# Productivity when forwarding fresh and dried logging residues

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**Abstract:**
*In Sweden, logging residues are commonly left on the logging site to dry during a summer before they are forwarded to the landing. Recently the interest for forwarding of logging residues directly after the harvesting operation has increased. It is perceived to have a number of advantages, e.g. the same forwarder that was used to forward sawlogs and pulpwood can be used, more of the material is recovered, increased forwarder productivity and the site can be replanted during the first summer after the cut. In order to examine if drying of residues prior to forwarding affected forwarder productivity a field study was made. In three blocks residues from half of the area were forwarded directly after the cut early in June and the remaining residues were forwarded in the last week of August. Results show that there were no differences in productivity measured as dry tonnes per effective hour between forwarding of freshly cut residues and dried residues given the same concentration of residues per ha. Average productivity for both treatments was 7.9 tonnes of dry matter per effective hour. However, a conservative estimate based on literature is that at least 10 % more dry matter will be recovered when residues are recovered directly after the cut rather than if they are left on average 6 to 8 months on the logging site. This corresponds to a productivity increase with approximately 4 % if residues are forwarded directly after harvest.*

**Keywords:** keyword, keyword, keyword, keyword

## 1 Introduction

There has been a lot of development affecting logging residue forwarding during the last decade. The most important is an increase of load utilization of the machines, actual load weights has increased from between 5000 to 8000 kg up to a span from 8000 to 12000 kg. This has been accomplished through dedicated logging residue bunks, rear supports for the load, and other additions to the loading compartment. Load utilization is still low, approximately 75 per cent, since many of the forwarders used have a load capacity of 14 to 16 metric tons. Furthermore there still are contractors that use the same technical solutions as 10 or 15 years ago and thus still have a load utilization of approximately 50 per cent.

During the last years forwarding of freshly cut residues during or soon after the round wood harvest has gotten more attention. It is considered to increase forwarder productivity, enable the use of the round wood forwarder for forwarding of residues, and increase the area where residue harvest is possible. Finish studies show that the increase in productivity is small, ca 2 %, given the same forwarding conditions (Asikainen et al, 2001). However, there might be an additional effect on productivity and on the profitability of the biomass business if, as some claims, the extracted volumes are higher when fresh residues are forwarded compared to when they are seasoned on the logging site.

The aim of this study was to determine if forwarding of fresh residues decreases forwarder time consumption per ton dry matter and if it affects forwarder load size in odt.

## 2 Material and Methods

The study was made on a final felling site close Åsbro (N58 59.243 E15 05.948). The site was harvested in beginning of June 2010. After harvesting the site was divided into three blocks dependent on terrain and residue concentration. Each block was split in two plots and within blocks treatments were randomly allocated to the plots. Fresh residues were forwarded June 16 and 17, dry (seasoned) residues were forwarded August 25 and 26.

Forwarding was done with a John Deere 1110D forwarder equipped with four set of bunks and a two rearward leaning posts as a rear support for the load (figure 1). It was operated by an experienced operator who mostly work in residue forwarding interspersed with some round wood forwarding.

**Figure 1: The load area on the forwarder. Note the framework on the bunks and the rearward extension with the two slightly rearward leaning additional rear posts.**

Blocks were establish to ensure that the the forwarding conditions, i.e. terrain and residue concentrations, were comparable between treatments. Each block was split in two plots. Each plot should be big enough for extraction of a minimum of three forwarder loads. The overall characteristics of the blocks were:

Block 1. The harvested trees were evenly mixed between pine (*Pinus Sylvestris*) and spruce (*Picea Abies*), yielding a low residue concentration. Seed trees of pine were left. The ground conditions were fairly good, a few stones and a 12 % average slope equaling surface structure class 1 and slope class 2 according to the classification scheme (Berg 1992). Forwarding was done down hill.

Block 2. The harvested trees were dominated by pine (>75 %), and the residue concentration were on a medium level. Seed trees of pine were left. The ground was flat with no stones (surface structure 1 and slope 1).

Block 3. The harvested stand was an almost pure spruce (>90 %) stand yielding a high residue concentration. The ground was flat with no stones (surface structure 1 and slope 1).

Ten loads were studied per treatment, 3 loads per treatment in block 2 and 3, and 4 loads per treatment in block 1. Each forwarded load was considered as a replicate and was laid into a separate pile at roadside. Each pile was thereafter transported to the mill in Frövi where it was weighed and samples were taken for moisture content determination. Moisture content of the samples by weighing them fresh and after drying at 105 °C until no lose further weight loss occurred (i.e. according to SCAN-CM 39:94).

The time study of the forwarding work was done as a comparative time study with snap back timing (Bergstrand 1987). Time recording was made with Allegro hand-held computers equipped with Skogforsk SDI software. Forwarding work was split into 10 elements (table 1). All measured times for each load has been summarized per work element and divided by the oven dry mass of the load to get times in centiminutes per oven dry ton (odt). For the analysis of forwarder speed time per load has been used. In the analysis the elements *Boom out*, *Grapple*, *Collection*, *Boom in*, *Release*, *Driving when loading*, and *Unloading* have been summarized in the main work element *Loading & unloading.* Only effective times have been included in the analysis, thus no delays are reported.

**Table 1: Definition of work elements**

| Work element | Description |
|---|---|
| *Boom out* | From that the boom starts moving from the trailer until the grapple is opened and lowered over a residue pile. |
| *Grapple* | From *Boom out* until the grapple is closed and has lifted the residue pile |
| *Collection* | From *Grapple* until the operator finishes to add residues into the grapple |
| *Boom in* | From the grapple has lifted the complete burden until it is lowered over the trailer |
| *Release* | Release of the residues from the grapple and adjustments of residues on the load |
| *Driving when loading* | The forwarder moves with load although the load not is full at the same time as the boom not is moving |
| *Unloading* | From that the forwarder has stopped on the landing and the boom starts to move until the grapple is laid to rest on the empty trailer |
| *Driving empty* | From that the forwarder starts to move on the landing until the boom starts to move to load the first residue pile |
| *Driving with load* | From that the forwarder starts to move with full load until it stops on the landing |
| *Delay* | Non productive time (phone calls, down time, etc.) |

Work elements has been analysed with analysis of covariance, using a general linear model in SAS, in order to detect treatment effects in element time per odt. The inverse of residue concentration per 100 m of strip road has been used as covariate except for in the analysis of *Driving empty* and *Driving with load* were travelled distance has been used as covariate. The following model has been used:

$$T = \mu+\alpha^{(T)}+\alpha^{(B)}+\alpha^{(T\times B)}+\beta\times C+\varepsilon$$

where $\alpha^{(T)}$ is the fixed effect for treatment, $\alpha^{(B)}$ is the fixed effect for block, $\alpha^{(T\times B)}$ is the interaction effect, $\beta\times C$ is the effect of the covariate, and $\varepsilon$ is the random error.

## 3 Results

There were no differences in load size expressed in odt between treatments. The average load was 4.1 odt (gross weight 7.1 ton) when fresh residues were forwarded and 4.2 odt (gross weight 6.7 ton) when dried residues where forwarded. Load weights varied from 3.15 to 4.84 odt, with both the lightest and heaviest loads occurring when fresh residues were forwarded.

There were no differences in travel speeds between treatments. The forwarder traveled with a speed of 50.3 m per minute when traveling empty and a speed of 39.4 m per minute when loaded.

When forwarding dried residues the total time was 759,1 centiminutes $odt^{-1}$ and for fresh residues the total time was 764.4 centiminutes $odt^{-1}$. This corresponds to a productivity of 7.9 odt $E_0h^{-1}$ in both treatments. When the total time is split in the three main elements no differences between dried and fresh residues can be found for any of the elements (table 3). The covariate $1/odt_{100}$ has a highly significant effect on *Loading and unloading* time (table 3) as has the covariate traveled distance for the elements *Driving unloaded* and *Driving with load* (data not shown).

**Table 2: Time consumption and level of significance for the comparison of treatments for the main work elements**

| Work element | Dried [cmin/odt] | Fresh [cmin/odt] | Significance |
|---|---|---|---|
| *Loading & unloading* | 509,8 | 508,1 | NS (p=0.166) |
| *Driving empty* | 130,5 | 134,4 | NS (p=0,770) |
| *Driving with load* | 118,8 | 121,9 | NS (p=0,614) |

**Table 3: Full Ancova table for *Loading and unloading***

| Source | DF | Type III SS | DF | F | p |
|---|---|---|---|---|---|
| Treatment | 1 | 4684.05 | 4684.05 | 2.12 | 0.166 |
| Block | 1 | 2171.53 | 2171.53 | 0.98 | 0.337 |
| Treatment*Block | 1 | 5125.17 | 5125.17 | 2.32 | 0.149 |
| Covariate ($1/odt_{100}$) | 1 | 26686.29 | 26686.29 | 12.06 | 0.003 |

The time (cmin $^{odt-1)}$ for *Loading and unloading* can be modeled as:

$$T=187.9+653.2odt_{100}^{-1}$$

since neither treatment nor block had a significant influence. This model explains 74.9 % of the variation ( $R^2$) vs the full model that explains 78.5% of the variation (cf figure 2).

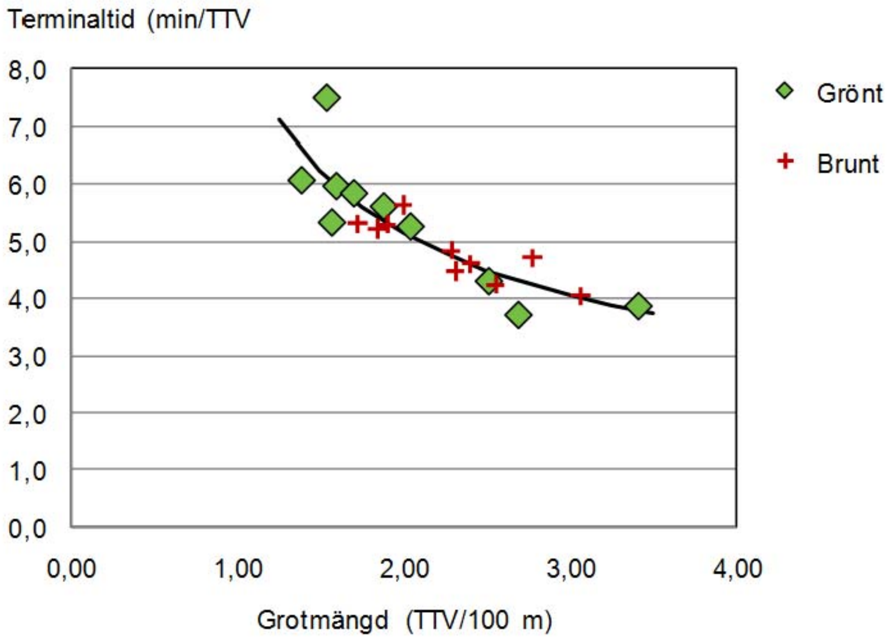


**Figure 2: Loading and unloading time vs the residue concentration per 100 m of striproad**

### 3.1 Loading and unloading time

When analyzing the detailed work elements that make up the *Loading and unloading* time, differences between forwarding of dried and green residues can only be found for the work elements *Collection* and *Unloading* (table 4). A probable explanation for the increased *Collection* time is that dried residues ar brittle and more prone to falling apart than the fresh residues. The increased *Unloading* time for fresh residues might be explained by the higher gross mass of the residues.

**Table 4: Time consumption and level of significance for the comparison of treatments for the detailed work elements included in the main work element *Loading and unloading***

| Work element | Dried [cmin/odt] | Fresh [cmin/odt] | Significance |
|---|---|---|---|
| *Boom out* | 64.4 | 61.3 | NS (p=0,291) |
| *Grapple* | 50.0 | 49.1 | NS (p=0,834) |
| *Collection* | 53.6 | 36.3 | Sign (p=0,0146) |
| *Boom in* | 77.5 | 76.5 | NS (p=0,723) |
| *Release* | 49.0 | 48.4 | NS (p=0,799) |
| *Driving when loading* | 128.8 | 142.3 | NS (p=0,389) |
| *Unloading* | 89.1 | 106.9 | Sign (p=0,008) |

## 4 Discussion

In an earlier study a 2 per cent difference in forwarder productivity were found between fresh and dried residues (Asikainen et al , 2001). However, in the current study no significant difference between treatments was found, and it is doubtful that a 2 per cent difference could have been detected given the small sample and the variability in time consumption. A common theory explaining why the productivity should be higher when forwarding fresh residues is that the biomass recovery is higher thus increasing the forwarded amount of residues per meter of strip road. Such an effect would not be detectable as residue concentration per meter of strip road was used as a covariate in both our and the Finnish model. There are no large differences in estimated time consumption between our model and the model of Asikainen et al. (2001). However, the material that we base our results on is small and based on only one part of the country, one operator and one machine. Thus, further studies are necessary.

The study shows that the *Collection* work was more efficient when fresh residues were forwarded compared to when they had been left to dry on the logging site. A probable reason for this is that as residue piles are drying, the branches gets more brittle and grass and other vegetation starts to grow up through the edges of the piles. This makes it more demanding to pick up the pile from the ground. On the other hand, surprisingly, *Unloading* was less efficient when the residues were fresh. A possible explanation can be the differences in gross weight of fresh and dry residues and perhaps fresh residues are more prone to get tangled up in the load.

Studies of residue recovery rates for fresh and dried residues (cf. Filipsson & Andersson, 2001) indicates that 10 per cent is a plausible estimate of the increased in recovery rate when fresh residues are forwarded. If one assumes that the recovery of dried residues is 2 odt per 100 m of strip road this gives a recovery of 2.2 odt per 100 m when fresh residues are forwarded. Given a time for *Driving loaded* of 132,5 centiminutes, *Driving with load* 120.4 cmin and *Loading and unloading* time calculated according to the model, this corresponds to a 4 per cent higher productivity when forwarding fresh residues. As this estimate is based on the short forwarding distances of the study and only effective work time has been considered in the calculation, it is an overestimate of the possible productivity increase in actual operations.

## 5 Conclusion

There were no differences in productivity measured as dry tonnes per effective hour between forwarding of freshly cut residues and dried residues given the same concentration of residues per meter of strip road.

## 6 References

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