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Research paper

Sustainable use of eucalypt biomass grown on short rotation coppice for bioenergy

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ABSTRACT

Bioenergy is one of the alternatives to reduce the dependence of global energy on fossil fuels. The short rotation coppice (SRC) of eucalypt species appears as an interesting option for forest biomass production in a short time. However, the harvesting of whole trees (included the crown) in SRC systems has implications on sustainable land use. More information is required on the increase of biomass as renewable energy resource to achieve the sustainability of these crops. The main objective of this research was to evaluate the sustainable use of biomass from very high-density eucalypt plantations, managed at tropical conditions for bioenergy. To accomplish this objective, the tree was fractionated into three fractions: stem, branches, and leaves, and there was determination of the dry matter, energy yield, and nutrients export. This experiment used a short rotation coppice, a hybrid clone of *Eucalyptus urophylla* × *Eucalyptus grandis*, of 2 years old. According to the results obtained, the density planting and fertilization levels have a greater influence on the dry matter yield, energy yield, and nutrient exports. The higher density planting reaches mean values of 30.9 tonnes of dry matter per hectare (t DM ha^{-1}) and 743.3 GJ ha^{-1}. Considering the biomass yield and nutrients export of short rotation coppice of eucalypt, the higher density planting with the lower dose of fertilization is more indicative of sustainable use. The leaves have an important participation in nutrients export and should be retained in the soil of forest.

1. Introduction

Biomass resources will be one of the most important factors for environmental protection in the 21st century [1]. Actually, biomass accounted for about 10% of global primary energy supply (estimated 56.6 EJ) according REN [2] and studies suggest that biomass will continue to increase by 2050 [3].

Some agricultural and forest species have greater potential for providing biomass to energy; these species are called energy crops and they must meet certain conditions, such as adaptation to the environment in which they are growing, with resistance to pathogens and climate, among others and good features as an energy source [4,5].

Short rotation woody crops differ from conventional forestry in a number of aspects. Management of the trees is conducted with high planting density and intensive silvicultural treatments (weeding, fertilizing, and irrigating) and these management methods respond with very rapid growth [6]. The main species used worldwide in the production of forest biomass for energy purposes are as follows: eucalypt (*Eucalyptus*), willow (*Salix*), and poplar (*Populus*). Other alternatives, such as *Paulownia* and *Robinia*, are also increasing, especially in Europe. Table 1 presents the productivity of these species in different parts of the world.

In Brazil, the eucalypt is the most important forest species for wood supply, occupies an area of 5.56 million hectares [16], and the average stem wood productivity is about 25 t DM ha^{-1} $year^{-1}$ for conventional silviculture [17]. Recently, there was testing of this species to high-density planting and it reached double productivity, becoming an important option for energy generation [18].

During the harvesting of short rotation coppice (SRC), all aboveground biomass (stem, branches, and leaves) was chipped and used for energy, and not debarked stems, as in conventional plantations [19]. When compared to the traditional system, the

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Table 1
Biomass production of dedicated energy crops around the world.

Espécie	Dry matter yield (t DM ha^{-1} $year^{-1}$)	Rotation (years)	Planting density (trees ha^{-1})	Countries	Ref.
Eucalyptus bridgesiana	6.5	2	6,667	Italy	[7]
Eucalyptus spp.	14.1	3	4,167	New Zealand	[8]
Eucalyptus globulus	5.3	3	4,000	Australia	[9]
Eucalyptus occidentalis	7.3	3	4,000	Australia	[9]
Eucalyptus grandis	16.0	3.5	3,400	EUA	[10]
Eucalytpus amplifolia	17.8	3.5	3,400	EUA	[10]
Populus alba	5.4	3	1,111	Italy	[11]
Populus spp.	10.6	2	5,900	Italy	[12]
Salix spp.	10.6	3	1,111	Italy	[11]
Salix spp.	4.2	4	12,000	Sweden	[13]
Paulownia sp.	5.3	2	1,650	Spain	[14]
Robinia pseudoacacia	3.0	4	9,200	Sweden	[15]

harvesting of SRC has fewer steps, and the use of forage harvester avoids the stationary chipping terminal, preventing additional costs with other machines and equipment (Fig. 1).

The harvest of whole tree in SRC of eucalypt highlights an environmental issue. Instead, what happens with other species (as poplars and willow) in temperate climate, some eucalyptus do not shed their leaves in the dry season, and this has direct implications on sustainable land use, due to the greatest macro- and micro-nutrients content in the leaves and bark [21,22].

More information about the increase of biomass as renewable energy resource is required to achieve the sustainability of SRC. Thus, the design and management of very high-density forests should focus not only on the energy and biomass yield, but also on the nutrients export. So, preferably, it must be a used species or clones of rapid growth, with high performance and high efficiency in the use of nutrients [8,23].

To evaluate the sustainable use of SRC of eucalypt for bioenergy, the tree was analyzed in three fractions: stem (wood and bark), branches, and leaves. Therefore, the goals of this study were: (1) to determine the biomass and energy yields of the very high-density energy plantations, gaging the effect of different spacing and fertilization regimes; (2) to estimate the nutrients export under these same conditions; and (3) to evaluate the sustainability of whole tree use as efficient energy crops.

2. Materials and methods

This work was carried out in Botucatu city (22°53′09″S and 48°26′42″W) located at São Paulo state in Brazil. The local area has an average altitude of 872 m, a mean annual precipitation of about 1428 mm $year^{-1}$, and an annual average temperature of 20 °C.

Management of the plantations of interspecific hybrid clone, *Eucalyptus urophylla* × *Eucalyptus grandis*, at 2 years old was with distinct conditions of higher planting density and fertilization. All plots were established at two different spacing modules: 2.8 × 0.5 m (7142 trees $hectare^{-1}$) and 2.8 × 1.5 m (2380 trees $hectare^{-1}$); and Table 2 describes two different fertilization regimes (dose 1 and dose 2).

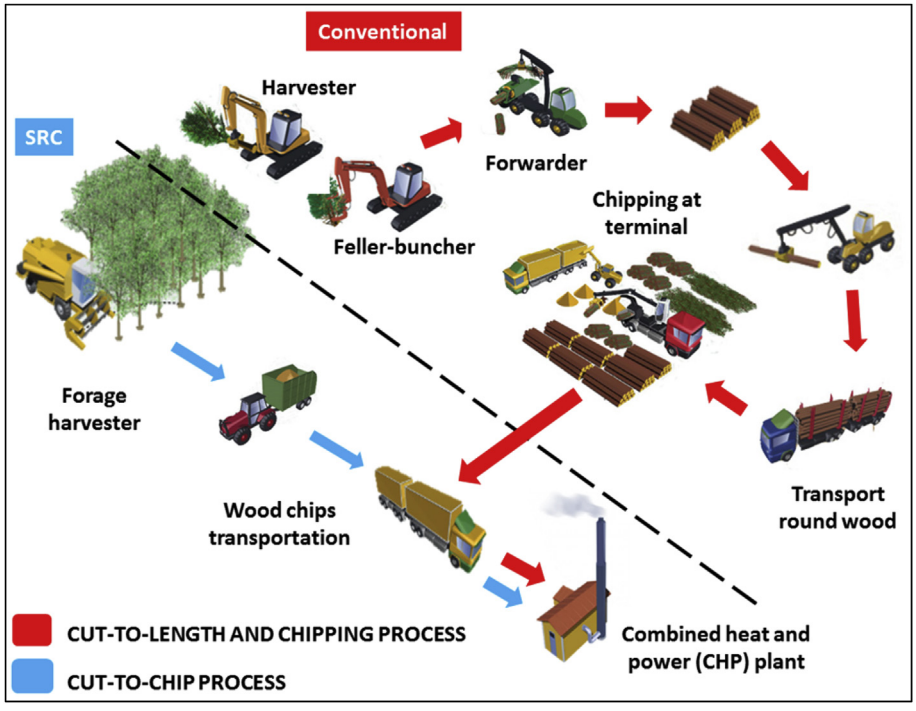

Fig. 1. Comparation between shot rotation coppice and conventional harvesting systems. Forest Energy Portal [20] modified by author.