G Model
EURAGR-25457; No. of Pages 10
ARTICLE IN PRESS
Europ. J. Agronomy xxx (2015) xxx–xxx
Contents lists available at ScienceDirect
European Journal of Agronomy
journal homepage: www.elsevier.com/locate/eja

Sugar beet rotation effects on soil organic matter and calculated humus balance in Central Germany

Philipp Götze[a,*], Jan Rücknagel[a], Anna Jacobs[b], Bernward Märländer[b], Heinz-Josef Koch[b], Bettina Holzweißig[a], Michael Steinz[a], Olaf Christen[a]

[a] Department of Agronomy and Organic Farming, Martin Luther University Halle-Wittenberg, Betty-Heimann-Str. 5, 06120 Halle/Saale, Germany
[b] Institute of Sugar Beet Research, Holtenser Landstrasse 77, 37079, Göttingen, Germany

ARTICLE INFO

Article history:
Received 2 February 2015
Received in revised form
21 November 2015
Accepted 9 December 2015
Available online xxx

Keywords:
Total organic carbon
Microbial biomass carbon
REPRO
Humus unit
Long-term field trial
Chernozem

ABSTRACT

In order to quantify the influence of land use systems on the level of soil organic matter (SOM) to develop recommendations, long-term field studies are essential. Based on a crop rotation experiment which commenced in 1970, this paper investigated the impact of crop rotations involving increased proportions of sugar beet on SOM content. To this end, soil samples were taken in 2010 and 2012 from the following crop rotation sequences: sugar beet–sugar beet–winter wheat–winter wheat (SB–SB–WW–WW = 50%), sugar beet–sugar beet–sugar beet–winter wheat (SB–SB–SB–WW = 75%), sugar beet–grain maize (SB–GM = 50%) and sugar beet-monoculture (SB = 100%); these were analysed in terms of total organic carbon (TOC) and microbial biomass carbon (MBC) content, MBC/TOC ratio and the TOC stocks per hectare. In addition, humus balances were created (using the software REPRO, reference period 12 years) in order to calculate how well the soil was supplied with organic matter. In the field experiment, harvest by-products (WW and GM straw as well as SB leaves) were removed. After 41 years, no statistically significant differences were measured between the crop rotations for the parameters TOC, MBC, MBC/TOC ratio and the TOC stock per hectare. However, the calculated humus balance was significantly affected by the crop rotation. The calculated humus balance became increasingly negative in the order SB–SB–WW–WW, SB–SB–SB–WW, SB monoculture and SB–GM, and correlated with the soil parameters. The calculated humus balances for the reference period did not reflect the actual demand for organic matter by the crop rotations, but instead overestimated it.

1. Introduction

Supplying soils with enough organic matter to maintain stable levels of soil organic matter (SOM) is an important criterion of sustainable land use. SOM has a positive impact upon essential characteristics of soil fertility, although a supply of organic matter which exceeds the site's normal levels can cause increased mineralisation and nutrient loss (Johnston et al., 2009). Apart from site-related soil properties, SOM content is mainly influenced by cultivation practices (Christensen and Johnston, 1997). The amount of residual aboveground and below-ground biomass during a crop rotation influences the soil's total organic carbon (TOC) content as well as microbial biomass carbon (MBC) (Havlin et al., 1990; Karlen et al., 1994). Sugar beets (SB) are characterised by low levels of crop and root residues, especially when compared to cereals (Klimanek, 1997), and as such they are thought to contribute little organic matter to the soil.

Furthermore, the frequency and intensity of soil tillage influences the conversion rate and the content of the SOM (Balesdent et al., 2000). This means that low SOM content may be expected in the case of crop rotation sequences with high proportions of root crops which require intensive tillage, such as SB and potatoes. Steinbrenner and Smukalski (1984) reported that the crop rotation system with the highest proportion of SB and potatoes also had the lowest SOM content. Beck (1975) also arrived at similar conclusions in his investigations, in which potato and SB monoculture displayed significantly lower TOC contents than cereal monoculture. By contrast, Deumelandt et al. (2010) were only able to ascertain a tendency towards slightly lower TOC content in SB monoculture when compared with SB grown in crop rotation. The same applies for Kunzová (2013) who observed no differences in terms of TOC content in a 9-field crop rotation system when compared to two-phase crop rotation with SB and spring barley.

* Corresponding author. Fax: +49 345 5527023.
E-mail addresses: philipp.goetze@landw.uni-halle.de (P. Götze), jan.ruecknagel@landw.uni-halle.de (J. Rücknagel), jacobs@ifz-goettingen.de (A. Jacobs), maerlaender@ifz-goettingen.de (B. Märländer), koch@ifz-goettingen.de (H.-J. Koch), michsteinz13@gmail.com (M. Steinz), olaf.christen@landw.uni-halle.de (O. Christen).

http://dx.doi.org/10.1016/j.eja.2015.12.004
1161-0301/

The impacts of agricultural land use on SOM can be estimated using humus-balancing models (Brock et al., 2013). A stable calculated humus balance is also necessary in the context of agricultural subsidies and farms need to prove that their soil has a sufficient supply of organic matter. In the corresponding benchmark values for balancing humus (Körschens et al., 2005), SB, potatoes and silage maize are considered the highest in terms of depletion of TOC. Therefore, crop rotations with high proportions of these crops require considerable amounts of organic matter in order to maintain a stable calculated humus balance. For farms carrying out intensive SB production, which also incorporate other root crops as part of their crop rotations, Deumelandt and Christen (2008) calculated negative balances, which were attributed to an insufficient supply of organic matter.

In future cropping systems, it is possible that crop rotations with increased frequency of SB will become established in practice. On the one hand, a high yield potential and large amounts of readily fermentable carbohydrates make SB particularly suitable for biogas production (Hoffmann et al., 2012; Starke and Hoffmann 2014), offering an alternative to growing maize (Jacobs et al., 2014). On the other hand, if quota regulations for SB are discontinued, changes in global sugar prices may result in increased frequency of SB in crop rotations. If global prices rise, the growing demand will be met by increasing SB acreage in existing growing areas (Gocht et al., 2012). In order to minimise transportation costs, declining global prices would result in intensification in the areas sown with SB which are situated in close proximity to processing factories (Isermeyer et al., 2005). Therefore, these changing economic requirements could lead to increasing cropping concentrations for SB in crop rotation. Thus, considering the SB's status as a humus depleting crop, this would likely affect the SOM content.

However, appropriate long-term field experiments are necessary to quantify the influence of SB in crop rotations on SOM (Märländer et al., 2003). The high degree of spatial and temporal variability of TOC dynamics mean that reproducible results cannot be expected until a trial period of at least 20 years has elapsed (Körschens, 2010). The study presented here is based on the SB crop rotation experiment in Etzdorf, Germany, which commenced in 1970. This experiment compares crop rotations with increased proportions of SB including monoculture, to investigate impacts on TOC and MBC content, as parameters linked to SOM and the convertible fraction of SOM respectively. The TOC stock per hectare and the MBC/TOC ratio were also measured and calculated humus balances prepared to ascertain whether they correlate with the identified soil parameters. The overall aim was to determine whether effects of crop rotation on soil parameters can be predicted using calculated humus balances.

2. Materials and methods

2.1. Field site and experimental design

The investigations were performed at a long-term field trial in Etzdorf (Saxony-Anhalt, Ger-many, 51°43′N; 11°76′E, altitude 134 m), which was commenced in 1970 and is run by the University of Halle-Wittenberg. The soil type was classified as a Haplic Chernozem (FAO, 2006). The soil texture in the tilled soil (0–30 cm) was that of a silt loam (250 g kg^{-1} clay, 50 g kg^{-1} sand), while the pH value was 6.9. For the calculated humus balance reference period (1998–2011), the mean annual temperature was 9.3 °C (min. 7.6 °C, max. 10.1 °C), and the mean annual precipitation was 491 mm (min. 350 mm, max. 663 mm).

The crop rotation experiment had a block design with two replications (plot size 26.4 m^2, 8.8 m × 3.0 m), with each crop rotation field sown every year. Four crop rotations were compared for the investigations presented here; they were characterised by increasing concentrations of sugar beet (SB, *Beta vulgaris L.*) and decreasing SB cropping intervals (Table 1). The other crops in the crop rotations were winter wheat (WW, *Triticum aestivum L.*) and grain maize (GM, *Zea mays L.*).

Table 1
Crop rotations at the long-term field trial Etzdorf (SB—sugar beet; WW—winter wheat; GM—grain maize).

	Crop rotation			
Year 1	SB[a]	SB[a]	SB[a]	SB[a]
Year 2	SB	SB	GM	SB
Year 3	SB	SB	SB	WW
Year 4	SB	WW	GM	WW
SB concentration [%]	100	75	50	50
Cropping interval for SB [years]	0	1/0/0	1	2/0

[a] Plots with soil analysis.

Table 2
Description of symbols used in equations 1–5 (TOC—total organic carbon).

Symbol	Description	Unit
$M_{TOC,equiv}$	TOC mass adjusted to equal soil masses	[t ha^{-1}]
$M_{TOC,0\text{–}30\,cm}$	TOC mass in 0–30 cm soil horizon	[t ha^{-1}]
$M_{TOC,T\,add}$	TOC mass in additional soil horizon	[t ha^{-1}]
$M_{TOC,equiv}$	Mass of heaviest soil at 0–30 cm	[t ha^{-1}]
$M_{soil,0\text{–}30\,cm}$	Soil mass at 0–30 cm	[t ha^{-1}]
$conc_{TOC,0\text{–}30\,cm}$	TOC concentration at 0–30 cm	[g kg^{-1}]
$conc_{TOC,0\text{–}30\text{–}45\,cm}$	TOC concentration at 30–45 cm	[g kg^{-1}]
$\rho_{b,0\text{–}30cm}$	Dry bulk density at 0–30 cm	[t m^{-3}]
$\rho_{b,30\text{–}45cm}$	Dry bulk density at 30–45 cm	[t m^{-3}]
$T_{0\text{–}30}$	Horizon depth	[m]
T_{add}	Additional horizon depth needed to reach $M_{soil,\,equiv.}$	[m]

As the experiment has progressed, management of the land has changed somewhat. Firstly, the SB–GM rotation began in 1986 and, secondly, the application of farmyard manure was modified during the last two decades. From 1970 to 1991, 10 t ha^{-1} of farmyard manure was added each year. From 1991 to 2006, the plots were fertilized every three years with 30 t ha^{-1} farmyard manure. Since 2007, no farmyard manure was applied.

Mineral nitrogen fertilizer was applied at 160 kg N ha^{-1} on SB and GM, while the amount used on the WW depended on the requirements calculated for each year. The resulting crop residues (SB leaves, WW straw) were removed from all plots. Primary soil tillage was performed in the autumn using a mouldboard plough to a depth of 30 cm. Before SB and WW were sown, a rotary harrow was used for seed-bed preparation, while for GM, seed-bed preparation, using a rotary tiller as well, was combined with the sowing itself.

2.2. Soil analysis

In the spring of 2010 (41st trial year) and 2012 (43rd trial year), soil samples were taken from the first crop rotation field (SB plots) of the crop rotations described in Table 1. Thus, for the SB monoculture and the SB–GM rotation soil samples were taken from the same plots in both years, whereas for the SB–SB–SB–WW and SB–SB–WW–WW rotation, soil samples were taken from different plots in both years. For sampling, the plots were divided into a lower and an upper sub-plot. In each of these plot halves, a boring rod was used to extract a composite sample from soil depths of 0–30 cm and 30–45 cm in order to determine the soil's chemical and biological parameters (soil depth 30 cm only). Soil cores were also extracted ($n = 4$ per depth, $V = 250$ cm^3, $h = 6$ cm, diameter = 7.28 cm) in order to determine dry bulk density at soil depths 2–8 cm, 12–18 cm, 22–28 cm and 35–41 cm.

Dry combustion (ISO 10694:1995-03-01) was used to analyse the total carbon content (TC) of the boring rod samples. The total