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Impact on soil physical properties of using large-grain legumes for catch crop cultivation under different tillage conditions

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ABSTRACT

In Central Europe, various plant species including large-grain legumes and their mixtures are grown as catch crops, particularly between grains harvested early and subsequent summer crops. This article investigates the question of how soil structure in the topsoil is influenced when catch cropping with large-grain legumes (experimental factor A: without catch crop, with catch crop) under different ploughless tillage conditions during catch crop seeding (experimental factor B: deep tillage/25–30 cm, shallow tillage/8–10 cm). Five one-year trials were performed using standard machinery at various sites in Germany. Soil core samples extracted from the topsoil in the spring after catch crop cultivation served to identify air capacity, saturated hydraulic conductivity and precompression stress. The above-ground and below-ground biomass yields of the catch crops were also determined at most of the sites. In addition, the soil compaction risk for the working steps in the experiments was calculated using the REPRO model.

The dry matter yield of the catch crops varied considerably between the individual trial sites and years. In particular, high levels of dry matter were able to form in the case of early seeding and a sufficient supply of precipitation. The soil structure was only rarely affected positively by catch crop cultivation, and catch crops did not contribute in the short term to loosening already compacted topsoils. In contrast, mechanical soil stresses caused by driving over the ground and additional working steps used in cultivating catch crops often led to lower air capacity in these treatments. This is consistent with the soil compaction risks calculated using the REPRO model, which were higher in the treatments with catch cropping. Catch crop cultivation also only resulted in improved mechanical stability at one location. The positive effect of deep ploughless tillage on air capacity and saturated hydraulic conductivity, however, became more clearly evident regardless of catch crop cultivation. In order for catch crop cultivation with large-grain legumes to be able to have a favourable impact on soil structure, it is therefore important that cultivating them does not result in any new soil compaction. In the conditions evaluated, deep tillage was more effective at loosening compacted topsoil than growing catch crops.

1. Introduction

In Central Europe, various plant species are grown as cover crops in winter and catch crops sown in July/August, particularly between species of grain harvested early and subsequent summer crops like sugar beets (*Beta vulgaris* subsp. *vulgaris*), maize (*Zea mays* L.) and spring barley (*Hordeum vulgare* L.) (Lütke Entrup, 2000). Cover crops such as rye (*Secale cereale* L.) and common vetch (*Vicia sativa* L.) cover the soil during winter and are tolerant of frost. Their above-ground biomass can be used in the spring after seeding as animal feed or in anaerobic digestion plants. By contrast, species with rapid juvenile growth are preferred for use as catch crops in summer; these species are killed by frost under the prevailing climatic conditions in the winter months. Their above-ground biomass is only used as green manure. White mustard (*Sinapis alba* L.), oil radish (*Raphanus sativus* var. *oleiformis*) and phacelia (*Phacelia* Juss.) are

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particularly popular as catch crops (Buhre et al., 2014). Currently, however, more and more farms are considering using large-grain legumes such as field beans (*Vicia faba* L.).

The cultivation of both cover crops and catch crops is supposed to serve a wide range of functions. Particularly when combined with direct or mulch seeding, catch crops reduce the risk of soil erosion when cultivating the subsequent crop (Bechmann et al., 2009) as well as associated nutrient losses (Ulen, 1997). Non-leguminous catch crops, but also mixtures of non-leguminous and leguminous catch crops, reduce the nitrate concentration in soil solutions, thus preventing mineral nitrogen from shifting down into deeper soil layers during winter (Hooker et al., 2008; Rinnofner et al., 2008). On the other hand, by fixing biological nitrogen in the soil, leguminous catch crops can serve as a source of nitrogen, particularly in systems like organic farming which do not use mineral nitrogen (Watson et al., 2002; Rinnofner et al., 2008). Catch crop plant growth serves as an essential source of food for earthworms (Schmidt et al., 2003; Reeleder et al., 2006) and can thus contribute to increasing soil biodiversity. Cover crops can raise the soil organic carbon content (Higashi et al., 2014) and change its characteristic composition (Ding et al., 2006).

In addition to – and also sometimes in interaction with – the functions mentioned, one general advantage of cultivating catch crops is the improvement of soil structure. Previous studies have focused mainly on the water stability of soil aggregates (Breland, 1995; Ball-Coelho et al., 2000), measuring soil strength using a penetrometer (Folorunso et al., 1992; Raper et al., 2000) and identifying dry bulk density (Breland, 1995). Furthermore, the above-mentioned studies considered the effect of cover crops on soil structure. Very few documented studies have investigated these questions using catch crops. But catch crops may also contribute to improving soil structure – particularly those which have strong taproot systems, provide extensive and longer-term shade and produce high levels of above-ground and below-ground biomass. In principal, legumes are more effective at stabilising the soil structure than non-legumes (Cochrane and Aylemore, 1994 cited in Hamza and Anderson, 2005).

For economic reasons, catch crops are often grown using ploughless tillage. The depth of tillage can be very shallow (<8–10 cm) but also include the whole topsoil (25–30 cm). Varying tillage intensity impacts upon physical soil properties (Tebrügge and Düring, 1999), and combined with catch crop cultivation this in turn may affect soil structure.

Therefore this study investigates the question of how important physical and mechanical soil properties in the topsoil are influenced when cultivating large-grain legumes as catch crops, with varying depths of ploughless tillage. In order to describe the effects of cultivation techniques on soil structure and to characterise soil performance, Horn and Kutilek (2009) recommend also using an intensity-based parameter (e.g., saturated hydraulic conductivity) in addition to a capacity parameter (e.g., air capacity). In the topsoil, an intact soil structure displays air capacity of at least 8% by volume and saturated hydraulic conductivity of 10 cm d^{-1} (Werner and Paul, 1999). Additionally, mechanical precompression stress is an important, direct mechanical criterion of a soil's susceptibility to compaction (Arvidsson and Keller, 2004).

In this article, the investigation of physical and mechanical soil properties was deliberately conducted shortly after seeding of the main crops, because under the prevailing conditions in Central Germany the roots of summer crops like spring barley (*Hordeum vulgare* L.) and sugar beets (*Beta vulgaris* subsp. *vulgaris*) reach depths of more than 30 cm – and hence the transitional layer between the topsoil and subsoil – just 30–40 days after seeding (Damm et al., 2013). Also bearing in mind the tillage technique, potential effects on soil structure in the topsoil of cultivating catch crops are therefore particularly relevant shortly after the main crop

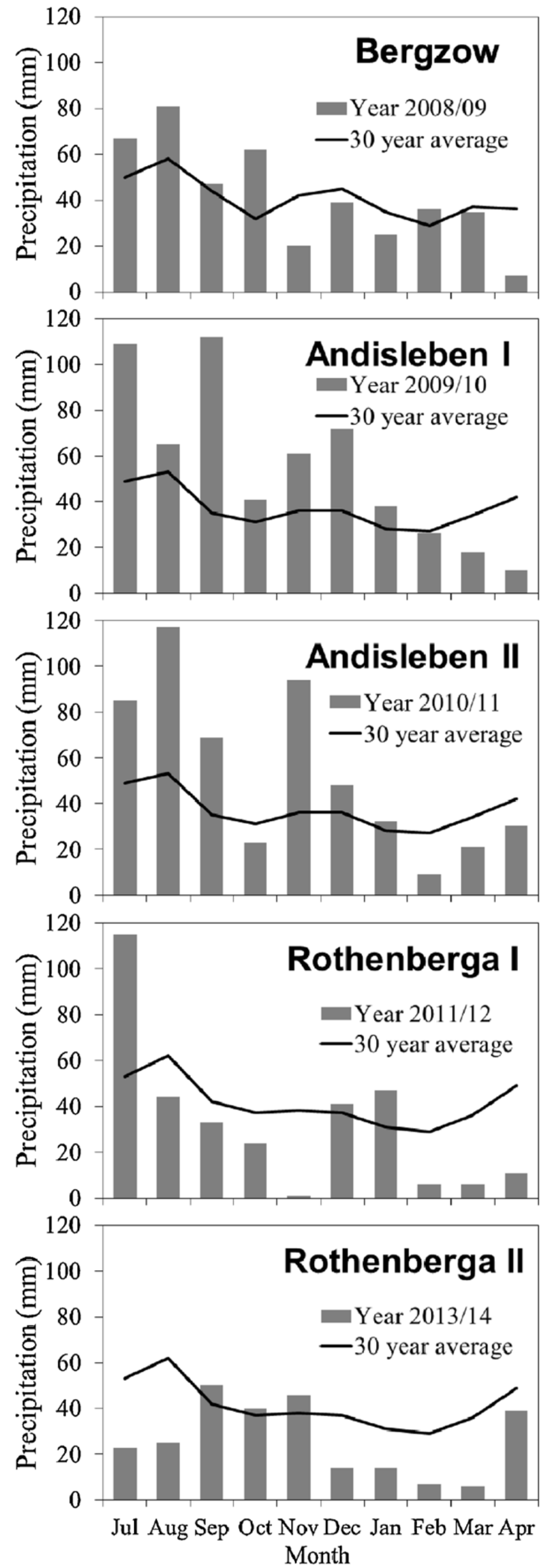

Fig. 1. Monthly cumulative precipitation (July–April) for the experimental sites and years.