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ALTERED PROPERTIES OF LIGHT SOILS IMPROVED WITH LIME-TREATED SEWAGE SLUDGE OR ITS MIXTURE WITH SUGAR BEET FLUME WASHING EARTH AND STRAW ASH

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ABSTRACT

In a 3-year pot experiment changes in selected properties of acid light loamy sand induced by lime-treated sewage sludge (LS) admixture were studied. Single LS admixtures were applied in the following doses: 2% and 5% that corresponds to 56 and 140 $Mg \cdot ha^{-1}$, respectively; the same amounts were mixed with sugar-beet flume washing earth from a sugar plant sediment tanks (for a 10% dose it corresponds to 280 $Mg \cdot ha^{-1}$) and ash from a straw-fired boiler (corresponding to 0.9 $Mg \cdot ha^{-1}$). The results were compared to a control sample (0 – soil only) and to a standard mineral NPK fertilisation for maize.

Lime-treated sewage sludge strongly reduced soil acidity, increased the total of exchangeable cations, and therefore the capacity of a sorptive complex. It also enriched the soil in organic matter and available forms of P, K, and Mg. LS effect was most frequently proportional to the applied dose. 3 years after the treatment N and P content in the soil fertilised with single sewage sludge dose remained still much higher than in the soil annually fertilised with NPK; the content of K was found similar.

Combined admixture of sugar-beet flume washing earth and ash from straw-fired boiler with sewage sludge raised its land reclamation value since it slowed down mineralisation processes of organic matter, stabilised soil reaction and improved the quality of soil sorptive complex.

Key words: agricultural utilisation of sewage sludge, lime treated sewage sludge, sugar-beet washing earth from a sugar plant sediment tanks, sugar plant flumes, ash from straw-fired boiler.

INTRODUCTION

For the few last decades the problem of agricultural utilisation and management of sewage sludge has focused a live interest and gained much attention. Among the variety of studied materials hard to utilise sludge have been also found. Their high fertilisation value, capacity for improving soil physical properties and rebuilding organic matter have been proved, though on the other hand, they may provide a heavy metal source and pose health hazard [1,9,17].

In Poland only sludge that meet specific requirements and is processed accordingly [16,22] is allowed for agricultural use. A special technology to stabilise sludge, in which preliminary dehydrated sludge is mixed together with lime, hydrated lime or quicklime, or with other alkaline materials such as fly ash or cement klin dust. The heat created in the process facilitates further sludge dehydration and supported by an increased pH (up to 12) it reduce pathogens. The described technology is in Poland relatively new, and is called, in relation to the lime dose applied per 1 kg d.m. of sludge, either hygienisation or stabilisation, for CaO dose ranges 0.15-0.25 kg and 0.5-1.2 kg, respectively.

Sludge processed that way can be applied as manure, or when dried and granulated it can be sown directly onto the fields. It does not require lagoon storage, therefore nutrient losses and environmental nuisance are prevented. Moreover, its heavy metals contents represents much lower phytoavailability than in a digested sludge [3], and the elements movement into the soil profile in a smaller degree [5].

For that reason from the beginning of 80-ies such sludge have been extensively used in the western countries not only for fertilisation purposes but also for soil liming [8]. According to Willett et al. [20] both soil neutralisation and improvement in chemical and physical parameters of soils induced by sludge that underwent such a treatment are quicker, more effective and last longer than induced by an agricultural lime. Such affluence is maintained even for significant overdoses when compared to typical agronomic rates [5,8,19]. Their favourable influence on soils originates from their great buffer properties disclosed due to the presence of functional groups in organic compounds that are capable of binding aluminium from acid soils and turn it into a non-toxic to plants [18]. In addition Brown et al. [5] have observed that, unlike $CaCO_3$, the processed sludge raised pH not only more effectively but it also went more in-depth, since the effect was not limited to the surface horizons of the soil profile, i.e. to the depth of 20-30 cm, but was detected also in subsoil. The effect has been most likely attributed to the action of created hydrophilic low-particle complex compounds of organic acids whose Ca can easily migrate into the soil profile. Such mechanism seems very likely due to significant content of fulvic and phenol acids in the lime-treated sewage sludge [14,15]. Hence, their favourable presence on acid and highly acid soils where digested sludge cannot be applied seems plausible. In addition, the results presented by Little et al. [7] proved admissible doses of limed sludge to be twice higher that the rate calculated for liming needs and without running the risk of crops reduction observed for similar doses of applied agricultural lime.

It should be remembered, however, that lime-treated sewage sludge is abundant in easily oxidable carbon which tends to mineralise when introducing sludge into the soil [18], especially if the soil is light, deprived of clay fractions. Thus, it seems reasonable to combine sewage sludge with waste having a high small particle fraction, like waste from sugar beet flumes, so called sugar-beet washing earth, which despite widely ranging properties and size grading (from silt to silty loam), displays high fertilisation capacities and its trace element content does not exceed natural limits [4,10-12]. Typical for sludge potassium deficiency can be compensated by adding another waste element, namely ash from straw-fired boiler. As we see, combining various material with sludge can result in its increased usability on one hand, and provide a variety of opportunities for various waste utilisation in agriculture on the other. The presented paper is an attempt to asses agricultural usability of limed sewage sludge applied in extensive doses both alone and in combination with sugar flume washing earth or straw ash.

METHODOLOGY

The results presented below comprise part of studies carried out at Lublin Agricultural University, Institute of Agricultural Sciences in Zamość, as a multifactor pot experiment performed between 1996 and 1998. The studies were founded from the proceeds of Natural Environment Protection and Water Management, Voivodship

Zamość department. It was conducted in polyethylene pots filled with 8 kg d.m. of control soil with size grading typical for light loamy sand. The control soil had a defective sorptive complex, it was acid, humus, nitrogen, potassium, and magnesium deficient but rich in available phosphorus. The control was fertilised once with two doses of sewage sludge hygienised with quicklime and the same doses supplied with sugar-beet washing earth (sludge from factory sugar beet flumes) and ash from straw-fired boiler. To compare agricultural worth of the studied material to annual fertilisation results, an NPK pattern typical for the tested plant was also applied. The sole application of sugar beet washing earth and straw ash was also studied, but due to their greater efficiency as factors enhancing sewage sludge, only the related results were included into the further considerations, which comprises therefore the following six combinations:

- control sample - soil, no addition applied, denoted as **0**,
- annual, fertilised with minerals, **NPK**,
- soil plus 2% of sewage sludge, an equivalent of 56 Mg d.m.$\cdot$ha^{-1}, **2% LS**,
- soil plus 5% of sewage sludge, an equivalent of 140 Mg d.m.$\cdot$ha^{-1}, **5% LS**,
- soil supplied with 2% of sewage sludge and sugar-beet washing earth in the amount of 10% sewage sludge, i.e. an equivalent of 280 Mg d.m.$\cdot$ha^{-1} + straw ash from a burning oven - 2.5 g/pot, equivalent to 0.9 Mg d.m.$\cdot$ha^{-1}, (**2% LS + W**), w here w stands for waste,
- soil plus 5% of sewage sludge and sugar beet washing earth mixed with straw ash in the amount as above, (**5% LS + W**).

Limed sewage sludge was produced in a new, mechanical and biological sewage treatment plant in Zamość and met all the requirements specified for waste meant to be utilised in agriculture [16]. According to the treatment plant representative, the parameters of the applied sewage sludge remain under systematic control and have not deteriorated by now, so 13 thousand Mg are being distributed onto the fields annually. Washing earth was collected in Werbkowice sugar beet factory (Lubelskie Voivodship) in a dose determined as suggested elsewhere by Reszel et al. [12,13], where the dose has been determined as optimal with regards to both the cost of its application and fertilisation value of the waste. Straw ash measure was based on a typical amount that is produced in a standard farmstead utilising an average of 8-12 Mg of straw within one heating season. Properties of the soil and other materials are summarised in Table 1.

Table 1. Properties of the experimental material

Parameter		Control soil	Lime-treated sewage sludge	Sugar-beet flume washing earth	Ash from straw-fired boiler
Dry matter, %		95	25	70	98
Organic carbon, g kg^{-1}		6	250	15	ND
$CaCO_3$, g kg^{-1}		<10	90	17	ND
pH in 1M KCl		5.1	9.0	7.4	ND
Total N, g kg^{-1}		0.5	35.3	1.5	2.7
Total P, g kg^{-1}		0.4	15.8	0.4	9.6
Total K, g kg^{-1}		3.8	3.0	3.8	66.1
Total Mg, g kg^{-1}		1.2	5.1	1.3	6.2
Total Ca, g kg^{-1}		5.0	68.1	3.9	20.1
Particle-size distribution, %	1-0.1 mm	66	ND	1	ND
	0.1-0.02 mm	21	ND	63	ND
	<0.02 mm	13	ND	36	ND

ND – not determined

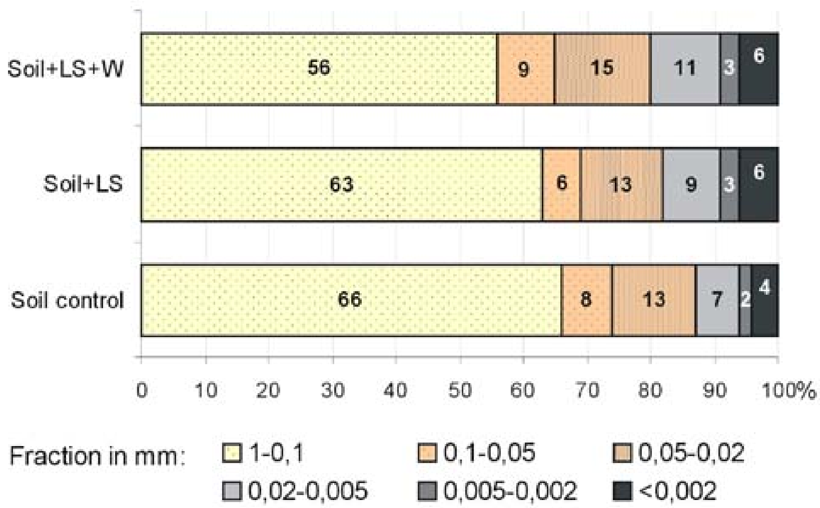
Once waste was mixed into the soil, in the early spring of 1996, the mixture properties were determined by means of relevant methods, namely, particle-size analysis with Cassagrande's method modified by Prószyński, sorptive capacity by hydrolytic acidity measurements by Kappen's method, alkaline cations after extracting 1 M NH_4Cl of pH equal to 7.0; Mg^{2+} and Ca^{2+} concentrations were determined with AAS, while K^+ and Na^+ by means of flame photometry; and organic carbon content according to Tiurin's method; the latter analysis was also carried out after the experiment, in autumn 1998. Each year, at the beginning of the vegetation season and also at the end of the 3-year experiment, the following features were determined: pH in 1 M KCl, total N content (Kiejdahl's method), available forms of P, K (Egner-Riehm's method) and Mg (Schachtschabel's method).

Mono-cultivated maize for green forage served as a tested plant; it was protected from rainfall and watered solely with deionised water. The results of the experiment, performed in 3 independent series, were subjected to variation analysis; the least significant differences (LSD) were calculated with error risk not higher than 5%.

RESULTS AND DISCUSSION

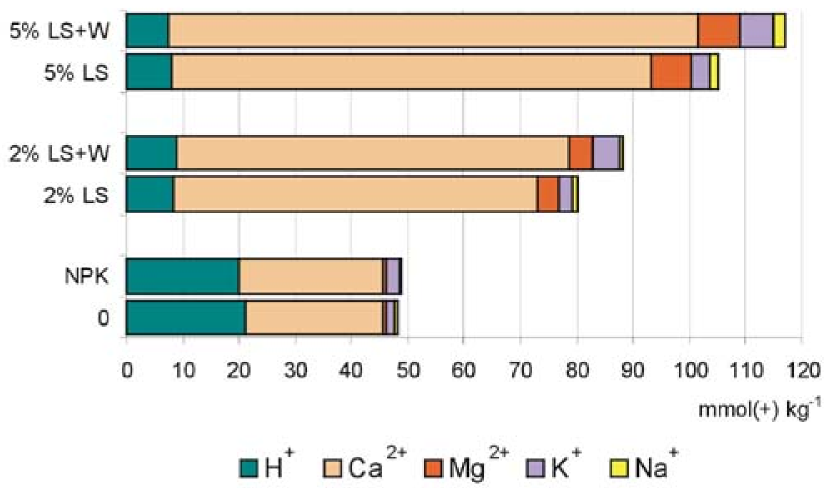
Though the admixture of sewage sludge increased clay particles content in soil with relation to sand and silt fraction (Fig.1), it did not significantly alter the size grading; it was also observed by Sloan et al. [19] in their studies. Admixture of the remaining waste led to further reduction of sand fraction and associated increase of both silt and clay fractions. Nevertheless, despite all the modifications the agronomic soil taxonomy remained unchanged, i.e. the soil stayed light with up to 20% clay fraction. The result seems plausible in the light of Logan's and Harrison's research [8] in which they examined 28 sewage sludge samples stabilised with various alkaline materials (N-Viro Soils) and observed that they contained few particles of size smaller than <0.1 mm, on average less than 7% of the <2 mm fraction, and less than 1% of <0.05 mm fraction. The trend observed after adding sugar beet washing earth of silt loam composition to the soil (see, Table 1) was also found predictable.

Fig. 1. Observed changes in size grading for soil after sewage sludge introduction and its mixture with sugar beet washing earth and straw ash, 1996 (average values, unrelated to the applied dose)



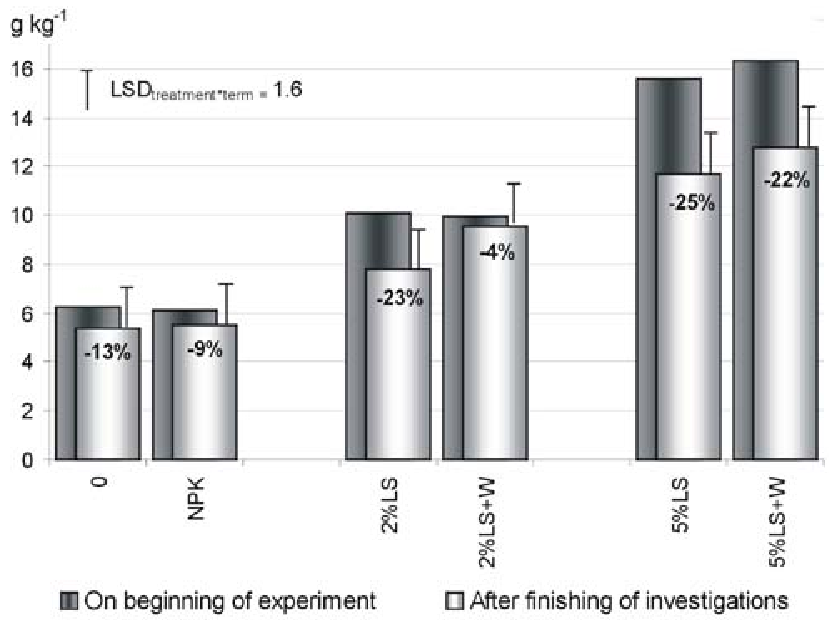
Both doses of sewage sludge reduced soil hydrolytic acidity to a similar level, i.e. by an average 60% in relation to the control, and proportionally to the applied amount they increased alkaline exchangeable cations concentration in soil, hence the soil sorptive capacity (Fig.2). An important role played in this case the content of organic matter in the sludge, which was confirmed by a positive correlation between sorptive capacity and the organic carbon content in the soil ($r=0.90$, $p<0.001$). Under the influence of sewage sludge the sorptive complex of the control soil, far from ideal at the beginning, was improved; the smaller dose led to narrowing the miliequivalent Ca^{2+} to Mg^{2+} ratio from 41 to 17, while for the higher one the ratio reached 12, nearing the optimal value. Apparently, soil deacidification induced by sewage sludge application proved more beneficial than application of agricultural calcium, which deteriorates the ratio in question [6]. Due to introduction of sugar beet washing earth combined with straw ash, not only sorptive capacity of the substrate increased, but also the amount of exchange cations of Ca^{2+} and Mg^{2+}, as well as K^{+} for which the effect was the most pronounced. The observed increment in K^{+} concentration induced by sewage sludge admixture reached 96% and 62%, for the smaller and higher doses, respectively. It should be noted here that too wide exchange cations Ca^{2+} to K^{+} ratio for the soil fertilised with sewage sludge only was reduced from 27 to 14, and from 24 to 16 after introducing sludge-other waste mixture for the smaller and higher dose, respectively. All the factors then, show advantageous character of fertilisation with different waste mixed together.

Fig. 2. Size and quality of the soil sorptive complex influenced by the studied waste admixture, 1996



The increment in organic carbon content resulted mainly from sewage sludge admixture into the soil, especially for the higher dose (Fig.3). Admixture of straw ash and sugar-beet washing earth despite giving in significant rise in organic-C, also proved advantageous because it notably reduced decomposition of organic matter introduced with the smaller dose, though the effect was less pronounced for the higher one. As it was demonstrated in the previous paper [15], the processes undergone in the period of merely 3 years by organic matter originating from the sewage sludge introduced into soil, lead to humus development. It can be deduced from the improved carbon to nitrogen ratio, lowered value of E_4/E_6 ratio for humic acids, reduction in the mobile forms fractions such as fulvic acids and low-molecular weight carbon compounds soluble in 0.05 M H_2SO_4 which is accompanied by a simultaneous growth of stable structures [15].

Fig. 3. Organic carbon content changes after the end of the experiment in relation to the initial state



Similarly to other authors [5,7,18-20], an increase in pH of the soil proportional to the applied admixture dose of limed sewage sludge was observed (Table 2). An improvement in the soil pH, neutral and alkaline for smaller and higher dose, respectively, proved nearly stable over the period of 3 years since only a slight change was observed at the end of the experiment, while for both the control and fertilised annually with NPK soils, pH decreased significantly. The remaining waste, despite lack of their further influence upon the changes induced by sewage sludge admixture, over the 3 years period tended to stabilise soil reaction. Namely, together with the higher sewage sludge dose they maintained stable pH, while with 2% dose they caused pH to grow slightly after finishing the experiment.

Table 2. Reaction and abundance of substrates at the beginning (1996) and after finishing (1998) the experiment

Treatment	Total N g kg^{-1} of soil			pH in 1M KCl			Available, mg·kg^{-1} of soil								
							P			K			Mg		
	1996	1998	mean	1996	1998	mean	1996	1998	mean	1996	1998	mean	1996	1998	mean
0	0.54	0.40	0.47	5.1	4.7	4.9	69	51	60	47	10	28	5	3	4
NPK	0.54	0.46	0.50	5.4	4.7	5.1	84	55	69	82	21	51	3	4	3
2% LS	1.16	0.78	0.97	7.1	7.0	7.1	285	192	238	78	21	49	25	7	16
2% LS + W	1.12	0.88	1.00	7.0	7.3	7.2	233	177	205	143	28	86	37	8	23
5% LS	1.71	1.26	1.49	7.3	7.2	7.2	536	438	487	110	23	57	48	28	38
5% LS+ W	1.86	1.32	1.59	7.3	7.3	7.3	587	373	480	192	22	107	65	12	38
mean	1.16	0.85		6.5	6.4		299	214		109	21		30	10	
LSD for:															
treatment	0.11			0.2			40			8			4		
term	0.06			0.1			23			4			2		
treatment by term	0.16			0.3			57			11			5		
				reaction [22]:			content [22]:								
				acid	neutral		very low	low		medium		high		very high	
				alkaline											

Sewage sludge also turned out to be a very good source of basic macroelements, since their abundance (see Table 1). The overall N content in the soil, as well as available P and Mg forms, and K content, though in a smaller degree, raised proportionally to the applied dose of the sludge. Washing earth and straw ash mixed together with the lower dose initially even lowered N and P levels in comparison to the sewage sludge applied solely (the differences, however, fell safely within the statistical error margin) but it definitely enhanced the effect of the higher dose (Table 2). Nevertheless, regardless the applied dose, the levels of available K and Mg in the soil were distinctly increased. It is obvious that after 3 years of maize cultivation the content of the analysed elements in the pots has been significantly lowered, but still in the combinations with the sewage sludge, applied both solely and together with the remaining waste, concentrations for N and P stayed orders of magnitude higher than in the soil fertilised annually with mineral fertilisers. Similarly, higher content of available Mg was noted, especially for the 5% dose. It should be underlined that the effect occurred despite the heaviest nutritional elements absorption from soil.

CONCLUSIONS

1. High doses of lime treated sewage sludge, in the amount of 56 and 140 Mg d.m.·ha^{-1}, introduced into a light soil of acid reaction once only, induce efficient soil deacidification, improves soil sorptive properties, provides significant amount of organic matter and distinctly enhances the soil in nutrient elements much more effectively than standard mineral fertilisation.
2. Combined application of sewage sludge together with sugar beet washing earth and straw ash utilised as an energy source, enhances sewage sludge value land reclamation by slowing down organic matter decomposition, stabilising the reaction and quality of the soil sorptive complex.
3. Substrates to which waste was applied displayed high N and P content even after 3 year maize cultivation, hence the influence can be prolonged by supplying additional doses of K and Mg.
4. Agricultural management of limed sewage sludge and its mixtures with other waste is recommended not only for the waste management reasons, but also due to opportunity it provides for natural recycling the elements absorbed from soil, and therefore limiting mineral fertilisation. The subject requires further studies to determine the right components and optimal doses for both specific soils and cultivated plants.

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