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Compaction and sowing date change soil physical properties and crop yield in a loamy temperate soil

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ABSTRACT

Timing of tillage operations is of utmost importance in arable farming because tillage performed under inappropriate soil water conditions results in soil structural damage and creation of undesirable seedbeds for crop establishment and growth. In a field experiment on a loamy soil in Ås, Norway, we investigated the effect of compaction and sowing dates on (i) seedbed physical properties, (ii) crop yield, and (iii) the range of water contents for tillage. The experiment was established in 2014 and the same experimental treatments were repeated in 2015, 2016 and 2017. The sowing dates included early (A1), normal/timely (A2) and late (A3) sowing dates. The compaction treatments applied each year were done wheel-by-wheel by a MF 4225 tractor weighing 4.5 Mg with a single pass (B1) and compared with a control treatment (B0). This study reported soil physical properties for only 2016 and small grain cereal yield for the four years. The soil pore characteristics determined were soil bulk density (ρb), volumetric water content (θ), air-filled porosity (ε_a), air permeability (k_a) and pore organization indices ($PO_1 = k_a/\varepsilon_a$ and $PO_2 = k_a/\varepsilon_a^2$); strength properties measured were tensile strength (Y), soil penetration resistance (PR), degree of soil fragmentation by drop-shatter test, and water contents for tillage by calculating the range of water content for tillage ($\Delta\theta_{RANGE}$). The interaction of compaction with sowing date, generally affected soil pore characteristics, particularly at 1–5 cm depth. The A1 treatment significantly affected the strength characteristics of seedbed by decreasing soil friability and increasing Y at 1–10 cm depth, and PR down to 27 cm depth. The A3 treatment decreased yield of spring-sown small grain cereal crops, but this may be ascribed to a shorter growing season rather than an influence of soil physical properties. The A1 and A3 decreased the range of water contents for tillage compared to the A2, although the difference was not significant at any of the depths studied. Findings of the study have practical implications for cropping regimes in colder climates where farmers can be faced with a short growing period by showing that cultivation in wet soil conditions such as early spring can adversely affect seedbed physical properties and soil workability for subsequent tillage operations.

1. Introduction

Tillage is an integral part of arable farming practices— it induces changes in soil structure that may be beneficial or detrimental to soil physical properties and crop growth. In a conventional cultivation, secondary tillage means harrowing after primary tillage with the aim of preparing the soil for seeding, also called seedbed preparation, by creating optimum physical conditions for crop establishment and growth (Arvidsson et al., 2000). In this paper, the term “tillage” without an adjective refers to secondary tillage for seedbed preparation. One important aim of tillage is to fragment soil in order to minimize the proportion of large aggregates (Ojeniyi and Dexter, 1979). It is, generally accepted that soil aggregate size range of 1–5 mm is required for good seedbed that favors seed emergence and growth (Russell, 1961). This is because such seedbed has good aeration, water holding capacity, and improve soil-seed-contact area (Braunack and Dexter, 1989b).

Soil workability is a key condition in tillage. In seedbed preparation, soil workability is the ease with which a well-drained soil can be tilled

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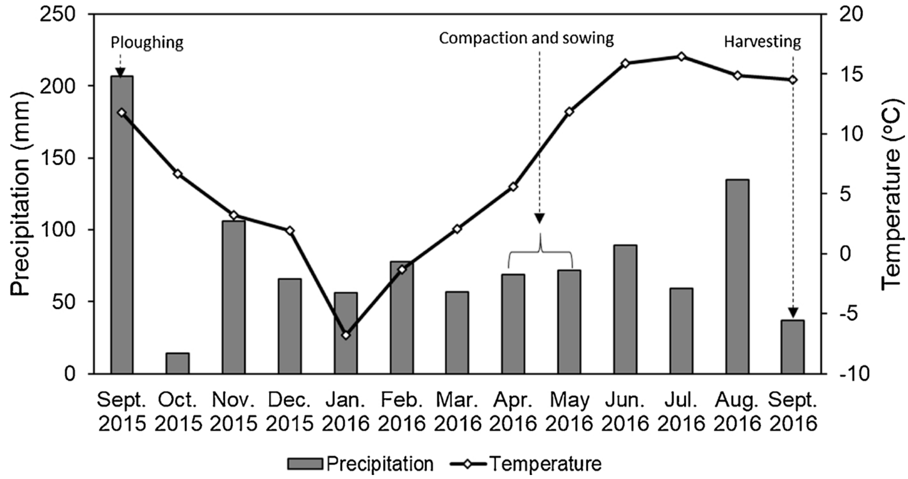

Fig. 1. Mean monthly precipitation and air temperature of the experimental site from September 2015 to September 2016.

to produce an optimum seedbed for crop establishment (Dexter, 1988). Moisture content at tillage is a major factor affecting soil workability. Soil is workable over a range of water content ($\Delta\theta_{RANGE}$) between an upper (wet tillage limit, θ_{WTL}) and a lower (dry tillage limit, θ_{DTL}). $\Delta\theta_{RANGE}$ decreases with decreasing soil organic matter content and with increasing clay content and soil bulk density (Dexter and Bird, 2001). This suggests that farmers can be faced with cultivation problems in regions with hard-setting soils (Mullins et al., 1988) and in colder climates with a short period for spring or autumn cultivation.

Improved tires and power of modern field machinery mean that farmers are able to till in less-than-ideal soil conditions such as early spring tillage in temperate regions like Northern Europe. Therefore, modern agricultural machinery might improve trafficability, that is, the ability of soil to support and withstand field traffic without irreversible soil degradation (Rounsevell, 1993), at the expense of increased risk of detrimental effects from tillage, and the farmers' decisions on tillage and sowing date become crucial.

When performed in less-than-ideal soil conditions, tillage can produce short- and long-term detrimental effects on soil. The described tillage effects on germination, emergence and growth of the current crop can be considered short-term effects. On the other hand, changes induced by tillage which persist over cropping seasons or years can be considered long-term effects. Structural degradation in the topsoil due to tillage in too wet conditions has been shown to persist until the following autumn (Munkholm and Schjønning, 2004), which can affect the water contents for tillage and seedbed preparation for a subsequent winter crop. Therefore, tillage-induced soil structural degradation in spring might reduce soil workability for autumn tillage and complicate scheduling of these operations. It must be emphasized that there is a lack of quantitative information on this effect as reviewed by Obour et al. (2017).

In addition to the short- and long-term effects, in too wet soil condition, tillage can create a seedbed composed of large and strong soil fragments because of kneading. According to Dexter and Birkas (2004), large soil fragments have less agronomic value because they do not favor good soil-seed-contact area. Further, large soil fragments can impede crop emergence and root growth (Nasr and Selles, 1995), which adversely affect crop yield. In too dry soil condition, soil becomes strong and high specific energy is required for soil crumbling. Also, tillage can produce undesirably finer fragments, which are susceptible to surface crusting, and wind and water erosion (Braunack and Dexter, 1989a). Therefore, knowledge of the effects of sowing date on seedbed physical properties is a pre-requisite for decision support for scheduling and planning tillage operations to create optimal seedbeds for crop establishment.

The objectives of the study were to quantify the effect of compaction and sowing dates on (i) seedbed physical properties, (ii) crop yield, and (iii) the range of water contents for tillage. Tillage is most often conducted in either spring or autumn, but in this study, only spring tillage is considered. Three sowing dates, namely early, timely/normal and late, were chosen as being representative of real farming practice of carrying out early, normal and delayed spring tillage. We focused on soil strength characteristics, namely tensile strength, friability, penetration resistance and soil fragmentation to assess soil workability. We hypothesized that the strength of soil aggregates and soil fragmentation will differ for different compaction treatments and sowing dates. The hypothesis was tested by comparing the strength properties of soil after early, normal and late sowing in spring.

2. Materials and methods

2.1. The experimental site

Soil samples were collected from a compaction experiment in Ås, Norway (59° 39′ 47″ N 10° 45′ 49″ E). Mean annual precipitation and temperature in the area are 785 mm and 5.3 °C, respectively (Wolff et al., 2017). The monthly precipitation and temperature data covering the period September 2015 and September 2016 (Fig. 1) were obtained from a meteorological station located about 1 km from the experimental site. The period covers autumn plowing of the field in 2015, cultivation in the spring and harvest in autumn 2016. Daily precipitation and air temperature cycles prior to the specific field operations and sampling are also shown (Fig. 2a–d).

Soils at the site are characterized as loam over silt loam and silty clay loam and are classified as Luvic Stagnosol (Siltic) in the World Reference Base (WRB) classification system (WRB, 2006). Soil textural characteristics for the upper layer (0–15 cm depth) are: 22% clay (< 2 μm), 29% silt (2–20 μm), 29% fine sand (20–200 μm), 15% coarse sand (200–2000 μm) and 4.5% soil organic matter.

2.2. Experimental design and treatments

The experiment was established in 2014 and the same experimental treatments were repeated in 2015, 2016 and 2017. This study investigated results for soil physical properties for only 2016. The design was a randomized split-plot in two replications comprising two factors. The main plot treatment was sowing date and the split-plot treatment was compaction. The sowing dates included early (A1), normal/timely (A2) and late (A3) sowing dates (Fig. 3). The compaction treatments applied each year included no compaction (B0) and compaction by a MF 4225 tractor weighing 4.5 Mg with one pass (B1). Compaction was done wheel-by-wheel. The front and rear tires of the tractors were