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# Impact of skidder and high-lead system logging on forest soils and advanced regeneration

**M. MODRÝ, D. HUBENÝ**

*Mendel University of Agriculture and Forestry, Faculty of Forestry and Wood Technology, Brno, Czech Republic*

**ABSTRACT**: The applied skidding technology strongly influences the impact of harvest on the ecosystem and success of natural regeneration. The impact of skidder SLKT 81 and high-lead system Larix 3T on forest soil and natural regeneration was compared under analogical site and stand conditions in a production beech forest in the environs of Brno, Czech Republic. The skidder was found to have greater effects on the soil surface consistency, soil properties and natural regeneration than the high-lead system operations. Although high-lead system operations are more friendly to all parts of forest ecosystem, the skidder may not cause excessive damage when applied under suitable terrain and climatic conditions.

**Keywords**: high-lead system; skidder; forest soil; natural regeneration; disturbance; harvest technology

The harvest phase of forest management brings along major disturbances of forest ecosystems. In many cases these disturbances can retard future stand development and contribute to the instability of forest ecosystem. Disturbance of the soil surface, change in physical and chemical properties of soil, damage to natural regeneration and to remaining trees are the main impacts of logging including skidding operations in a forest stand.

The movement of heavy machinery and timber through forest stand causes disturbances of the soil surface, which can lead to increased vulnerability of soil to erosion. The erosion threat is increased in clear-felled stands where the protective function of forest cover is eliminated. The proportion of disturbed soil surface ranges from about 7% of stand area at high-lead system yarding (LAFFAN et al. 2001) to 23–39% of stand area with ground-based skidding (e.g. RAB 1994; WILLIAMSON 1990). Air-borne technologies (helicopter logging, fully suspended skyline system yarding), which are friendly to the soil surface, are extremely time-consuming and expensive and thus they are restricted to areas of exceptional nature value or inaccessible areas.

Changes related to harvest operations occur in both physical and chemical soil properties. Changes in soil bulk density, porosity and aeration are the most often studied (e.g. HERBAUTS et al. 1996; WOODWARD 1996) and well described ones. All studies generally report an increase in bulk density and a decrease in soil porosity. Changes in chemical properties are less known and the references are often contradictory (findings on the behavior of sorption complex differ between WOODWARD 1996 and HERBAUTS et al. 1996). Differences in findings are probably caused by differences in the sorption complex behavior among soil types.

Although changes in soil properties related to harvest activities have been studied frequently, the mechanisms of their influence on a forest ecosystem are still poorly known. The influence of nutrient and water regimes on the growth of seedlings was a subject of several controlled experiments (MADSEN 1995; MINOTTA, PINZAUTI 1996; MADSEN, LARSEN 1997) but it is difficult to interpret these results in the complex forest ecosystem behaviour; direct studies are missing. Some of the long known phenomena have only recently been attributed to harvest-related soil compaction (GAERTIG et al. 2002). The restoration of properties of compacted soils is a long lasting process; soils may require between 5 (DEMKO 1995) and 40 (SLIVKA 1990) years to recover.

In addition to disturbances and changes in soil properties, harvest brings about further negative impacts under natural regeneration systems. These impacts include direct damage to natural regeneration and injuries to remaining mature trees. Damage to natural regeneration was investigated in tropical forests (WOODWARD 1996; FREDERICKSEN, PARIONA 2002) but references from Europe are missing. Major disturbances of natural regeneration

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require expensive artificial regeneration often connected with site preparations necessary to eliminate the competition of weeds.

Injuries to remaining trees in natural regeneration systems are common and can also cause significant economic losses. DEJMAL (1988) reported very low chances of trees to survive until harvest without trunk injuries resulting from collisions with harvested timber. These injuries can decrease timber production directly or indirectly by opening the gateways for fungal infections. Financial losses resulting from fungal infections at logging scars on trees in spruce forest were estimated by SIMANOV and HRONÍČKOVÁ (1988). According to MENG (1978), the frequency of tree injuries depends mainly on the length of transported timber; the applied technology does not have any effect.

Appropriate selection of logging technology and the operations carried out under suitable climatic conditions are the key tasks for minimizing the impact of harvest on the forest ecosystem. The knowledge of processes taking place in the forest ecosystem during harvest is essential. Although changes in soil physical and chemical properties were subjects of numerous studies worldwide (e.g. RAB 1994; HERBAUTS et al. 1996; WOODWARD 1996; LAFFAN et al. 2001; GAERTIG et al. 2002, and others), a majority of these studies is related to ground-based operations and direct comparison of impacts of various technologies is missing.

This study was aimed to directly compare the impact of two common skidding technologies – high-lead system (Larix 3T) and conventional skidder (SLKT 81) on an ecosystem under analogical site and stand conditions. We examined disturbances of the soil surface, changes in soil physical and chemical properties and impacts of harvest on natural regeneration in the second phase of shelterwood regeneration system.

## METHODS

### Study site and plots

A study was conducted in the Forest Training Enterprise Masarykův les at Křtiny, north of Brno, Czech Republic (49°17´03´´N, 16°41´47´´E) in 120-years-old production beech (*Fagus sylvatica* L.) forest. Calcareous Cambisol was a prevailing soil type. Natural regeneration, which was the basis of future stand generation, was abundant in the stand. The terrain inclination was about 15°, facing east.

In the central part of the stand, 81 sampling plots were established in the regular matrix 30 × 30 m. Plots were circular with 2m diameter (area 3.14 $m^2$), making up the total sampling area of approx. 254 $m^2$. Four transects of random length (150–250 m) and direction were laid out to estimate the soil surface disturbance after harvest.

### Applied technologies

Harvest and skidding were carried out in winter 2001/2002, mostly on frozen ground and snow cover of about 20 cm. Whole-tree logging method with manual chainsaw felling and branching was applied. High-lead system yarding with Larix 3T was used in one part of the stand, ground-based skidder SLKT 81 in the other. With Larix 3T, timber was yarded uphill, semi-suspended. Four cableway draglines were used in the stand. With SLKT 81 timber was skidded downhill.

The slash was manually dragged to piles in the stand; cableway draglines were covered with slash to eliminate water erosion.

### Field and laboratory methods

The full inventory of natural regeneration was carried out on sampling plots before (September 2001) and after (April 2002) harvest and skidding operations. The number of living tree seedlings lower than 1.5 m was recorded in the autumn inventory. The number of living seedlings lower than 1.5 m, number of slightly damaged and number of heavily damaged seedlings were recorded in the second inventory. Seedlings were recorded as slightly damaged when bark was scratched on less than the half-diameter of the stem or when the lateral axis was broken. Seedlings were recorded as seriously damaged when bark was scratched on more than a half of the stem diameter or the central axis was broken.

Soil surface disturbance was recorded after the harvest on 4 random transects over 1 m distance. Four classes of soil surface disturbance were recognized: 0 – without obvious impact of harvest; 1 – visual marks of harvest activity, without disturbance of soil surface consistency; 2 – broken consistency of humus horizon; 3 – broken consistency of mineral horizon. In total, 992 points were investigated, 526 on the high-lead system yarded part of the stand and 466 on the skidder part of the stand.

Before harvest, the soil was sampled at 6 locations at the depth of 2, 12 and 25 cm for physical and chemical properties. To assess the changes co-occurring with soil disturbance, the soil was re-sampled after harvest at 4 locations for each surface disturbance class.

Soil samples were analyzed for basic physical and chemical properties. Soil particle density was determined by Guy-Lussac pycnometers. Samples of standard volume (100 $cm^3$) collected by calibrated core samplers were oven-dried and weighed to determine bulk density (dry weight/volume). Porosity was calculated from bulk and particle density (porosity = 100 – bulk/particle density × 100). Soil moisture content was determined by gravimetry (soil moisture = (fresh weight – dry weight)/dry weight). Particle-size analysis was performed by pipette method. De-ionized water/0.05 mol/l $CaCl_2$ (25 ml) was added to a sieved air-dried samples (10 g), shaken, left overnight and pH was measured at room temperature. Cation exchange capacity and base saturation in calcareous soils were determined by extraction methods of 1 mol/l $BaCl_2$ (GILLMAN 1979).

Table 1. Densities of seedlings (mean ± S.E.) in the high-lead system and skidder parts of forest stand. Different letters show significant differences between means (ANOVA, $P \leq 0.05$)

| | High-lead system | Skidder |
|---|---|---|
| Density before harvest | 17.3 ± 1.1$^{b}$ | 11.1 ± 1.4$^{a}$ |
| Density after harvest | 13.1 ± 1.1$^{b}$ | 8.3 ± 1.5$^{a}$ |
| Density of slightly damaged seedlings | 0.1 ± 0.1$^{a}$ | 0.3 ± 0.1$^{b}$ |
| Density of seriously damaged seedlings | 0.3 ± 0.2$^{a}$ | 0.7 ± 0.2$^{b}$ |

### Data analysis

One-way ANOVA (significance test criterion $P \leq 0.05$) was used to compare means. Since the soil properties of particular horizons differed significantly within each disturbance class, all analyses had to be undertaken separately for each horizon. Linear regression (significance test criterion $P \leq 0.05$) was used to examine a relation between the total number of seedlings on plot and that of missing or damaged ones. To estimate the processes taking place in the soil with disturbed surface, ANOVA model examining the effect of horizon and disturbance class as factors and interaction between horizon and disturbance class was used. All data analyses were computed with SYSTAT 10.0.

## RESULTS

### Disturbance of natural regeneration

The density of natural regeneration prior to harvest was significantly higher in the part logged by high-lead system than in the part logged by skidder (17.3 and 11.1 ind./m$^2$ in high-lead system and skidder terrain, respectively); a similar relation was retained also after harvest (13.1 and 8.3 ind./m$^2$ in high-lead system and skidder terrain, respectively). The difference between autumn and spring seedling densities was not significant; and the proportion of missing seedlings was not significantly different between high-lead system and skidder terrain (Table 1).

The number and proportion of damaged seedlings was higher in skidder than in high-lead system part of the stand for both slightly and seriously damaged seedlings (Table 1). The number of slightly and seriously damaged seedlings was independent of the seedling density before harvest (linear regression).

### Disturbance of soil surface

In the high-lead system part of the stand, 60% of soil surface was without visible disturbance (disturbance class 0) compared to 38% in the skidder part. 28% of surface of the high-lead system part of the stand and 33% of the skidder part belonged to disturbance class 1. The largest differences were found in the proportion of soil with disturbed humus horizon (disturbance class 2–9% in the high-lead system part, 27% in the skidder part). The disturbance class 3 occupied 2% of soil surface in both high-lead system and skidder parts of the stand (Fig. 1). The terrain with broken soil surface consistency (disturbance classes 2 and 3) occupied 12% in high-lead system and 29% in skidder part of the stand.

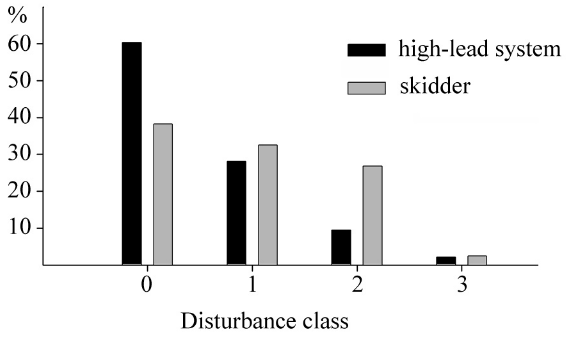

Fig. 1. Proportion of soil surface disturbance classes in the high-lead system and skidder parts of forest stand

Table 2. Basic soil physical and chemical properties in September 2001 and April 2002 (disturbance class 0). Different letters show significantly different means (ANOVA, $P \leq 0.05$)

| | September 2001 | | | April 2002 | | |
|---|---|---|---|---|---|---|
| Horizon | Ahck | Bck1 | Bck2 | Ahck | Bck1 | Bck2 |
| Sampling depth (cm) | 2 | 12 | 25 | 2 | 12 | 25 |
| Particle density (g/cm$^3$) | 2.1 ± 0.07$^{a}$ | 2.6 ± 0.07$^{a}$ | 2.7 ± 0.07$^{b}$ | 2.2 ± 0.08$^{b}$ | 2.6 ± 0.08$^{b}$ | 2.7 ± 0.08$^{b}$ |
| Soil moisture by weight (%) | 35.6 ± 1.82$^{b}$ | 24.0 ± 1.82$^{a}$ | 21.2 ± 1.82$^{a}$ | 19.2 ± 2.23$^{a}$ | 21.9 ± 2.23$^{a}$ | 22.4 ± 2.23$^{a}$ |
| Potential reaction (pH/CaCl$_2$) | 3.5 ± 0.27 | 3.3 ± 0.27 | 3.3 ± 0.27 | 3.6 ± 0.33 | 3.5 ± 0.33 | 4.4 ± 0.33 |
| Cation exchange capacity (mmol/100 g) | 72.1 ± 4.50 | 61.7 ± 4.50 | 58.0 ± 4.50 | 76.1 ± 5.51 | 71.7 ± 5.51 | 59.6 ± 5.51 |
| Base saturation (%) | 8.6 ± 4.36 | 7.4 ± 4.36 | 12.8 ± 4.36 | 24.9 ± 5.34 | 23.2 ± 5.34 | 29.5 ± 5.34 |

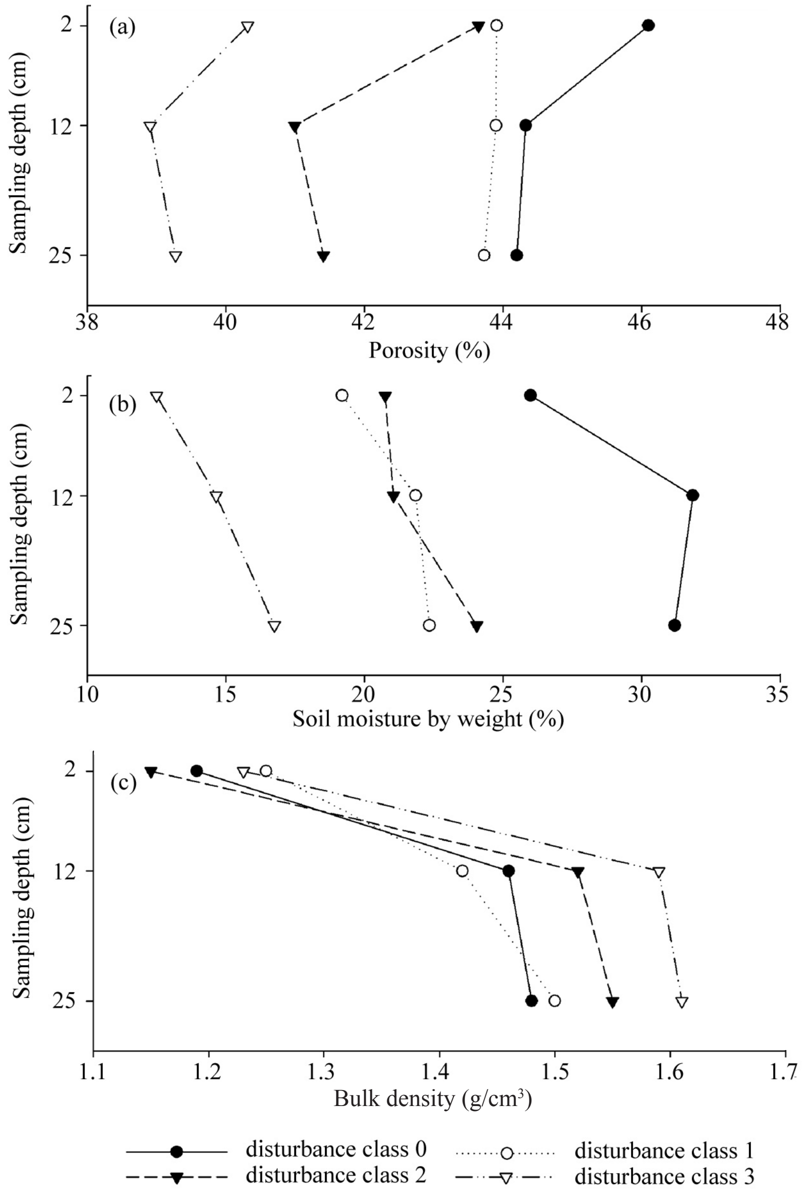

Fig. 2. Changes in soil physical properties with depth: (a) porosity, (b) soil moisture by weight, (c) bulk density

**Changes in soil physical and chemical properties**

There were only slight differences in soil physical and chemical properties recorded between autumn and spring samplings of soils without visible surface disturbance (Table 2). Significant differences were found in the moisture content of the uppermost horizon only (36% and 19% in autumn and spring sampling, respectively).

Within the spring sampling, a significant effect of soil surface disturbance class was found on bulk density, porosity, moisture content, potential reaction and base saturation. The interaction horizon × disturbance class had a significant effect on cation exchange capacity only. The porosity was highest in the uppermost horizon of disturbance class 1 and then decreased with increasing disturbance class from 46% to 40% in the

Table 3. Overview of ANOVA model taking into account horizon, disturbance class and interaction between horizon and disturbance class. Significance of the values (*P*) of each factor and interaction and $R^2$ of the model are shown

| Soil characteristic | Significance (*P*) | | | $R^2$ |
|---|---|---|---|---|
| | Horizon | Disturbance class | Horizon * Distubance class | |
| Bulk density | 0.000 | 0.016 | 0.181 | 0.76 |
| Porosity | 0.666 | 0.005 | 0.538 | 0.37 |
| Soil moisture | 0.032 | 0.000 | 0.911 | 0.71 |
| pH ($CaCl_2$) | 0.029 | 0.001 | 0.911 | 0.41 |
| Cation exchange capacity | 0.000 | 0.135 | 0.034 | 0.69 |
| Base saturation | 0.133 | 0.000 | 0.752 | 0.49 |

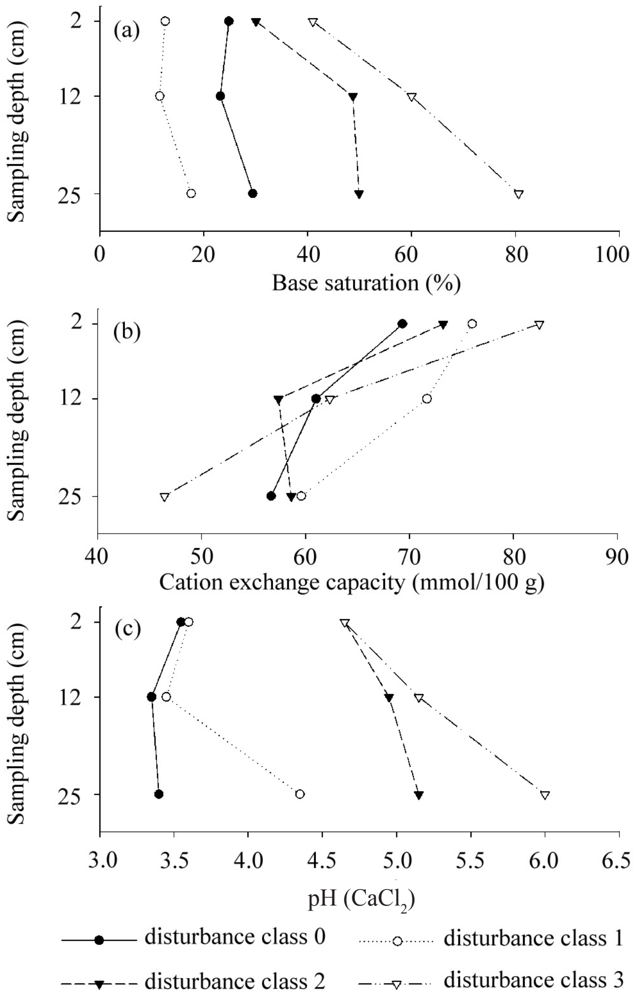

Fig. 3. Changes in soil chemical properties with depth: (a) base saturation, (b) cation exchange capacity, (c) pH (CaCl$_2$)

uppermost horizon, from 44% to 39% in the middle horizon and from 43% to 39% in the lowest horizon (Fig. 2a). Moisture content decreased with increasing disturbance class, it was highest in disturbance class 1 (Fig. 2b). Bulk density of soil samples increased significantly with disturbance class (Fig. 2c) and with sampling depth (from 1.2 g/cm$^3$ to 1.6 g/cm$^3$ for the uppermost and lowermost horizon, respectively). Base saturation increased with increasing disturbance class (Fig. 3a) as well as potential reaction (pH/CaCl$_2$) (Fig. 3c). The results of ANOVA model examining the effects of horizon and disturbance class on soil properties after harvest are overviewed in Table 3.

There were no significant differences in particle size classes partitioning among the horizons and thus the means of the whole profile could be compared to assess the effect of disturbance class. The proportion of fine material (clay and silt) decreased with increasing disturbance class while the proportion of fine and coarse sand increased with increasing disturbance class (Fig. 4); only the changes in clay and fine sand were found significant (ANOVA, $P \leq 0.05$).

## DISCUSSION

### Disturbance to natural regeneration

The density of living seedlings decreased significantly in both the high-lead system and skidder part of forest stand (average difference about 3.7 ind./m$^2$). This decrease can be ascribed to damage during harvest operations, dieback during relatively harsh winter or deer browsing.

The density of damaged seedlings is significantly higher in the skidder part of the stand than in high-lead system part for both slightly and seriously damaged seedlings. This trend can be ascribed to the movement of skidder in the forest stand. Although the snow cover played a positive role in decreasing the impact of harvest on the forest ecosystem, it could not eliminate the impact of skidder traffic. On the other hand, it is necessary to state that the decrease in seedling density (0.73 ind./m$^2$ slightly and 0.32 ind./m$^2$ seriously damaged) is negligible compared to the remaining seedling density (8.3 ind./m$^2$) which is still about 8 times higher than the recommended afforestation standards. The high-lead system yarding is significantly

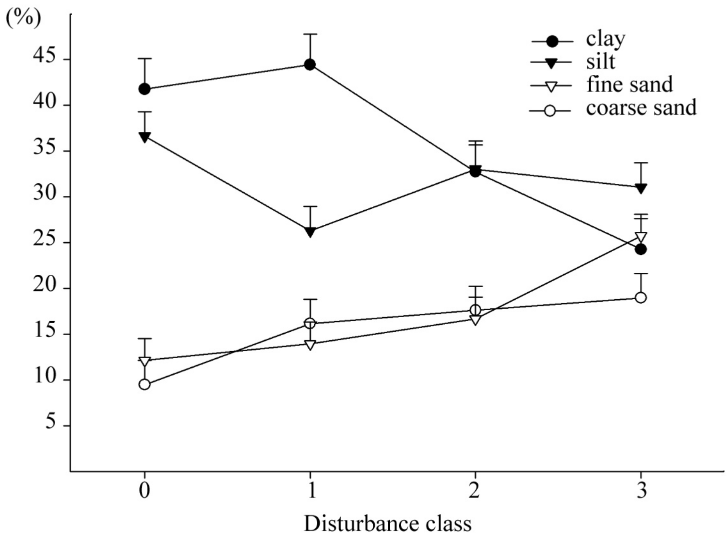

Fig. 4. Changes in partitioning of particle size classes with soil disturbance classes

more friendly to natural regeneration, mainly because damage is caused by harvested timber only.

### Disturbance of soil surface

Trends of soil surface disturbance are similar to those of natural regeneration disturbance. An assumption that the high-lead system yarding has lower impacts on the soil surface than the skidder was confirmed. The 12% proportion of soils with broken surface consistency corresponds to a study of LAFFAN et al. (2001) from Tasmania, where the proportion was 7%. The difference can be ascribed to fragile shallow limestone-based soils at the Brno study site. Disturbance class 3 accounts for 2% only compared to 3% in the above-mentioned Tasmanian study; in both cases it is restricted to the draglines. The proportion of soil with broken surface consistency (disturbance classes 2 and 3) in the skidder terrain made up to 29% and corresponds to data published elsewhere (WILLIAMSON 1990 – 23–39%; RAB 1994 – 25%).

MADSEN (1995) reported about 10 times higher densities of undamaged beechnuts and sprouting seedlings in mineral soil seedbed than in mixed soil seedbed suggesting higher suitability of mineral soil for seedling establishment. On the other hand, soils with broken consistency of mineral horizons (disturbance class 3) are extremely prone to erosion in the experimental stand conditions (long slopes, limestone-based soils). The erosion threat is highest in high-lead system draglines, which are straight and perpendicular to contours. Because of that, high-lead system draglines require post-harvest treatment. Draglines in experimental stands were covered with slash, which seems to be appropriate to slow down and disintegrate the water runoff.

### Changes in soil physical and chemical properties

No major changes occurred in the properties of undisturbed soils sampled before and after harvest. Only the moisture content in the uppermost horizon was significantly higher before harvest than after harvest, probably as a result of actual climatic conditions. Since the soils of disturbance class 0 were selected, very likely no activity occurred directly at the sampling place and significant changes could not be expected.

Changes in properties related to harvest activity were revealed by differences in properties between soil disturbance classes. A significant effect of disturbance class on several characteristics was found. Significant decrease in porosity and increase in bulk density correspond to the results of WOODWARD (1996) and HERBAUTS et al. (1996). The effect is highest in the top 10 cm in all cases. The increase in potential reaction corresponds with data of HERBAUTS et al. (1996); WOODWARD (1996) did not found any significant differences in pH before and after harvest. References to changes in the sorption complex properties with harvest activity are contradictory, probably because of various soil types investigated. While the increase in CEC corresponds to WOODWARD (1996), it is contradictory to HERBAUTS et al. (1996).

The consequences of changes in soil properties are long-lasting and far-reaching. Several studies reflected the importance of soil water and nutrient regimes for the growth of seedlings (e.g. MINOTTA, PINZAUTI 1996; MADSEN, LARSEN 1997). GAERTIG et al. (2002) directly related lower aeration of compacted soils with oak decline in south-western Germany. The regeneration of soil properties depends on the rate of compaction, soil type, vegetation cover and activity of soil micro- and macrofauna; published data vary strongly among the authors. While DEMKO (1995) reported approximate restoration of soil bulk density in 5 years, SLIVKA (1990) reported an about 40-years long process necessary to restore soil properties.

The extent of soil disturbances was probably strongly influenced by almost ideal climatic conditions during harvest. Heavy frosts (up to –20°C) together with the long-lasting snow cover helped to minimize the impact of harvest operations on soil.

## CONCLUSION

The study confirmed that high-lead system yarding is more friendly to all parts of forest ecosystem than ground-based operations. However, the erosion threat resulting from dragging semi-suspended loads is high and draglines have to be treated responsibly. Although the impact of ground-based technology on soil surface and natural regeneration is higher than that of high-lead system, the results showed that ground-based operations conducted under suitable conditions do not necessarily bring about large disturbances of forest ecosystem and do not threat the success of natural regeneration systems.

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## Vliv přibližování traktorem a lanovkou na lesní půdu a přirozenou obnovu

**M. Modrý, D. Hubený**

*Mendelova zemědělská a lesnická univerzita, Lesnická a dřevařská fakulta, Brno, Česká republika*

**ABSTRAKT**: Aplikované těžební a dopravní technologie významně ovlivňují dopad těžby na lesní ekosystém a přirozenou obnovu. Lesní kolový traktor SLKT 81 a lanovky Larix 3T byly srovnány z hlediska dopadu na lesní půdu a přirozenou obnovu v analogických porostních a stanovištních podmínkách v bukovém porostu v okolí Brna (Česká republika). Traktor měl vyšší dopad na soudržnost půdního povrchu, půdní vlastnosti i na přirozenou obnovu. Ačkoliv lanovky jsou k lesnímu ekosystému výrazně šetrnější, ani přibližování traktorem nemusí způsobit nadměrné škody, pokud je realizováno ve vhodných porostních a klimatických podmínkách.

**Klíčová slova**: lanovka; traktor; lesní půda; přirozená obnova; poškození; těžební technologie

Těžba a přibližování dříví s sebou přinášejí nejzávažnější narušení lesních ekosystémů. Pohyb dříví a těžební techniky způsobuje narušení soudržnosti povrchu půdy, změnu fyzikálních a chemických vlastností půdy, poškození přirozené obnovy a v neposlední řadě poškození stromů hlavního porostu v předmýtních a mýtních těžbách. Negativní vlivy těžby a přibližování dříví lze výrazně omezit výběrem vhodné technologie a klimatických podmínek v době těžby.

Narušení soudržnosti povrchu půdy je jedním z nejčastějších poškození ekosystému, vznikajících během přibližování dříví. Podle přibližovací technologie se rozsah pohybuje přibližně od 7 % plochy porostu u lanovkového přibližování (LAFFAN et al. 2001) do 23–39 % plochy porostu u traktorového přibližování (RAB 1994; WILLIAMSON 1990). Těžba a přibližování má prokázaný vliv také na fyzikální a chemické vlastnosti půdy (HERBAUTS et al. 1996; WOODWARD 1996). Obecně se těžba projevuje zvýšením objemové hmotnosti a snížením pórovitosti půdy, údaje o změnách chemických vlastností se mezi jednotlivými autory liší.

Poškození přirozené obnovy je častým průvodním jevem těžeb v přirozeně obnovovaných porostech a přináší s sebou především ekonomické ztráty v důsledku nezbytného doplňování, popřípadě úplné umělé obnovy porostu. Poškození stromů hlavního porostu má za následek jednak přímé snížení přírůstu, jednak sekundární ztráty na produkci způsobené znehodnocením dříví dřevokaznými houbami. Škody vznikající během obmýtí ve smrkovém porostu odhadli SIMANOV a HRONÍČKOVÁ (1988).

Studie je zaměřena na přímé porovnání dopadu dvou technologií – speciálního lesního kolového traktoru SLKT 81 a lanového dopravního zařízení Larix 3T – na lesní ekosystém, konkrétně na rozsah a závažnost narušení půdního povrchu, změnu fyzikálních a chemických vlastností půdy a poškození přirozené obnovy.

Práce byla realizována ve 120letém bukovém porostu na ŠLP Masarykův les Křtiny v období září 2001 až duben 2002. Dominantním půdním typem byla kambizem dystrická, přirozená obnova byla v porostu velmi hojná. Základem pro posouzení dopadu na přirozenou obnovu byla síť 81 pokusných plošek; každá měla plochu 3,14 m$^2$. Narušení povrchu půdy bylo sledováno na čtyřech náhodně zvolených transektech o délce 150–250 m. Fyzikální a chemické vlastnosti půdy byly analyzovány před těžbou ze šesti sond a po těžbě ze čtyř sond pro každý stupeň narušení půdního povrchu. Před těžbou a po ní byla provedena inventarizace přirozené obnovy. Na podzim 2001 byl určen počet všech živých semenáčků stromů nižších než 1,5 m. Na jaře 2002 byla inventarizace zopakována, přičemž byl zaznamenán také počet lehce a těžce poškozených semenáčků.

Hustota přirozené obnovy před těžbou byla vyšší v části přibližované lanovkou než v části přibližované traktorem; podobný poměr zůstal zachován i po těžbě. Rozdíl mezi jarními a podzimními počty se mezi technologiemi významně nelišil. Počet a podíl poškozených semenáčků byl významně vyšší v části těžené traktorem a byl nezávislý na hustotě semenáčků před těžbou (tab. 1).

Vlastnosti půdy se téměř nelišily mezi jarním a podzimním vzorkováním půdy bez narušení povrchu. Statisticky významný rozdíl byl pouze u vlhkosti půdy, která byla pravděpodobně ovlivněna momentálními klimatickými podmínkami (tab. 2). V rámci jarního vzorkování byl zjištěn statisticky významný vliv stupně narušení půdního povrchu na objemovou hmotnost, pórovitost, vlhkost, potenciální reakci a nasycenost bázemi. Pórovitost a vlhkost se stupněm narušení půdního povrchu klesala, objemová hmotnost stoupala. Podíl jemného materiálu (jíl a prach) klesal s rostoucím stupněm narušení půdního povrchu, podíl písku a štěrku naopak stoupal. Tyto trendy byly statisticky významné pouze u jílu a písku.

Potvrdil se předpoklad vyššího dopadu přibližování traktorem na půdu i přirozenou obnovu. Podíl zničených a poškozených semenáčků však byl stále poměrně nízký a zbývajících přibližně 8 zdravých semenáčků na m$^2$ je stále několikanásobně vyšší než doporučované zalesňovací počty. Rozsah poškození půdního povrchu odpovídal podobným studiím (LAFFAN et al. 2001; WILLIAMSON 1990; RAB 1994). Nebezpečnými z hlediska eroze jsou především lanové dráhy lanových dopravních zařízení. Ty byly v tomto případě překryty vrstvou klestu, což se zdá být dostačujícím opatřením ke zpomalení a rozptýlení povrchového odtoku vody. Změny půdních vlastností odpovídají obecným trendům v dalších studiích (HERBAUTS et al. 1996; WOODWARD 1996).

Rozsah poškození půdního povrchu a přirozené obnovy stejně jako změn půdních vlastností byl pravděpodobně ovlivněn téměř ideálními podmínkami pro těžbu (mráz, trvalá sněhová pokrývka). Ukázalo se, že za takových podmínek je aplikace kolových traktorů dostatečně šetrná a nemusí nezbytně znamenat nadměrné škody na lesním ekosystému.

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*Corresponding author:*

Ing. MARTIN MODRÝ, Ph.D., Sněhurčina 692, 460 15 Liberec 15, Česká republika
tel.: + 420 485 164 389, fax: + 420 485 226 321, e-mail: martin.modry@volny.cz