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Recycling urban biosolids in pastures of the Southeast of Portugal

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SUMMARY – Dry matter yields and heavy metals concentrations in pasture, as affected by the application of urban biosolids (UB) and mineral fertilisers (MF), are compared in three successive years of a field experiment in the Alentejo region. The experimental layout was a split-plot design, with two plots of natural and sown pasture, each one with three fertilisation treatments ("nil", mineral, and organic). The UB was applied once. Total dry matter yields of natural pasture did not differ among treatments in 2005, but in 2006 and 2007 highly increased in both MF and UB treatments ($P \leq 0.05$). Total yields of sown pasture did not differ among treatments. In 2005 and 2006, Cd, Cr, Cu, Ni, Pb, and Zn plant top concentrations in the UB treatment were adequate for the normal pasture growth and did not show any potential risk of toxicity for sheep. This strongly suggests the adequacy of UB application in pasture lands of this region, namely in natural pastures.

Keywords: Sewage sludge, degraded soil, heavy metals, pasture, production.

***RESUME** – "Recyclage des biosolides urbains pour les pâturages dans le SE du Portugal". Les productions et les concentrations en métaux lourds dans des pâturages, obtenues par l'application d'une boue d'épuration urbaine (BEU) traitée et des fertilisants minéraux (FM), sont comparées sur trois années consécutives d´un essai mis en place dans la région de l'Alentejo. Le dispositif expérimental était en "split-plot", avec deux blocs de pâturage naturel et semé où trois traitements de fertilisation (nulle, minérale et organique) étaient testés. La BEU était appliquée une fois. Les productions totales du pâturage naturel n'étaient pas différentes entre traitements en 2005, mais en 2006 et 2007 elles ont beaucoup augmenté dans les traitements minéral et organique ($P \leq 0,05$). Les productions totales du pâturage semé étaient semblables entre traitements. En 2005 et 2006, les concentrations de Cd, Cr, Cu, Ni, Pb et Zn dans l'herbage du traitement organique étaient adéquats pour le développement normal des plantes et n'ont pas montré de risque potentiel de toxicité pour les ovins. Cela suggère fortement l'adéquation de l'application de BEU aux sols sous pâturage de cette région, en remplaçant les FM, spécialement en pâturage naturel.*

***Mots-clés :** Boue d'épuration urbaine, sol dégradé, métaux lourds, pâturage, production.*

Introduction

The urban solids (UB) production in the Alentejo region sharply increased in the last decades, reaching a 45 t/day- estimated value- in 2006 (Gonçalves and Leitão, 2001).

In wide areas of the interior of this region, soils under natural pasture have often low fertility and/or are easily eroded. The application of urban biosolids (UB) to these soils is the most economical use for UB, relatively to other disposal options, like landfill, sea discharge, or incineration (Smith, 1996). On the other hand, pasture yields may be improved, due to the richness of UB in organic matter and nutrients. Also, soil conservation may be promoted, by increasing soil coverage with plants. However, the occurrence of heavy metals in UB may induce toxicity to the plants or harmful effects on the grazing animal's health.

In Portugal, the UB application to the agricultural soils is regulated by Decreto-Lei no. 118/2006, stipulating the highest allowed amounts of heavy metals in the UB and the receiver soils.

Under the scope of the research project AGRO 414 (2004-2007), we compared the application of a treated UB and the mineral fertilisation, regarding their effects on pasture yields in three years of a field experiment. The concentrations of cadmium (Cd), copper (Cu), chromium (Cr), nickel (Ni), lead (Pb), and zinc (Zn) in the herbage were examined too, for the 1^{st} and 2^{nd} growing seasons.

Material and methods

The experiment was established in the autumn of 2004, on a complex of soils derived from schists and grauwacks (Haplic Luvisols and Eutric Leptosols). Topsoil (0 -15/20 cm) was slightly acid (5.3-5.5), with low and medium organic matter contents (10-50 g kg^{-1}), low available phosphorus (P), potassium (K), molybdenum (Mo), and zinc (Zn) contents, and relatively high exchangeable magnesium (Mg) for plant production. *Aqua regia* extractable Cd, Cu, Cr, Hg, Ni, Pb, and Zn contents were lower than the limit values imposed by Decreto-Lei no. 118/2006.

The experimental layout was a split-plot design, with two plots (1.5 ha) of natural and sown pasture, each one with three plots (0.5 ha) referent to three fertilisation treatments ("nil", mineral, and organic). A mixture of treated UB from the Alvito and Vila Nova de Baronia plants, with concentrations of the same heavy metals below the legislated values, was applied in 2004, at a rate of about 13 t/ha. Mineral fertilisation included N, P, K, Zn, and Mo (2004) and P and K (2006). It was planned to achieve a dry matter yield 3-6 t/ha of sown pasture as regards to the P and K rates. Among the elements analysed in both mineral and organic fertilisers, nitrogen (N), calcium (Ca), and Zn entered in the topsoil in higher amounts through the UB application than with the mineral fertilisation, while the opposite occurred for P and K (Table 1).

Table 1. Amounts of elements introduced in topsoil through the UB and MF application (per ha)

Element	2004		2006	Element	2004		2006
	UB	MF	MF		UB	MF	MF
N (kg)	194	25	-	Cd (g)	69	-	-
P (kg)	14.5	61	16.4	Co (g)	71	-	-
K (kg)	15	104	56	Cr (g)	1320	-	-
Na (g)	-	24	-	Cu (g)	1630	-	-
Ca (kg)	372	198	-	Hg (g)	nd	-	-
Mg (kg)	33	-	-	Ni (g)	195	-	-
Mo (g)	-	50	-	Pb (g)	630	-	-
S (kg)	-	95	-	Zn (kg)	10	3.6	-

nd = not detected; UB = Urban biosolids; MF = Mineral fertilisers.

The mixture of sown species (30 kg ha^{-1}) consisted of eight legumes species (*Trifolium subterraneum, Trifolium michaelianum, Trifolium vesiculosum, Trifolium resupinatum*, *Trifolium incarnatum*, *Ornithopus sativus*, *Ornithopus compressus*, and *Biserrula pelecinus*), and three perennial grasses (*Lolium perenne*, *Dactylis glomerata*, and *Phalaris aquatica*).

Pasture fodder biomass was taken in one harvest (1^{st} season, 2004/2005), two harvests (2^{nd} season, 2005/2006), and three harvests (3^{rd} season, 2006/2007), by sampling the inside of exclusion cages (6 per plot). Dry matter yield corrected at 100-105^{o}C was determined. Plant tops concentrations at the 1^{st} and 2^{nd} seasons (two samples/plot) were analysed for Cd, Pb, Cu, Cr, Ni, and Zn, by wet digestion with nitric and perchloric acids (Ulrich *et al.*, 1959) and flame atomic absorption spectroscopy (FAS). Dry matter yields of each cut, total dry matter yields, and foliar heavy metal concentrations were statistically analysed using analysis of variance and the L.S.D. test for comparisons of means, either for the pasture types, or for the fertilizer treatments ($P \leq 0.05$).

Results and discussion

Dry matter yields

For each growing season, the interaction of the three variation factors Pasture type, Fertilizer treatment, and Harvest date was not significant, meaning that the correspondent production values did not differ statistically. This may be due to the relatively high coefficients of variation (60%, 31%, and 36% for the yields of 2005, 2006, and 2007, respectively). However, trends towards higher dry matter yields induced by the sowing and/or the fertilisation were observed (Table 2).

Table 2. Mean dry matter yields (kg ha^{-1}) for the harvests of the three growing seasons

Pasture types	Fertilizer treatment	2005	2006		2007		
			1st cut	2nd cut	1st cut	2nd cut	3rd cut
Natural	0	403	1118	2161	372	1053	874
	UB	948	2916	3743	1031	2083	1312
	MF	802	1996	2918	1285	1764	1738
Sown	0	569	2267	4270	1194	2412	2496
	UB	1074	3203	3806	1622	1996	1661
	MF	1595	2789	3367	1135	2418	1746

UB = Urban biosolids; MF = Mineral fertilisers.

In 2005, the application of UB or MF promoted relevant increases (not significant) higher than 400 kg ha^{-1} of both pasture types, in comparison to the yields of the respective control treatments. The abnormal reduced precipitation during the 1st growing season (175 mm since September 2004 until June 2005), limited the emergence and growing of the indigenous and sown pasture species, and consequently induced low yield levels and great variability within the several plots.

Total dry matter yields evaluated in 2006 and 2007 highly responded to fertilisation in the plots with natural pasture (Table 3). In 2006, the increases were of about 3400 and 1650 kg ha^{-1} and in 2007, they were of about 2100 and 2500 kg ha^{-1}, at the UB and MF treatments, respectively. The highest production was reached at the UB application in 2006.

Table 3. Total dry matter yield (kg ha^{-1}), for two pasture types and three fertiliser treatments

Year	Natural pasture			Sown pasture		
	Control	UB	MF	Control	UB	MF
2005	403^{h}	948^{h}	802^{h}	569^{h}	1074^{gh}	1595^{gh}
2006	3279^{ef}	6659^{a}	4914^{cd}	6537^{ab}	7009^{a}	6156^{abc}
2007	2299^{fg}	4426de	4787^{d}	6102^{abc}	5280^{cd}	5298^{bcd}

UB = Urban biosolids; MF = Mineral fertilisers; Values in the same row or column bearing the same subscripts do not differ ($P \leq 0.05$).

For the same years, no significant differences were found among treatments in the yields of sown pasture. In fact, the control treatment (without fertilisation) also reached the highest production level, which can be at least in part explained by enough water availability in soil during the 2nd and 3rd growing periods (precipitation of 466 mm and 490 mm, between September and June, respectively).

Heavy metal plant composition

Plant tops Cd concentrations were not discussed, as they could not be detected by FAS.

The Cd, Cu, Cr, Ni, Pb, and Zn contents in the UB and MF treatments were within the adequate or no phytotoxic ranges of heavy metals concentrations for the plant growing (Table 4), according to Alloway (1990), Pendias and Pendias (1991), and Bergmann (1992). They were also adequate as regards to the sheep' diet (Table 4), as indicated by the NRC (1980), cited by Smith (1996).

The foliar concentrations in 2005 and 2006 only significantly increased with the UB or MF application of 2004, for the Ni, Pb, and Zn elements, in both pasture types (Table 5).

Table 4. Adequate or no phytotoxic ranges of heavy metals concentrations for plant growth and maximum tolerable dietary levels of heavy metals for sheep (mg kg^{-1})

Ranges	Cd	Cr	Cu	Ni	Pb	Zn
Plants	0.05 - 3.0	0.02 - 14.0	5.0 - 30.0	0.02 - 8.0	0.2 - 20.0	1.0 - 400
Sheep	5.0	1000	30	50	25	300

Table 5. Heavy metals contents (mg kg^{-1}) in the pastures, evaluated in 2005 and 2006

Year	Harvest	Plot	Cr	Cu	Ni	Pb	Zn
2005	Single	NP	2.3^{bcd}	4.7^{gh}	0.7^{i}	3.8^{ghi}	48^{j}
		NP and UB	1.5^{fgh}	5.0^{fgh}	1.0^{hi}	3.2^{hij}	50^{ij}
		NP and MF	1.7^{defg}	4.3^{hi}	1.4^{ghi}	3.7^{ghi}	58^{i}
		SP	2.8^{bc}	7.6^{c}	1.8^{fg}	6.1^{bc}	46^{j}
		SP and UB	2.2^{cde}	3.5^{ij}	1.8^{fg}	4.6^{efg}	40^{k}
		SP and MF	2.2^{cde}	2.8^{j}	2.9^{e}	4.4^{efg}	56^{hij}
2006	1st	NP	4.9^{a}	9.8^{ab}	2.8^{e}	5.3^{cde}	115^{e}
		NP and UB	5.2^{a}	10.5^{a}	1.6^{gh}	7.3^{a}	191^{b}
		NP and MF	2.9^{b}	8.9^{b}	2.3^{e}	6.7^{ab}	254^{a}
		SP	1.6^{efg}	6.5^{cde}	1.5^{gh}	3.1^{hij}	92^{f}
		SP and UB	2.1^{def}	7.4^{c}	2.3^{ef}	5.7^{bcd}	137^{d}
		SP and MF	2.0^{def}	7.0^{cd}	4.5^{d}	7.2^{a}	164^{c}
2006	2nd	NP	1.1^{ghij}	6.8^{cde}	4.8^{cd}	2.6^{j}	91^{f}
		NP and UB	0.5^{j}	5.0^{fgh}	6.4^{a}	2.8^{ij}	46^{j}
		NP and MF	0.6^{ij}	6.1^{def}	6.5^{a}	4.0^{fgh}	79^{fg}
		SP	0.7^{ij}	5.7^{efg}	5.8^{bc}	3.8^{gh}	72^{gh}
		SP and UB	1.2^{ghi}	6.2^{de}	5.6^{b}	4.2^{fg}	66^{ghi}
		SP and MF	0.8^{hij}	6.5^{cde}	5.5^{b}	4.9^{def}	94^{f}

NP = Natural pasture; SP = Sown pasture; UB = Urban biosolids; MF = Mineral fertilisers.
In each column, values with the same letter do not differ ($P \leq 0.05$).

Concerning natural pasture, the Zn content responded to MF application in 2005 and 2006 (1st cut), reaching at this harvest the highest increase. The UB treatment also affected the Zn content in the same date of 2006. The Pb content increased equally in the UB and MF treatments at the 1st date of 2006, but at the 2nd harvest of this year, only responded to the MF application. At this harvest, the Ni concentration reached the highest value with both UB and MF treatments.

As regards to the sown pasture, the Ni content increased in 2005 and 2006 (1st cut) in the MF treatment. At this harvest of 2006, the Ni content also responded to the UB application. The Pb and Zn contents increased at the 1st cut of 2006 for both UB and MF treatments, but mainly with the last one. At the 2nd harvest of 2006, the contents of these elements only responded to the MF treatment.

Conclusions

The sowing of pasture adapted species proved to increase greatly dry matter yields in this region, especially when water availability in soil is not a limiting factor.

The UB application may replace mineral fertilisation, namely in natural pasture, without hazardous effects of heavy metals on plant growth and grazing animal's health.

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