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Compost Amendments Affect Yield and Mycorrhizal Colonization of Corn (*Zea mays L.*) in Marginal Soils

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Abstract

Soil degradation problems have emerged as a major concern and are threatening the agricultural productivity in the world. In this investigation we studied whether or not compost application to a marginal soil (obtained from a field in Kamptal, Austria) can affect plant growth and root colonization by the arbuscular mycorrhizal fungus *Glomus mosseae* of corn (*Zea mays* L.).

The two composts tested were produced from biowaste alone or a mixture of biowaste and horse manure. Stable and mature composts were applied to the soil at a rate of 20% on a dry weight basis. Corn was planted in pots containing 6 kg of soil and grown in a greenhouse. The growth performance, yield and mycorrhizal root colonization was recorded after 9 weeks. The results indicate that compost application to marginal soils increased plant height, leaf area index and biomass dry matter yield of corn significantly ($p<0.001$) compared to the control without compost treatment. Plant height of 197 centimeter per plant, leaf area index of 3190 cm^2 per pot and dry matter yield of 270 g per pot was highest in the pure biowaste compost.

Roots from the pure biowaste compost treatment showed lower mycorrhizal colonization than roots of the biowaste/horse manure compost treatment. The highest mycorrhizal colonization (52%) was obtained in the control treatment. The reduced mycorrhizal colonization in the compost variants can possibly be attributed to the enhanced nutrient availability in compost treatments, as enhanced nutrient levels, such as phosphorus, in soils are known to reduce arbuscular mycorrhizal root colonization.

To summarize, we conclude that compost amendments although decreasing root colonization by symbiotic arbuscular mycorrhizal fungi improve the productivity of marginal soils and thus, could be of considerable interest specifically to farmers in developing countries with a lack of highly productive agricultural lands.

1 Introduction

Soil organic matter (SOM) is important for the soil as a source of and a sink for plant nutrients, the promotion of water retention, the reduction of erosion, and controlling the fate of applied pesticides (Gregorich et al., 1993). The continued depletion of SOM, as a result of extensive agricultural production, is an urgent problem in most soils throughout the world (Rivero et al., 2004). In Sub-Saharan Africa, the decrease in soil fertility is a fundamental impediment to agricultural growth and a major reason for slow growth in food production and poverty alleviation (Donovan and Casey, 1998). In some pocket areas in Europe such problems are also quite common. In the Kamptal valley (Austria) some agricultural fields are abandoned for forestry use because of their failure to produce crops due to low fertility levels. Therefore, there is a need to develop strategies to assure the development of organic matter (OM) that is gradually consumed and oxidized. The levels of SOM can be increased by the application of organic resources. In maintaining the quality and fertility of soils the content and quality of SOM is the most important factor (Reeves, 1997; Stevenson, 1994).

Both treated and untreated organic resources are different in their chemical and biological composition, and their risks in land application also differ (Rivero et al., 2004). Some of the risks involved in organic resource incorporation can be related to the high levels of toxic constituents and therefore the greater risk of heavy metals entering the food chain via plant uptake. There are also problems related to an excess supply of P, K and nitrates, a possible phytotoxcity of applied immature compost as well as the application of poor quality OM to the soil. The use of sludge can also result in persistent and apparent inhibition of arbuscular mycorrhizal (AM) fungi colonization due to toxic effects of NH_4^+ (Lambert et al., 1991).

One way to improve the quality of applied organic wastes is composting (the controlled microbial decomposition of organic matter), which yields excellent quality (stabilized) organic products that may be used as soil conditioners and/or organic fertilizers (Kulcu and Yaldiz, 2004). The quality of compost can be evaluated by different parameters such as determining the intensity and degree of humification process (Gressel et al., 1995; Stevenson, 1994) or the development of the C/N (Chiumenti et al., 2005). The beneficial effects of compost incorporation on soil properties, crop growth and soil microbiological activity and densities have been reported by several studies (Etana et al., 1999; Garcia-Gil, et al., 2000; Perez-Piqueres et al., 2006; Rivero et al., 2004; Terrance et al., 2004). More specifically, the biological activity in soils is related to the decomposable fractions of SOM that serve as the substrate for the flora and fauna found in a particular soil ecosystem (Tabatabai, 1996; Weil and Magdoff, 2004). Therefore, bioassay (crop and microbial) tests can be responsive, simple, cheap and appropriate indicators of soil quality changes due to organic fertilization. There are scarce publications on the suitability of composted biowaste (B) and horse manure (HM) wastes as a source of nutrients and soil improvement strategy in marginal soils. Such prob-

lems are high particularly in Sub-Saharan Africa as the area is classified as suitable for corn production (e.g., Byerlee, 1997).

Mycorrhizal fungi are stated to be a powerful component in soil environments and soil sustainability (soil quality) through soil rehabilitation and erosion control by stimulating soil aggregation (Abbott et al., 1992; Ortas, 2002). The symbiotic association of higher plant roots with arbuscular mycorrhizal (AM) fungi increases the transport of water and low mobile mineral nutrient from the soil to the plant (Fitter, 1997; Smith and Read 1997; Turk et. al., 2006). The major role of AM-fungi is to supply infected plant roots with phosphorus (P), which is a highly immobile element in soils. Nonetheless, the mycorrhizal function is strongly influenced by the soil environment, particularly those factors that control mineral fertility.

The aim of this study was to assess the growth response of corn in marginal soils treated with composted biowaste and horse manure composts and to asses the effects of these composts on mycorrhizal colonization of corn root.

2 Materials and methods

2.1 Production of compost

Laboratory experiments of composting process took place at the BOKU, Institute of Waste Management Laboratory as described in Getinet Desalegn et al., (2006). The two feedstocks of "B" (pure biowaste) and its blend with "HM" (horse manure) [("BHM" = biowaste/horse manure) (1:1)] wastes were composted in 200-liter waste bins over a 20-week period. The two composts were treated identically once the experiment began in October 2005. The composts were turned using a pitch fork once a week starting week 2 of the experiment until week 16. Thereafter, the material was allowed to mature with no turning during the curing phase until week 20.

2.2 Soils

The soil used was a gray Cambisol (coarse textured and young soils) type obtained from the Kamptal valley (Austria). The soil (0 to 20 cm depth) was collected at the beginning of the greenhouse experiments on April 2006, sieved through a 5-mm mesh and mixed with the composts. The main soil characteristics are presented in Table 1.

2.3 Treatments

Two composts/soil mixtures obtained from "B" and "BHM" and a control treatment (soil without compost) were compared. Six pots containing 6 kg of soil and compost (20 %) mixture in dry weight base (w/w) were prepared for each block, giving a total of 18 pots. The experimental set up was a complete randomized design with six replications.

Tab. 1: Characteristics of composted feedstocks and control soil used in the experiment. Treatments: "B" = composted biowaste, "BHM" = composted biowaste/horse manure and C = control (soil-only).

Parameters	"B"	"BHM"	Control
Moisture content [%] [DM]	48.0	53.5	22.2
pH [H_2O] [DM]	8.0	7.8	6.4
TOC [%] [DM]	18.5	26	1.01
TON [%] [DM]	1.47	1.75	0.09
C/N	13	15	11
Humic acids [OD/g oDM]	750	600	ND*
E4/E6	5.8	4.6	ND
EC [µS/cm]	2,500	3,400	65
NH_4-N [mg/kg] [DM]	210	583	11
NO_3-N [mg/kg] [DM]	2,600	2,200	115
P_2O_5 [mg/100g] [DM]	290	270	9.0
K_2O [mg/100g] [DM]	1,200	1,600	31
$CaCO_3$ [%] [DM]	7	6	0
Organic matter [%] [DM]	46	52	ND

*Not determined

2.4 Corn growth

On April 30th 2006, nine corn seeds (*Zea mays* L.), cultivar LG2306 (2005 harvest) were planted in each pot. After one week, plants were thinned to 2 plants per pot and after 2 weeks to 1 plant per pot. Plants were grown in the greenhouse with temperatures ranging from 20 to 30° C. Pots were watered once a day to 60 % of the water holding capacity. After 65 days of growth (silking stage) the plant height was determined and plants were harvested. The part above ground was separated into stem and leaf. The leaf area index was measured using scanning planimeters (LI-COR - model 3100, area meter, Lincoln, NE, USA). The plant material was dried for one week at 40 °C to determine the dry matter yield. For the determination of the N, P, K, Ca, Mg and TOC content dried stem and leaf samples were ground separately using a Wiley Mill Model 4 grinder with a 0.5 mm sieve.

2.5 Mycorrhizal colonization

Roots were washed thoroughly with running water on a sieve and a sub-sample was taken from the middle section of auxiliary roots 4 cm below the crown root. Each sub-sample was placed and preserved in a test tube that contained 50 % ethanol. To stain the AM fungus in the roots, roots were cut into ~1 cm segments

and cleared in 10 % KOH for 5 min at 90° C, rinsed 3 times in water and stained in a 5 % ink-vinegar solution (black ink, Shaeffer) for 5 min at 90° C (Vierheilig et al. 1998). Roots were subsequently destained in acidified water (using a few drops of vinegar). Colonization was determined according to the gridline intersect method described by Giovannetti and Mosse (1980).

2.6 Statistical analyses

The experimental data were statistically analyzed using SPSS 11.5 software (SPSS, 2003). One-way analysis of variance (ANOVA) with Tukey HSD ($P < 0.05$) was performed to find the effects of treatments. Finally, linear regression and the Pearson correlation between the mycorrhizal colonization and shoot % P of composts and control soil were determined as well.

3 Results and discussion

3.1 Corn growth

The application of the "B" (biowaste) and the "BHM" (biowaste/horse manure) composts affected the corn plant height, shoot dry matter yield and leaf area index significantly ($P < 0.001$) (Table 2). The highest values (corns plant height, shoot dry matter yield and leaf area index) were observed in the "B" compost and the lowest yield was observed in the soil-only control treatment. The main factor responsible for the higher yield responses in compost-treated soil may be the enhancement of the plant nutrient levels (K, Ca, Mg, N and P). The "B" compost produced substantial yield increases compared to the "BHM" treatment. That might be due to a more timely mineralization in "B" than in "BHM" relative to the plant´s NPK demand, resulting from a slight difference in the stability and maturity of these two composts (e.g., degree of humification) (Table 1). The highest nitrogen content of 2.11% in the corn shoot of the "B" compost treatment might be attributed to its higher available nutrients than in "BHM". Bernal et al. (1998) found that the addition of compost with different transformation times to soil affected plant growth, mainly at the first harvest due to nitrogen immobilization. The addition of organic matter to soil, especially in the form of stabilized compost, results in increased mineralization of nitrogen and also micronutrients (Dick and McCoy, 1993); therefore it might have led to higher N contents in our compost-treated plants.

Tab. 2: Effect of "B" (biowaste) and "BHM" (biowaste/horse manure) compost on corn growth and mycorrhizal colonization. Different letters within the columns under leaf or stem only indicate significant difference at $p<0.001$). Treatments: B = composted biowaste, BHM = composted biowaste/horse manure and C = control (soil-only).

Treatments	Plant height [cm]	Leaf area index [cm²]	Shoot dry matter yield [g/pot]	AM-fungal colonization [%]

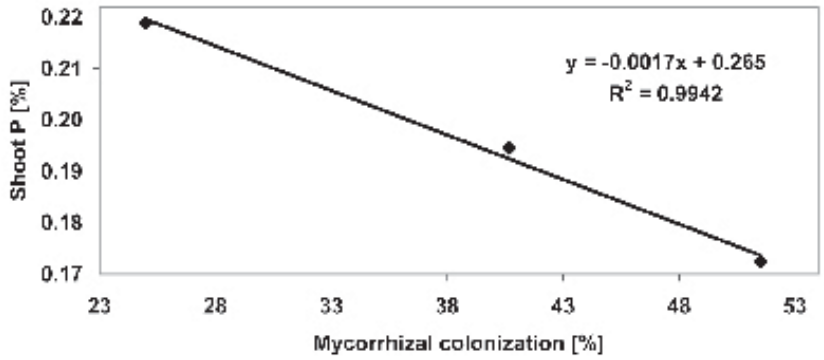


Fig. 1: Relationship between mycorrhizal colonization and % P of shoot in compost and control treatments (each point consists of 6 replicates).

"B"	197±5[a]	3190±77[a]	270±4[a]	25±6[a]
"BHM"	170±4[b]	2639±108[b]	227±5[b]	41±5[b]
Control	101±3[c]	1371±66[c]	94±3[c]	52±3[c]

3.2 Mycorrhizal colonization

Mycorrhizal colonization levels are shown in Table 2. The lowest root colonization was observed in plants grown in the "B" compost treatment, whereas plants grown in control soil-only treatment were extensively colonized. There was a significant negative correlation between the colonization level and the P content in the corn shoot ($R^2 = 0.9942$, $P<0.05$) (Figure 1). In corn it has been reported before that fertilization can reduce AM root colonization (Gavito and Miller, 1998a). Overall, it seems that the initial soil fertility mediates this response. Gavito and Miller (1998b) suggested that fertilization of naturally infertile soils reduces AM root colonization, while fertilization of naturally fertile soils has little or no effect.

3.3 Corn tissue

The nutrient composition of K, Ca, Mg, P and N in the corn shoot was affected in the compost treatments, whereas the C content was similar in all treatments (Table 3). The nutrient (K, Ca, Mg, P and N) content in the control treatment was significantly lower ($P<0.01$) than the compost treatments. Shoots of corn grown in B treated pots had consistently the highest nutrient content (K, Ca, Mg, P, and N; Table 3). That may be a reflection of the better quality of the "B" compost compared to the "BHM" compost in terms of nutrient release and composition.

Tab. 3: Effect of B (biowaste) and "BHM" (biowaste/horse manure) composts on corn shoot K, Ca, Mg, P, N and C content (n = 6). Different letters within the columns under leaf or stem only indicate significant difference at $p<0.001$). Treatments: "B" = composted biowaste, "BHM = composted biowaste/horse manure and C = control (soil-only).

Treatments (% DM)	**K**	**Ca**	**Mg**	**P**	**N**	**C**
	----------LEAF----------					
B	4.1^{a}	0.45^{a}	0.28^{a}	0.22^{a}	2.1^{a}	47.3^{abc}
BHM	3.7^{b}	0.40^{bc}	0.27^{bc}	0.20^{bc}	1.6^{b}	45.5^{abc}
C	2.8^{c}	0.28^{bc}	0.19^{bc}	0.17^{bc}	1.1^{c}	46.1^{abc}
	----------STEM----------					
B	5.0^{a}	0.27^{a}	0.26^{a}	0.28^{a}	0.8^{a}	44.7^{abc}
BHM	4.5^{b}	0.16^{bc}	0.17^{bc}	0.20^{b}	0.7^{b}	44.7^{abc}
C	3.4^{c}	0.15^{bc}	0.15^{bc}	0.16^{c}	0.5^{c}	44.7^{abc}

The average contents of Mg, Ca and P were not significantly different between "BHM" and control treatments.

4 Summary and conclusions

Our findings have shown that composting can contribute to produce agriculturally useful compost if suitable materials are used and composting is operated properly.

The greater availability of K, Ca, Mg, P and N in the compost treatments resulting in an enhanced plant growth is an indicative for a general improvement in the chemical fertility of this marginal soil. On the other hand, although the positive effect of compost on soil microbial activity is well known, we found a negative relationship between AM colonization and quality of applied compost.

This study could have practical relevance in developing countries where there are more degraded agricultural lands and reluctant farmers to use organic resources on their fields. Mainly due to the lack of observable effects of organic materials on their crop yield and soil quality, farmers show little interest in the use of organic resources.

A proven positive effects of compost on their crop yield and soil quality since the beginning could assure them to use organic resources in their fields. Therefore compost quality improvement needs to get much more attention. Additional long-term field/greenhouse studies are needed to better understand the effects of compost incorporation on soil physical, chemical and biological properties of marginal soils.

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