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The positive relationship between soil quality and crop production: A case study on the effect of farm compost application

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ABSTRACT

In order to ensure sustainable agriculture, and for evaluating the effects of management practices on soil processes, tools for assessing soil quality are required. The development and use of a multiparameter index, which includes a wide range of soil properties, have been tested and found useful by several studies. However, soil quality measurements are 'stand-alone' tools unless they are either linked to important soil functions, used to characterize (agro)ecosystems or used to predict sustainability or productivity. In our study, the relationship between crop production and soil quality was assessed in a six year old field experiment studying the effect of farm compost (FC) amendment in a crop rotation of potato, fodder beet, forage maize and Brussels sprouts. To justify the hypothesis that repeated FC amendment results in both improved soil quality and consequently higher crop yields, a wide range of chemical, biological and physical soil properties were measured and integrated into a soil quality index (SQI). Next, crop yields were used as a functional goal to verify the causal relationship between SQI and crop production. Our results showed that there were significant changes in chemical, physical and biological soil quality as a result of repeated FC amendment. This was evidenced for example by a remarkable increase in both soil organic carbon (SOC) and total N content. Microbial biomass, the relative amount of bacterivorous nematodes and earthworm number were significantly increased as well and, together with SOC and total N, indicated as the dominant factors in assessing soil quality. The integration of these key indicators into the SQI revealed higher SQI values when FC was applied. In addition, crop yields were increased in all FC treated plots by which SOC was pointed out as the most important indicator influencing crop production. Finally, a causal relationship was observed between soil quality and the yield of potato and fodder beet. We conclude that our SQI may be a promising and useful tool to compare different (soil) management practices in relation to a strategic, regional goal, e.g., sustainable high yields. Before generalizing, we recommend a thorough validation of our SQI in other long-term field experiments.

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1. Introduction

Intensive agricultural management has brought economic and social development but it has also contributed to land degradation in terms of soil organic matter decline, soil erosion, biodiversity loss and ground and water contamination (Kirschenmann, 2010). During the last two decades, there is growing awareness that besides the production of food and fibers, the maintenance of environmental quality is also one of the functions of soils (Glanz, 1995; Liu et al., 2006).

In an attempt to reverse the trend of declining soil quality, researchers try to identify suitable soil management practices (Sharma et al., 2008). Tools for assessing soil quality are required in order to ensure sustainable agriculture, and for evaluating the effects of management practices on soil processes. Monitoring individual changes in predominant physical, chemical or biological soil properties is one way of assessing soil quality. Ideally, evaluation of soil quality should involve all three indicators (Bhardwaj et al., 2011) since agricultural management affects all major components – physical, chemical and biological – of a soil system. Moreover, the combination of several indicators into a single index could help to interpret data from different soil measurements and show whether management systems are having the desired result for productivity and environmental protection (Sharma et al., 2005).

Soil quality measurements are 'stand-alone' tools unless they are either linked to important soil functions, used to characterize (agro)ecosystems or used to predict sustainability or productivity (Herrick, 2000). Within the framework of agricultural production,

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high soil quality should maintain high productivity without significant soil or environmental degradation (Govaerts et al., 2006; Griffiths et al., 2010). Although the development and use of a multiparameter index have been tested and found useful by several studies (Bhardwaj et al., 2011; Diack and Stott, 2000; Doran and Parkin, 1994; Mandal et al., 2008; Sharma et al., 2008), most of the research efforts focused only on the assessment of soil quality. Few of them have related soil quality with crop yields (de Lima et al., 2008; Hanse et al., 2011; Parfitt et al., 2005; van Eekeren et al., 2010).

In our study, the relationship between crop production and soil quality was assessed in a six year old field experiment studying the effect of farm compost amendment. Compost amendment is a management option likely to enhance soil quality and crop yields as indicated by a considerable body of research (Arthur et al., 2010; D'Hose et al., 2012; Diacono and Montemurro, 2010; Leroy et al., 2008). To justify the hypothesis that repeated farm compost amendment results in both improved soil quality and higher crop yields, key soil quality indicators were identified after which a soil quality index (SQI) was calculated by integrating these indicators. Crop yields were used as a functional goal to verify the causal relationship between SQI and crop production.

2. Materials and methods

2.1. Study site and experimental layout

A long-term field experiment was initiated in 2004 at Ghent University's experimental farm in Melle situated at 50°59′N, 03°49′E at an elevation of 11 m above sea level. Climate is fully humid temperate with warm summers (Kottek et al., 2006) with approximately 725 mm of annual precipitation and a mean annual temperature of 9 °C. Weather data (average monthly temperatures, total radiation and total precipitation) of the experimental site were registered for the period 2004–2010. Growing conditions were fairly close to normal (average values for the period 1907–2010). The soil is an Alfisol with a loamy sand texture (USDA). The clay (<2 μm), silt (2–20 μm), fine sand (20–200 μm) and coarse sand (200–2000 μm) content is 86, 116, 758 and 40 g kg^{-1}, respectively. The experimental design was a strip–split plot design (Gomez and Gomez, 1984) with three replicates. During the experimental period, crop was the horizontal factor, fertilizer nitrogen (N) the vertical factor and farm compost (FC) the subplot factor. Four crops were grown in the following succession: fodder beet (FB; *Beta vulgaris* L. ssp. *vulgaris* var. *crassa*), forage maize (FM; *Zea mays* L. ssp. *mays*), Brussels sprouts (BS; *Brassica oleracea* L. var. *gemmifera*) and potato (Po; *Solanum tuberosum* L.). Soil was usually tilled in mid-April. The field was ploughed and rotary-harrowed once the soil was dry. Fertilizers and farm compost were spread by hand on the plots and incorporated in the soil by rotary-harrowing till a depth of 10–15 cm. Plots received 0, 100 or 200 kg N ha^{-1} y^{-1}, applied as ammonium nitrate 27% N and 0 or 50 m^3 FC ha^{-1} y^{-1} further indicated as FC0 and FC1 plots, respectively. FC was analyzed prior to each application. This revealed substantial differences in composition from year to year (Table 1). Methods for compost analyses are described in Steel et al. (2012).

We attempted for equal P and K fertilization for each plot. As it is known that compost releases nutrients slowly, unlike mineral fertilizers, we used the amount of plant-available P and K in the compost instead of total P and K as a basis for equal P and K fertilization. FC0 plots received 332 kg K ha^{-1} y^{-1} from muriate of potash (33.2% K). On the FC1 plots, the amount of plant-available K that was applied through the compost was completed with muriate of potash up to 332 kg K ha^{-1} y^{-1}. Compost was the only phosphate source for the FC1 plots. FC0 plots received triple superphosphate (19.6% P) in an amount equivalent to the plant-available P amount applied with the farm compost on FC1 plots. Plant-available K and P were defined as the amount of K and P extracted (1:5 vol/vol) in ammonium acetate at pH 4.65. As we expected a shortage of P in the soil after several years, from 2010 on, FC0 plots received 35 kg P ha^{-1} y^{-1} while on the FC1 plots, the amount of plant-available P in the compost was completed with triple superphosphate up to 35 kg P ha^{-1} y^{-1}. In the mean time, we also lowered the K fertilization up to 249 kg K ha^{-1} y^{-1} on all plots. Forage maize and fodder beet were sown and potatoes were planted between 20 April and the beginning of May in all years. Brussels sprouts were planted by the end of May. Weeds were controlled with appropriate herbicides. Fungicides in Brussels sprouts and potato, and insecticides in Brussels sprouts, were applied according to good agricultural practice. Sowing and planting were performed using small agricultural equipment. The experiment is explained in more detail in D'Hose et al. (2012).

2.2. Soil sampling and analysis

Soil samples were drawn after the sixth (fall 2009) and during the seventh (spring and fall 2010) cropping season of the study. Because of practical limitations, all samples were taken at one N fertilizer level, being 200 kg N ha^{-1} y^{-1}. This level was chosen based on two considerations: (i) 200 kg ha^{-1} is regarded as being closest to current practice for the four crops and (ii) we wanted to be sure not to detect a N effect only from the application of compost. The soils were analyzed for soil organic carbon (SOC), hot-water extractable carbon (HWC), total N, ammonium lactate extractable P and K, bulk density (BD), penetration resistance (Pen), aggregate stability, microbial biomass C (Cmic), earthworms, nematodes and ergosterol (indicator for fungal biomass). Sampling date(s) and depth and the analytical methods used for measuring the soil properties mentioned above are given in Table 2. To classify the aggregate stability of the treatments, the stability index (SI) was calculated using the equation:

$$SI = (MWD_{dry} - MWD_{wet})^{-1}$$
$$\text{with } MWD = \sum_{i=1}^{n} X_i T_i$$

where MWD is the mean weight diameter (mm), X_i is the mean diameter of each size fraction (mm) and T_i is the proportion of the total sample mass in the corresponding size fraction.

To describe the characteristics of the nematode community (other than total nematode density), 100 randomly chosen nematodes were identified to genus level and assigned to one of five trophic groups: bacterivores (bacnem), fungivores (fungnem), omnivores, predators or plant-parasitic nematodes (ppnem) (Yeates et al., 1993). Species of the Tylenchidae were classified as plant feeders (Ferris et al., 2004). The genus *Filenchus* of the Tylenchidae was considered fungal feeding (Okada et al., 2005).

The total number and the percentage of each trophic group in the community were calculated. Each nematode taxon was also assigned to a functional guild using a combination of feeding-group and life-history traits expressed as cp (colonizer-persister) scores ranging from 1 (r-strategist, colonizers) to 5 (K-strategist, persisters). Based on these cp values and feeding-groups, the maturity index (MI) and other comparable indices ($\sum$MI, $\sum$MI 2–5), enrichment index (EI), structure index (STI) and channel index (CI) were calculated as defined by Bongers (1990) and Ferris and Bongers (2009).

2.3. Crop yields

Crop yields were determined annually from 2004 on. Crops were harvested in fall using small agricultural equipment. After each

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