DEFINING PHYSICAL PROPERTIES OF THE SOIL THAT INFLUENCE MECHANIZATION IN FORESTS

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Abstract

In the recent years there has been a growing number of studies on soil cultivation in stumpy forests areas. However, the development and improvement of suitable soil cultivation machines is unfeasible without knowing the proper characteristics of the soils. The complex structure of soil makes it very difficult to describe its general mechanical regularities. Beyond that, the presence of stumps causes further problems to forestry. Reviewing the literature, we have found that the physical and mechanical characteristics of soils with roots are hitherto unidentified. The available scientific literature does not provide relevant information how the presence of roots affects the soil's resistance against cultivating tools.

One of our research goals was to study the physical and mechanical properties of forest soils, as well as the effect of tree roots on these physical-mechanical characteristics. We have set up correlations in order to predict soil penetration resistance.

Using mechanical and statistical methods, we have fitted a surface to the measured data points, which relates the changes of soil resistance to the diameter of the trees and to the distance from the trees.

Keywords

machine improvement, stumpy areas, soil cultivation, machines for soil preparation, penetrometer, soil resistance

Introduction

In the recent years a growing emphasis has been placed on the development of machinery providing solutions for the cultivation of stumpy forest areas (Horváth 1997, Horváth 1998). However, the development of such soil tillage machines (also called soil cultivation machines) is unfeasible without knowing the precise characteristics of the soils (Bánházi 1984, Mészáros et al. 1965, Rázsó 1958, Sitkei 1991).

Soil, being a three-phase disperse system is a mixture of solid, liquid and gaseous substances, can be charactarized with a spatially and temporally changing proportion of these components. Besides of that, the interrelation between these components is not unchanging either (Sitkei 1986). Indeed, soil can not be characterized with only one single physical or mechanical parameter. Soil cultivation machines alter primarily the physical features of the soil, while in turn the mechanical properties of the soil also have a significant reaction on the tools (Sitkei 1967, Sitkei 1981). Physical features of the soil involve textural and structural properties. Mechanical behaviour of the soil is defined by the type and extent of the deformation triggered by a distinct force (pressure, shearing stress). Regarding agricultural soil cultivation mechanical properties are of the highest importance.

Because of the inhomogenity and complex build-up of soils it is highly difficult to establish general mechanical principles for soils and to find proper mechanical parameters for characterization. The currently used paramteres for soil-characterizing do not reflect the mechanical behaviour of the soils under all possible circumstances. The relationships established from research data can not be generalized without certain restrictions (Kaifás 2006).

Regarding forestry practice the presence of roots and stumps gives rise to further problems, as these could increase the stability of the soil significantly. Reviewing the applying scientific literature we have concluded that the physical as well as mechanical characteristics of rooty soils are hitherto unknown. Our knowledge on the morphology of the root system of trees, on its arrangement in the soil and on its branching properties are all very incomplete (Csiha and Keserű 2003, Kárász 1984; Kárász 1986, Köstler et al. 1968, Majer 1958, Majer 1961). During the last decades special devices have been developed, which are suitable for soil characterization thru measuring the degree of soil compaction. Although these devices were equipped with differently shaped probes, the basic method of the measurement remained unchanged through these years (Bánházi, 2000). These mechanically-operated devices (penetrometers) record the level of the resistance required to make the probe penetrate into the soil. Mesuring soil resistance with the penetrometer is one of the most frequently applied methods nowadays to study the compaction of the soil, the depth of different compacted layers as well as the change of physical characteristics of the soil in time and space. Many researchers have concluded in their studies that soil resistance acquired with the penetrometer is a much more sensitive indicator of soil compaction than volumetric mass.

The pressurized probe can be applied in the following fields:

- examination of the effect of different soil cultivation methods and systems;
- surveying the state of soil, detecting soil defects;
- characterizing soils with different physical properties;
- measuring soil water content and soil water flow;
- monitoring long-term soil resistance changes under different cultivation systems and plant (crop) sequences.

Materials and methods

The aim of our research was to investigate the mechanical and physical properties of forest soils as well as researching the effects of tree roots on the afore-mentioned properties of the soil, that is how the resistance of the soil changes as a function of tree species, stem diameter, and distance from the stem.

As finding out the precise arrangement of the roots and their possible impact by digging up the complete root system is extremely time consuming, we have searched for a method instead which would result the required data relatively fast. It seemed evident to draw conclusions from the soil resistance measurements in order to learn about the effects of the root system.

Soil resistance was measured using the „3T System" electronic soil layer indicator, which acquires the soil's water content and compaction at 1 cm depth steps. The device indicates the water content of the soil related to the field capacity (pF 2.5) in volume percent. The compaction of the soil was determined from the penetration resistance of the probe (cone, 60°, 12,5 mm diameter) and is given in kPa unit. The device stores all the measured data which can be evaluated using a computer.

Measurement sites were assigned in the subcompartments 79/B and 80/N at the Tanulmányi Erdőgazdaság Ltd. (Sopron, Hungary). Major parameters of the subcompartments are listed in Table 1.

Table 1. Major parameters of the investigated subcompartments

Parameter	Subcompartment	
	79/A	80/B
Soil characteristics:		
- genetic soil type:	Brown forest soil with clay illuviation	Brown forest soil with clay illuviation
- physical soil type:	Adobe	Adobe
- hydrology:	Independent from water source	Independent from water source
- thickness of fertile layer:	Very thick	Very thick
Forest stand properties:		
- tree species:	Sessile oak, larch	Sessile oak, pine, hornbeam, black locust
- age [year]:	109	81
- $d_{1,3}$ [cm]:	42	28
- stems per hectare [stem/ha]:	132	480

Three stems were chosen at each of the measurement sites. Soil resistance was recorded around the assigned trees along concentric circles. The radius was increased in 0,5 meter steps until 3 meter was reached. For the sake of comparison, control measurements have also been carried out at the centre of gravity of the three stems, assuming that roots have no more influence at that point. The exact positions of the measurements have been determined (using polar coordinates) which will make a later reconstruction of the investigations possible.

Altogether eight measurement sites with 24 stems were assigned for the analysis. Experiments were designed to cover the complete diameter range of the trees of the stand. As forestry practice applies diameter at breast height to characterize stem diameter, this convention was followed (diameters at stump and at breast height can be interconverted using tables). The investigated trees were all sessile oaks.

Measurements were carried out to a maximum depth of 40 cm. Soil cultivation is basically done within this depth and the major part of the root system of trees can be found near the surface of the soil. According to Köstler et al. (1968) 65-85% of the longitudinal extension of the roots is located within the upper 10 cm of the soil. Evaluation of the measured data was done using a large number of measurements as the variance of pointwise measurements is rather high; measurement precision is greatly influenced by not-yet-rotten roots, left back from earlier loggings and by stones.

Results and discussion

The data recorded by the 3T System device was exported to ASCII files and these files were processed further using Microsoft Excel. This was followed by the statistical evaluation (correlational analysis and regression analysis) using STATISTICA software which is suitable for fitting multivariate functions and also for graphical representation of the results. The strength of the association between the variables was quantified using Pearson's correlation coefficient (r).

Figure 1 summarizes the measured data for soil resistance, variables: *var1* diameter,
var2 distance from the stem,
var3 soil resistance.

Table 2 shows the respective correlation matrix for the variables.

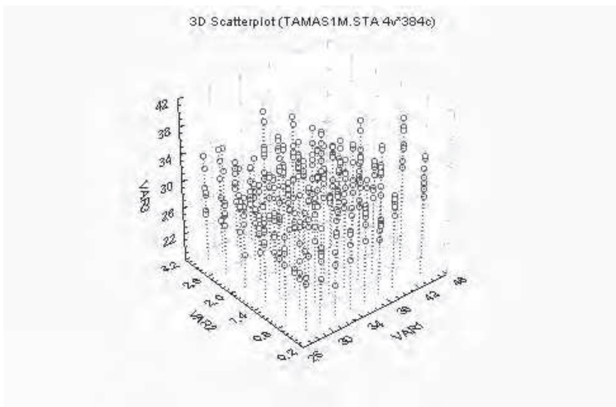

Figure 1. Values of measured soil resistance

Table 2. The correlation matrix for the whole database

	diameter	distance	soil resistance	water content
diameter	1,00	0,00	0,28	0,21
distance	0,00	1,00	-0,23	-0,19
soil resistance	0,28	-0,23	1,00	0,52
water content	0,21	-0,19	0,52	1,00

The pairwise investigation of the variables reveals that the goodness of the correlations are very poor that is there is no, or only a very weak connection between the parameters.

These results however do not preclude that some better type of correlation models could be established from the data further on.

For a better illustration of the dependence of the soil resistance from the diameter and from the distance, the soil resistance values measured at identical distances from a stem were averaged and surface fitting analysis was carried out for these average values. The correlation matrix for these average values is included in Tab. 3.

Table 3. The correlation matrix of average values

	diameter	distance	soil resistance	water content
diameter	1,00	0,00	0,40	0,20
distance	0,00	1,00	-0,49	-0,37
soil resistance	0,40	-0,49	1,00	0,62
water content	0,20	-0,37	0,62	1,00

The strating point for the surface fitting analysis was the typical second order equation of a surface. With the modification of this equation using the Rosenbrock és quasi-Newton iteration method the following equation was fitted to the data set.

$$p = a_1 \cdot r^2 + a_2 \cdot d_{1,3}{}^2 + a_3 \cdot (r \cdot d_{1,3})^2 + a_4 \cdot d_{1,3} + a_5 \cdot r^{a_6} + a_7$$

where: p [100 kPa]: soil resistance,
r [m]: distance from the stem,
$d_{1,3}$ [cm]: diameter of the stem.

The constants a_1, a_2, a_3, a_4, a_5, a_6, a_7 are the coefficients of the model. Values are summed up in Table 4.

Table 4. The coefficients of the regression model

a_1	a_2	a_3	a_4	a_5	a_6	a_7
0,077571	-0,011850	-0,000443	1,121044	0,000002	12,53775	6,555678

The value of the correlation coefficient (r) indicating the goodness of the surface fit is r=0,72213. This value can be qualified as adequate regarding the type of measured values and the surface fitting. Better values for the correlation coefficient (i.e. better model) could possibly be obtained by the further refining of measured data (e.g. using 3-period moving average models which have already been applied in economic calculations and have also become widespread in technical fields lately).

The adapted regression model does not interpret the physical relationship between the variables but is indeed capable to predict the tendency of changes and is suitable for carrying out interpolations too. While substituting the values of diameter and distance into the model function, partial equations, showing the change of the soil resistance for a given diameter and distance can be obtained stepwise.

Figure 2 depicts the fitted surface and the measured data points.

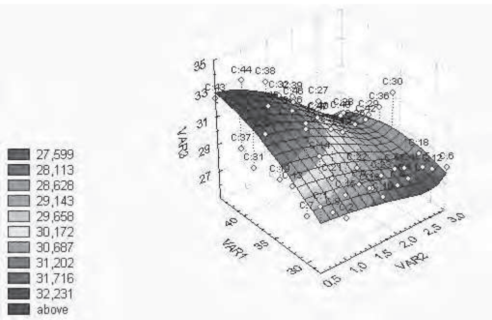

Figure 2. Connected surface

According to the measured data it can be established that around the stems in a radius of 1-1,5 meters the higher soil resistance is caused by the presence of roots. In absence of respective control locations it could not be estimated if there are any measurable differences in resistance between soils with and without roots, beyond 1,5 meters distance from the stems. In the case of stems having a diameter at breast height less than 30 cm, the influence of the root system on the change of the soil resistance could not be detected.

However, with stems having larger diameters the relation between the two parameters was not always evident either, primarily the best results have been found for single standing trees. The three-meter-sized theoretical growing space, calculated from the stems per hectare value is usually much smaller because of the natural arrengement of the trees (i.e. impact of the neighbouring trees). At these locations and at those sites with higher stems per hectare, soil reistance proved to be relatively uniform due to the evenly distributed root system throughout the soil of the whole subcompartment.

References

1. Bánházi J. (2000): A talajtömörségről. Mezőgazdasági Technika, 5:6-7.

2. Bánházi J. szerk. (1984): A szántóföldi munkagépek működésének elméleti alapjai. Mezőgazdasági Kiadó, Budapest.

3. Csiha I. – Keserű Zs. (2003): Gyökérfeltárások tapasztalatai száraz, homoki termőhelyeken. Alföldi Erdőkért Egyesület Kutatói Nap kiadványa, Kecskemét. 56-63.

4. Horváth B. (1997): Tuskózás nélküli erdőfelújítási technológiák gépesítése. V. Erdészeti Szakmai Konferencia (WOOD TECH) kiadványa, Sopron.
5. Horváth B. (1998): Erdészeti gépgyártás Magyarországon. Profi Erdőgazda. 1: 18-19
6. Kaifás F. (2006): Talajok (szemcsés anyagok) szilárdsági tulajdonságainak vizsgálata. MTA Agrár-Műszaki Bizottság Kutatási és Fejlesztési Tanácskozásának kiadványa, Gödöllő. 299-305.
7. Kárász I. (1984): Egy mérsékelt övi tölgyes cserjefajainak gyökérzete. Kandidátusi értekezés, Eger. 110 p.
8. Kárász I. (1986):Gyökérvizsgálatok Magyarországon. Botanikai közlemények. 73:19-23.
9. Köstler, J. N. – Brückner, E. – Biebelriether, H. (1968): Die Wurzeln der Waldbäume. Verlag Paul Parey, Hamburg und Berlin.
10. Majer A. (1958): Bükk erdőtípusok gyökérszint vizsgálata. Magyar Tudományos Akadémia Agrártudományi Osztályának Közleményei, 14:117-134.
11. Majer A. (1961): Gyökérösszenövések előfordulása és jelentősége. Erdészeti Kutatások, 165-183.
12. Mészáros I. – Sitkei Gy. – Kégl J. (1965): A mezőgazdasági gépek vizsgálata. Akadémiai Kiadó, Budapest.
13. Rázsó I. szerk. (1958): Mezőgazdasági gépek elmélete. Tankönyvkiadó, Budapest.
14. Sitkei Gy. (1967): A mezőgazdasági gépek talajmechanikai problémái. Akadémiai Kiadó, Budapest.
15. Sitkei Gy. (1981): A mezőgazdasági anyagok mechanikája. Akadémiai Kiadó, Budapest.
16. Sitkei Gy. (1986): Mezőgazdasági és erdészeti járművek modellezése. Akadémiai Kiadó. Budapest.
17. Sitkei Gy. (1991): Compaction of agricultural soils with viscoelastic behavior under conifined and conditions. Proc. of 5th European Conf. of the ISTV, Budapest. 257-264.