STUDIES REGARDING SOIL COMPACTION IN WESTSIK CROP ROTATION EXPERIMENT

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Abstract

The soil compaction results from cohesive forces between soil particles and their resistance to sliding past or over one another. Soil compaction is an important characteristic affecting soil properties, such as cultivation, root growth and water maangement. Characterisation of soil compaction is usually made by measuring the response of a soil to a range of applied forces. Penetrometers are widely used to measure the soil resistance. Penetration is expressed as force per unit cross-sectional area of the cone-base. Penetrometer measurements can be done relatively quickly and easily, and can provide valuable data for estimating resistance to root growth in soil, and may also be used for detecting layers of different soil strength.

Studies have shown that cultivated fallow and monocropping destroy soil structure, increase evaporability and soil compacting. In turn, by growing green manure lupine crop, farmers increase water infiltration and retention of nutrients and thereby not only improves the ability of soil to sustain plant in drought conditions but help to reduce both wind and water erosion. Legumes play an important role in the regenerative soil conserving strategy. Root and green manure crops add organic matter to the soil, assists in dissolving insoluble nutrients, brings up nutrients from the subsoil and improves the water holding capacity of the soil. The crop rotation system should improve soil condition by including deep rooted plants and plants with a fibrous root system to improve the stability of soil aggregates. The beneficial effect of lupine green manure crop on the yield of subsequent crops has been known from the ancient times. There is also evidence suggesting that an improved soil structure increase biological activity in the soil and enables plants to utilise soil moisture and nutrients more effectively. The aim of present paper is to assess the environmental benefits from using penetrometer to characterize soil bulk density at various depths and help to develope precision farming technologies in Nyírség region. Results of the study suggest that soil cultivation and nutrient managed can be based on site-specific soil compaction mapping using digital penetrometer. The second aim of this paper is to study the effects of lupine on the penertation resistance mearured in the subsequent crops.

Key words: soil compaction, soil penetration resistance, lupin

INTRODUCTION

The first use of penetrometer in soil science is connected to Parker and Jenny (1945). They quantified the soil resistance by measuring the energy required to drive a soil-sampling tube into the soil. This is achieved by using a hammer of 9.1 kg lifted 30 cm above the tube and then measuring the distance the tube moved into the soil. The resistance is expressed as Joule /cm. The first dynamic penetrometer was design by Scala 1956, who measured soil strength for road design. Penetration resistance depends on such soil properties as water content, bulk density and soil potential, texture, aggregation, cementation, and mineralogy. Soil scientists have related changes in penetration resistance as caused by tillage, traffic, or soil genetic pans to root growth, crop yields, and soil physical properties Bradford, (1986). Correlation between penetration resistance and crop root growth and water and nutrient exploration have been obtained Stelluti et al., (1998), and cone penetrometers have been used extensively in soil science studies to identify natural and induced compacted layers Henderson, (1989) or to predict related soil properties (Henderson et al 1988).

It has been recognized that compaction affects both root growth and soil water and air availability to roots, and that increased penetrometer resistance is correlated with compaction when all other factors are held constant Baver et al., (1972). Increased interest in the effects of soil compaction on soil quality has created a demand for tools which measure soil penetration resistance on a routine basis Romig et al., (1995). Correlation between penetration resistance, crop root growth, water and nutrient exploration have been obtained by Stelluti et al., (1998). Cone penetrometers have been used extensively in soil science studies to identify natural and induced compacted layers by Henderson, (1989) or to predict related soil properties by Ayers and Bowen, (1987).

Soil water content and bulk density are the most significant among the soil parameters that affect penetration resistance. Young et al. (1998) concluded that soil moisture is the dominant factor influencing the force required to push a penetrometer into the soil, with increasing moisture content the penetration resistance decreased. Stitt et al. (1982) conducted a comprehensive study of factors affecting penetration resistance in coarse-textured soils. The highest correlation coefficients were found for a regression model that included soil water content, soil particle roughness and bulk soil density. In an experimental study by Henderson et al. (1988) it was found that penetration resistance was only slightly affected with a decrease of soil water content to about 70% of field capacity. However, the penetration resistance increased exponentially with a further reduction of the water content of the sandy soil. This study showed that penetration resistance increased with an increase of bulk density across the whole measured water content range.Soil moisture varies both spatially and temporally and interpretation of penetrometer data is difficult because water content or density measurements can not be taken at the exact same spatial location as the penetration resistance measurement.

MATERIALS AND METHODS

Survey was conducted at the Westsik Crop Rotation Experiment, which is approximately 12,4 ha and situated on two sand dune. One side of the experimental field is separated by a stream called Érpatak, while the other side is separated by well established forest area. The soil is a sandy with clay content less than 10 % spacially changeble. The organic carbon content of the cultivated soil layer is (0,5-1,2 %). Low clay contents does not allows for soil moisture to be held strongly for prolonged periods of time. This soil is agriculturally important and represents 0,5 million hectares soil in Nyírség region.

The treatments of Westsik crop rotation experiment were intended to increased soil fertility by different organic matter amendments as the original purpose was to evaluate the cumulative effects of organic matters on light, poorly structured sandy soil with a long history of arable cropping. The intention of this paper to consider only a small part of the experiment.

F-1 rotation: Sand improvement by fallow

Crop 1: fallow; weeds are ploughed under before flowering
Crop 2: rye without fertilisation
Crop 3: potato without fertilisation

F-2 rotation: Sand-improvement with lupine green manure grown as main crop

Crop 1: lupine green manure with 63 kg/ha P_2O_5 and 56 kg/ha K_2O
Crop 2: rye with 31 kg/ha P_2O_5 and 28 kg/ha K_2O fertilisation
Crop 3: potato with 36 kg/ha N fertilisation from 1952

F-3 rotation: Sand-improvement with lupine root manure

Crop 1: lupine main crop for seed with 63 kg/ha P_2O_5 and 56 kg/ha K_2O
Crop 2: rye with 31 kg/ha P_2O_5 and 28 kg/ha K_2O fertilisation
Crop 3: potato with 36 kg/ha N fertilisation from 1952

The F-1 rotation received no fertilisers and organic material treatment except the rye and potato roots and straw incorporated into the soil. The fallow in this block was a green one i.e. the plant material produced in the vegetation period was ploughed into the soil before the flowering of weeds. The F-2 rotation represents green manure treatment, where lupine was grown as a main crop and incorporated into the soil 4-5 weeks after flowering. The phosphorus and potassium fertilisers in this treatment were applied the previous autumn before the lupine was sown. The F-3 rotation represents lupine root manure treatment, where lupine was grown for grain and the total organic material, except for the grain, was incorporated into the soil.

To map within plot variation a total of 45 sampling place were measured per plots dividing the plots into 9 subunites according to the xxx. At each site the soil penetration resistance, moisture content and soil temperature were measured. Average soil water content of the top 120 cm layer was also measured at 10 cm increments.

RESULTS AND DISCUSSION

Lupines can successfully be grown on sandy soils. This fact gives lupines a distinct advantage since other green manure crops usually fail on low fertility soils. Lupines are commonly thought to be best adapted to sandy soils and it has also been widely reported that they require limited amount of water or fertilisers. Soil texture varies significantly in Nyírség region and it has a direct effect production capability, crop yield, on water-holding capacity, cation-exchange-capacity, nitrogen loss. Plant nutrients are stored differently as soil textures vary and uniform application of nitrogen to varying soils results in a wide range of nitrogen availability to the crop. Nitrogen applied in excess of the crop usage results in a waste of the grower's input expense, a potential negative effect on the environment, and in some crops a reduction of crop quality, yield, and harvestability. Inadequate nitrogen levels on the other hand represent a lost opportunity for crop yield. Growing lupine on the other hand can reduce potential for compaction and increase soil fertility (Borbély et al. (2000), Márton et al (2002), Henzsel és Csáki (2002).

Penetration resistance due to crop rotation

<u>Fallow (F-1):</u> Crop rotation F-1 models the traditional farming practice, which was widely used in the Nyírség region even at the beginning of the 20th century. Vilmos Westsik included this crop rotation in the experiment as a control treatment. The Nyírség region was short of adequate pastures and farmers were driven to leave a small proportion of their lands uncultivated and have it grazed by farm animals. This type of fallow combined with grazing is a version of the crop rotation practised in the Kunság region. Simple fallow would have increased the danger of wind erosion; but continuous grazing on fallow lands saved the area from the proliferation of weeds. Earlier, Vilmos Westsik had already called attention to the economic problems of fallow entirely lacking nutrient management. One of the most important aims of starting the experiment was the development of a crop rotation system, which could replace fallow. This objective was attempted through experiments with straw manure, green manure from main or second crop lupine and the production of green fodder crops were carried out. Each treatment was aimed at the study of the more efficient utilisation of fallow fields.

Lowest penetraton resistance was measured in in the first sampling places close to the stream callad Érpatak. Mh-4, Mh-5 and Mh-6 sampling place has higher penetraton resistance. The penetraton resistance on third part of the plot was very chanchable. In case of Mh-7 it was relativelly high in the 40-60 cm soil layer and relatively low under this layer. In sampling place Mh-9 penetration resistance was high.

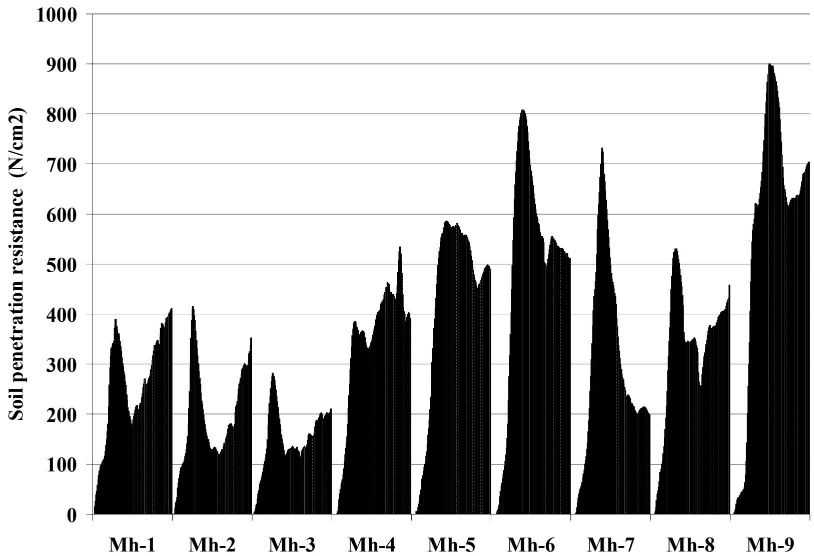

Figure 1. Soil penetration resistance in the fallow treatment measured in rye sown after fallow at a depth of 0-120 cm

Green manuring with lupine as a main crop (F-2): On the drifting sand dunes of the Nyírség, yellow lupine appeared the most suitable plant for green manure. Due to its huge and deep root system it can tolerate dry periods well. Its transpiration coefficient is the most favourable of all cultivated lupine species. Lupine also tolerates, or rather requires, the acidity of the soil.In the crop rotations based on green manure from lupine main crop the lupine was sown in the second half of March and was ploughed under in the first ten days of July when the seeds had already fully developed in the pods. This way, lupine produced the highest organic matter yields and the amount of nitrogen fixed on a unit of land was also the highest. Plant material ploughed under goes through a fermentation process in the soil. Rate of mineralisation depends on (i) the carbon-nitrogen ratio (C/N ratio) of the material ploughed under, (ii) moisture available in the soil and on (iii) temperature. The water content and the C/N ratio of lupine are similar to those of the farmyard manure. Soil moisture and temperature conditions are also conducive to the mineralisation of organic matter. As a result of the process, large quantities of plant nutrients are released which can be used easily and very efficiently.

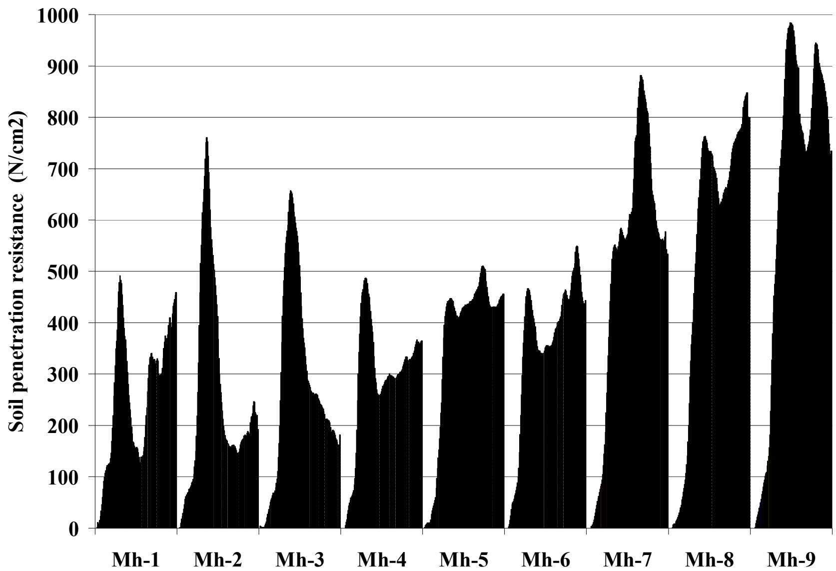

Figure 2. Soil penetration resistance in the lupin green manure treatment measured in rye sown after lupine green manure at a depth of 0-120 cm

Vilmos Westsik advised green manuring from main crop lupine for the improvement of the less productive sandy soils where second crop lupine could not be grown successfully. It is beyond doubt that green manure from main crop lupine is still the most suitable solution, when a large proportion of sandy soils with unfavourable growing conditions temporarily gets out of cultivation as a result of the changing economic situation, and when the volume of industrial input must be reduced because of the disadvantageous input-output price ratio of agricultural production. These days, when the issues of environmental pollution and agricultural over-production have come to the fore, the crop rotation developed for sandy soils and based on main crop lupine green manure can provide useful and practical information and offer direct guidelines for production in the Nyírség region. The effects of lupine on the soil penetration resitance is not evident. Soil penetration resitance was higher in many samlind places, which contradict to the previous observations of Borbély et al. (2000), Márton et al (2002), Henzsel and Csáki (2002).

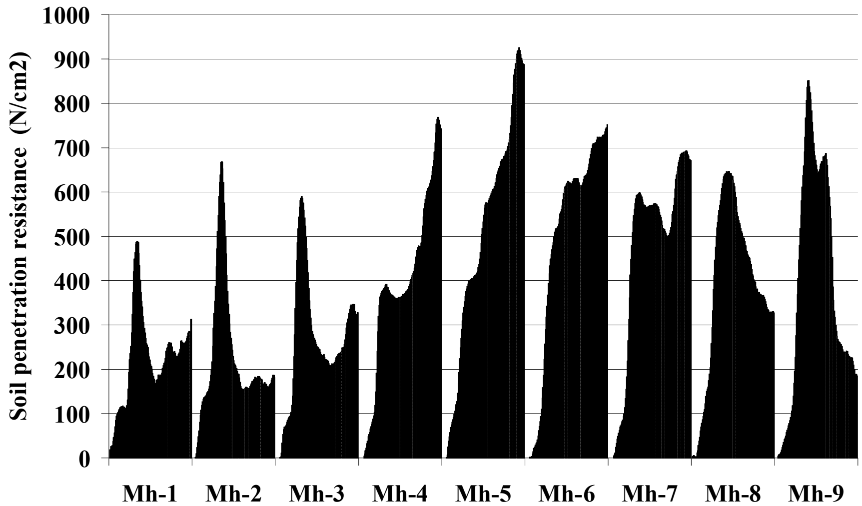

Figure 3. **Soil penetration resistance in the lupin root manure treatment measured in rye sown after lupine at a depth of 0-120 cm**

Sand improvement with lupine root manure (F-3): Agricultural production in the Carpathian basin is predominated by cereals; it has partly ecological and partly economic reasons. However, leguminous crops have advantage over cereals. They contain more protein and ensure more favourable amino acid composition in the root and stem residues. All the nitrogen fixed by the lupine main crop can be recycled into the soil by green manure. In the case of fodder crops, recycling is only partial. The best example is crop rotation F-3 when part of the fixed nitrogen is taken away from the land with the grain. In respect of soil penetration resistance there is on difference between F-2 and F-3, where lupine used as green manure crop or harvested for seed.

Understanding the physical characteristics of soil is of particular importance to farm managers. Issues such as tillage, soil compaction, root growth, gas exchange and hydraulic properties are all functional of a soils strength. The use of the dynamic cone penetrometer has allowed repeatable and comparable soil strength assessments. An advantage of the penetrometer is that the force applied can be quantified so that comparisons can be made between brands and models. The dynamic cone penetrometer is a cheap instrument that measures both a soils shear and compressive strength. As soil strength is functional of soil moisture the penetrometer can also be an indicator of changes in soil moisture across a study site as well as down a profile. For this reason we examined the wolumetric water content of the soil at sampling places. The results are summarised in Figure 4.

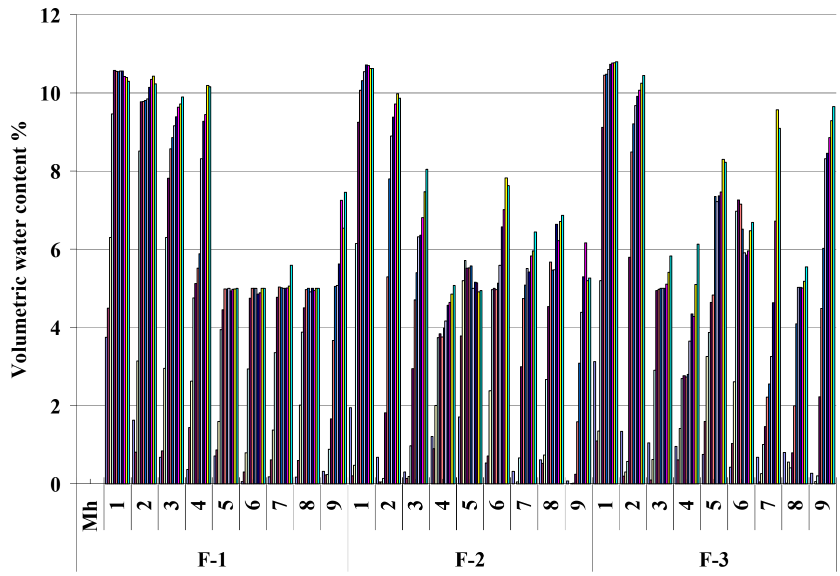

Figure 4. **Volumetric water content in treatments of Westsik crop rotation experiment**

The water content of soil was higher in Mh-1, Mh-2 and Mh-3 sapling places, which can serve as an explanation for the lower penetration resistance. In each crop rotation the water conten was lower in Mh-4, Mh-5 and Mh-6 sampling place, where the penetration resistance was high. Soil mechanical impedance affects root growth and water flow and controls nutrient transport below the rooting zone. Among the soil parameters affecting soil strength, soil water content and bulk density are the most significant. Field water content changes both spatially and temporally, limiting the application of penetrometers as an indicator of soil strength. Considering the presence of large water content variations within a soil profile and across a field and the large influence of water content on soil strength, there is a need for a simultaneous evaluation of field water content and soil resistance data. Bengough *et al*. 2002) found an exponential relationship between with moisture content and penetration resistance. This can be attributed to water molecules decreasing the cohesion between the particles as well as acting as a lubricant between the clay particles, thus reducing the frictional forces that need to be overcome to shear the soil.

CONCLUSIONS

With our technology, the data produced by the penetrometer must be interpreted semi-qualitatively because differences in strength at field capacity are difficult to separate from effects of water content and it has been proved that water content affects penetration resistance. The volumetric water content was low near the soil surface and increases with soil depth, whereas the penetration resistance increases from the surface to about the 40-50-cm depth (plough pan) and usually decreases from there on. The depth distribution of penetration resistance followed a similar spatial pattern with depth and spacial distribution of sampling places in the crop rotation experiment. Our analysis can translate the data into penetration profiles, which may be useful for discerning hard pans or compacted layers. The penetrometer proved valuable because it enabled us to envisage the differences in soil structure at field capacity as a function of depth and soil management history.

REFERENCES

1. Ayers, P.D., and H.D. Bowen. 1987, Predicting soil density using cone penetration resistance and moisture profile. ASAE Trans. 30:1331–1336.
2. Baver, L.D., W.H. Gardner, and W.R. Gardner. 1972, Soil physics. 4th ed. John Wiley & Sons, New York.
3. Bradford, J.M. 1986, Penetrability. In A. Klute (ed.) Methods of soil analysis. Agron. Monogr. 9. ASA and SSSA, Madison, WI.
4. Borbély, F.-Csáki, I.-Henzsel, I., 2000, A fehérvirágú csillagfürt hatása a talaj fizikai állapotára (Penetrométeres vizsgálatok savanyú barna erdőtalajon). A Magyar Tudományos Akadémia Szabolcs-Szatmár-Bereg Megyei Tudományos Testülete Előadások Összefoglalói. Nyíregyháza.
5. Henderson, C.W.L. 1989, Using a penetrometer to predict the effects of soil compaction on the growth and yeld of wheat on uniform, sandy soils. Aust. J. Agric. Res. 40:498–508.
6. Henderson, C., A. Levett, and D. Lisle. 1988, The effects of soil water content and bulk density on the compactibility of some western Australian sandy soils. Aust. J. Soil Res. 26:391–400.
7. Henzsel, I.- Csáki, I., 2002, A talajellenállás vizsgálata különböző tápanyag-gazdálkodási rendszerekben. Tartamkísérletek, Tájtermesztés, Vidékfejlesztés, Nemzetközi Konferencia. Debrecen, Nyírlugos, Nyíregyháza, Livada, 2002. június 6-8. 376-382. o.
8. Márton, Á. – Szabóné Csalló, K. – Henzsel, I., 2002, Penetrométeres mérési eredmények riolittufával kezelt területeken. Tessedik Sámuel Jubileumi Mezőgazdasági Víz- és Környezetgazdálkodási Tudományos Napok. Szarvas, 2002. augusztus 29-30.
9. Parker ER, Jenny H, 1945, Water infiltration and related soil properties as affected by cultivation and organic fertilization. Soil Science 60, 353–376.
10. Romig, D.E., M.J. Garlynd, R.F. Harris, and K. McSweeney. 1995, How farmers assess soil health and quality. J. Soil Water Conserv. 50:229–236.

11. Scala AJ, 1956, Simple method of flexible pavement design using cone penetrometers. Proceedings of the 2nd Australian and New Zealand Conference on Soil Mechanics and Foundation Engineering, pp. 73-83 New Zealand Society of Soil Mechanics and Foundation Engineering: Christchurch.
12. Stelluti, M., M. Maiorana, and D. DeGiorgio. 1998, Multivariate approach to evaluate the penetrometer resistance in different tillage systems. Soil Tillage Res. 46:145–151.
13. Stitt, R.E., D.K. Cassel, S.B. Weed, L.A. Nelson. 1982, Mechanical impedance of tillage pans in Atlantic Coastal Plain soils and relationships with soil physical, chemical, and mineralogical properties. Soil Sci. Soc. Am. J. 46:100–106.
14. Young, G.D., B.A. Adams, and G.C. Topp. 1998, A portable cone index and water content penetrometer. p. 180. In Agronomy abstracts. ASA, CSSA, and SSSA, Madison, WI.