Agriculture, Ecosystems and Environment 211 (2015) 94–101

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Repeated soil application of organic waste amendments reduces draught force and fuel consumption for soil tillage

Clément Peltre[a,*], Tavs Nyord[b], Sander Bruun[a], Lars S. Jensen[a], Jakob Magid[a]

[a] Department of Plant and Environmental Sciences, Faculty of Science, University of Copenhagen, Thorvaldsensvej 40, Frederiksberg DK-1871, Denmark
[b] Department of Engineering, Aarhus University, Hangøvej 2, 8200 Aarhus, Denmark

ARTICLE INFO

Article history:
Received 17 November 2014
Received in revised form 2 June 2015
Accepted 5 June 2015
Available online xxx

Keywords:
Soil organic carbon
Draught
Tractor fuel
Organic amendments
Soil tillage

ABSTRACT

Soil application of organic waste products (OWP) can maintain or increase soil organic carbon (SOC) content, which in turn could lead to increased porosity and potentially to reduced energy use for soil tillage. Only a few studies have addressed the effect of SOC content on draught force for soil tillage, and this still needs to be addressed for fields that receive diverse types of organic waste of urban, agricultural and agro-industrial origin. The objective of this study was to determine the effect of changes in SOC induced by repeated soil application of OWP on draught force for soil tillage and tractor fuel consumption. Draught force was measured for tillage with conventional spring tillage tines, as well as bulk density, soil texture and SOC content in the CRUCIAL field experiment, Denmark in which diverse types of OWP had been applied annually for 11 years. The OWP included household waste compost, sewage sludge and cattle manure. The results showed that repeated waste application increased the SOC content from 1.4% SOC for the control NPK treatment to up to 3.5% SOC for the compost applied at an accelerated rate. Bulk density was also changed by OWP additions and strongly correlated with SOC. Specific draught for soil tillage was significantly explained by SOC, clay content, bulk density and soil cohesion, and could be expressed as a linear function of SOC and clay content explaining 67% of the variance. However, no evidence was found that the composition of SOC accumulated for different organic wastes influenced the specific draught. Overall, the decrease in draught force could lead to a decrease in tractor fuel consumption for soil tillage of up to 25% for compost applied at an accelerated rate and up to 14% for compost applied at a normal rate. This reduced fuel consumption could have a significant impact if taken into account in environmental assessments of organic waste recycling.

1. Introduction

Soil application of organic amendments derived from waste materials of urban, agricultural, industrial or municipal origin (referred to as organic waste products: OWP) can be used to maintain or even increase soil organic carbon (SOC) levels (Schils et al., 2008). Soil application of OWP results in various direct and indirect agronomic and environmental effects (Marmo, 2008). Some positive effects are related to the enhanced SOC contents and changed SOC composition, such as improved aggregate stability and soil porosity (Annabi et al., 2011; Grosbellet et al., 2011). Other effects are due to the potential substitution of mineral fertilisers through the inputs of nutrients such as N, P, K provided by OWP, thus avoiding high fossil energy costs and hence the global warming impact of synthetic fertilisers (Diacono and Montemurro, 2010). Finally, OWP application on soil has a potential for climate change mitigation through the sequestration of atmospheric CO_2-C in SOC (Lal, 2004). In Europe, the recycling of organic biodegradable waste is expected to increase in future, while decreasing waste landfilling and incineration without energy recovery (European Commission, 2010). Land application of OWP after biological treatment (e.g. composting or anaerobic digestion) is likely to be one of the most environmentally-friendly waste management options. However, detailed environmental assessments are not yet available that include all the agronomic and environmental effects to allow a proper comparison with other waste management options. This is due to the lack of references reporting the environmental effects of OWP addition on soil, which therefore impedes the identification of the best biological treatment in terms of environmental performance. One of the main measurable effects of repeated soil application of OWP is the increase in soil porosity and therefore the decrease in soil bulk density (Martin et al., 2009; Schjønning and Thomsen, 2013). This is also expected to result in a potential decrease in draught force for soil tillage and therefore to a

* Corresponding author.
E-mail addresses: peltre@plen.ku.dk, cpeltre@yahoo.fr (C. Peltre).

http://dx.doi.org/10.1016/j.agee.2015.06.004
0167-8809/

potential decrease in tractor fuel consumption (Watts et al., 2006). The energy saved due to lower resistance during tillage operations is currently being ignored in environmental assessments of waste treatment options involving land application of waste. The composition of SOC accumulated might also differ according to the type of OWP applied (Leifeld et al., 2002; Spaccini et al., 2009). Some OWP such as composts have a high content of humified, slowly biodegradable macro-organic particles, typically accumulating as porous, coarse particulate organic matter in soil, whereas other types of OWP such as sewage sludge are dominated by microbial debris, which will be incorporated quickly into the fine organo-mineral fraction of SOC (Doublet et al., 2010). Such contrasting effects on the composition of SOC fractions formed from different OWP products could lead to different effects on tillage resistance, regardless of the amount of OWP carbon applied or retained in SOC.

Long-term field experiments (LTE) with land application of different types of OWP, such as the CRUCIAL experiment initiated in 2003 in Denmark (Magid et al., 2006), constitute a unique resource for assessing the environmental and agronomic effects of OWP soil application. Long-term experiments allow measurements of the effect of OWP on soil, which is difficult to evaluate under laboratory conditions and over short-term periods. As such they also constitute a unique possibility for testing the effect of OWP application on draught force and energy consumption during tillage operations. However, only a very few studies have investigated the relationships between soil carbon and draught force for soil tillage, showing that the latter is mostly dependant on soil carbon and clay content (McLaughlin et al., 2002; Watts et al., 2006; Liang et al., 2013). The relationship for soils receiving different types of OWP including OWP of urban or agro-industrial origin has, to the best of the authors' knowledge, never been investigated.

The objectives of this study were to test whether OWP application impacted draught force for soil tillage and to evaluate the relationships between soil characteristics and draught force. It was hypothesised that draught force and fuel consumption depend greatly on SOC content, and that relationships between SOC and draught force are OWP-specific.

2. Materials and methods

2.1. The CRUCIAL field experiment

The CRUCIAL field experiment is located on the experimental farm of the University of Copenhagen, Denmark (20 km west of Copenhagen: 55°40′51.7″N 12°16′35.8″E). It was initiated in 2003 and has mainly been cropped with spring cereals (Magid et al., 2006). Thirty-year averages for annual precipitation and annual air temperature were 600 mm and 7.6 °C, respectively, with maximum and minimum daily air temperatures of 15.8 °C (July) and −0.9 °C (January). The soil from the CRUCIAL experiment is a sandy loam, Luvisol (FAO classification) with on average 26.2% coarse sand, 43.6% fine sand, 14.3% silt and 12.6% clay. It is organised in a randomised block design with three blocks and includes 11 treatments. Each plot is approximately 891 m^2 (27 × 33 m) and the plots are separated by three-metre wide strips of grass. The treatments are as follows: household waste compost (normal rate: CH; accelerated rate: CHA; for explanations, see below), sewage sludge (normal rate: S; accelerated rate: SA), cattle manure (accelerated rate: CMA), cattle slurry (CS), animal deep litter (DL, very straw-rich manure), human urine (HU), NPK fertiliser (NPK) and unfertilised (U, no mineral or organic fertiliser applied). The municipal solid waste compost was made from pre-sorted municipal solid waste mixed with garden and park waste using a combined biogas–composting process, i.e. lixiviates from the organic waste were used to produce biogas in the anaerobic treatment phase and the residues were subsequently composted and matured. The sewage sludge originated from a public treatment plant receiving waste water from households and industries from 11 municipalities in greater Copenhagen that are home to approximately 300,000 people (Spildevandscenter Avedøre). The human urine was collected from an eco-village (Munksoegaard; http://www.munksoegaard.dk/index_en.html) that has urine-diverting toilets. Prior to field application, the urine had been stored in airtight tanks for at least six months. The waste/fertiliser were applied yearly and incorporated by ploughing to a 20 cm depth. The normal rate of OWP or mineral fertiliser was based on N-input equivalent to approximately 100 kg available N ha^{-1} yr^{-1}, depending on the crop grown. The application rates of OWP were adjusted to account for the N mineral fertiliser equivalent (MFE, a measure of OWP N provision to the crop relative to mineral fertiliser N) value. The MFE values were based on Danish legislation for regulating the maximum rates of fertiliser use (MFLF, 2013; Poulsen et al., 2013). The accelerated rates of application were introduced at the start of the experiment in 2003 in order to approach possible eco-toxicological limits for Zn and Cu more rapidly, in the context of other studies exploring potential soil contamination by organic waste application (Magid et al., 2006; Poulsen et al., 2013; Lekfeldt et al., 2014). These accelerated rates aimed at applying approximately three times the normal available N levels (Table 1), which again were chosen to be directly related to the rate of available N farmers would usually apply based on Danish legislation.

2.2. Draught force measurements and fuel consumption

Draught force (DFr) was measured in all the plots of the CRUCIAL field experiment on 28 March 2014. The measurement setup consisted of three spring tines (model: Kongskilde Vibro Flex, Kongskilde Industries A/S, Skaelskoervej 64, DK-4180 Soroe, Denmark) mounted on a toolbar (described in detail in Nyord et al.

Table 1
Average characteristics and application rates of the different organic wastes applied over the 11 years of the CRUCIAL field experiment.

Treatment[a]	Applied rate (Mg ha^{-1} FM)	Dry matter content (% FM)	Organic C content (% DM)	Total N content (% DM)	Average C applied yearly (Mg C ha^{-1} yr^{-1})	Average N applied yearly (Mg N ha^{-1} yr^{-1})
CH	31.6 (10.4)	68.5 (0.9)	21.5 (5.2)	1.4 (0.8)	4.7	0.30
CHA	95.6 (33.8)	68.5 (0.9)	21.5 (5.2)	1.4 (0.8)	14.1	0.92
CMA	85.8 (17.4)	26.4 (1.5)	43.1 (2.5)	2.1 (0.3)	9.8	0.47
CS	51.7 (8.6)	7.6 (0.2)	41.7 (2.6)	3.0 (0.3)	1.6	0.12
DL	43.7 (12.9)	36.3 (5.4)	32.4 (4.1)	1.5 (0.4)	5.1	0.23
HU	77.3 (10.4)	0.5 (0.1)	–	48.5 (0.7)	–	0.17
S	18.8 (6.3)	31.0 (1.4)	30.6 (3.7)	5.4 (0.5)	1.8	0.31
SA	49.3 (15.9)	31.0 (1.4)	30.6 (3.7)	5.4 (0.5)	4.7	0.82

[a] Household waste compost at normal (CH) and accelerated (CHA) rates, cattle manure at an accelerated rate (CMA), cattle slurry (CS), deep litter (DL), human urine (HU), sewage sludge at normal (S) and accelerated (SA) rates. Fresh matter: FM; dry matter: DM. Standard deviations presented in brackets.