Strip Road Compaction Caused by Logging Technology (Measured by Penetrologger and Deflectometer)

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Abstract:
The study deals with assessment of compaction grade caused by machinery which was measured by cone penetrometer (penetrologger Eikelkamp) and portable falling weight deflectometer (Loadman II). The compaction grade is investigated after exactly specified number of machinery passes. Both devices measure the compaction on different principles and therefore measured values are related to third independent soil characteristics i.e. soil porosity. Penetration resistance and elasticity modulus were measured in the axes of the striproad, between track and axes, directly in track and 40 and 80 cm side of the track, respectively. The soil porosity was obtained from Kopecky metal rings samples in the laboratory. Samples for porosity evaluation were taken from three layers under the striproad i.e. in 7, 14 and 21 cm depth and the same schema as penetration resistance and elasticity modulus measurement was used for sample collection. The influence of the soil moisture content was eliminated and was uniform. Results graphically show significant differences of compaction grade towards the depth and towards side of track with respect to number of passes.

Keywords: penetration resistance, deflection, soil compaction, Kopecky metal rings

1 Introduction

Actually high demands are put on the forestry sector with respect to fast processing of timber and with low cost. Therefore highly performed mainly robust machinery is applied. Disadvantage of the robust machinery can be seen in negative influence on the environment which is mainly caused by its mass when the machinery is applied in inappropriate time. Becker (1999 in Skoupy 2011) presents, that application of heavy machinery is causing damages of both fine and coarse roots, which is immediately interrupting function of sorption.

Root system area of spruce ranges located within few centimetres (8-20 cm), therefore any change of soil physical conditions (porosity, aerating) may impact growing and development of root system. Gebauer (2005) presented the development of spruce root system which grew in compacted soil and found significantly lower (38 %) root system area. The root growing in soil needs to overpower axial and radial soil pressure and soil friction (Greacen 1986 in Gebauer 2005).

Synergy problem of compaction by heavy logging system passing on strip roads is rutting. Compaction may activate disturbances in gas exchange in soil. In case when the exchange of gases in soil is reduced, carbon dioxide ventilation decreases and therefore its accumulation in soil increases (Wilpert 1999 and Neruda 2010). This affects both soil organisms activity which is corresponding to soil structure and moisture content, but also income of nutrition, respectively.

Quality of the soil is topic which becomes on popularity. Generally, the quality is assessed using three main aspects: physical, chemical and biological. Those aspects are considered to be important for assessment of soil degradation or amelioration and also for identification of management method ensuring sustainable soil exploitation. According to Dexter (2004) soil physical conditions seems to be however the most important, because they have high impact on chemical and biological processes in soil.

Forest soil is poly-dispersive system, where the basic is in spatial arrangement of primary and secondary structure of elements; those elements compose from soil particles of different size, shape and characteristics. From this point of view can be described using physical characteristics which are colour, texture, porosity, consistence and structure (Rejšek 1999). Those specific characteristics are dependent on interaction between solid, liquid and fluid elements.

Traditionally, the specific pressure 50 kPa is accepted as limiting. Contact pressure of wide tyre is between 100 and 280 kPa which means, that passing of any machinery on soil with higher moisture content causes changes of soil characteristics. Only during positive weather conditions (dry, frost) can be expected minimal changes of soil structure (Ulrich et al. 2008). Dexter (2004) describes soil compaction as decreasing volume of specific amount of soil. Compaction causes increasing of basic density, decreasing of porosity and when heavy also destruction of soil aggregates. It leads to deterioration of other physical soil characteristics for example water permeability, amount of moisture content in soil horizon and water motion in soil.

Soil microedaphon is concerned with significant processes of organic and mineral matter transformation i.e. humification, oxidation of ammonia, ferrum, sulphur, manganese, decomposition of sulphates and nitrates etc. In compacted low aerated soils the activity of microedaphon is limited and therefore the quality of humus decreases (Javurek and Vach 2008).

The critical values of selected soil physical characteristics according to Lhotsky (2000) are presented in Table 1. Immediately those are exceeded the plants and also microedaphon is negatively affected.

Table 1: Critical values of specified soil physical characteristics (Lhotsky 2000)

	Soil type (volume of particles less than 0.01 mm in %)					
	Clay (> 75)	**Till to clay-loam (75-46)**	**Argilaceous (45-31)**	**Sandy loam (30-21)**	**Sabulous (20-11)**	**Sandy (< 10)**
Basic density (g.cm^{-3})	> 1.35	> 1.40	> 1.45	> 1.55	> 1.60	> 1.70
Porosity	< 48	< 47	< 45	< 42	< 40	< 38
Penetration resistance (MPa)	2.8-3.2	3.3-3.7	3.8-4.2	4.5-5.0	5.5	> 6.0
by moisture content	28-24	24-20	18-16	15-13	12	10

Ampoorter (2010) presented, that regeneration is of long duration process which is based on frizzing and melting of soil water, swelling up and shrinkage of soil particles and biological activity of roots and soil organisms. The soil regeneration in natural conditions is of long duration, in average 10 to 15 years and more. Literature presents also highly time demanding regeneration process according to soil type. Shaffer (2005) in Ampoorter (2010) presented that duration 30-40 years was not enough to fully restore gas diffusion and root hair density in footprint. Disturbance of soil activity is very difficult to measure in reality. Therefore are used supporting values, for example increase of soil density, soil moisture content, volume of pores, water infiltration, air respiration and other.

Generally is known, that more passes significantly increases consequence on soil. After two or three passes the compaction becomes more evident and generally is the highest. On plastic soils then may occur expression to the site i.e. rutting. Therefore the main principle is to minimize the number of passes. With this finding may bear the logical problem i.e. is better to use lighter machine with smaller payload and accept more passes or to use heavier machine with higher capacity and ensure less passes (Neruda 2008).

Compaction caused by machinery, number of passes, soil type and moisture content all those play role. Finally, no simple and exact device for compaction measuring on forest soils is available. Therefore the aim of the study was to compare measuring of compaction by penetrometer (penetrologger) and/or deflectometer with porosity investigated using Kopecky metal rings.

2 Material and methods

Since the aim of the study was focused on measurement of soil physical characteristics caused by logging technology using different principles and devices authors tried to carry out this study on soil with good homogeneity and which is perspective to use both penetrometer and deflectometer. The limiting criteria of soil and stand choice were: skeleton content, root system development in top layer of soil, sufficient available homogenous area/length of striproad and easy accessibility. For the first site selection were used stand and typology maps. After the first selection the preliminary survey using both measuring devices were carried out to confirm perspective measurement.

2.1 Method of measuring by deflectometer

For the measurement was chosen portable falling weight deflectometer Loadman II developed for the purpose of measuring the rigidity of road body structural layers including sub-base layers. The falling weight induces a non-destructive shock wave spreading in the soil, which evokes reaction according to actual soil properties. The difference of reaction is measured by velocity pick-ups and by sensors measuring the accelerated reaction of the surface (accelerometers).

First we removed all objects that could have affected the behaviour and results of the measurements (stones, branches). Then the instrument was placed at a vertical position and its base was (if necessary) levelled by twisting so that the entire instrument area was properly seated on the soil. Prior to the first measurement, the instrument was calibrated according to the size of the reaction base plate. The diameter of the reaction base plate was 132 mm and the calibration module of elasticity was chosen to be E 160 as advised by the manufacturer. *Note: This value was determined by the manufacturer to be a value with the highest correlation towards conventional deflectometers.* During the measurement, the instrument was at all times subtly held in vertical position so that the measurement could not be affected by the grip. In cases with the removed litter, it was necessary to assure a full seating of the instrument on the ground surface by twisting movements. The measurement was made three times: exactly on the sample plot (presented below) and followed measurements at least in 40 cm steps in the striproad direction with the removed humus layer. All measurement results were stored in the instrument's memory under different locality identifications and the mean value was calculated. The sample plots composition is presented below.

2.2 Method of measuring by penetrometer

The measurement was made by using Eijkelkamp manual penetrometer. The work procedure of measuring by penetrometer presented by Matys et al. (1990) was modified for manual penetrometer. Soil bearing capacity was measured by using a cone type with 3.3 cm^2 cone base area and 60^o top angle. The values of soil resistance to the penetrating point were measured by the pressure gauge (instrument part). The penetration rate was ca. 2 cm per second – with equal pressure exerted onto both handles. The measurement was made five times: exactly on the sample plot (presented below) and followed measurements at least in 40 cm steps in the striproad direction. All measurement results were stored in the instrument's memory under different locality identifications and the mean values in 7, 14 and 21 cm deepness were calculated.

2.3 Method of measuring by physical Kopecky metal rings

The primary sample plot where the measurements were taken was subsequently subject to the soil sampling by means of physical Kopecky metal rings in order to detect the porosity, specific density and actual soil moisture content. A soil pit was excavated on the plot into a depth of 30 cm. In this soil pit, we levelled the walls to a flat vertical position first in 7 cm deepness, followed in 14 and 21 cm deepness and took a sample of mineral soil by using physical Kopecky metal rings. Wet soil samples were weighed in laboratory conditions with the accuracy of grams and inserted into an oven where they were dried at a temperature of 105°C (+/- 2°C) for 8 hours. Then the soil samples were weighed in dry condition and moisture contents of soils in the individual sites were calculated. The porosity was investigated using pictometers.

2.4 Segmentation

The transport line was segmented into 4 parts, first part was passed by farm tractor twice, next four times and other six and eight times. In each part was designed transect on which the sample plots were identified. They start from the centre of striproad towards both sides and ends in the stand. The segmentation and sample plots composition is demonstrated on figure 1. The segmentation of physical Kopecky metal rings sampling is shown on figure 2.

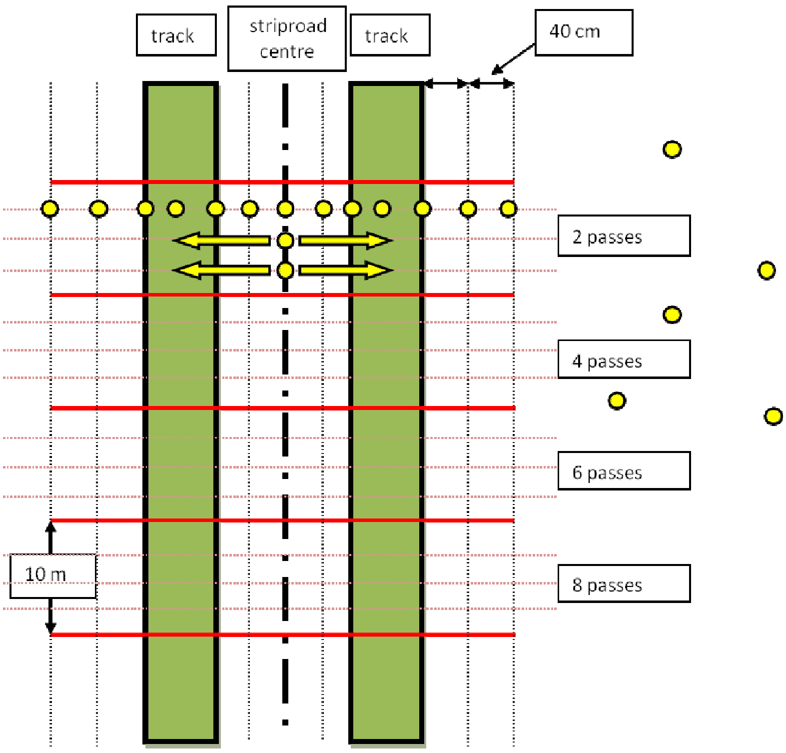

Figure 1: Composition of the sample plots for measuring with penetrometer and deflectometer

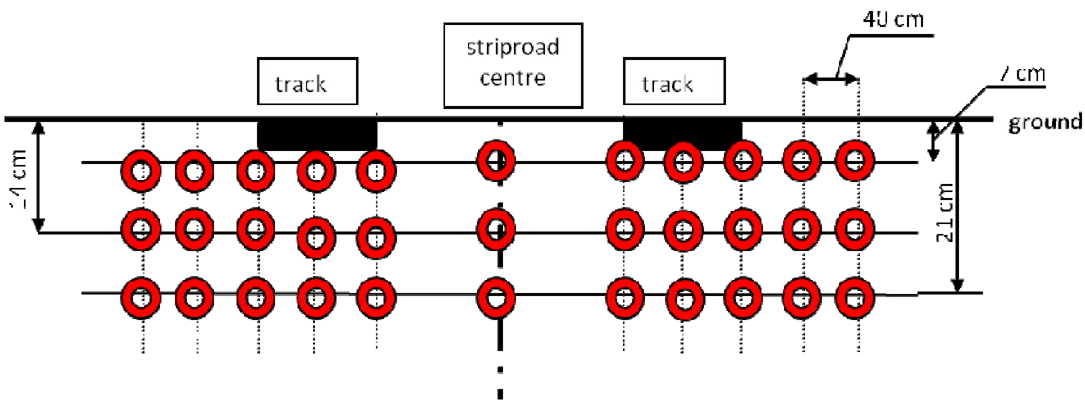

Figure 2: Composition of the physical Kopecky metal rings sampling

3 Results

Locality of survey was chosen in piedmont of Drahanska upland. The soil on the site was gley, slope up to 2 %. Stand composition 80 % of ash, 8 % of maple, 7 % of lime and minority of beech and spruce. Chosen extraction machine was farm tractor John Deere 6230 with 6000 kg of mass including forestry equipment. This type of machinery was chosen due to the fact, that this type of machinery is widely used in the Czech Republic (circa 50 %). Front axle weight was 2800 kg and rear axle 3200 kg. The strip road was historically established and used. However, last 20 years the striproad was not used for any purpose.

3.1 Soil penetration resistance and porosity

Penetration resistance is in conversion to porosity as visible from figures 3 to 5. The higher specific density, which leads to higher penetration resistance, the lower porosity. Standard porosity of the soil was roughly 45 %. Immediately after two passes porosity decreased, which is slightly visible from figure 3. The penetration resistance graduates with deepness. The lower layer of soil the higher penetration resistance of the soil, and the lower porosity. Also we can mention that with increasing deepness the penetration resistance of the soil is nicer figured out. However, the number of passes was not dominant on this soil type. Few excesses for example in figure 3 after 4 passes may be caused by heterogeneity of the soil in this segment.

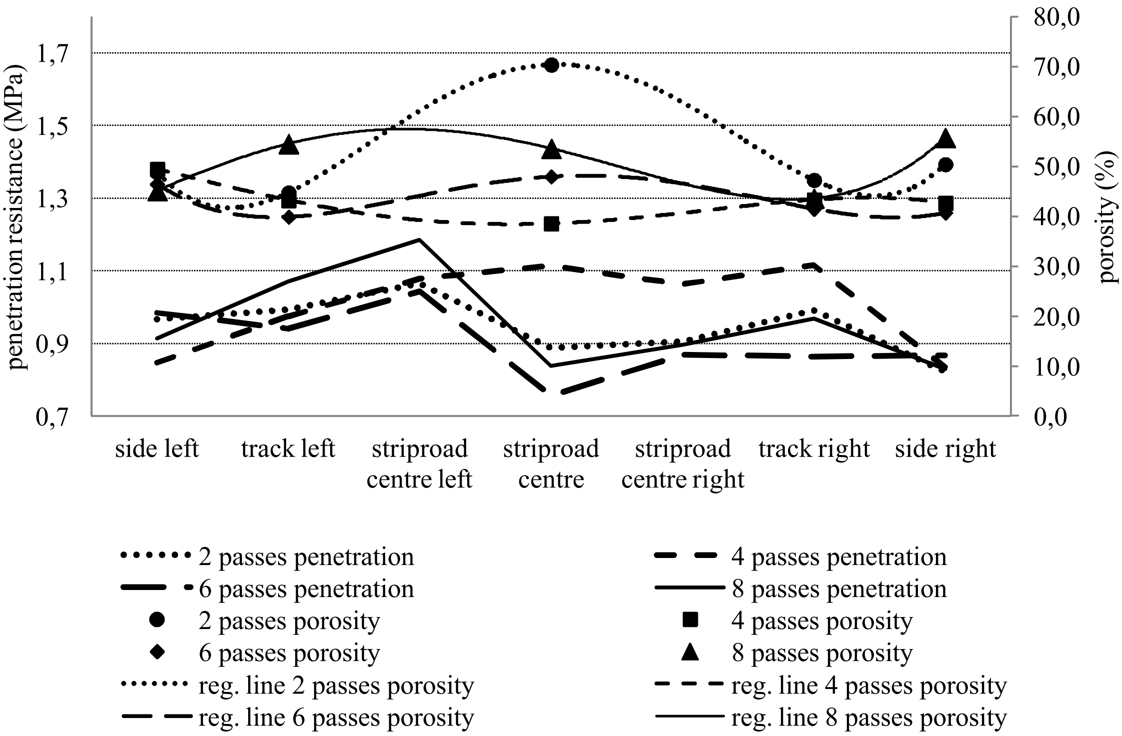

Figure 3: Penetration resistance and porosity in 7 cm deepness after specific number of passes

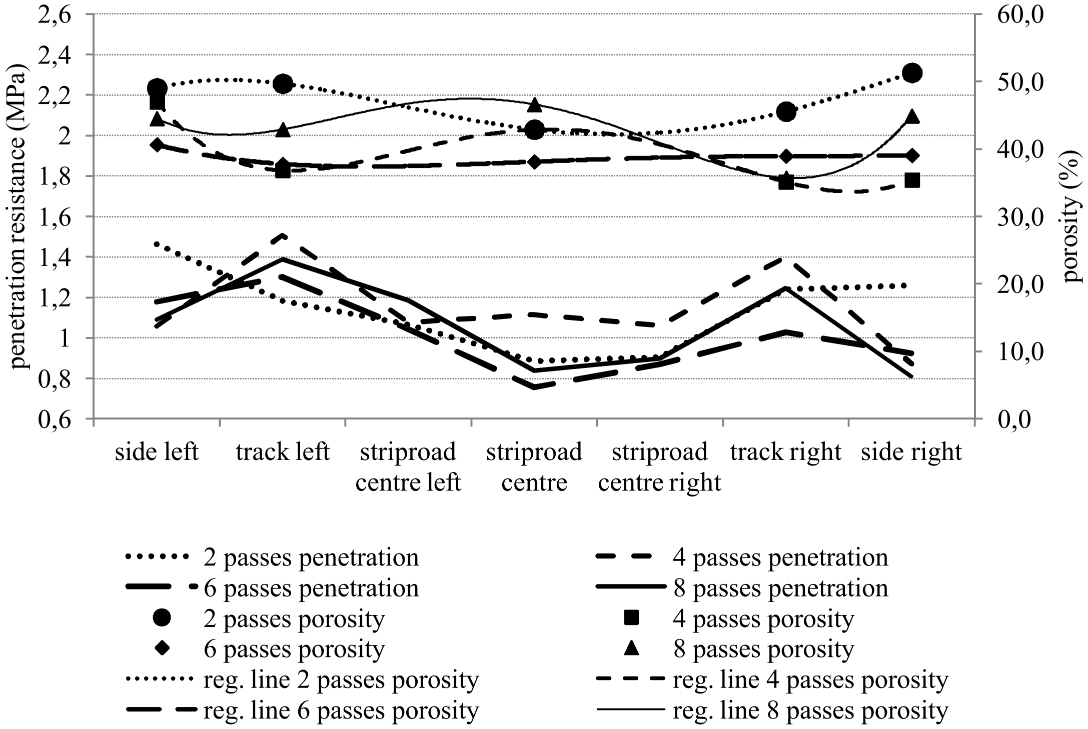

Figure 4: Penetration resistance and porosity in 14 cm deepness after specific number of passes

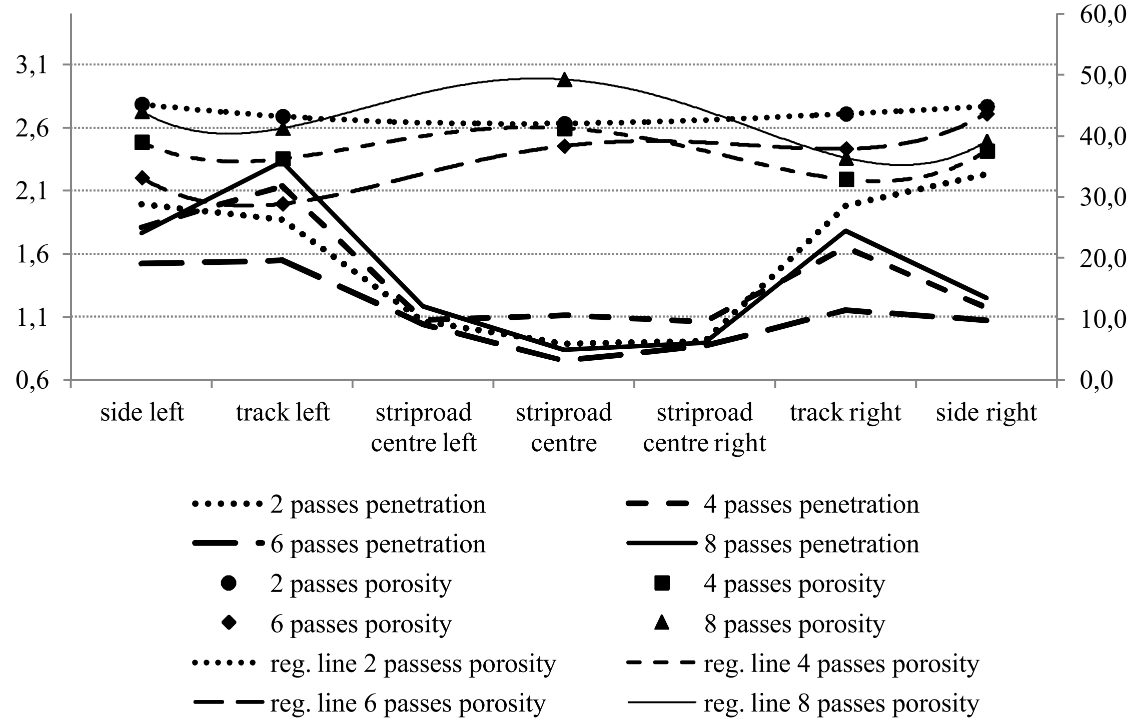

Figure 5: Penetration resistance and porosity in 21 cm deepness after specific number of passes

3.2 Soil deflection

Deflection of the soil was measured by Loadman II deflectometer. According to the results presented in figure 6 can be stated, that deflection of the falling weight rises with compaction. Deflection after 6 passes on the right side of the striproad was not able to measure due to the complete cover of the area by stumps or coarse roots of the stump. However, the trend of the deflection after 6 passes is visible from the left side of the curve too. Generally, the precision of measurement results was not verified clearly and the use ability of the deflectometer for strip road compaction measurement is not fully clear.

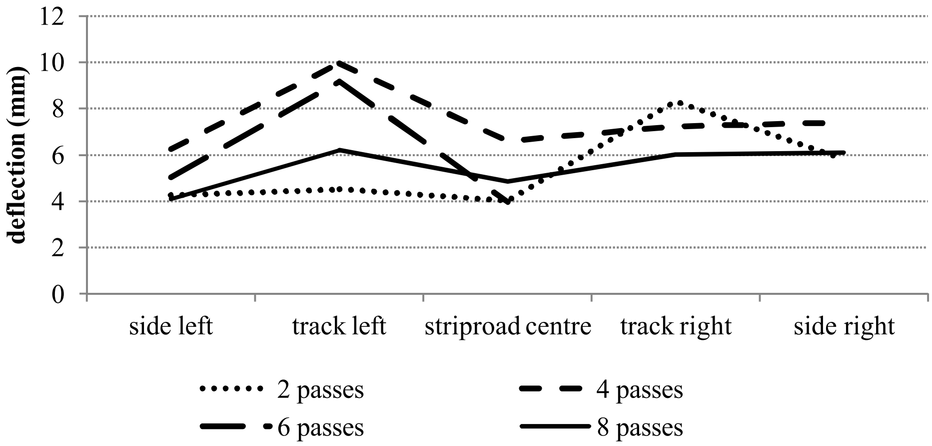

Figure 6: Soil deflection after specific number of passes

3.3 Moisture content and porosity investigated from Kopecky metal rings

To ensure stable moisture content and to investigate porosity in different deepness of the soil all the Kopecky metal ring were also investigated to receive values of those soil characteristics. As visible from table 2 the porosity of the soil decreases with deepness. The moisture content also decreases with the deepness. However, values in single layers were almost uniform which can be seen from minimum and maximum values of the characteristics. Decrease of the porosity and moisture content is probably caused by soil evolution and process of settlement.

Table 2: Minimum, maximum and mean values of moisture content and porosity in specific deepness

	Minimum value	Maximum value	Mean value
moisture content in 7 cm	20.3	27.8	24.1
moisture content in 14 cm	15.7	22.4	19.2
moisture content in 21 cm	13.4	18.9	16.0
porosity in 7 cm	39.2	52.6	46.5
porosity in 14 cm	37.1	47.3	41.4
porosity in 21 cm	36.5	42.7	39.2

4 Discussion

The strip road was newly established and therefore no previous historical compaction should not exist and the soil should be as much as possible uniform. Immediately after two passes the compaction occurred. However, penetration resistance of the soil increases with the deepness of the soil. This phenomena is probably caused by increasing resistance with decreasing moisture content and porosity in deeper layers of soil. This fact is supported and visible from the figures 3-5.

Any usage of logging machinery causes disruptions on forest environment. Mainly, passes of machinery are causing ruting and/or soil compaction. Simanov (2008) has presented that during first five passes the soil disruption dramatically raised and the effect of next passes not such influence the curve of damages. The passes can cause deep ruts, which are in steep terrain source of erosion. Water infiltration in ruts is slow due to the compaction in top soil layer and moreover the soil is not capable to absorb water in pores which are destructed by compaction. This water is moving in ruts very fast and small to medium fragments of soil aggregates are wafted. However, the compaction gradient with number of passes (mentioned by Simanov, 2008) of this soil type was not confirmed. No significant differences of compaction gradient were found with respect to number of passes. Also no rutting occurred even after eight passes. This is probably because of high plasticity of this soil type in wet conditions and very high bearing capacity in dry conditions, respectively.

Forces caused by passing machinery are distributed in the soil both directions i.e. horizontally and vertically, respectively. Vertical forces are affecting soil straightly under the wheels, horizontal forces are affecting both sides of rut and as far they are as loosing the effect, but are more visible deeper under the ground. In this study were carried out plenty of measurements, which should answer the question about usability of devices for striproad compaction measurement in forestry sector. Two different devices have been evaluated falling weight deflectometer Loadman II and penetrologger Eijkelkamp. It is author opinion, both devices are usable for forest soil compaction. The results from both devices are comparable. The precision of penetrometer records is higher. However, deflectometer is measuring the soil in the whole profile because of stress waves caused by falling weight. The profile depends on reaction plate of the device; the depth of profile is 1.5 multiple of reaction plate diameter. This is an advantage of this device, because the soil volume affecting the measurement is several times bigger comparing to penetrologger. This corresponds also with results presented by Klvac et al. (2010b).

Authors have to mention advantages and disadvantages of both devices. Doubtless disadvantage of deflectometer Loadman II is mass of the device which is circa 17 kg compare to penetrologger which is weighting circa 3.4 kg. The handling with both devices is quite easy and comparable for both devices. Strong disadvantage of penetrologger is measuring process. Penetrologger is measuring just one point (very small area) and because of many obstacles in forest soil plenty of measurements are disqualified after contact with root, stone or similar obstacle in the soil. The maximum depth could be 80 cm. The deflectometer is measuring larger area in nondestructive way and whole soil profile under devices is taken into the account. However de maximum depth influence of the device is only 1,5 multiple of bottom plate, i.e. for this type of portable falling weight deflectometer 20 cm. Next disadvantage of penetrologger is physically hard work to push the peak into the soil if soil is hardly compact. And additionally to adjust stable penetration speed is sometimes tricky. As conclusion, both devices are usable for determination soil compaction in praxis. It is necessary, however, to set up the limits of different soil types in the Czech Republic.

Common width of the striproad is 4m in the Czech Republic. As was predicted the highest compaction on strip road was on the wheel track and the centre of striproad was affected too, but with lower intensity. From the wheel track towards the edge of strip road the compaction slowly decreased. 50 cm from the edge of striproad was compaction still visible on each plot. 1m from the edge was compaction visible only in cases when wheel track was on the edge of striproad (Klvač et al., 2010a). Those results were more less also confirmed in this study.

Fully mechanised technology requires strip roads every 20m hence circa 16 - 20 % of forest soil is affected by compaction. Using farm tractor equipped with winch the striproad frequency could be lower (up to 40 m distance). With respect to number of passes, rate of compaction, machine payload, sustainable forest management and soil production potential is then disputable when and on which soil type is better to apply machine with lower payload, which may caused the same compaction disruption on smaller (half) proportion of area affected even if the number of passes is higher.

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