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THE IMPACT OF DIFFERENT CARRIAGES ON SOIL AND ROOTS – WHEELS AND TRACKS IN COMPARISON

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Abstract: *Comprehensive field studies revealed distinct differences in soil structural changes and root damages by quality and extent, depending from traffic of wheeled or tracked machines. Surveys were done on skid trails from different sites in flat and sloped terrain. Beside midsized harvesters and forwarders alternatively equipped with tracks on bogies, tracked harvesters were subject of the studies. Soil structural alterations were investigated by means of conventional soil physical methods and computed tomography. Registration and description of root damages were done using a new damage classification system (DCS).*
In general wheeled machines cause greater soil structural changes than tracked ones. Obviously, tracks are more soil gentle, especially on slopes. Bogie-tracks are more soil protective on slopes than on flat terrain, although their "compaction" level is somewhat lower than for wheels alone. Concerning damages to main roots, wheeled machines mainly cause bark peeling while tracked ones and tracks on bogies severely affect the wooden body by cracking, splintering and breakage. Beside this, size and intensity of root damages are also correlated with carriage types. Polyurethane tracks as substitutes for steel tracks reveal results comparable to those of wheeled machines.
Recommendations for the use of wheeled and tracked vehicles are given according to slope and stand conditions.

1. Machines, soils and stands

Wheeled and tracked harvesters of different size as well as forwarders were in the focus of investigations. In dependence of their total weight and constructive concept, axle loads as well as wheel loads are varying in a wide range. Wheel loads and tire parameters cause a specific contact area pressure (CAP). In interaction with soil moisture it is the steering value for structural deterioration of soils. Despite the fact that it is a static value and dynamic forces can reach a three fold higher magnitude, it serves as bases for comparisons among machines. Our field studies covered representative soils and spruce stands of southern Bavaria. Their economic importance as well as their extension and their susceptibility to root and butt rots outline the imperative of the studies. Some data about soils and stands (table 1) and technical data of involved machines are given below (table 2). One noticeable fact is that on forest soils (usually soft top layers) bogie-tracks, mounted on the load axle, increase the contact area substantially and consequently lower the CAP. The relevant maximum moves to the other axle at lower values. Therefore their use is a matter of soil protection.

Table 1: Soils and stands. Texture, Atterberg limits and soil moisture for the trials. Age and extracted masses for the spruce stands investigated

stand	soil				stand	
	texture	plasticity limit (m %)	liquid limit (m %)	soil moisture (m %)	age	extracted mass (cbm/ha)
1	Loamy Sand	17	26	22	55	112
2	Clayey loam	24	63	25	60	96
3	Silty loam	17	27	19	65	110

Table 2: Machine characteristics

stand	machine	carriage	weight (kg)	contact area pressure relevant maximum (kPa)
1	JD (Timberjack) 1270 B	6 wheels	16500	225
1	Königstiger 1650 T	steel tracks	28000	101
2	MHT 9002 HV	steel tracks	11000	83
2	MHT 9002 HV	Felastec tracks	10200	59
1	Rottne Rapid G	8 wheels	21900	289
3	Dasser TRS 10.8	8 wheels	25500	345
3	Dasser TRS 10.8	8 w. + 2 bogie tracks	27000	219

Technical data for harvesters and forwarders involved. Contact area pressure was calculated for specific axle loads and tires using "Pro For".

2. Methods and Results

2.1 Soil structural changes

All of the strip roads are part of new openings in regular thinning. The average width is 3,6 m to 4,0 m for the heavy tracked harvester. Strips are represented by five testing plots (fig.1) for soil investigations. Results concerning soil structural changes are based on the analysis of 100 ccm soil cores and soil structural analyses of 850 ccm samples by means of X-ray computed tomography (CT).

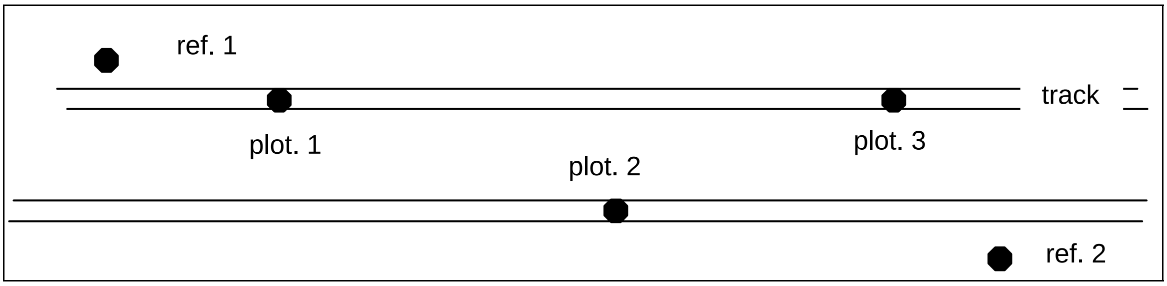

Figure 1: Experimental layout for soil physical investigations. ref. x = testing plot in undisturbed soil; plot. y = testing plot in the track

Bulk density increases up to 34 % (fig. 2) correlated with reductions of the total pore volume up to 28 % after wheeled traffic are in consistency with literature data (Froehlich & McNabb, 1983; Hildebrand & Wiebel, 1982; Kremer 1998; Matthies et. al., 1995). Tracks can reduce compaction twice to three times depending from the slope while tracks on bogies can cause reductions up to 30 % (similar findings: Denninger, 1998; Jansson & Johansson, 1998).

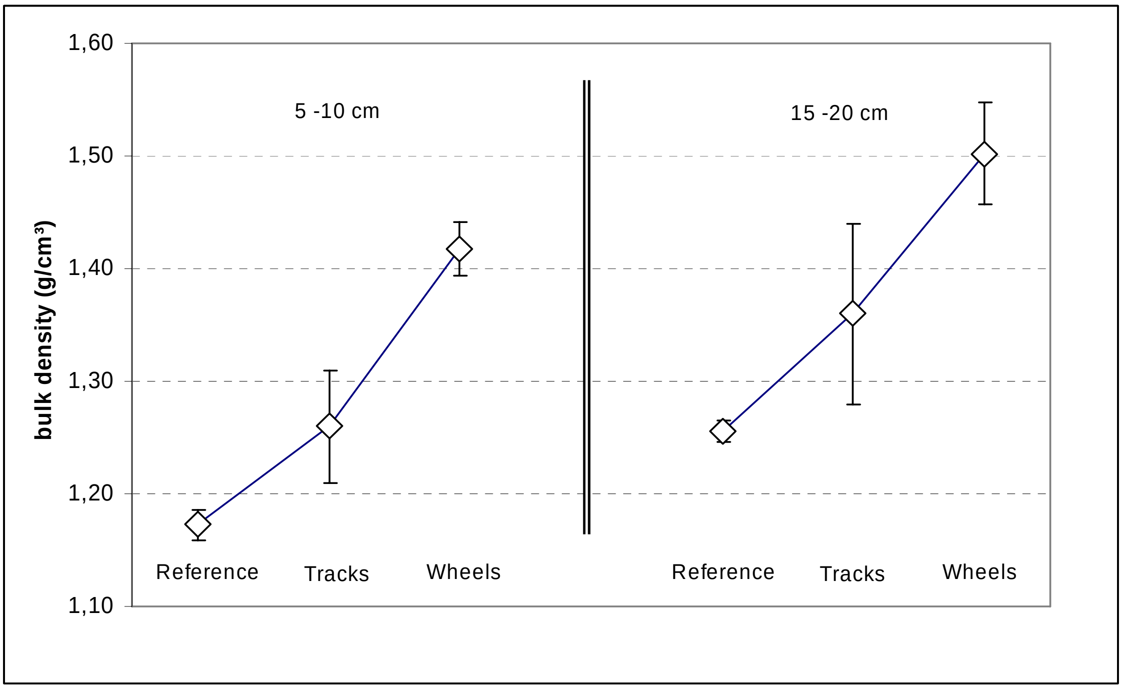

Figure 2: Example of compaction in the slope

Bulk density increase of 35 % for the wheeled harvester compared to 8 % for the tracked one. Structural changes due to a single pass on loamy sand at moderate water content.

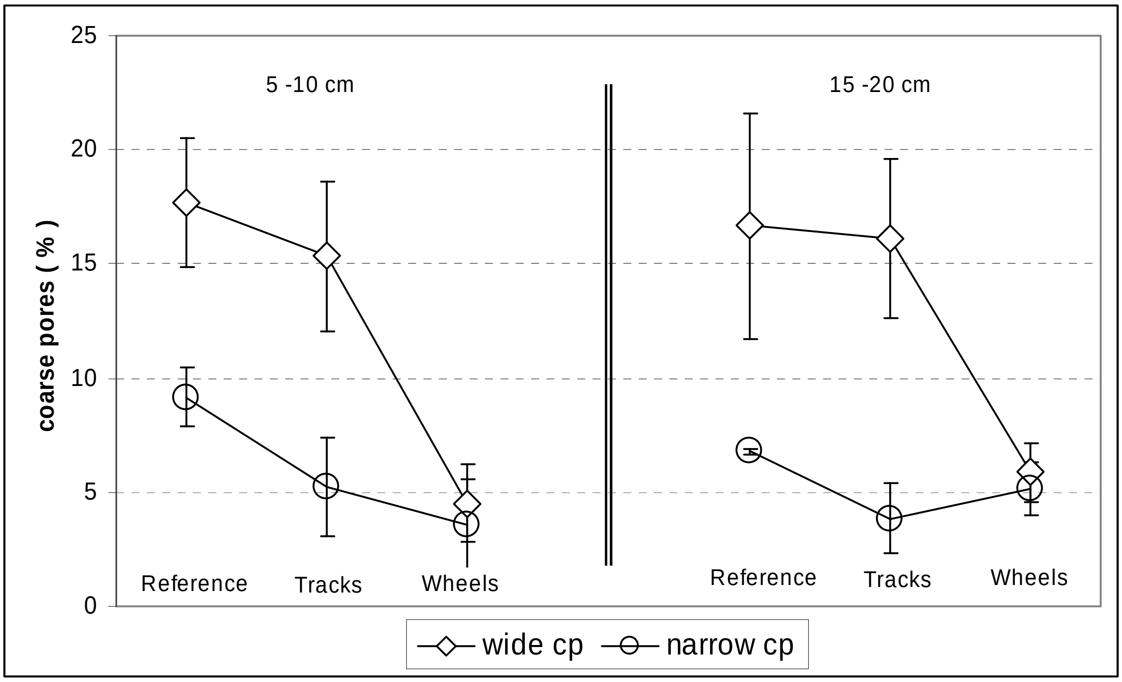

Figure 3: Example for deletion of coarse pores due to compaction

Severely affected wide coarse pore space with reductions up to 72 % under wheels in contrast to negligible effects under tracks. Structural changes due to a single pass on loamy sand at moderate water content.

Anyhow, more important are shifts in pore size distribution. Considerable reductions of 72 % in the wide coarse pore volume have been detected in wheel trafficked soils. However, it was almost not affected in case of tracked harvesters (fig.3). The air pore volume was reduced below the critical value of 6 % only after passage of the wheeled machines. In contrast the amount of narrow coarse pores suffered disturbances at a very low level.
Due to these pore space alterations combined with strongly affected pore connectivities, water and air conductivities were reduced by 95 % maximum. Comparing the levels of intrinsic air permeabilities, for example, they were constantly higher in case of samples from tracked machine strip roads (fig. 4).

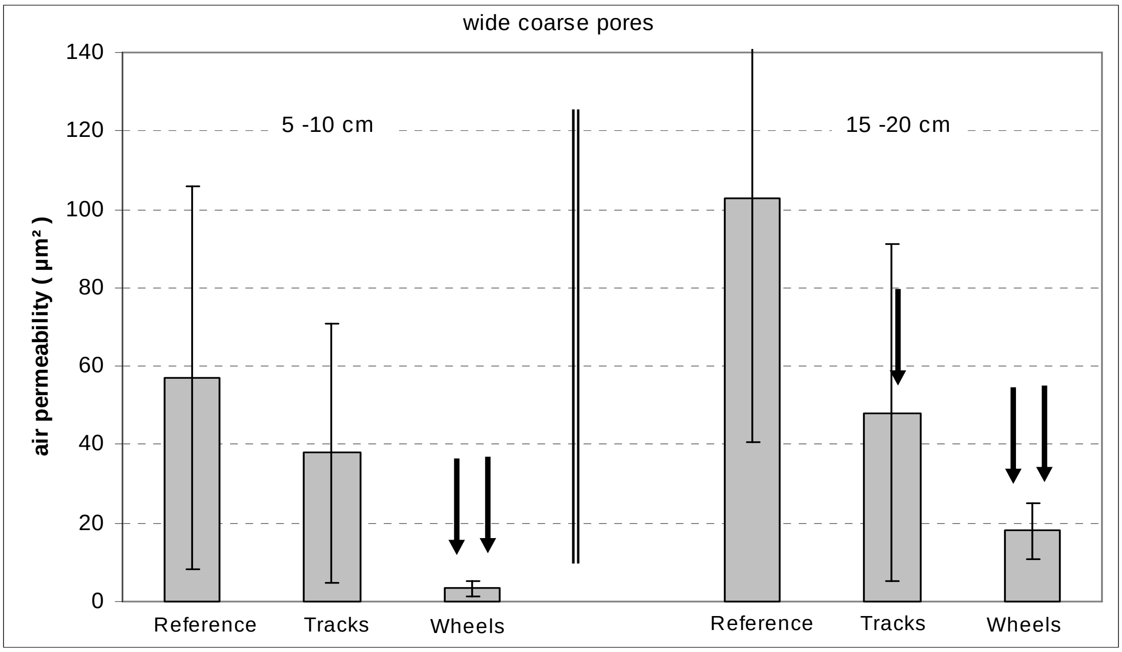

Figure 4: Example for strongly reduced air permeabilities due to compaction

Severely limited values due to wheeled, compared to slight shifts after tracked traffic. Arrows indicate class shifts according to the v. Bruggen classification (1966).

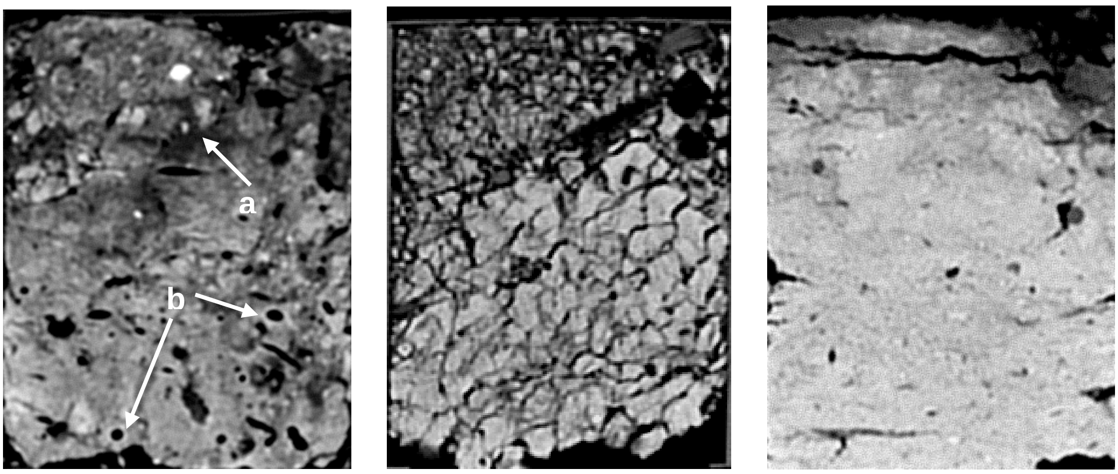

Figure 5: Comparative X-ray CT- images showing soil structural changes

Natural structure (left) is slightly changed due to traffic with tracked (middle) and almost lost after the impact of wheeled machines (right). Zones with a higher amount of organic matter (a) and earth worm burrows (b) are easily detectable.
Similar statements can be given for the saturated water conductivities. Critical values were only reached under wheeled machines.
Regarding the whole harvesting system (harvester followed by forwarder), considerably higher levels of disturbances were detected. The tracked system showed advantages in the slope but on flat terrain both systems do afflict the relevant ecological functions comparably.
The findings concerning soil structural changes can be visualized using X-ray computed tomography. Images from 12 cm high acrylic cylinder cores of 10 cm in diameter showed evidence of the structural changes (fig. 5). Reference soil structure with loose aggregation, zones of higher organic matter contents and noticeable macro pores are shown in the left picture.
The track based harvester did not cause much compaction as one can easily see. There is a slight packing but the pore system is nearly unaffected. Compared to that, the wheeled machine caused severe compaction shown by the homogeneous structure and the brighter colour. The previously intact pore system (left hand) is almost completely destroyed.

2.2 Main root damages

Furthermore, the studies served for investigating the different impacts of wheeled and tracked machines on the main root system of spruce of approx. 50 – 60 years in age. Beside strip roads being trafficked by the harvester types only, combinations with forwarders were investigated too, allowing to separate the individual contributions to the overall impact on roots. The damages occurring were classified into five classes according to MENG (1978) as shown in table 3.

Table 3: The extended classification of root damages according to MENG (1978)

Class	**Description**	
1	**bark damage**	bark is squeezed
2		bark is peeled of
3	**wood body infringement**	wood is squeezed and cracked
4		wood is splintered
5		root rip or breakage

2.3 Types of root damage

Class 1 and 2 are minor damages, which means only bark squeezing and peeling are present, whereas classes 3 to 5 mean greater impacts on the main root system by damaging the wooden body, i.e. cracking, splintering and breakage, respectively (Leinß, 1991; Dimitri, 1980; Vasiliauskas, 1994) .
Results of the evaluations revealed that wheeled carriages do affect 26 % of the strip road border trees, while conventional steel tracks affect 43 %. Felastec tracks are ranging at 33%.
Regarding the main roots 23 % (wheels) to 31 % (tracks) of all roots ranging into the strip road were damaged.
The findings for tire- and track-caused damages are in consistency with literature (Bredberg et.al., 1976; Bredberg & Wästerlund, 1983).
Out of these damages, 76 % belong to squeezing and peeling (class 1 and 2) regarding the wheeled machine (fig. 6), while the steel-tracked ones predominantly caused cracking and splintering of the wooden root body as well as breakage (classes 3 to 5).
Forwarders following harvesters do cause a distinct increase in percentage of minor damages belonging to class 1 and 2.
Bogie-tracks with 40 % of the damages within classes 4 and 5 are more root protective compared to steel-tracks with 65 %.

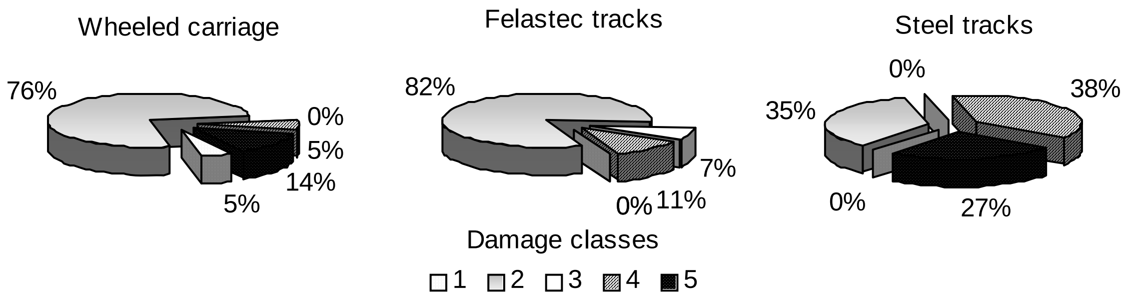

Figure 6: Extent of damages to main roots

The effect of different carriage types on the extent and quality of main root damages .

As a matter of fact tracked machinery is hazardous for roots especially in case of narrow strip roads and trees with a shallow root system like spruce. A potential risk for fungal infection lies in the tremendous inner surface being opened in splintered roots as it is the case for classes 3 to 5. This might implicate severe problems in future regarding stand stability and timber quality.
Steel-tracked machines in general cause a five fold higher damaged root surface area (table 4) and a two fold higher percentage of root breakage compared to wheeled machines whereas the forwarder causes a considerable increase of the damaged root surface only for both systems.

Table 4: Damage surfaces according to carriage types

Carriage type	damage surface (cm^2)	damage distance to stem (m)	tree distance to the track (m)
Wheels	24	1,08	1,06
Felastec tracks	59	1,09	1,01
Steel tracks	126	1,02	1,04

The damaged root surface area increases under steel tracks more than factor 5. A substantial lower level of damaged area has been detected under Felastec tracks.

Furthermore the dimensions of the damaged area also depend from the slope (fig. 7). It increases from flat to steep terrain: from 13 % on flat terrain (slope 0 - 8 %) to 33 % on steep terrain (slope 44 - 55 %) for damaged area class of 101 - > 300 cm^2 as an example.

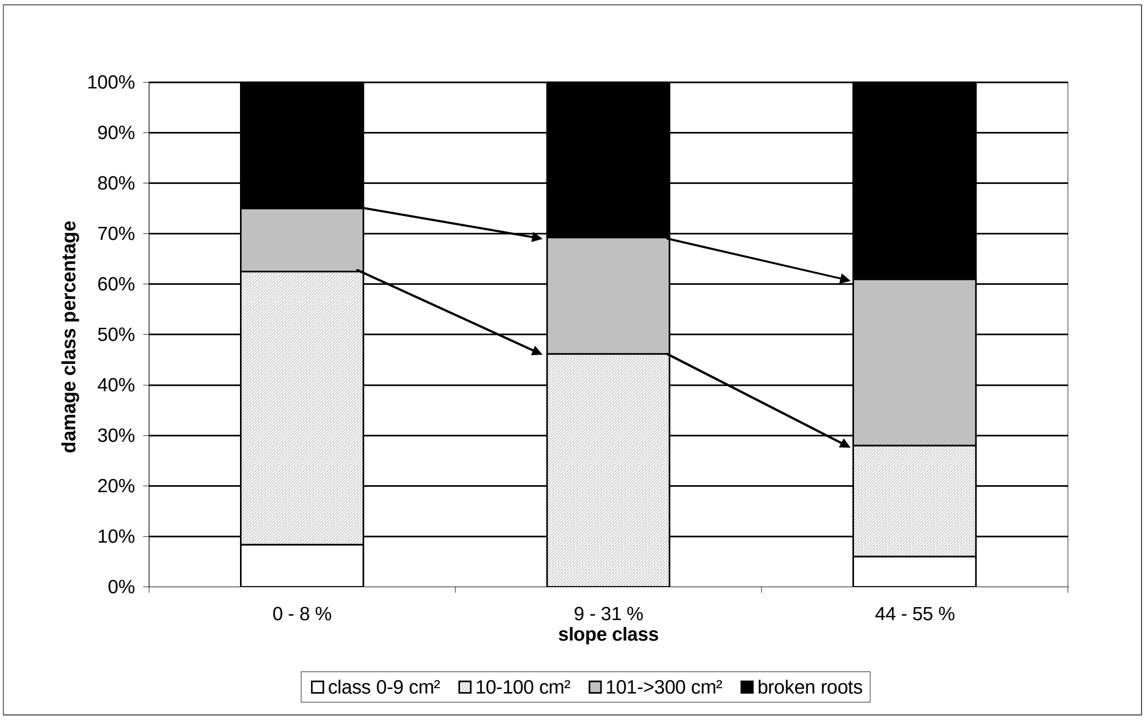

Figure 7: Surface of main root damaged area

Increasing surfaces of damages to main roots in dependence of slope classes caused by a steel-tracked harvester.

Damages being observed mainly occurred within the first 12 cm of soil. This seems to be a „threshold depth“ beyond which the soil itself protects the roots from severe damage.

4. Conclusions

When comparing the different effects of wheeled and tracked machines on soil and roots it becomes obvious, that general recommendations for their operation in forests are hard to derive. The results presented unambiguously reveal advantages for tracked machines regarding soil structure and related soil physical characteristics. Although the successively following forwarder blurs them out to a considerable extent, tracked forest machines should be given clear priority from the soil's point of view especially on slopes. On the other hand severe root injuries caused by steel tracked machines contradict this.
The task in our opinion, is to find a compromise by trying to minimize the impacts on soil structure and root system as far as possible depending on site, morphology and stand age. From this point of view some recommendations for the operation of wheeled and tracked forest machines can be given.

– **On forest sites with slopes up to 30 % and young to midaged spruce stands wheeled machinery should be given preference.**
  Although wheeled machines are likely to have higher ground pressures and, therefore, are affecting soil structure more than tracked ones, the dimensions of young to midaged trees offer the chance to use smaller machinery with acceptable contact area pressure. In combination with a proper soil moisture (soil texture and machine dependent) and well maintained tires (low inflation pressure) the risk of harmful soil structural alteration can be kept within acceptable limits. The risk of severe root damage (splintering, breakage) is limited, too.

– **On forest sites with slopes up to 30 % as well as on moistly to wet soils and young to older spruce stands (bhd ≤ 50 cm) Felastec-tracked machinery should be given preference.**
  Prevailing tree dimensions require machinery with pronounced stability for save tree manipulation. High machine masses are the consequence, which give clear preference to tracked machines regarding soil protection. Due to flexible crawler bars, serious root injuries and possibly related fungus infections are not to be expected. The risk of fast timber rotting becomes smaller.

– **On forest sites with slopes greater than 30 % steel-tracked machinery should be used.**
  Due to the asymmetrical root system, especially on slopes > 40 %, the risk of root damages becomes smaller. The lower contact area pressure of tracked machines is evident. Therefore, steel-tracked machinery on steep terrain can fairly meet both objectives – soil and root protection.

The studies gave clear evidence for the advantages as well as the risks of wheel and track based forest machines in respect to soil and roots. In addition the effects of forwarder traffic could be extracted. Anyhow, the consequences and recommendations for the practitioners are not that easy to handle as they are somewhat conflicting, whether the trees or the soil is in the focus. Despite this, we can expect construction improvements especially in case of tracked machines. Felastec-tracks are introduced. The crawler bars are mounted flexible crossways moving direction with upward bended plate tips. A promising tool for root protection. In addition a tracked forwarder prototype was already tested, which might keep the low ground pressure advantage of track based harvesting systems. Technical development is not at the end of the pipe and further achievements will certainly help us on the way to better practices concerning soil and stand protection. These are mandatory efforts in our intention to guarantee a sustainable forest management.

5. References

Froehlich, H.A. McNabb, D.H. (1983), "Minimizing soil compaction in pacific northwest forests." -*6th North American Forest Soils Conference on Forest Soils and Treatment Impacts*

Hildebrand, E.E. & Wiebel, M. (1982), „Der Einfluß der Befahrung auf die Qualität von Forststandorten, dargestellt an bodenphysikalischen Kenngrößen." – *AFJZ*, 153, ½, 24-34.

Kremer, J. (1998), „Befahrungsbedingte Strukturveränderungen von Waldböden und ihre Auswirkungen auf das Wachstum von Fichten, Kiefern und Buchen auf ausgewählten Standorten." – *Dissertation Uni München* – GCA-Verlag: 177 S.

Matthies, D., Weixler, H., Guglhör, W. & Löffler, H. (1995), „Bodenuntersuchungen zu befahrungsbedingten Strukturveränderungen auf Waldstandorten in Bayern." - *Abschlußbericht Kuratoriumsprojekt A30*, Freising: 121 S.

Denninger, W. (1998), „Vergleich der Einsatzeignung von Raupen-Harvestern mit Rad-Harvestern in der Holzernte." - *Holz-Zentralblatt* 79, 1160-1162.

Jansson, K.-J., & Johansson, J. (1998), „ Soil changes after traffic with a tracked and a wheeled forest-machine : a case study on a silt loam in Sweden." – *Forestry* 71, 57-66.

Bredberg, C.-J., Hakansson, S.-G. & Molberg, L. (1976), „Root and soil damages by rubber and steel tracks. – *Resaerch Notes* 101, Royal College of Forestry, Garpenberg Sweden

Bredberg, C.-J. & Wästerlund, I. (1983), „Wurzel- und Bodenschäden durch Fahrzeuge. – *Forstwiss. Centralblatt* 102, 86-98.

Leinß, Ch. (1991), „Untersuchung zur Frage der nutzungstechnischen Folgen nach Fäll- und Rückeschäden bei Fichte (Picea abies (L.) Karst.). - *Mitteilungen der Forstl. Versuchs- und Forschungsanstalt,* Freiburg, Baden-Würtembreg, Heft 157

Meng, W. (1978), „Baumverletzungen durch Transportvorgänge bei der Holzernte; Ausmaß und Verteilung, Folgeschäden am Holz und Versuch ihrer Bewertung.“ – *Diss. Freiburg i. Breisgau,* 159 S.

Dimitri, L. (1980), „Untersuchungen über die Widerstandsfähigkeit der Fichte (Picea abies Karst.) gegenüber dem Wurzelschwamm Fomes annosus (F.) Cooke“*, J.D. Sauerländer Verlag*, Frankfurt am Main

Vasiliauskas, R. (1994), „Spread of decay from stem wounds into roots of Norway spruce.” – *Proceedings of the Eighth International Conference on Root and Butt Rots*, SLU Info/Repro, Uppsala 1994, 213-216.

6. Acknowledgement

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