to 65% of the agricultural surface area in 2006 and to 80% in 2013. In the latter year, the landfill sludge disposal decreased by 8%, whereas its incineration increased by 4%; however, these rates do not account for the use of sludge in non-agricultural soils.

The incentive to apply sludge in agricultural areas is significantly given the ability of this waste product to serve as a fertiliser and their soil positively influence. Conversely, the continual use of mineral fertilisers causes a loss of soil organic matter and other negative impacts (e.g. a decrease in soil fauna or contamination of water bodies) and reduces the capacity of soil to crop production. Considering its different components, the organic matter content in sludge improves the density, porosity and water retention capacity of soil and promotes the activation of microorganisms and soil enzymes. The biosolids application (sanitised, stabilised and dry) favours germination and plant growth, increases the production of various crops and improves the quantity of plant protein and dry matter. The application of this waste product can produce a seasonal shift that causes the early flowering/fruiting of crops (e.g. flax and cotton) and reduce the growing period. Different risks are associated with the chemical composition of sludge, which are primarily related to its heavy metal content. The use of sludge affects the final concentration, solubility (the relative presence of fulvic and humic acid may aid the removal of heavy metals) and final bioavailability of heavy metals in the soil. Similarly, an excessive accumulation of metals negatively influences the development of mycorrhizae. An uncontrolled biosolids application can provoke a soil nutrient excess (N, P) and potentially contaminate aquifers. Deficits in the levels of K and Mn in plants have also been detected, which signals the need for chemical fertilisers to maintain sustained medium-term and long-term production. The sludge use also favours the persistence of pesticides that are applied during crop cultivation [3]. Another consideration is the high variability in sludge composition, which is dependent on the inputs of wastewater treatment plants, season and type of waste post-treatment. Therefore, the sludge chemical composition must be determined prior to its application in crop soils, and field assays should be performed to determine the fertilisation capacity of sludge and its environmental implications.

2. Material and methods

2.1. Process of obtaining biosolids

According to the legislative norms established by the Autonomous Community of Galiza (NW Spain), all sludge that originates from the purification process of urban wastewater must receive treatment prior to its use in order to sanitise and stabilise it, as well as reduce its volume. Thus, this waste product receives added value due to a chemical treatment process that sanitises and pasteurises sludge, which improves its use as a fertiliser. Both urban and industrial wastewater may be employed as an input. **Figure 1** shows a general outline of the entire purification process, which occurs in a timeframe of less than 1 h. Several chemical reagents are sequentially administered as a function of the type of treatment that is necessary to achieve sanitation. The system of reactors and ducts is closed and completely automatic, which minimises noise pollution and dust. Sludge is treated by an acidification process (with the addition of nitric, phosphoric and/or sulphuric acid) to sanitise and stabilise the organic residue, followed by its neutralisation with anhydrous ammonia. The product is submitted to a thermal process of drying and granulation. The entirety of the process is denominated as Verdiberia-Active Sludge Pasteurisation (Plateau-ASP-ActiSolids©), which includes an enhancement of fertilising capacity (via enrichment with organic N).

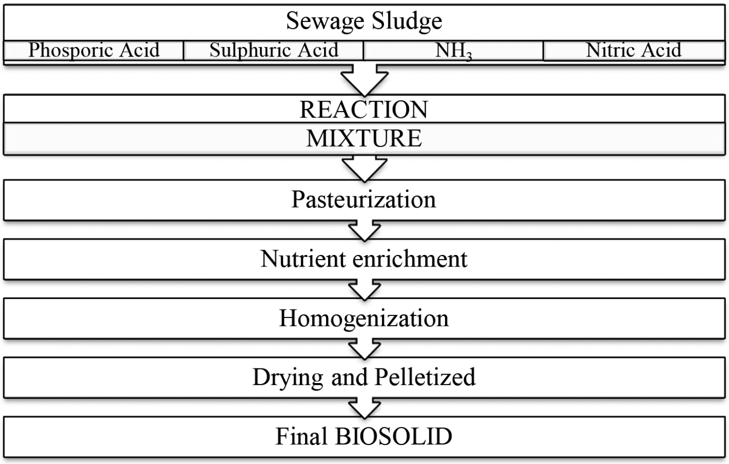

Figure 1. General process to obtain Verdiberia-ASP biosolid.

2.2. Design of field assay and elemental analysis of biosolid and soils

The field assay was conducted on a private agricultural farm in the municipality of Cospeito (Lugo province, Galiza, NW Spain; 43° 15' 13.15'' N, 7° 26' 31.76'' W). This municipality is characterised by an elevated intensity of agricultural-livestock use. **Table 1** lists the temperature and rainfall conditions that correspond to the study period (June–October 2013), which are characterised by mild average temperatures and moderate precipitation [4].

2013	June	July	August	September	October
Temperature	16.1	18.2	18.5	16.4	12.9
Rainfall	52	34	36	68	137

Table 1. Average temperature (°C) and total rainfall (mL) during the study period (corn sawing–corn harvesting).

At the assay site, four parcels of 3 × 4 m^2 were randomly and completely distributed for each of the following treatments:

- Control (CT): no application of fertiliser
- Biosolid 1 (BS1): 3000 kg ha^{-1} VerdiberiaASP NP + 450 kg ha^{-1} of potassium sulphate.
- Biosolid 2 (BS2): 7000 kg ha^{-1} VerdiberiaASP NP + 450 kg ha^{-1} of potassium sulphate.
- Mineral fertiliser (MF): 1270 kg ha^{-1} de 15-15-15 + 140 kg ha^{-1} of potassium sulphate.

The soil had an acidity level within the tolerable range for maize crops (pH of 5.5 in water and 10.7% saturation of Al, as an indicator of the cation-exchange capacity); thus, the parameters were not adjusted. To characterise the fertilisation treatments, the P levels of the soil were considered to be normal; however, the K levels were below the desired range. Based on these results and following the indications by [5], 190 kg ha^{-1} of N, 120 kg ha^{-1} of P_2O_5 and 260 kg ha $^{-1}$ of K_2O were defined as the base soil conditions for the maize crops in this study (**Table 2**).

	mg kg^{-1}		cmol(+) kg^{-1}					
pH	**K**	**P**	**Ca**	**Mg**	**Na**	**K**	**Al**	**Sat Al**
5.52	179.66	41.05	3.50	0.70	0.11	0.46	0.57	10.74

Table 2. Initial main soil parameters (available K and P).

The site was prepared with a mouldboard and rotary plough. The fertilisers were completely incorporated in the soil in the study area according to common practice and uniformly distributed throughout the parcel 1-day prior to maize crop sowing as the final step in the process, which was performed on June 5, 2013. The Automat (Advanta) maize variety (*Zea mays* L.) was employed with a planting density of 70,000 plants ha^{-1}. Potatoes had been cultivated the previous year before sowing, by this, the terrain was ploughed and the following phytosanitary treatments were applied as follows: 31.3% S-metolachlor herbicide + 18.7% terbuthylazine herbicide (4 L/ha; SIPCAM Inagra) and 48% liquid chlorpyrifos insectide (1 L/ha).

Soil samples were collected before the maize sowing (control plots without application of fertiliser), 30 days after sowing and at the end of harvest on October 10, 2013.

The pH was measured in a 1:2.5 suspension of soil:water. The C and N contents were determined using a Leco CNS 2000 Autoanalyser, and assimilable P was quantified by colorimetry following the Olsen method [6]. Several elements (Ca, Mg, Na, K and Al) were extracted with a 1 N solution of NH_4Cl [7] and were quantified by spectrophotometry using atomic absorption/emission techniques. Heavy metal soil content was measure through ICP before nitric acid digestion. The parameters that were measured for sludge are summarised in **Tables 3a** and **3b**.

To estimate production, cobs were harvested from ten central plants in each parcel. The fresh weight and dry weight were measured after dried in an oven at 60°C. The grains were subsequently separated to quantify the total production (kg ha^{-1}) and the output (Harvest Index = dry weight grain/dry weight cob). In addition, the following weighted production indices were estimated as follows:

Sustainable Yield Index (SYI) [8]

$$SYI = \left(Y - \sigma_{n-1}\right) Ym^{-1}, \text{ with}$$

Y = fertilization treatment yield, σ = standard deviation, Ym = maximum yield (among all treatments) and in the same way the Relative Yield Index (RYI) was calculated, to establish a reference for maximum production with respect to the control:

$$RYI = \left(Y - Yc\right) Ym^{-1}, \text{ with}$$

Yc = Control treatment yield,

and the Agronomic Efficiency (AE) Index, to estimate the nitrogen use efficiency of the crop [9],

$$AE = \left(Y_F - Y_0\right) Nap^{-1}, \text{ with}$$

Nap = N applied in kg ha^{-1}

2.3. Statistical analysis

The resulting means were compared by a two-factor analysis of variance (two-way ANOVA) with the goal of estimating the influence of the crop grow time period (30 days after sowing–harvest time, which varied according to the specific influence of the crop). A simple ANOVA was performed to determine the significance of the differences in the analysed parameters among treatments in terms of changes in soil characteristics and crop production. The normality of the data was verified (Kolmogorov–Smirnov test), and the homogeneity of variance was verified (Levene test). For cases in which the distribution of the variance was not homogeneous, the Games–Howell test was applied. Assuming homogenous variance, the least significant difference (LSD) method was employed. To compare with the control plot, a bilateral Dunnett's test was performed.

Bilateral Spearman's correlations were calculated for the different production indices, and the regressions between these previously uncorrelated indices and the dose of N and P that was administered by the distinct treatments were also established.

All statistical analyses were performed using SPSS [10].

3. Results

3.1. Contribution of sludge to soil heavy metal content

Considering the maximum concentration limits of heavy metals in the biosolid and its maximum final contribution to soils as a function of the utilised volume, neither surpassed the limits that were established by normative legislation for the heavy metals that were considered [11]. As listed in **Table 3a**, their levels fell below legal limits for all cases. For example, the Cr content and the Pb content were sixfold and 115-fold lower than the established kg ha^{-1} limits for the application of biosolids.

The biosolid obtained through the Active Sludge Pasteurisation processes shows a lower humidity percentage, for example [12] reported about 16.6% of dry matter, a low OM content [13] or more available P [14].

	Cr	Cu	Pb	Zn	Ni	Cd	Hg
Biosolid	69.5	168.3	20.5	450.2	27.95	3.0	2.23
Legal limit	1000	1000	750	2500	300	20	16
kg ha^{-1} (BS2)	0.4	1.1	0.13	2.9	0.18	0.02	0.01
Legal limit	3	12	15	30	3	0.15	0.10

d.m. = dry matter, BS2 = Biosolid dose applied by 7000 kg ha^{-1}.

Table 3a. Biosolid heavy metal content and legal limits (mg kg^{-1} d.m.).

pH	7.98
EC (dS m^{-1})	48.8
Humidity (%)	9.56
OM (%d.m.)	24.16
C/N	1.39
N—total (%d.m.)	10.09
N—nitric (%d.m.)	1.02
N—ammonia (%d.m.)	2.49
N—urein (%d.m.)	0.24
N—organic (%d.m.)	6.34
P_2O_5—total (%d.m.)	8.72

pH	**7.98**
P_2O_5—ammonia citrate-water soluble (%d.m.)	6.37
K_2O—total (%d.m.)	1.74
K_2O—water soluble (%d.m.)	0.42

d.m. = dry matter, EC: electrical conductivity, OM: organic matter.

Table 3b. Biosolid chemical characterization.

3.2. Evaluation of sludge incorporation rate into soil

The differences in the soil parameters were evaluated between the control parcels at the beginning of the experiment and the parcels that correspond to various treatments during the month of July, 30 days after the initial application of the different fertilisers (**Table 4**). These findings demonstrated a decrease in the pH levels of the treatments compared with CT and in the C/N and C/P ratios for the BS2 treatment, as well as a higher P availability in the same treatment, caused an increase in the relative concentrations of N and P; these elements are specifically provided by pasteurised and minerally enriched sludge. Given that sludge presents very low C/N, N/P and C/P ratios, as 62.8% of N is organic and 73.1% of P is present is its available form, and the soil pH showed a significant decrease after the initial application of sludge (considering the initial pH of the biosolid = 7.98), we can conclude that the fertilisers are rapidly incorporated in the soil. By other hand, during the month of June, a rainfall level of nearly 50 mLm^2 and an average temperature of 16.1°C fostered the biological activity of the soil, which also favours the mineralisation process (**Table 1**).

	pH	C/N	N/P	C/P	P_a
CT	5.6	13.5	62.5	844.9	50.9
	0.2	0.2	17.3	231.1	8.3
	a	**a**	**a**	**a**	**a**
MF	5.0	13.1	57.8	756.5	53.4
	0.2	0.4	15.9	199.6	9.8
	b	**ab**	**ab**	**ab**	**ab**
BS1	4.7	12.8	45.2	572.5	69.8
	0.3	0.5	9.3	101.9	9.4
	b	**ab**	**ab**	**ab**	**ab**
BS2	4.6	12.3	31.7	390.3	103.8
	0.1	0.4	3.4	34.2	9.8
	b	**b**	**b**	**b**	**b**

Only significance differences are showed (different letter means statistical significance difference at $\alpha < 0.05$). P_a = available P.

Table 4. Differences between fertiliser treatments and control 1 month after sawing time (Dunnett test). Mean and standard deviation values.

3.3. Analysis of temporal changes in soil nutrient content

The independent comparison of the variables over the course of the evaluated time period in terms of their variation enable us to determine whether time serves a role in the evolution of soil characteristics (**Table 5**). After the first time period (30 days after fertilisation and sowing), a significant decrease in soil pH occurred in the BS2 treatment compared with CT and MF. At the end of the harvest, we also observed a decrease in pH for all treatments compared with CT. The average value of the decrease shifted from 0.9 to 0.5 pH units; however, this difference is not statistically significant ($\alpha = 0.25$).

During the first period, only the BS2 treatment had a lower C/N ratio than the CT and MF treatments. In the second period, which corresponded to the end of the harvest, this ratio in BS2 was significantly lower than the CT, MF and BS1. This finding signifies that the relative quantity of N at the end of the experiment increased compared with the CT content for BS2 application (**Table 6**).

Differences in the N/P ratio were detected in the first period (BS2 < CT,MF), whereas BS2 treatment presented lower values for the second period compared with the CT and MF treatments, and BS1 lower than CT and MF.

Only the BS2 treatment demonstrated a lower C/P ratio over the course of the first period compared with the CT and MF. Over the course of the second period, BS1 and BS2 treatments presented lower values for this ratio compared with the CT and MF treatments, and the comparison of BS1 with BS2.

For the concentration of available P, the same behaviour was observed for the two time periods. Both BS1 and BS2 presented higher P values than that of the CT and MF, with differences between BS1 and BS2.

	pH	**α**	**C/N**	**α**	**N/P**	**α**	**C/P**	**α**	**P_a**	**α**
J	BS2 < CT	0.01	BS1 < CT	0.04	BS2 < CT	0.01	BS2 < CT	0.01	BS1 > CT	0.02
	BS2 < MF	0.02	BS2 < MF	0.03	BS2 < MF	0.03	BS2 < MF	0.02	BS1 > MF	0.04
			BS2 < BS1	0.03					BS2 > CT	0.02
									BS2 > MF	0.01
									BS2 > BS1	0.01
O	MF < CT	0.05	BS2 < CT	0.01	BS1 < CT	0.01	MF < CT	0.03	BS1 > CT	0.01
	BS1 < CT	0.02	BS2 < MF	0.01	BS1 > MF	0.01	BS1 < CT	0.01	BS1 > MF	0.02
	BS2 < CT	0.01	BS2 < BS1	0.01	BS2 < CT	0.01	BS1 < MF	0.01	BS2 > CT	0.01
					BS2 < MF	0.01	BS2 < CT	0.01	BS2 > MF	0.01
					BS2 < BS1	0.01	BS2 < MF	0.01	BS2 > BS1	0.01
							BS2 < BS1	0.01		

(J: 1 month after sawing time, O: harvest time).
Only soil characteristics with significance differences are showed. α = significance level.

Table 5. Differences between treatments for each period of soil sample.

	CT		**MF**		**BS1**		**BS2**	
	J	**O**	**J**	**O**	**J**	**O**	**J**	**O**
pH	5.6	5.4	5.0	5.1	4.7	4.9	4.6	4.8
	0.2	0.1	0.2	0.1	0.3	0.1	0.1	0.1
OM	7.1	7.7	6.7	7.3	6.7	7.0	7.0	7.1
	0.8	0.5	0.6	0.3	0.6	0.4	0.5	0.8
C	4.1	4.5	3.9	4.2	3.9	4.1	4.0	4.1
	0.4	0.3	0.3	0.2	0.4	0.2	0.3	0.4
N	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C/N	13.5	13.4	13.1	13.1	12.8	13.1	12.3	11.7
	0.2	0.3	0.4	0.5	0.5	0.4	0.3	0.4
C/P	844.8	1192.8	756.0	1013.5	572.3	651.8	390.3	381.5
	231.2	104.1	199.4	95.0	101.8	91.9	34.2	54.0
N/P	62.5	89.0	57.8	77.2	45.2	50.2	31.7	32.7
	17.3	7.8	15.9	5.5	9.3	8.7	3.4	4.9
K_a	313.6	300.8	409.3	343.1	408.7	274.2	471.2	384.3
	82.6	123.5	121.9	142.4	37.8	65.9	199.1	107.0
					a	**b**		
P_a	50.8	37.7	53.4	42.2	69.8	63.2	103.8	108.9
	8.2	4.9	9.8	5.7	9.4	5.7	7.8	16.8
Ca	6.0	4.8	5.8	4.9	4.7	5.2	5.7	5.1
	0.5	0.2	1.2	0.9	1.1	1.9	1.3	0.2
	a	**b**						
Mg	1.4	1.3	1.4	1.3	1.1	1.4	1.7	1.8
	0.3	0.1	0.5	0.4	0.3	0.5	0.2	0.1
Na	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2
	0.01	0.1	0.1	0.1	0.1	0.1	0.1	0.01
K	0.8	0.8	1.1	0.9	1.1	0.7	1.2	1.0
	0.2	0.3	0.3	0.4	0.1	0.2	0.5	0.3
Al	0.2	0.4	0.5	0.7	1.0	0.7	0.6	0.6
	0.1	0.1	0.2	0.2	0.5	0.4	0.3	0.01
Al_{sat}	2.8	5.7	5.7	9.0	13.0	9.6	7.3	6.8
	1.7	1.7	4.3	4.8	7.5	6.3	4.8	0.7

(J = sawing time, O = harvest time) OM, C, N, Al_{sat} = Al saturation (%), P_a = available P (mg kg^{-1}), Ka = available K, Mg, Na, Al (cmol^{+}kg^{-1}).
Different letters show statistical differences ($\alpha < 0.05$) between time periods for the same treatment.

Table 6. Mean and standard deviation values for soil parameters.

Comparing the two periods (July–October), significant differences are detected for the decreasing Ca and the available K content in soil for the CT and BS1 treatments, respectively. No other significant difference was detected. Based on these results, we propose that the applied fertiliser was sufficient for achieving adequate crop production, whereas the extraction of these elements and nutrients over the course of the study did not appear to serve an important role in the variation of their content in the soil.

3.4. Total differences in the soil nutrient content as a function of cultivation time and applied treatments

From a general perspective, differences between treatments were observed. The two-way ANOVA (time vs. treatment) only showed significant differences among the distinct treatments ($\alpha = 0.01$); both time and the interaction of time with treatment type were not significant ($\alpha = 0.10$, $\alpha = 0.90$). These results confirm the results of the temporal evolution of soil characteristics as described in the previous section, which indicates that the factor of crop growth does not appear to serve a fundamental role in the modification of the soil parameters. However, the results indicate that the different treatments are responsible for the variations. Significant differences in pH values are detected, which significantly decreased over the course of the experiment relative to the control after the treatments with distinct doses of biosolid (not statistically significant between each treatment) and mineral fertilisation. However, differences in the percentage of Al saturation, for which a decrease in pH does not represent a limitation of the availability of nutritional elements in the soil, were not observed.

	pH	**C/N**	**N/P**	**C/P**	**P_a**
CT	5.5	13.4	89.4	1202.0	37.7
	0.2	0.4	13.6	202.4	5.7
	a	**a**	**a**	**a**	**a**
MF	5.1	13.1	77.7	1018.4	42.2
	0.1	0.5	11.4	150.6	6.6
	b	**a**	**a**	**a**	**a**
BS1	5.0	13.1	49.8	649.3	63.2
	0.1	0.5	6.5	76.9	6.6
	b	**a**	**b**	**b**	**b**
BS2	4.8	11.7	39.0	451.7	108.9
	0.2	0.4	11.6	120.3	19.4
	b	**b**	**c**	**c**	**c**

Table 7. Soil parameters differences at harvest time (mean and standard deviations values). Only are showed significance differences (different letter mean significance difference at $\alpha < 0.05$. Games–Howell test for pH and P). P_a = available P (mg kg^{-1}).

The same tendency is detected in the relationships between nutrients and the C/N ratio, which has a significantly lower value for the BS2 treatment, in addition to the N/P and C/P ratios for

BS1 and BS2. Anyway, the C/P and N/P rates are enough higher to promote a P soil accumulation [15, 16].

With regard to the available P content in the soil, we obtain a greater value in BS2 compared with the other treatments and a greater value in BS1 compared with the MF and CT. In a similar way [17] found more soil P after harvest time (**Table 7**). Therefore, we can assume that the application of biosolid produces a relative enrichment of N and P, which also indicates a potential eutrophication risk due to excess available P as it does not appear to be regulated by crop extraction. [13, 18] report the sewage sludge application as an available P fountain, and by other hand, the C/P and N/P ratios are mainly controlled by P supply [19]. Its content in the soil and the total quantity provided by the biosolid exceed the corresponding maximum limits that were established by legislative norms [11] (48 mg kg^{-1} for P). Based on these established limits, only one application per year of the product tested in this study is permissible. For P [20], recommended a maximum of 150 kg ha^{-1} in order to prevent eutrophication risk.

3.5. Production, output and agronomic efficiency of crop

Table 8 summarises the significant differences for the indices that are related with crop production: grain yield (kg ha^{-1}), harvest index, RYI, SYI and AE and their correlations. Corn yield is significantly greater for the BS1 and BS2 treatments (similar for both) than for the CT and MF. In the same sense [21, 22], find largest corn production after sludge applying versus mineral fertilization.

	Kg ha^{-1}	**Harvest rate**	**SYI (%)**	**RYI (%)**	**AE**
CT	7295.9 (2434.3) **a**	86.1 (0.05) **a**	34.5 (17.3) **a**	–	–
MF	9431.3 (2180.3) **b**	82.6 (0.05) **b**	51.4 (15.5) **b**	17.1 (11.3) **a**	14.4 (10.3) **a**
BS1	11184.1 (1755.0) **c**	88.3 (0.03) **ac**	66.9 (12.4) **c**	27.9 (11.3) **b**	16.7 (7.7) **a**
BS2	10588.5 (1688.0) **c**	86.8 (0.03) **ac**	63.1 (12.0) **c**	23.5 (11.7) **b**	7.3 (4.0) **b**
		Pearson correlations: r^2, (α)			
	Kg ha^{-1}	Harvest rate	SYI	RYI	AE
Kg ha^{-1}	1	0.24 (0.01)	1.00 (0.01)	0.62 (0.01)	0.71 (0.01)
Harvest rate		1	0.28 (0.01)	0.17 (0.05)	n.s.
SYI			1	0.63 (0.01)	0.67 (0.01)
RYI				1	0.61 (0.01)
AE					1

Table 8. Differences found for production index and correlation values. Mean and standard deviation values.

For the RYI and SYI, differences follow a similar pattern to production levels. This finding may be attributed to the fact that the difference between production (BS vs. MF) and their low variability are the two factors with more influence in the yield index [yield coefficients of variation (%), CT = 34, MF = 23, BS1 = 16, BS2 = 16]. In the case of AE, the BS1 treatment was significantly greater than the corresponding BS2 treatment, which indicates that a direct relationship does not exist between the contribution of N and grain production. This tendency is confirmed when we analyse the regressions for the distinct production indices and different doses of N, which are not correlated. As observed in **Table 9**, the values of r^2 are low, and a statistically significant relationship between the coefficients and the constants was not observed in any case. [23, 24] find that an excessive N fertilization results in low-use efficiency, without any yield benefits and long-term environmental consequences, soil acidification, N-leaching… [25] does not find any relationship between grain yield and N application rates (r = 0.26). Similar pattern was obtained to P addition and yield index, but, for example [26] find a positive relationship between P addition and corn yield response.

$Y = N \times 1.27 + 9932.5$		
$r^2 = 0.016$	$\alpha_1 = 0.16$	$\alpha_2 = 0.01$
$HR = N \times 4.8 \times 10^{-5} + 0.84$		
$r^2 = 0.044$	$\alpha_1 = 0.02$	$\alpha_2 = 0.01$
$Y = P \times 4.2 + 10464.8$		
$r^2 = 0.215$	$\alpha_1 = 0.69$	$\alpha_2 = 0.13$
$HR = P \times 8.5 \times 10^{-5} + 0.84$		
$r^2 = 0.239$	$\alpha_1 = 0.68$	$\alpha_2 = 0.03$

α_1, α_2 = Significance value for N, P and constant coefficients.

Table 9. Regression values for corn yield (Y) (kg ha^{-1}) and harvest rate (HR) in relationship with N and P applied.

4. Conclusions

The application of the Verdiberia-ASP-NP (Plateau-ASP-ActiSolids©) biosolid, which originates from the sludge of urban treatment plants, was demonstrated to be suitable for maize production (*Zea mays* L., Automat-Advanta variety). This suitability can significantly increase the yield compared with equivalent mineral fertiliser.

This product does not present a risk of increasing the heavy metal concentration; considering the elemental concentration of the biosolid in total quantities (kg ha^{-1}), the resulting values were substantially lower than the established normative limits.

From the analysis of temporal variation, the values measured for the C/N, C/P and N/P ratios during the evaluation time period indicate that sludge rapidly incorporated into the soil with a high rate of mineralisation.

Although the application of this biosolid produced a slight decrease in the pH value at the end of the harvest period, this tendency is not present for the percentage of Al saturation. The availability of nutrients is not negatively affected.

The doses that were employed in this study administered a level of nutrients (NPK) that was adequate for crop development; at the end of the harvest, an excess of available P was detected in the soil. This result may represent a potential problem and the cause of eutrophication of the ground water layers.

Significant relationships between the contribution of nitrogen and phosphorous and the production indicators have not been observed. The rate of mineralisation of the biosolid should be established prior to use in field applications to adequately administer the correct dose depending on the production crop.

Author details

Emilio Carral[*], Adolfo López-Fabal, Socorro Seoane, Teresa Rodríguez, Carlos Caaveiro and Elvira López-Mosquera

*Address all correspondence to: emilio.carral@usc.es

Higher Polytechnic School, University of Santiago de Compostela, Lugo-Galiza, Spain

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