The influence of organic fertilizers application on phosphorus and potassium bioavailability

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ABSTRACT

A prerequisite to use organic fertilizers in a sustainable way is to quantify the amount of phosphorus and potassium available for plants that could be taken up by a crop. The objective of this study was to evaluate direct and subsequent influence of organic fertilizers addition (poultry manure and two types of composts) on the changes of bioavailability of phosphorus and potassium in soil and their accumulation in the aboveground oat biomass (*Avena sativa* L.) during three years. The available phosphorus and potassium contents in soil had a degressive trend during the years of experiment. The lowest contents of these elements in soil were found in all treatments in the last year of the experiment. The plants took up the least P and K after application of compost derived from predominant sewage sludge portion. A stronger correlation ($R = 0.88$; $P < 0.05$) was found between available content of K in soil treated with organic fertilizers and K content in the aboveground biomass of oat than in the case of P ($R = 0.45$; $P < 0.05$).

Keywords: organic fertilizers; compost; poultry manure; soil; phosphorus; potassium; oat; uptake

Organic waste can be a valuable and inexpensive fertilizer and source of plant nutrients. Positive effects of organic waste on soil were reported in several studies (Jedidi et al. 2004, Odlare et al. 2007). Information on the availability of phosphorus and potassium following compost addition to soil may help to a better management of P and K fertilization of the crop in respect to plant growth and environment protection (Scherer 2004). The effect of composting on phosphorus availability is not very clear. Several studies (Courtney and Mullen 2007, Gil et al. 2007) suggest that organic sources of P are more effective for plant absorption than inorganic ones. Phosphorus availability from all animal excrements and manures is high (> 70%). Adding of high soluble P quantities brings the soil to saturated stage and a part of the added P remains in the available form and can be leached easily (Kleinman et al. 2000). Mineral K is available for uptake by plants and for exchange and fixation on the secondary clay minerals, and leaching (Mengel and Kirkby 1978). Therefore, the concentration of K in the compost and the governing reactions in soil determine the quantity of compost required to meet K demand by the crop.

This work has a twofold aim: to evaluate direct and subsequent influence of poultry manure and composts addition on the changes of bioavailability of phosphorus and potassium in soil, and to observe the accumulation of these elements in the aboveground oat biomass during three years.

MATERIAL AND METHODS

The bioavailability and uptake of the elements were investigated in a pot experiment with Luvisol (pH/KCl = 6.4, C_{org} = 1.71%, 139 mg available P/kg, 225 mg available K/kg) amended with organic fertilizers (poultry manure, compost I and compost II).

Compost I contained sewage sludge, wheat straw and poultry manure. Compost II was based on greenwaste biomass; its composition is shown in Table 1. The contents of important elements in composts and in their components are listed in Table 2.

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Table 1. Weight portion of feedstock in raw compost (in % dm)

Compost I	(%)	Compost II	(%)
Sewage sludge	52	wood chips	25–30
Poultry manure	21	grass	25–30
Straw	27	leaves	10–27
		vegetable waste	10–20
		tobacco	4–8

Table 2. The total contents of chosen elements in composts and in their components in dry matter (%)

Sample	N	P	K
Poultry manure	5.48	1.19	1.82
Straw	1.29	0.15	1.20
Sewage sludge	3.51	2.39	0.54
Compost I	3.00	1.85	1.29
Compost II	2.33	0.56	2.84

Soil was air-dried and passed through a 5 mm sieve, and 5 kg of soil (based on dry weight) was thoroughly mixed with organic materials and fertilized with major nutrients in the form of NH_4NO_3, K_2HPO_4, KCl and H_3PO_4 in the first year of the experiment. The amount of nutrients was set up according to the ratio of N, P, K in applied fertilizers and was calculated as the rate of 0.3 g N/kg of soil. The rate of P and K was set according to their highest amount in individual organic fertilizers and mineral nutrients were added to equilibrate the amount in all treatments (Table 3). Prepared soil with mixture of organic materials was placed into plastic pots and sown with oat (*Avena sativa* L. cv. Zlatak). Treatments were set up in four replications. After emergence, oat plants were thinned, 20 of them were left per pot and grown up to harvest. Soil moisture was regularly controlled and kept at 60% of its maximum water holding capacity. After harvest of oat, soil samples were taken and the soil was left in pots slowly air-drying, stored and used again in second and third years of experiment. Only nitrogen at the rate of 0.75 g as NH_4NO_3 was added into each pot in following years.

The amount of available portion of P and K in soil after harvest was determined in the extract of Mehlich III (Mehlich 1984). Plant material was decomposed by modified dry ashing procedure as follows: an aliquot (~1 g) of the dried and powdered aboveground biomass was weighed to 1 mg into a borosilicate glass test-tube and decomposed in a mixture of oxidizing gases (O_2 + O_3 + NO_x) at 400°C for 10 h in Dry Mode Mineralizer Apion (Tessek, Czech Republic). The ash was dissolved in 20 ml of 1.5% HNO_3 (electronic grade purity, Analytika Ltd., Czech Republic) and kept in glass tubes until the analysis (Miholová et al. 1993).

Contents of phosphorus in soil extracts was determined colorimetrically using the SKALAR SAN^{PLUS} SYSTEM and in plant digests by inductively coupled plasma optical emission spectrometry with axial plasma configuration (ICP-OES, VARIAN VistaPro, Varian, Australia). Potassium contents in both soil extracts and plant digests were determined by flame atomic absorption spectrometry (F-AAS, VARIAN SpectrAA-300). A quality of plant analyses was assessed by certified reference materials RM 12-02-03 Lucerne.

Data were evaluated by one-way ANOVA. Tukey's test was used for comparison of means and statistical significance of hypotheses was assessed at $\alpha < 0.05$. All statistical analyses were performed using Statgraphics programme, version 5.1 (Manugistics 1997).

RESULTS AND DISCUSSION

Lower yield of dry oat biomass was achieved after the application of organic fertilizers in the first

Table 3. The input of nutrients in organic and mineral forms into soil of the pot experiment (g/pot)

Treatment	N		P		K	
	organic	mineral	organic	mineral	organic	mineral
NPK	0.0	1.5	0.00	0.92	0.00	1.82
Poultry manure	1.5	0.0	0.33	0.60	0.50	1.32
Compost I	1.5	0.0	0.92	0.00	0.65	1.17
Compost II	1.5	0.0	0.36	0.56	1.82	0.00

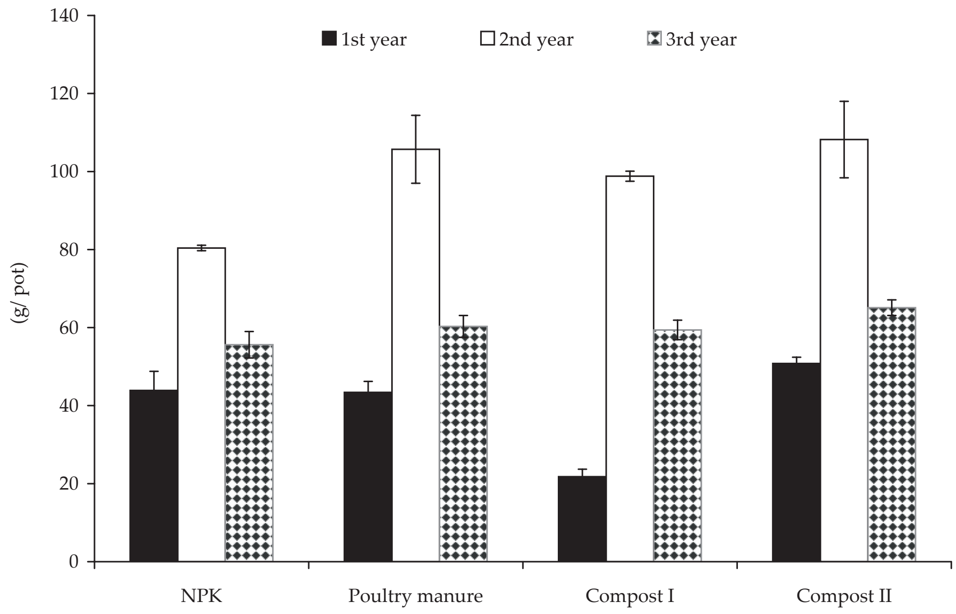

Figure 1. The yields of dry oat biomass within a three-year period (g/pot)

year of the experiment (Figure 1). It is consistent with the results obtained in the study of Leroy et al. (2007) who found clear yield depression of maize on plots amended with compost at the beginning of a 7-year experiment in contrast to an upward trend in the last application years, proving a significant residual N effect from cumulative compost application. The yield after compost II application was 2.3 times higher compared to compost I in our experiment and the difference was significant. Bazzoffi et al. (1998) found that urban refuse compost produced a lower maize grain yield than mineral fertilization; similarly, Businelli et al. (1990) observed a decrease of maize yield with compost application compared to mineral fertilization. The highest yield of dry oat biomass was achieved in the second year. There are several explanations for this finding. The soil in every pot was fertilized with 0.75 g of nitrogen and the amount of released nutrients from organic fertilizers was increased; moreover, root debris decomposed during vegetation contributed to higher yields. Organic fertilizers increased the yield significantly in this year compared to mineral fertilizers. Next year the yields decreased on 60 g per pot and were steady among the treatments. The lowest yield of oat biomass was found in mineral NPK treatment again. Gil et al. (2007) found that grain yield of maize after compost application did not decrease in relation to conventional fertilization.

Available soil phosphorus content was decreasing during three years of studies (Figure 2). The values determined at NPK and poultry manure treatments were almost the same. The phosphorus content in soil fertilized with compost I and compost II was lower compared to mineral NPK treatment. Warman and Termeer (2005) compared organic and conventional fertilizers in two years of field experiment. They found that nutrient availability from the organic amendments (especially N and P) was considerably lower than 50% at the end compared to beginning of the experiment. The sludges, however, provided higher nutrient availability than the compost. Gil et al. (2007) accomplished a comparison of the effect of compost plus mineral with conventional mineral fertilization. The available P concentration in soil significantly increased to the same extent with both treatments after one year. Cooperband et al. (2002) assessed phosphorus value of different-age poultry litter composts and raw poultry litter. Available soil P was the highest in plots amended with 15-month old compost, followed by raw poultry litter amended plots. Immature composts immobilized soil P in the first year of study. In our experiment, phosphorus content did not increase after application of compost I containing sewage sludge with high phosphorus content. Zhang et al. (2006) conducted a four-year experiment testing the influence of compost which was applied to less productive soil only in the first year. They found that the release of phosphorus from compost was steady throughout the duration of whole experiment. In our experiment, the lowest content of phosphorus was measured in soils treated with compost II. It was lower by

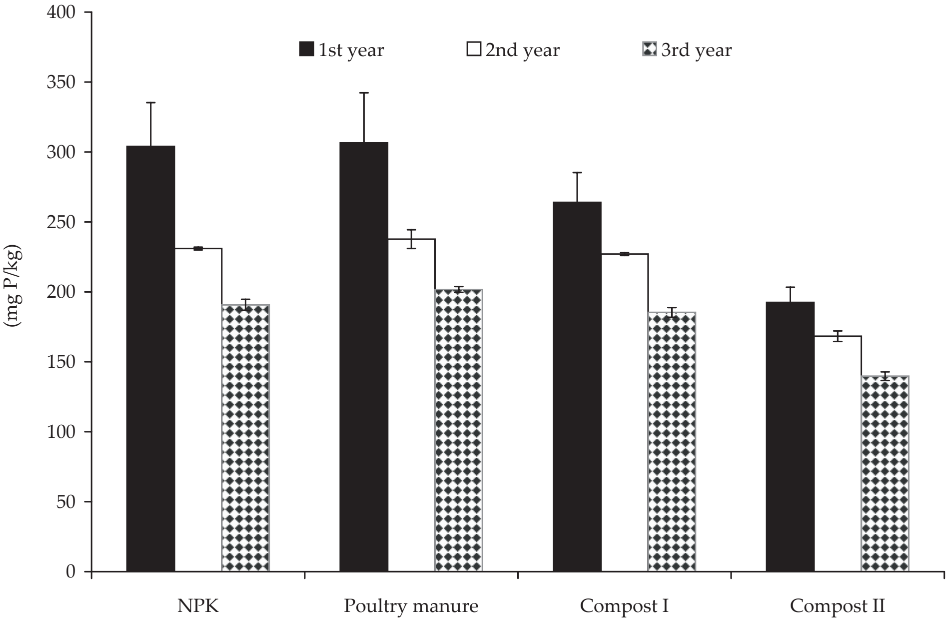

Figure 2. Content of soil available phosphorus extracted by Mehlich III (mg/kg)

36.6% compared to the control NPK treatment. It could be explained by a high binding strength of phosphorus in this compost made of green waste. On the other hand, a lower P content was found at all treatments in the second year of experiment. The lowest content was measured at compost II treatment again; the value was lower by 27% compared to control. The contents of phosphorus in soil after NPK, poultry manure and compost I showed statistically significant differences.

Since yield formation alone is not a suitable parameter to gain information about the phosphorus availability, P uptake of oat biomass was taken into consideration. The uptake of phosphorus fluctuated markedly in the first year of experiment (Figure 3). Threefold lower uptake was found at compost I treatment compared to the control. The highest uptake of P was obtained at oat grown in soil treated with mineral NPK (0.52 g P/pot). This was the highest value of uptake during three years. The

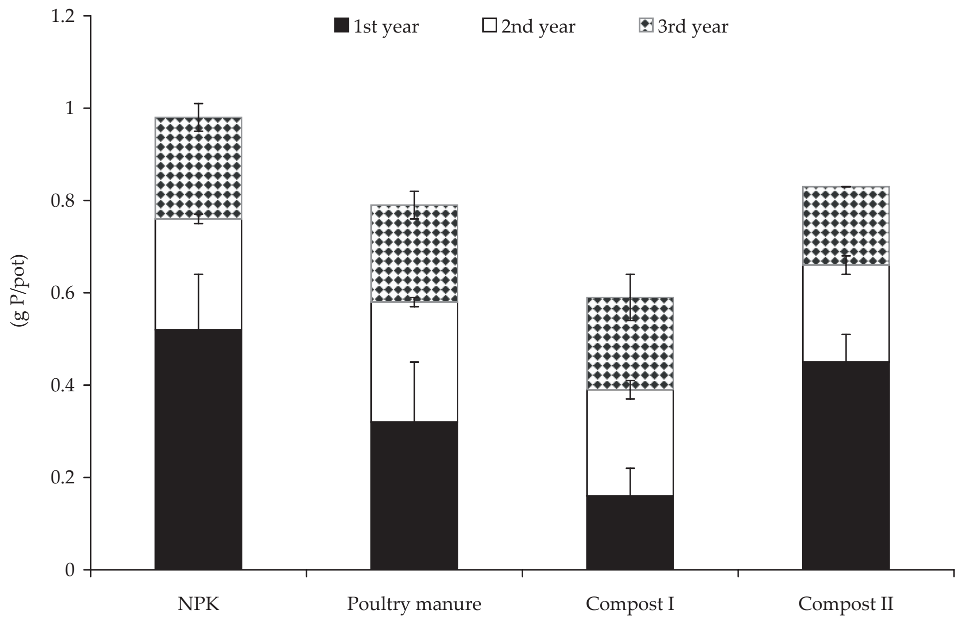

Figure 3. Uptake of phosphorus by aboveground oat biomass within a three-year period (g/pot)

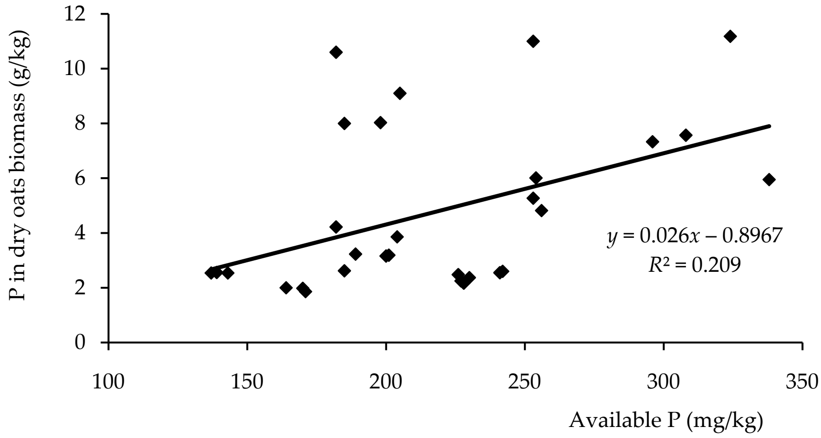

Figure 4. Linear regression analysis of available P content in soil treated with organic fertilizers and content of P in dry oat biomass

lowest P uptake was shown at compost I treatment (0.16 g P/pot), while he highest uptake among all organic fertilizers was found at compost II treatment. It might be explained by better mineralization of the material as well as by high addition of mineral P and thereby higher availability to plants. Oat fertilized with compost I (without mineral P addition) took up the lowest amount of P among treatments. Apparently, plant available compost P was fixed by the soil resulting in low phosphorus uptake (Scherer 2004). Cooperband et al. (2002) found that corn P uptake was the highest in plots amended with 15-month old compost and raw poultry litter, even though other composts contained 1.5–2 times more total P than raw poultry litter. Sinaj et al. (2002) found better utilization of P by white clover grown in the sandy acidic soil amended by compost compared to clayey calcareous soil. Results obtained in the sandy acidic soil suggest that white clover initially used a fraction of the rapidly exchangeable compost P, while at a later stage plant roots enhanced the mineralization of compost organic P and took up a fraction of the mineralized P. These relations were not observed in the clayey calcareous soil, probably because of its high sorption capacity for P. Bar-Tal et al. (2004) found that phosphorus and potassium uptake by wheat amended with the annually highest compost rate (120 ton/ha) was much higher than in control plants fertilized with minerals. This conclusion was confirmed in our experiment only in the case of potassium but not phosphorus. It is necessary to realize that organic fertilizers mostly contained the addition of mineral fertilizers (Table 3). Sikora and Enkiri (2005) studied phosphorus uptake by fescue (*Festuca arundinacea* Schreb.) from poultry litter compost (PLC) and triple superphosphate (TSP) applied to silty loam soil. No significant differences were found between the treatments, and a single quadratic equation described P uptake with increased P rate. These data indicated that PLC added to soils on a total P basis provided the same amount of fertilizer equivalents as TSP. The uptake of P decreased in our experiment in the second and third year. The initial addition of mineral P did not play so important role for P uptake compared to the first year. Values did not fluctuate very much within time. Statistically significant difference was found only between poultry manure and compost II treatments (d_{min} = 0.043) in the second year and no one in the last year. The total phosphorus uptake by oat biomass after three years was 60, 49, 36 and 51% from initial available content in soil treated with NPK, poultry manure, compost I and compost II, respectively. A medium correlation ($R = 0.45$; $P < 0.05$) was found between available content of P in soil treated with organic fertilizers and P content in aboveground biomass of oat (Figure 4).

Soil potassium behaved similarly as phosphorus. Available potassium content in the first year statistically differed from other years (Figure 5). The highest values of available K were measured in the soil treated with NPK. In the experiment of Gil et al. (2007), available K significantly increased in soil fertilized with compost plus mineral fertilizers, whereas its concentration did not change with mineral fertilization compared to the initial soil. Plant available potassium increased in the plots amended with compost and sewage sludge of the field experiment described by Odlare et al. (2007). Similar values of K content were measured

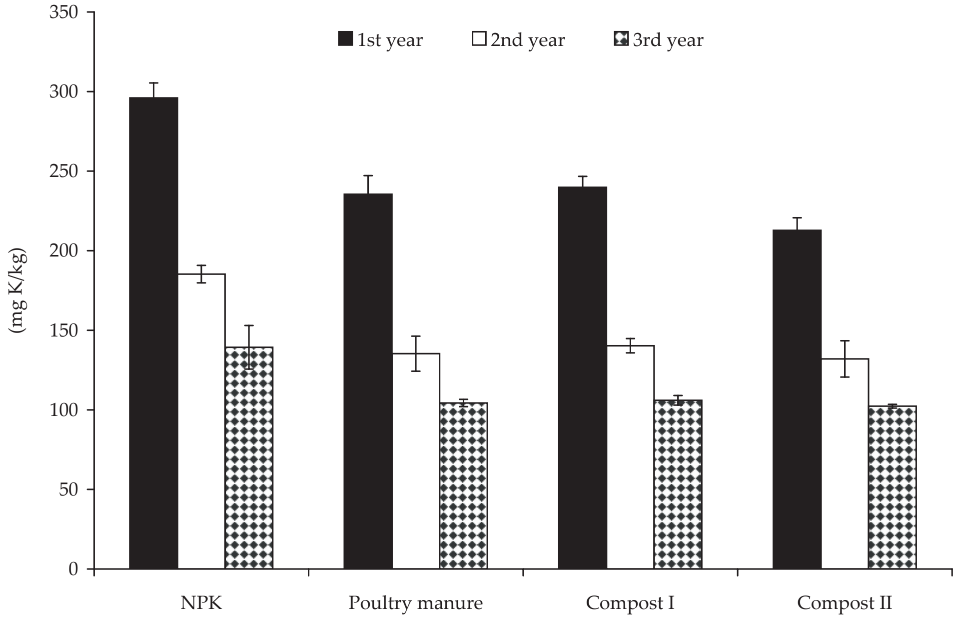

Figure 5. Content of soil available potassium extracted by Mehlich III (mg/kg)

in soils fertilized with compost I, compost II and poultry manure every year. The lowest available content of potassium was always found in the soil treated with compost II containing no mineral K addition. Poultry manure application decreased available potassium concentration, too. Analyses with ANOVA showed no significant differences between available K content in soil treated with inorganic and organic portions of fertilizers.

Plant uptake of potassium differed from phosphorus, mainly in the second year of experiment (Figure 6). Substantial decrease of potassium uptake was not observed in any treatments compared to phosphorus in the second and third years and correlated with yield of biomass. It can be explained by very high total K uptake and its accumulation in biomass. In the first year the lowest uptake of K by oat grown in soil amended with compost I was found out. It was 0.5 g/pot (by 37% less than NPK). Poultry manure and compost II application increased uptake of K by plants (0.91 g and 1.04 g per pot, respectively). In the second year the K uptake was markedly higher than in the first one. The highest uptake (1.77 g/pot) was found

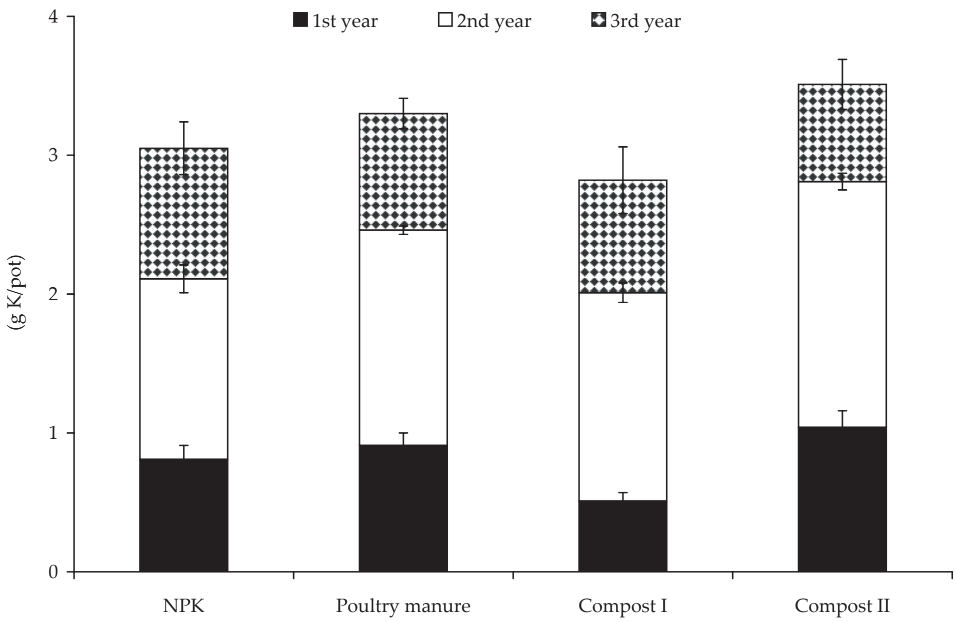

Figure 6. Uptake of potassium by aboveground oat biomass within three years period (g/pot)

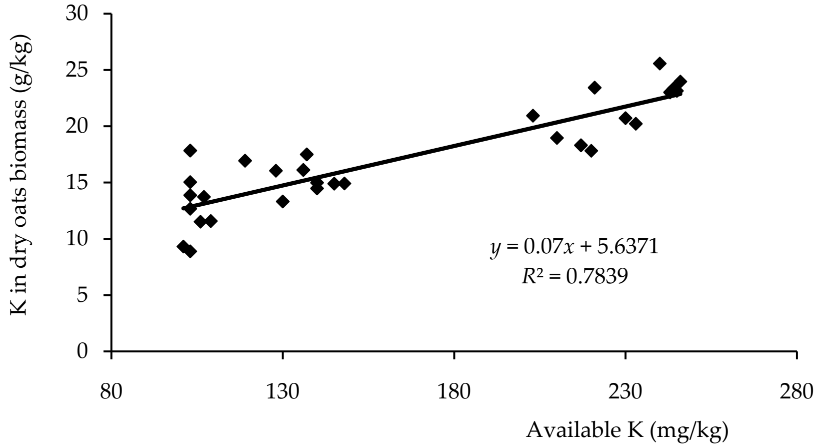

Figure 7. Linear regression analysis of available K content in soil treated with organic fertilizers and content of K in dry oat biomass

at compost II treatment. It was by 37% more than control NPK. Compost II contained potassium only in organic form. The effect of mineral K on the uptake was irrelevant. Drying of samples before storage in winter and re-wetting in spring could contribute to a release of K from organic mater of compost and soil supply. Treatments did not differ, except for poultry manure and compost I (d_{min} = 0.176). The K uptake decreased in the last year. The values almost did not fluctuate and showed no statistical differences. Bartl et al. (2002) found higher contents of P and K in plants grown in soil fertilized with NPK than with composted biowaste but the differences were not always statistically significant. There was a strong correlation (R = 0.88; P < 0.05) between available K content in soil after organic fertilization and potassium content in plants (Figure 7), compared to indirect proportional dependence between available K content in soil after organic fertilizers and K uptake by plants (R = 0.28; P < 0.05). It was apparently caused by high variability of dry oat biomass production. Total uptake of potassium after three years was 103, 112, 96 and 119% of initial available potassium in soil treated with NPK, poultry manure, compost I and compost II, respectively.

Our results confirmed that organic fertilizers could substitute the conventionally used mineral fertilization. They can even increase the yields of oat biomass more than mineral fertilizers. It can be concluded that the application of biosolids to the soil decreased the uptake of phosphorus, but not potassium, compared to mineral fertilizers. In the case of both elements it resulted in the decrease of plant available P and K in soil.

REFERENCES

Bar-Tal A., Yermiyahu U., Beraud J., Keinan M., Rosenberg R., Zohar D., Rosen V., Fine P. (2004): Nitrogen, phosphorus, and potassium uptake by wheat and their distribution in soil following successive, annual compost applications. J. Environ. Qual., *33*: 1855–1865.

Bartl B., Hartl W., Horak O. (2002): Long-term application of biowaste compost versus mineral fertilization: Effects on the nutrient and heavy metal contents of soil and plants. J. Plant Nutr. Soil Sci., *165*: 161–165.

Bazzoffi P., Pellegrini S., Rocchini A., Morandi M., Grasseli O. (1998): The effect of urban refuse compost and different tractors tyres on soil physical properties, soil erosion and maize yield. Soil Till. Res., *48*: 275–286.

Businelli M., Gigliotti G., Giusquiani P.L. (1990): Application of urban refuse compost in agriculture. I: Effect on maize productivity, nutrient and heavy metal location in plants. Agrochimica, *34*: 454–466.

Cooperband L., Bollero G., Coale F. (2002): Effect of poultry litter and composts on soil nitrogen and phosphorus availability and corn production. Nutr. Cycl. Agroecosys., *62*: 185–194.

Courtney R.G., Mullen G.J. (2007): Soil quality and barley growth as influenced by the land application of two compost types. Biores. Technol., doi:10.1016/j.biortech.2007.06.034

Gil M.V., Carballo M.T., Calvo L.F. (2007): Fertilization of maize with compost from cattle manure supplemented with additional mineral nutrients. Waste Manag., doi:10.1016/j.wasman.2007.05.009

Jedidi N., Hassen A., Van Cleemput O., M'Hiri A. (2004): Microbial biomass in a soil amended with different types of organic wastes. Waste Manag. Res., *22*: 93–99.

Kleinman P.J.A., Bryant R.B., Reid W.S., Sharpley A.N., Pimentel D. (2000): Using soil P behavior to identify environmental thresholds. Soil Sci., *165*: 943–950.

Leroy B.L.M.M., Bommele L., Reheul D., Moens M., De Neve S. (2007): The application of vegetable, fruit and garden waste (VFG) compost in addition to cattle slurry in a silage maize monoculture: Effects on soil fauna and yield. Eur. J. Soil Biol., *43*: 91–100.

Manugistics (1997): Statgraphics Plus for Windows User Manual. Manugistics, Inc., Rockville.

Mehlich A. (1984): Mehlich 3 soil test extraction: A modification of Mehlich 2 extractant. Commun. Soil Sci. Plant Anal., *15*: 1409–1416.

Mengel K., Kirkby E.A. (1978): Principles of Plant Nutrition. International Potash Institute, Bern.

Miholová D., Mader P., Száková J., Slámová A., Svatoš Z. (1993): Czechoslovak biological certified reference materials and their use in the analytical quality assurance system in trace elements laboratory. Fresenius J. Anal. Chem., *345*: 256–260.

Odlare M., Pell M., Svensson K. (2007): Changes in soil chemical and microbiological properties during 4 years of application of various organic residues. Waste Manag., doi:10.1016/j.wasman.2007.06.005

Scherer H.W. (2004): Influence of compost application on growth and phosphorus exploitation of ryegrass (*Lolium perenne* L.). Plant Soil Environ., *50*: 518–524.

Sikora L.J., Enkiri N.K. (2005): Comparison of phosphorus uptake from poultry litter compost with triple superphosphate in codorus soil. Agron. J., *97*: 668–673.

Sinaj S., Traore O., Frossard E. (2002): Effect of compost and soil properties on the availability of compost phosphate for white clover (*Trifolium repens* L.). Nutr. Cycl. Agroecosys., *62*: 89–102.

Warman P.R., Termeer W.C. (2005): Evaluation of sewage sludge, septic waste and sludge compost applications to corn and forage: yields and N, P and K content of crops and soils. Biores. Technol., *96*: 955–961.

Zhang M., Heaney D., Henriquez B., Solberg E., Bittner E. (2006): A four-year study on influence of biosolids/MSW compost application in less productive soils in Alberta: Nutrient dynamics. Compost Sci. Util., *14*: 68–80.

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