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Yield variation of spring cereals in relation to selected soil physical properties on three clay soil fields

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ABSTRACT

The crop growth is highly dependent on growth conditions which vary from year to year making precision farming challenging. In the present paper was first investigated whether varying soil physical properties reflect the within-field yield variation of small grain cereals and how do the variations in weather conditions between growing seasons affect the within-field yield variation. Secondly, the potential biomass accumulation of the crop in existing soil and weather conditions was simulated. The simulated and experimentally based site-specific total biomasses were compared in order to find out whether the soil data explains the observed variations in yield.

Three experimental fields size of 3–4 ha were established to examine the spatio-temporal yield variation during three years. The clay content of soils was high (> 46%) and soils were classified as Stagni-Vertic Cambisols. Correlations between soil water retention properties and crop yield were studied. Top and subsoil saturated (SWC), field capacity (FC) and permanent wilting point (PWP) water content, and saturated hydraulic conductivity of soil (K_{sat}), were determined from 19 to 24 places on each field once during the three years experimental period. During growing seasons, soil moisture content and leaf area index (LAI) were determined at same places biweekly, and yield was harvested. Spring barley (*Hordeum vulgare*) was grown on two fields, and spring wheat (*Triticum aestivum*, 2 years) and spring oilseed rape (*Brassica napus* L., one year) were grown on the third field.

The measured grain yields correlated with selected soil physical properties only in few cases. The observed spatial variation in the biomass was in most cases found to be higher than the simulated. Therefore, the above mentioned parameters were not enough to predict the yield correctly in case of high variations. There were other factors decreasing the observed yield e.g. lodging, cold summer, extremely high precipitation and slopes in field. According to our results it is evident that it is very difficult to predict site-specific biomass accumulation solely by soil properties in order, for instance, to fertilize in a site-specific manner. Therefore one needs to measure the crop during the growing season in order to simulate the biomass accumulation for precision farming purposes.

1. Introduction

Precision farming is a cultivation method aiming to crop oriented cultivation methods with site-specific actions. The spatial variation of soil properties form differences in growing conditions inside a field affecting the growth of the cultivated crop (Diacono et al., 2012; Gales, 1983; Lark et al., 1998; Keller et al., 2012; Raun et al., 2011; Scharf et al., 2006; Taylor et al., 2003; Timlin et al., 2001). The crop growth response is, however, not always similar between the growing seasons. In previous studies it has been shown that the spatial pattern of a yield varies between the years (Blackmore et al., 2003; Marques da Silva, 2006) indicating that the best and worst yielding areas of a field are not located on permanent positions. It is evident that spatio-temporal variation of crop biomass accumulation within a field depends on soil properties as well as on the weather conditions during a growing season and on the interaction between soil properties, crop growth stage and prevailing weather conditions. This brings challenges to cultivation in precision farming since site-specific actions may change from year to another depending on growing circumstances (Derby et al., 2005; Girma et al., 2007).

Spatial differences in the soil physical properties have been found to cause yield variation also in areas which in a common soil survey are considered homogenous (Morgan et al., 2003; Mzuku et al., 2005; Várallyay, 2002). Therefore the knowledge of soil physical properties affecting soil moisture content at certain water potentials, infiltration and hydraulic conductivity is essential for increase in water use efficiency (Jacobsen et al., 2012; Steduto et al.,

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2007) and nutrient use efficiency of the crop as noted by Derby et al. (2005) and Girma et al. (2007). Even though the temporal yield variation in rain-fed cultivation is mainly due to the amount and timing of the precipitation (Sadras et al., 2012; Taylor et al., 2003) it is also inevitably affected by the spatial soil properties (Cox et al., 2003; Derby et al., 2005; James and Godwin, 2003; Keller et al., 2012; Timlin et al., 2001). In dry conditions, sufficient amount and timing of precipitation depends on site-specific water holding capacity and soil hydraulic conductivity. Further the variations in the macroporosity and saturated hydraulic conductivity (K_{sat}) affect wet soil conditions (e.g. aeration (Simojoki, 2000)) and determine the yield variation under high precipitation (Blackmore et al., 2003; Keller et al., 2012). Variation in macroporosity affects also the root system distribution and growing velocity since roots grew fast in macropores having the same or larger diameter than the root diameter (e.g. Eissenstat and Caldwell, 1988).

In precision farming the spatial and temporal growth variation are to be considered in cultivation actions and therefore the knowledge of variation sources is essential. Spatial variation in soil water holding (Blackmore et al., 2003; Cox et al., 2003) and hydraulic properties (Keller et al., 2012) has been suggested to explain the part of yield variation that is not stable in time and space (Blackmore et al., 2003; Cox et al., 2003; Wood et al., 2003). We addressed the question of yield variation due to spatial variation in soil properties by investigating the relationship between the measured yield variation and measured site- and depth-specific soil properties, and by simulating the radiation and water limited biomass accumulation. An analytical model for C3-crop biomass accumulation was used in this study (Hautala and Hakojärvi, 2011). The model describes the maximal biomass accumulation when growth is limited only by radiation or water.

The overall objective of the study was to compare the yield variation with measured site- and depth-specific soil properties for the first time in this extent. Extensive information about crop growth and selected soil physical properties from three different clay soil fields and three consecutive years was used. The first objective of the study was to compare the effect of spatial variability of soil moisture properties on within-field yield variation and to evaluate the part of the within-field yield variation that was due to variation in the precipitation. For this purpose the correlations between the soil properties and yield were evaluated. The second objective was to compare the effect of site- and depth specific soil properties to the temporal yield variation with simulated biomass accumulation.

2. Materials and methods

2.1. Experimental fields

Two successive three-year studies to examine the spatio-temporal variation of the yield of small grain cereals were carried out at MTT Agrifood Research Finland in 2002–2009. Both studies were conducted on clayey soils where the variations of the selected soil physical properties, crop yield and yield quality were mapped.

Two of the fields (further denoted as Jokioinen 1 and Jokioinen 2) located in Jokioinen (60°49′ N, 23°28′ E) both with a size of 3 ha (Ristolainen et al., 2006). The soil of these fields ranged from clay loam to clay and the soils were classified (FAO, 1998) as Stagni-Vertic Cambisols (Yli-Halla and Mokma, 2001). The mean clay (particle size < 0.002 mm) content of soil in Jokioinen 1 field was 460, 560 and 630 and in Jokioinen 2 field 580, 680 and 790 g kg^{-1} in the depths of 0–0.2, 0.2–0.35 and 0.35–0.6 m, respectively. Preceding the measurement period the fields were cultivated with conventional agricultural practices with a crop rotation of silage grass during 3–4 years followed by grain crops during two years. During the experimental period of 2002–2004, spring barley (*Hordeum vulgare* L., varieties Annabell, Inari and Prestige) was grown on both fields. Two years preceding and during the experiment period, the fields were topsoil stubble cultivated to a depth of 0.15–0.18 m in autumn. In spring, the fields were harrowed and combi drilled (fertilization and seeding at the same time) with conventional machines. The fields were fertilized every year at the time of sowing based on the results of soil nutrient content analyses. During the years 2002–2004, the nutrients (N-P-K) provided were in the field Jokioinen 1 78–6–9, 91–7–10.5 and 91–7–10.5 kg ha^{-1} and in the field Jokioinen 2 91–0–3.5, 91–2–3.5 and 78–6–9 kg ha^{-1}, respectively.

The third field (further denoted as Vihti) with a size of 4.5 hectares was located in Vihti (60°21′ N, 24°22′ E). The soil of this field ranged from sandy clay loam to silty clay and was classified (FAO, 1998) as Stagni-Vertic Cambisols. The average clay content of the soil was 490, 640 and 780 g kg^{-1} in the depths of 0–0.3, 0.3–0.6 and 0.6–0.9 m, respectively. The field was under conventional small grain cereal cultivation preceding the measurement period. During the experimental period, spring wheat (*Triticum astivum* L., variety Amaretto), spring oilseed rape (*Brassica napus* L., variety Marie) and spring wheat were grown in the years 2006, 2007 and 2008, respectively. The year preceding the experiment the field was ploughed to a depth of 0.20–0.25 m. During the experiment period, the field was direct drilled after the first year when it was sown with conventional combi drill. During the years 2006–2008, the nutrients (N–P–K) provided were 138–11–16, 100–10–60 and 140–11–16 kg ha^{-1}, respectively.

2.2. Soil sampling and laboratory analyses of K_{sat} and water retention

Within each field, the information about spatial variation of soil physical properties and crop growth was gained from 20 (Jokioinen 1), 19 (Jokioinen 2) and 24 (Vihti) sampling locations (Fig. 1) during the experiment period. From the fields Jokioinen 1 and 2 large undisturbed soil cores with a diameter of 0.15 m and length of 0.60 m were taken into PVC pipes with a tractor driven soil auger (Persson and Bergström, 1991 modified by Pöyhönen et al., 1997). In the laboratory the samples were cut into three subsamples to represent the functional layers: plough layer (0–0.2 m), plough pan (0.2–0.35 m) and subsoil (0.35–0.6 m) (Ristolainen et al., 2006). Site-specific soil water retention properties from three different depths were gained this way in each sampling location on all the fields Jokioinen 1 and 2. In the field Vihti, undisturbed 200 cm^3 (height 0.049 m, diameter 0.072 m) soil core samples were taken from layers between 0.05–0.10 and 0.3–0.35 m. Site-specific values for water retention properties and K_{sat} were determined in the years 2002, 2003 and 2007 for fields Jokioinen 2, 1 and Vihti, respectively.

Before determinations, the samples were saturated with boiled water from bottom to upwards to avoid air entrapment and soaked for five days. Saturated hydraulic conductivity measurements were made by the constant head method (Youngs, 1991). The samples were further placed on ceramic plates to measure the water content at field capacity (at water potential of -10 kPa, pF 2). Water content at wilting point (at water potential of −1500 kPa, pF 4.2) was analyzed with the osmotic method by placing a small soil sample in a cellulose acetate bag and using polyethylene glycol (PEG, molecular weight 20,000) solution according to Aura (1975).

2.3. Field measurements during growing seasons

To enable the comparison of the soil physical properties and growing conditions of the crop in a field, the soil moisture content was monitored at each sampling location of each field (Fig. 1) during the growing season. Water uptake of spring sown barley