doi:http://dx.doi.org/10.15414/afz.2015.18.si.98-101

Humus, nitrogen and energy balances and greenhouse gas emissions of organic farming with biowaste compost fertilization

Eva Erhart[1*], Harald Schmid[2], Kurt-Jürgen Hülsbergen[2], Wilfried Hartl[1]

[1] *Bio Forschung Austria, Vienna, Austria*

[2] *Technical University Munich, School of Life Sciences Weihenstephan, Freising, Germany*

Soil organic matter plays a key role for soil quality and holds a large carbon sequestration potential. Compost fertilization is a way to increase soil organic matter content. Here, humus, nitrogen and energy balances and greenhouse gas emissions were calculated for a 14-year field experiment using the model software REPRO. Humus balances showed that compost fertilization at a rate of 8 t ha^{-1} y^{-1} (C1) resulted in a positive balance of 115 kg C ha^{-1} y^{-1}. With 14 and 20 t ha-1 y^{-1} compost (C2 and C3), respectively, humus accumulated at rates of 558 and 1021 kg C ha^{-1} y^{-1}. With mineral fertilization at rates of 29 to 63 kg N ha^{-1} y^{-1} (N1, N2, N3), balances were moderately negative (-169 to -227 kg C ha^{-1} y^{-1}), while a clear humus deficit of -457 kg C ha^{-1} y^{-1} showed in the unfertilized control. Compared with measured soil organic carbon (SOC) data REPRO predicted SOC contents fairly well with the exception of the treatments with high compost rates. Here REPRO clearly overestimated SOC contents for this site. Nitrogen balance was about zero in the control and in treatment N1, 10 to 20 kg N ha^{-1} y^{-1} in C1, C2, N2 and N3, and 29 kg N ha^{-1} y^{-1} in C3. Energy efficiency, as described by the output/input ratio, was highest in the control, followed by C1. Mineral fertilization treatment N3 was most energy intensive. The REPRO GHG balance indicated net carbon sequestration already with medium compost rates (C2), and net carbon sequestration of 1700 kg CO_2-eq ha^{-1} y^{-1} in C3. Mineral fertilization yielded net GHG emissions of around 2000 kg CO_2-eq ha^{-1} y^{-1}. The highest GHG emissions had the unfertilized control due to SOC decline. The findings underline that compost fertilization holds a potential for carbon sequestration and for the reduction of greenhouse gas emissions.

Keywords: modelling, REPRO, soil organic carbon, greenhouse gas emissions

1 Introduction

The most important benefit of using compost is the increase in soil organic matter (SOM). Numerous experiments show that compost fertilization regularly leads to a distinctive increase in the humus content of the soil. Such increases were reported from field trials with 3 to 20 years duration, with annual compost applications ranging from 6 to 90 t ha^{-1} and situated on a broad range of sites and soil types (Clark et al., 1998; Diez and Krauss, 1997; Hartl and Erhart, 2005; Stöppler-Zimmer and Petersen, 1997).

Soil organic matter plays a key role in maintaining soil aggregation and aeration, hydraulic conductivity, and water availability; cation-exchange and buffer capacity; and the supply of mineralizable nutrients (Khan et al., 2007). Because these qualities of soil organic matter are crucial for agricultural use, humus balancing methods were developed in order to estimate changes in soil humus content of agricultural fields. Humus balances calculate the balance between organic matter input from crop residues and organic fertilizers, and humus mineralization.

The aim of the present study was to assess the effect of compost fertilization on humus, nitrogen and energy balances and greenhouse gas emissions with a modelling approach.

* **Correspondence:** Eva Erhart, Bio Forschung Austria, Esslinger Hauptstraße 132, A-1220 Vienna, Austria. E-mail: e.erhart@bioforschung.at

2 Material and Methods

In order to assess the effects of compost fertilization as compared to the use of mineral fertilizers, the field experiment with compost fertilization 'STIKO' was set up in 1992 near Vienna, Austria, on a Molli-gleyic Fluvisol. It included three treatments with compost fertilization (C1, C2 and C3 with 8, 14 and 20 t ha^{-1} y^{-1} wet wt. on average of 14 years), three treatments with mineral nitrogen fertilization (N1, N2 and N3 with 29, 46 and 63 kg N ha^{-1} y^{-1} on average) and an unfertilized control (0) in six replications. Except for the fertilization, the experiment was managed according to the European Union (EU) regulation 2092/91 on organic farming. In the field trial, biowaste compost from the composting plant of the City of Vienna was used. Data from the field experiment (from 14 experimental years) were fed into the model software REPRO to calculate humus, nitrogen and energy balances and greenhouse gas emissions. The model software REPRO (REPROduction of soil fertility; Hülsbergen, 2003) couples the balancing of C, N and energy fluxes. For the determination of the net greenhouse effect, REPRO calculates C sequestration in the soil, CO_2 emissions from the use of fossil energy and N_2O emissions from the soil.

3 Results and Discussion

Humus balances showed that compost fertilization at a rate of 8 t ha^{-1} y^{-1} (C1) resulted in a positive humus balance of +115 kg C ha^{-1} y^{-1}. With 14 and 20 t ha^{-1} y^{-1} compost (C2 and C3), respectively, humus accumulated at rates of 558 and 1021 kg C ha^{-1} y^{-1}. With mineral fertilization at rates of 29 – 63 kg N ha^{-1} y^{-1} (N1 – N3), balances were moderately negative (-169 to -227 kg C ha^{-1} y^{-1}), while a clear humus deficit of -457 kg C ha^{-1} y^{-1} showed in the unfertilized control.

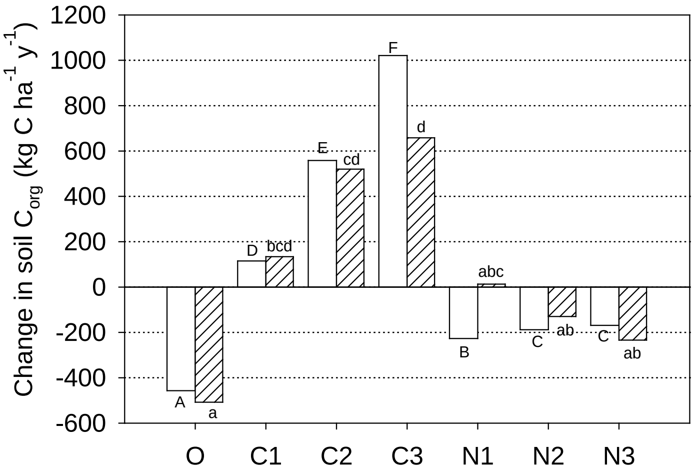

Figure 1 Humus balance (kg C ha^{-1} y^{-1}). Plain bars: Results of the humus balance. Hatched bars: derived from soil analysis. Treatments with the same letters are not significantly different at $P \leq 0.05$

Compared with measured soil organic carbon data REPRO predicted soil organic carbon contents fairly well with the exception of the treatments with high compost rates. Here REPRO clearly overestimated soil organic carbon contents for this site.

N balance was about zero in the control and in treatment N1, 10 to 20 kg ha^{-1} y^{-1} in treatments C1, C2, N2 and N3, and 29 kg ha^{-1} y^{-1} in treatment C3. Soil organic nitrogen increased for 53 kg N ha^{-1} y^{-1} in treatment C2 during the experiment, which corresponds to 43 % of the nitrogen applied via compost. While soil N concentration was calculated to decline for 43 kg ha^{-1} y^{-1} in the unfertilized control and for 16 to 22 kg ha^{-1} y^{-1} in the mineral fertilizer treatments, it increased for 11 to 97 kg ha^{-1} y^{-1} in the compost treatments. Significant increases in soil organic nitrogen in the compost treatments had also been measured earlier at the field experiment (Hartl and Erhart, 2005). It is essential to include Δ SON in the nitrogen balance, otherwise N losses would be distinctly overestimated in the compost treatments and underestimated in the mineral fertilizer treatments.

Averaged across years, the unfertilized control had the lowest energy input (6.0 GJ ha^{-1} y^{-1}). In the compost treatments, total energy input was 27 % to 60 % higher, while in the mineral fertilizer treatments it was 50 % to 70 % higher than in the control. Treatment N3 had the highest energy input (10.2 GJ ha^{-1} y^{-1}). Direct energy use ranged from 39 % of the total energy inputs in N3 to 63 % in the control. Fuel consumption was slightly higher in the compost treatments due to compost application. Regarding indirect energy inputs, fertilizer made the greatest contribution to total energy input with 30 % to 38 % in the treatments with mineral fertilization, although the amounts of fertilizer applied were relatively low. Energy efficiency, as described by the output/input ratio, was highest in the control, followed by C1. Mineral fertilization treatment N3 was most energy intensive.

The greenhouse gas balance indicated net carbon sequestration already with medium compost rates (C2), and net carbon sequestration of 1700 kg CO_2-eq ha^{-1} y^{-1} in C3. Mineral fertilization yielded net greenhouse gas emissions of around 2000 kg CO_2-eq ha^{-1} y^{-1}. The highest greenhouse gas emissions had the unfertilized control due to the degradation of soil organic matter and lowest organic matter input. If GHG emissions are calculated using soil carbon data from soil analysis instead of those derived from the humus balance, net carbon sequestration is lower in C2 and C3.

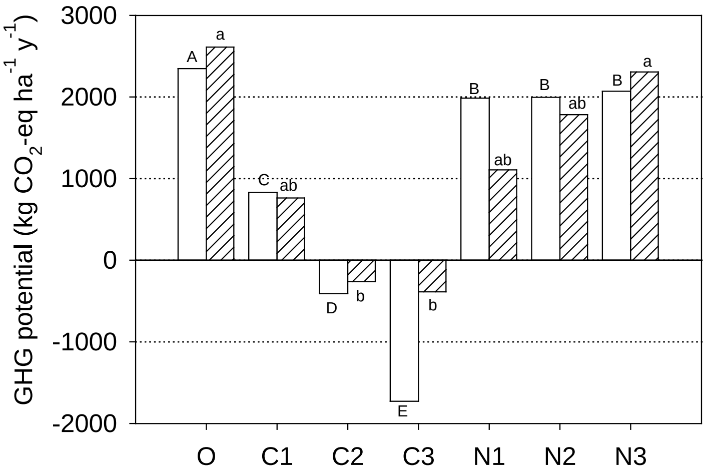

Figure 2 Greenhouse gas (GHG) potential (kg CO_2-eq ha^{-1} y^{-1}). Plain bars: calculated with soil carbon sequestration derived from the humus balance. Hatched bars: calculated with soil carbon sequestration derived from soil analysis. Treatments with the same letters are not significantly different at $P \leq 0.05$

4 Conclusions

Humus and GHG-balances calculated with REPRO corroborated that compost has a positive effect on the soil by increasing SOC stocks and showed that compost fertilization holds a high potential for carbon sequestration and for the reduction of greenhouse gas emissions.

5 Acknowledgements

Financial support was provided in the Project BIORES-AT-HU by the European Union through the European Regional Development Fund in the framework of the programme “European territorial co-operation Austria-Hungary 2007-2013” and co-financed by the City of Vienna.

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