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Impact of projected climate change on workability, attainable yield, profitability and farm mechanization in Norwegian spring cereals

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ABSTRACT

In cold-temperate climate with high soil water content in spring, the farmer often faces the choice between topsoil compaction during seedbed preparation and delayed sowing, both of which may reduce attainable cereal yield. The objective of this study was to explore whether future climate change with increasing precipitation would aggravate this dilemma. We generated weather based on historical and projected future climate in South-eastern and Central Norway. Using this weather data as input, we simulated spring workability, attainable yield, timeliness costs, and mechanization management with a workability model and a mechanization model. The projected climate changes resulted in improved workability for spring fieldwork and higher attainable yield in South-eastern Norway, and either positive or negative changes in Central Norway compared to historical conditions. We observed a general increase in variability of workability and attainable yield, and a larger risk of extremely unfavourable years in the most unfavourable scenarios in Central Norway. Changes in profitability and mechanization management were small, but followed the same pattern. The negative effects in the most unfavourable climate scenarios in Central Norway were in contrast to positive effects in earlier studies. We explained discrepancies by differences in research methods and purpose. However, simulated sowing dates of annual crops should consider workability of the soil, in terms of water content. Under worst-case conditions, in need of a certain time window to complete their spring fieldwork, farmers might adapt to impaired spring workability by working the soil at higher water content than simulated in our study. The consequence would be a larger loss of attainable yield and less profitability in the future. We anticipate that negative effects may also be expected in other northern cold-temperate regions with high soil water content in spring.

1. Introduction

The timing of seedbed preparation and cereal sowing in spring is crucial for realizing yield potential, especially in northern regions with cold-temperate climate. If the cereal seedbed preparation and sowing, in this paper collectively termed spring fieldwork, is done too early, in unfavourably wet soil, the farmer risks loss of attainable yield due to topsoil compaction (Bakken et al., 1987; Hofstra et al., 1986; Håkansson, 2005; Marti, 1983; Njøs, 1978) and oxygen deficiency during germination (Wesseling and van Wijk, 1957). If it is delayed, on the other hand, the farmer risks loss of attainable yield due to a shorter crop growing season (Riley, 2016). Consequently, there is only a limited number of available days for spring fieldwork, referred to as the window of opportunity (Edwards et al., 2016; Singh et al., 2011).

Within this time window, the soil is considered workable, i.e. it can carry machinery and be tilled without any significant topsoil compaction that could hamper germination and root growth (Rounsevell, 1993). In addition to soil water content, the degree of compaction depends on machinery related factors, like number of passes, wheel track area, wheel load, wheel equipment, inflation pressure, operating speed, traction and wheel slip (Etana and Håkansson, 1996; Ljungars, 1977), all of which are assumed to be constant or negligible in this paper. According to discussions in Rounsevell (1993) and Edwards et al. (2016), with small to moderate ground contact stress, we can assume that the soil is trafficable when it is workable. Therefore, in this paper we use the term workable to represent both. Rounsevell and Jones (1993) showed sensitivity of workability to historical climate variability in the UK. Similarly, Maton et al. (2007) simulated number of available sowing days, based on frost, temperature and soil water content in France. Accordingly, the window of opportunity for spring

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fieldwork is especially narrow in northern regions (Edwards et al., 2016; Reeve and Fausey, 1974).

Due to feasibility, northern farmers rarely restrict their spring fieldwork to the ideal conditions of the window of opportunity. The daily decision on whether to do fieldwork or not is based on the farmer's individual and rather subjective perception of urgency, which is depending on soil type, current soil water content, weather forecast, and number of working days required to complete spring work. The latter is commonly about 10 days in Norway and largely depending on farm size, and working capacity of machinery and men, here collectively termed working capacity. This individual perception of urgency leads the farmer to decide for fieldwork at a certain soil water content, here referred to as the workability threshold. Thus, each farmer may have an individual workability threshold, and the daily decision may have individual economic consequences.

Whether the fieldwork is done too early or too late, the farmer experiences loss of attainable yield, in economic terms here called timeliness costs. By balancing the farm specific risk of the two different types of timeliness costs, farmers have long been adapting to year-to-year climate variability to maximize short-term profit (Bryant et al., 2000; Cerf et al., 1998; Choi et al., 2016; Maton et al., 2007; Maxwell et al., 1997;Peltonen-Sainio et al., 2009a; Riley, 2016; Smit et al., 1996; Urban et al., 2015; Witney and Oskoui, 1982; Reeve and Fausey, 1974). In order to maximize long-term profitability, farm management balances those potential timeliness costs with machinery costs. A large working capacity increases the chance to complete spring work within the window of opportunity, but is also associated with high machinery costs (de Toro, 2005; Elliot et al., 1977; Søgaard and Sørensen, 2004; Witney and Oskoui, 1982). Similar to the balance between the two different timeliness costs, the balance between timeliness costs and machinery costs is depending on year-to-year climate variability. Hence, long-term machinery management and profitability may be influenced by future climate change, due to potential changes to the window of opportunity.

Climate change may aggravate the already difficult timing of spring work. Many climate impact studies predict a longer thermal growing season in Northern Europe (Bindi and Olesen, 2011; Carter, 1998; Carter et al., 1991; Harding et al., 2015; Olesen and Bindi, 2002; Parry et al., 2007; Peltonen-Sainio et al., 2009b; Persson and Kværnø, 2017). However, a longer thermal growing season does not necessarily facilitate earlier sowing of spring cereals (Maton et al., 2007; Menzel et al., 2006; Van Oort et al., 2012a,b). During coming decades, more precipitation during winter and spring, and increased precipitation variability are expected in northern regions like Scandinavia, Canada, northern Europe and Midwestern US (Bedard-Haughn, 2009; Coumou and Rahmstorf, 2012; Urban et al., 2015; Groisman et al., 2005; Hov et al., 2013; Trnka et al., 2011). This could mean a higher soil water content in spring, and a narrower and more variable window of opportunity for spring fieldwork. Thus, as discussed by Van Oort et al. (2012a,b), the earlier sowing projected by climate impact studies may not be realizable.

Projected future yield increases may be too optimistic, if they are based on preponed sowing dates that do not consider soil water content in spring (Choi et al., 2016; Van Oort et al., 2012a, 2012b). Many studies of climate change impact on crop production have used dynamic crop simulation models. In general, these models consider soil water content. However, the potential impact of soil water content on the window of opportunity for spring fieldwork, and on soil structure and timeliness costs have often not been fully considered, sometimes even neglected (Bergez et al., 2006). Consequently, simulated yield potentials do neither capture loss of attainable yield due to delayed sowing, awaiting optimal soil water content, nor loss due to topsoil compaction, if the crop is sown under unfavourably wet soil conditions. Furthermore, the formation of crop yield is strongly dependent on the weather conditions during different growth stages, and the timing of the phenological development depends on the interaction of preponed sowing date and weather (Dobor et al., 2016; Kirby, 1969; Peltonen-Sainio and Jauhiainen, 2014; White et al., 2011). In order to adapt to future climate change and to avoid additional loss of attainable yield, simulations should resemble realistic management practices (Bergez et al., 2006) and consider soil workability in spring and potential timeliness costs.

Some studies on climate change impact in crop production considered workability thresholds. Rounsevell and Brignall (1994) found that overall soil workability in autumn might not be improved by future climate change in the UK, because the positive effect of an increase in temperature may be offset by the negative effect of an increase in precipitation. Cooper et al. (1997) simulated unchanged or increased number of workable days in early spring in Scotland. Eitzinger et al. (2013) simulated future increases in spring precipitation and reductions in number of workable days in spring in some regions in Central/South-eastern Europe. Tomasek et al. (2017) simulated earlier but fewer workable days in future Midwestern US. Regions like Scandinavia, which under current climate conditions normally has a narrower window of opportunity for spring fieldwork than the regions in the studies above, could expect even greater future challenges in spring, which may alter attainable yield, farmers' machinery management and profitability.

The few available studies concerning future workability in Scandinavia are in contrast to these expectations. In simulations by Rötter et al. (2011), soil water content did not affect future spring sowing dates in Finland considerably, and Trnka et al. (2011) and Rötter et al. (2013, 2012) simulated increase in number of workable days in spring in the future, in Scandinavia and Finland, respectively. However, one of these studies did not include the projected increase in winter and spring precipitation (Rötter et al., 2011), two considered early spring fieldwork to be limited by temperature only (Rötter et al., 2013, 2012), and three of them used a workability threshold of relatively high soil water content for late spring fieldwork (Rötter et al., 2013, 2012; Trnka et al., 2011). A further problem of many studies is that workability thresholds often are not specified detailed enough to allow straightforward comparison. In addition, the process-based modelling approach, used in most studies, does not capture within-farm variation in workability, sowing dates, and its consequences on attainable yield. Lastly, no attempt has been made to simulate possible impact of climate change on timeliness costs and farm mechanization management.

The objective of this study was to explore how projected future climate change affects workability, fieldwork throughout the spring period, and farm profitability under Norwegian conditions. We simulated historical and future climate, workability, attainable yield and timeliness costs for spring work on autumn-ploughed soils in two important cereal-growing regions with contrasting climate in Norway. We based sowing dates on a representative workability threshold (0–20 cm) and calculated the loss of attainable yield by combining effects of topsoil compaction (due to soil-specific high soil water content) and delayed sowing (if later than predefined optimum sowing day). Thus, in this paper, we use the term "attainable yield" to express timeliness-limited yield potential for a given soil, where crop growth is only limited by spring fieldwork timeliness, i.e. topsoil compaction or delayed sowing or both. Finally, we exemplify the use of timeliness costs in the adaptation of long-term farm mechanization management to climate change.

2. Material and methods

In order to determine spring workability, attainable yield and timeliness costs for spring cereals under historical and projected future climate conditions for South-eastern (SE) Norway and Central (C) Norway, two important cereal-growing regions in the country, the following steps were taken.

First, generated daily historical and future weather data were used