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Realtime soil moisture measurement during field work

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Abstract. Soil moisture affects grain germination. If the seeds are sown in dry soil the germination is poor and the emergence is uneven. In Finland, the fieldwork during the spring sowing season takes a couple of weeks and during this period the soil is drying or it is wetting if there are rains. If the seeds can be sown to optimal soil moisture content this enhances germination and increases the yield.
Soil moisture content and temperature was measured before spring tillage. By utilizing these results a prototype of soil moisture measurement system was built utilizing commercial NIR-technology moisture sensor. This system could be used in harrows and drills so that the work is done to proper soil moisture content. The principle functioned reliably when properly calibrated and mounted. The measuring system could be further improved with narrower light beam so that the falling soil aggregates would not have interference to the results. This kind of instrumentation could be used in implements.
Harrowing and sowing season could be prolonged with a small impact on yield if the seeds could be sown to advantageous moisture content. This would be also economical because the work capacity and machine sizes could be reduced. Also risk of soil compaction would be less.

Keywords: moisture, precision farming, tillage, NIR-technology.

INTRODUCTON

Seed germination depends mainly on three soil factors, water availability, temperature and gases (porosity). When the seeds are sown they uptake moisture from the soil and their moisture content increases. For germination it is essential that there is water available for uptake and the seeds have a good contact with the soil. Seeds have critical moisture content for germination. For instance for corn the critical moisture content in seed is 30% and in wheat 40% (McDonald 2015).

According to Haller (1984) the moisture content and porosity of the soil during sowing has a strong effect on yield, germination and number of grains in the ear. Soil moisture content and porosity around seeds affects germination. Poor porosity, which is due to compaction or moisture content and shortage of moisture in the beginning of germination decrease the yield

Alakukku (2006) studied germination in laboratory in different soil moisture contents and in two different soils. During ten days incubation time, the optimum soil moisture content for germination was in clay soil 45–80 % of field capacity and in sandy soil 20–70%. At this moisture content, germination was nearby 100%.

The optimum temperature for germination of barley and oats is 20 °C (Isleib 2012). Germination happens also in lower temperatures but it is slower. Minimum germination temperatures are hard to determinate. Isleib (2012) gives minimum temperatures for barley 4 °C, oats 6 °C and potato 7 °C. Temperature response depends on species, variety, growing region and quality of seeds.

The soil porosity and water content accomplishes air supply of the seed. Seeds need oxygen for germination and the carbon dioxide content must be low enough, under 0.03% (McDonald 2015).

Under Nordic countries conditions the traditional seedbed preparation is 2–3 harrowing followed by sowing. This implies a major risk of soil compaction because the soil is still around the field capacity after winter. One must wait for the soil to dry before seedbed preparation can be started. Late sowing implies risk on seed germination because of delays, so the early sowing of spring cereals without or limited harrowing should be more useful if done by a new types of sowing machines Arvidsson (1997) and Arvidsson et al. (2000).

Tamm (2009) examined the yield decrease compared to best sowing day. He found out that yield decreased in average 1.4% day^{-1}. Recommendation for field work in borealis condition during spring time is one week time. If the spring works starts in optimum condition, then after one week the last fields will produce about 10% less yield. Part of this decrease could be avoided by sowing the seeds into correct moisture content.

Tillage methods also have an influence how the soil is dried and warmed. A five year study of zero versus conventional tillage was conducted under central Alberta conditions to determine soil temperature and percent moisture in soil by Malhi & OSullivan (1990). The result was that soil temperatures in the spring at 2.5 or 5.0 cm depths were generally lower under zero tillage than conventional tillage. On the average of 10 recording dates over 3 years, soil temperature at a depth of 2.5 cm. under zero tillage was 2.8 °C lower than under conventional tillage. Percent soil moisture in the top layer (0–15 cm.) on the average of 5 years was 7.2% greater on zero tillage plots than on conventional tillage plots.

Soil moisture content during harrowing or sowing can be determined with Time Domain reflectometry (TDR), capacitive method, impedance method or with spectroscopic methods. The main problem with these methods is that soil density, temperature and electrical conductivity can have an influence on the results (Drücker et al., 2009). The spectroscopic methods are least influenced by these but it measures only surface moisture content. Drücker et al. (2009) used a dielectric measurement system with high frequency (100 MHz), which eliminated the influence of soil density. The sensor was mounted on a cultivator so that it operated in untreated soil. To exclude soil texture and conductivity they sorted the data according to the soil conductivity. Also Andrade-Sanches et al. (2004) studied a dielectric sensor for moisture measurement. They found out that the sensor was insensitive to soil texture but sensitive to soil salinity. Price & Gaultney (1993) used a near infrared sensor (NIR) in measuring soil moisture content. They used a multiple wavelength sensor technology so that measurements would operate on all soils with one calibration. NIR principle measures only the surface moisture content. For this reason the sensor was built on shank which was travelling in the soil and measured the moisture content at that depth. In field tests the sensor detected with 82% accuracy the optimum sowing depth.

Besides the plants we have also to see what the tractability of the soil is. In soft soils also the machinery will have problems to move which can cause a compaction problem. Rotz et al. (2008) give for spring tillage values from 92% to 100% of field capacity as limits for workability. Clay soils have lower values and sandy soils higher. For fall tillage the values are from 99% to 104%. Toro & Hansson (2004) give thresholds for soil workability for secondary tillage in top layer 85% of field capacity and in 3–7 cm depth 107%. For ploughing the threshold is 110%.

Harrowing and sowing season could be prolonged with a small impact on yield if the seeds could be sown to advantageous moisture content. This would also be economical because the work capacity and machine sizes could be reduced. Also risk of soil compaction would be less.

The aim of the study was to find out what kind of moisture profile soils have before spring work and if moisture sensors functions in these circumstances when mounted on an implement.

MATERIALS AND METHODS

Soil moisture and temperature in spring before the tillage work started was measured in Viikki (E025°00', N60° 13'). The soil texture was silty clay. The moisture content was measured with Decagon ECH2O EA-10 capacitive meter and the temperature was measured with Fluke TM 1300 meter. The moisture and temperature profiles were measured in 5 cm thick layers from the top to 30 cm depth and from ten different spots and average value for each layer was calculated from these values.

Spectroscopic method was chosen for the implement soil moisture measurement prototype because it is contactless and it is least influenced by soil properties. Water absorbs NIR (Near Infra Red) light especially at the wavelengths of 1,450, 1,950 and 2,950 nm wavelengths (Plamer & Williams, 1974). In reflecting measurements 1,930 nm wavelength is often used because of higher sensitivity (Järvinen et al., 2007). Commercial NIR sensor IRMA 7 D was used in the experiments (www.visilab.fi). It is operated in 1,950 nm wave length and its measuring frequency is 400 Hz. The sensor is mainly used in measuring paper moisture content in paper machines. It measures the moisture content to 150 µm depth from the top (Launonen & Stenlund, 2007). The equipment was assembled to a three point hitch frame and it had a coulter in front of it, Fig. 1. This made possible to use it in different working depths and the coulter made an even surface for the sensor. The NIR beam of light at 225 mm distance was 190 x 105 mm and the measurement result was the average from this area. If the travelling speed is 3 m s^{-1} and the length of the beam is 190 mm, measuring frequency of 16 Hz is enough for almost continuous moisture measurement.

The sensor was calibrated with gravimetric method in the laboratory. Also the effect of inclination and step response were measured in the laboratory. Inclination can happen during measurement if the furrow done by the coulter is V-shaped. Step response was measured to see how quickly the instrumentation reacted to a change.

Figure 1. IRMA 7 D sensor mounted to a three point hitch frame.

RESULTS AND DISCUSSION

Fig. 2 shows the results of layered moisture and temperature measurements before spring work. The top layer of the field was already quite dry (34% of field capacity) but in the lower layers the moisture content was clearly higher. In 5–10 cm layer the moisture content is 50 % of field capacity, which means that in this layer the moisture content is in optimum range concerning germination but in the top layer it is already too dry. The temperature of the soil does not however change much in deeper depths. According to Fig. 2 the soil temperature in 5–10 cm layer is almost the same as in top layer, so it does not have much effect on germination. This means that it would be favorable to have sowing depth in the 5–10 cm layer.

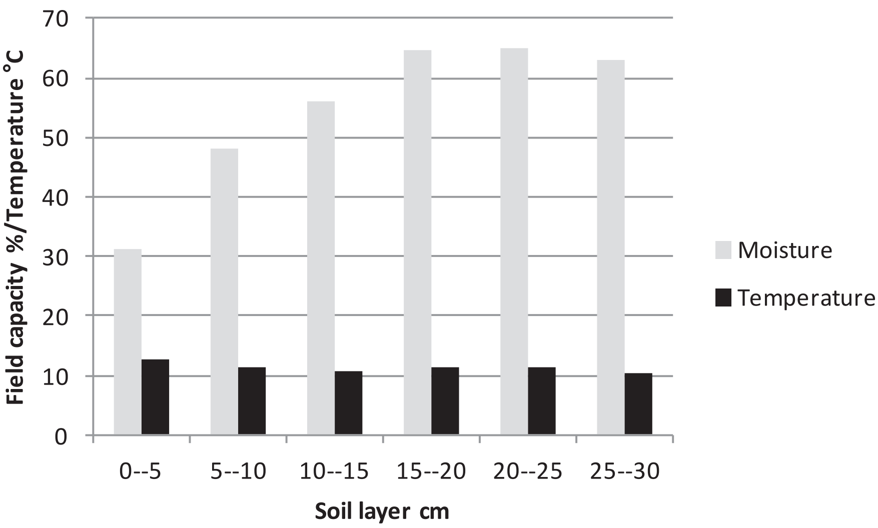

Figure 2. Temperature and moisture profiles of a field before spring tillage.

The soil moisture measurement prototype sensor was calibrated in laboratory with four different soil types and six different moisture contents. It was noticed during the calibration that light soil color (heavy clay) gave a little bit different calibration curve. When compared to gravimetric moisture measurement the sensor had an inaccuracy of 0.1–0.6 percentage point depending on the soil type. For soil moisture measurement during work this is accurate enough to determine the optimum working depth.

The sensor sensitivity to inclined surface and internal deviation were measured before the field tests. The sensitivity tests indicated that the sensor gave higher moisture values for the same sample as the angle of the measured surface increased in relation to the horizon. Measures of dispersion were also affected by the increasing angle; the greater the angle, the greater the variance and standard deviation of the average soil moisture.

The internal deviation of the sensor was determined with three different soil samples by measuring the same sample a longer time. The standard deviation of the sensor reading was depending on the soil type from 0.1 to 0.6 percentage point.

Fig. 3 shows a field measurement with the protoype. At 10 second the sensor is lowered down and the moisture measurement starts. At 50 seconds the fastening of the coulter has loosened and the coulter has turned to a new position and soil aggregates have started to fall in to the furrow causing errors in the reading. The sensor worked reliably during the testing. It gave the soil moisture content in sufficient accuracy for harrowing and drilling. This was controlled on the field with comparative moisture measurements.

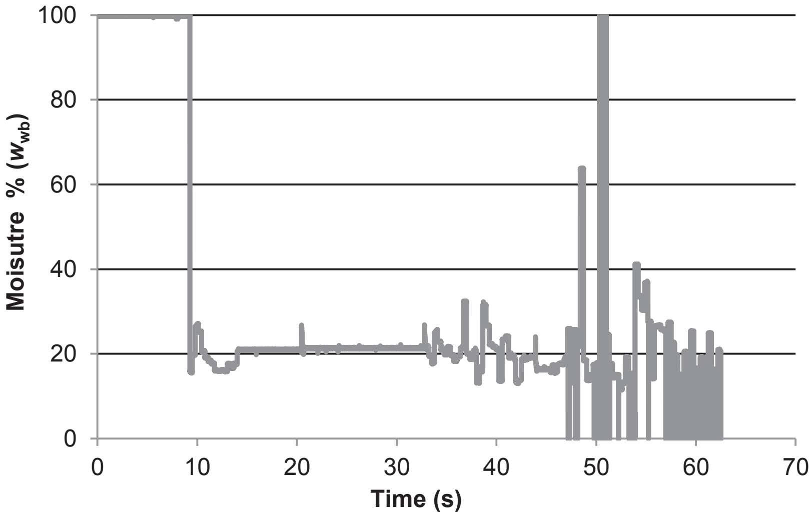

Figure 3. Soil moisture measurement with IRMA sensor.

The prototype was meant for only to study the suitability of the measurement principle. For harrowing and drilling work a smaller sensor with proper coulter and attachment is needed.

CONCLUSION

The top layer of the field during spring work can be too dry for proper germination. It is then profitable to use a deeper harrowing or sowing depth in these cases. The study showed that before spring work the soil moisture profile of the soil was clearly observable and suitable moisture content for germination can be found in deeper layers.

Real time soil moisture measurement could make possible automatic work depth control. The NIR spectroscopy used in this study could be one solution because it is contactless and the sensor is easy to assemble on an implement and it could be easily changed from one implement to another. The sensor used was reliable enough for real time soil moisture measurement. The measurement is however affected by the inclination of the reflecting surface and therefore needs an even surface and for this reason a coulter is needed in front of the sensor. The sensor properties could be improved with a narrower light beam so that the falling soil aggregates would not have interference to the results. The commercial sensor used in the study is mainly used in paper machines. The construction of the sensor should be minimized and improved for implement use.

Different soils types (clay, sandy, organic) have different reflecting properties and the device should be further tested. For instance the reflecting of light is different in dark and light soils.

Harrowing and sowing season could be prolonged with a small impact on yield if the seeds could be sown to advantageous moisture content. This would be also economical because the work capacity and machine sizes could be reduced. Also risk of soil compaction would be less.

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