Compost-induced improvements of soil physical properties in agricultural fields on loess

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Abstract

The objective of this study was to investigate the impact of three types of compost on soil physical properties of a silt loam in a long-term experiment. Soil organic carbon (SOC) was measured every other year and moisture content was monitored since 2005; consistency limits were determined on samples taken 15 years after the start of the experiment. SOC continuously increased in the amended plots, while it remained stable or decreased in the control plots. Bulk density (ρ_b) increased (and correspondingly, available pore space decreased) in the control plots. The consistency limits were higher in the amended plots; for two treatments the change at the plastic limit was significant, compared to the control. In this paper, the influence of SOC on consistency limits and moisture conditions and retention will be highlighted with regard to soil workability.

Introduction

Evaluating the environmental impacts or benefits of exogenous organic matter (EOM) application in agriculture has been attempted for various aspects including greenhouse gas emissions, aggregate stability or nutrient availability [e.g. 1]. Such evaluation is of particular importance for the life cycle assessment (LCA) of a given EOM. As a result of the demand for waste recycling, composts of varying origins are being produced and used as amendments in agriculture. This practice should not only reduce the amount of waste being incinerated, but also exert other positive effects, such as improving soil quality, sequestering carbon or replacing mineral fertilizers [2, 3]. In order to assess the impact of three different composts, soil organic carbon (SOC) content and a number of soil physical properties were investigated and compared among composts, manure and a control treatment in a long-term field experiment. We will investigate EOM effects on soil physical properties relevant to workability in terms of available days for soil tillage.

Material and Methods

Field experiment

The long-term experiment Qualiagro was set up near Paris at Feucherolles, France in 1998 on a loess-derived silt loam (787 g/kg silt, 152 g/kg clay). Annual average precipitation and temperature are 583 mm and 11°C, respectively (data recorded at on-site weather station). The effects of 4 different amendment types and a control (CNT) treatment on agricultural soils with a maize-wheat rotation are studied. Three composts and a manure are applied every other year, at a rate of 4 Mg C/ha, after wheat harvest; mineral N fertilizer is applied at an optimum (N_{opt}) level for half of the plots and at a minimum (N_{min}) for the other half. The plots (Fig. 1), arranged in a randomized block design, have a size of 450 m²; each treatment is replicated four times (total of 40 plots). The composts include municipal solid waste compost (MSW), co-compost of green wastes and sewage sludge (GWS), and biowaste compost (BIO); cattle manure (FYM) is applied as a reference. Soil moisture contents are monitored every 10 to 14 days (growing season) in five of the plots (one of each treatment), which are equipped with time domain reflectometry (TDR) probes at 20, 40, 60, 80, 100, 130, and 160 cm.

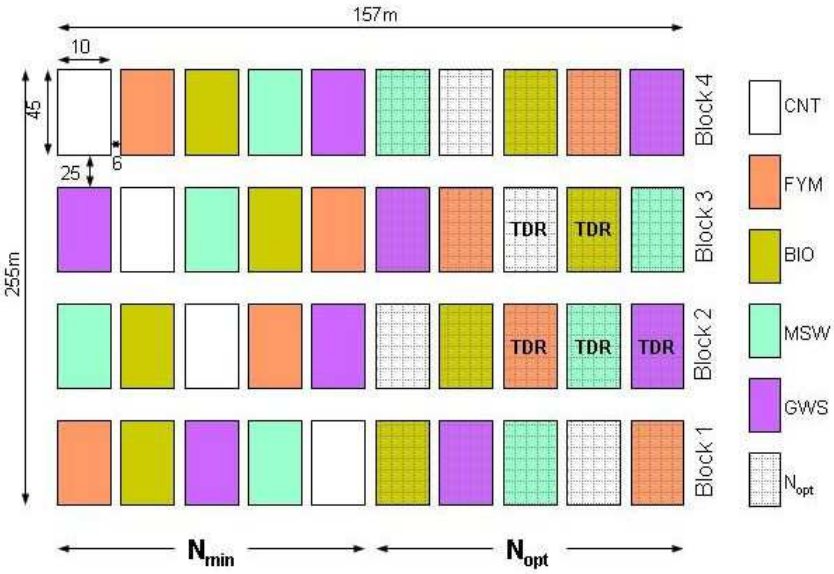

Figure 1 Layout of the experiment (CNT=control, FYM=manure, BIO=biowaste compost, MSW=municipal solid waste compost, GWS=green waste and sewage sludge compost, N_{min}=N at minimum rate, N_{opt}=N at optimum rate); 5 plots are equipped with TDR probes.

Soil physico-chemical properties

Various parameters, including SOC content, have been measured and monitored since the beginning of the experiment [4]. The available days for tillage can be calculated for each treatment by inferring measured and simulated soil moisture data with the upper and lower tillage limit derived from soil plastic limits (also referred to as Atterberg consistency limits [5]), and water retention characteristics. The soil's plastic limits, plastic limit (PL) and liquid limit (LL), were determined according to the Casagrande methods [6].

Results and discussion

Soil properties

In Qualiagro, the EOM from composts and FYM increased SOC content from initially 10.5 g/kg on average to a range of 9.35 (CNT N_{min}) to 15.58 (GWS N_{opt}) g/kg. As SOC influences soil physical properties like pore size distribution, bulk density (ρ_b), plastic limits, and water retention characteristic, it consequently also affects the workability of a soil. We will present workability as influenced by SOC increases after compost application.

Table 1 Soil organic carbon, SOC and bulk density, ρ_b for 1998 (average value), and for selected treatments SOC in 2011, ρ_b in 2009, and PL and LL in 2013

	SOC 2011 (g/kg)	ρ_b 2009 (Mg/m³)	PL 2013 (%)	LL 2013 (%)
CNT N_{min}	9,3	1,41	25,0	32,0
CNT N_{opt}	$10,4^{d*}$	$1,39^{b}$	$25,3^{b}$	$31,8^{b}$
FYM N_{opt}	$14,4^{b}$	$1,33^{a}$	$27,9^{a}$	$35,2^{a}$
MSW N_{opt}	$12,8^{c}$	$1,34^{a}$	$26,8^{ab}$	$35,6^{a}$
GWS N_{opt}	$15,6^{a}$	$1,31^{a}$	$28,2^{a}$	$34,9^{a}$
BIO N_{opt}	$15,2^{a}$	$1,30^{a}$	$27,1^{ab}$	$34,8^{a}$
1998	10,5	1,32	/	/

* Superscripted letters indicate statistically significant differences at the 5% level (Newman-Keuls test).

Plastic limits

The plastic and liquid limits indicate threshold water contents at which the consistency of the soil changes. The plastic limit (PL) is the limit between brittle (water content below PL) and plastic (water content above PL) soil behaviour. The water content at which the behaviour of soil changes from

liquid to plastic is termed the liquid limit (LL). PL and LL are given for the treatments at N_{min} and CNT N_{opt} in Table 1, along with SOC content and ρ_b.
Clay and SOC content greatly affect the plastic limits, both of which have a large influence on soil water retention. SOC increases the plastic limits by increasing the water adsorptive capacities, while SOC-induced aggregation decreases them due to reduced particle surface areas [7]. Keller and Dexter [6] demonstrated a strong effect of OM on plastic limits for sites with a gradient in OM content (same texture), but also discussed the inconsistent results found by other authors; they further proposed pedotransfer functions based on clay and/or OM content. Paradelo et al. [8] found a positive correlation between the plastic limits and total OC for compost amended soils (at higher application rates). A study on compost, sludge, and manure also reported significant positive correlations of PL and LL with SOC; application rate and type (for PL) were also crucial [9].
In the present study, LL and PL increased in the amended plots (not significantly for all treatments), while lower values were found in the plots not receiving any organic amendments (Table 1). The positive correlation between OM and plastic limits is in agreement with the studies mentioned previously. Within the plasticity chart, soils from all treatments remain in the category of inorganic silts of medium compressibility.

Soil workability
Adamiade et al. [10] investigated the effect of SOC on workable days in terms of trafficability –using models and pedotransfer functions- for a comparable silt loam near Paris (Boigneville), finding no significant difference. However, their study site also included different tillage systems and soil depths, which may have obscured the impact of SOC on trafficability. Besides looking at workability rather than trafficability and using a different approach, where water content, water retention and plastic limits were measured, we used samples from topsoils under identical tillage conditions.
Various equations are reported in the literature to determine the range and optimum water content (θ) for tillage using water retention data and PL. Dexter and Bird [11] define the upper tillage limit (UTL) at $\theta_{UTL}= \theta_{PL}$, further their data suggests that the lower tillage limit (LTL) can be approximated by $\theta_{LTL}=0.8* \theta_{PL}$. Apart from that, field capacity (FC) plays an important role, as it describes the moisture conditions most commonly encountered in the field (weather-dependant); a soil with good workability can generally be described by $\theta_{FC}<\theta_{PL}$ [6].
EOM changes SOC and related properties: soil water content and plastic limits determine the workability of a soil. When soil water content, as continuously monitored with TDR probes, is within the limits given by the water contents at UTL and LTL, available days for tillage can be determined. It will be tested, in how far the changes detected affect workability and whether more days are available for tillage.

Conclusion and perspectives
Direct relations between compost-derived EOM and soil physical properties should be established and used to improve the assessment of impacts of compost application on soils and to provide the agronomic and economic value of organic wastes recycled in agriculture. Hence, if an impact of compost on workability in terms of available days for tillage, via altered water retention and plastic limits, can be verified, then these results can be further used as a new indicator for evaluations in LCA. At the same time, the results should also be of interest for farmers, as more available days would be directly applicable.
An increased number of days with good tillage conditions is relevant, especially during spring and fall, when tillage operations occur. Simultaneously the risk of deterioration of soil structure -and hence quality- would be reduced, while the number of days with unfavourable tillage conditions would decrease.

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