BIOMASS AND BIOENERGY 70 (2014) 553–556

Available online at www.sciencedirect.com

ScienceDirect

http://www.elsevier.com/locate/biombioe

Short Communication

Allocation of five macroelements and quality of fuels derived from Norway spruce wood obtained by thinning operations

Leonardo Cerasino [a], *Nicola La Porta* [a,b,*]

[a] *Sustainable Agro-Ecosystems and Bioresources Department, IASMA Research and Innovation Centre, Fondazione Edmund Mach, Via E. Mach 1, 38010, San Michele all'Adige, Trento, Italy*

[b] *MOUNTFOR Project Centre, European Forest Institute, Via E. Mach 1, San Michele all'Adige, Trento, Italy*

ARTICLE INFO

Article history:
Received 14 June 2013
Received in revised form
4 August 2014
Accepted 13 August 2014
Available online 22 September 2014

Keywords:
Wood minerals
Ecological sustainability
Soil fertility
Tree harvesting systems
Tree mass allocation
Fuel chip quality

ABSTRACT

The use of forest biomass for energy production is growing in Europe and biomass energy plants market is constantly increasing. However, there is the need to define the environmental sustainability issues dealing with the emerging renewable energy scenario. In particular, the polluting emissions (i.e. PMx, NO_x and ozone) caused by the biomass combustion heavily impact on the air quality. In this context, the elemental characterization of the wood and the element allocation in the different tree organs, can provide important information about the quality of the derived wood fuels and give hints about the choice of the most appropriate combustion technique and/or the right wood fuel for a given combustion technique. Moreover, since elements have different concentrations in the different plant tissues, the preventive knowledge of the elements allocation can lead to the identification of the best harvesting strategy aimed at producing wood fuel with the lowest possible ash forming elements and environmental impact.

This work focuses on the allocation in three tree compartments (foliage, branches and stem) of five important macroelements (K, Mg, Ca, N and P) in Norway spruce (*Picea abies*), and points out the possible effects of different harvesting strategies and tree age on the quality of the wood fuels. Results suggest that the Stem Only Harvesting is preferable to Whole Tree Harvesting system in terms of prevention of mineral content loss, as well as is preferable to avoid forest biomass from young trees because of the poorer fuel quality of the wood chips.

1. Introduction

Today there is an increased activity on use of wood as producer of energy with main drivers being climate change, shortage and increasing prices of fossil fuel sources and safety in energy supply.

However, intensive use of forest biomass is debated since fundamental ecological processes may be influenced

* *Corresponding author*. Fondazione Edmund Mach, Via E. Mach 1, 38010, San Michele all'Adige, Trento, Italy. Tel.: +39 0461 615 396, +39 338 7888736 (mobile); fax: +39 0461 650 956.

E-mail address: nicola.laporta@fmach.it (N. La Porta).

http://dx.doi.org/10.1016/j.biombioe.2014.08.006

negatively thus making up a trade-off with the benefits of using an otherwise sustainable source of energy [1].

The use of “wood fuels” presents several drawbacks from environmental and technological points of view: during combustion and biomass conversion processes, many undesired phenomena may happen, like corrosion, formation of deposits, production of ash, harmful gases (such as NO_x, HCl) and particulate matter (PMx). These negative phenomena are linked to the presence of some elements during combustion, especially those indicated as “ash forming elements” (Si, Al, Fe, Ca, Mg, Na, K, P, S, Cl) [2–5]. Therefore, the quality of a given biomass is positively correlated with the energy content (linked to the presence of C, H and O), but is negatively correlated to the presence of these elements. Ash elements in particular are very variable as they depend on the plant species, the growing site, the plant physiology (season, age. assortment) and the plant management [6]. The knowledge of the relationships between all these and other factors [7] and the elemental content in the biomass could provide valuable criteria for sustainable management of wood stocks for energy purposes [8].

In this work we have focused our attention to the Norway spruce (*Picea abies*) species, which is one of the most important wood fuel sources in Europe. We investigated the effect of the plant age upon the allocation of five important elements, i.e. four ash elements (K, Mg, Ca, and P) plus N, which is endowed with the emission of harmful gases. We then used these data to determine which harvesting strategy, between Stem Only Harvesting (SOH) and Whole Tree Harvesting (WTH), could be the most suitable for getting a better quality biomass and for being the more ecologically sustainable.

2. Material and methods

2.1. Experimental sampling

Sampling was carried out in two different stands representative of the Trentino (Eastern Italian Alps) forests. Stand 1 was a commercial thinning plot (middle aged stands) located in the Commune of Molina di Fiemme (46°16′ N, 11°26′ E) at elevation ca. 1020 m a.s.l., with Norway spruce 87%, slope gradient 35%, soil type Brown Podzol and humus type Moder. Stand 2 was an unthinned precommercial plot (young stands) located in the commune of Ziano (46°17′ N, 11°34′ E) at elevation ca. 1080 m a.s.l, with Norway spruce 90%, slope gradient 29%, soil type Brown Podzol and humus type Mull. Both soil stands were classified as medium fertility by the Forest Management Plan of the Autonomous Province of Trento [9]. Collection of biomass samples [7] was carried out in September 2011 and in each stand, four representative trees were randomly sampled. The stands were fully stocked, with a closed canopy and no visual crown damage. Diameters at breast height (DBH) were measured for all trees. Young stand was ca. 25 years old and averaged 14.8 cm DBH while middle aged stand was ca. 64 years old and averaged 32.4 cm DBH. Care was taken to select trees with regular growth and absence of tension and compression wood, or any decay, which can result in natural anomalous concentrations of certain elements. Wood core samples, including bark, were taken at DBH from the base of the trunk, using a chainsaw to extract ca. 20 cm thick radial cross sections. These sections were double wrapped into clear contamination-free polyethylene plastic bags and kept chilled to limit sap migration before arrival in the laboratory. After arrival in the laboratory of the Fondazione Mach, wood samples were chipped into pieces of less than 2 cm. Living branch and needle samples were collected from the upper part of the crown on the same trees and treated as a bulk sample. Needles were free of fungal damages, herbivores, or decay and characterized by good growth, without discoloration or defoliation. Needles of all ages were manually separate and washed with deionised water. Needle, branch and stem wood samples, including bark, were dried in oven to constant weight at 40 °C. For each tree ca. 8 kg of dry core wood, 8 kg of dry branches and 1 kg of dry needles were collected, from which 200 g was grounded and homogenised and from which 100 mg were further chemically analysed for nutrient elements.

After homogenization, four subsamples of each dried grounded material were processed for chemical analysis. A total of 24 plant samples were analysed in four replicates (96 total analyses).

2.2. Chemical analysis

Ultra-pure grade reagents were used. Approx. 100 mg of dried grounded plant material were digested with sulphuric acid, salicylic acid, oxygen peroxide according to standard procedures [10]. The resulting digested solution was adequately diluted with ultra pure water and then the analysis of cations (K, Mg and Ca) was performed by ion chromatography [11], while the analysis of N and P were performed by spectrophotometric methods, measuring nitrate and orthophosphate according to the method of Chapman and Pratt [12]. Limits of quantification were 0.1 g kg^{-1} dry weight for K and Mg, 1 g kg^{-1} for Ca, 0.02 g kg^{-1} for N and P.

2.3. Equipment

The ion chromatographer was a Dionex DX120 (Dionex Corp., Sunnyvale, CA, USA) equipped with a cation exchange column. The spectrophotometer was a Varian CaryBio 50 (Varian Inc., Palo Alto, CA, USA).

3. Results and discussion

Main elemental concentrations found in plant tissues, as mean value and standard error, are reported in Table 1. Tissues have been grouped in three main compartments (stem with bark, branches and foliage). Values are in agreement with those reported in previous studies [13,14] for the same species. It is possible to observe a clear increasing trend in element concentrations from the stem to the foliage. This observation is related to the physiology of the different tissues and can be assumed as valid for all elements in general. In particular, we can note how concentrations in leaves are several times higher than in the other compartments, as leaves are particularly rich in water.

Moreover, element concentrations are generally higher in young than in middle-aged plants in all compartments. P represents a relative exception, as its values are more similar in the two ages. This observation is particularly evident in

Table 1 – Mean element concentrations (g kg^{-1} dry weight) in the three main plant compartments (stem, branches and foliage). Standard errors are reported in brackets.

Tree age	Compartment	Ca	Mg	K	N	P
Middle-aged	Stem	2.3 (0.4)	0.2 (0.03)	1.8 (0.3)	0.4 (0.03)	0.2 (0.03)
	Branches	2.9 (0.6)	0.7 (0.1)	3.3 (0.4)	0.9 (0.1)	0.3 (0.04)
	Foliage	9.4 (0.9)	1.5 (0.2)	11.6 (1.3)	8.1 (0.9)	2.4 (0.2)
Young	Stem	3.1 (0.5)	0.5 (0.07)	2.3 (0.3)	0.7 (0.06)	0.3 (0.04)
	Branches	4.4 (0.7)	0.8 (0.1)	3.0 (0.6)	4.9 (0.3)	0.5 (0.07)
	Foliage	13.9 (1.0)	2.2 (0.2)	12.0 (1.0)	11.9 (0.7)	2.4 (0.3)

stem and branches, as they undergo progressive lignification with age with reduced content of living tissues, and consequently, water and solutes.

Since our aim was the evaluation of the quality of wood products as energy source, we needed to know the absolute amount of elements in the three compartments. To do so, we have used the biomass proportions developed in the spruce allometric study by Kantola & Mäkelä [15] for young and middle-aged trees (25 and 67 years old, respectively) that fits quite well with our sampling. According to these authors, proportions among stem, branches and foliage are 42-27-31 and 85-9-6, for young and middle-aged trees, respectively. In Fig. 1 we have reported the relative allocation of elements for the two classes of ages. In older plants (Fig. 1a) there is a similar distribution for cations (Ca, Mg, and K): 55–75% is present in the stem, 10–20% in the branches, and finally 20–30% in the leaves. On the other hand, N and P contents are both approx. 35% in stem, 10% in branches, and 50% in leaves. In younger plants (Fig. 1b) all elements have similar allocation, and while the elements content in branches is similar to older plants (between 10 and 20%), there is a redistribution between foliage and stem: more than 60% of the elements content is located in the leaves and only 5–20% in the stem.

It is therefore clear that the quantity of the considered elements in the harvested material will greatly be dependent both on the harvesting procedure and on the plants age. In Fig. 2 we compare the amounts of elements contained in wood material obtained using SOH and WTH from middle-aged and young trees. In SOH (upper graph), the wood coming from young plants contains higher amounts of minerals compared to the older ones. In WTH (bottom graph), the difference in mineral content between the two classes of age is much more pronounced: approximately twice as much for Ca and K, three

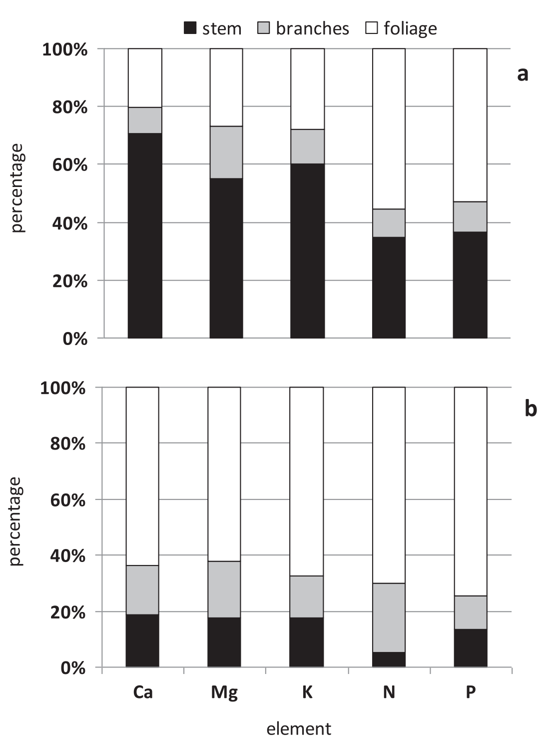

Fig. 1 – Elements allocation (expressed in mass percentage) in the three compartments (stem, branches and foliage) in middle-aged (a) and young (b) plants. Percentages were calculated from compartments element concentrations taking into account the appropriate allometric factors described in Kantola & Mäkelä [15].

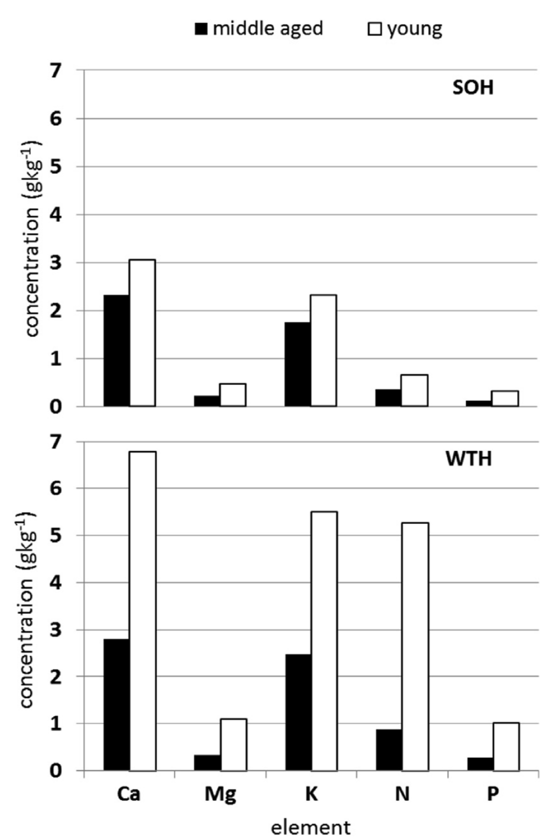

Fig. 2 – Comparison of the element content in harvested material in relation to the harvesting method (stem only, SOH; and whole tree, WTH).

times for Mg and P, five times for N. Another important result to underline is the fact that the mineral content in wood is always higher in WTH than in SOH for all elements and all classes of age.

4. Conclusions

The need of replacing fossil fuels with renewable energy sources is increasing the interest in forest biomass utilization for energy production. Our investigation has provided some more information about the allocation of five important elements in Norway spruce (*Picea abies*) in relation to the age of the plant. Our results have shown that *i)* younger plants have higher elements' content (as whole tree content); *ii)* in young plants more than 60% of the elements' content is located in the foliage; *iii)* harvested biomass from young plants induces higher removal of elements from the forest especially in the case of WTH. Under a sustainable vision of the use of wood biomass for energy purposes, our results suggest that the SOH is the preferable harvesting system compared with WTH for two reasons: firstly, SOH provide biomass with a lower ash content and nitrogen, and therefore with a higher quality in terms of technological performance and emission of toxic pollutants; secondly, SOH determines a lower mineral content loss in the forest ecosystem, thus reducing the mineral removal from forest, maintaining soil fertility that, together with the higher deadwood content, preserves a dynamically richer concentration of microorganisms, useful to mycorrhizal symbiosis and to control serious root decay pathogens. It is worth noting, however, that in order to correctly assess the ecological impact of the harvesting processes, several other important information must be considered [8] that are missing in our investigation, such as the actual mineral removal (and mineral release) per hectare or the atmospheric fixation of some elements. Therefore our data only give a partial picture of the whole system. Finally, an important aspect, which is worth discuss is represented by the economic sustainability of different harvesting strategies [16]. Although SOH may offer superior fuel quality and reduced risk for soil fertility impacts, it is also much more costly than WTH especially on first thinning operations. If WTH actually caused a higher and practically significant soil fertility impact, such impact would still need to be balanced against the drawbacks and impacts of neglected or delayed thinning, when WTH offered the only cost-effective option to timely thinning.

Acknowledgements

This work is part of the BIOMASFOR project (Potentiality, technological-energetic innovations and sustainability of the forest biomasses in Trentino) co-funded by CARITRO (Cassa di Risparmio di Trento e Rovereto) Foundation by the grant No. 101 awarded to Dr. Nicola la Porta. We gratefully thank Mr. Andrea Zampedri for technical assistance and Mrs. Tessa Say for revision of the English text. We also wish to thank Dr Ralph Overend, Dr Walter Haslinger and three anonymous reviewers for their valuable comments on an earlier version of the manuscript.

REFERENCES

[1] Röser D, Asikainen A, Raulund-Rasmussen K, Stupak I. Sustainable use of forest biomass for energy. A synthesis with focus on the Baltic and Nordic Region. Dordrecht, The Netherlands: Springer; 2008.

[2] Jenkins BM, Baxter LL, Miles Jr TR, Miles TR. Combustion properties of biomass. Fuel Process Technol 1998;54(1–3):17–46.

[3] Klass DL. Biomass for renewable energy, fuels, and chemicals. San Diego: Academic Press; 1998.

[4] Nussbaumer T. Combustion and co-combustion of biomass: fundamentals, technologies, and primary measures for emission reduction. Energy Fuel 2003;17(6):1510–21.

[5] Van Lith SC, Jensen PA, Frandsen FJ, Glarborg P. Release to the gas phase of inorganic elements during wood combustion. Part 2: influence of fuel composition. Energy Fuel 2008;22(3):1598–609.

[6] Tao GC, Geladi P, Lestander T, Xiong SJ. Biomass properties in association with plant species and assortments. II: a synthesis based on literature data for ash elements. Renew Sust Energy Rev 2012;16(5):3507–22.

[7] Barton GM. Definition of biomass samples involving wood, bark and foliage. Biomass 1984;4(4):311–4.

[8] Lattimore B, Smith CT, Titus BD, Stupak I, Egnell G. Environmental factors in woodfuel production: opportunities, risks, and criteria and indicators for sustainable practices. Biomass Bioenergy 2009;33(19):1321–42.

[9] PDA forest management plans of autonomous province of trento [Italian]; 2009 [cited 2014 Jul 09], http://www.ricercaforestale.it/.

[10] Temminghof EJM, Houba VJG. Plant analysis procedures. 2nd ed. Dordrecht, The Netherlands: Kluwer Academic Publishers; 2009.

[11] Watson ME, Isaac RA. Analytical instruments for soil and plant analysis. In: Westerman RL, editor. Soil testing and plant analysis. 3rd ed. Madison, WI: Soil Science Society of America; 1990. p. 691–740. SSSA book series no. 3.

[12] Chapman HD, Pratt PF. Methods of analysis for soils, plants and waters. Priced publication 4034. University of California-Berkeley, Division of Agricultural Sciences; 1961.

[13] Alriksson A, Eriksson HM. Variations in mineral nutrient and C distribution in the soil and vegetation compartments of five temperate tree species in NE Sweden. For Ecol Manag 1998;108(3):261–73.

[14] Palviainen M, Finèr L. Estimation of nutrient removals in stem-only and whole-tree-harvesting of scots pine, Norway spruce, and birch stands with generalized nutrient equations. Eur J For Res 2012;131(4):945–64.

[15] Kantola A, Mäkelä A. Development of biomass proportions in Norway spruce (*Picea abies* [L.] Karst. Trees Struct Funct 2006;20(1):111–21.

[16] Spinelli R, Magagnotti N. Comparison of two harvesting systems for the production of forest biomass from the thinning of *Picea abies* plantations. Scand J For Res 2010;25(1):69–77.