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ENVIRONMENTAL ASPECTS OF KAISER S2 HARVESTER UTILIZATION IN MOUNTAIN TERRAINS

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Abstract

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This paper deals with evaluating the ecological impacts of Kaiser S2 harvester utilization in mountain terrains. The harvester was used in bark beetle calamity and secondary felling in mixed forest (spruce, fir, beech) stand with average incline of 70%. Assisting its movement in these extreme conditions were two supporting bases, which were used to stabilize it in the stand. Our aim was to determine the damage to the trees, underwood and stand soil. The resulting damage of remaining stand was 6.19%, which is, considering the demanding terrain conditions and in comparison with the outcomes of other research, a relatively acceptable value. Damage to the underwood was not found, due to its insufficient height and low representation. Measurements of damage to the soil by its compression indicated that the heaviest damage was under the supporting bases, where a heavy surface damage was found by creation of holes up to 15 cm deep. This type of damage is not dangerous, because it does not create a continuous track dangerous in storm rainfall and subsequent soil erosion. Soil compression in the track and on unimpaired soil reached lower levels. All of the measurements of compression by static penetration were carried out only to the depth of 15 cm due to high soil skeleton. This also negatively affected the measurements, which had to be repeated in many cases.

damage to the soil, Kaiser S2 harvester, soil compression, static penetration

In mountainous regions of Slovakia there is a major problem – mass spruce forest decline. Spruce stands are most commonly initially damaged by abiotic and subsequently by biotic wood-destroying agents. The most important biotic agents are pests (e.g. bark beetle). Mainly the dead and relatively isolated clusters and groups of spruces with smaller area are ineffective and uneconomic to skid through the means of cableways. It seems to be advantageous to utilize tractor logging systems based on harvesters and forwarders or their combination with other technologies. Most harvesters are constructed on wheel undercarriage, which is unsuitable for use in mountain terrains. Tracked or walking machines are more suitable for such terrains. These are capable of overcoming large terrain irregularities, extreme obstacles or gullies. This is possible due to their special construction with vertically and horizontally swinging arms ended with wheels and stabilizing bases. They can overcome inclines higher than 100% and in comparison with other technologies these machines are notable for their low weight.

Every logging system leaves marks in the stand after the works. When choosing particular system the most important aspects to consider are environmental factors, because the pick of logging system has great impact on remaining stand and stand soil. Mainly damage to the remaining stand, such as scraped bark on root swellings and lower parts of trunk can cause infection by wood-decaying fungi and thus rotting of the wood, which lowers wood quality. In soil damage the main characteristic to look at is its compression, which lowers its capillary capacity, and subsequent threat of water erosion in tracks created by the machine, if the machine was utilized in inclined terrains.

The aim of this paper is to determine damage to the remaining stand and stand soil of a Kaiser S2 harvester at work in mountainous terrain.

MATERIAL AND METHODS

The measurements of stand soil damage and remaining stand were carried out in management-plan area Demänová in stand No. 819. This stand was damaged by a wind calamity and subsequently by insects. Species which was most damaged was spruce. Processing method of whole stem logging employed combined means of Kaiser S2 harvester and LKT 81T. The harvester (Fig. 1) processed the calamity and in unimpaired it carried out a secondary felling. The weight of the harvester was 9 980 kg, engine performance 116.9 kW, tires 600/50-22.5, harvester head WOODY 50 and reach of the hydraulic crane was 8.5 meters.

Sample plots

Sample plots for soil damage were established so that damage was visible and thus measurable. They were chosen to contain the track and stabilizing base of the machine. We established 4 sample plots of 20 × 20 m for investigating soil damage. The sample plot for investigating damage to the remaining stand was constituted of transect created along both sides of the skidding road within the reach (8.5 m) of the hydraulic crane (HC).

Taxation characteristics of stand No. 819 (Tab. I, II)

A two-daylight stand of north-east exposure. Average slope incline was 70%, age of the first etage was 105 years, the age of the second etage was 70 years, the soil was rocky at some places, at some places there were cliffs, terrain type 10.

Investigation of remaining stand and underwood damage

Damage to the trees and underwood was investigated after the harvester finished works in the stand. No measurements were carried out on the stand before the works took place. Ratio of damaged trees and size of the lesions was investigated (Meng, 1978), their position on the trunk, intensity (Butora-Schwager, 1989) and the number of damaged underwood trees.

Investigation of stand soil damage

We investigated soil damage according to McMahon method (1995). Its compression was investigated through static penetration. Static penetration is one of many practical methods for determining soil compression and soil regeneration examination in following years. The method is

1: *Harvester Kaiser S2 in operation*

I: *Taxation characteristics 1. etage*

Species	Representation	Height (m)	Diameter (cm)	Volume	Class	Stock m³ (1 ha)	Stock m³ (total)
Spruce	45	27	35	1.05	26	135	557
Fir	35	26	36	1.44	26	105	433
Beech	20	17	35	0.77	16	30	124

II: *Taxation characteristics 2. etage*

Species	Representation	Height (m)	Diameter (cm)	Volume	Class	Stock m³ (1 ha)	Stock m³ (total)
Spruce	50	18	27	0.41	24	173	1 072
Fir	30	15	25	0.34	20	73	454
Beech	20	18	28	0.48	24	68	423

based on correlation between physico-mechanical characteristics of soil and its penetration resistance. In our case a „06.15 Penetrologer Set" EIJKELKAMP equipment was used with a cone of 1 cm² and angle of 60° (Fig. 2). The device contains a ThetaProbe hygroscope, which records humidity in 6cm depth for individual measurements (Fig. 3), also used was a back stop, which lays horizontally on the soil and through it with an even speed the penetrometer is stuck into soil. Also used was a GPS antenna, depth sensor and an extension of the penetrometer rod.

The measurements were carried out on unimpaired soil (60 measurements), in the track (80 measurements) and where the supporting bases were placed (60 measurements). During the measurements the series, number of penetrations, the value of penetration resistance and humidity were recorded. All measured data were downloaded from the penetrometer to a PC through an Eijkelkamp PenetroViewer program.

We identified the direction of harvester's movement from a video recording, which served as a basis for the chronometric measurements. The harvester did not create visible tracks. Visible damage to the soil (Fig. 4) was noticed mainly where the supporting bases were deployed (Fig. 5). Besides soil compression their depth was also measured with 1 cm accuracy. The dimensions of the supporting bases were 80 × 60 × 20 cm.

2: *Measurement of soil compression*

3: *Measurement of humidity with ThetaProbe*

4: *The supporting base of the machine*

5: *The mark left by the supporting base*

RESULTS AND DISCUSSION

A. Damage to the remaining stand and underwood

The machine was moving on an existing skidding road during the secondary felling. The harvester produced 69 trees.ha^{-1} on average on both sides of the road. On the damaged trees we observed location of the lesion (Fig. 6, 7). Lesions were located on the root swellings, on the trunk ranging from 0.3 to 1 m and above 1 m (Tab. III). On these damaged trees we inspected the dimensions of the lesions according to Meng (1978). From the total number of trees after the logging took place, which was 226 pcs. ha^{-1}, was mechanically damaged 14 pcs.ha^{-1}, which is 6.19%.

6: *The most common location of damage on the trees*

7: *The most common location of damage on the trees*

On most of the trees (64.29%) the damage was minor (11–50 cm²). On five trees the damage was negligible (less than 10 cm²) 35.71%.

Most common was damage to the stump with root swelling and trunks above 1 m height (42.85%). Skinning of the trunk was caused by falling of the felled tree and in negligible rate by the hydraulic crane of the harvester.

Tree species most commonly harmed was spruce and fir. Regarding the intensity of the damage, most common type of damage was, according to classification, "wood exposed, unharmed". Within the reach of the HC was also natural underwood, mainly spruce and fir. Damage to underwood has not been found, mainly because of insufficient height and separate underwood presence.

III: *Review of mechanical damage intensity*

Stand no.			819
Stand age			105
Logging system			Harvester Kaiser S2
Average terrain incline			70 %
Mixture of tree species			Spruce, fir, beech
Month during which works took place			July
No. of trees	Before the logging	pcs.ha⁻¹	295
	Logged	pcs.ha⁻¹	69
		%	23.39
	Remaining	pcs.ha⁻¹	226
Location of lesion	Root	pcs.tr⁻¹	1/Spruce (7.15 %)
	Stump with root swelling	pcs.tr⁻¹	4/Fir, 2/Spruce (42.85 %)
	Trunk from 0,3 to 1m	pcs.tr⁻¹	1/Beech (7.15 %)
	Trunk more than 1m	pcs.tr⁻¹	2/Fir, 1/Beech, 3/Spruce (42.85 %)
Size of lesions	negligible (less than 10 cm²)		5 pcs (35.71 %)
	Very small (11 to 50 cm²)		9 pcs (64.29 %)
	small (51 to 100 cm²)		0
	Mid-sized (101 to 200 cm²)		0
	large (201 to 300 cm²)		0
	Very large (300 cm² and more)		0
Intensity of damage	1. upper layer of the bark damaged		2 pcs (14.28 %)
	2. bark compressed		0
	3. wood exposed, unharmed		11 pcs (78.57 %)
	4. wood exposed, lightly harmed		1 pcs (7.15 %)
	5. wood exposed, heavily harmed		0
Underwood	No. of trees damaged		0

The damage of remaining stand determined by us 6.19% is in comparison with other data 9% (Slugeň, 2007) and (Raab, 2002) lower. It is necessary to point out that the results of mentioned authors were processed from data acquired from greater number of stands and that the harvester was moving on skidding trails. In our case the movement was on the skidding road, which enabled an easier movement.

B. Damage to the stand soil

Increasing humidity is the reason of decreasing resistivity to compression of the soil. The more water the soil contains, the more the surface is usually softer, considering of course the soil type. Critical water content for upper soil horizons is between 39 to 49% and 24 to 48% for lower soil horizons (Raab, 2002).

On Fig. 8 the average humidity in the track, supporting base and on unimpaired soil is shown.

Data was processed with STATISTICA Release 6, in which we calculated and graphically illustrated average with 95% confidence interval. The graph depicts a slight increase of relative humidity near the track in comparison with humidity at the supporting base and in the stand. Relative humidities do not have a statistically significant difference. Average humidity in the stand untreated with logging was 23.55%, in the track 28.38% and at the supporting base 24.63% with a 95% confidence interval.

a) Damage to the stand soil by supporting bases of the machine

The stand soil was damaged in form of holes by the supporting bases of the machine during works of Kaiser S2 harvester. Average depth of the holes was 15.8 cm. The damage, regarding its intensity, was classified as moderately damaged, which is described by 8–15 cm depth of damage. It is necessary to point out, that this classification is elaborated for damage in the track, not for individual spots of damaged soil.

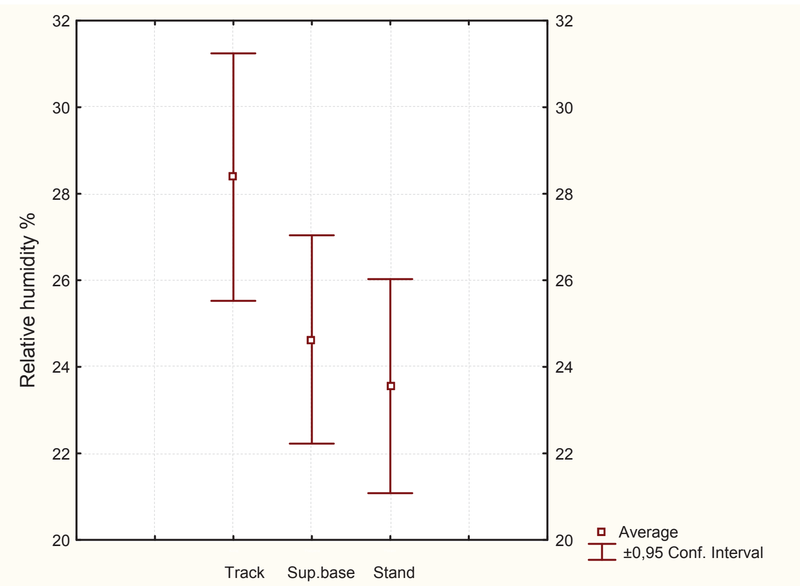
During data processing acquired by measuring the compression we took the penetration resistance in the 0–15 cm depth interval into account. Other measured data did not or just slightly exceed 15 cm. The reason for that was soil with very high skeleton. From the measured data arithmetic averages were worked out (Fig. 9).

On the graph we can see that the penetration resistance values have similar progress on particular series with greater or lesser differences. The biggest difference is at 15 cm depth (0.4 MPa). The progress of individual average values could have been affected by many factors, but mainly it was due to soil skeleton.

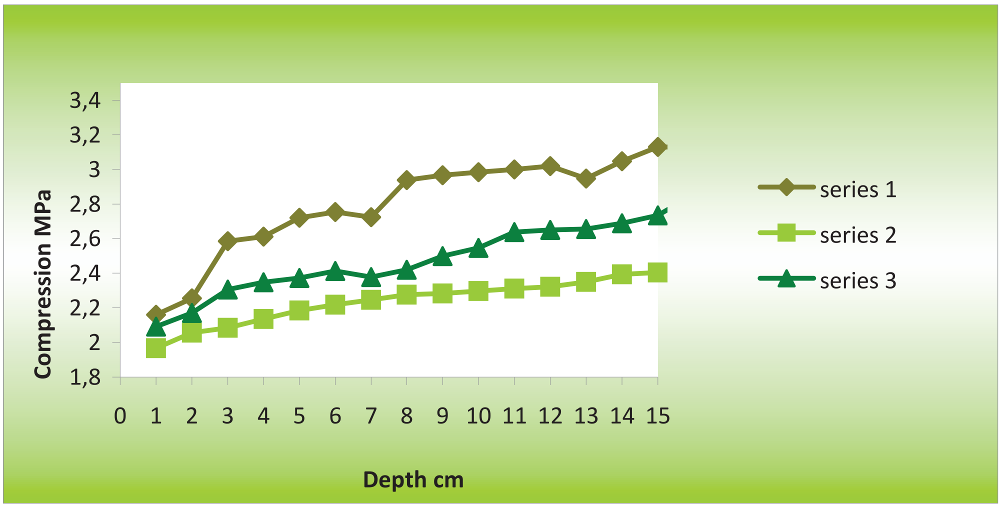
The dependence of soil resistance and depth of measurement along with humidity was subject of multi-variable regression and correlation analysis (Tab. IV), which confirmed the dependency of soil resistance on depth and humidity and is depicted red in the table. Depth has greater influence on the resistance than humidity. Depth and humidity affect the variability of the dependent variable by 14.48%. The higher the values are, the greater the resistance of soil. Mean strength of dependence was R = 0.38.

We constructed a 3D graph in Statistica program for determining the dependence of damage to the stand soil on said variables. The advantage of this graph is that it depicts the dependence of depth of the penetration, soil humidity and penetration resistance (Fig. 10).

On the 3D we can see that the outcomes have proven statistically significant influence of all of the values on the penetration resistance of the soil. The dependence is depicted by red colour. Increasing depth and humidity increases the penetration resistance.



8: *Average humidity observed during research*

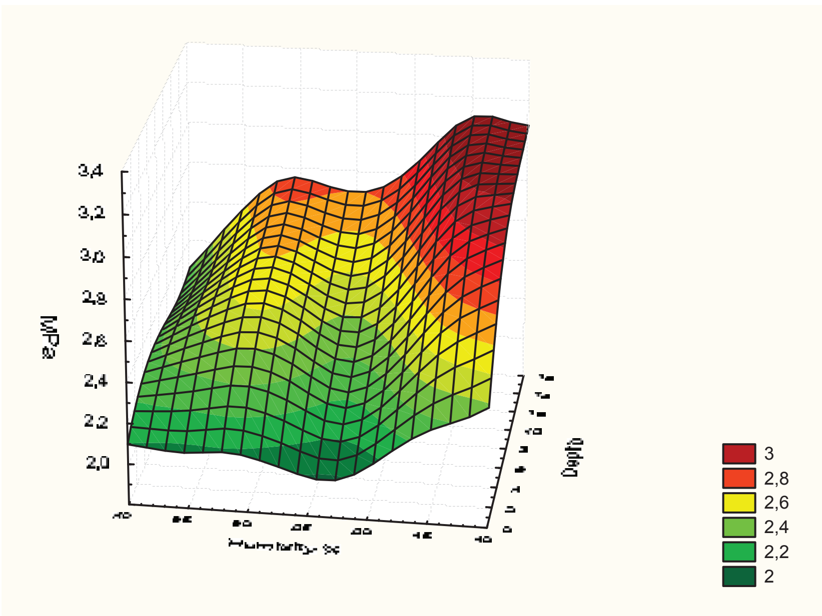


9: *Average values of penetration resistance at the supporting base*

IV: *Multi-variable regression and correlation analysis of penetration resistance at the supporting base*

Outcomes of regression with dependent variable: Resistance (Mpa)
R = 0.38425021 R2 = 0.14764823 Adjusted R2 = 0.14483053
F (2.605) = 52.400 p < 0.0000 Std. dev. of approximation: 0.54209

Independent variables N = 608	Beta	Std. dev. Beta	B	Std. dev. B	t (829)	p-level
Absolute term			2.583770	0.085888	30.083080	0.000000
Depth (cm)	0.332701	0.037535	0.042146	0.004769	8.837190	0.000000
Humidity (%)	–0.193966	0.037535	–0.015720	0.003042	–5.167670	0.000000



10: *Variance of penetration resistance at the supporting base on measurement depth and soil humidity*

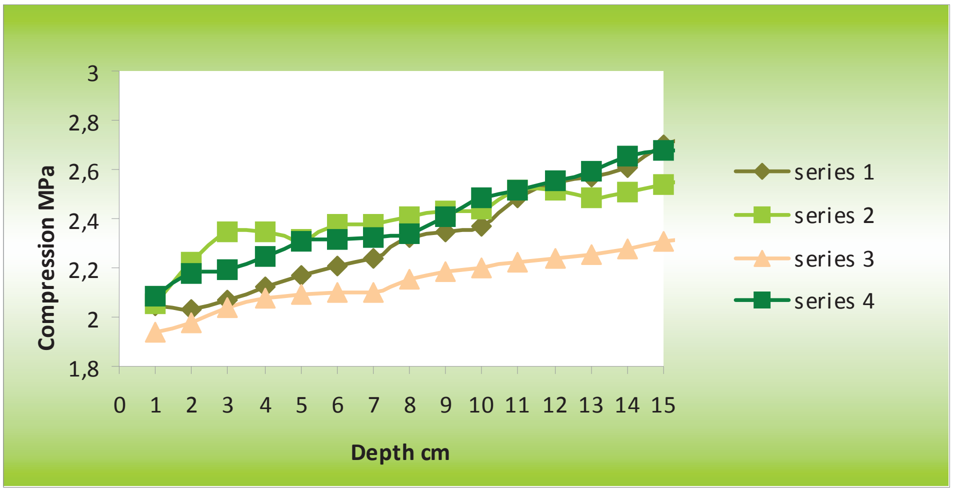
b) Damage to the stand soil by machine passage

As the machine did not leave visible tracks we determined only soil compression. Obtained data was subject to multi-variable regression and correlation analysis (Tab. V), which confirmed statistical significance of measurement depth and humidity on soil resistance. Measurement depth has the most significant influence on the soil resistance and is depicted with red colour in the table.

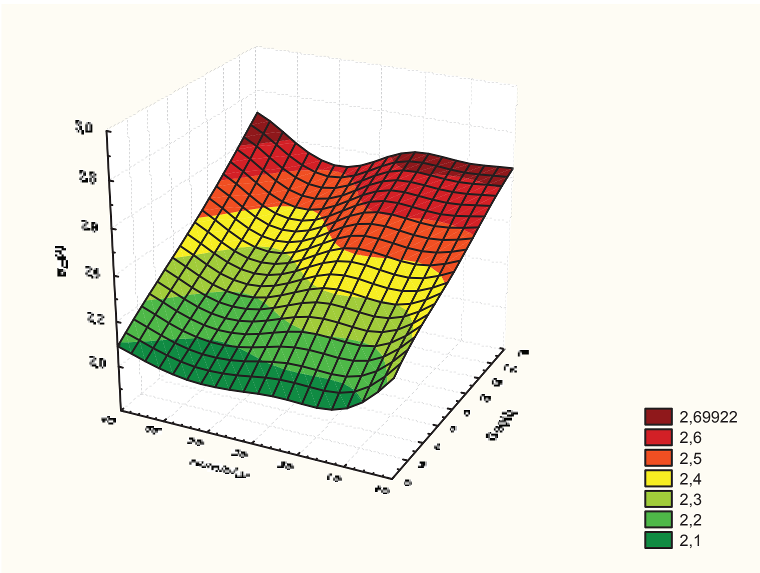
V: *Multi-variable regression and correlation analysis of soil penetration resistance at the track*

Outcomes of regression with dependent variable: Resistance (Mpa)
R = 0.34524952 R2 = 0.11919723 Adjusted R2 = 0.11707225
F (2.829) = 56.093 p < 0.0000 std. error of approximation: 0.42679

Independent variables N = 832	Beta	Mean error Beta	B	Mean error B	t (829)	p-level
Absolute term			2.119012	0.050020	42.363520	0.000000
Depth (cm)	0.342413	0.032596	0.033718	0.003210	10.504810	0.000000
Humidity (%)	–0.044166	0.032596	–0.001970	0.001454	–1.354950	0.175804



11: *Average values of penetration resistance at the track*



12: *Change of the penetration resistance in the track dependent on the depth and humidity*

On Fig. 11 we can see je that data from series 1, 2 and 4 of the penetration resistance has minimal differences. The third series has minimal difference compared with series 1 to about 5 cm depth of the penetration and the biggest difference is about 0.3 MPa is in 12 cm depth. Minimal value on the graph is 1.9 and maximum 2.7 MPa. With increasing depth of the penetration the resistance increases. In view of other authors (Slugeň, Ferenčík *et al.*, Kindernay, Dvořák) the penetration resistance should increase from 15 cm to about 30 cm depth. From this depth the values mostly decrease.

A 3D graph was created for determining the dependence of the penetration resistance (Fig. 12).

On Fig. 12 there is a statistically significant influence of all data on the penetration resistance.

13: *Steer angle of the wheel*

14: *Local damage to the soil*

The dependence is depicted by red colour. With increasing depth the penetration resistance increases.

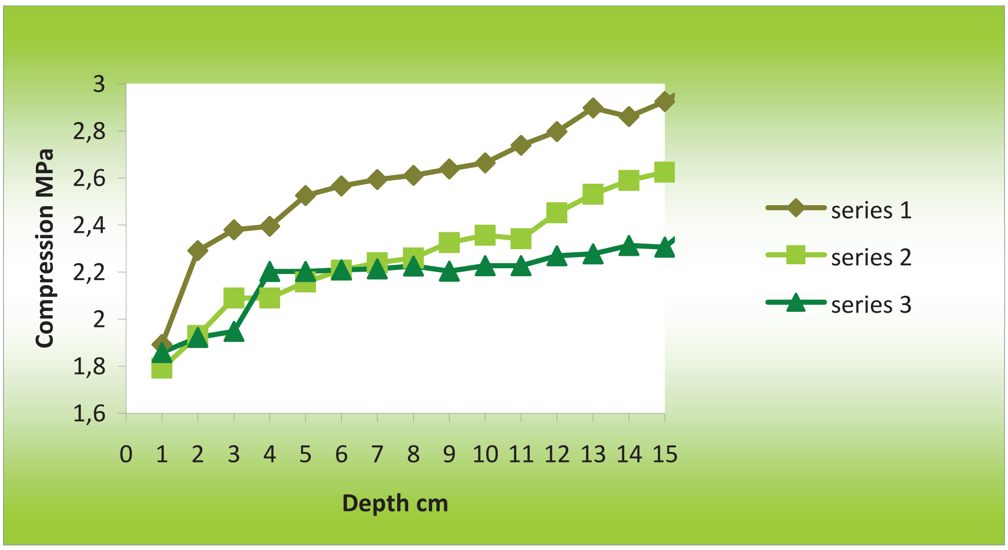
Kaiser S2 works caused local damage to the top level of the soil with the wheels equipped with antiskid chains. Because the wheels are mounted on vertically and horizontally swinging arms, they were in different angles while moving through the stand.

Fig. 13 depicts alignment of the wheels (the yellow arrow) against the machine axis. The movement of wheels turned towards the axis of the machine like this could be compared to movements of rotovators, which serve for soil preparation for forest regeneration. Fig. 14 and Fig. 13 (the red arrow) depicts local damage to the top level of the soil. The mark was not deep in all cases, thus we did not consider it to be damage. It reached depth of max. 5 cm. It is quite convenient as soil preparation for better seed germination from natural seeding.

VI: *Multi-variable regression and correlation analysis of resistance in the stand*

Outcomes of regression with the dependent variable: resistance (Mpa)
R = 0.36745406 R2 = 0.13502249 Adjusted R2 = 0.13200337
F (2.573) = 44.722 p < 0,00000 Std. error of approximation: 0.55029

Independent variables N=576	Beta	Std. dev. Beta	B	Std. dev. B	t (829)	p-level
Absolute term			2.034269	0.086813	23.432780	0.000000
Depth (cm)	**0.367450**	0.038853	0.047041	0.004974	9.457430	0.000000
Humidity (%)	0.001714	0.038853	0.000140	0.003182	0.044110	0.964829



15: *Graph of average values of penetration resistance in the stand*

c) Results of penetration resistance in the stand unimpaired by exploitation

For comparison we performed 3 series of measurements on places unimpaired by exploitation. As the previous data, measurements were 0 to 15 cm deep with 1 cm rate of grade. The dependence of penetration resistance was submitted to correlation and multi-variable analysis, where all values influence the dependent variable by 13.20% (Tab. VI). Mean strength of dependence was R = 0.38.

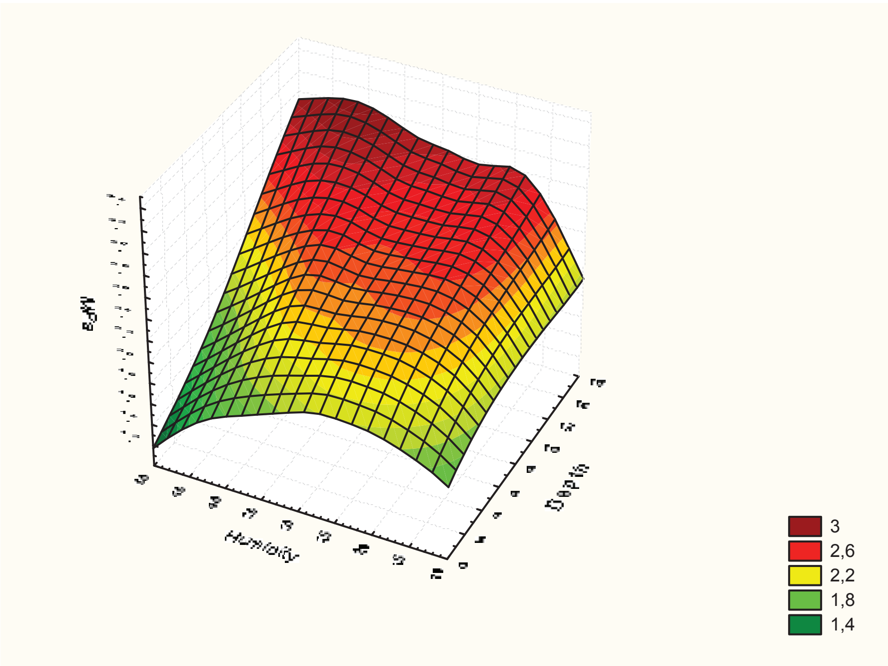
The progress of measured data can be seen on Fig. 15. The biggest difference is between first and third series of measurements. Lowest value is 1.8 MPa and highest is 2.9 MPa.

From the measured data we elaborated a 3D graph in Statistica program, which depicts dependence of penetration depth, soil humidity and penetration resistance (Fig. 16).

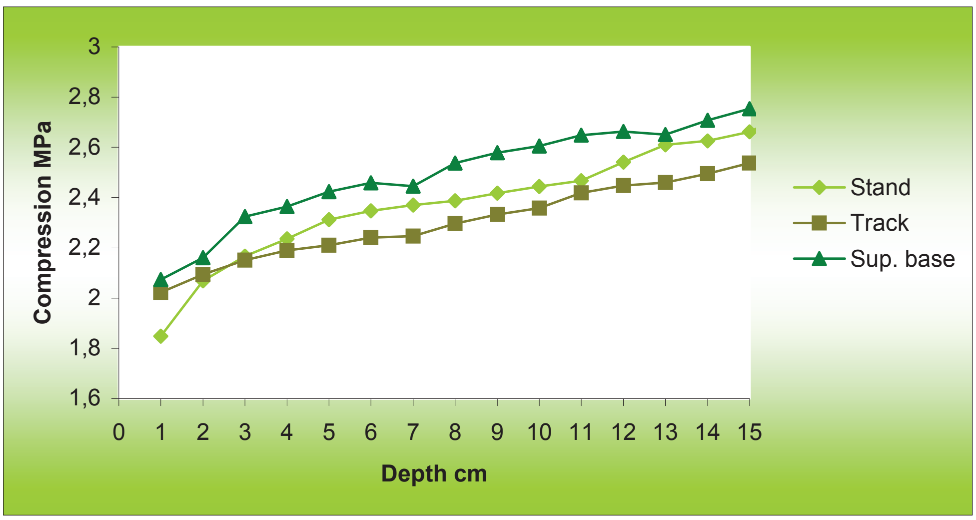
Comparison of stand soil damage measurements

From all measured data at the base, track and in the stand on unimpaired soil average values of penetration resistance were calculated (Fig. 17).

The difference of resistance values at the track and in the stand is minimal. Average resistance at the track was 2.31, at the base 2.51 and in the stand 2.39 MPa. For this evaluation the average penetration resistance at the track was, for depth 3 cm and more, lower than resistance in the unimpaired



16: *Change of penetration resistance of soil in the stand, dependent on the depth and humidity*



17: *Average values of penetration resistance in the stand, track and base* stand soil. This can be due to high soil skeleton and lower weight of the machine. Negligible track formation and low soil compression can be due to special movement and air inflated tires. The tires should not be filled with water because o better terrain adhesion. The highest average penetration resistance values were at the base and reached maximum of 2.8 MPa.

Compared to Slugeň's results (2007), we reached higher values of penetration resistance in the track and in the stand, the author performed measurements to 20 cm depth. His data shows stand soil compression in the 15 cm depth at 0.67 MPa, whereas we reached value of 2.6 MPa. At the track the author mentions 1.63 MPa penetration resistance, our measurements determined the resistance to be as high as 2.5 MPa in 15 cm depth. Compared with data from Ferenčík *et al.* (2008) our results are higher too. Mentioned author measured 25 cm depth and the compression in the stand ranges from 0.5 to 2.6 MPa, where in comparison our data shows values of 1.8 to 2.6 MPa. Compared with Dvořák (2008) our values of penetration resistance are higher. The measurements by said author were carried out to 52 cm depth in the stand and 40 cm in the track. Maximum value at the track was 3.4 MPa and 3.1 MPa in the stand. Kindernay (2010) also studied compression of soil. The measurements were 25 cm deep, for comparison we took data ranging from 0 to 15 cm depth into consideration. Our average values at the track are lower, in 7 cm depth they are about 2.2 MPa, which is 0.7 MPa lower compared to Kindernay's findings. In 15 cm depth the author mentions 3.0 MPa, which is 0.5 MPa more than our findings. The compression in the stand is 0.1 MPa lower in 7 cm depth and in 15 cm depth the difference is 0.1 MPa higher in our results. The highest increase of penetration resistance as the author found out was from 0 to 7 cm depth.

CONCLUSIONS

Utilization of any logging system should be applied in compliance with sustainable forest management with all production and nonproduction forest functions. As with every logging system, harvester system damages the stand, underwood and stand soil. Damage to the stand can lead to secondary damage, mainly fungi infestation and stand soil erosion. Many domestic and foreign researches were acknowledged that harvester system is less harmful than utilization of classic means (Ulrich, 2002; Dvořák, 2005). Therefore we should try to minimize damage to the remaining stand.

In the stand we studied the mechanical damage reached moderate levels. The most commonly damaged tree species were spruce and fir, mainly with skinned bark. Damage to the underwood was not determined, due to its insufficient height and sparse representation. Soil damage was created by mechanism passage and was negligible. Distinctive damage was detected only in places under the supporting bases of the mechanism. This type of damage was sparse and did not present danger because of possible water erosion.

For practise we would recommend to use different type of supporting bases, which the producer has in stock. The lower part of these supporting bases has four spikes, which in stabilization do not damage or cut the root system compared with the bases used, the circumference of which is equipped with a heavy steel frame. When using combined harvesters it is of utmost importance to have a skilled operator, who has to be most considerate to the stand and soil.

In conclusion we can say that the system, based on obtained data, damaged the stand soil, underwood and stand itself minimally. Therefore we can recommend it for use in mountain and classic terrains.

SUMMARY

Damage to forest stands in exploitation and haulage has negative impacts, mainly in premature stands, on the quality of the timber and loss of growth. The aim of this paper is to determine negative aspects of Kaiser S2 harverster utilization in mountainous terrain with average incline of 70%. This special type of harvester is equipped with a combined undercarriage, which enables it to work in difficult conditions. For additional stability it uses two supporting bases located in the rear of the machine. It worked on removal of a bark beetle calamity and simultaneously it performed a secondary felling. For determining the damage to the remaining stand and underwood a continual sample plot was established on which it moved. Its width was given by the reach of the hydraulic crane on both sides. Sample plots with 400 m^2 area were established for detecting damage to the stand soil. Sample plots of the same size were established on unimpaired soil. Tree damage of the remaining stand was determined by Meng's method (1978). Damage to the stand soil was determined through McMahon method (1995) and soil compression by static penetration method, utilizing a „06.15 Penetrologer Set" from EIJKELKAMP. All measured data was processed and evaluated statistically. Resulting damage to the remaining stand reached 6.19%, damage to the underwood was not determined. Damage to the stand soil in form of track creation by machine movement was negligible, occasionally resulting to top soil layer scraping when the machine was turning the wheels. Damage to the soil by its compression was strongest in the track, but due to high skeleton of the soil the static penetration measurements could be only 15cm deep. That is the reason why our measurements of soil compression are not entirely comparable to other authors, whose measurements were into greater depths. We can say

that due to higher skeleton, the soil bearing capacity is higher and compression is not the standard damage indicator. In greater inclines it is desirable to emphasize surface damage and thus rainfall erosion. Kaiser S2 harvester deployment in mountainous terrains we can, based on our data, rate as appropriate and justified.

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