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Soil functioning and conservation tillage in the Belgian Loam Belt

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ABSTRACT

One of the most frequently used techniques to combat soil erosion on agricultural fields is conservation agriculture (CA). Conservation tillage techniques (CT), together with residue management and rotation are the pillars of CA. Studies have shown that CT can indeed be very effective in combating soil erosion. While several studies have demonstrated how CT may affect (the distribution of) carbon in the soil and documented compaction risks under CT, much less information is available with respect to the potential effects of CT on within-soil water movement and nutrient status. We therefore investigated the effect of superficial (0.15–0.2 m depth) and deep (0.3–0.4 m depth) CT on soil properties of agricultural silt loam soils in Belgium. From 2008 to 2010, we analyzed the effect of CT on water content, hydraulic conductivity, penetration resistance, bulk density, organic carbon and nitrate content of the soil. At the same time the effect of CT on root growth and crop yield was analyzed.

We found that soil structural differences between conventional mouldboard ploughing and deep CT tended to be very small and did not have any effect on root growth and/or crop yield. Furthermore, we were not able to detect any significant difference between the different implements used in CT. The application of superficial CT however, led to an increase in penetration resistance in the upper soil layer hindering vertical soil water movement and root growth on one trial field. Crop yield was not affected due to a sufficient water and nutrient supply. Effects of deep CT on water availability and water movement were very limited and suggest that deep CT may slightly improve water availability only during dry summer periods.

Total carbon content was not affected by CT, but its distribution through the plough layer changed whereby the carbon content in the upper few centimetres of soil increased while a decrease was noted at greater depths. The reduction of the nitrate content observed in deeper soil layers indicates that reduced tillage did not lead to increased nitrate leaching and may even help to reduce this problem if adequate catch crops are planted.

We conclude that, on the Belgian silt loam soils, deep CT can be practiced whereby good soil functioning can be ensured. As crop yields were also similar, deep CT is a viable alternative that may contribute to soil protection. The use of superficial CT cannot be recommended due to a compaction risk.

1. Introduction

Conservation tillage encompasses a variety of tillage practices from sub-soiling to no-till, but generally would not involve inverting the soil (SOWAP, 2010). Conservation tillage seeks to reduce soil disturbance and to maximize soil cover by residues. Conservation agriculture removes the emphasis from the tillage component alone and addresses a more enhanced concept of the complete agricultural system (Verhulst et al., 2010). Next to reducing soil disturbance, it also recommends the preservation of a soil cover and the use of crop rotations. The preferred techniques of conservation agriculture depend on biophysical and system management conditions, and farmer circumstances (*Verhulst* et al., 2010).

Many studies have addressed various aspects of conservation tillage over the last decades (e.g. Zentner et al., 2002; Silburn et al., 2007; Triplett and Dick, 2008; Alvarez and Steinbach, 2009; Maguire et al., 2011). In Europe, much of the research on conservation tillage has been carried out in semi-arid environments (e.g. Lampurlanes et al., 2001; Sanchez-Giron et al., 2007). This is not surprising given its potential beneficial effect on soil moisture conservation and erosion reduction. However, research has shown that the application of conservation tillage has also

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potential in the more temperate agro-ecological zones of Europe, such as the Belgian Loam Belt (e.g. Cannell, 1985; D'Haene, 2008; Morris et al., 2010; Van den Putte et al., 2010).

As in most parts of Europe, the application of CT in the Belgian Loam Belt is still limited (Bielders et al., 2003), but interest is growing (Wauters et al., 2010; Dumez and Van Zeebroeck, 2011). CT is primarily used as a means to protect soils from erosion which is a serious problem in this area when conventional mouldboard ploughing is used (e.g. Steegen et al., 2001). The most common application of conservation tillage consists of the use of deep or superficial non-inversion tillage instead of mouldboard ploughing, followed by a seedbed preparation. Non-inversion tillage is carried out using a variety of implements. Conservation tillage is most often practiced together with other CA techniques: crops are grown in rotation (e.g. wheat–potato/vegetables–wheat–sugar beet/maize), and green manure crops are commonly grown as a nitrogen (N) catch crop after the main crop, thus providing soil cover over winter and crop residues that remain at the surface during establishment of the next-season's crop.

The beneficial effect of CT in terms of runoff and soil loss reduction in the Belgian Loam Belt was clearly demonstrated by Leys et al. (2007) and Leys et al. (2010). Experimental studies also confirmed that CT increased earthworm activity (e.g. Rothwell et al., 2005; Valckx et al., 2009) and enhanced soil infiltration capacity (e.g. Leys et al., 2010) in the study region.

While reducing erosion and increasing soil infiltration capacity is essential, it is also important to apply tillage techniques that allow optimal water movement within the soil, avoid compaction, and maintain an optimal soil nutrient status.

The effect of tillage on compaction has been the subject of several studies. Tillage may produce more homogeneous soil in the tilled layer but induce heterogeneity in the form of compaction under the tilled zone and under the wheels of the tractor pulling the tillage implement (*Munkholm* et al., 2008) and compaction is an important stress that can limit crop productivity (Whalley et al., 2008). Different types of machinery used for CT may have different impacts on soil structure, thereby affecting compaction and hence also water movement and availability as well as root growth.

Carbon (C) and N dynamics may also be affected by a change from conventional ploughing to superficial or deep non-inversion tillage. The tillage technique that is used determines the placement of residues which affects N and C dynamics. The latter also depend on soil temperature and soil water content which can also be influenced by the tillage technique (Zhang et al., 2007; Buragiene et al., 2011). Understanding tillage effects on N dynamics is all the more important because a surplus of nitrate implies a risk of leaching into the ground and surface water (Burkart et al., 2006). In Flanders, the threshold of 50 mg NO_3^- l^{-1} is exceeded in 33% of the measured small water bodies in agricultural areas (VMM, 2010) and the same problem is seen at other places in Europe (e.g. Hansen et al., 2010). CT is sometimes hypothesized to increase the leaching risk due to an increased pore connectivity within the soil (e.g. Sainju et al., 1999), but data comparing N dynamics under conventional ploughing and under superficial and deep conservation tillage are limited and inconclusive (Holland, 2004).

Little is also known on root development and water availability under non-inversion tillage. Van den Putte et al. (2010) performed a meta-analysis of yields under CT and noted that yield responses to CT were different between crops, with limited yield depressions for maize contrasting with small yield increases for potatoes and sugar beets. The reasons for these differential responses are not fully understood but might be related to differences in water availability, whereby an improved water availability under CT during dry periods may have a stronger positive effect on yields for crops with a shallow rooting system.

Our lack of knowledge of soil quality under CA has several negative effects. It hampers our ability to correctly predict possible benefits or disadvantages that may be associated with the implementation of CA as well as our ability to purposefully adjust CA techniques in order to get optimal yields and/or environmental effects. Not only is this an important scientific hiatus: it also hampers the introduction of CA techniques as farmers are rather reluctant to adopt techniques which may have unknown negative consequences. The main objective of this study was therefore to investigate how deep and superficial conservation tillage affect soil properties and soil functioning in the loess-derived silt loam soils in Belgium whereby special attention was paid to those aspects of soil quality that were not documented in previous studies. We used a farm-based approach in this study whereby we sampled intensively on a field that was under CT for 5 years and we did additional measurements on 6 fields that were under CT for 1–3 years. We analyzed the effect of CT on soil compaction, soil hydrology, root development and carbon and nitrogen amounts through detailed field measurements over the full crop growth season.

2. Materials and methods

2.1. Field experiments

Experiments on tillage techniques are labour-intensive and time-consuming: it is therefore difficult to combine a sufficient level of detail within the measurements with a sufficient number of observations so that statistically valid conclusions can be drawn. We therefore opted for a two-tier strategy whereby intensive measurements were carried out on a single field on which CT techniques had already been implemented for several years (called the experimental field hereafter) and to carry out less intensive measurements on six other fields (called farmer fields hereafter). The main idea behind this concept was that the collection of data on a larger set of fields would allow for statistically valid conclusions while the detailed measurements on a single field should provide more insight in the mechanisms and processes explaining the observed trends.

The main experiment (experimental field, Table 1) was established in 2004 on a silt loam soil in Huldenberg (50°46′N, 4°36′E) on a slope of ca. 7.7%. The experiment was arranged as 3 contiguous strips, each with an area of 250 m × 18 m. On each strip, four replicate plots were installed with an area of 10 m × 18 m. The tillage treatments applied on this field were traditional mouldboard ploughing to a depth of 0.25 m (MP), deep conservation tillage to a depth of ca. 0.3 m (DCT) and superficial conservation tillage to a depth of 0.15 m (SCT). Conservation tillage was performed with a chisel (details see Table 2) on both strips whereby only the depth of tillage was adapted. From the trial establishment in spring 2004 to fall 2010 the following crop rotation was practiced: maize (*Zea mays* L.), winter wheat (*Triticum aestivum* L.), oats (*Avena sativa* L., catch crop), sugar beet (*Beta vulgaris* L.), winter wheat, winter wheat, yellow mustard (*Sinapis alba* L., catch crop), maize and winter wheat. The present study mainly focuses on the 2009 maize growing season and the consecutive winter wheat growing season (2009–2010). Tillage dates are shown in Table 1. Particle size distributions and other soil specifications of the experimental field are shown in Table 3.

The farmer fields were established between 2008 and 2009 (Table 1) on silt loam soils with slopes ranging from 0 to 3%. On each field four to five tillage treatments were arranged in contiguous strips of ca. 100 m × 12 m that were replicated 2 times. Each strip was divided in two, so that 4 plots per tillage treatment were created. Because of logistical reasons, the layout on field 1 and 6 was somewhat different. On field 1 five tillage