Agronomy Research **13**(2), 348–353, 2015

Direct and indirect energy input in the harvesting of Scots pine and Norway spruce stump-root systems from areas cleared for farmland

R. Lauhanen[1,*], J. Ahokas[2] and J. Esala[1]

[1]Seinäjoki University of Applied Sciences, School of Food and Agriculture, Ilmajoentie 525, FI60800 Ilmajoki, Finland
[2]University of Helsinki, Faculty of Agriculture and Forestry, Koetilantie 5, Helsinki, Finland
[*]Correspondence: risto.lauhanen@seamk.fi

Abstract. The aim of this study was to find the net energy and energy ratios for the recovery of Scots pine and Norway spruce stump-root systems when clearing land for cultivations. The energy analyses were carried out for direct and indirect energy under Finnish conditions. In the base study case for direct energy input; the net energy yields for stump-root system harvesting were 446–698 GJ ha^{-1}, and the energy ratios were 22–33. In the case of indirect energy input the net energy yields were 440–692 GJ ha^{-1}, and the energy ratios were 17–26. The proportion of indirect energy was low, because the amount of operating hours annually was high. When calculating indirect energy, only the energy input of machine manufacturing was used, since there was no data on the indirect energy used for repair and maintenance of the machines. The energy assessment for repairing and maintenance operations for heavy forest machines and vehicles in bioenergy procurement will need to be assessed.

Key words: agricultural land, bioenergy, clarification of forest land, energy assessment, forest machines, wood-based energy.

INTRODUCTION

New agricultural land is needed in Finland, especially for dairy farms. During 2000–2011 a total of 95,000 hectares of forest area was cleared for farmland (Niskanen & Lehtonen, 2014). In western Finland, peatlands with poor forest stands particular have been cleared for farmland, as well as clear-cut spruce stands with low stone-index (see Niskanen & Lehtonen, 2014).

The European Union aims to prevent climate change and to increase the use of renewable bioenergy (e.g. Hakkila, 2004; Laurila & Lauhanen, 2010). In Finland forest bioenergy consists of small-diameter stems from young stands and logging residues with stump-root systems from forest regeneration areas (e.g. Hakkila, 2004; Laitila et al., 2012). In addition, agro-biomass, e.g. reed canary grass and straw are also used for bioenergy in Finland (e.g. Mikkola, 2012).

In Finland, stumps are harvested for fuel for power plants with a boiler size of 5 MW or more (Laurila & Lauhanen, 2010). The energy content of stumps and roots is 130–200 MWh ha^{-1}, i.e. 468–720 GJ ha^{-1} (Hakkila, 2004; Lauhanen et al., 2014). It is rational for the forest-owners to sell forest biomass to energy companies, and to get stumpage price for the wood (Lauhanen et al., 2014).

Stump-root system extraction is essential in clearing forest for farmland. Incomes from stumps increase the profitability of preparing new farmland (Lauhanen et al., 2014). There have been debates on the environmental effects of the utilisation of stumps and roots. The ratio of output to input energy (i.e. energy ratio) has been discussed as well. (Lauhanen et al., 2014).

The energy inputs for forest energy production and the energy contents of forest energy have also been discussed. The direct energy input of forest energy has been 2–4% of the output energy in the earlier studies (Laitila et al., 2012). The indirect energy input for forest machines in bioenergy procurement has not been published previously in Finnish conditions. The indirect energy input of machine manufacturing, repairing and maintaining the machines should also be assessed as it has been for agricultural machinery (Mikkola & Ahokas, 2010).

The hypothesis for this study is that the high amount of operating hours of forest machines will result in low indirect energy input of forest machines in stump-root system supply chain.

The objective of this study was to calculate the net energy and energy ratios for the recovery of Scots pine and Norway spruce stump-root systems under Finnish conditions.

MATERIALS AND METHODS

Energy terms and work chains

The energy content of stump-root systems were based on the earlier studies (Hakkila, 2004; Laurila & Lauhanen, 2010; Laitila et al., 2012). The direct energy input was based on the fuel consumption of forest machines, stump crushers and stump trucks (Laitila et al., 2012). The indirect energy input contained the energy input of tractor manufacturing (Hakkila, 1989; Mikkola & Ahokas, 2010).

The work chain contained: stump-root extraction by excavator, forwarder use on the work site, stump crusher use at the forest road-side storage as well as the truck transportation of crushed stumps from the forest road-side storage to the power plant. (Laurila & Lauhanen, 2007; Laitila et al., 2012). It is not rational to transport the uncrushed stumps and roots too long distances due to their low energy density in truck load (see Hakkila 1989).

Energy content of stump-root systems

The energy content of stump-root systems was assumed to be 468 GJ ha^{-1} (= 130 MWh ha^{-1}) for Scots pine mire, if all stump-root systems were harvested. (Hakkila, 2004). Timber removal from the clear cutting area was 260 m^3 ha^{-1}. The energy content of the stump-root systems was assumed to be 720 GJ ha^{-1} (= 200 MWh ha^{-1}) on mineral soil, if all of the Norway spruce stump-root systems were extracted. (Laurila & Lauhanen, 2010; Lauhanen et al., 2014). In this case, the timber removal was 400 m^3 ha^{-1}. Consequently, the energy contents of 468 GJ ha^{-1} and 720 GJ ha^{-1} for the stump-root systems were applied in the analyses.

Work site and work productivity

In the calculations, the typical work site area was 3.0 hectares. In which case the energy content of the stumps was 1,512–2,160 GJ ha^{-1} depending on the forest type. Stump-root system extraction by excavator took 3.0 days with one work shift per day; i.e. typical work productivity was 1.0 hectare per day (Fig. 1) (Laurila & Lauhanen, 2007). The same productivity rate was assumed for the forwarder on the work site (Laurila & Lauhanen, 2007). The work productivity for the stump crusher was assumed to be 100 loose cubic meters per operating hour at the forest road-side storage; based on Lauhanen et al. (2014). The crushed stumps were transported by truck from the forest road-side storage to the power plant the transportation distance being 45 kilometers (Laitila et al., 2012).

Figure 1. Excavator in stump-root system extraction on one peatland forest site (Jussi Laurila).

Direct and indirect energy

The direct energy input was calculated on the basis of the work site information and the fuel consumptions of the forest machines and vehicles (Tables 1, 2) (Laitila et al., 2012; Lauhanen et al., 2014). The energy content was 35.1 MJ per one litre of fuel. Thus, total direct energy input in the supply chain was 64.8 GJ from forest work site to power plant (Table 1).

Table 1. Fuel consumptions of the work machines and vehicles in the stump-root system supply chain. The work site was 3.0 hectares, and the transportation distance for the chip-truck was 45 kilometres. Legend: Weight = machine weight in tons, Hours = operating hours per work site of 3.0 hectares, Fuel = fuel consumption litres per an operating hour, and Energy = fuel-based direct energy input in GJ. (Laitila et al., 2012; Lauhanen et al., 2014)

Work machine	Weight	Hours	Fuel	Energy
Forwarder	10	27	12	11.4
Crusher	36	9	65	20.5
Truck	20	9	50	15.8
Total	87	72	1,845	64.8

Table 2. Fuel consumptions of the work machines in the logging residual (residual wood) supply chain. Legend: Weight = Machine weight in tons, Hours = operating hours per work site of 3.0 hectares, Fuel = fuel consumption litres per an operating hour, and Energy = fuel-based direct energy input in GJ. (Laitila et al., 2012; Lauhanen et al., 2014)

Work machine	Weight	Hours	Fuel	Energy
Harvester	10	27	0	0.00
Forwarder	10	27	12	11.37
Crusher	36	9	65	20.53
Truck	20	9	50	15.80
Total	76	72	1,359	59.10

According to Hakkila (1989), the indirect energy input of tractor manufacturing was assumed to be 158.9 MJ kg^{-1}. First, this value was multiplied with the mass of the machine or vehicle (kg). Secondly, this indirect energy input (GJ) was related to work site hours per the life-time of the machine or vehicle in hours. The technical life-time of the machinery was assumed to be 4.0 years, i.e. 12,000 hours totally (Lauhanen et al. 2014). These numbers were equal to 3,000 operation hours per one machine or one vehicle in forest energy procurement (Laitila et al., 2010; Lauhanen et al., 2014).

Energy analyses

In the calculations energy analyses were computed for stump-root system extraction from Scots pine and Norway spruce stands (cf. Mikkola & Ahokas, 2010). The net energy was the difference between the energy content of the stump-root systems and the energy inputs for the forest machines and vehicles (in GJ ha^{-1}). The energy ratio was obtained, when the energy content of the stump-root systems was divided by the energy inputs of the machines and vehicles (Mikkola & Ahokas, 2010).

The sensitivity analyses were also calculated with the varying fuel consumptions of excavators (i.e. 12 litres per an operating hour and 18 litres per operating hour) (Laitila et al. 2012; Lauhanen et al. 2014).

Before stump-root system extraction the residual wood needs to be harvested, too (Laitila et al., 2012) Additional and comparative energy analyses were also assessed (Table 2). The energy contents of the residual wood were 396–566 GJ ha^{-1} (= 110–160 MWh ha^{-1}).

One-grip harvester is a forest machine that carries out tree-felling and prepares saw logs and pulp wood for the mills. (Lauhanen et al., 2014). On clear-cutting work sites one-grip harvester also makes the small piles of saw logs and pulp wood and also the low piles for residual wood (Laitila et al., 2012; Lauhanen et al., 2014). This is conventional work for one-grip harvester, and that is why the energy input for the one-grip harvester in this work was assumed to be 0.00 GJ (Table 2) (Laitila et al., 2012). After one-grip harvester, the forest forwarder removes the small wood piles into great wood storages along the forest road sides. (Laitila et al., 2012; Lauhanen et al., 2014).

RESULTS AND DISCUSSION

In the case of direct energy input, the net energy yields for wood stump-root system harvesting were 446–698 GJ ha^{-1}. The energy ratios were 22–33. In the case of indirect energy, the yields were 440–692 GJ ha^{-1}, and energy ratios were 17–26.

The case of an excavator of 21 tons with the fuel consumption of 12.0 liters per an operation hour was also calculated in the sensitivity analysis. In which case, the net energy yields for wood stump harvesting were 448–700 GJ ha^{-1}. The energy ratios were 24–37. In the case of indirect energy input, the net energy yields were 442–694 GJ ha^{-1}, and energy ratios were 18–28.

For the harvesting of residual wood, in the case of direct energy the net energy yields were 386–566 GJ ha^{-1}. The energy ratios were 40–59. In the case of indirect energy input the net energy yields were 384–564 GJ ha^{-1}, and energy ratios were 33–47. The fuel consumption was lower for the logging of residual wood than for stump-root system logging, but also the energy content of the residues was lower than that of stumps.

This direct energy assessment produced results that were comparable with the results of Laitila et al. (2012). The energy yields and ratios for indirect energy of forest stump-root systems and residual wood however, were new.

According to Hakkila (1989), the indirect energy input of tractor manufacturing in was assumed to be 158.9 MJ kg^{-1}. Later Mikkola & Ahokas (2010) and Mikkola (2012) used the value of 86.8 MJ kg^{-1} energy input for the manufacturing energy of modern agricultural machines, but we applied the higher value given by Hakkila (1989). The share of indirect energy input for the manufacturing of forest machines was however low in this study, since the life-time of the machines was rather short and there were lots of annual technical operation hours. Thus, these energy assessment calculations confirmed the hypothesis for this study.

We had no sufficient data for the indirect energy input of the forest machines and vehicles, because the energy input data for the repair and maintenance was not available. The inventory on the energy input of the repair and maintenance of forest machines is thus needed in the further studies.

The fuel consumption of the machinery affected the results. Sensitivity analyses and the evaluation of the initial parameters were important in the calculations. However, the energy input of the forest roads and earlier forest stand operations were not included in the calculations, since it was difficult to evaluate them as Mikkola (2012) stated for the calculations in agriculture. On the other hand, the forest roads and earlier forest operations were assumed to be constant in the calculations. The modern forest energy terminals were excluded in the calculations. In which case, the indirect energy of terminals should be assessed as well. Also, the wood stump material loss was not included in the analyses.

CONCLUSIONS

Stump-root system extraction and collection of logging residues are essential in clearing of forest for farmland. The results showed that the net energy of harvesting of the stump-root systems and logging residues was clearly positive. Landowners and farmers sell stump-root systems and logging residues for energy when they clear forest for farmland. Farmers usually outsource the clearing work to contractors.

The direct energy input of the clearing work was detected to be equal as in the earlier studies. The indirect energy input of forest biomass utilization was assessed in this study for the first time in Finland. The proportion of indirect energy input was low due to the high annual number of operating hours. For indirect energy input only the energy used in machine manufacturing was used in the calculations, because there was no sufficient data on the indirect energy input of repair and maintenance of the machines.

ACKNOWLEDGEMENTS. Dr. Hannu J. Mikkola gave valuable comments for the manuscript. University of Helsinki and Seinäjoki University of Applied Sciences provided work sites and facilities for this study. Mr John Pearce checked the English text. M.Sc. Tuomas Hakonen and M. Sc. Ismo Makkonen helped in the photograph processing.

REFERENCES

Hakkila, P. 1989. Utilization of forest residual biomass. Springer-Verlag, Berlin, 568 pp.

Hakkila, P. 2004. Wood energy technology programme in 1999–2003. The production of forest chips. Loppuraportti. *Tekes. Teknologiaohjelmaraportti* **5,** 1–135. (in Finnish)

Laitila, J., Heikkilä, J. & Anttila, P. 2010. Harvesting alternatives, accumulation and procurement cost of small-diameter thinning wood for fuel in Central Finland. *Silva Fennica* **44**(3), 465–480.

Laitila, J., Asikainen, A. & Pasanen, K. 2012. The procurement technology, logistics and carbon dioxide emissions. *Metlan työraportteja* **240,** 171–184. http://www.metla.fi/julkaisut/workingpapers/2012/mwp240.htm Accessed 16.1.2015. (in Finnish)

Laurila, J. & Lauhanen, R. 2007. The productivity and operating costs for the stump-root system harvesting and forwarding. In: Lauhanen, R. & Laurila, J. (eds.) Bioenergian hankintalogistiikka. Tapaustutkimuksia Etelä-Pohjanmaalta. *Seinäjoen ammattikorkeakoulun julkaisuja* **B33,** 68–92. (in Finnish)

Laurila, J. & Lauhanen, R. 2010. Moisture content of Norway spruce (Picea abies (L.) Karst.) stump wood at clear cutting areas and roadside storage sites. *Silva Fennica* **44**(3), 427–434.

Lauhanen, R., Ahokas, J., Esala, J., Hakonen, T., Sippola, H., Viirimäki, J., Koskiniemi, E., Laurila, J. & Makkonen, I. 2014. Mathematics for B.Sc. and M.Sc. students in forestry. *Seinäjoen ammattikorkeakoulun julkaisusarja C. Oppimateriaaleja* **6,** 1–167. (in Finnish)

Mikkola, H. 2012. Finnish field crop production for energy. Potential, energy ratios and net energy. Helsingin yliopisto, Maatalous-metsätieteellinen tiedekunta. *Maataloustieteiden laitos. Julkaisuja* **10,** 1–93. (in Finnish)

Mikkola, H. J. & Ahokas, J. 2010. Indirect energy input of agricultural machinery in bioenergy production. *Renewable Energy* **35**, 23–28.

Niskanen, O. & Lehtonen, E. 2014. Maatilojen tilusrakenne ja pellonraivaus Suomessa 2000–luvulla. Development of parcel structure and clearing of new fields in Finland in the 2000s. *MTT Raportti* **150,** 1–27. http://www.mtt.fi/mttraportti/pdf/mttraportti150.pdf Accessed 2.1.2015. (in Finnish)