Effects of long-term farmyard manure applications on soil organic matter, nitrogen mineralization and crop yield – a modeling study –

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Abstract

To develop sustainable cropping systems we need to predict both short-term and long-term effects of management practices on soil fertility. For this purpose agro-ecosystem simulation models are valuable tools. We used the Daisy model to simulate a three-year crop rotation (beetroot, onion, white clover, potato) over a period of 40 years. With this rotation, three rates of farmyard manure were tested (0, 15, 28 t ha^{-1} year^{-1}). After 40 years without manure soil organic matter carbon (SOM-C) decreased by approximately 40%, and increased by 27% with the highest application rate. SOM turnover did not reach equilibrium at the end of the experiment. Nitrogen mineralization from SOM followed in the long-term (40 years) the slowly changing time courses of SOM. However, manure applications affected mineralization and hence crop yield and nitrogen losses much more in the short-term (1 to 2 years) than in the long-term.

Introduction and Objectives

Soil fertility is strongly affected by type and amount of soil organic matter (SOM), which in turn is influenced by soil texture, by local climate and by management practices such as soil tillage, crop rotation and organic fertilization. To develop sustainable cropping systems we need to predict both short-term and long-term effects of management practices on soil fertility. Under a constant long-term management regime SOM turnover reaches equilibrium, where the properties of SOM stay constant over time. At this point rates of mineralized and added nitrogen (N) and carbon (C) are the same. Changes in soil management inevitable lead to changes in SOM and hence to changed C and N mineralization.

The objective of our study was to quantify the effects of changed application rates of organic fertilizers. The application of organic fertilizers, such as farmyard manures, affects several processes in plants and soils. However, in our study we focused on (1) the amount of N mineralized from SOM and manure, (2) the impact of mineralized N on crop yield and N losses to the environment and (3) the time span required for reaching a new equilibrium of SOM turnover.

Methods

The study was carried out with the agro-ecosystem simulation model Daisy (Abrahamsen and Hansen 2000). Parameter files for crops and manure were taken from the Daisy home page (2006). Farmyard manure was parameterized as 'Cattle manure' described in Daisy's library, but we changed decomposition rates according

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to Petersen et al. (2004), and C-, N-, NO_3, NH_4 and dry matter fraction according to KTBL (2005). Soil properties were set according to an experimental field of our research station Großbeeren, located near Berlin, Germany. Humus content was set to 0.009 kg kg^{-1} and fractions of sand, silt and clay to 0.91, 0.041 and 0.046 kg kg^{-1}, respectively.

We simulated a three-year crop rotation, that is customary for vegetable growers in Lower Saxony, Germany (Laber personal communication): **Beetroot** *(Beta vulgaris subsp. rapacea)* 15th May to 30th Sep – **fallow** – **Onion** *(Allium cepa)* 1st May to 15th Aug – **White clover** *(Trifolium repens)* 30th Aug to 1st May – **Potato** *(Solanum tuberosum)* 30th May to 30th Oct – **fallow**. In the simulation, farmyard manure was applied in year 1 of the crop rotation on 1st of October and 1st of May, and in year 3 on 30th of October. This rotation was repeated over 40 years. Three manure application rates were tested: (0) **no manure**, (1) **15 t wet weight ha^{-1}** [containing 75 kg N ha^{-1} and 10,500 kg C ha^{-1}], (2) **28 t wet weight ha^{-1}** [containing 140 kg N ha^{-1} and 39,200 kg C ha^{-1}]. Initially the crop rotation was simulated with historical weather data from the site in Großbeeren. However, year-to-year variation of weather interacted with the effects of fertilizer treatments. Therefore, to illustrate fertilizer effects more clearly, simulations shown in this paper were carried out with weather of a single year (1990), which was repeatedly used over 40 years. The averages of air temperature and global radiation were 10.5 °C and 117 W m^{-2}, respectively.

Results and Discussion

Under our experimental conditions an average application rate of 15 t ha^{-1} $year^{-1}$ farmyard manure lead to constant soil organic matter carbon (SOM-C), whereas application of 0 and 28 t ha^{-1} $year^{-1}$ resulted in decreased and increased SOM-C (Fig. 1 A). After 40 years without manure, SOM-C decreased by approximately 40%, and increased by 27% with the highest application rate. This shows that soil management strongly affected SOM. The time-courses of SOM for both the zero and the high manure application rates did not show saturation. Therefore, even 40 years after the onset of the experiment a new equilibrium of SOM turnover was not reached.

The long-term nitrogen mineralization from SOM followed the time courses of SOM-C (regression lines in Fig. 1 b). The long-term effect, which is shown by the slope of the regression lines, was minor compared to the short-term effects of manure applications and crop rotation, which are described by the variation around the regression lines. Time courses of nitrate leaching closely mirrored the time courses of N mineralization (Fig. 1 c). N losses of up to 60 kg ha^{-1} $year^{-1}$ indicate the need to reconsider amount and timing of manure application in order to reduce N losses. The maximum rooting depth on our site was one meter. We therefore considered N as being “leached” when transported to a soil depth below one meter. N losses would be less on fields where roots can grow deeper and catch the leaching N.

Dry matter yields of beetroot, onion and potato were similarly affected by the treatments. Therefore, only beetroot is shown as an example (Fig. 2). Manure application rates had a substantial effect on yield. Highest yields were obtained with 28 t ha^{-1} $year^{-1}$. A long-term effect on crop yield was obvious only with zero manure application, where crop growth was strongly limited by N shortage.

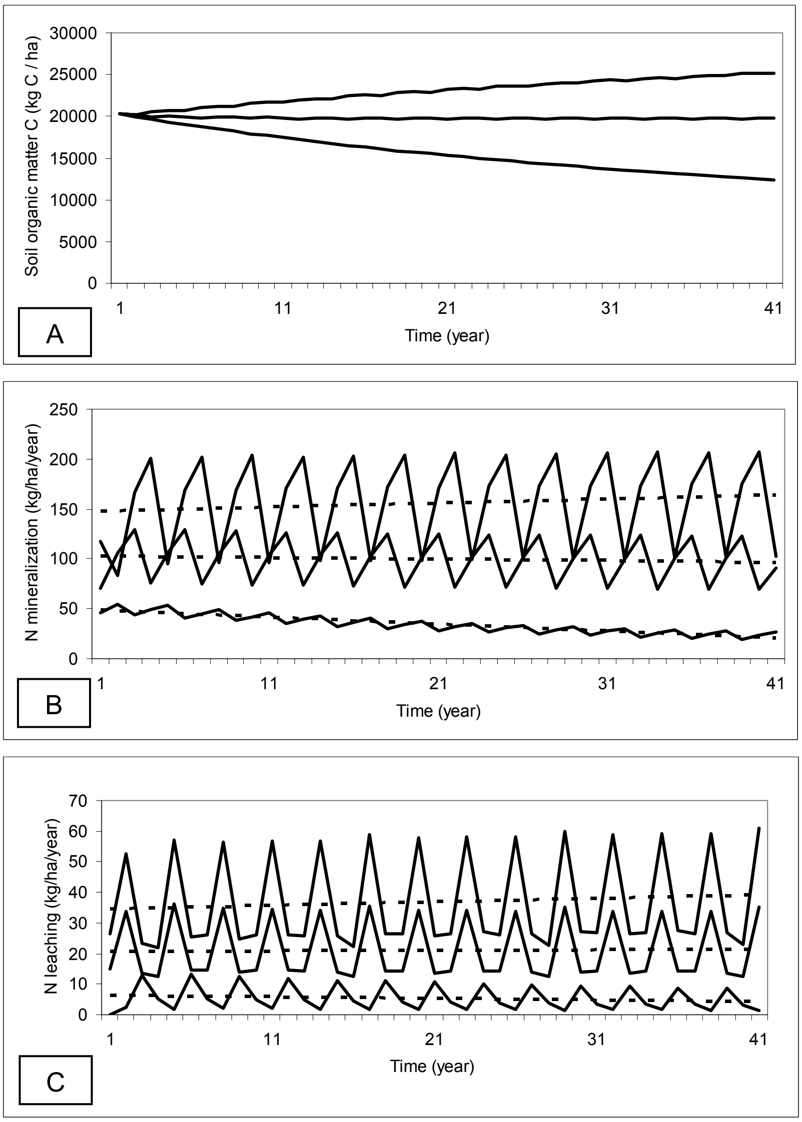

Fig. 1 Soil organic matter carbon (A), nitrogen mineralization (B) and nitrate leaching below one meter soil depth (C) as affected by time and by manure application rate. Solid lines show data for application rates of 0, 15 and 28 t ha^{-1} (bottom, middle and top line, respectively), dashed lines are regression lines.

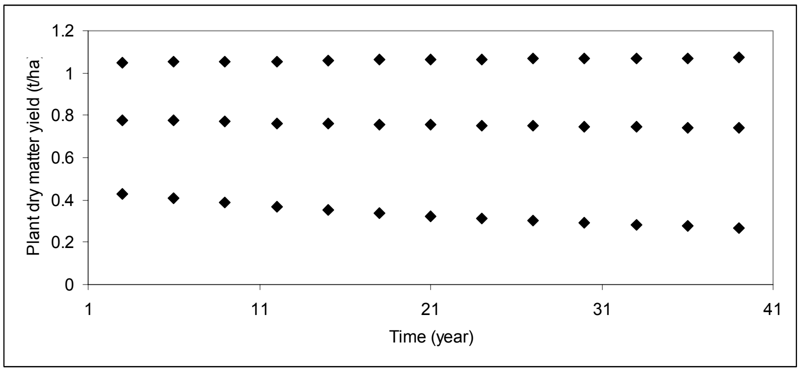

Fig. 2 Dry matter yield of beetroot as affected by time and by manure application rate. Dots show data for application rates of 0, 15 and 28 t ha^{-1} (bottom, middle and top line, respectively)

Conclusion

Modelling is a valuable tool to analyse short-term and long-term processes in agro-ecosystems. Models are able to predict effects of soil management on SOM turnover, and thereby help to identify management strategies with high crop yield and little N losses to the environment. The Daisy model has been validated successfully in agricultural crop rotations (e.g. Muller 2006). In a forthcoming study, we will compare our simulations with data from experiments with long-term vegetable crop rotations.

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References

Petersen B.M., Berntsen J., Hansen S., Jensen L.S. (2004) : CN-SIM : a model for the turnover of soil organic matter. I. Long- term carbon and radiocarbon development. Soil Biology & Biochemistry 37:359-374.

Muller T, Thorup-Kristensen K, Magid J, Jensen LS, Hansen S. (2006): Catch crops affect nitrogen dynamics in organic farming systems without livestock husbandry - Simulations with the DAISY model. ECOLOGICAL MODELLING 191:538-544.

Daisy home page (2006): http://www.dina.kvl.dk/~daisy/index.html, (accessed 2006-08-01).

KTBL (ed.) (2005): Faustzahlen für die Landwirtschft, KTBL-Schriftenvertrieb im Landwirtschaftsverlag Münster-Hiltrupp, Germany, 13th Edition.