Influence of compost and digestates on plant growth and health: potentials and limits

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Key words: compost quality, plant growth, soil fertility, plant health

Abstract

Composts can influence soil fertility and plant health. These influences can be positive or negative, depending of the quality of the composts. In order to estimate the potential of Swiss composts to influence soil fertility and plant health, one hundred composts representative of the different composting systems and qualities available on the market were analyzed.

The organic substance and the nutrient content of the composts varied greatly between the composts; the materials of origin were the major factor influencing these values. The respiration rate and enzyme activities also varied greatly, particularly in the youngest composts. These differences decreased when the composts become more mature. Maturity, the degradation stage of the organic matter, depended not only on the age of the compost, but also on the management of the process. The N-mineralization potential of compost added to soil showed that a high proportion of young composts immobilized the nitrogen in the soil. Two compost parameters allow to predict the risk of nitrogen immobilization in soil: the NO_3- and the humic acids contents.The phytotoxicity of the composts varied very much even in mature composts, showing that the storage of the compost plays a decisive role. While the majority of composts protected cucumber plants against Pythium ultimum*, only a few composts suppressed* Rhizoctonia solani *in basil. With respect to disease suppression, the management of the maturation process seems to play a major role.*

In field experiments, some biologically immature composts immobilized nitrogen in soil and reduced growth of maize. With additional fertilization, however, it was possible to compensate this effect. Digestates and composts increased the pH-value and the biological activity of soil. These effects were observable also one maize season after compost application.

In conclusion, big differences were observed in the quality of composts and digestates, and in their impact on soil fertility and plant health. The management of the composting process seems to influence the quality of the composts to a higher extent than the materials of origin or the composting system. More attention should be paid to biological quality of composts, in order to produce composts with more beneficial effects on crops.

Introduction

Composts and digestates can influence soil fertility and plant health. These influences can be positive or negative, depending of the quality of the products and on their utilization. Inadequate management of the composting process may result in composts containing plant pathogens, weed seeds or toxic compounds which can cause damage to the crops. In contrast, well-managed composts can have the capacity to stimulate plant growth and to protect crops against diseases. While a lot of work has been done with only few composts, little is known on the quality spectrum of the different composts produced, and of their different influences on plant growth and plant health.

In order to estimate the potential of Swiss digestates and composts to positively influence soil fertility and plant health, one hundred composts and digestates representative of the different composting and methanization systems were analyzed. In addition to the characterization of quality of the different products, two field experiments were performed to evaluate the short term influence of composts and digestates on soil fertility and plant growth.

Materials and methods

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Samples from one hundred and one composts and digestates were collected from different composting and methanization plants according to the guidelines and recommendations with respect to waste fertilizers (FAC 1995). The product description is according to ASCP Guidelines 2001 (Fuchs et al., 2001). All plants process only source-separated organic material. The samples were chosen in such a way that they are representative of the composts produced in Switzerland. The samples were either tested immediately after collection, or stored at 3°C until testing.

Nutrients and heavy metals were analyzed with ICP-AAS according to the official Swiss methods (Schweizerische Referenzmethoden, 2005).

Humic acids were determined according to Gerzabek et al. (1993) by alkaline extraction using 0.1 molar Na-pyrophosphate solution.

The influence of compost on nitrogen mineralization in soil was determined with the incubation experiment according to the official Swiss methods (Schweizerische Referenzmethoden, 2005). Five to 10 percent of compost was added to a reference soil, placed in PVC boxes (12 x 10 x 5 cm, with aeration holes), wetted and incubated at 25°C. The mineralized nitrogen (NH_4 and NO_3) in the soil was determined after 0, 2, 4, 6 and 8 weeks.

The activity of four enzymes was determined: fluorescein diacetate according to Inbar et al. (1991), dehydrogenase, protease and cellulase according to Alef and Nannipieri (1995).

The phytotoxicity tests were performed according to Fuchs and Bieri (2000). In the open phytotoxicity tests, the growth of cress (*Lepidium sativum* L.), salad (*Lactuca sativa* L.) and bean (*Phaseolus vulgaris* L. var. *nanus* L) in pots (Ø 10 cm) filled with compost was compared with the growth in reference substrate BRS-200 (Biophyt Ltd, CH-Mellikon). In the closed phytotoxicity test, PVC boxes (1 liter) were half-filled with compost or reference substrate BRS-200, cress sown onto it, then the boxes were closed hermetically. The growth of the plants in the boxes was then observed.

Two disease suppressivity tests were performed: cucumber (*Cucumis sativus*)-*Pythium ultimum* and basil (*Ocymum basilicum*)-*Rhizoctonia solani*. Both tests were performed in 200-ml plastic pots. Compost (20 % v/v) was added to the soil. In the cucumber-*Pythium* test, the pathogen was grown for 7 days on autoclaved millet, and then added to the soil. In the basil-*Rhizoctonia* test, the pathogen was also grown on millet which was placed on the bottom of the pots before the plants were sown. Damping-off of the cucumbers was evaluated 10 to 15 days after sowing. In the basil-*Rhizoctonia* test, the living plants were counted after one, two and three weeks.

Two field experiments were performed in maize: in 2004, the experiment was made in a loamy soil and 2005 in a sandy soil. Digestates and composts were applied in the spring before the maize was sown (100 m^3 per ha). Eight weeks after sowing, N_{min} and plant height were measured. At harvest, total yield was determined. After harvest, soil samples were taken and analyzed chemically and biologically.

Results

Chemical characteristics of the Swiss composts

The chemical characteristics of the different products are presented in tab. 1. The values for the different composts varied greatly. The contents of salts, nitrogen, phosphorus, potassium, magnesium and calcium depends predominantly on the materials of origin. The organic matter and the density are mainly influenced by the maturity of the products. However, high variability was observed for all parameters within a product category. For example, the salt content, which should be low in the composts for covered cultures and private gardening, varied between 328 and 1539 [g KCL equivalent / 100 g fresh matter]. Through a more consistent choice of the materials of origin, the compost producers could obtain a more constant salt content in the final product.

Tab. 1: Chemical characteristics of Swiss composts[1]

	Digestate for agricultural use[2]	Compost for agricultural use[2]	Compost for horticultural use[2]	Compost for covered cultures and private gardening[2]
salt content[3] [mg KCl/100g FM] median (minimum; maximum)	970 (704; 1384)	862 (361; 1580)	787 (173; 2657)	660 (328; 1539)
pH[3] median (minimum; maximum)	8.5 (8.0; 8.8)	8.2 (7.5; 8.7)	8.1 (7.6; 8.7)	7.9 (7.2; 8.5)
density [g/l] median (minimum; maximum)	468 (321; 631)	556 (412; 851)	609 (434; 836)	715 (631; 904)
dry matter [% FM] median (minimum; maximum)	53.1 (45.4; 75.2)	50.8 (28.2; 73.4)	56.7 (40.8; 71.1)	56.3 (32.2; 64.5)
organic matter [% DM] median (minimum; maximum)	50.3 (28.9; 73.4)	47.7 (17.0; 80.1)	38.1 (23.9; 54.7)	30.6 (20.9; 52.8)
total N [g/kg DM] median (minimum; maximum)	15.3 (9.4; 20.3)	16.6 (8.7; 26.0)	14.6 (9.2; 27.6)	15.1 (8.6; 25.2)
total P [g/kg DM] median (minimum; maximum)	3. 6 (2.0; 8.0)	3.0 (1.7; 6.1)	3.0 (1.3; 12.7)	3.3 (2.1; 8.8)
total K [g/kg DM] median (minimum; maximum)	12.5 (6.4; 20.8)	12.0 (5.7; 25.2)	11.6 (2.2; 20.7)	10.7 (5.5; 27.8)
total Mg [g/kg DM] median (minimum; maximum)	6.8 (3.7; 9.7)	4.8 (3.6; 10.3)	6.5 (4.4; 10.7)	6.5 (4.4; 13.3)
total Ca [g/kg DM] median (minimum; maximum)	46.6 (23.0; 57.8)	53.1 (24.0; 83.7)	64.0 (35.0; 91.5)	44.5 (69.4; 29.5)
Fe [mg/kg DM] median (minimum; maximum)	8.9 (3.7; 12.3)	8.8 (2.9; 16.7)	10.1 (5.4; 14.7)	12.0 (6.1; 15.8)

[1] according to the “Guidelines and Recommendations of the Research Centre for Agricultural Chemistry and Environmental Science with respect to waste fertilisers” (FAC 1995).

[2] product description according to ASCP Guidelines 2001 (Fuchs et al., 2001)

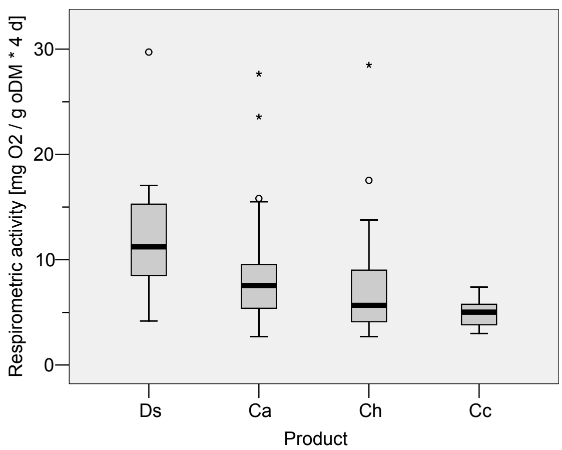
[3] value determined in 1:2 water extract

Characterisation of the biological activities of the Swiss digestates and composts

Respiration rate decreased with compost maturation (fig. 1), as already shown by different authors (Paletski and Young, 1995; Lasaridi and Stentiford, 1998; Popp et al., 1998). Interesting to notice is the reactivity of digestates, which show a very intensive biological activity as soon as they are coming in contact with oxygen. This reactivity of digestates can also be observed by the enzymatic ativities of the products (fig 2). However, the evolution of the activity of four enzymes during composting differed greatly (fig. 2). The FDA (fluorescin diacetate activity) and the protease activity differed significantly between the different product classes (fig. 2). Their activities are decreasing with the advancement of product maturity. A similar evolution, but less evident, is observable in the cellulase activity. By contrast, the dehydrogenase activity was less influenced by the maturity of the products.

Figure 1. Respirometric activity of Swiss composts. Products according to ASCP Guidelines 2001 (Fuchs et al., 2001).

Ds=digestate solid, Ca=compost for agriculture, Ch=compost for horticultural used, Cc=compost for covered cultures and private gardening.



Influence of composts and digestates on plant growth

Plants react on compost or digestate quality as a whole. Sometimes, all of the above-mentioned chemical parameters of a compost are good, but plants do not develop well in it for unknown reasons. To assess this risk, the phytotoxicity tests are used. The four phytotoxicity tests used react differently to compost quality. The open cress test is the least sensitive, and the plants showed growth depression only in the digestates (fig. 3Co). The open lettuce test is more sensitive, and only the more mature products allowed a good growth of the plants. In the closed cress test, the plants are not only in contact with the compost, but are also strongly influenced by the gases which evaporate from the compost. This test is therefore very sensitive, and only composts with high plant compatibility allowed a good growth of the cress (fig. 3Ccl).

Digestates are generally less compatible with plant growth than composts. In all test systems, an evolution in the plant compatibility was obvious, with the plants growing better in more mature composts (fig. 5). Nevertheless, there was considerable variation within a product class. This fact shows that the management of the composting is at least as important for the biological quality as the maturation advancement.

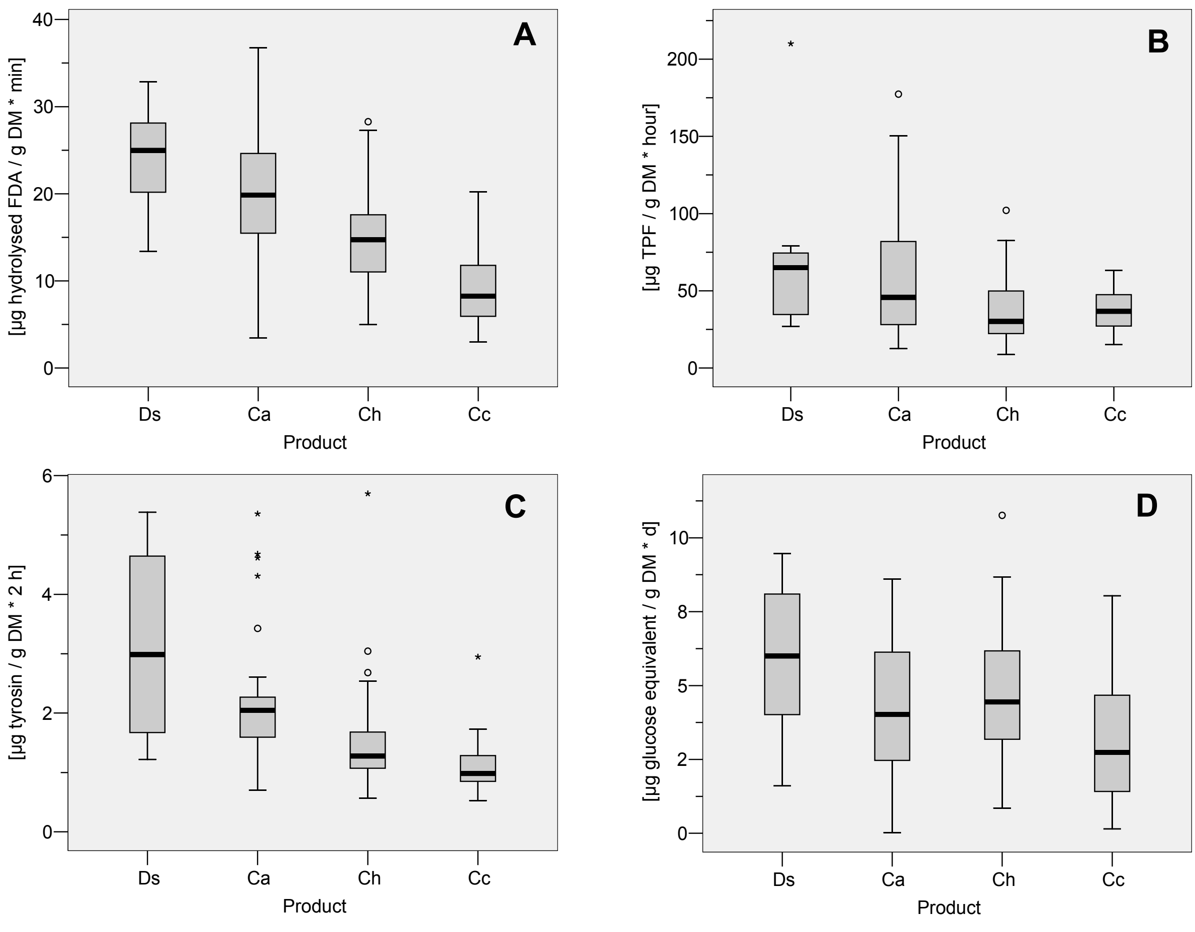


Figure 2. Enzymatic activities of Swiss composts. A: FDA activity; B: dehydrogenase activity; C: protease activity; D: cellulase activity.

Products according to ASCP Guidelines 2001 (Fuchs et al., 2001): Ds=digestate solid, Ca=compost for agriculture, Ch=compost for horticultural used, Cc=compost for covered cultures and private gardening.

Capacity of Swiss composts and digestates to protect plants against soil borne diseases

The suppressive potential of the composts against two pathogens was tested: *Pythium ultimum* and *Rhizoctonia solani*. *P. ultimum* causes damage mainly during germination. *R. solani* can attack the plant later and cause important damage also to larger plants.

The great majority of the composts significantly reduced the incidence of *P. ultimum* on cucumber. No differences were observed between the products of the different classes (fig. 4P). The protection of basil against *R. solani* was clearly less efficient (fig. 4R). It seems that the capacity of the composts to protect basil against *R. solani* reached a maximum at the stage Ch (fig. 4R). In agreement with other authors, we assume a general protection mechanism for *P. ultimum* and a specific mechanism in the case of *R. solani* (Hoitink et al., 1997; Fuchs, 2002, Fuchs and Larbi, 2005).

In both cases, there was large variability within the product classes. This indicates that the management of the composting process is a major factor influencing the suppressive capacity of the composts.

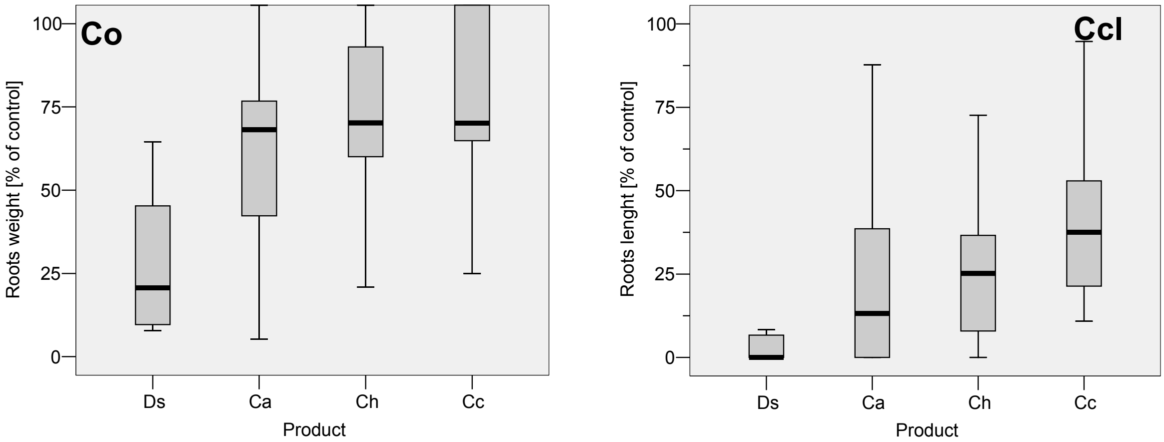


Figure 3. Phytotoxicity of Swiss composts, determined with the open (Co) and closed (Ccl) cress biotest.
The growth of plants in pots filled with compost was compared with the growth of plants in reference substrate (Co, S and B). Products were sampled according to ASCP Guidelines 2001 (Fuchs et al., 2001): Ds=digestate solid, Ca=compost for agriculture, Ch=compost for horticultural used, Cc=compost for covered cultures and private gardening.

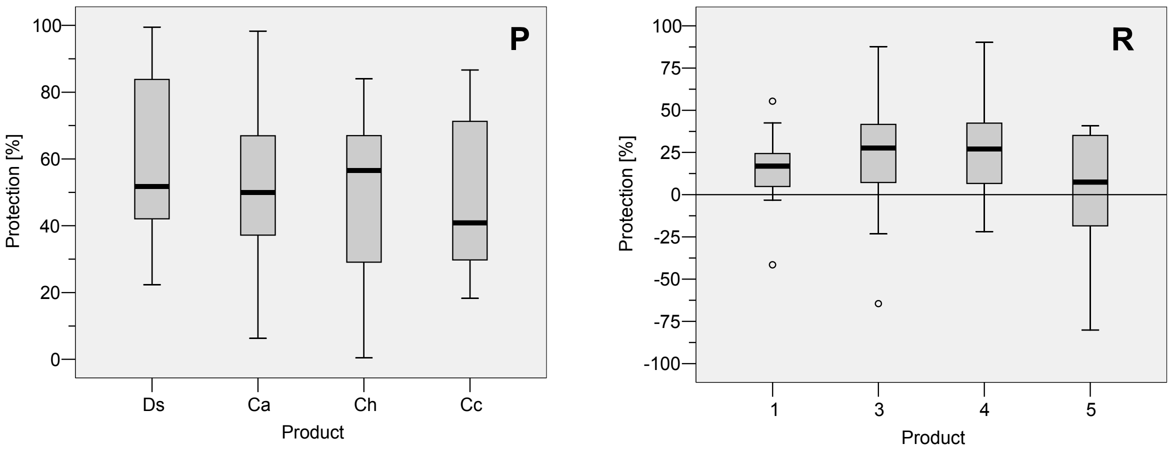


Figure 4. Capacity of Swiss composts to protect plants against soilborne diseases.
P: protection from cucumber against *Pythium ultimum*; R: protection of basil against *Rhizoctonia solani*. Products sampled according to ASCP Guidelines 2001 (Fuchs et al., 2001): Ds=digestate solid, Ca=compost for agriculture, Ch=compost for horticultural used, Cc=compost for covered cultures and private gardening.

<u>Influence of digestates and composts on the mineralized nitrogen content of soils</u>

The mineralized nitrogen in soil greatly influences plant growth. The influence of compost on the mineralized nitrogen content in soil depends, beyond the quantity of available nitrogen, also on the microbiological activity of the compost. Normally, digestates contain a high amount of mineralized nitrogen, mainly as ammonia, and they contain relatively low quantities in the form of lignin rich materials. Therefore, nitrogen immobilization is not expected after the utilization of such products. In our experiments, this was not always the case (fig. 5Ds). The reason for the immobilization of nitrogen in soil by some digestates is that these products are not used fresh, but after an inadequate subsequent treatment, during which the digestate has been dry and has lost all the ammonia.

In the other products, the evolution of the nitrogen immobilization risks can be clearly observed (Fig. 5). The composts for agricultural use are mainly young composts rich in undegraded lignin. The degradation of these woody substances in soil leads to a momentary immobilization of the available nitrogen (Fig 5Ca). When the composts were more mature, this risk decreased (fig. 5Ch and 5Cc).

Two compost parameters allowed to predict the risk of nitrogen immobilization with compost: the nitrate and the humic acids contents. As soon as the nitrification process began and nitrate was present, the composts did not immobilize nitrogen in the soil (fig. 6). Further, no relevant nitrogen immobilisation was observed with composts with a content of humic acids higher than 130 [mg / g oDM] (fig. 6).

Application of Swiss digestates and composts in the field

Two field experiments were performed in 2004 (loamy soil) and 2005 (sandy soil). Digestates and composts were applied in the spring before a maize crop. After harvest, soil samples were taken and analyzed.

The four composts for agriculture tested immobilized nitrogen in soil and had a negative influence on maize growth at the beginning of the culture (fig. 7). These results confirm the results obtained in the laboratory: compost with almost no NO_3-N Nmin and with humic acids contents lower than 130 [mg / g oDM] immobilized nitrogen also in the field (tab. 2). Notice that this point is relevant only for compost, and not for digestates (tab. 2). Nitrogen fertilization after 8 weeks (at the moment of the observations of fig. 7) allows correcting the nitrogen deficiency, so that at harvest no significant differences in the yield of the different treatments were observed (data not shown).

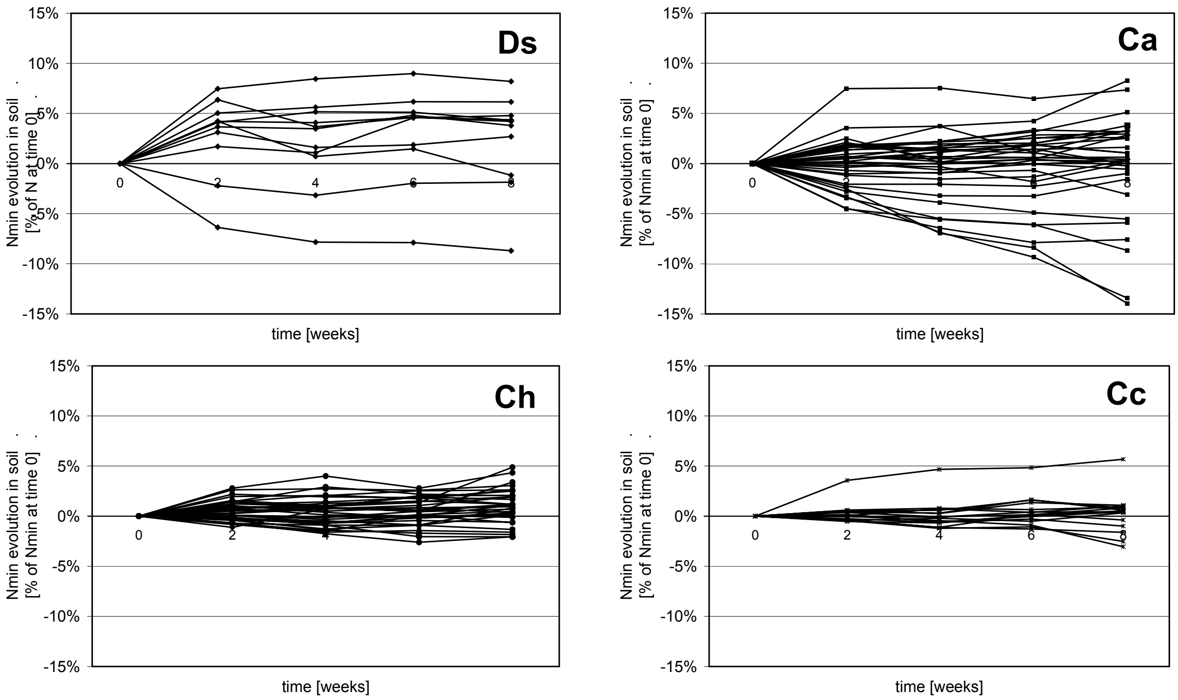


Figure 5. Influence of the addition of different composts to soil on the evolution of its mineralized nitrogen content.
For each compost, the mineralized nitrogen after 2, 4, 6 and 8 weeks are compared to the mineralized nitrogen present in the soil immediately after compost addition. Products according to ASCP Guidelines 2001 (Fuchs et al., 2001): Ds=digestate solid, Ca=compost for agriculture, Ch=compost for horticultural used, Cc=compost for covered cultures and private gardening.

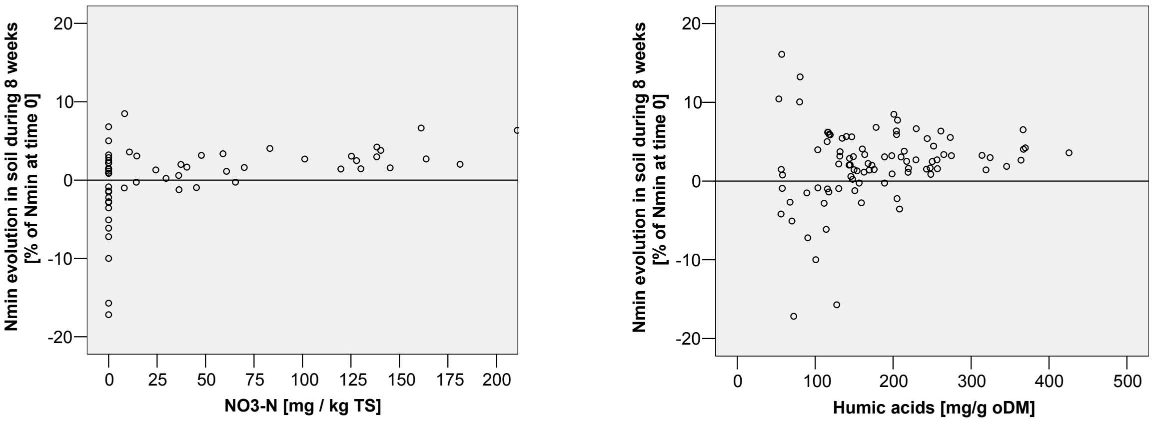


Figure 6. Relation between the evolution of mineralized nitrogen content in soil and nitrate content (left) and humic acids content (right) of compost.
For each compost, the mineralized nitrogen during 8 weeks is compared to the mineralized nitrogen present in the soil immediately after compost addition.

The digestates and the composts enhanced the soil pH for about 0.5 units (fig. 8). This effect is still observable after the harvest of maize. All the products enhanced also the biological activity in the soil. However, no influence could be observed on the disease receptivity of the soil. The enhancement of the pH did not correspond exactly with the Ca content of the composts, although in 2004 the two composts with the greatest quantity of calcium caused the highest rise of the soil pH (tab. 2)

Table. 2. Calcium contents, pH, nitrogen caracteristics, FDA-activities and humic acids content of the digestats and composts used in the fields experiments

Compost	Ca [g / kg DM]	NH_4-N [mg / kg DM]	NO_3-N [mg / kg DM]	N-supply or immobilization in soil during 8 weeks[1] [% of Nmin at time 0]	FDA activity [µg hydrolysed FDA / g DM*min]	humic acid content [mg / g oDM]
Field experiment 2004 (loamy soil)						
Digestate						
D1	46.6	606.7	260.7	-2.2	23.4	67.9
D2	65.2	1980.1	0.2	16.1	20.3	57.1
Compost for agriculture						
Ca1	68.4	35.9	0.2	-5.1	17.6	70.3
Ca2	49.7	66.8	0.2	-7.2	20.6	90.7
Compost for horticulture						
Ch1	81.5	4.4	65.4	-0.3	14.0	189.1
Ch2	64.3	119.8	267.7	2.7	14.1	364.1
Compost for covered cultures						
Cc1	91.5	4.5	45.3	-1.0	8.8	130.3
Cc2	63.7	10.0	59.0	3.4	15.9	163.7
Field experiment 2005 (sandy soil)						
Digestate						
D1	38.4	398.4	480.9	0.8	25.1	58.1
D2	152.3	1821.9	0.0	10.5	13.4	53.5
Compost for agriculture						
Ca1	39.4	19.3	0.0	-17.2	25.2	72.5
Ca2	58.2	132.2	0.0	-10.0	6.5	100.9
Compost for horticulture						
Ch1	65.7	0	366.1	5.5	10.6	273.4
Ch2	65.5	6.6	215.4	3.4	8.2	265.1
Compost for covered cultures						
Cc1	65.5	0.0	234.9	2.1	3.0	144.9
Cc2	60.8	9.6	363.8	4.4	6.8	252.0

[1] Incubation experiment by 25°C

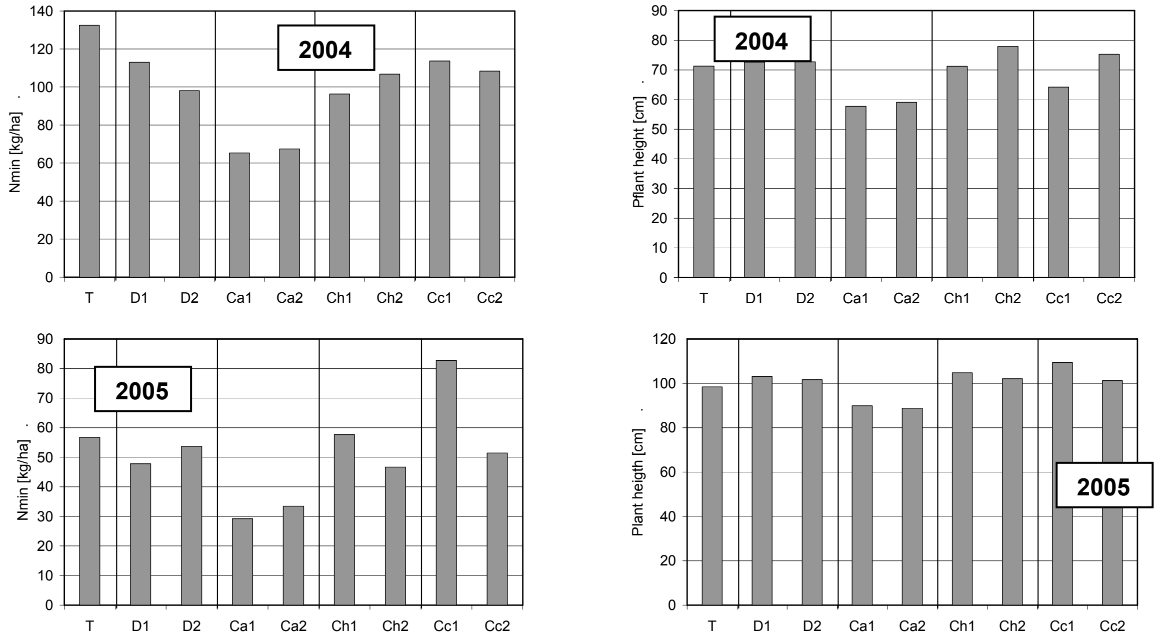


Figure 7. Influence of application of digestates and composts on the mineralized nitrogen content in soil and on the growth of maize. Application of 100m^3/ha before sowing. 2004: loamy soil; 2005: sandy soil. Measurement 8 weeks after sowing. Products sampled according to ASCP Guidelines 2001 (Fuchs et al., 2001): T: no digestate/compost; D=digestate solid, Ca=compost for agriculture, Ch=compost for horticultural used, Cc=compost for covered cultures and private gardening.

To characterize the biological activity of the soil, its enzymatic FDA activity was investigated after the maize harvest. Almost all digestates and composts increased the FDA activity between 10 and 30% (fig. 9). This shows that compost and digestate have a prolonged effect on the biology of the soil. The biological activity of the soil was not correlated with the biological activity of the compost or digestate applied (tab. 2). So it is probable that activity the soil microorganisms is enhanced by compost amendement, and that the activity of the compost microorganisme are not responsible for the observed enhanced enzymatic activities in the soil after the maize harvest.

The influence of digestates and composts on the receptivity of soil to diseases was investigate with the two pathosystems cucumber / *Pythium ultimum* and basil / *Rhizoctonia solani*. No influence of digestates or composts could be observed on the disease receptivity of the soil after one maize season (data not shown)..

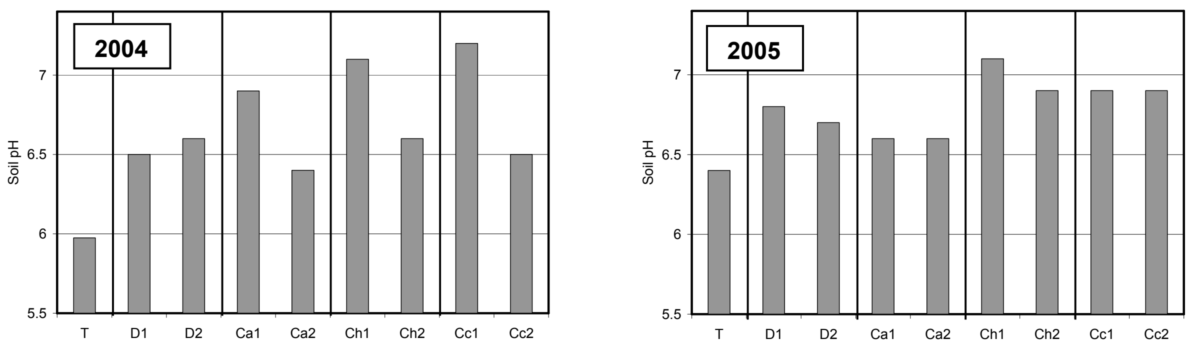


Figure 8. Influence of application of digestates and composts on the pH of the soil. Application of 100m^3/ha before sowing. 2004: loamy soil; 2005: sandy soil. Measurement 6 weeks after sowing. Products sampled according to ASCP Guidelines 2001 (Fuchs et al., 2001): T: no digestate/compost; D=digestate solid, Ca=compost for agriculture, Ch=compost for horticultural used, Cc=compost for covered cultures and private gardening.

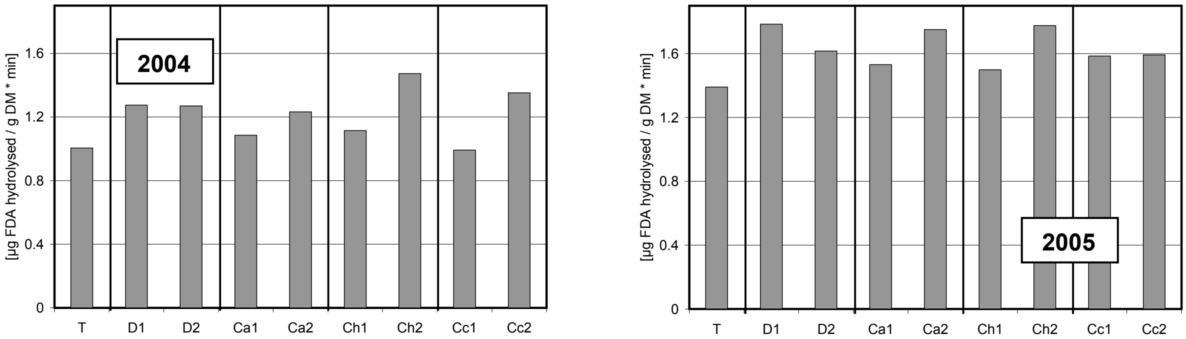


Figure 9. Influence of application of digestates and composts on the microbiological activity of the soil. Application of 100m^3/ha before sowing. 2004: loamy soil; 2005: sandy soil. Measurement 6 weeks after sowing. Products sampled according to ASCP Guidelines 2001 (Fuchs et al., 2001): T: no digestate/compost; D=digestate solid, Ca=compost for agriculture, Ch=compost for horticultural used, Cc=compost for covered cultures and private gardening.

Conclusions

In general, it was observed that the quality of the Swiss composts is good. No major problems were observed in any sample. One important reason for this is that only source separated organic materials are composted. Nevertheless, the characteristics of the different digestates and composts vary in an important way. Some parameters like the nutrient contents, the heavy metal contents and the salinity are influenced principally by the materials of origin. Other parameters like density, organic matter, enzymatic and respirometric activity and phytotoxicity are principally influenced by the maturity of the products. The potential for nitrogen immobilization is affected by maturity, by the composition of the composted materials and by the management of the composting process. The major influence of the biological quality of the composts (phytotoxicity and suppressive potential) seems to be due to the management of the composting process.

The differences observed between the different composts indicate clearly that the choice of the right compost for the envisaged utilization is very important. The results confirm that the four product classes proposed in Switzerland are useful for practice (solid digestate (Ds), compost for agricultural use (Ca), compost for horticultural use (Ch), compost for covered cultures and gardening (Cc)). They should be refined for some parameters, for example for the nitrogen immobilization potential. This is a very important parameter for the compost users, and this characteristic can show large variation especially in digestate and young composts. Field experiments carried out in the last two years show that the incubation tests presented here correlate very well with the performance of maize in the field (data not shown). More attention should be given to nitrogen immobilization, particularly when compost is used in spring.

In the field experiment, the digestates and composts showed very interesting effects on the soil pH and on the microbiological soil activity after one season of maize. These effects were observed in fields managed with good agricultural practise and with good fertility potential. Bigger effects are likely in fields with structural or fertility problems.

Acknowledgments

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