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Effect of organic farming on a Stagnic Luvisol soil physical quality

Tomasz Głąb [a,*], Katarzyna Pużyńska [b], Stanisław Pużyński [c], Joanna Palmowska [a], Klaudia Kowalik [a]

[a] Institute of Machinery Exploitation, Ergonomics and Production Processes, University of Agriculture in Krakow, ul. Balicka 116B, 31-149 Krakow, Poland
[b] Department of Agrotechnology and Agricultural Ecology, University of Agriculture in Krakow, Krakow, Poland
[c] Department of Agronomy, West Pomeranian University of Technology, Szczecin, Poland

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A B S T R A C T

The organic farming system is reported as having an influence on soil chemical, biological and physical features. The objectives of this study were to examine the physical quality of Stagnic Luvisol soil subject to organic and conventional farming with crop rotations that included root crops and legumes. The experiment was established in 2008 as a split-plot randomised block design to examine the effects of these farming systems, i.e. conventional (CFS) and organic (OFS), and the sub-plot treatment of the crop species in the following crop rotation: potatoes, winter wheat, oats/common vetch mixture and winter spelt wheat.

Undisturbed soil samples were collected in 2014 to determine the water retention parameters and morphometric characterization of soil pores. The soil moisture characteristic curve was determined in pressure chambers with ceramic plates. The macropore system for the investigated soil was characterised using image analysis on sections of soil samples hardened with polyester resin.

With OFS treatment, significantly higher values for the soil bulk density were recorded than with CFS. The bulk density was also affected by crop species. Higher values were characterised for winter wheat and oat/vetch mixture than for potatoes and spelt. The highest porosities in terms of transmission pores and fissures were noted for potatoes cultivated in the CFS system, whereas with CFS the soil under winter wheat was characterised by the lowest contribution of large pores. The highest water retention in terms of PWC (productive water retention) and AWC (available water retention) was obtained for the CFS system. Organic farming resulted in lower macroporosity, 0.65% on average, whereas with conventional farming this was 0.82%. These differences were more pronounced in terms of small pores with diameters 50–100 μm. For different crops, the level of macroporosity significantly changed. Soil housing potatoes and spelt was characterised by a higher macropore volume, in the diameter ranges 50–1000 μm. The farming systems applied significantly changed all tested plant biomass production. The highest grain and potato tuber yields were characterised for CFS. However, the highest root biomass crop species produced in the OFS treatment than in the CFS.

1. Introduction

Organic farming is defined as a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions (IFOAM, 2005). The main standard excludes the use of artificial fertilisers, pesticides and genetic engineering. The organic system includes the maintenance of long-term soil fertility, compatibility with natural cycles, and the maintenance of agricultural and natural biodiversity (de Ponti et al., 2012). Many comparative studies between conventional and organic farming systems have reported that organic farming influences soil chemical, biological and physical features and affects biomass quantity and quality production.

Organic farming has an important effect on soil chemical quality. The improvement in soil quality is probably connected with higher organic fertiliser rates. From a long-term perspective, organic management is expected to increase soil organic matter content (Sacco et al., 2015; Stockdale et al., 2001). Schjønning et al. (2002) observed that conventional agriculture without the application of organic manure reduces the soil's ability for crop production by worsening its fertility. However, the beneficial effect of organic farming on soil chemical properties is sometimes questioned. Gosling and Shepherd (2005) reported no significant differences in total soil organic matter, total nitrogen or C:N ratio between conventionally and organically managed soils.

The results obtained so far indicate that organic management significantly enhances biological activity and has positive effects on the environment (Papadopoulos et al., 2006). Microbial biomass has been found to be higher in organically managed soils than in conventionally managed ones (Schjønning et al., 2002). Some findings have shown that organic farming is associated with a significantly higher level of biological

* Corresponding author.
E-mail address: rtglab@cyf-kr.edu.pl (T. Głąb).

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activity and a higher level of soil organic matter (Oehl et al., 2004; Pulleman et al., 2004).

Organic farming affects not only the biological and chemical properties of soil but also its physical features. Organic farming practices have been associated with improved soil physical properties through the addition of soil organic matter, increased earthworm populations, biodiversity, and soil fertility. This system has been recognised as having greater potential for soil structural improvement than conventional management (Król et al., 2013; Pulleman et al., 2004; Shepherd et al., 2002). Papadopoulos et al. (2006) observed that soils under organic management had higher SOM content and provided more stable soil aggregates than was the case with conventionally managed soils. Nevertheless, organic farming may cause a higher risk of soil compaction (Ball and Crawford, 2009; Pulleman et al., 2003). Higher soil compaction may be a result of the more intensive tractor traffic connected with intensive mechanical weed protection (Sandhu et al., 2010). Comparison in terms of porosity revealed that organically managed soils had greater micro- and mesoporosity than is the case in conventional systems and less porosity at the macroscale due to the few large pores observed under conventional management. Organic farming may have higher soil water retention and thus higher potential water-limited crop yields relative to conventional farming (Droogers et al., 1996). However, Hathaway − Jenkins et al. (2011) reported no significant differences between organic and conventional management for any of the soil physical properties measured. They explained this effect through the complex interactions between previous land use, current cropping cycle and tillage regime.

Organic agriculture is aimed at producing high quality food, but lower yielding is expected. When compared to conventional farming systems, yield reductions are frequent, ranging between 20 and 40% for arable crops and 0–30% for forage crops (Seufert et al., 2012; Stockdale et al., 2001). According to Seufert et al. (2012), these yield differences are highly contextual, depending on system, crop species and site characteristics. Kirchmann et al. (2008) found organic crop yields to be 25 to 50% lower than conventional ones. They observed that the main factors limiting organic yields were lower nutrient availability and poorer weed control. During system transition from conventional to organic, yield reductions are made more evident. Conversion of an agricultural system to an organic one requires time for soil biological activity to adapt to its new situation (Cong et al., 2006; Gopinath et al., 2009). Meta analyses of yield differences between organic and conventional agriculture (de Ponti et al., 2012; Ponisio et al., 2014) have shown that organic crops can match conventional yields in some studies, whereas in others they cannot. According to Kirchmann et al. (2016), such contradictory results are mainly due to inconsistencies in scale and boundary conditions. Yield determining factors such as the species used in rotation (particularly legumes), rates of nutrient supplied, soil fertility status have so far seldom been taken into account in the evaluation.

It is reported that the effect of organic farming on soil quality and crop production is not easy to predict. It is usually the result of interactions between other agronomic factors, such as crop rotation, tillage operations, soil type and texture and climate conditions. Crop rotation results in different fertilisation and tillage demands and seems to be the most important factor modifying soil quality and its productive ability. From the organic farming point of view, the greatest advantage of crop rotation is the introduction of crops which improve soil fertility and soil structure. It has been recognised that the presence of legumes and root crops in the crop rotation cycle increases the organic matter content and this may improve soil quality (Miglierina et al., 2000). It has also been observed that the impact of different crops on soil condition is not permanent and varies during the whole rotation cycle. For crops where soil is not rich in organic matter, the main factor affecting physical properties in the soil is mechanical soil tillage. Soil tillage usually has a short-term direct influence on soil properties (Malicki et al., 1997). The findings of the experiment by Głąb et al. (2013) showed that crop rotation did not play a significant role in permanent modification of soil pore systems. Particular crops could differ in their impact on soil porosity, but this effect is not permanent and is only visible in the year when this crop is cultivated, or sometimes has an impact in the following year.

Therefore, the effects of organic farming practices on soil physical and hydrological properties in relation to conventional farming systems are still not fully recognised. The objective of this study was to examine the physical quality of a Stagnic Luvisol soil subject to organic and conventional farming with crop rotations that included root crops and legumes.

2. Materials and methods

2.1. Experimental design

The field trial was located at the experimental station in Mydlniki, Department of Agrotechnology and Agricultural Ecology, University of Agriculture in Krakow, Poland (50°04′ N, 19°51′ E, 280 m a.s.l). The experiment was established as a split-plot randomised block design with four replications to examine the effects of the main-plot treatment of farming system, i.e. conventional (CFS) and organic (OFS), and the sub-plot treatment of the crop species in the following crop rotation: potatoes (*Solanum tuberosum* L. Cv. Cyprian), winter wheat (*Triticum aestivum* L. Cv. Akteur), oats/common vetch mixture (*Avena sativa* L. Cv. Celer, *Vicia sativa* L. Cv. Hanka), and winter spelt wheat (*Triticum spelta* L. Cv. Frankenkorn).

The crop rotation was established in 2008. Each crop was grown each year, so the field experiment consisted of 32 plots with each plot's area of 24 m^2 (3×8 m). The soil was conventionally tilled using an inversion mouldboard plough. Soil tillage for winter crops was performed with a shallow moldboard plough after harvest of the preceding crop. The seedbed preparation consisted of 20 cm deep autumn ploughing and one pass of a rotary harrow. Tillage for potato was done with a mouldboard plough to 20 cm depth to incorporate cattle manure. Then, two months later, deeper ploughing to 30 cm depth was applied. In spring, before planting, a rotary harrow and strip-bucket potato planter were used for potato planting. Moreover, a few passes of a row-crop cultivator and passive potato ridger for ridging were used to control weeds in the ecological farming system. Common winter wheat and winter spelt wheat, as well as an oat/vetch mixture, were sown with a commercial combined seeding machine at a depth of 2–4 cm, while potatoes were planted with a chain planter at the depth of 8–10 cm. The wheat and spelt were sown in September, whereas oat mixed with vetch and potatoes were sown in April. The distance between rows was 13 cm for cereals and 65 cm for potatoes. Mechanical harrowing was performed to control weeds in cereals when needed on all crops in the organic farming system. Chemical plant protection was only used in crops in the conventional farming system. Cereal harvest occurred in July and potato harvest in September. At harvest time, straw and total grain weight were determined from the whole plot.

Mineral fertilisation was only performed for crops in the conventional farming system. Winter common wheat was fertilised with 120 kg N and 34.9 kg P and 91.3 kg K. Winter spelt wheat received only 80 kg N and 21.8 kg P and 58.1 kg K per hectare. Oats/vetch mixture was treated with fertilisation of 80 kg N and 52.3 kg P and 124.5 kg K per hectare. Potatoes were fertilised with 50 kg N and 21.8 kg P and 83.0 kg K per hectare and also received cattle manure at a rate of 33 t ha^{-1} (141 kg N and 61.9 kg P and 161.0 kg K per hectare). Nitrogen fertilisation in winter common wheat and spelt wheat was split into two doses applied at the beginning of stem elongation and booting, corresponding to the 21, 31 and 41 stages of the Zadoks scale (Zadoks et al., 1974). P and K fertilisers were applied in a single application before the seedbed preparation.