COMPARATIVE STUDY OF THE IMPACT OF WHEELED AND TRACKED FOREST MACHINES ON SOIL AND ROOTS

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Abstract: *In a comprehensive field trial we tried to point out differnces in quality and extent of soil structural changes and root damages due to traffic of wheeled and tracked forest machines. Four striproades in a fir stand were opened in flat and inclined terrain on a site with sandy loam. The machines were common midsized wheeled and tracked forest harvesters and a wheeled forwarder. Conventional soil physical and –mechanical methods were used in order to investigate the soil structural changes. For the root damage studies we developed an extended method according to MENG.*
Regarding the findings the wheeled harvester caused greater soil structural changes than the tracked one on the slopes as well as on flat terrain. A considerably higher impact was detected after passage of the forwarder. This proved the major influence of the forwarder. Tracks obviously have advantages on the slopes while on the plains no differences regarding soil could be detected.
An important finding was the fact that root symmetry is changing with slope. Concerning damages to main roots, the wheeled machines mainly caused bark peeling while the tracked one destroyed the wood body ending up in root rip or breaking. On top of it the surfical area of damage was generally much bigger.
Recommendations for the use of wheeled and tracked vehicles are given according to slope and stand conditions.

1. Methods and Results

Each of the 8 strip roads were represented by five testing plots (Figure 1) for soil investigations. Results concerning soil structural changes are based on the analysis of 240 soil cores, 80 data sets of a CPN-strata gauge and soil structural analyses of 80 large cylinder samples by means of X-ray computed tomography (CT).

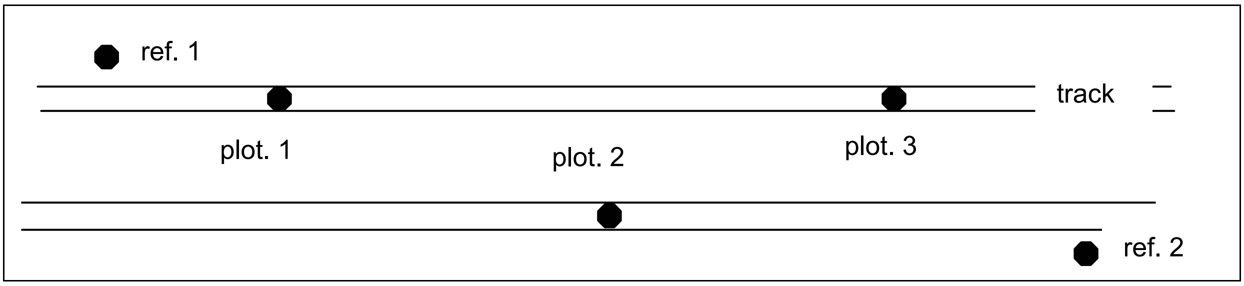

Figure 1: Experimental layout for soil physical and –mechanical investigations. ref. x = testingplot in undisturbed soil; plot. y = testing plot in the track

The increase in bulk density was twice to three times higher after wheeled traffic than after tracked one. Changes up to 35 % for bulk density (Figure 2) and correlated reductions of total pore volume up to 28 % are in good correspondance with literature. Anyhow, more important are shifts in the pore size distribution. Considerable reductions of 74 % in the wide coarse pore volume have been detected in some cases. However, it was not affected in case of the tracked harvester (Figure 2). The air pore volume was only reduced below the critical value of 6 % after passage of the wheeled system. Due to these pore space alterations combined with strongly affected connectivities water and air conductivities were reduced by 3 classes maximum. Comparing the levels of the saturated water conductivities, for example, they were constantly higher in case of samples from tracked machine strip roads. Similar statements can be given for the intrinsic air permeability. Only on flat terrain both systems afflict it comparably. Critical ki-values below 50 µm² were only reached in case of the wheeld machine.

The findings concerning soil structural changes can be visualized using computed tomography. Images from 12 cm high acrylic cylinder cores of 10 cm in diameter showed evidence of the structural changes (Figure 3, top: reference to the left, trafficed soil to the right). The track based harvester did not cause much compaction as one can easily see.

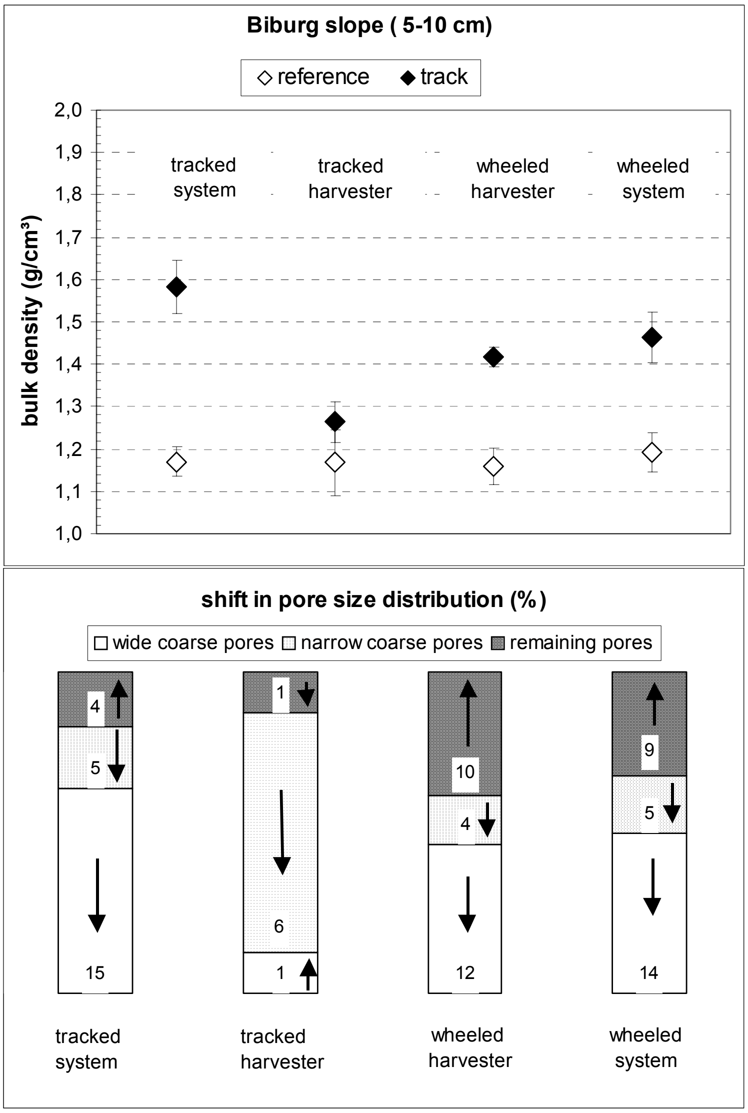

Figure 2: Changes in bulk density (top) and shift in pore size distribution (bottom) on the testplots; inclined terrain at a soil depth of 5 - 10 cm

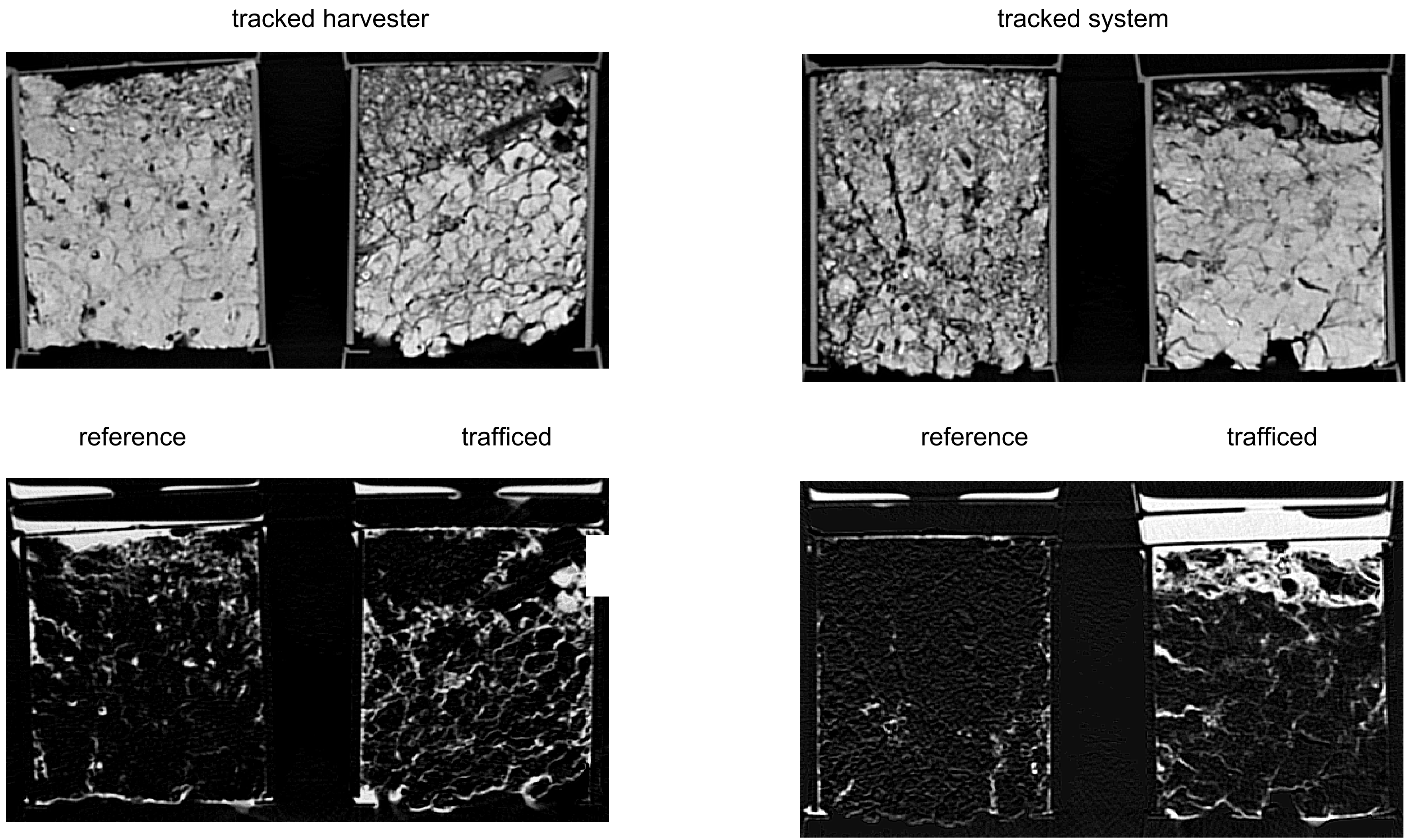

Figure 3: Comparative CT-images showing soil structural changes (top) due to traffic with tracked vehicles. Changes in drainage capacity (bottom) shown by substraction images; water is showing up in bright colours while soil structure is eliminated

There is a slight packing but the pore system is nearly unaffected. The tracked system, however, caused a severe compaction shown by the homogeneous structure and the brighter colour. The previously intact pore system (left hand) is almost destroyed completely.

By means of dynamic CT and using water as a contrasting media one can visualize and measure the water flow. The same cylinder cores as shown above were sprayed with water simulating a heavy rainfall. 20 minutes later images show the waterfilled pores in bright colours. The reference (left side) has partialy drained already. After traffic with the tracked harvester the drainage capacity remains quite good while it is strongly affected in case of tracked system. There is clear evidence that the water is still present on the top of the soil column after 20 minutes and the infiltration is considerably reduced.

2. Root system and root damages

In order to investigate root damages a systematic survey of the root system was carried out. One important finding was that the symmetry of the root system changes in accordance to slope (Figure 4). On flat terrain the trees are rooting in all directions around the tree. With increasing slope (22-31 %) trees are predominantly rooting parallel to the line of gravity, that means in our case at an angle of 180 and 360 degrees. On slopes of 40-55 % the trees are forming an asymmetrical root system having three supporting points (120°, 240° and 360°) to guarantee tree stability.

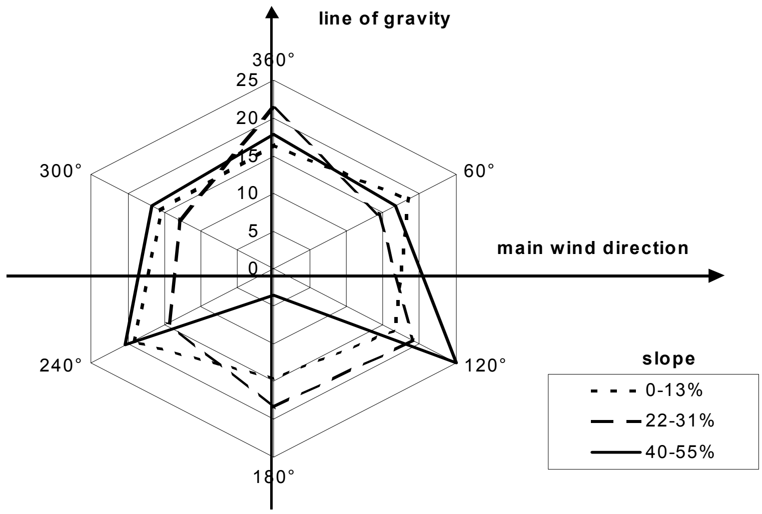

Figure 4: Symmetry of the rooting system for spruce in a 50 years old stand on a sandy loam according to different terrain conditions

Furthermore, the study served for investigating the different impacts of wheeled and tracked machines on the root system of spruce of approx. 50 years in age. Beside strip roads being trafficed 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 occuring were classified into five classes according to Meng (1978) as shown in Table 1.

Table 1: 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 infringement	wood is squeezed and cracked
4		wood is splintered
5		root rip or breakage

3. Types of root damage

Class 1 and 2 are minor damages, that means only bark squeezing and peeling are present, whereas classes 3 to 5 mean greater impacts on the root system by damaging the wooden body, i.e. cracking, splintering and breakage, respectively.

The results of evaluation show that 30 % of all roots ranging into the strip road were damaged independent from the machine type. Out of these 70 % belong to squeezing and peeling (class 1 and 2) regarding the wheeled machine, while the tracked one predominantly caused cracking and splintering of the wooden root body (classes 3 to 5). Figure 5 is also illustrating that the forwarder causes a distinct increase in percentage of damages belonging to class 1 and 2.

As a matter of fact tracked machinery is hazardous for roots especially in case of narrow strip roads and trees with a shallow root sytem 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.

4. Extent of root damages

Tracked machines in general cause a four fold higher damaged root surface area (mean: 200 cm^2) and a two fold higher percentage of root breakage compared to wheeled machines.

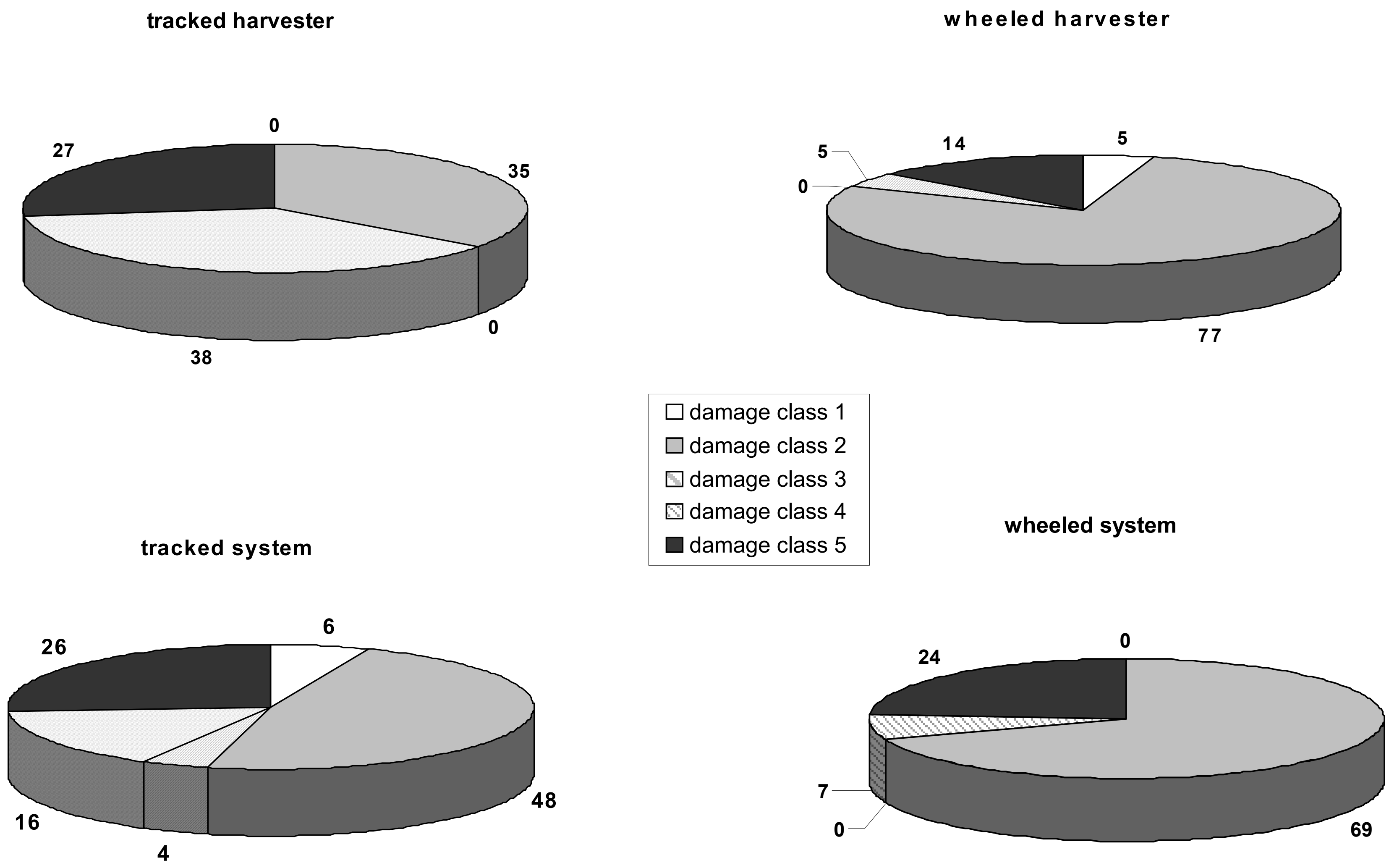

Figure 5: Extent of damages to main roots according to damage classes and different harvesters and harvesting systems

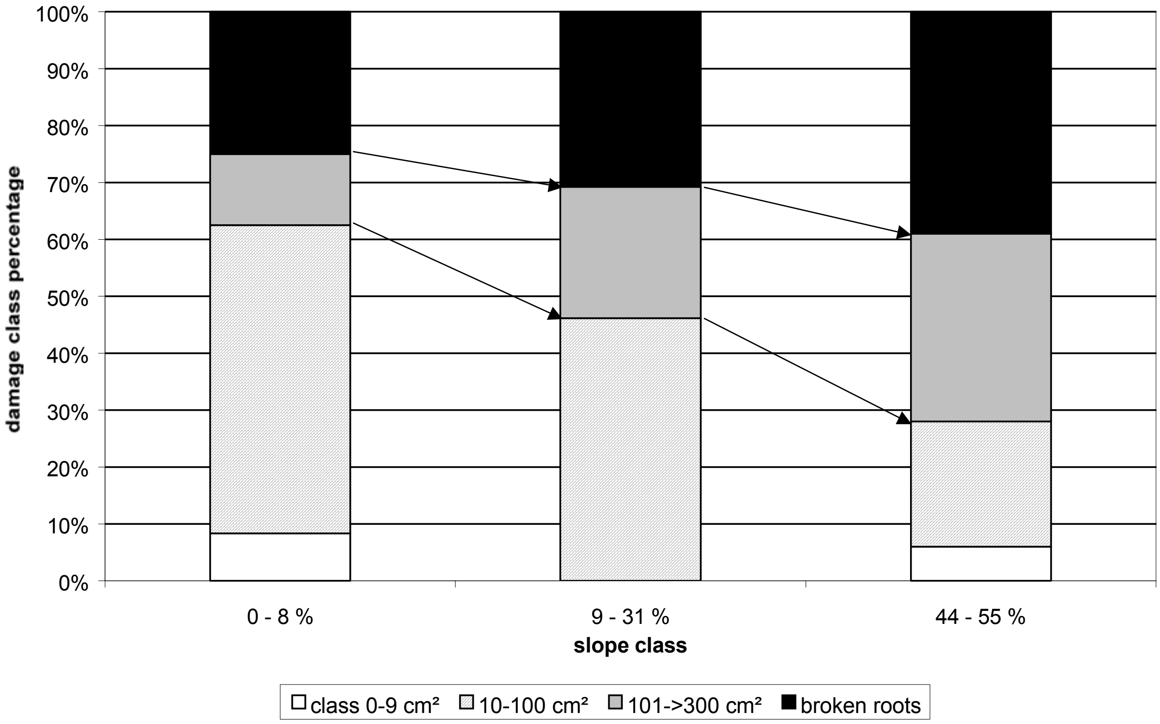

Figure 6: Surface of damaged area caused by a tracked harvester in different slope classes

Whereas the forwarder causes a considerable increase of the damaged root surface only for both systems.

Furthermore the dimension of the damaged area also depends from slope as one can see in Figure 6. It increases from flat to steep terrain: from 10 % on flat terrain (slope 0-8 %) to 30 % on steep terrain (slope 40-55 %) for damaged areas of 10-100 cm² as an example.
The damages being observed mainly occured 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.

5. Conclusions

While comparing the different effects of wheeled and tracked machines on soil and roots it becomes obvious, that generell recommendations for their operation in forests are hard to derive. The results presented unambigiously 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. On the other hand severe root injuries cause by this kind of machines contradict this.

Table 2: Recommendations for the use of wheeled and tracked forest machines derived from the effects on soil and roots for different terrain situations

Terrain conditions	soil	roots	Result
1. plane	tracked harvester both systems	tire harvester tire system	? tire system
2. slope < 30 %	tracked harvester tracked system	tire harvester tire system	? ?
3. slope > 30 %	tracked harvester tracked system	tracked harvester tracked system	tracked harvester tracked system

How to overcome this dilemma? One possibility could be to attribute absolute priority to soil or root protection, which requires a careful consideration of the risk potentials differing in time and extent. The other possibility, we are encouraging, is a compromise trying to minimize the impacts on soil structure and root system as far as possible depending on site morphology and stand age.

- **On forest sites with slopes up to 30 % and young to midage trees 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 midage trees offer the chance to use smaller machinery with acceptable ground pressure. In combination with a proper soil moisture (soil type 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 % and midage to old trees tracked machinery should be given preference.**
  The 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. Serious root injuries and possibly related fungus infections are postponed to a late stage of stand development. The risk of fast timber rotting becomes smaller.

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

The recent study 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 practioners are not that easy to handle as they are somewhat conflicting, whether the trees or the soil is in the center of focus. Despite this, we can expect constructural improvements especially in case of tracked machines. Latest developments introduced tracks being 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. The technique is not at the end of the pipe and further developments will certainly help to follow our intention of a sustainable forest management.