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Short-term effects of loosening and incorporation of straw slurry into the upper subsoil on soil physical properties and crop yield

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ABSTRACT

Subsoils that are compacted, nutrient-poor or low in soil organic matter (SOM) often limit crop growth and yield. Improvement of subsoil conditions by deep loosening is laborious and expensive and its positive effect may not last. This study investigated the effect of deep loosening and injection of slurry made from cereal straw (30 Mg dry mass ha^{-1}) at 25–34 cm depth on soil properties and crop performance in a Swedish field experiment that started in autumn 2015 and monitored soil and crop properties during 2016. Loosening + straw incorporation into subsoil resulted in significantly higher soil organic carbon (SOC) content, potential plant-available water and porosity and lower bulk density (BD) in spring 2016 compared with the control. In autumn 2016, penetrometer resistance (PR) and BD were both significantly lower and SOC and porosity were significantly higher in the loosening + straw treatment compared with the control and loosening only (29–34 cm). Furthermore, BD was significantly lower in the loosening + straw treated subsoil than in the top soil layer of the control (0–10 cm). Observations indicated that more continuous pores were found in the loosening + straw treatment than in other treatments. Roots and soil faunas were found more frequently where straw was incorporated. Grain yield increased by 5.6% due to loosening + straw addition (P = 0.03) and by 4% due to loosening only (P = 0.06). These results indicate that loosening + straw input into upper subsoil had a positive short-term influence on soil physical properties, potential plant-available water and grain yield. Straw addition prolonged the positive effect of loosening.

1. Introduction

Subsoil that is compacted, saline, acidic, nutrient-deficient or low in soil organic matter (SOM) can limit crop growth, yield and quality (Kautz et al., 2013; Rengasamy et al., 2003). However, previous research has mainly focused on topsoil horizons (Kautz et al., 2013; Lorenz and Lal, 2005; Rengasamy et al., 2003), probably due to lack of techniques and management options for subsoil improvement and to underestimation of the role of subsoil in plant nutrient acquisition (Kautz et al., 2013). Compacted soil has poor structure and is characterised by high bulk density (BD) and high penetration resistance (PR) (Etana and Håkansson, 1994; Hammel, 1994; Schjønning and Rasmussen, 1994), and reduced porosity (Hassan et al., 2007).

Improving subsoil by loosening is expensive (Håkansson and Reeder, 1994; Jones et al., 2003) and its effect may not last, as soils recompact (Kooistra and Boersma, 1994; Larney and Fortune, 1986; Munkholm et al., 2005). Therefore, combining loosening with other soil amelioration practices may be relevant (Hamza and Anderson, 2005).

Subsoil improvement was achieved in a Swedish study when loosening of clay subsoil was combined with addition of burned lime to stabilise soil structure, which increased crop yields by about 7% over a 10-year period (Westlin, 2010). Structural stabilisation of loosened subsoil may also be achievable through addition of organic material, thereby forming new aggregates (Gill et al., 2008; Khalilian et al., 2002; Leskiw et al., 2012), minimising re-compaction (Hamza and Anderson, 2005; Leskiw et al., 2012) and enhancing soil fertility. However, combining deep loosening and incorporation of organic material into subsoil is not common practice due to lack of scientific results and technical solutions (Hamza and Anderson, 2005).

The aims of the present study were to investigate the short-term effect of deep loosening and injection of straw slurry (30 Mg dry mass ha^{-1}) into the upper subsoil on soil physical properties, crop growth

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and yield.

2. Material and methods

2.1. Experimental site and treatments

The field study was carried out on a Eutric Cambisol (FAO, 2014) at Säby (Uppsala, Sweden; 59°49′N, 17°42′E) used for arable crops for more than 100 years. The upper subsoil (25–35 cm) at the site consists of silt loam (20.5% clay, 60.6% silt, 18.9% sand) and the pH in H_2O (1:2.5) is 6.5. The field study was laid out in a randomised block design with four blocks as replicates and a plot size of 75 m square (3 m width and 25 m length) and five treatments, of which three treatments (subsoil loosening, subsoil loosening + straw incorporation and control) are reported in this paper.

2.2. Subsoiling and incorporation of straw slurry

Straw with a density of 0.39 kg dm^{-3}, consisting of 0.53% nitrogen (N), 0.042% phosphorus (P), 0.74% potassium (K) and 45% carbon (C), with pH 6.6 and C:N ratio 85, was submerged in water to produce slurry (91% water and 9% straw of total volume) for injection. The water-holding capacity was about 5.5 mL g^{-1} straw. The deep loosening machine used (Combiplow Gold, AGRISEM International, France) had a working width of around 3 m, with four vertical tines spaced 74 cm apart and bearing a winged tip 32 cm wide (Fig. 1). The net subsoil area affected by loosening was 43% per plot (32 cm width x 9 cm depth). Loosening and straw incorporation were performed at a speed of 1.5 km per hour to 25–34 cm depth. During loosening of the soil, the straw slurry was injected under pressure into the upper subsoil through rectangular openings in metal pipes welded behind each vertical tine and mounted on the back of a slurry tank.

The organic amendment was applied at about 30 Mg dry mass ha^{-1}. Due to the small openings in the injector pipes, incorporation of the straw slurry was limited to lines of about 8 cm width x 9 cm depth. The distance between straw lines in the upper subsoil was 68.5 cm. At places where space in the upper subsoil to accommodate the large pulse of straw was limited, around 15–20% of the slurry ended up on the soil surface. Moreover, variations in injection pressure and driving speed of the tractor caused uneven distribution of straw slurry between and within straw lines. The soil area affected by loosening + straw treatment was 43%, of which 11% was enriched with straw slurry. On a volume basis, considering a soil depth of 50 cm, the proportion of soil affected by loosening was 15% and the proportion affected by loosening + straw was 15%, of which 4% was treated with straw slurry. Loosening and loosening + straw injection lines were marked and soil and crops were sampled randomly along the lines. Final yield was measured from combine-harvester data for the whole plot.

2.3. Soil sampling

Soil samples for analysis of soil organic carbon (SOC), total soil N and bulk density (BD) were taken in spring before sowing and in autumn after harvest in 2016. Four samples were taken with an auger at 29–34 cm in each plot and pooled to a composite sample. The topsoil (0–10 cm) was only sampled in the control because top soil in the other treatments was affected by the loosening operation. Soil samples were collected on the same occasion and close to the spot where BD cylinders were sampled. Chemical analyses were carried out on air-dried and sieved (2 mm mesh size) soil using dry combustion (LECO CNS Analyser; LECO Corporation, St. Joseph, MI 49085, USA) (Nelson and Sommers, 1996).

Soil BD was determined as described by Blake and Hartge (1986) by extracting four samples per plot, using cylinders (inner diameter 7.2 cm) of 10 cm height for the topsoil (0–10 cm) and 5 cm for the upper subsoil (29–34 cm). Gravimetric water content in spring and total porosity (% pore space) in spring and autumn were determined on the same soil samples used for BD measurements. Total porosity was calculated using the formula proposed by Vomocil (1965), assuming a particle density of 2.65 g cm^{-3}. Particle density was corrected for straw addition in the loosening + straw slurry treatment, which was denoted as 1.41 g cm^{-3} (average of decomposed and undecomposed straw) (Guerif cited in Soane, 1990). Saturated water content (θ_{sat}), water content at field capacity (θ_{fc}) and wilting point (θ_{wp}) were estimated from a pedotransfer function (PTF) used to predict hydraulic properties of Swedish soils (Model 8 in Kätterer et al., 2006). The results were associated with different soil pores to calculate pore size distribution. The difference between θ_{fc} and θ_{wp} multiplied by the thickness of the soil layer was considered to represent plant-available water in that specific soil layer (Allen et al., 1998). Penetration resistance (PR) was

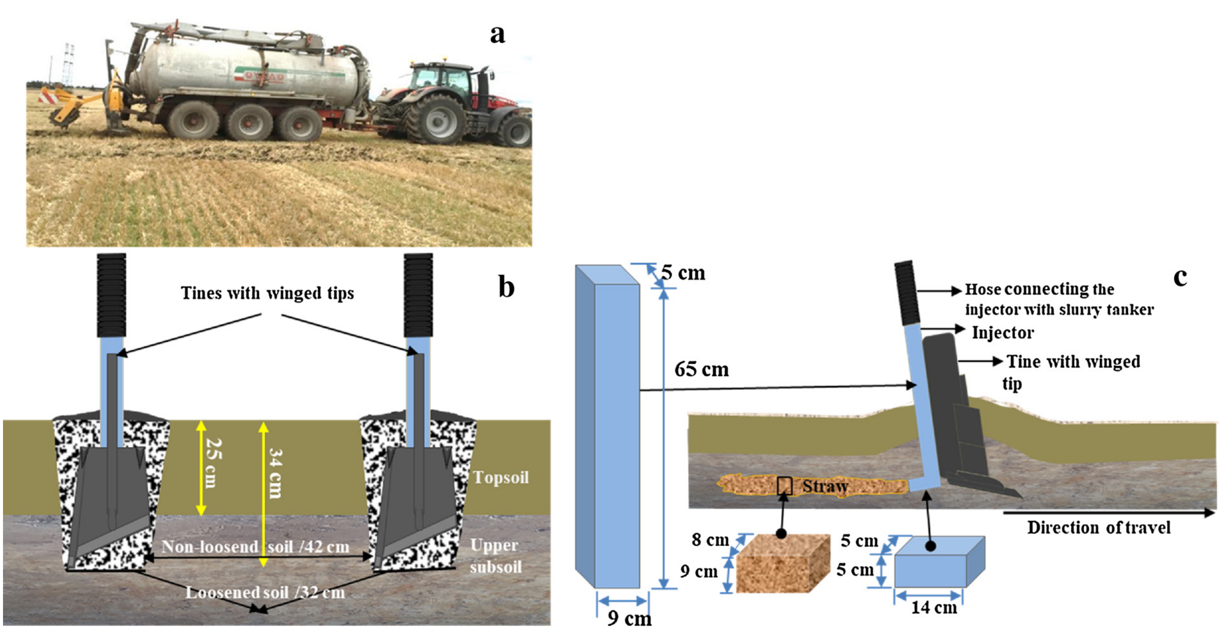

Fig. 1. The loosening and straw slurry injection system: (a) tractor-mounted equipment (b) front view of tines with injectors (there are two additional tines and injectors) and (c) side view of tine with its injector.