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Short time effects of biological and inter-row subsoiling on yield of potatoes grown on a loamy sand, and on soil penetration resistance, root growth and nitrogen uptake

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ABSTRACT

Soil compaction, especially subsoil compaction, in agricultural fields has increased due to widespread use of heavy machines and intensification of vehicular traffic. Subsoil compaction changes the relative distribution of roots between soil layers and may restrict root development to the upper part of the soil profile, limiting water and mineral availability. This study investigated the direct effects of inter-row subsoiling, biological subsoiling and a combination of these two methods on soil penetration resistance, root length density, nitrogen uptake and yield. In field experiments with potatoes in 2013 and 2014, inter-row subsoiling (subsoiler) and biological subsoiling (preceding crops) were studied as two potential methods to reduce soil penetration resistance. Inter-row subsoiling was carried out post planting and the preceding crops were established one year, or in one case two years, prior to planting. Soil resistance was determined with a penetrometer three weeks after the potatoes were planted and root length density was measured after soil core sampling 2 months after emergence. Nitrogen uptake was determined in haulm (at haulm killing) and tubers (at harvest). Inter-row subsoiling had the greatest effect on soil penetration resistance, whereas biological subsoiling showed no effects. Root length density (RDL) in the combined treatment was higher than in the separate inter-row and biological subsoiling treatments and the control, whereas for the separate inter-row and biological subsoiling treatments, RLD was higher than in the control. Nitrogen uptake increased with inter-row subsoiling and was significantly higher than in the biological subsoiling and control treatments. However, in these experiments with a good supply of nutrients and water, no yield differences between any treatments were observed.

1. Introduction

Soil compaction in agricultural fields has increased in recent decades due to intensive farming practices, including short crop rotations and use and intensification of heavy machinery. The compaction effect of heavy traffic may persist for more than a decade (Berisson et al., 2012) and is especially unfavourable when the pressure is applied while the soil water content is high (Heesmans, 2007; Hamza and Anderson, 2005). In cereal fields, yearly traffic wheel intensity of up to 150 Mg km ha^{-1} has been recorded, while in potato (*Solanum tuberosum* L.) fields the maximum value recorded is much higher, 300 Mg km ha^{-1} per year (Håkansson, 2000). Soil compaction occurs both in the topsoil and subsoil and results in reduced porosity, especially of large pores, and increased bulk density. However, it is a more complex and costly problem to alleviate subsoil compaction than compaction in the topsoil (Zink et al., 2010; Håkansson, 1994). In most fields a compacted soil layer, known as the plough pan, can be detected in the upper subsoil. The shape, strength and thickness of the plough pan are often related to the pressure applied to the topsoil (Spoor et al., 2003; Håkansson and Reeder, 1994; Barraclough and Weir, 1988). High root penetration resistance in combination with reduced movement of water in the soil reduces water and nutrient availability to crops (Wolkowski and Lowery, 2008; Stalham et al., 2005; Arvidsson and Jokela, 1995; Håkansson, 1994) and may change the distribution of roots between soil layers and in some cases confines root development to the upper part of the soil profile wich restricts plant availability to water and minerals (Miransari et al., 2009; Lipiec et al., 2003; Unger and Kaspar, 1994; Douglas and Crawford, 1993).

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Potato is a crop with a sparse, shallow root system sensitive to drought and soil compaction at all stages of growth, from emergence to harvest (Stalham et al., 2005; Lynch et al., 1995). However, there is great variation in root biomass and overall structure of the root within the crop (Wishart et al., 2013; Iwama, 2008). In optimal soil conditions, it has been observed that potato roots can produce large amounts of root biomass, with a root depth of 1.40 m (Stalham and Allen, 2001). An explanation to the shallow roots of potato crops in practical field conditions may be the inability of the potato root system to penetrate compacted soil layers as for example the plough pan (Gregory and Simmonds, 1992). At soil penetration resistance greater than 1 MPa, potato root growth is greatly reduced, whereas roots of other crops can penetrate soil with resistance values of between 2 and 3 MPa (Stalham et al., 2007). The inability of the potato crop to penetrate compacted soil may be explained by the morphology of the potato root system, which is fibrous and branched with most of the root growth originating from lateral and basal roots (Weaver, 1926). When growing, roots rearrange the closest soil particles by pushing particles aside or in front of the root apex. However, at unfavourable levels of soil penetration resistance the root elongation rate decreases and the diameter of roots increases markedly, leading to clustered root growth and restricted root extension (Bengough and Mullins, 1990; Taylor and Ratliff, 1969).

Agronomic practices such as deep cultivation or subsoiling designed to reverse soil compaction in deeper soil layers have been tested in many studies (Ekelöf et al., 2015; Canarache et al., 2000; Holmstrom and Carter, 2000). Subsoiling can improve plant growth and encourage deeper rooting (White et al., 2005). Bishop and Grimes (1978) observed a significant increase in rooting throughout a soil layer of 0.76 m depth when subsoiling was carried out on a sandy loam. Mechanical deep subsoiling has with a positive potato yield result recently been studied in Sweden (Ekelöf et al., 2015) and the growers are very interested to use this method. However, the drawback is that deep subsoiling has limited longevity and needs to be employed on an annual basis, as loosened soil is very susceptible to re-compaction (Raper et al., 2005; Busscher et al., 2002; Hamilton-Manns et al., 2002). For example, Busscher et al. (1986) found that on a loamy sand subsoiled to a depth of 0.5–0.6 m, soil strength increased to 1.5–2.5 MPa one year after subsoiling, although the effects of subsoiling were still visible. Subsoiling may also lead to acceleration of organic matter decomposition, resulting in weaker, less stable soil that is more susceptible to subsequent compaction (Brady and Weil, 2008; Canarache et al., 2000) and, in addition, has negative environmental effects as this method requires high traction force and fuel. The yield response to subsoiling is however inconsistent (Stalham et al., 2005). In some studies, tuber yield was found to increase by 6–14% (Henriksen et al., 2007; Bishop and Grimes, 1978), while other studies found no effect of subsoiling on yield (Holmstrom and Carter, 2000). According to Stalham et al. (2005) these diverging results may be because i) there was no real problem with compaction in the fields studied, ii) the subsoiling was carried out when soil was at or above its plastic limit, doing more harm than good to the soil structure, iii) the working depth was incorrect, or iv) good water supply masked the effects of subsoiling.

Crops with deep root systems have been shown to have positive effects on soil structure by creating useful structural features such as root channels in deep soil layers that can be utilised by the following crop (Perkons et al., 2014; Löfkvist, 2005; Ishaq et al., 2001; Cresswell and Kirkegaard, 1995). In addition, plant root exudates stimulate the occurrence of soil organisms such as earthworms and microbes that contribute to the formation of bio-pores and a more stable soil structure through secretion of substances and humus compounds that bind soil particles together (Gregory, 2006; Dexter, 1990).

In the context of subsoil loosening, plants with root systems able to penetrate compacted soils is of special interest (Löfkvist, 2005). Materechera et al. (1991) proposed that crops with greater root diameter may be better at penetrating compacted soils than crops with small root diameter. This is in line with Chen and Weil (2010) who found that the taproot-forming species forage radish (cv. Daikon) and rapeseed (cv. Essex), both belonging to the Brassicaceae family, showed greater penetration capability than rye on fine loamy soils. Using a computer-assisted tomography technique, Hamza et al. (2001) observed that radish plants destabilised soil and loosened compaction by temporary decreases and increases in root diameter after the commencement of transpiration. Legumes may also be effective in improving soil structure, in some cases more effective than non-legumes, due to their strong root system and ability to produce substantial amounts of high quality residues (Snapp et al., 2005; Jones et al., 1998; Cochrane and Aylmore, 1994).

Soil compaction modifies the soil nitrogen (N) balance. This is an effect of alteration of soil aeration status contributing to N losses and decreased N mineralisation, and of soil water properties leading to a change in the pattern of N transport and root growth (Lipiec and Stepniewski, 1995; Lipiec and Simota, 1994). By reducing soil compaction the crop root system may expand and grow larger which, in return, facilitates crop N uptake. This is of special importance considering N uptake efficiency from deeper soil levels (White et al., 2005; Westermann and Sojka, 1996; Pierce and Burpee, 1995; Miller and Martin, 1986). By monitoring the pattern of nitrate depletion, Asfary et al. (1983) found that potato roots were substantially more active below 0.30 m than at shallower depth. High root density in the subsoil is therefore of great importance at later stages of growth, when nitrate in the topsoil is depleted (Strebel et al., 1983).

The use of different preceding crops for potato has not been extensively studied (Griffin et al., 2009). In addition, there is little information about the effects of combining a preceding crop with mechanical subsoiling in potato production. The objectives of this study were thus to determine the effects of mechanical, inter-row subsoiling after planting, biological subsoiling with preceding crops and a combination of these two methods on: i) soil penetration resistance, ii) root length density (RLD) and root distribution, iii) N uptake and iv) total yield. Our hypothesis was that combining inter-row and biological subsoiling would have a more pronounced effect in reducing soil penetration resistance, which in turn could encourage deeper rooting and thus lead to better N acquisition by potato plants and thus to increased yield.

2. Materials and methods

2.1. Experimental site and design

Field experiments with potatoes were conducted in 2013 and 2014 on a soil classified as an Arenosol according to WRB (IUSS Working group, 2015), at the experimental farm Helgegården (56°1′20″N, 14°3′45″S), Kristianstad, Sweden (Table 1). According to soil penetration resistance data a clear plough pan was indicated (Fig. 1). The crop rotation during the previous 12 years is presented in Table 2. A conventional subsurface drainage system was installed at the experimental fields in 2000.

The experiments were arranged in a split-plot block design with four replicates. The factor in the main plot was preceding crop and in the subplots inter-row subsoiling/no inter-row subsoiling. The experimental plots consisted of units measuring 12 m by 20 m, which were laid out in the year when preceding crops were established and divided into two (6 m by 20 m) in the year the potato crop was planted (8 rows per subplot) and the inter-row subsoiling treatment was applied. The outer rows were used as guard rows.