Long term effects of excessive organic waste application.

Effets à long terme d'épandages excessifs de déchets organiques.

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Abstract

The change of soil properties, crop yields and crop contents from the last seven years of a field experiment, started in 1976, with high amounts of sewage sludge and pig slurry application (2 and 5 tons of organic matter per hectare and year) are discussed. Levels of zinc and cadmium reached or even exceeded actual limits of Swiss legislation. We observed that the essential elements (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. A lowering of the soil pH-value by a few tenths increased the solubility of the heavy metals in the soil.

Keywords : sewage sludge, pig slurry, long term field experiment, plant nutrition, heavy metals

Résumé

Les modifications des propriétés du sol, des rendements des cultures et de leur teneur au cours des sept dernières années d'un essai au champ débuté en 1976, avec apports excessifs de boues et de lisier de porc (2 à 5 tonnes de M.O. par ha et par an) sont discutés. Les niveaux de zinc et cadmium atteignent, voire dépassent, les valeurs seuils établies par la législation suisse. Les éléments essentiels (cuivre et zinc) sont principalement concentrés dans les grains alors que le cadmium s'accumule dans les parties végétatives (paille, feuille) des plantes. Une diminution du pH s'accompagne de l'augmentation de la solubilité des métaux traces dans le sol.

Mots-clés : boues, lisier porc, essais au champ longue durée, nutrition, cultures, métaux lourds.

1. Introduction

Sewage sludge and pig slurry of good quality are very valuable organic fertilizers. Because both contain a high amount of nitrogen and organic matter, they are potentially dangerous for water resources. Less is known about adverse long-term effects of metals in the soil on crop yield and metal uptake after excessive organic waste application.

The following paper shows the results obtained between 1991 and 1997 in a field trial with very high amounts of sewage sludge and pig slurry. The trial was installed in 1976 and is aimed at contributing towards a solution of the problems associated with the use of sludge and pig slurry.

2. Experimental design

2.1. Aims of the trial

The trial aims at clarifying the middle and long term effects of the application of large amounts of treated sewage sludge (SS) and pig slurry (PS) on

- the soil: physical, chemical and biological parameters;
- the plants in a crop rotation: yield, contents of nutrients and heavy metals

2.2. Methods of fertilizer application, crop rotation and soil cultivation

Two different quantities of sewage sludge and pig slurry were used, resulting in the following six different treatments :

- 0 = no fertilizer
- min = mineral standard fertilizing (N,P,K,Mg)
- SS2 = sewage sludge 2 t organic matter per hectare and year
- SS5 = sewage sludge 5 t organic matter per hectare and year
- PS2 = pig slurry 2 tons organic matter per hectare and year
- PS5 = pig slurry 5 tons organic matter per hectare and year

The amount of organic matter (OM), plant nutrients and heavy metals applied annually are shown in Table 1. The values represent the average amount over the 21 years of fertilizer application. The allowed zinc and copper contents of pig-feed as well as the mean contents of sewage sludges were lowered several times since 1976. Unwin (1996) suggested to estimate metal loadings to the soil from calculations based on the metal content of feedingstuffs or on analyses of slurry and manures.

Between 1976 and 1984 wheat, grass-clover and silage maize were cultivated in a simple 3-year rotation. In 1985, after 9 years, the trial was modified. Cabbage, celery and spinach were grown. Between 1988 and 1990 a silage maize period of three years followed. In 1991 the trial was started again with a prolonged crop rotation (Table 2).

Treatments	OM	N	P	K	Ca	Mg	Cu	Zn	Cd

1	0	0	0	0	0	0	0	-	-	-
2	min	0	140	45	220	69	57	**	**	**
3	SS2	2000*	200	130	250	365	81	1.7	6.9	0.014
4	SS5	5000*	400	350	250	980	98	4.4	18.6	0.039
5	PS2	2000*	320	95	240	160	52	0.6	2.7	0.002
6	PS5	5000*	800	260	430	450	83	1.8	7.9	0.006

* rounded values. ** not determined ; 0 = without fertilizing since 1976, min = mineral standard fertilization, SS = sewage sludge, PS = pig slurry.

Table 1
Amounts of organic matter (OM), plant nutrients and heavy metals of each fertilizing treatment (kg/ha, per annum).

Year	Culture
1991	sugar beet « KAWETINA »
1992	winter wheat « RAMOSA » / catch crop fodder
1993	potatoes « DESIREE »
1994	spring barley « MICHKA »/ grass-clover mixture
1995	grass-clover mixture « STM 200 MEDIA »
1996	silage maize « LG 11 » / winter triticale
1997	winter triticale « MERIDAL » / oats-vetch mixture

Table 2
Crop-rotation

Soil cultivation aimed at effective mechanical weeding for a clean seed bed, essential for the growing of a good crop. This was mainly achieved with a plough. In some instances, the plough was replaced by a rotary harrow. Great care was taken in the cultivation of the soil in order to avoid damages.

2.3. Trial plan

The trial was 12m wide and 104m long and divided into 6 parts (4m x 13m) for the six different treatments. Each treatment was repeated four times and chosen at random.

2.4. Soil properties

At the beginning of the trial, the soil was thoroughly analysed and classified with soil profiles. The following gives a short description of the trial field:

- location : Liebefeld, 3km south-west of Berne, on moraine deposits (alluvial plain), 564m above sea level;
- soil texture : sandy clay soil (medium heavy), slightly stony;
- soil type : poorly developed para-brown earth, pH-value approximately 6, humus content 3.5%

2.5. Climate

During the last seven years, the average temperature was 9.1°C with a mean maximum of 31.9°C and a mean minimum of -12.2°C. The annual average rainfall was 1036 mm and the annual average sunshine duration 1627 hours.

3. Results and discussion

3.1. Development of soil characteristics

Table 3 shows different soil characteristics for 1986 and 1994. 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. The pH-value on the plots with no fertilizer application decreased by 0.7 units from 6.0 to 5.3. With mineral standard fertilizing the pH-value decreased only slightly. On the other hand, the sewage sludge application clearly increased the pH-value by 0.1 to 0.8 units. However, pig slurry application significantly lowered the pH-value compared to the original situation in 1976.

An increase in the **organic carbon content** of the soil was observed in the treatment with 5t organic matter of sewage sludge (SS5). As shown by Mediavilla et al., 1995 this also had a positive effect on the porosity and bulk density of the soil.

A significant increase in the **phosphate** content was measured in the treatments with large amounts of pig slurry and sewage sludge. Apparently, the plants could not utilise all the supplied phosphate. Where large amounts of pig slurry were applied, the P-test value increased from 5-10 up to levels of 90 (standard range 8-16). Ecologically and from an agricultural point of view, such levels are undesirable. There is always a danger of phosphate losses when such high concentrations occur. The level of phosphate also increased slightly up to 20 in the mineral standard fertilizer treatment. The last revision of the Swiss fertilizing recommendations (Walther et al., 1994) took these results into consideration and suggested a reduction of recommended phosphate doses.

The **total copper** contents of soil at the beginning of the trial was between 10 to 30 ppm. During the trial period, these levels increased to 30 and 54 ppm at high application levels of pig slurry and sewage sludge respectively. The increase in the soil copper content was less significant with pig slurry than with sewage sludge application. The new Swiss guidelines prescribe an upper limit of 40 ppm (Swiss Federal Council (1998, in preparation): Ordinance Relating to Soil Impairments).

Concerning **total zinc** contents in the soil similar observations could be made. The initial amount detected was 40 to 60 ppm. High amounts of pig slurry increased the zinc contents only slightly. High sewage sludge applications, however, increased the levels to 150 ppm and more. The new allowed guideline level (150 ppm) is exceeded.

Average values for each treatment (0-20cm), <u>underlined</u> values exceed the guide values										
	pH (H_2O)	C org %	P-Test[1)]	K-Test[2)]	Cu		Zn		Cd	
					ppm total[3)]	ppb soluble[4)]	ppm total[3)]	ppb soluble[4)]	ppm total[3)]	ppb soluble[4)]
1986										

0	5.2	1.44	6.9	1.15	18.2	n.a.	47.7	n.a.	<0.250	n.a.
min	5.7	1.60	23.5	5.00	18.5	n.a.	48.4	n.a.	<0.250	n.a.
SS2	6.2	1.73	16.4	5.25	26.7	n.a.	94.4	n.a.	0.308	n.a.
SS5	6.4	2.01	20.7	4.10	36.9	n.a.	150.8	n.a.	0.698	n.a.
PS2	5.3	1.65	38.4	4.33	21.8	n.a.	57.8	n.a.	<0.250	n.a.
PS5	5.2	1.82	93.8	2.85	24.5	n.a.	68.3	n.a.	<0.250	n.a.
1994										
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	Cu		Zn		Cd	
	ppm total[3)]	ppb soluble[4)]	ppm total[3)]	ppb soluble[4)]	ppm total[3)]	ppb soluble[4)]
Ordinance Relating to Pollutants in Soil 1986.	50	700	200	500	0.8	30
Ordinance Relating to Soil Impairments 1998, (proposed)	40	700	150	500	0.8	20

[1)] P-Test value (Method: CO_2-saturated water, 1: 2.5): 8 - 16 sufficient, 16.1 - 32 reserve, >32 enriched
[2)] K-Test value (Method: CO_2-saturated water, 1 : 2.5): 2 - 4 sufficient, 4.1-8 reserve, >8 enriched
[3)]Total content: Extracted by nitric acid (2 M HNO_3), 1 : 10
[4)]Soluble content: Extracted by sodium nitrate (0.1 M $NaNO_3$), 1: 2.5
0 = without fertilizing since 1976; min = mineral standard fertilization, SS = sewage sludge; PS = pig slurry; n.a. = not analysed.

Table 3
Soil characteristics measured in 1986, 1990 and 1994 as well as Swiss guide values for heavy metals in soil.

The initial amounts of **total cadmium** found in the soil were 0.2 to 0.25 ppm. The level increased to 0.4 and 0.84 ppm in the sewage sludge treatments. Present and new guidelines allow a maximum cadmium level of 0.8 ppm. Pig slurry application did not increase the values.

In 1994 the **soluble heavy metal contents** in the soil were measured. In no treatment the copper content was higher than the allowed guideline level. For soluble zinc the guideline values were slightly exceeded in the mineral fertilizing treatment and clearly exceeded in the no fertilizing and pig slurry treatments. The amounts of soluble zinc and cadmium in the soil are strongly related to the soil pH-value. Therefore, the highest soluble contents of zinc and cadmium were found at low pH-values even if the total contents were low.

McGrath et al. (1995) from Rothamsted Experimental Station (UK) report that N_2-fixation by free living heterotrophic bacteria was inhibited at soil metal concentrations of (ppm): 127 Zn, 37 Cu and 3.4 Cd. It is concluded that prevention of adverse effects on soil microbial processes and ultimately soil fertility, should be a factor which influences soil protection legislation.

3.2. Crop yields

The yields of the unfertilised treatment (0) was lower then all the other treatments by a factor of two or more for all cultures except grass-clover mixture. Compared to the standard mineral fertilizing treatment sugar beet, winter wheat and potatoes reacted with statistically significant lower yields in some cases of high sewage sludge or pig slurry application. Probably these crops do not tolerate such high amounts of nitrogen. In contrast, high sewage sludge and pig slurry applications showed higher or equal yields for spring barley, grass-clover mixture, silage maize, triticale and oats vetch mixture. The high application of nitrogen and other nutrients was best tolerated by silage maize and grass-clover mixture. The adverse effect of high amounts of nitrogen in case of pig slurry application increased with the duration of the experiment.

3.3. Heavy metal contents of crops

The copper, zinc and cadmium contents of the harvested crops are shown in table 5. Compared to mineral standard fertilizing some of the crops grown on the treatments with sewage sludge or pig slurry showed statistically significant higher contents of **copper**.

Due to the relatively high amount of **zinc** found in sewage sludge and pig slurry (see table 1) the zinc content of the crops was significantly higher in comparison to the mineral fertilizer treatment. The highest zinc contents for most of the crops were found on the pig slurry treated plots. The significant decrease of soil pH-values in unfertilized and pig slurry treated plots obviously increased the solubility of zinc in the soil which was the reason for increased plant uptake.

High applications of organic fertilizer moderately influenced the **cadmium** content of crops. Often the highest cadmium contents were found in unfertilized plots. This is probably due to the combined effects of low pH, low organic matter content of the soil and reduced plant growth.

In agreement with Stadelmann and Frossard (1992) we found that in most cases the essential elements (copper and zinc) were concentrated in the generative parts of the plant (grain). On the other hand, cadmium was mainly found in the vegetative parts of the plant (straw of wheat and barley). When applied in excess, both organic fertilizers induce high heavy metal contents in the plants.

Cu (mg/kg dry matter)	**sugar beet 1991**		**winter wheat 1992**		**potatoes 1993**	**spring barley 1994**		**grass-clover mixture 1995**
	root	**leaves**	**grain**	**straw**	**tuber**	**grain**	**straw**	
0	5.18	10.8	4.75	2.23	6.59	9.20**	5.50	9.04*
min	5.06	8.7	4.50	2.03	6.76	6.67	4.30	7.99
SS2	5.66**	10.6	5.50*	1.90	5.48	7.35*	4.37	11.24**
SS5	6.25**	11.0	5.50*	1.93	6.55	7.62**	3.41	11.29**
PS2	4.90	9.6	5.50*	2.65	8.48**	7.09	4.09	8.15
PS5	4.87	9.3	7.25**	3.85*	10.15**	8.71**	5.09	10.69**

ssd5	0.43	2.5	0.98	1.37	0.61	0.61	1.40	0.94
ssd1	0.60	3.5	1.35	1.89	0.84	0.84	1.92	1.30

Zn (mg/kg dry matter)	**sugar beet 1991**		**winter wheat 1992**		**potatoes 1993**	**spring barley 1994**		**grass-clover mixture 1995**
	root	**leaves**	**grain**	**straw**	**tuber**	**grain**	**straw**	
0	42.8**	195**	47.5	18.6	19.6	49.5**	29.2**	50.0*
min	31.8	100	42.5	12.5	18.4	38.3	15.8	43.8
SS2	49.1**	233**	53.8**	26.3**	17.1	47.5**	23.2*	58.0**
SS5	35.9	156*	50.3*	13.7	15.7	46.3*	18.4	52.9**
PS2	53.3**	185**	64.5**	35.9**	22.7**	55.3**	29.7**	57.5**
PS5	65.8**	220**	73.0**	67.5**	33.5**	76.7**	50.1**	65.6**
ssd5	7.5	55.1	6.0	9.8	2.7	6.3	6.4	5.8
ssd1	10.3	75.7	8.3	13.5	3.7	8.7	8.8	8.0

Cd (mg/t dry matter)	**sugar beet 1991**		**winter wheat 1992**		**potatoes 1993**	**spring barley 1994**		**grass-clover mixture 1995**
	root	**leaves**	**grain**	**straw**	**tuber**	**grain**	**straw**	
0	315**	1097**	74.9**	143	190.3**	53.1	138.3**	109.2**
min	228	535	51.6	117	94.9	46.8	73.4	86.3
SS2	190	539	67.0*	142	70.8	41.4	52.1	86.1
SS5	161	423	84.6**	120	51.2	46.7	49.2	76.2
PS2	263	643	70.7*	204**	60.1	49.5	83.6	84.6
PS5	243	560	72.7**	234**	59.5	58.2**	92.2	62.9
ssd5	41.1	132	14.1	28.5	32.5	7.9	19.0	11.7
ssd1	66.5	182	19.3	39.1	44.7	10.9	26.2	16.1

(0 = no fertilizer, min = mineral standard fertilizing, SS2 / 5 = sewage sludge 2 / 5 t organic matter per hectare and year, PS2 / 5 = pig slurry 2 / 5 tons organic matter per hectare and year)

Table 5
Contents of copper, zinc and cadmium detected of crops

Note: *ssd5 = smallest significant difference, means followed by one star (*) are significantly different from mineral standard fertilizing treatment at P = 0.05; ** ssd1 = smallest significant difference at P = 0.01; n = 4.

4. Conclusion

The main conclusions are the following :

4.1. No fertilizing and application of high amounts of pig slurry decreased the pH-values of the soil. The nutrient contents in the soil, especially phosphate, increased considerably through the application of high amounts of organic fertilizers.

4.2. Large amounts of organic fertilizers, mainly pig slurry, significantly decreased the yield of several crops probably due to nitrogen surplus.

4.3. Crops grown on unfertilized and pig slurry treated acid soils are mostly enriched with heavy metals. Compared to mineral standard fertilization crops grown

on sewage sludge treated soils often show significantly increased heavy metal contents, especially zinc. A well-balanced fertilization adjusted to the plant nutrient uptake is the best guarantee for an harmonised crop content.

4.4. For a sustainable plant production, livestock density (pigs included) should be strictly adapted to the surface of agricultural land. A limit of three livestock units per hectare seems to be too high from an ecological and an agricultural point of view (increased soluble zinc content in the soil, partly increased contents of copper, zinc and cadmium in crops in treatment PS2).

4.5. To keep soils clean for future generations it is absolutely necessary to lower heavy metal limits in soils, sewage sludges and animal feedingstuffs. A first step in this direction was taken in Switzerland by the revision of the guide values for soils in 1998.

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