PENETRATION RESISTANCE AND YIELD VARIATION AT FIELD SCALE

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ABSTRACT

The characterization of soil variability at field or subfield scale using conventional methods is a labor intensive, very expensive, and time-consuming procedure, particularly when high-resolution data is required. One property that can be measured fairly easy is soil penetration resistance. Since the mechanical properties of the soil around the penetrating cone are complicated and depend on several factors, the result from a penetrometer can be difficult to interpret. The low specificity should however not be seen as a disadvantage rather as a way to detect any change in soil physical conditions

To measure the penetration resistance across entire fields efficiently a tractor pulled penetrometer was used. The horizontal penetrometer shows values that are in the same range as a standard vertical penetrometer.

Four different fields in Sweden were used in this study. Yield was compared with penetration resistance as well as EM38-measurements at field scale. Penetration resistance varies considerably across all fields. There are however strong indications that penetration resistance can be used to find areas where the physical state of the soil has limited yield.

Keywords: Soil variability, penetration resistance, field scale, yield.

INTRODUCTION

Yield variations within a field can be substantial, and although the temporal variability can be large (Blackmore 2000, Blackmore et al. 2003, Bakhsh et al. 2007), temporally stable yield patterns are often also true (Blackmore 2000, Blackmore et al. 2003, Bourennane et al. 2003). If the reasons for these variations are known, site-specific inputs can save resources, the negative effects on the environment can be reduced and yield levels can be maintained or even increased (Robert 1999). A large number of studies were conducted in the early 1990s in attempts to explain yield variations within fields by variations in plant nutrient status. The relationships obtained turned out to be quite weak (Mallarino et al. 1999). Relationships between soil physical parameters and yield, especially in the subsoil, are seldom studied, often due to labour intensive, and therefore expensive, traditional methods of measuring such parameters. However, soil physical properties may be able to explain a significant proportion of the variations in yield. For example, a large Swedish study on yield variations in sugar beet showed that factors influencing root development and water transport in soil had the largest effect on yield (Berglund et al. 2002).The spatial variation in cone index and other physical parameters has been studied by a number of researchers but few have studied the relationship with yield (Isaac et al. 2002, To and Kay 2005).

When commercial yield mapping started it was expected that some yield patterns within fields would be temporally stable due to permanent soil characteristics behaving the same each year (Blackmore et al. 2003). Yield variability within fields is however seldom temporally stable. Studies have shown that yield variability in fields change from year to year and are not stable enough to use to predict yield the following year (Lamb et al. 1997, Blackmore et al. 2003) It is therefore interesting to find something more temporally stable to use for predictions into the future and to use for site specific management over several years.

Maps of soil penetration resistance could reveal areas potentially limiting root growth (Adamchuk et al. 2004) and thus yield since restricted root growth may lead to temporal drought stress which limits the potential yield especially under rain fed crop management (Hemmat et al. 2008). Since the mechanical properties of the soil around the penetrating probe is complicated and depend on several factors, the result from a penetrometer if difficult to interpret. The fact that penetration resistance is related to so many different properties (bulk density, water content, water potential et. c.(Kilic et al. 2004)) makes the penetrometer an excellent screening tool. It is very unlikely that a change in soil physical conditions will not be picked up by a measurement with a penetrometer. The low specificity should not be seen as a disadvantage rather as a way to detect any change in soil physical conditions (Hartge et al. 1985).

The influence of soil moisture on soil penetration resistance can be minimized by restricting measurements to conditions of constant soil moisture conditions, e.g. at field capacity. Penetration resistance is only slightly affected by water content to about 70 % of field capacity (Henderson 1989).

Intensive grid sampling is inefficient and virtually impossible to use at farm or field scale. In order to get detailed information on-line sampling and remote sensing is needed. By using a horizontal penetrometer you sample at a much denser interval and a reliable transect should be possible to map.

Manor et al. (1989) tested a horizontal penetrometer to measure mechanical impedance in soil layers in order to improve correlate cone index to soil bulk density, texture and soil moisture content. This was reported to work especially in the lower horizons (below 25-30 cm).

The first objective of the present study was to develop a site-specific, horizontal, on-line, soil penetrometer capable of measuring soil penetration resistance across entire fields in a reasonable time. The second objective was to study the correlation between horizontal soil penetration resistance and yield. Measurements were conducted in Sweden at two different farms.

MATERIAL AND METHOD

The field experiment was carried out on Kvarnbo farm in Uppland, Sweden (59°50'N, 17°32' E) and at Bona-Wäsby farm in Uppland, Sweden (59°24' N, 17°34' E). At Kvarnbo farm the same field was used at both years and at Munsö a new field was used each year (three years).

A four-share parallel-plough was modified to support three parallel, horizontally mounted, soil penetrating cones The cone angle was 30° and the cone diameter 63 mm. The effects of penetration rate and penetrometer diameter are of lesser importance than penetration cone angle. The cone was connected to a Bosch draught sensor capable of registering forces between –25 kN and +25 kN (Figure 1). The instrument was capable of measuring soil penetration resistance at three depths (10, 30 and 50 cm) as well as speed and position which were recorded with a Trimble SweeEight GPS every second. The instrument was used at a speed of approximately 1.5 m s^{-1} and was equipped with a stone release mechanism and a simple system to record actual working depth every second. The 1000 Hz signal was averaged to 1 Hz and converted to force using the sensors calibration equations.

The horizontal design was chosen because a horizontal penetrometer allows you to measure a larger area much faster. The penetrometer was used at 10, 30 and 50 cm depth. 30 cm depth was used at all measurements, 10 only the first time and 50 only 2004, 2005 and 2006. The measurements were carried out in the spring or in the fall. The aspiration was to measure as close to field capacity as possible. The penetrometer was used on both fallow and in growing crop.

Figure 1. Detailed picture of the horizontal penetrometer and its components.

RESULTS

The results were analyzed by pairwise correlations and simple linear regression. Yield and horizontal penetration resistance measurements were interpolated by ordinary kriging to a 10 m grid using the GIS program ArcGIS 10 (ESRI, http://www.esri.com) and the expansion Geostatistical Analyst.

Figure 2 and 3 are examples of yield (Figure 2) and penetration resistance (Figure 3) results. Certain patterns can be observed but it is difficult to get steady results over all years and fields.

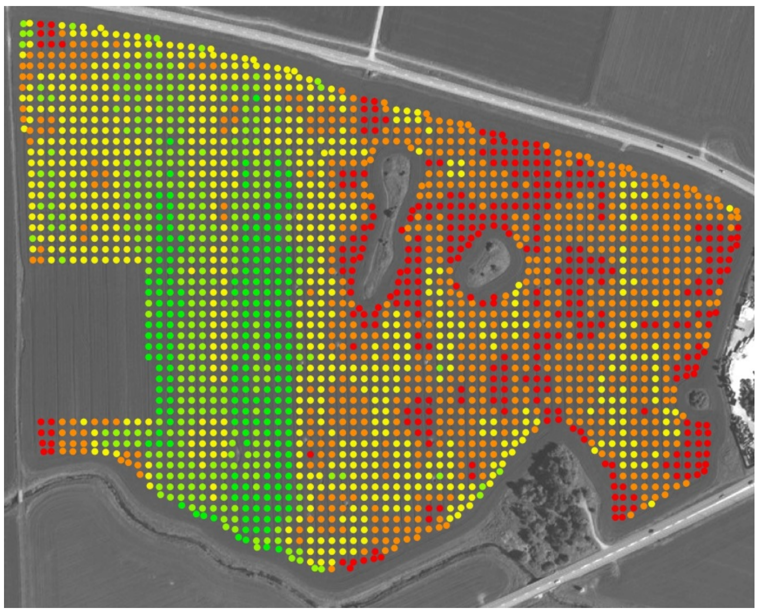

Figure 2. Yield at Kvarnbo farm in 2004 (spring barley). The yield ranges from 7,2 t/ha to 10,3 t/ha.

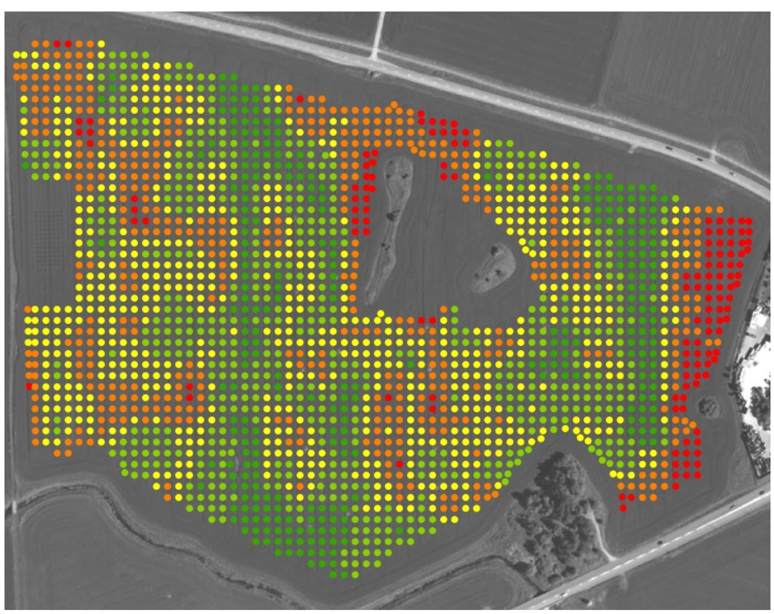

Figure 3. Horizontal penetration resistance at Kvarnbo farm. The penetration resistance ranges from 1,1 MPa to 1,6 MPa.

The horizontal penetration resistance and the yield are usually negatively correlated. At Kvarnbo farm all years except 2000 showed negative correlation between yield and penetration resistance. 2000 was a very wet year and yield patterns this year was opposite of the other years. Highest correlation between yield and penetration resistance was obtained in 1999 with an r^2 of 0.65. The yield this year was relatively low and the year was very dry. The soil's ability to hold plant-available water and the roots opportunity to penetrate the profile then becomes crucial. Generally speaking, the relationships were strongest at low yield levels, i.e. when the soil physical parameters can be assumed to have been limiting for the crop.

You also tend to get stronger correlations between yield and penetration resistance at 50 cm rather than 30 cm. However, in order to be able to conduct measurements at 50 cm depth in a good way you need a stone free soil. We did not have that and consequently only dared to do this once at Kvarnbo farm. At Munsö farm we also tried at 50 cm but nearly wrecked the equipment in the process.

The measurements on these two farms and four fields show that on-line measurement with a horizontal penetrometer is an interesting approach to explaining yield variations at field level, primarily to identify areas where the soil structure can be yield limiting.

REFERENCES

Adamchuk, V. I., J. W. Hummel, M. T. Morgan and S. K. Upadhyaya (2004). "On-the-go soil sensors for precision agriculture." Computers and Electronics in Agriculture 44(1): 71-91.

Bakhsh, A., R. S. Kanwar and R. W. Malone (2007). "Role of landscape and hydrologic attributes in developing and interpreting yield clusters." Geoderma 140(3): 235-246.

Berglund, K., J. Blomquist, B. Christensson, B. Gerhardsson, O. Hellgren, H. Larsson, T. Rydberg and T. Wildt-Persson (2002). "Slutrapport 4T." www.sockerbetor.nu

Blackmore, S. (2000). "The interpretation of trends from multiple yield maps." Computers and Electronics in Agriculture 26(1): 37-51.

Blackmore, S., R. J. Godwin and S. Fountas (2003). "The analysis of spatial and temporal trends in yield map data over six years." Biosystems Engineering 84(4): 455-466.

Bourennane, H., B. Nicoullaud, A. Couturier, D. King, J. Stafford and A. Werner (2003). Assessment of spatial correlation between wheat yields and some physical and chemical soil properties. Precision agriculture: Papers from the 4th European Conference on Precision Agriculture, Berlin, Germany, 15-19 June 2003., Wageningen Academic Publishers.

Hartge, K. H., H. Bohne, H. P. Schrey and H. Extra (1985). "Penetrometer Measurements for Screening Soil Physical Variability." Soil & Tillage Research 5(4): 343-350.

Hemmat, A., V. I. Adamchuk and P. Jasa (2008). "Use of an instrumented disc coulter for mapping soil mechanical resistance." Soil & Tillage Research 98(2): 150-163.

Henderson, C. W. L. (1989). "Using a Penetrometer to Predict the Effects of Soil Compaction on the Growth and Yield of Wheat on Uniform, Sandy Soils." Australian Journal of Agricultural Research 40(3): 497-508.

Isaac, N., R. Taylor, S. Staggenborg, M. Schrock and D. Leikam (2002). "Using Cone Index Data to Explain Yield Variation Within a Field." CIGR E-Journal 4: 13.

Kilic, K., E. Ozgoz and F. Akbas (2004). "Assessment of spatial variability in penetration resistance as related to some soil physical properties of two fluvents in Turkey." Soil & Tillage Research 76(1): 1-11.

Lamb, J. A., R. H. Dowdy, J. L. Anderson and G. W. Rehm (1997). "Spatial and temporal stability of corn grain yields." Journal of Production Agriculture 10(3): 410-414.

Mallarino, A., E. Oyarzabal and P. Hinz (1999). "Interpreting within-field relationships between crop yields and soil and plant variables using factor analysis." Precision Agriculture 1(1): 15-25.

Manor, G., R. L. Clark and D. E. Radcliffe (1989). "Horizontal Penetrometer for Trench Walls." Agricultural Engineering, Vols 1-4: 1779-1785.

Robert, P. C. (1999). Precision agriculture: research needs and status in the USA. Precision agriculture '99: Proceedings of the European conference on precision agriculture, Sheffield, UK, Sheffield academic press.

To, J. and B. D. Kay (2005). "Variation in penetrometer resistance with soil properties: the contribution of effective stress and implications for pedotransfer functions." Geoderma 126(3-4): 261-276.