Forest Ecology and Management 338 (2015) 57–67

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Negative effects of stem and stump harvest and deep soil cultivation on the soil carbon and nitrogen pools are mitigated by enhanced tree growth

Gustaf Egnell *, Arnis Jurevics [1], Matthias Peichl [1]

Department of Forest Ecology and Management, Swedish University of Agricultural Sciences, SE-90183 Umeå, Sweden

A R T I C L E I N F O

Article history:
Received 1 October 2014
Received in revised form 3 November 2014
Accepted 11 November 2014
Available online 6 December 2014

Keywords:
Stump harvest
Site preparation
Soil carbon
Forest production
Nitrogen
Climate change

A B S T R A C T

New energy policies in many forest rich countries have promoted the utilization of industrial and logging residues for energy purposes. This practice is, however, questioned from a climate change mitigation point of view, particularly when it comes to the harvest of coarse woody biomass like stem wood and stumps.

Stump harvest removes slowly decomposing biomass with its carbon (C) and nutrients. The harvest operations also cause soil disturbance that may stimulate mineralization of the soil organic pool, and thereby further increase the C and nutrient loss from the site. However, increased mineralization and expected decrease in amount of competing vegetation could make more nutrients available that stimulates growth of the new tree generation and thereby compensates for the soil C loss.

Based on two field experiments, located in southern and northern Sweden, we present C and nitrogen (N) pool data in soil (0–70 cm depth) and tree biomass 22 and 24 years after stem and stump harvest and deep soil cultivation (SS-DSC) in comparison to conventional stem-only harvest and a manual patch scarification (S-PS). The SS-DSC management practice represents a "worst case" in terms of potential C and N loss.

We tested the hypotheses that SS-DSC (i) will reduce C and N pools in the soil; (ii) will increase C and N pools in the planted trees; (iii) will not have any effect on the total C and N pools (soil and tree biomass) as compared to S-PS.

Soil C and N pools were lower following SS-DSC in line with hypothesis (i) but only statistically different for C at the northern site. Tree biomass C and N pools were significantly increased by the SS-DSC treatment in line with hypothesis (ii). As a result, the total C and N pools were not significantly affected by SS-DSC in line with hypothesis (iii).

The main conclusion from these results is that judgments on the effects of silvicultural measures on the forest C and N balances or net greenhouse gas emissions cannot be based on measurements of single C or N pool changes (i.e. in the soil or in the trees only) – it has to be based on changes in the total C or N pool. The trade-off between soil and tree biomass C and N pools is discussed in terms of possible causes, current forestry practices, and the climate change mitigation potential of soil *vs.* tree biomass C.

1. Introduction

Following the two oil crises in the 1970s, the UN conference on environment and development in Rio 1992, the Kyoto protocol (United Nations, 1998), and the Renewable Energy Directive in Europe (Directive 2009/28/EC), policies in many countries have shifted in favour of renewable energy sources. This has stimulated the development of market and supply of biomass for energy – a renewable energy source with assumed climate benefits (Berndes and Hansson, 2007). Currently, biomass constitutes a substantial source of energy in many European countries (Ericsson and Nilsson, 2006; Ericsson et al., 2004; Hansson et al., 2009). For instance, in Nordic countries industrial residues from the forest industry (e.g. bark, sawdust, shavings) are already fully used, and increased demand has been met with the use of logging residues: non-merchantable wood, branches, tops and stumps (Mantau et al., 2010).

---

* Corresponding author. Tel.: +46 90 7868455; fax: +46 90 7868163.
E-mail addresses: Gustaf.Egnell@slu.se (G. Egnell), Arnis.Jurevics@slu.se (A. Jurevics), Matthias.Peichl@slu.se (M. Peichl).
[1] Tel.: +46 90 7868455; fax: +46 90 7868163.

http://dx.doi.org/10.1016/j.foreco.2014.11.006

The climate benefits of using biomass from long rotation forestry for energy is, however, questioned (Johnson and Curtis, 2001; Zanchi et al., 2012), particularly when it comes to coarse woody biomass like stumps, that decompose more slowly than tops and branches (Pingoud et al., 2012; Repo et al., 2012; Zanchi et al., 2010). Biomass combustion releases carbon dioxide (CO_2) immediately, whereas decomposition of the same biomass left in the forest would release CO_2 at a slower rate. Additionally, the next generation of trees initially accumulates carbon (C) at a relatively slow rate and reaches the maximum C storage only at the end of the rotation period. This creates a time lag before emitted CO_2 from direct combustion of biomass is balanced by CO_2 emitted due to decomposition if the biomass would have been left on site together with CO_2 captured in regrowth in the subsequent stand. This time lag together with the additional CO_2 emissions required to deliver the same energy service as compared to a fossil fuel, is referred to as the C debt (Holtsmark, 2013, 2012; Manomet Center for Conservation Sciences, 2010). Thus, time and rate differences between CO_2 emissions after combustion and C sequestration in forest biomass make combustion of coarse woody biomass less favourable in the short run in comparison to material substitution alternatives (Helin et al., 2012) or decomposition in the forest (Krankina and Harmon, 1995; Melin et al., 2009). But in the long run, stumps provide a source of renewable energy, which leads to overall reduction of CO_2 emissions by substituting fossil fuels and sequestering C in new tree biomass (Agostini et al., 2013; Melin et al., 2010).

Harvest of tops and branches results in a moderate increase in biomass removal at the expense of a substantial increase in nutrient removal from a site because of their higher nutrient concentrations compared to stem wood (Ouro et al., 2000). This is also the case for nitrogen (N), the primary growth limiting nutrient in the boreal and hemi-boreal forest (LeBauer and Treseder, 2008; Tamm, 1991). Harvest of tops and branches for energy purposes and associated nutrient removal, therefore, has the potential to reduce tree growth and consequently C sequestration in the subsequent stand. This has also been shown following whole-tree harvest in final cut (Egnell, 2011) and in thinning (Helmisaari et al., 2011). In contrast, short-term studies (5–10 years) do not reveal any negative growth effects following whole-tree harvest (Fleming et al., 2006; Tamminen and Saarsalmi, 2013).

Since stumps and roots also contain nutrients, stump harvest may cause additional loss of nutrients. Although nutrient concentrations in stumps and coarse roots are relatively low compared to that of the aboveground biomass, the nutrient loss could be significant if a substantial fraction of the more nutrient rich fine roots is harvested (Hellsten et al., 2013; Major et al., 2012). This may cause additional growth losses and consequently a lower C sequestration in the subsequent tree biomass (Weatherall et al., 2006). Stump harvest also has a direct negative impact on the soil C pool simply by the removal of C contained in the stump-biomass (Hope, 2007) – a C pool that otherwise would be slowly released to the atmosphere as the stumps decompose (Repo et al., 2012; Shorohova et al., 2012), while leaving some recalcitrant C fractions in the soil (Berg et al., 2009).

Stump harvest operations typically cause soil disturbance which can stimulate mineralization of the soil organic pool, and thereby further increase the C loss from the site (Kataja-aho et al., 2012; Örlander et al., 1996a). The increased mineralization might also increase the N release (Kataja-aho et al., 2012). This release may lead to further N losses through leaching during the initial years following the clear-cut, unless it is utilized by the trees or other vegetation (Piirainen et al., 2007). On the other hand, increased N mineralization due to soil disturbance and reduced competition for soil N from field and bottom vegetation may lead to increased N availability for the subsequent tree crop (Kataja-aho et al., 2012). This may favour seedling establishment and growth (Örlander et al., 1996b). In other words, the potential forest growth loss caused by the increased N loss following more intensive harvest practices, may be counteracted by stimulated subsequent tree growth due to increased nutrient availability resulting from reduced competition and enhanced mineralization rates following stump harvest operation and/or site preparation. This implies that soil C pool losses could be partly or fully compensated for by tree biomass C pool gains. These gains have potential to substitute fossil fuels and materials with a larger C footprint than wood (Agostini et al., 2013). This points out the importance to take both the soil and tree biomass C pool into account when evaluating the C balance following silvicultural measures like stump harvest and site preparation.

To date, little is known about the soil C and N response to stump harvest. Walmsley and Godbold (2010) concluded in their review of environmental impacts of stump harvest that more empirical studies in this field are needed. For instance, Karlsson and Tamminen (2013) studied effects of stump harvest on soil C and N, however, they accounted only for the humus and the upper 10 cm of the mineral soil. Thus, there is an urgent need to improve our understanding of stump harvest effects on soil C and N in deeper layers. The objective of this study is to provide such knowledge together with corresponding C and N pool data in the subsequent tree crop, making it possible to analyze tradeoffs between the soil and tree pools.

We present C and N pool data in soil (0–70 cm depth of the mineral soil, including litter and field vegetation) and tree biomass in two field experiments 22 and 24 years after stem and stump harvest and intense deep soil cultivation in comparison with conventional stem-only harvest and a moderate site preparation (i.e. manual patch scarification). Our main hypotheses were that, compared to conventional stem-only harvest:

i. Stump harvest and deep soil cultivation reduce C and N in the soil (including litter and field vegetation).
ii. Stump harvest and deep soil cultivation increases the accumulation of C and N in the subsequently planted trees.
iii. The total (soil and tree biomass) C and N pools are less affected by stump harvest and deep soil cultivation (relative to conventional harvest) than when comparing soil C and N pools only.

2. Materials and methods

2.1. Experimental sites

The two experiments at Degerön and Norrkvarn were established to study the long-term effects of intensive mechanical soil preparation on growth, yield and stand structure (Örlander et al., 2002). The less fertile experimental site, hereafter called Degerön, is situated in northern Sweden, Västerbotten County, 60 km from Umeå (Fig. 1). The more fertile site, Norrekvarn, is situated in southern Sweden, Kronoberg County, 40 km from Växjö. Degerön is established on a dry, sandy, fluvial sediment, whereas Norrekvarn is established on a mesic till soil (silt with some sand and clay), with a moderately developed hardpan at 50–60 cm depth. Other site features are given in Table 1.

2.2. Experimental design and treatments

At both study sites, two treatments were replicated on 30 × 30 m plots surrounded by 5 m buffer zones in a randomized block design with four replicates (Fig. 1). Blocking was based on site and stand characteristics of the previous stand with the aim to keep them similar within each block. The treatments included