EFFORTE –

'Efficient forestry by precision planning and management for sustainable environment and cost-competitive bio-based industry'

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Contents

EFFORTE project objectives

The Efforte project is built on the idea that forests and forestry provide a great potential to meet challenges of tomorrow by providing the Bio-based industry with efficiently processed raw material resulting in low carbon footprint. To realize this and systematically replace fossil fuels and other non-renewable raw materials it is of great importance to find novel technologies and methods to improve and guarantee sustainability within the forestry.

The project is built on three different areas of development

- Trafficability (Better knowledge on soil properties, in particular soil mechanics)
- Efficiency in sustainable forest management and silviculture (development and utilization of novel technology, planning and decision tools)

Precision forestry (in mapping, characterizing, planning and operations by using information from different sources such as terrain maps and models, harvester data models for predicting detailed yield and operational cost and additional information from earlier silvicultural and harvesting operations)

1. Introduction

Forestry and forest products might be an important alternative in a biobased and circular economy since products and materials based on wood can replace fossil-based materials and products (Lundmark et al., 2014). The demand for wood has consequently increased during the last decades and is expected to increase even more in coming years (Annon 2006). In addition competitiveness and cost consciousness drives development of more efficient and cheaper methods. This has resulted in heavy mechanization, productivity and the development of efficient forestry systems from the 1950s and until today's forestry (Fryk, 2002). The side effect is a significant risk for driving damages on soil and water. Soil compacting can cause growth losses and traces adjacent to streams and lakes can lead to increased supply of sediments, nutrients and heavy metals (Munthe & Hultberg, 2004). It is therefore very important to avoid soil damage in and adjacent to water flows. The impacts of heavy traffic on forest soils are well reviewed by Cambi et al., (2015).

The forestry thus has a great responsibility to reduce this negative impact on soil and water and avoid the most serious damages close to water, nature conservation and recreation. This is possible to accomplish with:

- Increased knowledge about how forestry affects the environment
- Changed attitudes about the importance to reduce negative impact on soil and water
- Improved and implemented new methods and technique to reach the “traceless forestry”
- Machinery and equipment development
- Use of advanced harvesting planning and operator tutoring tools.

This review aims to describe different technical solutions used on sensitive soils, to protect water in the landscape and built on terrain machines, all with the purpose to decrease negative impacts on the environment, soil and water.

2. Additional accessories, equipment and methods

2.1 Harvester residuals

Harvest residuals are important in reinforcement of the ground while driving with heavy vehicles in the terrain. The covering effect of residue mat has been found in many studies (Wronski et al., 1990, McDonald & Seixas, 1997, Han et al., 2006, Kärhä et al., 2010, Labelle et al., 2015). In Norway spruce thinnings we can get a residue mat of 15-20 kgm^{-2} to protect soil and roots on strip roads, when we use protective cutting method, where most removed trees are processed on strip roads and the treetops are turned parallel to the axis of strip roads. Use of this harvester working technique reduces the harvester productivity some 5 %, but gives a good cover for soil and reduces damage (Sirén et al., 2013). Poltorak et al., (2018) found, that mixed-wood brush mats of 15 and 20 kg/m^2 give significant soil protection with respect to soil displacement and rutting in mechanized harvesting operations. In final fellings Eliasson and Wästerlund, (2007) showed that slash thickness has effect on soil compaction and soil density. At 10 cm soil depth every 10 cm (0-20 cm) of slash reduced relative soil compaction with 12.9% and 4.5% per 10 cm slash at 20 cm soil depth. In that study slash thickness had no influence on rut depth. The rutting was thus relatively small over all. In a present study at Skogforsk (not published yet) rutting was heavily reduced when using slash on moist fine-grained soils. The study also indicates less fuel consumption and higher terrain transport speed when driving on slash, figure 1 (not published yet).

Fig. 1. Rutting after 6 passages while driving on slash (right) and after 1 passage with no protection.

In the study a full loaded forwarder where driving up 6 times on strip roads (100-150 m length) of 4 different treatments; Covered with slash, covered with wood mats and no cover. A fourth strip road was used as reference. Results indicates less rutting with slash and in addition the fuel consumption where reduced and the speed of the forwarder was increased (not yet published).

2.2 Tyres and variation of tyre pressures

There has been a trend for eight-wheeled machinery in forestry, both in harvesters and forwarders. Reasons for this are avoiding of soil damage and operator ergonomy. At the same time the sizes and weights of machines have increased, and today the typical weights for forwarders and harvesters are near 20 tons. Use of wider tyres have generalized, and the typical tyre width is 700 mm. Even the harvester does not carry the load and typically has only one pass on strip road, proper equipping is very important also for harvester. If the harvester disturbs the soil and causes ruts, it is very difficult to avoid more damaging in forwarding.

Lowering the tyre pressure is one possibility to minimize soil damage and rutting. The recommended tyre pressures depend on tyre, but are typically 350-550 kPa. When using lower tyre pressure, the instructions of tyre manufacturer must be remembered. In forest conditions the lowered tyre pressures can be 250-300 kPa. Even lower tyre pressures like 150 kPa have been used in tests (Sakai et al. 2008), but these “field” pressures cannot be used in practical operations, where we have stones and stumps. The guarantees of tyre manufacturers do not cover these very low pressures (Kärhä et al., 2010).

Use of “field” pressures remarkably decreases rut depth (Lövgren et al, 1996). In the study on peat field eight-wheeled forwarder was equipped with 600 mm and 800 mm wide tyres, and three different pressure levels were tested. For 600 mm wide tyres tested pressure in machine rear were 170, 300 and 430 kPa. Lowering of pressure reduced the rut depth 40-45 % with both tyre sizes. With lowest tyre pressure the rut formation with 600 mm tyre was near that of 800 mm tyre with normal pressure.

Eliasson, (2005) studied effect of tyre pressure on rut formation and soil compaction on mineral soil clearfelling site. The compared tyre pressures were 300, 450 and 600 kPa. Test machine was a 8-wheeled Timberjack 1710B -forwarder with full load, and measurements were carried out after 2 and 5 passes. First pass was driven with 6-wheeled harvester. Rut depths were not significant affected by tyre pressure but increased significantly with the number of machine passages. Soil density was significantly increased by 0.075 Mgm^{-3} by the harvester passage. Soil density increased significantly with increasing number of forwarder passages, but tyre pressure did not significantly influence this increase.

Kärhä et al., (2010) tested the influence of tyre pressure in thinning of spruce swamp. The tested tyre pressures were f.ex. for eight-wheeled forwarder (John Deere 1110 D) the recommended level, 360/550 kPa (front/rear), the lowered level 240/340 kPa and the minimum level 120/140 kPa. Lowering the tyre pressure reduced the rut formation. When the average rut depth with recommended pressure was 3 cm after harvester, with the lowest pressure the average rut depth was only 0.5 cm, the same level, which was reached with tracks on. With forwarder the lowered tyre pressure did not remarkably affect the rut depth, but allowed more passes (Kärhä et al., 2010). Even the use of lower tyre pressure has potential in reducing soil damage, risks for tyre break in forest conditions restricts the use. Due to this CTI (Central Tyre Inflation) is not in use in forest machinery.

Marra et al. (2018) studied the effect of tyre pressure and soil compaction on rut formation on a mineral agricultural soil. The compared tyre pressures were 150 and 300 kPa. Test machine was a fully loaded 8-wheeled Komatsu 830 forwarder. Measurements was carried out before the first pass and after 1, 3, 5, 7, 10, 20, 30 and 60 forwarder passages. The rut depths were significantly deeper with the higher tyre pressure already after 3 machine passes. This result was rather remarkable since already the higher pressure (300 kPa) can be considered as a very low tyre pressure in normal operational use. The soil compaction increased with increased number of machine passes, but no significant difference between high and low tyre pressure was found for soil compaction in this study.

2.3 Tracks chains and extra wheels

In poor bearing conditions use of tracks reduces rut formation. Compared to rather wide and soft tires, tracks on the bogie reduce the rut depth by up to 40 % and cone index in the ruts by about 10 %, although the tracks increase the mass on the trailerrear part of a forwarder by 10–12 % (Bygdén et al. 2003). When bogie tracks are used, the tyre pressures should be close to maximum levels. In last years the development in tracks has been active, and tracks for different soil conditions have come to markets. For the machine contractor, machine equipping can allow more year-round operation, but demands investments. The price of a pair of tracks is some 10 000 euros. There are special tracks for sensitive soils and peatlands, but these tracks can most often not be used in snowy conditions. The weight of a pair of tracks is near 2 tons, so the use of tracks increases the machine mass.

On sensitive soils the track type affects vehicle flotation. In Finland more than 20 % of harvesting potential is on peatland forests, where we need solutions for non-frozen period harvesting. There has been much development work on this field (Högnäs 1997), and there the tracks have had an important role. Also other track materials than steel have been tested. Examples of this are Moccasin-tracks made of polyurethane and rubber tracks (Bruun Twoo-forwarder and Valmet Botnia) have been tested (Högnäs 1997). Rubber tracks have shown good bearing properties in tests, but have had durability problems. In Sweden there have also been test with different forwarder concepts, both with long tracks, rubber tracks and individual steered wheels.

Three alternative forwarder concepts

In 2012-2017, three concept forwarders (Figure 2) were constructed and tested in collaboration between manufactures and Skogforsk; the *Xt28* pendulum arm forwarder (eXtractor AB); the rubber tracked *Gentle* (Komatsu Forest and BAE Hägglunds) and the *OnTrack* (Ponsse and Prinoth).

Fig. 2. The concept machines tested by Skogforsk in 2012-2017, Xt28, Gentle and OnTrack (left to right).

The Xt28 was developed for uneven and hilly terrain, and for minimized slippage and shearing. It has a fully hydraulic drive train powering individual hydraulic wheel hub motors. The frame is coupled by two articulation joints and its six wheels are mounted on pendulum arms. Dampening is achieved by complementing active suspension and passive shock absorbers. The automated levelling gives the machine good properties for work in slopes and on rocky, uneven terrain, reducing vibration and dynamic forces conveyed to the soil.

The two other concept forwarders address the problems with heavy transports on the usually even soft soils. Full length track systems were chosen for the superiour flotation properties, utilizing rubber tracks with internal dampening systems, aiming to reduce shearing and vibrations.

Gentle was based on a Komatsu 845 forwarder chassis mounted on the rubber track system from the all-terrain armored vehicle BvS10 manufactured by BAE Hägglunds. The undercarriage includes suspended pendulum arms carrying the road wheels, improving chassis suspension and reducing vibrations transferred to the cabin.

OnTrack, is a fully operational rubber-tracked forwarder. A Ponsse Buffalo long frame forwarder provides the chassis, while the rubber tracks are the Panther T6 (front) and T12 (rear) manufactured by Prinoth. Each track has two internal bogies with steel road wheels.

In tests on farmland and on vibration tests and speed tests all three concepts showed promising results (Björheden et al, 2018). All three machines gave less vibration than a conventional forwarder and the results indicated less soil disturbance than a conventional forwarder (Komatsu 845). The rubber tracks on "On track" showed less rutting than the steel tracks.

The concept machines show promising results for use on soft, sensitive soils (Gentle, OnTrack) and for work on rough, sloping terrain (Xt28). The reduction of rutting and vibration levels indicate that a higher proportion of the input energy is used for traction, and less energy is lost to the soil and to the machine chassis. Much work remains before the concepts are ready for practical forestry, but the results strongly encourage continued development efforts (Björheden et al. 2018)

Extra wheel in forwarder

Ovaskainen & Poikela, (2018) studied extra wheel of forwarder (Fig 3) to decrease soil disturbance and to increase extraction rounds with full load on the strip roads. The study investigated the technical functionality and impact of the extra wheel on strip road rutting in peatland conditions. The key idea behind the extra wheel is to improve forwarder mobility by pressing the ground from the center of the strip road. Extra wheel functioned technically well and it increased driving times approximately with two rounds with full load. Another key idea behind this solution is that it might be possible to replace special bearing capacity tracks that are needed only in peatland with this wheel. On good bearing capacity lands, the wheel can be lifted up.

Figure 3. Extra wheel in forwarder to decrease ground pressure.

2.4 Machine weights

Even the sizes and weights of machinery have increased, there has been much development in machines and tracks. Today there are 10-wheehed forwarders and forwarders with extended bogies on the markets. Ala-Ilomäki et al., (2011) compared the rut formation of modern and older machinery in pine bog. The old light 10-tonne six-wheeled forwarder Ponsse S 15 (in the figure 6W, the black dot) with tracks in rear was compared with modern eight-wheeled Ponsse Wisent with different Olofsfors-tracks and with the ten-wheeled prototype machine. The differences in rut formation between machines and tracks were clear (Fig. 4)

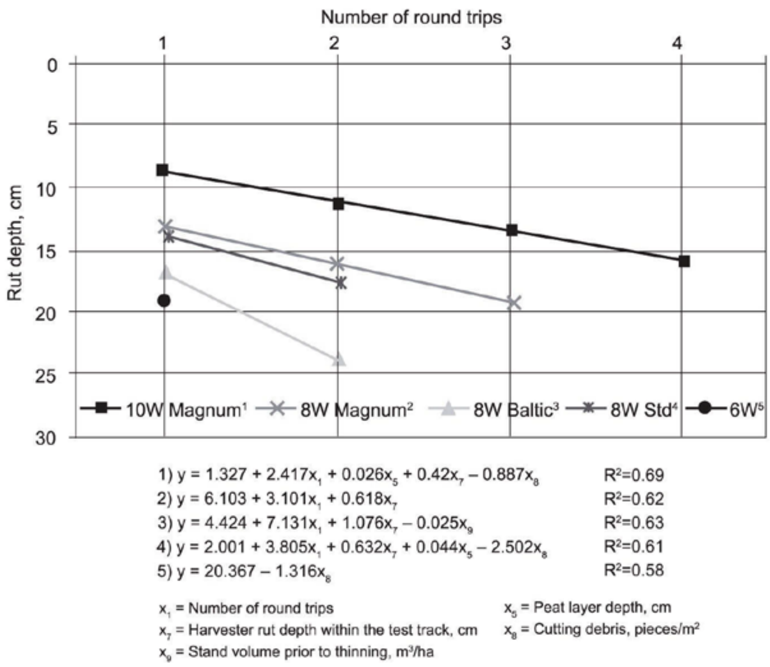

Fig. 4. Rut depth by number of return trips (one pass empty and one pass loaded with a load of 8 t) on the pine bog site (Ala-Ilomäki et al., 2011)

Excavator-type tracks have shown good capabilities especially on peatlands (Kärhä et al., 2010). In Finland they were first used in tracked Prosilva forwarder. In last years excavator-type tracks have had wider use both in harvesters and forwarders (Fig.5). One advantage of this track type is a continuous cover to the ground (Fig. 6)

Fig. 5. John Deere harvester equipped with excavator-type KOPA-tracks (Photo: Koneosapalvelu)

Fig 6. Excavator-type tracks have a good carrying capacity on soft soils. Excavator-type track in Prosilva-forwarder. (Photo: Jari Ala-Ilomäki/Luke).

Chains are often used both in harvesters and forwarders to give a good grip to the ground. Common solution is to have chains in front and tracks in rear of machines. However, in critical bearing conditions tracks are often used in both bogies. Earlier harvesters were mainly six-wheeled machines, but in the last years the percentage of eight-wheeled harvester has increased rapidly. In challenging bearing conditions six-wheeled harvesters can be equipped with wheel-tracks.

2.5 Sorters and flexible load frames

In Scandinavian cut-to-length method harvester cuts the trees to different wood assortments. We typically have several tree species on the cutting sites, and to the get the full value of wood material trees are cut to different assortments. In common situation we have 6-10 different assortments on the site.

In last decades the main focus in research and development has been in harvesters. However, if we look f.ex. soil damage, forwarding should be in the focus there. Manner, (2015) well summarizes the development situation and potential in forwarding. One important question, which affects both forwarding productivity and soil damage, is the choice between one assortment or mixed assortment loads. This question has been studied and discussed by Manner et al., (2013) and Väätäinen et al., (2013).

Väätäinen et al., (2013) studied the influence of different driving and loading tactics in thinning. In the study VRP (Vehicle Routing Problem) optimization was used, and different loading and driving alternatives was compared with the operator´s actual performance. The optimal driving technique was very near to the technique, where the total amount of driving is minimized. This means the use of mixed assortment loads and needs information on the location and volumes of different assortments. Today we can get the amount and locations of assortments from harvester HPR-files. With optimized and tutored forwarding we can reach remarkable increase in productivity, save in fuel costs and reduce in soil damage.

When forwarding a mixed assortment load, the unloading takes more time than with one assortment loads. Keeping the different assortments separated in the load helps in unloading. There can be different kind of “pockets” in the loadspace. Sorters (Fig. 7) are quite moderate investment and easy to install and they make driving of mixed assortment load more effective. When forwarding much room taking assortments like logging residues, the machine carrying capacity can to be taken to full use by using flexible load frames. With them we can decrease the number of loads, increase productivity, save fuel and soil.

Fig. 7. Sorters help in keeping wood assortments separated and make unloading of mixed assortment loads more effective. (Photo: Moisio Forest Oy).

2.6 Bridges and protective mats

Use of bridges in harvesting operations in Finland has not been very common, but some experiences and results are presented by Kontinen, (2014). In the study use of bridges were studied on ditches. The tested bridges (Fig. 8) were manufactured from wood. The length of bridges was 4 m, width 1 m and thickness 12.5 cm. They were tested before trials, and they tolerated the pressure of 140 kN before breaking.

Fig.8. Wooden bridge tested by Kontinen, (2014). (Photo: Pekka-Jussi Jääskeläinen).

Time consumptions both in loading of the wooden bridges and settling them on ditches were moderate. Handling of bridges goes well with forwarder. Use of bridges effectively reduced soil damage. They have use especially on peatland harvesting with many ditch crossings, but they can also be used in highly trafficked places, f.ex. near landings. However, it may be challenging to get bridges to operational use (Kontinen, 2014).

Portable log bridges have also been tested on soft flat soil in Sweden. The study was done at SLU, it is unpublished but the main results has been presented at a conference (Nordfjell & Östlund 2015). A standard 8 wheeled John Deere 1110 D loaded forwarder with tracks on the rear bogie was used. The total weight was 28.5 tons. Three pairs of comparison was done on very soft and wet fine textured moraine soil with con index 1.6 to 2.5 MPa. Measurements was done after 1, 2, 5, 10 and 20 passes with the machine. The results showed significant differences in rut depths or sinking of the log bridges already after one passage. The rut depths after 20 passes was in average between 42 and 52 cm without log bridges, and between 8 and 10 cm with log bridges. The 7-14% increase of cone index when using a log bridge was not significant. However, without log bridges it was a significant increase of cone index on 23-58%. Log bridges are commercial produced and marked on the Swedish market.

Logging residue mat is a good and cost-effective way to protect soil. However, in many highly trafficked places, e.g. near landings, we possibly need other tools to protect soil. Often the landing area may be apart from the logging site, and transporting the residues could be laborious. On peatland harvesting the places with poorest bearing capacity often have a very small removal, and thus sufficient residue mat is not available. In these critical points wooden or rubber mats can be a solution to protect soil. Airavaara et al., (2007) made a survey on use of different mats in harvesting (Fig 9). In critical but quite short points the use can be a rational solution. Kontinen, (2014) found, that driving bridgemats and rubber mats did not work properly. Steel cables, which tie rubber mats together, can cause problems.

Fig.9. Movable soil protection solutions (Thor, 2000, Owende, Lyons & Ward, 2002, Blinn et al.,1998, Nordfjell,T & Östlund, A. 2015).

Even there can be operational difficulties to use different protective mats, their use can be recommended when working at landscape sensitive areas, protected areas or in the vicinity of urban areas (Kontinen, 2014).

In operational Swedish forestry portable bridges or some kind of "on site" construction is demanded when crossing of water is necessary in thinnings and final fellings. Most often wood bridges built with wood and logs on the site are used, fig 10. The use of bridges on water crossings has shown good effect concerning reducing the negative impact on water quality due to forest activities (Swedish forest agency, oral comment)

Fig 10. Wood bridge built with logs on the clear cut site.

3 Summary and conclusions

Some additional accessories, equipment and methods are described above. Some of them, like residue mat, can often be utilized with low costs. e.g. in Norway spruce thinnings use of protective cutting method decreases productivity only moderately, but gives good protection to soil and roots. Device like sorters are not an expensive investment, but with them you can raise productivity, minimize driving and thus decrease rutting. Investment on special tracks is more expensive, as you may need different tracks for winter and non-frozen period. But here we must remember, that also the life time of tracks is tied to the decree of machine utilization. Operating in sensitive sites is more costly than operating in high bearing mineral soils. Väätäinen et al., (2010) studied the cost effects of year-round harvesting on peatlands by discrete-event simulation method. Simulations were made for different winter lengths, shares of peatland sites, shares of sites harvested in non-frozen period with four different track installations for soft soils. When one third of the conventional logging machinery was equipped for peatlands, the share of peatland harvesting sites could be up to 40-50 % of the annual harvesting volume. However, machine equipping and extra costs in non-frozen period harvesting on peatlands caused extra costs. On the other hand, more year-round harvesting and increased use of machinery compared with the alternative of harvesting peatlands only in wintertime during frozen ground could reduce the machine costs and divide operations smoother through the year.

To be profitable, equipped machines for soft soil operations require high yearly working hours. An important factor is also the right selection of peatland sites to be harvested in function of soil bearing classification of sites.

In changing weather conditions and need for year-round harvesting operations, tailoring the machinery to demanding conditions is important. Minimizing of harvesting damage is needed to secure healthy forests and also the overall acceptability of forestry. With increasing wood demand the importance of these factors is escalating. Additional accessories and methods facilitate overcoming these challenges, together with the developed planning and operator tutoring software tools and big data utilization.

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