Equipping a Conventional Wheeled Forwarder for Peatland Operations

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Abstract

In Finland, peatland logging is generally conducted during the winter due to the inherently low soil bearing strength under unfrozen soil conditions. Mild winters the past several years have raised the issue of operations on unfrozen peatlands. Modifying wheeled logging equipment such that it was able to operate cost-effectively on sensitive sites and then switch back to normal, base machine specifications at other times would be a significant advantage.

The mobility and rut formation of a conventional 8-wheeled forwarder was studied with four different sets of chain/track equipment. Additionally, the forwarder was equipped with a rear, add-on axle resulting in a 10-wheeled forwarder. That modified forwarder was tested with the widest set of tracks on an abandoned peat field and on a pine bog.

Results indicate that the forwarder modifications significantly increased mobility and decreased rut formation on the test soils. On the pine bog, the 10-wheeled forwarder had the best mobility and the least rut formation of all equipment tested.

Keywords: Equipment, Finland, forwarder, mobility, peatland, rutting, tracks, trafficability.

Introduction

Peatland harvesting problems are a part of a larger problem of sensitive site harvesting. Nugent et al. (2003) describes sensitive sites as follows: "A sensitive forest site is where alterations to normal mechanized harvesting practices are required in order to avoid adverse effects on the ecological, economic and social functions of the forest." The percentage of total forested area in Europe classified as being sensitive ranges from 5% to 25% depending on the country (Owende et al. 2002).

In Finland, the annual growth of forests is 99.5 mm^3. As a result of extensive drainage operations during the 1960s and 1970s 24% of this growth comes from peatland forests (Metsätilastollinen vuosikirja 2007, 2009). In recent years the annual volume harvested from peatlands has been 5-6 mm^3. The most current recommendations for peatland forestry (Hyvän metsänhoidon suositukset turvemaille 2008) indicate that harvesting is estimated to reach 12 to 14 mm^3/year (Turvemailta lisää puuta ympäristöä kuormittamatta – uudet metsänhoitosuositukset turvemaille 2008).

Due to their inherently low ground-bearing capacity, peatland harvesting in Finland generally occurs during winter months. In the 1990s, the requirement of 20 cm of frost or 40 cm of snow cover on unfrozen ground resulted in an operating period of 60 days in Southern Finland and 160 days in Northern Finland (Eeronheimo 1991). During frequent mild winters, the period of frozen ground has typically been only a few weeks in the south.

To achieve the full potential of harvesting timber from peatlands, a longer operating period is needed. There are several ways to extend the harvesting period on sensitive sites. Above all, there is a need for cost-effective solutions which are readily adaptable to current equipment and operator abilities. The first approach is to equip existing machinery for sensitive sites. In the long run, the need for sensitive site machinery may result in special machinery for peatlands.

Since the mid-1990s, there has been a trend towards heavier machinery in Finland (Rieppo 2001). Since then, the mass of forwarders has increased by 20 to 40%, mainly due to requirements for higher technical availability. The trend has been toward 8-wheeled forwarders. The typical empty mass of an 8-wheeled medium-sized forwarder is 15 to16 t. The mass of a fully-loaded machine with tracks may exceed 25 t.

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The trend toward heavier harvesting machinery can reduce operability on sensitive sites. Timber harvesting machinery mobility on peatland forests relies on minimizing damage to the surface layer of the peatland as plant roots provide necessary flotation. The strength of the underlying decomposed peat material is usually inadequate to support forest machinery (Ala-Ilomäki 2006). As a consequence, nominal ground pressure (NGP) is crucial in peatland operations. Since the surface is disturbed by wheels and tracks during each pass, the number of passes should be kept to a minimum.

To lower the nominal ground pressure of harvesting equipment, the prevailing practice in peatland operations in Finland has been to use steel tracks on the bogies of wheeled machinery. The use of tracks has its disadvantages. They have a tendency to cause soil shearing and puncture the surface layer. This can be prevented to some extent by selecting tracks and running gear of appropriate design.

The purpose of this study was to evaluate the performance of different auxiliary devices in enhancing the mobility of forwarders and reducing soil damage on soft terrain. To measure the technological progress in the field of harvesting machinery, we also compared the results obtained from contemporary machinery with those from a forwarder that was state-of-the-art in the 1980s.

Materials and Methods

Machinery and Equipment

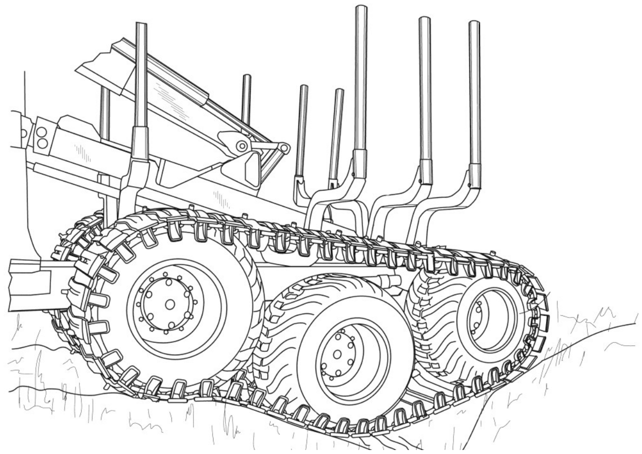
The forwarders were a 2005 8-wheeled Ponsse Wisent and a 6-wheeled mid 1980s Ponsse S15. The tire chains and tracks of the 8-wheeled forwarder were varied whereas the 6-wheeled forwarder acted as a reference to the published studies from the 1980s (Högnäs 1983, Sirén et al. 1987) as it was evaluated with only one set of tracks and chains. According to the manufacturer, the mass of the forwarders unloaded without chains or tracks and its distribution was as follows:

	Front axle, kg	Rear axle, kg	Total, kg
8-wheeled	9638	6496	16134
6-wheeled	5200	5330	10530

The equipment of the 8-wheeled forwarder was varied from its standard mineral soil set-up (chains on the front bogie and 850 mm wide tracks on the rear bogie). This was accomplished by applying tracks of different design and width used on both front and rear bogies, and finally by bolting an extra axle behind the rear bogie to reach a 10-wheeled set-up (Figure 1), where the widest set of tracks was used front and rear.

The extra axle was designed as an accessory for soft soils. Detaching it for operations on firmer soils can be accomplished in situ, as the attachment of the extra axle was rigid (i.e., it was not part of the pivoted bogie structure). The wheels on the extra axle were smaller in diameter than the bogie wheels to reduce resistance when maneuvering on firm soil. Additional information and code names for each forwarder is presented in Table 1.

Figure 1. Schematic figure of the detachable, rigidly mounted extra (rear) axle of the 10-wheeled forwarder. The wheels on the extra axle are smaller in diameter than the bogie wheels to reduce resistance when maneuvering on firm soil.



Test Sites and Measurement of Site Properties

The trials were conducted on an abandoned agricultural field on peat soil and on a pine bog in August. Both sites had been drained in the past. On the peat field, 10 test tracks 180 m in length were laid out. Site properties and rut depth were determined at 4 m intervals along the test tracks, resulting in a total of 45 measuring points per track. On the pine bog, the length of the five test tracks was 170 m and the number of measuring points per track at 4 m interval was 42. On the pine bog, the trees on the test tracks were cut two months prior to the study with an eight-wheeled mid-sized Ponsse HS10 Cobra-harvester.

At each measuring point, a 2 x 7 m study plot was laid out to determine site properties. Within each plot, peat layer depth was measured and two soil shear strength measurements were made. Additionally, the percent of area coverage of dwarf shrubs and herbs was estimated. On the peat field, the depth to the groundwater table was measured on every ninth plot along each test track. The pine bog was divided into six blocks for groundwater table measurements.

Within the pine bog, diameters of standing trees and stumps of removed trees were measured to estimate the volume of residual and harvested trees within a plot. The amount of cutting debris within a plot was determined as the number of tree tops and branches 3 cm or more in diameter on harvester wheel tracks. This was converted into pieces per m of track.

Measuring peatland surface layer strength has previously been a problem since the blades of a conventional shear vane cut the roots, whereas a penetrometer may be unable to detect the roots' influence. Plate load devices have been successfully used on peatland, yet manually operated devices tend to be cumbersome (Lee and Jarret 1978). Soil shear strength was therefore measured with a spiked shear vane newly developed at the Finnish Forest Research Institute on the basis of the muskeg fluke described by Radforth (1969). Rows of vertical steel spikes are attached perpendicular to a circular steel plate to replace the blades of a conventional shear vane. The spikes

Table 1. Technical data for the studied forwarders.

Equipment		Forwarder code name				
Front axle		1.10W Magnum	2. 8W Magnum	3. 8W Baltic	4. 8W Std	5. 6W
Tracks		Olofsfors Eco Magnum 710-26.5	Olofsfors Eco Magnum 710-26.5	Olofsfors Eco Baltic 710-26.5	-	-
Total track or tire width, mm		916	916	850	710	600
Chains		-	-	-	Ofa Matti 3T	Ofa Matti 2R
Track or chain mass, kg/pair		1772	1772	1622	400	400
NGP*, kPa		26	26	28	52	56
Rear axle						
Tracks		Olofsfors Eco Magnum 710-26.5	Olofsfors Eco Magnum 710-26.5	Olofsfors Eco Baltic 710-26.5	Olofsfors Eco Track 710-26.5	Olofsfors Combination Track 600-26.5
Total track width, mm		1023	1023	850	850	790
Mass, kg/pair		2614	1946	1622	1778	1250
Aux. axle set-up mass, kg		1000	-	-	-	-
NGP, kpa	empty	13	19	20	20	18
	loaded on peat field	21	31	35	35	34
	loaded on pine bog	23	35	40	40	39

* = Nominal Ground Pressure

are 0.15 m in length and 0.012 m in diameter. Their tips are tapered to facilitate penetration into the surface layer while causing minimal damage to the roots. The radius of the cylindrical sheared specimen is 0.0515 m and the height is 0.15 m.

Test Drive Techniques

On the peat field, two test tracks for each equipment/machine alternatives were selected randomly. Test drives consisted of seven passes loaded with a load of 6 t Rut depth and width was measured after each pass.

On the pine bog, one test track per studied configuration was selected randomly. Normal timber extraction was simulated, one return trip consisting of first driving empty and then returning loaded with a load of 8 t in the middle of the drainage ditches. The machine operator decided the number of safe return trips to make to avoid bogging down. The resulting ruts were measured for depth and width after each loaded pass. Impacts to the residual stand were assessed by counting the wounds caused by the machinery to the remaining residual trees after the test.

Site Properties

The conditions of the equipment study tracks for the peat field site are presented in Table 2. Conditions were generally fairly uniform considering the natural state of the sites. 10W Magnum and 8W Magnum tracks had the shallowest peat layer depth and 6W track the deepest, whereas shear strength was at its highest on 10W Magnum and 8W Magnum tracks, 8W Baltic and 6W had the weakest test tracks.

According to ANOVA results, shear strength on the pine bog was the sole variable not significantly different ($p \leq 0.05$) between the test tracks (Table 3).

Table 2. The average conditions for study variables on the peat field site test tracks. Standard deviations of the variables are presented in parentheses. Analysis of variance (ANOVA) results presented in italics (p≤0.05 compared to equipment of given number).

Variable	Equipment number and code name				
	1. 10W Magnum	2. 8W Magnum	3. 8WBaltic	4. 8W Std	5. 6W
Peat layer depth, cm	88 (14) *3, 4, 5*	83 (13) *3, 4, 5*	93 (13) *1, 2, 5*	92 (13) *1, 2, 5*	99 (6) *1, 2, 5, 4*
Depth to the ground water table, cm	35 (9) *3, 4*	33 (12) *4*	35 (8) *1, 4*	41 (9) *1, 2, 4, 5*	34 (5) *4*
Surface layer shear strength, kPa	25 (6) *2, 3, 5*	27 (6) *1, 3, 4, 5*	22 (5) *1, 2, 4*	25 (5) *2, 3, 5*	22 (6) *1, 2, 4*
Dwarf shrub coverage, %	21 (20) *2, 3, 4, 5*	40 (24) *1, 3*	30 (17) *1, 2, 5*	34 (24) *1*	35 (19) *1, 3*
Herb coverage, %	54 (36) *4, 5*	62 (34) *5*	53 (26) *4, 5*	64 (28) *1, 3, 5*	78 (20) *1, 2, 3, 5*

The variation in peat layer depth among the various pieces of equipment was considerable. The 10W Magnum test track had the shallowest peat deposit and the highest pre-thinning stand volume. The 6W test track had the deepest peat layer and the 8W Magnum test track the lowest stand volume. Due to the manual shear strength measuring device, the results are likely to represent the weakest end of spatial variation, since any tree roots greater than approximately 2 cm in diameter formed a hindrance to its operation. Thus, spots with big roots, and hence probably good bearing capacity, simply could not be measured. Groundwater level was fairly uniform across the area.

Results

The average rut depths after each pass or return trip were calculated and the differences between equipment were compared with analysis of variance (Tables 4 and 5, Figures 2 and 3). On the pine bog, the given results include the rut depth after one pass by the harvester used for cutting the timber on the test tracks.

On the peat field site, 10W Magnum and 8W Magnum clearly had the lowest rut formation. The difference between them was not always significant. The low sinkage did not facilitate the extended track of 10W Magnum to fully contact the ground. 8W Baltic and 8W Std formed the second group with higher rut formation. The 6W forwarder from the mid-1980s caused the deepest ruts, although the difference with 8W Std on the seventh pass was not significant.

Table 3. The average conditions for study variables on the pine bog site test tracks. Standard deviations of the variables are given in parentheses. ANOVA results given in italics (p≤0.05 compared to equipment of given number).

Variable	Equipment number and code name				
	1. 10W Magnum	2. 8W Magnum	3. 8W Baltic	4. 8W Std	5. 6W
Peat layer depth, cm	99 (27) *2, 3, 4, 5*	141 (18) *1, 3, 4, 5*	157 (18) *1, 2, 4,*	120 (19) *1, 2, 3, 5*	170 (40) *1, 2, 4*
Depth to the ground water table, cm	27 (2) *2, 3, 5*	25 (0) *1, 4*	25 (0) *1, 4*	27 (2) *2, 3, 5*	25 (0) *1, 4*
Surface layer shear strength, kPa	23 (7) -	25 (7) -	23 (8) -	25 (7) -	24 (6) -
Dwarf shrub coverage, %	55 (16) *2, 3, 4, 5*	68 (12) *1*	72 (13) *1*	65 (20) *1*	71 (12) *1*
Herb coverage, %	2 (3) *4, 5*	4 (4) -	2 (3) *4*	5 (5) *1, 3*	5 (9) *1*
Stand volume prior to thinning, m^3/ha	87 (61) *2*	45 (48) *1, 4, 5*	63 (58) -	73 (70) *2*	71 (64) *2*
Cutting debris, pieces/m^2	0.8 (0.7) *3*	0.6 (0.5) *3, 5*	1.3 (0.9) *1, 2, 4*	0.7 (0.6) *3, 5*	1.1 (1.0) *2, 4*
Harvester rut depth within the test track, cm	5.7 (3.1) *2, 4*	7.2 (2.7) *1*	6.4 (2.8) -	7.4 (2.1) *1, 5*	5.8 (3.7) *4*

On the pine bog, 10W Magnum had the best performance. Not only was its rut formation significantly lowest but also the number of safe return trips was the highest. Additionally, the overall mobility of the forwarder was in a class of its own. Due to greater wheel sinkage compared to the peat field site the large contact length of 10W Magnum was effectively utilized.

The rut formation of 8W Magnum and 8W Std did not differ statistically, yet they were significantly higher compared to 10W Magnum. The operator judged 8W Magnum capable of three return trips as opposed to two return trips of 8W Std. The rut formation of 8W Baltic, capable of two return trips, was significantly highest amongst the 8-wheeled machinery.

The 6W with tracks of dated design was no match to the modern forwarders. The operator judged it capable of only one safe return trip, and it had the significantly highest rut formation, with the exception of 8W Baltic on the first return trip (p=0.053).

The variables best explaining the variation in rut depth per tested equipment by number of passes on the peat field site (Figure 2) were the number of passes, coverage of dwarf shrubs and herbs, and peat layer depth. On the pine bog site (Figure 3), the number of return trips, peat layer depth, harvester rut depth within the test track and amount of cutting debris best explained the variation in rut depth.

Discussion

Finding fully comparable natural conditions for test drives is difficult. This is especially true in the forest, where both soil and stand conditions tend to vary. On the pine bog, significant variation in peat layer depth was observed, and for 10W it was among the variables best explaining the variation in rut depth.

Table 4. The average rut depth by number of passes on the peat field site. Standard deviation is given in parentheses and ANOVA results in italics (p≤0.05 compared to equipment of given number).

Number of passes*	Rut depth, cm				
	1. 10W Magnum	2. 8W Magnum	3. 8W Baltic	4. 8W Std	5. 6W
1	1.2 (1.0) *2*	1.0 (0.9) *1*	3.5 (1.2) *4*	3.3 (1.4) *3*	4.1 (1.3) -
2	2.0 (1.3) -	2.5 (1.1) -	5.3 (1.4) *4*	5.5 (1.7) *3*	6.2 (1.6) -
3	2.9 (1.5) -	3.5 (1.1) -	6.9 (1.5) *4*	6.9 (2.3) *3*	7.6 (1.6) -
4	4.1 (1.6) *2*	4.2 (1.0) *1*	8.0 (1.8) *4*	8.1 (2.3) *3*	9.2 (2.0) -
5	5.2 (1.4) -	4.7 (1.0) -	9.4 (2.2) *4*	9.5 (2.9) *3*	10.7 (2.0) -
6	6.2 (1.7) -	5.2 (1.2) -	10.7 (2.2) *4*	11.0 (3.5) *3*	12.1 (2.5) -
7	7.3 (1.9) -	6.4 (1.4) -	12.5 (2.3) *4*	13.5 (4.0) *3, 5*	14.0 (3.0) *4*

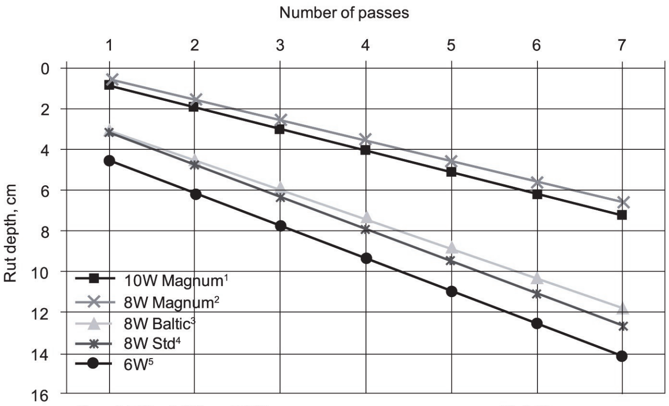
* = The forwarders were driven loaded only

Table 5. The average rut depth by return trip number on the pine bog site (includes rut depth after one pass by the harvester). Standard deviation is given in parentheses and ANOVA results in italics (p≤0.05 compared to equipment of given number).

Return trip number*	Rut depth, cm				
	1. 10W Magnum	2. 8W Magnum	3. 8WBaltic	4. 8W Std	5. 6W
1	6.4 (3.1) -	12.7 (2.4) *4*	16.3 (4.6) *5*	13.0 (3.5) *2*	18.6 (5.9) *3*
2	8.5 (3.2) -	16.6 (3.7) *4*	23.5 (6.5) -	17.9 (4.9) *2*	
3	11.3 (2.9) -	20.9 (4.2) -			
4	14.7 (3.9) -				

* = Return trip consists of one pass empty and one pass loaded

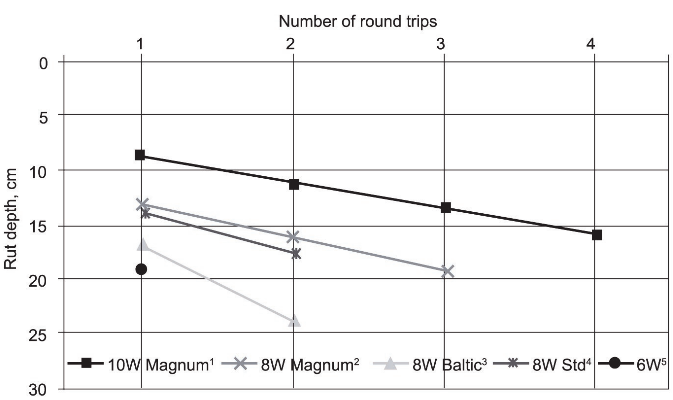
Figure 2. Rut depth by number of passes loaded with a load of 6 t on the peat field site. The forwarders can be divided into three groups, 10-wheeled, 8-wheeled and 6-wheeled, with the widest set of tracks clearly having the lowest rut depth.



1) $y = 0.548 + 1.052x_1 - 0.023x_2$ $R^2=0.69$
2) $y = 5.809 + 0.975x_1 - 0.08x_3 - 0.032x_4$ $R^2=0.69$
3) $y = 4.005 + 1.441x_1 + 0.063x_5 - 0.01x_2 - 0.113x_4 - 0.154x_6$ $R^2=0.83$
4) $y = 5.97 + 1.569x_1 - 0.023x_2 - 0.031x_3 - 0.071x_6$ $R^2=0.69$
5) $y = 0.839 + 1.594x_1 + 0.065x_5 - 0.016x_3 - 0.043x_6$ $R^2=0.73$

x_1 = Number of passes, x_2 = Dwarf shrub coverage, %
x_3 = Herb coverage, %, x_4 = Depth to the ground water table, cm
x_5 = Peat layer depth, cm, x_6 = Surface layer shear strength, kPa

Figure 3. Rut depth by number of return trips (one pass empty and one pass loaded with a load of 8 t) on the pine bog site. The performance of the 10-wheeled forwarder was outstanding.



1) $y = 1.327 + 2.417x_1 + 0.026x_5 + 0.42x_7 - 0.887x_8$ $R^2=0.69$
2) $y = 6.103 + 3.101x_1 + 0.618x_7$ $R^2=0.62$
3) $y = 4.424 + 7.131x_1 + 1.076x_7 - 0.025x_9$ $R^2=0.63$
4) $y = 2.001 + 3.805x_1 + 0.632x_7 + 0.044x_5 - 2.502x_8$ $R^2=0.61$
5) $y = 20.367 - 1.316x_8$ $R^2=0.58$

x_1 = Number of round trips, x_5 = Peat layer depth, cm
x_7 = Harvester rut depth within the test track, cm, x_8 = Cutting debris, pieces/m^2
x_9 = Stand volume prior to thinning, m^3/ha

The power of site conditions in explaining the variation in rut depth was generally poor due to the fact that the variation in site conditions, not being the main focus of the study, was limited. Also, due to the inherent spatial variation, point wise measuring of ground strength may fail to explain variation in rut depth especially on the pine bog. The effect of cutting debris and stand volume prior to thinning in reducing rutting on the pine bog was lower than anticipated. The amount of cutting debris was, however, low if compared to the study of McDonald and Seixas (1997). Spatial variation in ground strength seemed to induce rut formation on the pine bog as small root mat punctures tended to expand with increasing number of passes. The newly developed spiked shear vane proved capable of measuring the strength of peatland surface layer especially on the peat field site.

The number of passes or return trips and NGP proved to be decisive for rut formation. According to the results, NGP is the most important single machine characteristic regarding rut formation on peatland. Also, machine running gear configuration plays a key role. The old 6-wheeled forwarder clearly had the lowest mass amongst the machinery, but its single axle front end with short length of ground contact seemed to be a severe handicap on the pine bog with surface irregularities and large spatial variation in bearing capacity. It had a tendency to dive into a weak spot. The amount of cutting debris was important factor in reducing its rut depth.

The test was all about driving straight ahead and the probable disadvantages of bogies in turns did not affect the results. Rather surprisingly the rut formation of 8W Baltic was higher than that of 8W Std on the pine bog. The cause for this was not confirmed.

Track design was also considered an important factor in reducing rut formation. 6W had a definite handicap due to its 1980s tracks with curved track shoes with side links having a smaller radius of rotation in wheel contact compared to the outer face of the track. This forces some of the shoes to slide excessively along the ground during ground contact. A definite disadvantage of track use is the increase of machine weight.

The test tracks of 10W Magnum had, generally speaking, properties indicating trafficability among the best in the group, yet no single site variable proved crucial for rut formation. The concept of 10W Magnum proved successful from the mobility point of view, especially on the pine bog. This must partly be due to the extended ground contact length of the rear running gear helping to overcome the considerable natural spatial variation in ground strength. The scale of the variation is typically 1 to 2 m, facilitating sinkage of one wheel of a standard bogie. The extra axle construction stabilized the tilting of the bogie when transmitting high drawbar forces on soft terrain, further preventing an individual wheel from sinking excessively.

The increased contact length of 10W Magnum probably has the disadvantages of increased motion resistance on soils with good bearing capacity and increased lateral soil shearing in turns. On harder mineral soils conversion into 8W configuration is advisable. On sensitive sites, the 10W concept would undoubtedly benefit from a lower machine weight. This in turn could result in a purpose-built machine for peatland harvesting with possible limitations in mineral soil capabilities.

Conclusions

The study aimed at aiding in selecting the right harvesting machinery and equipment for a specific peatland site. Even a relatively heavy wheeled forwarder, when properly equipped, can be used in peatland forest harvesting with good results. The problem of timber harvesting on unfrozen peatland is by no means solved by this work as it merely deals with means to lower NGP. Especially cost-effective and reliable determination of peatland trafficability thus remains to be solved in further studies.

Developing harvesting machinery is only a part of the solution. New planning tools, such as LIDAR, may provide possibilities for estimating site trafficability. A lot can also be achieved in practical harvesting implementation for example by optimized routing on the site and different ground reinforcement methods.

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