NUTRITION POTENTIAL OF BIOWASTE COMPOSTS

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Introduction

Composts are important nutrient carriers. In Germany alone, with an estimated annual production of about 8 Mt (equivalent to 5 Mt DM), their nutrient potential represents almost 10 % of the phosphate, potash and lime currently applied as mineral fertilizers, as well as about 2.5 % of the mineral-fertilizer N applied in the whole German agriculture. To make efficient use of these nutrient amounts, composts require the targeted application as secondary raw material fertilizers (Gutser, 1997). Therefore, it is the aim of this paper to show the effects of macronutrients contained in biowaste composts, and to deduce general strategies for their use.

Nutrient contents of biowaste composts

The composition of biowaste composts is highly variable, according to their respective raw materials, composting conditions, and regional origin. The ranges in Table 1 include those figures frequently cited in the literature.

Table 1. Nutrient content of biowaste compost – normal range -

	total content [% dry matter]	soluble fraction [% total content]
organic matter	27 – 60	
lime ($CaCO_3$)	2 – 11	
nitrogen (N)	1.0 – 1.8	1 – 7 *
phosphorus (P)	0.2 – 0.5	25 – 45 **
potassium (K)	0.4 – 1.3	75 – 100 **
calcium (Ca)	1.5 – 6.0	
magnesium (Mg)	0.2 – 1.1	
sulfur (S)	0.1 – 0.5	6 – 11 ***

* NH_4-N + NO_3-N ($CaCl_2$ extract) ** CAL extract *** SO_4-S ($CaCl_2$ extract)

Biowaste composts consist to 30 – 60 % of organic matter (Table 1), which is largely humified and stabilized, especially in mature composts. Due to their different raw materials, biowaste composts (higher percentage of kitchen refuse) tend to be richer in organic matter and nutrients than pure green waste composts (generally higher percentage of woody components). However, the line between these two types of compost is vague. A major criterion for the quality of organic matter is its C/N ratio (see 1.1.1 N transformation in the soil). With few exceptions that are due to high percentages of wood, fresh biowaste composts, at the onset of rotting, have already C/N ratios of less than 20, that drop to less than 14 in the fully rotted mature composts. In contrast, the variation in the C/N ratios of fresh green waste compost is much higher (up to 30 and above).

Also for mature green waste composts, the C/N ratio is generally significantly higher than for biowaste composts.

Composts contain variable amounts of lime (alkaline components). Thus, they have a generally slightly alkaline pH value (pH 7 to 8). The lime content of composts correlates with their degree of rotting, and with their Ca and Mg contents (Ebertseder, 1997), so that it can be assumed that a substantial part of the lime is generated during the composting process, by precipitation of $CaCO_3$ and $MgCO_3$ respectively. The contents of Ca and Mg are frequently related to the geogenically determined lime content of the soils in the area of the respective composting plant.

Because of their high contents of lime and especially of organic matter, composts have primarily to be considered as soil conditioners. In addition, they contain substantial amounts of nutrients (Table 1), so that a targeted application as fertilizer (multinutrient fertilizer) becomes necessary. When comparing the ratio of the total contents of nitrogen, phosphorus and potassium in biowaste composts (N / P / K » 1 / 0.2 / 0.6) with the ratio found in various crops, it becomes obvious that, in comparison to vegetables (on average N / P / K » 1 / 0.2 / 1.3; Fink et al., 1999) composts are relatively low in potassium but rich in phosphorus. This leads to the conclusion that, with crop-yield orientated fertilizer application to vegetables, the P content, next to the N content, normally constitutes the limiting factor for compost use. In mostly agricultural crop rotations (high percentage of grain crops), the nutrient ratio of compost matches that of the removed crop yields rather well.

Besides the total nutrient contents, nutrient solubility is of special importance, as it gives an indication for the immediate plant availability. Because of the different chemical reactions and binding forms involved, the solubility of the various nutrients differs strongly. Especially N is mostly present in very stable organic forms, with only a very small soluble fraction. On average, less than 5 % of the compost N consists of immediately plant available ammonium (NH_4^+) and nitrate (NO_3^-). However, 35 % of the phosphorus and almost all of the potassium (normally ³ 75 %) are soluble in the CAL extract.

The sulfur content of bio-waste composts range from 0.1 to 0.45 % DM. Similar to nitrogen, only a very small fraction thereof (normally < 10%) is present in immediately plant available form (SO_4-S). Whereas for both sulfur and nitrogen, more than 90 % are normally incorporated in the organic matter, the N/S ratios of compost vary widely from 4 to 15 (Gutser and v. Tucher, 2000).

Nutrient effect

Compost application leads to humus accumulation in the soil. Consequently, to correctly assess the effect of the nutrients from compost, it is necessary to differentiate between a short-term effect in the year of application, and a long-term effect over the following years. This applies especially to those nutrients that are mostly present in organically-bound form (N, S).

Nitrogen

Nitrogen transformation in the soil

Generally, the nutrient effect of organic fertilizers depends largely on the transformation processes that take place in the soil after their application. This applies especially to nitrogen (N), for which its plant availability is tightly related to microbial transformations.

Primarily the degradability and C/N ratio of the organic matter determines, whether it comes to a net mineralization or immobilization of N after the application of an organic fertilizer. Mature composts still contain but only small amounts of easily transformable C compounds; their C/N ratio is normally 11 – 15, and thus only slightly above that of soils (ca. 10). With transformation processes on a low level, N immobilization and mineralization are almost in balance. The NH4 and NO3-N (Nmin) of mature composts can thus be considered as almost completely plant available in the year of application (Fig. 1).

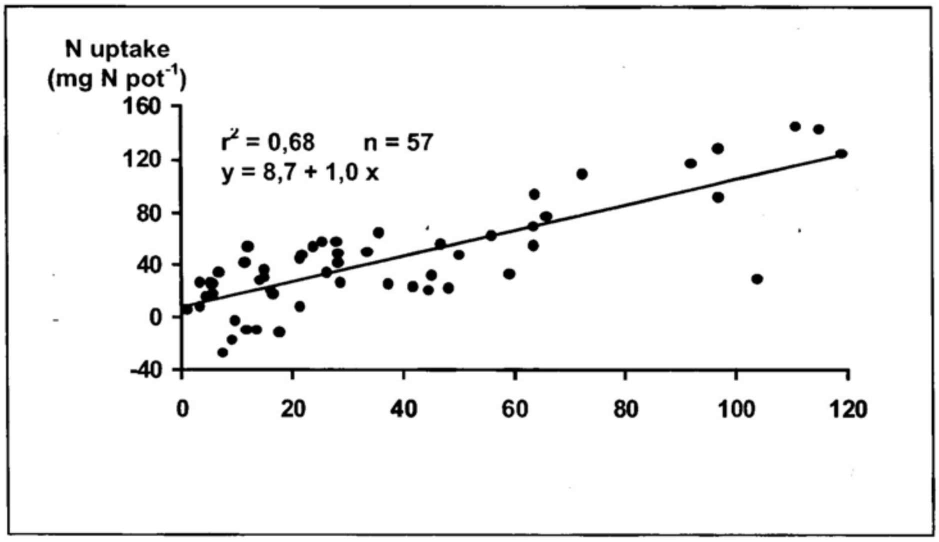

Fig. 1. Relation between N uptake of oats (difference to pots without N) and supply of soluble N with mature composts – pot trial (Ebertseder, 1997)

This does not apply to fresh and yet little stabilized composts. Most of their organic matter will still be transformed in the soil. This frequently leads to a net immobilization, so that less N is available for the plants than without compost application (possible yield reduction). Generally, remineralization on fertile soils is that rapid, that the yield of crops with a longer growing period is frequently not seriously affected. However, there are also fresh composts, especially those that contain a large portion of N-rich biowaste, which give a positive N effect that is clearly higher than that from average mature composts.

Parameters to estimate the possible N effect

To avoid N immobilization, especially in rapidly growing crops, and in order to calibrate the optimum supplemental mineral N-fertilizer application, suitable parameters are required by which the compost effect on yield and N supply may be quantified. For this purpose, biological methods to determine the degree of maturity (e.g. self-heating capacity, respiratory activity, enzymatic activity) are not very useful (Popp and Fischer, 1995, 1996).

A better parameter that can be used for all composts, independently of their degree of rotting, is the C/N ratio of the organic matter extractable by 2M K2SO4 solution (C/NK2SO4) (Ebertseder et al., 1995, 1996). It not only allows the differentiation between N supplying and N immobilizing composts, but also gives an indication for the N availability in the year of application (Ebertseder, 1997).

First results (Capriel et al., 1999) give rise to the expectation that it may be possible to substitute the relatively time-consuming chemical extraction methods, used hitherto to assess the plant available N potential, by simple and rapid spectroscopic analyses in the infrared range.

Short-term N effect

Independent of the degree of maturity, most of N from composts goes into the humus pool of the soil, either directly or via immobilization by microbial biomass. The immediate N effect in the year of application is very small, as confirmed by numerous field trials with a wide variety of crops on different sites. It often accounts for less than 5% of the applied compost nitrogen, and varies within a certain range with site- and crop-specific influences (vegetation period, soil tillage, etc.) (Fig. 2).

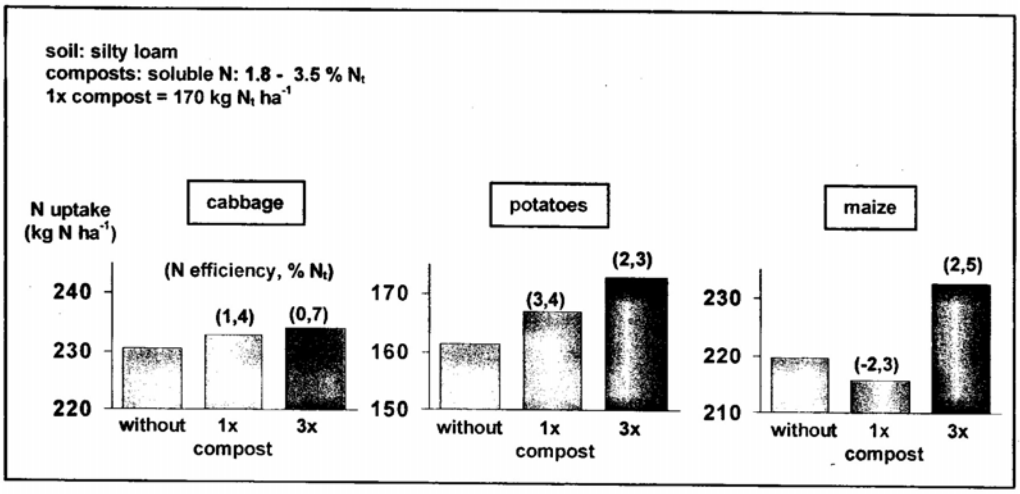

Fig. 2. Nitrogen efficiency of biowaste composts in the year of application – field trials – average of 2 composts and different additional mineral N levels (data from Popp, 1997, and Ebertseder, 1997)

Composts with a high percentage of green cuttings or garden waste (tree cuttings), under similar conditions for composting, generally give a slightly lower N effect than composts with a high percentage of bio-wastes (Scherer et al., 1996). Normally, a supplemental mineral fertilizer application has but little effect on the availability of the compost nitrogen. Also the combination of annual applications into one application for several years, gives no advantages for a better N utilization (% of supplied N). However, more compost N is then available for the plants in the year of application (Fig. 2, "3 x compost"), that has to be taken into account when calculating the mineral fertilizer supplement.

Possibilities to optimize the N utilization by the crops, constitute the choice of application date and the form of incorporation into the soil. Microorganisms and plant roots compete for nitrogen, that is normally the limiting growth factor. Therefore, strategies to place the compost short before or to the growing period to the crops, or to reduce the contact between compost and soil (application on the soil surface), offer the advantage of a slightly improved N utilization (up to about 10 %) that is, however, still much lower than that of mineral fertilizer (ca. 60 – 80 %).

Long-term N effect

Due to the small N effect in the year of application, more than 90 % of the compost nitrogen remains in the soil (increased soil N content). Already in the first consecutive year, the residual effect is only marginally different from the N release from soil organic matter (1.5 to 3.5 % per year, acc. to site). The site- and management-specific mineralization rate, both for soil nitrogen and compost nitrogen applied in a single year, is not increased by continuous compost application for several years (Table 2). The immediate effect of a compost incorporation on the net mineralization of soil nitrogen (reduced mineralization rate due to increased immobilization) is also not affected by a continued previous fertilizer application.

Table 2. Nitrogen mineralization in soils after different long-term fertilization, with and without the additional incorporation of biowaste compost (BWC) – Incubation trial in Mitscherlich pots; incubation: 296 days; 1 x compost = mean 170 kg N/ha×a (acc. to Ebertseder, 1997)

long-term fertilization	N content	N mineralization	
(20 years)	soil	without BWC	with additional BWC
	%	% N_t	% N_t
without N	0.10	3.3	1.7
mineral N	0.10	4.5	2.3
1 x compost	0.17	3.5	1.4
2 x compost	0.19	3.3	2.2

Generally, the N mineralization from organic matter (N release) is stronger on light sandy soils than on heavy soils. This is connected with a stronger compost transformation in the years following application. The soil type (e.g. sand, loam) and its relative mineralization rate have therefore, next to the application rate, the strongest effect on the enrichment of soil N by long-term application of compost, provided that climate, weather and crop management remain unchanged.

Long-term compost application on loamy soils, thus leads to a higher N accumulation and to a slightly slower increase in the N release than on sandy soils (Fig. 3). With increasing length of time, the N accumulation in the soil asymptotically reaches a maximum. Half of this maximum accumulation is reached after about 20 years on sandy soils, and after about 30 years on loamy soils.

An almost complete equilibrium between N supply and N mineralization (graph almost parallel to x-axis) is only reached after about 60 years (Fig. 3). This means that only after a relatively long period of time, the N amount annually released from the enriched soil pool (available for plants and N losses), becomes comparable to the annual supply.

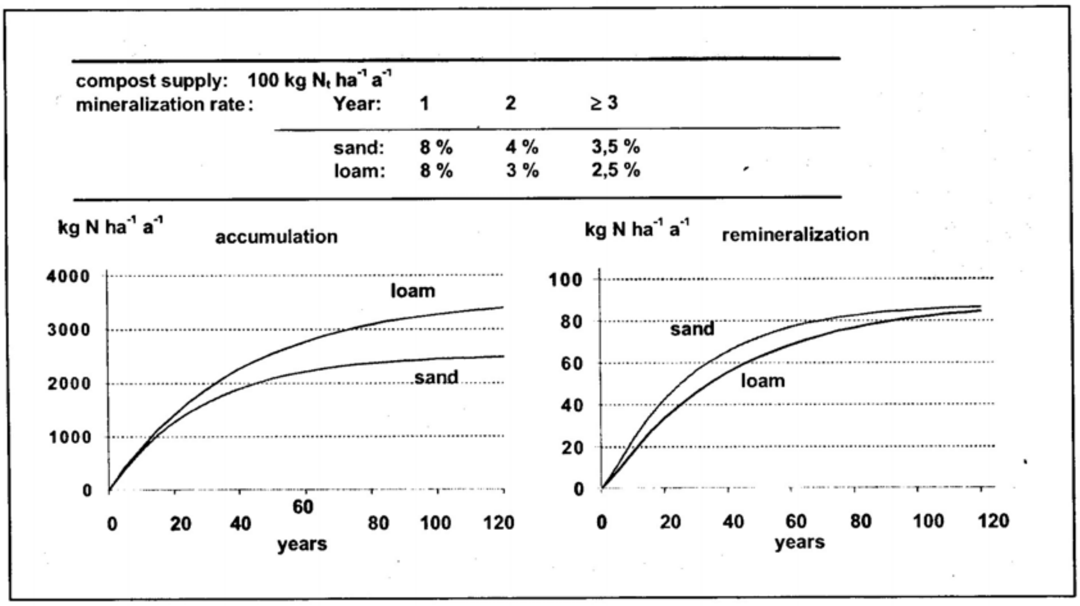

Fig. 3. Nitrogen accumulation and remineralization in different soils by long-term compost application – model calculation according to Gutser and Claassen (1994)

The significant increase in the N release from the soil, that becomes apparent in the model calculations, is confirmed in field trials already after a few years by an increased N uptake by the crops (Fig. 4). In accordance with N uptake the total N utilization increased with time, too (evaluation of the total period). But the N utilization in individual years and for individual crop rotations remains almost constant (mean < 1.5 % per year).

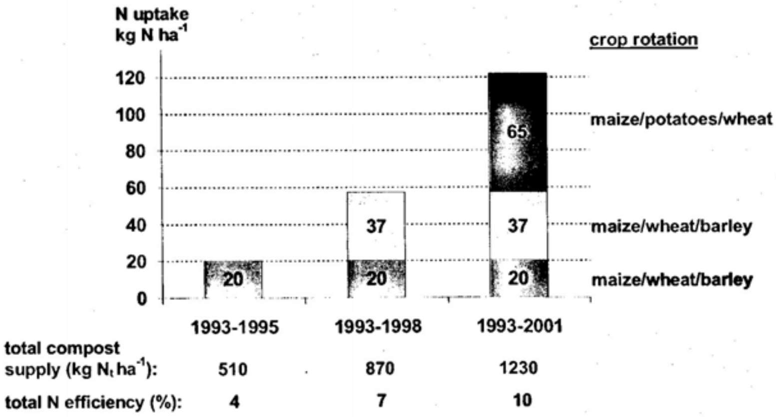

Fig. 4. Nitrogen effect of biowaste compost over a period of 3 crop rotations (9 years) - N uptake: difference to plots without compost

N mineralization is almost impossible to control and difficult to calculate. It coincides only partly with the N demand of the crops. A rather substantial amount of N is mineralized outside the vegetation period and is thus prone to leaching. It is therefore unavoidable that an enrichment of the soil with organic matter increases also the N-loss potential. This is confirmed by a lysimeter experiment, conducted in Weihenstephan (Fig. 5).

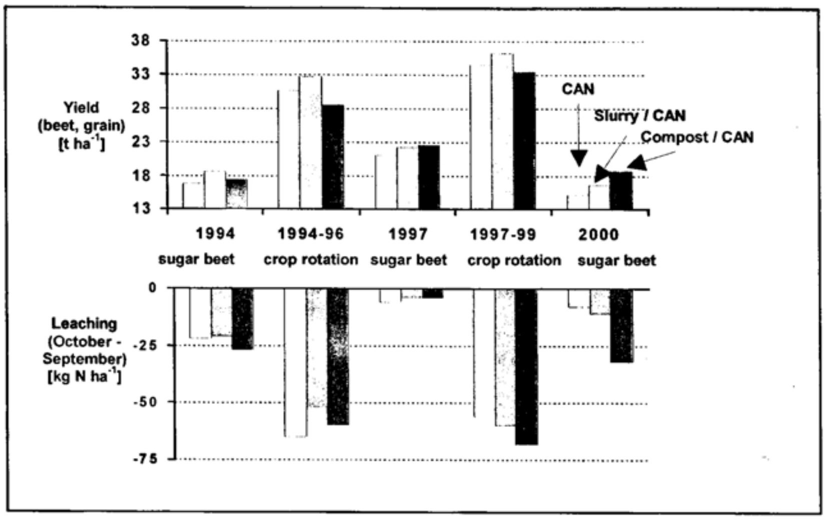

Fig. 5. Long-term nitrogen effect of biowaste compost and cattle slurry in a lysimeter trial (soil: silty loam; Crop rotation: sugar beet – winter wheat – winter barley (+ cover crop); mean precipitation: 810 mm y^{-1})Trial started in 1980 with uniform slurry/calcium ammonium nitrate (CAN) application. Since autumn 1993, biowaste compost every 3rd year prior, to sugar beet Fertilizer treatments (kg ha^{-1}): cattle slurry (120 N annually), biowaste compost (360 N every 3rd year) with CAN (60 N annually); CAN (mean 160 N annually).

Long-term compost application showed a good yield effect, also when compared to mineral fertilizer (calcium ammonia nitrate, CAN) and slurry, but simultaneously increases the N-leaching risk under the humid site-specific conditions of Weihenstephan (Fig. 5). Especially after the third compost application in September 1999 (at a rate of 360 kg N/ha), it was found that 20 kg N/ha more were leached until September 2000 than under the control treatments.

Strategies for compost use, which are meant to be compatible with the principles of sustainable agriculture and environmental needs, have to take into account this rise of the N leaching potential. It is invariably connected with compost application, and have to restrict the permissible annual N load. This generally excludes the possibility, even in the long run, to produce maximum yields by compost application alone. High yields always require an adequate mineral fertilizer supplement.

Phosphorus

About 35 % of the phosphorus in composts is present in soluble form (CAL extract) and about 20 % is bound organically (Cabrera et al., 1991; Ebertseder, 1997; Traoré et al., 1999). The organic P fraction within total P does not increase during the composting process. However, depending on the composting conditions (temporarily anaerobic) and on the composition of the original materials (percentage of domestic and kitchen waste), there is an increase in the share of difficultly soluble inorganic P compounds (Ca/Mg phosphates, Fe/Al phosphates) (Traoré et al., 1999). The P-transformation processes during composting, seem to be almost similar to those taking place in the soil with mineral-fertilizer P. The products of these transformation are rated as long-term fully plant available. Microbial processes (immobilization, mineralization) play only a minor role for the P availability of compost (different from N).

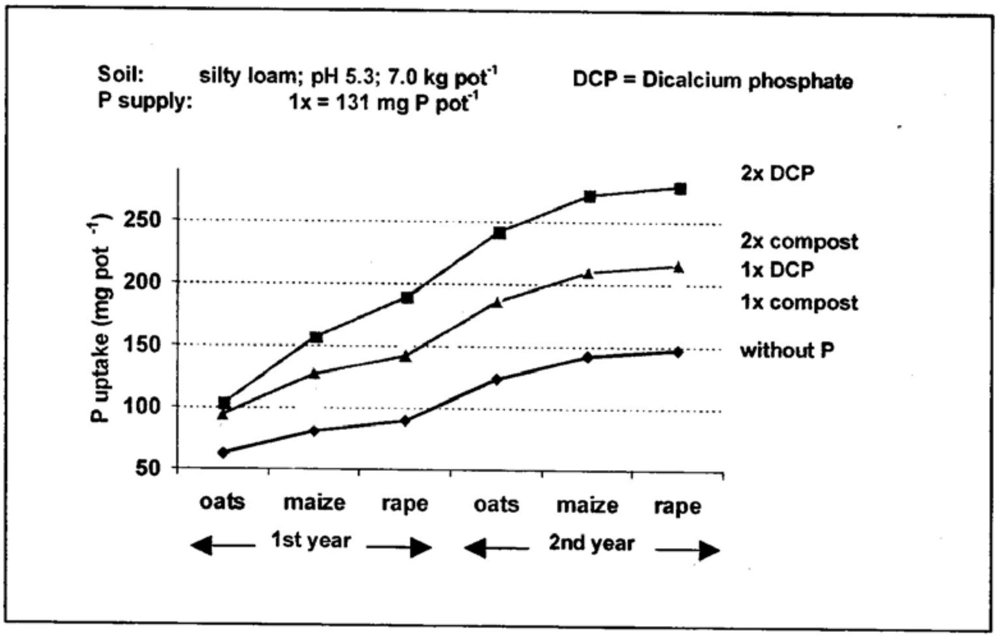

Fig. 6. P effect of biowaste compost (35% of Pt CAL soluble) and dicalcium phosphate (DCP) – pot trial, trial period 2 years, rotation: oats-maize-rapeseed (Ebertseder, 1997)

All in all, composts show a relatively good P-fertilizer effect, as confirmed for example by the results of a pot trial with biowaste compost (Fig. 6). However, compared to mineral fertilizers, the effect of compost phosphates is frequently slower, and their plant availability in the first years after the application thus lower. It should be noted that there are also large differences in the solubility of the various mineral fertilizers, and thus their plant availability on different soils (pH value, sorption conditions).

It is often not possible to directly establish the P effect of composts by field trials, as other factors (N availability, physical soil-condition) have a stronger effect on the yield development than phosphate, which is normally present in the soil in sufficient quantities. Sites on which compost has been applied for several years, often show an increased soil content of soluble phosphate, depending on the compost supply (Fig. 7). This observation has been made in many trials (Diez and Weigelt, 1980, Bischoff, 1988, Diez and Krauss, 1997) and confirms the high long-term P availability. Since plants live predominantly from the P pool of soil, it is suitable to fully include compost P in the calculation of the fertilizer rate, similar to P from farm-yard manure and mineral fertilizers.

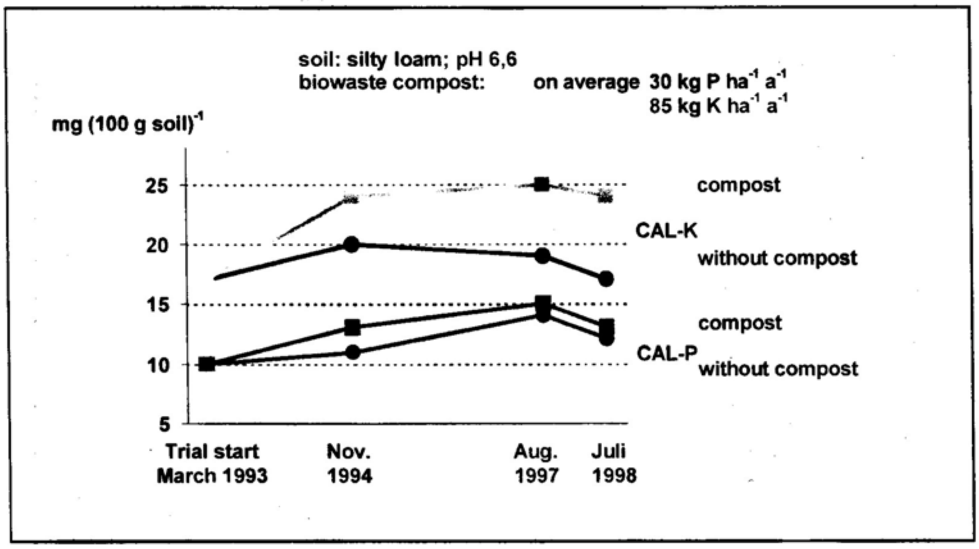

Fig. 7. Effect of biowaste compost on nutrient status of soil (CAL-Extract) – field trial -

Potassium

Normally, more than 75 % of the potassium in composts is soluble (CAL extract), so that the same good plant availability can be expected as for potassium from mineral fertilizers. The potassium in composts can thus be fully inserted into the calculation of the fertilizer requirement. Soil analysis also shows increased values for CAL-soluble K after compost application (Fig. 7).

Sulfur

Similar to nitrogen, the effect of sulfur from organic fertilizers is principally controlled by microbial transformation processes in the soil (mineralization, immobilization). Therefore, both the availability of N and S is widely governed by the same laws.

Short-term sulfur effect

The sulfur effect in the year of compost application is determined (i) by the SO4 S content, and (ii) by the C/S ratio. As well as nitrogen, sulfur is immobilized by incorporation into the microbial biomass, when easily degradable organic matter poor in S, is transformed in the soil. Sulfur immobilization is to be expected after the application of organic fertilizers with a C/S ratio of 80 and above.

Composts normally have C/S ratios < 75 (Gutser and v. Tucher, 2000). A significant immobilization of the applied SO4 sulfur is therefore not to be expected. The Smin fraction accounts for 5 to 10 % of the total sulfur content (see Table 1) and consequently the short-term utilization of the compost S by the plants is of a similar magnitude. In one-year pot trials (see also Gutser and v. Tucher, 2001) high additional yields were obtained with SO4 containing mineral fertilizers, but not with biocompost or farmyard manure (Fig. 8). The sulfur applied via organic fertilizer gave at best a mineral-fertilizer equivalent of about 5 to 15%.

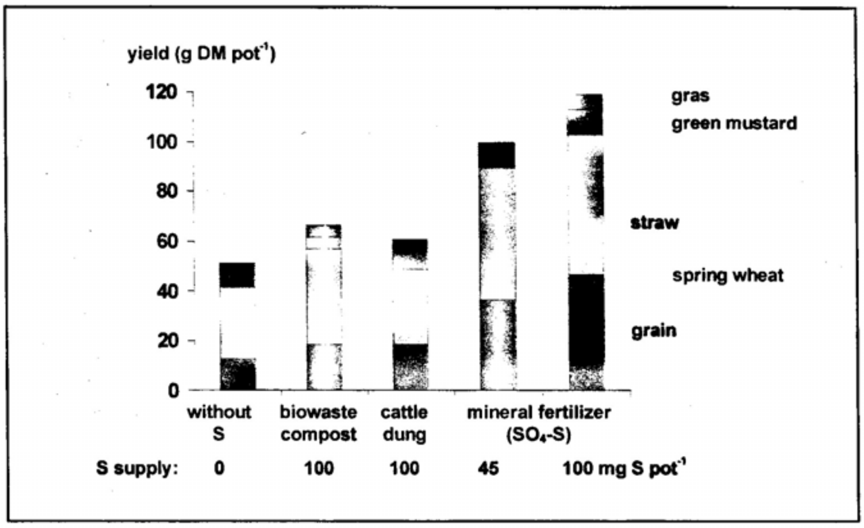

Fig. 8. Short-term sulfur effect of biowaste compost in comparison to mineral fertilizer and farm-yard manure – Yield of spring wheat, forage mustard and ryegrass pot trial, fertilizer: 45 and 100 mg S/Mitscherlich pot, resp.

Long-term sulfur effect

Ca. 90 % of the compost sulfur is organically bound. This fraction is not initially plant available in the year of the compost application. Together with the organic matter and similar to nitrogen it accumulates in the soil with continuing compost application, thereby increasing the capacity for N release (Fig. 9).

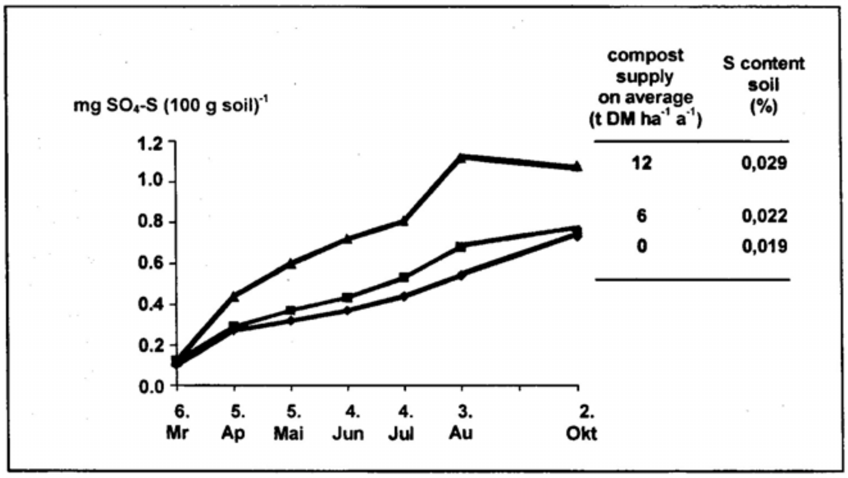

Fig. 9. Sulfur mineralization in long-term biowaste compost amended soils incubation experiment with surface soils from a 7 year field trial

The sulfur released from the soil organic matter can be used by the plants and does thus contribute to reduce the fertilizer S requirement. On a soil to which compost had been applied for 25 years (mean 10 – 12 t DM ha-1 a-1; S content: without compost 0.019 %, with compost 0.026 %), an optimum mineral-fertilizer S application to spring wheat resulted in yield increases of up to 12 % only, compared to 51 % on the control soil (pot trial; Gutser and v. Tucher, 2000). Whether the plants' S demand is met, depends not only on the amount of mineralized S, but also on the date on which it is released. Compared to N mineralization, S mineralization depends more on the temperature (Gutser and v. Tucher, 2001). Normally, it begins later (higher soil temperature). Therefore, the release from the soil S-pool can mainly be used by crops with a long growing period (e.g. sugar beet, maize, cabbage) and a late S demand, or by crops growing later in the year (second or third crops). S mineralization does not contribute significantly to meet the demand of crops with a high S demand in spring, especially not after a wet winter (S leaching).

Conclusions for compost use

For a removal-orientated fertilization, phosphorus and potassium from compost can be (at least in the long term) fully incorporated into the calculation of the fertilizer rate. To meet an average P demand of 25 – 30 kg P ha-1 a-1, about 7 – 8 t DM compost, equal to approx.. 120 kg N ha-1 a-1 are required. This N amount also represents the long-term permissible maximum quantity of compost, to curb N accumulation in the soil, and to restrict losses to the unavoidable.

The minor N effect in the year of application, and the hard-to-calculate N release from the soil N-pool, necessitate the targeted supplemental application of mineral fertilizer, in order to optimize crop yield and quality. Also this is feasible at a maximum compost application rate of 120 kg N ha-1 a-1. With increasing soil N accumulation and N release from the soil, the supplemental fertilizer applications can be reduced, especially in slowly-growing crops.

A significant contribution of compost to the S supply of the crops, can only be expected after long-term compost application and for slowly-growing crop species. On S deficient sites, a maintenance S-fertilization is normally required.

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