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Review

Quantifying consequences of removing harvesting residues on forest soils and tree growth – A meta-analysis

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ABSTRACT

Increasing attention is being paid to using modern fuelwood as a substitute for fossil energies to reduce CO_2 emissions. In this context, forest biomass, particularly harvesting residues (branches), and stumps and associated coarse roots, can be used to supply fuelwood chains. However, collecting harvesting residues can affect soil properties and trees, and these effects are still not fully understood. The main objective of the present study was to compile published data worldwide and to quantify the overall effects of removing harvesting residues on nutrient outputs, chemical and biological soil fertility and tree growth, through a meta-analysis. Our study showed that, compared with conventional stem-only harvest, removing the stem plus the harvesting residues generally increases nutrient outputs thereby leading to reduced amounts of total and available nutrients in soils and soil acidification, particularly when foliage is harvested along with the branches. Losses of available nutrients in soils could also be explained by reduced microbial activity and mineralization fluxes, which in turn, may be affected by changes in organic matter quality and environmental conditions (soil compaction, temperature and moisture). Soil fertility losses were shown to have consequences for the subsequent forest ecosystem: tree growth was reduced by 3–7% in the short or medium term (up to 33 years after harvest) in the most intensive harvests (e.g. when branches are exported with foliage). Combining all the results showed that, overall, whole-tree harvesting has negative impacts on soil properties and trees that may have an impact on the functioning of forest ecosystems. Practical measures that could be taken to mitigate the environmental consequences of removing harvesting residues are discussed.

Contents

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1. Introduction

In Western countries, the use of traditional fuelwood was low - or decreasing- until the end of the 1970s (Fig. 1). Then, there was an interest in using modern fuelwood, mainly due to oil crises in 1973 and 1979 (fuelwood demand increased in parallel with oil price); locally other reasons contributed to this increased demand (e.g. decision to phase out nuclear energy in 1980 in Sweden). To supply fuelwood chains, foresters developed alternative cropping systems (such as short rotation coppices, Ranger and Nys, 1986) and adapted harvest practices (Nicholls et al., 2009; Diaz-Yanez et al., 2013). One of the adaptations proposed was to remove those tree components that were conventionally left in the forest: the so-called "harvesting residues" such as branches, foliages, tree tops, small diameter trees and technically damaged trees (e.g. Nunez-Regueira et al., 2005; Diaz-Yanez et al., 2013). In Europe, the new harvest practices included the integration of a second passage for removing harvesting residues (through better planning and logistics for extraction). In North America, harvesting systems in which residues are left at roadside ("full-tree-to-roadside" systems; Morris et al., 2014) have been developed in the late 1980s for economic and safety purposes. There was therefore no new harvesting system as fuelwood is a by-product of residue piles and not a primary objective.

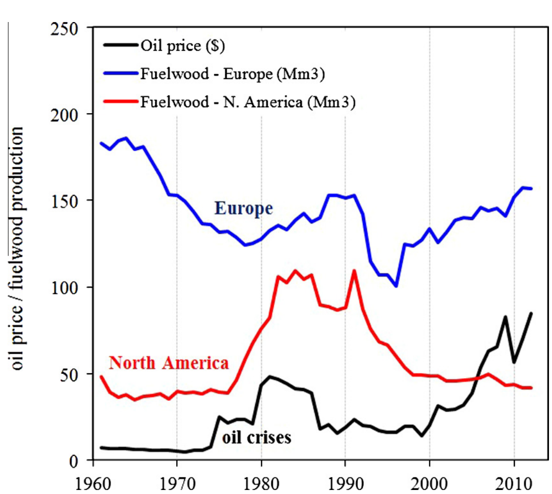

Fig. 1. Historical trends in oil price and fuelwood use in Europe and North America. Sources: oil price = World Bank Commodity Price Data (http://knoema.com); fuelwood = FAOSTAT (http://faostat.fao.org). Oil price in real 2005 US $ for crude oil. Fuelwood includes both traditional and modern fuelwoods. In Europe, the use of traditional fuelwood have decreased until the end of the 1970s. Then, there was a development of modern fuelwood and new interest in traditional fuelwood.

Early studies were carried out to assess possible environmental impacts of exporting harvesting residues (e.g. Tamm, 1969; Mann, 1984; Thompson et al., 1986; Mann et al., 1988; see also early studies in Scandinavia cited by Tveite and Hanssen (2013)). Experiment networks were also established, such as the North American long-term soil productivity study (LTSP) network (launched in 1989; Powers et al., 2005), the experiment network in Scandinavia (established in the 1970s and 1980s; Helmisaari et al., 2011; Tveite and Hanssen, 2013) or the Site Management and Productivity in Tropical Plantation Forests network (managed by the Center for International Forestry Research (CIFOR) since 1995; Nambiar et al., 2004; Nambiar, 2008). However, the demand for fuelwood decreased in the early 1990s following the collapse of the price of oil in the middle of the 1980s (Fig. 1). Interest in harvesting residues and related scientific research and funding consequently decreased. Since 2000, the emergence of developing economies (BRICS countries: Brazil, Russia, India, China and South Africa) triggered a long-term increase in the demand for energy causing a major trend toward an increase in the price of oil (Fig. 1). In the context of expensive oil and of climate change (IPCC, 2007), European countries introduced policies to promote the substitution of fossil fuel by renewable energies like fuelwood (European Commission, 2000) to enable national energy security (reduced oil dependence) and to decrease the emission of greenhouse gases (Stupak et al., 2007). One consequence of these policies was to revive interest in forest harvesting residues as a possible source of energy (Nicholls et al., 2009). Displacing fossil fuels is also the result of international competition for forest products, which led to diversification into new markets such as energy. It also should be noted that whole-tree harvesting in North America was mainly driven by the evolution of equipment for economic and safety purposes as explained before.

Already in the 1980–1990s in North America and even earlier in Scandinavia, some authors reported that collecting harvesting residues may negatively impact forest ecosystems (Tamm, 1969; Mann, 1984; Thompson et al., 1986; Mann et al., 1988; Johnson et al., 1991) because this kind of biomass (branches, foliage and tops) contains large amount of nutrients (Fahey et al., 1991; Yanai, 1991, 1998; Son and Gower, 1992) that are useful for the sustainability of ecosystem functioning and functions (Ranger and Turpault, 1999). Recently, the possible impacts of exporting harvesting residues were reviewed (Lattimore et al., 2009; Thiffault et al., 2011; Wall, 2012). Reviews and meta-analyses have also been carried out for LTSP installations in North America