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…national RAMIRAN Conference 2004, MURCIA (SPAIN)

Long-term excessive organic waste use on environmental impact and sustainability

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ABSTRACT

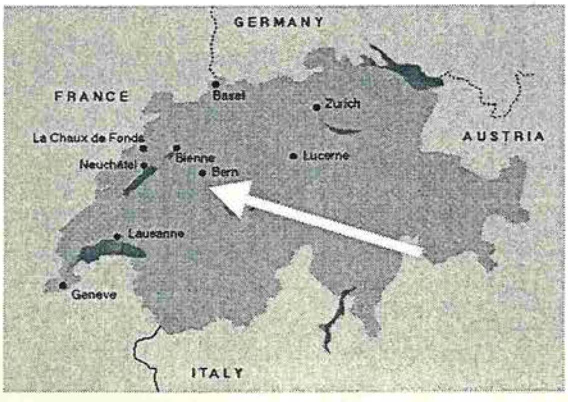
The effect of high amounts of sewage sludge and pig slurry (2 and 5 tons of organic matter respectively) applied in a 25 year field experiment were investigated. The change of selected soil properties, in crop yields and contents during the last five years were measured and discussed. The pH-value of the soil decreased in unfertilised plots or when high quantities of pig slurry was applied. Phosphate content increased considerably with high application of organic fertilisers.

Large amounts of nitrogen in pig slurry together with a decrease of pH-value decreased the yield of the several crops, especially red roots and celery considerably. Both, sewage sludge and pig slurry, in general are very valuable organic fertilisers. Nevertheless in consequences of hygienic reasons and risks of organic pollutants and heavy metals the agricultural use of sewage sludge will be forbidden from 2006 in Switzerland. On unfertilised acid soils the yield of various crops was very low and some crops were in addition enriched with heavy metals. Best guarantee for an equable crop contents in ecologically friendly and sustainable plant production is a well-balanced fertilisation adjusted to the plants nutrient uptake.

Key words: long term field experiment, fertilisation, pig slurry, sewage sludge, crop yields, heavy metals.

INTRODUCTION

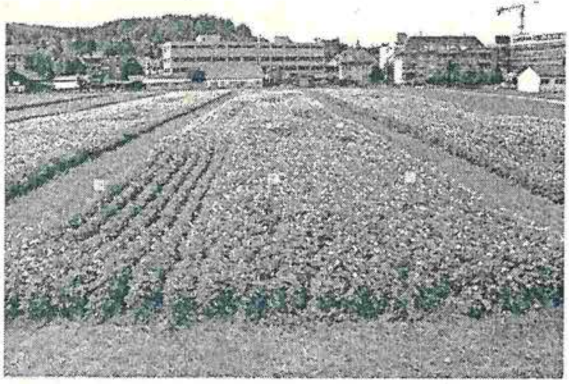
In a long term field experiment applying large amounts of treated sewage sludge and pig slurry the trial aimed to clarify the middle and long term effects with reference to the physical, chemical and biological properties the soil as to determine the plant yield in crop rotation.

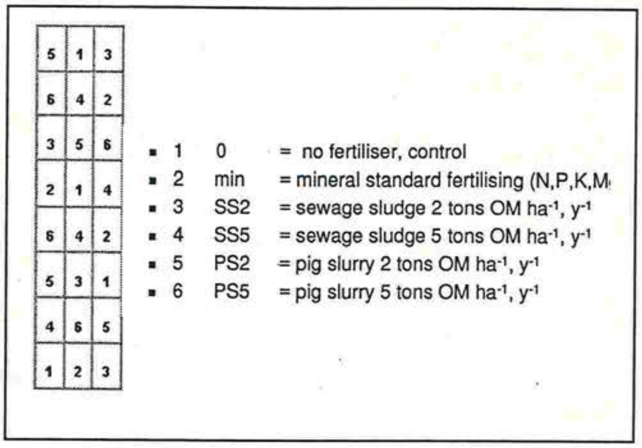


The quantitative limit f liquid organic fertiliser like as pig slurry and sewage sludge per unit area as well as the consequences of an over fertilisation where estimated (Siegenthaler et al., 2000).

MATERIAL AND METHODS

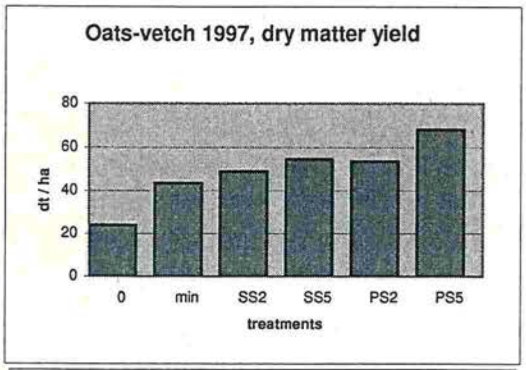
The experimental field at Liebefeld's Research Station near Berne (565 m above sea level, 1100 mm average precipitation, 9.7 ^{0}C average temperature) where 104m long and 12 m large, divided into 6 parts, 4 repetitions and six treatments with zero, 2 and 5 tons of organic matter per hectare and year of sewage sludge and pig slurry respectively. As a control a standard mineral fertilisation (N, P, K, Mg) were applied. The applied quantities of organic fertilisers correspond approximately ≈ 2 to 3 livestock unit (LU) and 4 to 6 LU for the high doses of sewage sludge and pig slurry respectively (Walther et al., 1994).



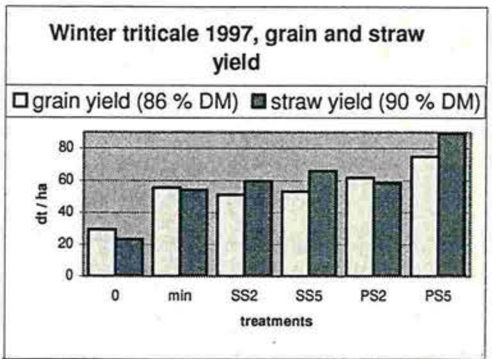


RESULTS AND DISCUSSION

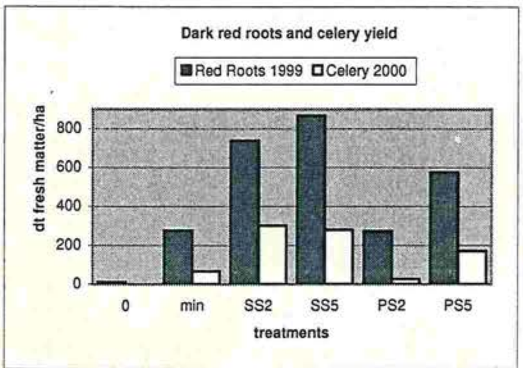
At the beginning of the trial in 1976 the **pH-values** in the top soil were between 6.0 and 6.4. Not surprisingly, the soil pH-value changed considerably during the trial time. The pH-values of the soil



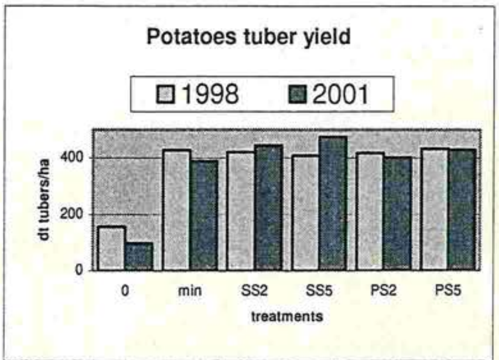
Smallest significant difference (ssd), ssd1 = 6.9; ssd5 = 9.6



Smallest significant difference (ssd) grain: ssd1 = 6.6; ssd5 = 8.9 straw: ssd1 = 0.7; ssd5 = 14.7



Smallest significant difference (ssd)
Red roots: ssd1 = 21.4; ssd5 = 29.4
Celery: ssd1 = 9.3; ssd5 = 12.8



Smallest significant difference (ssd) 1998: ssd1 = 6.9; ssd5 = 0'.7; 2001: ssd1 = 60.6; ssd5 = 3.2

reduced in the treatments where no fertiliser or high quantities of pig slurry were applied. In some cases (e.g. red roots and celery) too large amounts of nitrogen in pig slurry significantly decreased the yield. In case of high doses of sewage sludge and pig slurry, the levels of copper, zinc and cadmium in the soil increased remarkably in soil and plants during the trial period of more than twenty years.

Amounts of nutrients as well as total heavy metals applied by fertilisers during the 20 first years experimental period, (kg/ha; fallout unconsidered)

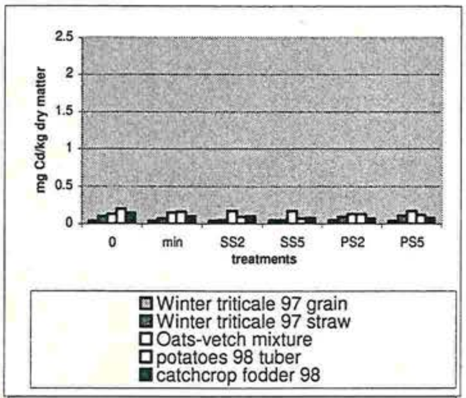
Treatment	OM	P	K	Cu	Zn	Cd
	kg ha^{-1} y^{-1}			kg ha^{-1} /20y^{-1}		
0	0	0	0	-	-	-
Min.	0	45	220	1)	1)	-
SS2	2000 2)	130	125	32.3	131.1	0.26
SS5	5000 2)	350	250	79.8	353.4	0.74
PS2	2000 2)	95	240	11.4	52.3	0.09
PS5	5000 2)	260	430	34.2	150.1	0.11

Resulting average values for each treatment in the soil (0-20cm)

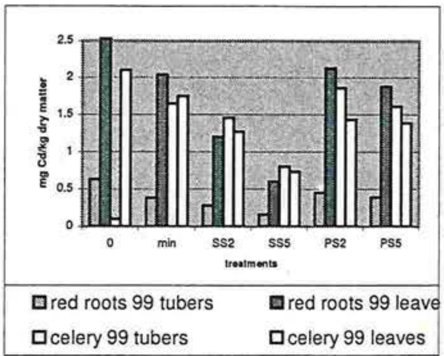
1994 Treatment	pH (H_2O)	C org %	P-Test 3)	K-Test 4)	Cu ppm Total 5)	Cu ppb Soluble 6)	Zn ppm Total 5)	Zn ppb Soluble 6)	Cd ppm Total 4)	Cd ppb Soluble 6)
0	5.3	1.31	6.2	0.7	24.2	76	51.0	928	0.258	11.6
Min.	5.6	1.43	19.9	3.7	23.5	85	53.0	505	0.220	5.3
SS2	6.1	1.71	11.7	5.2	35.1	100	91.9	200	0.476	<2.6
SS5	6.8	2.10	12.8	2.7	54.1	109	152.4	88	0.841	<2.6
PS2	5.1	1.48	30.7	2.8	27.0	121	57.0	1715	0.234	10.6
PS5	4.9	1.56	64.4	3.5	30.4	181	66.8	2268	0.216	9.2

Guide values Swiss Federal Ordinance Relating to Soil Contaminations 1998 (Swiss Federal Council, 1998)	Cu ppm 5) total	Cu ppb 6) soluble	Zn ppm 5) total	Zn ppb 6) soluble	Cd ppm 6) total	Cd ppb 6) soluble
	40	700	150	500	0.8	20

0 = without fertilising; min = mineral standard fertilisation, SS = sewage sludge; PS = pig slurry
1) not determined; 2) estimated value; 3) P-Test value (Method: CO_2-saturated water, 1:2.5): 8 - 16 sufficient, 16.1 - 32 storage, >32 enriched; 4) K-Test value (Method: CO_2-saturated water, 1:2.5): 2 - 4 sufficient, 4.1-8 storage, >8 enriched ; 5) Total content: Extracted by nitric acid (2 M HNO_3), 1 : 10; 6) Soluble content Extracted by sodium nitrate (0.1 M $NaNO_3$), 1:2.5; underlined values exceed Swiss guidelines values.



Smallest significant difference (ssd); Triticale grain: ssd1 = 0.01; ssd5 = 0.02; straw: ssd1 = 0.01; ssd5 = 0.01; Oats-vetch mixture: ssd1 = 0.12; swsd5 = 0.17; potatoes 98: ssd1 = 0.04; ssd5 = 0.05; catchcrop fodder: ssd1 = 0.03; ssd5 = 0.04



Smallest significant difference (ssd); Red roots tubers: ssd1 = 0.09; ssd5 = 0.12; leaves: ssd1 = 0.49; ssd5 = 0.67; Celery tubers: ssd1 = 0.36; ssd5 = 0.50; leaves: ssd1 = 0.36; ssd5 = 0.50

Levels of zinc and cadmium reached or even exceeded actual limits of Swiss legislation. We observed that the essential elements for plants (copper and zinc) are mainly concentrated in the generative parts (grain), whereas cadmium is mainly found in the vegetative parts (straw, leaves) of the plant. The cadmium content in red roots where ten time higher in comparison to triticale and fodder crops. Like Unwin (1996) we found on the other hand no strict correlation between the applied quantity of heavy metals by organic fertiliser and the crop metal content could be observed.

A lowering of the soil pH-value increased the solubility of the heavy metals in the soil so that in some cases plant uptake increased. The heavy metal of crops grown on unfertilised soils were increased because of increased soil pH values. In the view of the nutrient demand of plants and of the heavy metal accumulation in crops and soil an upper limit of three livestock units (LU = one 600 kg dairy cow producing 6000 kg of milk per year or ≈ 2.3 pig-places, eq. 315 kg Total-N and 45 Total-P per hectare) per hectare.

CONCLUSIONS

In case of high doses of pig slurry and sewage sludge the yields of some cultures decreased significantly and the heavy metal contents in soil and plants increased. Therefore the livestock unit (LU) per hectare (cattle, pig as well as poultry) have to be strongly limited. The LU should be restricted to a maximum of tree per hectare. For mountain area the corresponding values in Swiss legislation are regressively gradated to 1.1 LU/ha depending on the altitude.

In particular cadmium - a not essential element for plants – toxic for animals and humans – which is mainly found in vegetative parts of plants, without damaging these considerably it applies to consider for a sustainable agriculture. In condition that further generations can count on proper soil, it is absolutely necessary to limit and to decrease heavy metals in soil and in concerned fertilisers. Special attention should be given to the pH-values of soil (to correct by lime fertiliser where necessary) because crops grown on acid soil, also unfertilised ones, generally are enriched with heavy metals.

The challenges for a sustainable and environmental plant production are a well balanced fertilisation adjusted to the plant uptake, adaptation of the livestock units to available agricultural surface and an appropriate adaption of heavy metal limits in soil and in wastes within the corresponding legislation.

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ACKNOWLEGEMENTS

The authors wishes to thanks to Prof. Dr. Jacques Morel, assistant director and Olivier Félix, department head of Swiss Federal Office for Agriculture for theirs supports. Oskar Fankhauser for field work and sampling, Charlotte Dähler and Dr. Hans-Jörg Bachmann for sample analysis. Many thanks to Dr. Markus Hardegger and Maria Atkinson-Bernhard, Harrogate, UK for improving the English style of the manuscript.

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EFFECTIVENESS AND ENVIRONMENTAL IMPACT OF SWINE MANURE COMPOSTING

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Aims

The objectives of the composting trials were to test the effectiveness of a new prototype of turning machine, to make a qualitative evaluation of process and final product and to study the environmental impacts in term of gaseous emissions.

Methods

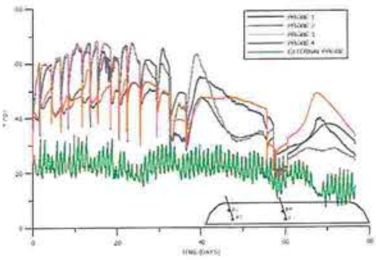
The parameters subject to monitoring were: process temperature, interstitial oxygen concentration, emission of noxious gases (CH_4, CO_2, NH_3, N_2O) and humification index. Other parameters, such as total and volatile solids, carbon and nitrogen, pH and microbial load were monitored but are not discussed in the present poster. Gas emission rates were evaluated before, immediately after and 1 hour after each turning through a closed chamber method.

Materials

The composting equipment is represented by a mechanical turning device, derived from the machines used for the extraction from silos of corn silage for animal feed. It features a front mill equipped with blades, characterized by a working width of 2.0 m, and an inclined elevator belt.
The feedstock was solid fraction of swine manure, which formed a windrow subject to turnings every 48 hours.

Temperature of the process

Temperature rapidly increased, reaching 60°C after 48 hours from windrow formation. The thermophilic phase proceeded for about 35 days, successively temperature slowly decreased. During the first phase, turnings had a positive effect on temperature increase and on compost aeration.

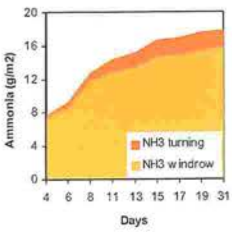


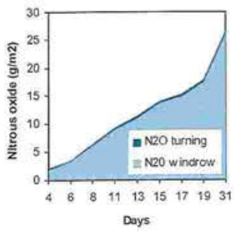
Humification Index

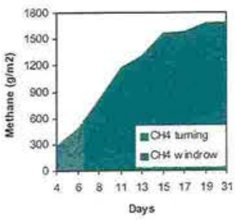
Humification index decreased from 0.75 to 0.50 during the thermophilic phase and settled below 0.30 at the end of the curing phase (75th day).

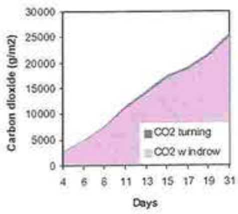
Gas emissions

CO_2 cumulative emission continuously increased during the process; however, emission rates during the first days were higher than those measured during the following weeks. CH_4 and NH_3 emissions had an increasing trend during the first 18 days of process, then emissions levels settled. N_2O emission continuously increased during the process, with the highest emission rates after the 18th day. Ammonia emissions during the turnings ranged from 0.14 to 0.25 g NH_3 h^{-1} m^{-2}; they were considerable higher than those measured during the days after turnings (0.01 – 0.07 g NH_3 h^{-1} m^{-2}). However, since the duration of emission peaks was extremely short, their contribution to the total emission was limited.









Conclusions

The turning equipment proved to be effective for composting the solid fraction of swine manure. The initial high moisture of the feedstock did not interfere with the correct evolution of the process and final compost had good qualitative characteristics.

Nitrogen lost in the form of ammonia and nitrous oxide amounted to about 3.4% of total nitrogen in starting material. Gas emissions measured during and immediately after the turning operations did not seem to give appreciable contribution to the overall emissions of the process. Methane emissions from the windrow were probably due to the establishment of anaerobic conditions in the windrow core. In fact, oxygen level in the core decreased below 1% of saturation 30 minutes after the first turnings. This suggests to perform more frequent turnings during the first days of process.

Aknowledgements

The present research was carried out in the frame of the National Project "Recycling of agricutural-industrial wastes" financed by the Italian Research Council and the Italian Ministry of University and Research (CNR-MIUR).

Composting as a management alternative for beef feedlot manure in southern Alberta, Canada

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Introduction

The County of Lethbridge in southern Alberta is one of the most concentrated feedlot regions in North America with a capacity of ~700,000 head, with some individual feedlots having >25,000 head.

Due to its high water content (~70% w/w), it is uneconomical to haul raw manure >15-20 km. Therefore, most manure is land-applied close to source at high application rates which is unsustainable in the long-term (Chang *et al.*, 1998; Chang and Entz, 1996; Hao and Chang, 2003).

Recently, composting has gained increased attention as a means of reducing the environmental impact of feedlot manure. At the Lethbridge Research Centre, composting research began in 1996 to answer some frequently asked questions on this manure management alternative.

Materials and methods

For experiments, manure was removed with a loader and truck from open feedlot pens and deposited in windrows (10 m long, 2.5 m wide, and 2 m high). Windrows were generally turned 7 times with a tractor-pull windrow turner over a 90 d period and then moved into curing piles for a further 90 d.

We have examined the effect of straw vs. wood chip bedding feedstocks on nutrient dynamics (N, C and P) during composting, and the effect of composting methods on GHG emissions (Hao *et al.*, 2001; 2004).

We have also looked at the fate of coliform bacteria (Larney *et al.*, 2003) and weed seeds (Larney and Blackshaw, 2003) during windrow composting.

Results

Despite winter air temperatures as low as -40 °C, windrow temperatures can be maintained at >60 °C. A drawback with summer composting is the loss of moisture from the windrow by evaporation. This necessitates the haulage of water to windrows which is an added expense.

We found that water mass loss with winter composting (44% of initial) was significantly lower than that for summer composting (83% of initial) [Larney *et al.*, 2000]. However, summer composting resulted in higher volume reduction (72% of initial) than winter composting (51% of initial) which resulted in lower haulage requirements for the finished compost.

For finished compost, available N as a percent of total N was significantly higher in wood chip-bedded material than straw-bedded in all 3 yr. Available N as a percent of total N varied from 4.6-6.3% for straw-bedded compost and from 6.8-11.0% for wood chip-bedded compost (Fig. 1).

In all three years, available N as a percent of total N decreased with composting. The sharpest decrease was for straw-bedded material in 1999, which fell from 43.7% of total N in the available form for raw manure to only 4.6% for compost (Fig. 1). The much lower levels of available N, compared to raw manure, should be taken into account when compost is used in cropping systems as a source of plant nutrients.

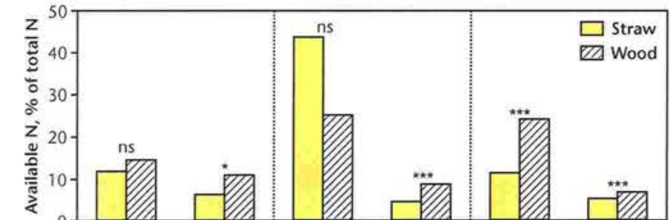

Figure 1. Effect of bedding type on available N as a % of total N for raw manure and finished compost, 1998-2000. Significant: *0.05; ***0.01% level; ns = non-significant.

For straw-bedded manure (average of three trials 1998-2000), total C concentration decreased with composting from 305 to 211 g kg^{-1}. Total N concentration decreased from 18.4 to 16.9 g kg^{-1}. In one study, nitrate-N increased from 6 to 550 mg kg^{-1} during active composting while ammonium-N decreased from 2270 to 500 mg kg^{-1}.

Unlike N, P is not lost during composting unless the windrows are subjected to runoff. Total P concentrations generally increase during composting, e.g. from a 3 yr average of 4 to 5.3 g kg^{-1}.

Greenhouse gas (GHG) emissions of CO_2, CH_4 and N_2O are associated with livestock and manure. Hao *et al.*, (2004) reported that most C was lost as CO_2 with CH_4 accounting for <6%. However, the net contribution to greenhouse gas emissions was greater for CH_4 since it is 21 times more effective at trapping heat than CO_2. N_2O emissions were 0.077-0.084 kg N Mg^{-1}, accounting for 1-6% of total N loss. Total GHG emissions, as CO_2-C equivalent during composting averaged 359 kg Mg^{-1}.

There was a rapid decline in *E. coli* levels in the first 7 d of composting (Fig. 2) with > 99.9% elimination (Larney *et al.*, 2003), even though windrow temperatures averaged 34-42°C which is lower than the recommended 55°C.

Land application of compost, with its non-detectable levels of *E. coli* compared to raw manure, should minimize environmental risk in areas of intensive livestock production.

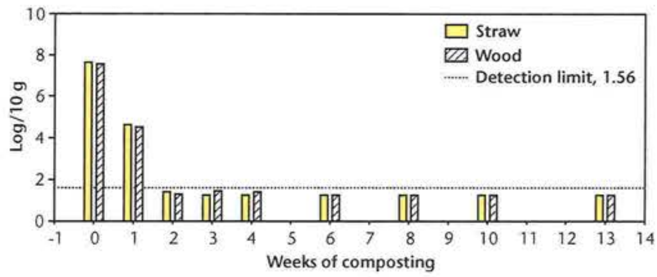

Figure 2. Effect of bedding on *E. coli* levels during composting.

Summary

Our results demonstrate beneficial effects of compost and composting for beef cattle feedlot manure in southern Alberta. The bottom line is that composting enables the export of nutrients from areas of high nutrient loading to soils which may be deficient in nutrients. This reduces the risk of environmental issues (water, soil and air quality degradation) in high nutrient loading areas and enhances soil quality in nutrient deficient areas.

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LRC©2004 Presented at the 11th International Conference of the FAO ESCORENA Network on Recycling of Agricultural, Municipal and Industrial Residues in Agriculture, October 6-9, 2004, Murcia, Spain

Shallow injection of slurry in open and closed slots on ley – technology, placement of slurry and ammonia emissions

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Conclusions

With appropriate tine design, slurry could be injected below the soil surface even in hard soil conditions with minimised ammonia emissions.

Methods

Slurry injector performance was validated in field experiments. Conventional slurry tankers with different types of injectors were used to shallow-inject (less than 0.05 m) slurry into open slots after the first cut, Fig. 1a-c. Slurry placement after spreading and ammonia volatilisation were measured. A 'tubulator' tine was developed for injection in closed slots (Fig 1d) and its performance was compared with an open slot injector.

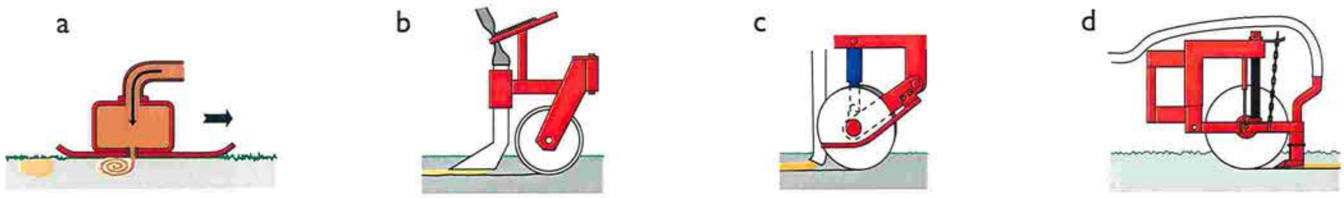

Fig. 1 a-d. Application methods used;
a: pressurised injection (PI);
b: shallow injection 1 with open slots; V-shaped disc tine (SIO1);
c: shallow injection 2 with open slots; tine consisting of two angled disc coulters (SIO2);
d: shallow injection in closed slots; tubulator tine.

Placement of slurry in soil

Open slot injection: Only the injector, with two angled disc coultes, could place the slurry below the soil surface level in all soils tested.
Closed slot injection: The tubulators placed the slurry below the soil surface in such a manner that, in most cases, no slurry was visible.

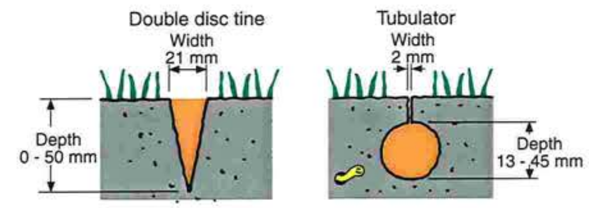

Fig. 2. Slurry placement into the soil after shallow injection in open and closed slots with a double disc tine and a tubulator tine, respectively.

Ammonia emissions

Figure 3 shows the ammonia losses after shallow injection and bandspreading, five experiments.

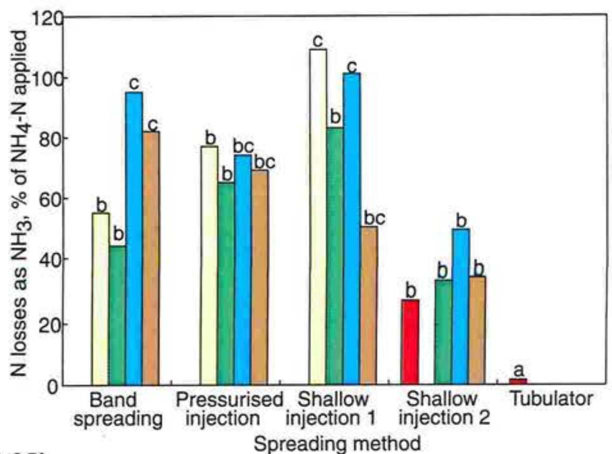

Fig. 3. Nitrogen losses as ammonia after spreading of cattle slurry with five different techniques from five different experiments

- Experiment 1
- Experiment 2
- Experiment 3
- Experiment 4
- Experiment 5

Means with different letters within each experiment are significantly different ($P < 0.05$).

Ramiran 2004, 11th International Conference – Murcia (Spain), 6-9 October 2004

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

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Introduction

Sludge is rich in nutrients such as nitrogen and phosphorous and contains valuable organic matter but tends to concentrate heavy metals and trace organic compounds present in wastewater.

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.

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

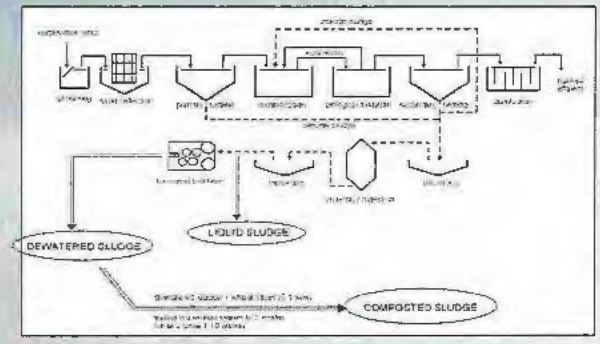

Figure 1. Layout of the municipal-industrial wastewater treatment plant and obtained sludge types.

Materials and methods

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 (120,000 population equivalent, see *Figure 1*). It has been applied every year in the autumn, prior to ploughing.

Sludge treatments include the factorial combination of the following:

- three types: liquid, dewatered and composted sludge (dewatered + wheat straw, 9:1 w/w respectively);
- two rates: 5 and 10 Mg DM ha^{-1} yr^{-1} (7.5 and 15 Mg DM ha^{-1} yr^{-1} until 1994).

Treatments have always been repeated on the same plots, with 12 randomised replicates.

All crop residues have been removed from the field, except sugar beet leaves.

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.

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 average)						
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	***	***

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 average)						
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	**

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

Table 1. Soil parameters in 2000, after 12 years of fertilisations.

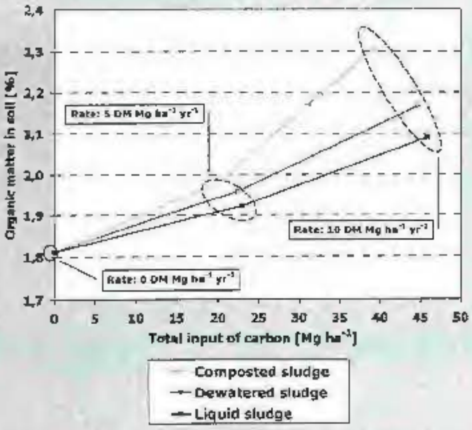

Figure 2. Effects of carbon input and sludge type on OM concentration in soil

Results

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 (*Table 1*). The composted sludge caused the most pronounced organic matter topsoil accumulation (*Figure 2*), thanks to its better organic matter quality. The increase of soil salinity was significant but slight. Significant accumulations of total zinc and copper were detected in amended topsoil. Apart from these essential elements, the toxic metals cadmium, chromium, nickel 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.

This field trial is going on and will focus on the risks of trace organic compounds accumulation in soil.

Research financed by the "Assessorate for Agriculture, Environment and Sustainable Development" of the Emilia-Romagna Region