EFFECTS OF 12 YEARS USE OF SEWAGE SLUDGE ON THE PLANT-SOIL SYSTEM

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ABSTRACT

The effects of municipal-industrial wastewater sludge, applied to soil in different forms and at two rates, have been evaluated on a winter wheat – maize – sugar beet rotation conducted on a silty-loam soil in the eastern Po Valley (Italy) since 1988.

On the whole, sludge proved to be an interesting surrogate for mineral fertilisers; applied at a correct rate they gave crop yields similar to the best mineral dressing and no evident phytotoxic effects.

Sludge increased organic matter, total nitrogen, and available phosphorous in the soil, with more evident effects at the highest rate. The composted sludge caused the most pronounced organic matter topsoil accumulation. Significant accumulations of total zinc and copper were detected in amended topsoil. Apart from these essential elements, the toxic metals cadmium, chromium, nichel and lead showed substantially no risk of agricultural products contamination.

On the whole, the application of sludge brought about notable benefits to soil fertility, associated with possible negative effects on water quality, due to increased phosphorous availability and on soil ecology due to zinc accumulation.

Keywords: *accumulation, organic matter, nitrogen, heavy metals.*

INTRODUCTION

Long-term research on sludge use on cropland are needed because many of its effects, e.g. organic matter variation and the possible build-up of toxic elements in soil, evolve slowly and are difficult to predict (Bergkvist et al., 2003; Gaskin et al., 2003). All aspects of sludge use should be considered: in particular, it is necessary to ascertain if these materials can surrogate inorganic fertilisation in crop production, with special regard to N supply, and how they modify soil characteristics, to prevent environmental pollution and crop contamination.

All this knowledge represents a prerequisite to verifying whether or not sludge is a real resource and to obtain its safe and profitable recycling on cropland.

MATERIALS AND METHODS

The effects of the utilisation of sludge and mineral fertilisers have been evaluated in a field experiment which started in 1988 and is still in progress, at the "M. Marani" experimental farm near Ravenna, in the eastern part of the Po Valley (Italy). Fertilisation treatments have always been repeated on the same plots (49 m^2 each) on which winter wheat (*Triticum aestivum* L.), sugar beet (*Beta vulgaris* L.), and maize (*Zea mays* L.) have been rotated, with all three crops grown every year in three contiguous fields with no irrigation. Plots are randomised within each field according to complete block designs, with 4 replicates.

The soil has silty-loam texture and is calcareous rich, initially had 7.8 pH, 13.9 meq $(100g)^{-1}$ cationic exchange capacity (CEC), and 1.6% organic matter (OM) content. Sludge derives from a treatment plant of municipal-industrial wastewater (120000 population equivalent). It has been applied every year in the autumn, prior to ploughing.

Sludge treatment includes the factorial combination of the following:

- 3 forms: liquid, dewatered and composted sludge (dewatered + wheat straw, 9:1 w/w respectively, turned for 2 months in an open platform and left for a further 1-1.5 months) (**Table 1**);

- two rates: 5 and 10 t DM ha^{-1} yr^{-1} (7.5 and 15 t DM ha^{-1} yr^{-1} until 1994). All crop residues have been removed from the field, except sugar beet leaves.

Crop yields have been quantitatively and qualitatively measured every year. In 2000, at the end of the first 12 years of the trial, soil (to a depth of 40 cm) and crop (wheat grain and straw, maize grain and stalks + cobs, sugar beet roots) samples were taken for analysis. On soil were determined : pH, salinity (EC – electrical conductivity, 5:1 soil/water paste), organic matter (OM, Walkley-Black Met.), total N (TKN, Kjeldahl Met.), available P (Olsen Met.) and the total concentration of Cd, Cr, Cu, Ni, Pb, Zn (EPA 3051/6010B Met.). On crop products were determined: total N, P, Cd, Cr, Cu, Ni, Pb, Zn (EPA 3051/6010B Met.).

***Table 1**. Main average characteristics of sludge applied over 12 years.*

	Liquid	Dewatered	Composted
pH in water	7.65	7.92	7.11
Dry matter (g kg^{-1})	32.5	236.1	518.2
Organic C (% DM)	31.3	29.6	26.3
Kjeldahl N (% DM)	6.12	4.25	2.95
$N-NH_4^+$(% DM)	2.01	0.62	0.43
P (% DM)	1.95	1.81	1.43
K (% DM)	1.71	0.71	1.11
Cd (mg kg^{-1})	2.55	2.65	2.06
Cr (mg kg^{-1})	221	230	186
Cu (mg kg^{-1})	749	790	649
Ni (mg kg^{-1})	236	238	195
Pb (mg kg^{-1})	127	123	103
Zn (mg kg^{-1})	1292	1328	1077
DH – degree of humification (%)	54.6	57.1	65.1
HR – humification rate (%)	36.0	38.6	41.3
HI – humification index (%)	0.83	0.75	0.54

RESULTS AND DISCUSSION

Crop yields

On wheat, at the lower application rate, sludge gave yields similar to mineral fertilisers, without reaching the peak productions. Rate doubling improved production in compost treatment only. Yield reductions with the heaviest N inputs were mainly due to wheat lodging. Liquid slurry was particularly detrimental to grain quality.

On maize sludge gave satisfactory grain productions again, on average better than that obtained with mineral fertilisers. The best results were obtained with liquid slurry applied at the lowest rate. Doubling the amount of all materials caused no significant yield increase.

The best root yields for sugar beet were obtained with liquid sludge. The double application rate improved sludge performance. However, sludge revealed extremely harmful to beet quality. In particular, liquid sludge caused important reductions in sugar content and high concentrations of melassigenic compound in root pulp. Compost gave significantly lower yields than the other materials and was found to be less detrimental to quality.

Soil chemical characteristics

Results of soil chemical analysis and variance analysis on data are reported in Table 2. .First of all, sludge application significantly increased the soil organic matter content in comparison with mineral dressing. The increment was greater at the double rate and with compost, probably thanks to its better OM quality, testified by the measured humification parameters (see DH, HR and HI in Table 1) (Figure 1). N build up was probably due to a greater proportion of the element that, bound to the organic matter, is less mobile. The marked increase in Olsen P can be explained not only by the high loading with sludge but also by an incremented availability in amended soil (Shober and Sims, 2003). The increase of soil salinity was significant but slight. All conductivity measurements were approximate to the lower limits of the definition level for very weakly saline soils (0.15-0.40 mS cm^{-1}).

On average, sludge applications caused a marked build up of total copper and zinc in the topsoil, while other heavy metal total concentrations were almost unaffected. The type of sludges had no significant influence on heavy metals build up.

***Table 2**. Soil parameters in 2000, after 12 years of fertilisations.*

Fertilisation	pH	O.M. %	Total N ‰	C/N	Olsen P mg kg^{-1}	E.C. mS cm^{-1}
Inorganic (4 levels avg.)	8.06	1.80	1.40	7.45	26.67	0.164
Sludge (6 types x rates avg.)	8.00	2.07	1.53	7.89	45.22	0.206
Significance	***	***	**	*	***	***
Sludge rates (3 types avg.)						
5 DM t ha-1 yr-1	8.03	1.95	1.43	7.96	35.67	0.190
10 DM t ha-1 yr-1	7.96	2.19	1.63	7.82	54.78	0.222
Significance	***	***	***	ns	***	***
Sludge type (2 rates avg.)						
Liquid	8.01	2.01	1.48	7.95	46.94	0.207
Dewatered	7.97	2.06	1.55	7.75	45.44	0.214
Composted	8.02	2.14	1.57	7.97	43.28	0.196
Significance	ns	ns	ns	ns	ns	ns

Fertilisation	Cd mg kg^{-1}	Cr mg kg^{-1}	Cu mg kg^{-1}	Ni mg kg^{-1}	Pb mg kg^{-1}	Zn mg kg^{-1}
Inorganic (4 levels avg.)	0.355	58.3	60.7	46.8	15.8	82.8
Sludge (6 types x rates avg.)	0.362	59.6	65.7	48.4	15.7	93.9
Significance	ns	ns	**	ns	ns	***
Sludge rates (3 types avg.)						
5 DM t ha^{-1} yr^{-1}	0.350	59.1	64.0	48.0	15.4	89.3
10 DM t ha^{-1} yr^{-1}	0.370	60.1	67.4	48.7	16.1	98.5
Significance	*	ns	ns	ns	ns	**
Sludge type (2 rates avg.)						
Liquid	0.354	59.0	63.6	48.0	15.9	89.6
Dewatered	0.370	61.3	67.0	48.9	16.1	96.9
Composted	0.363	58.6	66.4	48.3	15.2	95.1
Significance	ns	ns	ns	ns	ns	ns

*ns, *, **, *** differences between means not significant, significant at P?0.05, 0.01 and 0.001, respectively, according to ANOVA.*

On the whole, the concentration of all metals in the soil remained well below the EU regulation limits after 12 years of heavy applications of sludge. However, the observed build up of zinc can be hazardous, due to its role in controlling other metals availability, in conjunction with soil pH and organic matter, and its influence on nitrogen fixation, nitrification and decomposition microbial processes (Cela and Summer, 2003). Copper seems to be less problematic: in some instances (e.g. in light textured soils and for forage crops) Cu input can improve the quantity and quality of amended crop yield (Gaskin et al., 2003).

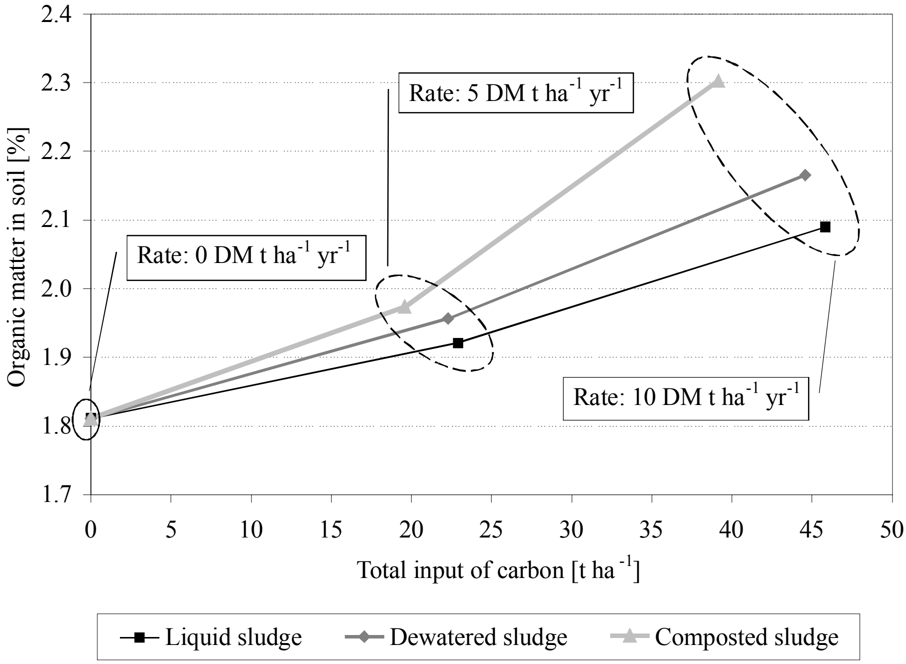

***Figure 1**. Effects of carbon input and sludge type on OM concentration in soil (year 2000).*

Nutrients and heavy metals concentration in products

Sludge applications significantly increased the content of N, P, Zn and Cu in wheat grain, N and Cu in sugar beet roots and only Cu in maize grain whilst the content of other toxic heavy metals (Cr, Ni, Pb and Cd) remained unaltered.

Up to now, no evident expressions of phytotoxicity have ever been detected on crops.

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