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Effect of ploughing depth and mechanical soil loading on soil physical properties, weed infestation, yield performance and grain quality in sole and intercrops of pea and oat in organic farming

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ABSTRACT

The effect of ploughing depth and mechanical soil loading on the performance of pea sole crops, oat sole crops and pea–oat intercrops was investigated in field experiments under organic farming conditions at two sites in Germany in 2009 and 2010. The two ploughing depths were short-term shallow ploughing to a soil depth of 7–10 cm and deep ploughing to 25–30 cm. Wheel loads of 26 and 45 kN, which correspond to typical rear wheel loads of field machinery used during sowing operations, were compared to an uncompacted control. Shallow ploughing resulted in a greater penetration resistance in the 14–28 cm soil layer compared to deep ploughing. An increase in mechanical soil loading intensity increased the bulk density and decreased the air capacity in the 10–15 cm soil layer, whereas the penetration resistance was not affected. The annual weed infestation in pea sole crops was higher after shallow than after deep ploughing at both sites. Pea–oat intercrops compensated for the higher weed infestation after shallow ploughing at one site due to their excellent weed suppressive ability. Dependent on oat productivity, pea–oat intercrops produced comparable or higher grain and protein yields than pea sole crops. Intercropped pea yield components and grain protein yields were significantly lower than those of sole cropped peas. The ploughing depth did not affect pea grain yields in either year and oat yields in 2009. Due to a better emergence, the grain and protein yield of sole and intercropped oats were significantly higher after shallow ploughing in 2010. Mechanical soil loading did not have any effect on the yield performance of pea sole crops, oat sole crops and pea–oat intercrops in 2009. In 2010, mechanical soil loading of 26 kN and 45 kN decreased the pea grain yield by 12.1% and 20.8% respectively, regardless of sole or intercropped. Neither the grain yield nor the grain quality of sole and intercropped oats was affected by the mechanical soil loading in 2010. Grain and crude protein yields of total crop stands decreased with increasing mechanical soil loading after deep ploughing, whereas no significant differences were revealed after shallow ploughing. The present study confirms the positive qualities of pea–oat intercrops with regard to weed suppression and plant performance. Shallow ploughing mitigates the risk of a decrease in crop performance caused by heavy field traffic and provides an alternative to deep ploughing even in low weed competitive organically farmed grain legumes.

1. Introduction

The management of organic cropping systems is based on long-term strategies and avoids cultivation practices that allow a rapid intervention in crop production e.g., application of synthetic pesticides and water-soluble chemical fertilizers (Watson et al.,

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2002). The organic crop production therefore largely depends on soil characteristics, inherited or modified through cultivation, as well as on the performance of fodder and grain legumes. Grain legumes like pea (*Pisum sativum* L.) are of particular concern for the maintenance or promotion of soil fertility in stockless organic farming systems or in mixed systems with low stocking density, in which an adequate nutrient supply is a major problem (Watson et al., 2002).

An alternative to the intensive deep soil cultivation with a mouldboard plough (25–30 cm) is the technique of shallow ploughing. A reduction of the ploughing depth of 10–20 cm compared to normal deep ploughing has several advantages with regard to climate and soil protection. As a smaller volume of soil is tilled using shallow ploughing, it reduces the CO_2 release from the soil into the atmosphere (Chen and Huang, 2009; Reicosky and Archer, 2007), the fuel consumption and therefore the fuel costs as well as the CO_2 emissions derived from fuel combustion processes (Kouwenhoven et al., 2002; Plouffe et al., 1995). As pointed out by Børresen and Njøs (1994) and Pagliai et al. (1998), soil aggregates after shallow ploughing tend to be more stable than after deep ploughing, which reduces the risk of surface crust formation and erosion. Furthermore, shallow ploughing has been shown to have higher microbial activity in the upper tilled soil layer than in the same horizon under deep ploughing (Curci et al., 1997; Vian et al., 2009).

The impact of the ploughing depth on the yield performance is inconsistent and depends largely on site-related and agronomic factors. Håkansson et al. (1998) have demonstrated that topsoil texture and ploughing depth effects on grain yields are related. The authors showed that in sandy, clay and clay loam soils deep ploughing resulted in the highest yields, whereas shallow ploughing led to a better soil structure and therefore gave the best results in soils with a high fine silt fraction. Furthermore, the cultivated crops seem to react differently on shallow or deep ploughed soils. Organically and conventionally farmed cereals had comparable, lower or higher yields after shallow than after deep ploughing (Baigys et al., 2006; Bakken et al., 2009; Riley and Ekeberg, 1998). In contrast, the limited number of studies comparing the impact of ploughing depth on pea yields supports the assumption that peas respond negatively to shallow ploughing (Baigys et al., 2006; Pranaitis and Marcinkonis, 2005). Others, however, found no effect of reduced tillage on pea grain yields (Neumann et al., 2007). An effect of the ploughing depth on the grain quality was mostly not detected (Bakken et al., 2009; Riley and Ekeberg, 1998).

Lower pea and cereal grain yields after shallow ploughing under organic and conventional conditions were often attributed to higher annual and perennial weed infestation compared to deep ploughing (Børresen and Njøs, 1994; Brandsæter et al., 2011; Håkansson et al., 1998). In spite of advantages for climate and soil, organic crop production after shallow ploughing may be limited by strong weed-crop competition. This is of special interest when crops with a weak weed competitive ability were cultivated, like semi-leafless peas grown as a sole crop (Spies et al., 2011).

A possible approach to successfully cultivate peas after shallow ploughing may be the intercropping of peas and cereals such as oat (*Avena sativa* L.). Pea–oat and other cereal intercrops produce a better weed suppression than pea sole crops (Begna et al., 2011; Corre-Hellou et al., 2011; Kimpel-Freund et al., 1998). Peas and cereals complement one another in the N use with the cereal being competitive to a greater degree in the use of soil mineral N and therefore forcing the pea to depend more on N derived from N_2-fixation than in pea sole crops. As a result, the N use in pea–cereal intercrops is more efficient than in pea sole crops (Hauggaard-Nielsen et al., 2009). These issues of pea–cereal intercropping contribute to the higher total grain yields in intercrops than in pea sole crops and result mostly in better pea, cereal or total intercrop grain quality properties (Begna et al., 2011; Hauggaard-Nielsen et al., 2001, 2008; Neumann et al., 2007).

In regions with slow warming and drying soils, the optimal spring pea sowing date often does not coincide with adequate soil conditions for seedbed preparation and sowing. A delay in sowing beyond the middle of March, however, is associated with a continuous decrease in pea yield performance (Aufhammer, 1998). Thus, farmers tend to prepare the seedbed and sow when the soil can be sensitive to soil compaction. Pea development and growth is considerably influenced by compacted soil structures. As a consequence of mechanical resistance, the root growth rate and length of peas were reduced (Boone et al., 1994; Castillo et al., 1982). Owing to an insufficient aeration in compacted soils, the *Rhizobium* nodulation on pea roots was significantly lower than under non-compacted soil conditions (Grath and Håkansson, 1992; Grath and Arvidsson, 1997). The reduced root growth, which limits the explorable soil volume, and the lower N_2-fixation were accompanied by a decline in uptake of nitrogen and other macro or micro nutrients (Castillo et al., 1982; Grath and Håkansson, 1992). These negative effects are coupled with an earlier senescence and considerable yield losses (Boone et al., 1994; Grath and Arvidsson, 1997; Vocanson and Jeuffroy, 2008). Grain legumes are considered particularly susceptible to compacted soils and more sensitive to abiotic soil conditions than cereals (Batey, 2009; Jayasundara et al., 1998). However, previous studies noted no significant difference in the sensitivity between peas and cereals (Grath and Arvidsson, 1997; Henderson, 1991). To date, no study of which we were aware has evaluated the influence of soil compaction during pre-sowing and sowing operations on the growth and the performance of grain legume–cereal intercrops.

Depending on the operation width and on wheel characteristics, 32–57% of the area is over run at seedbed preparation and 19–39% at sowing in ploughed fields (Kroulík et al., 2009). If the soil is sensitive to soil compaction, these operations can therefore have considerable impact on the growth, yield and grain quality of pea, oat and presumably pea–oat intercrops. Due to the absence of short-term strategies compensating for the effects of poor soil structure on plant growth and yield performance, this applies particularly to organic crop production. Also, Droogers et al. (1996) found that the probability of a loamy soil to be trafficable without risking soil compaction was lower under long-term organic management than under conventional management due to lower bulk density values at the soil surface and higher soil water contents. Thus, the authors concluded that the risk of soil compaction is higher under organic than under conventional farming, most notably under deep ploughing. The intensity of primary tillage influences the impact of seedbed and sowing operations on soil properties and plant growth. Owing to higher soil strength, a soil under reduced tillage supported a soil compaction in spring to a higher degree than a soil under deep ploughing to 25 cm soil depth (Wiermann et al., 2000). Bakken et al. (2009) suggested that the risk of soil compaction in the upper subsoil is higher under deep ploughing than under shallow ploughing, which is explained by the higher amount of loose soil under deep ploughing. However, there is currently only very limited published data on the effect of soil compaction during seedbed preparation or sowing on the soil structure and the crop production in deep and shallow ploughed fields.

In this study, the impact of ploughing depth and mechanical soil loading during seedbed preparation or sowing on the sole or intercropping of pea and oat under organic conditions is concerned. In doing so, we focused on soil physical conditions, weed infestation, yield structure and performance as well as on aspects of grain quality. Our main objectives were to (a) quantify the effect of shallow ploughing as well as of mechanical soil