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Climate and forest plantation: the carbon storage and energy biomass production in Southern Brazil

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RESUMO

Clima e plantios florestais: o armazenamento de carbono e a produção de biomassa para energia no sul do Brasil

A busca por fontes alternativas de energia tem se mostrado uma demanda global. Motivado pela preocupação com as mudanças climáticas e pelo esgotamento dos recursos naturais, o mercado mundial tem despertado interesse no estudo e adoção de fontes alternativas renováveis de energia. Uma das alternativas possíveis é o uso da biomassa florestal. Neste contexto, surge a necessidade da realização de estudos que busquem avaliar o crescimento e produtividade de diferentes espécies florestais cultivadas em diferentes espaçamentos de plantio. Desse modo, os objetivos deste estudo são: (i) avaliar a produção de biomassa para energia; (ii) determinar a estocagem e partição de carbono no sistema florestal (biomassa florestal + solo); (iii) determinar a eficiência do uso da radiação solar da espécie *Eucalyptus grandis*; and (iv) caracterizar a composição elementar e as propriedades de quatro espécies florestais *Eucalyptus grandis*, *Mimosa scabrella*, *Ateleia glazioviana* e *Acacia mearnsii* cultivadas em quatro espaçamentos de plantio no sul do Brasil. Um experimento de campo foi realizado de setembro de 2008 a setembro de 2018 na cidade de Frederico Westphalen, Brasil. A biomassa florestal foi determinada pelo método destrutivo. Também foram avaliados o poder calorífico, composição elementar, análise química imediata, eficiência do uso da radiação, coeficiente de extinção luminosa, a interceptação da radiação solar, o índice de área foliar, o particionamento de biomassa, o armazenamento de carbono e o rendimento energético potencial. As informações geradas neste estudo são relevantes e fornecem informações importantes para empresas interessadas na geração de eletricidade a partir de biomassa florestal e produtores florestais, uma vez que auxiliam no planejamento da escolha do espaçamento ótimo a ser utilisado para produção de biomassa para energia. A maior produção de biomassa, armazenamento de carbono e eficiência de uso de radiação foi obtida para a espécie *Eucalyptus grandis* cultivada no espaçamento de plantio (2,0×1,5 m), que resultou em maior quantidade de biomassa para produção de energia. Para as demais espécies florestais, o espaçamento ótimo de plantio para produzir biomassa para energia foi (2,0×1,0 m). Portanto, o uso de espaçamento reduzido de árvores deve ser priorizado e recomendado para futuras explorações de plantações de energia florestal.

Palavras-chave: Biomassa florestal; Carbono; Energia; Espaçamento de plantio

ABSTRACT

Climate and forest plantation: the carbon storage and energy biomass production in Southern Brazil

The search for alternative sources of energy has shown to be a global demand. Motivated by concern about climate change and the depletion of natural resources, the world market has attracted interest in the study and adoption of alternative renewable sources of energy. One possible alternative is the use of forest biomass. In this context, it is necessary to carry out studies that seek to evaluate the growth and yield of different forest species cultivated at different planting spacings. The aim of this study were: (i) to evaluate the production of biomass for energy; (ii) to determine carbon storage and partitioning in the forest system (above-belowground biomass + soil); (iii) to determine the radiation use efficiency of *Eucalyptus grandis*; and (iv) to characterize the elemental composition and properties of four forest species *Eucalyptus grandis*, *Mimosa scabrella*, *Ateleia glazioviana*, and *Acacia mearnsii* grown in four planting spacings in Southern Brazil. A field experiment was conducted from September 2008 to September 2018 in the city of Frederico Westphalen, Brazil. The forest biomass was determined by destructive method. Also, the calorific value, elemental composition, immediate chemical analysis, radiation use efficiency, light extinction coefficient, solar radiation interception, leaf area index, biomass yield and partitioning, carbon storage and potential energy yield were evaluated. Information generated in this study is relevant and provides information for companies interested in electricity generation from forest biomass and forest producers thereby assisting in the planning of optimal spacing to be used for biomass production for energy. The highest biomass production, carbon storage, and radiation use efficiency were obtained in the planting spacing (2.0×1.5 m) for the *Eucalyptus grandis*, which resulted in a higher amount of biomass for energy production. For the other forest species, the optimal planting spacing to produce biomass for energy was the (2.0×1.0 m). Therefore, the use of reduced planting spacing should be prioritized and recommended for future exploitation of forest energy plantations.

Keywords: Forest biomass; Carbon; Energy; Planting spacing

INTRODUCTION

The use of renewable energy sources is becoming increasingly necessary, if we are to achieve the changes required to address the impacts of global change and increase the environment protection. Of the renewable energy sources, forest biomass appears to be the most important in terms of technical and economic feasibility in the coming decades (HALL; HOUSE, 1994; BHATTACHARYA et al., 2003; MOLA-YUDEGO et al., 2017; WELFLE, 2017; FERREIRA et al., 2018; HAMMAR et al., 2019).

Forest biomass is one of the most promising strategies for the generation of renewable energy in Brazil (FAÉ GOMES et al., 2013; LOPES et al., 2016; FERREIRA et al., 2018). In this context, new studies involving forest species that present an energetic potential, such as *Eucalyptus grandis*, *Mimosa scabrella*, *Ateleia glazioviana*, and *Acacia mearnsii* are important for the Brazilian energy chain. Currently much attention has been focused on identifying and characterizing suitable forest biomass species and its essential characteristics, regarding ecological, silvicultural and structural factors, and those related to the energy potential of forest biomass in order to provide high-energy outputs, to replace conventional fossil fuel energy sources.

In this context an important question arises: When fossil fuels are depleted, will forest biomass converted to energy-fuel for several needs be enough to provide the energy needs of future generations? Certainly, forest biomass alone will not meet all the energy demand, however, together with different kinds of bioenergy (ESEN; YUKSEL, 2013; OH et al., 2010 et al., 2017; JHA; PUPPALA, 2017; SHUBA; KIFLE, 2018; MENDOZA MARTINEZ et al., 2019) that have been deeply investigated, produced and used in the last years, can provide a large amount of energy-fuel worldwide. According to GUO et al. (2015), bioenergy will provide 30% of the world's energy demand by 2050. The contribution of renewable resources in the Brazilian energy chain is among the highest worldwide, which corresponds to 43.5% of total energy demands in 2016 (EPE, 2017). Brazil have been conducted research for large-scale production of energy derived from wood, investing in fast-growing forest plantations dedicated to the production of wood for energy (forest energy plantations).

The concept of forest energy plantations was introduced in the 1980s to define forest plantations with a large number of trees per hectare in a short-rotation cycle, whose purpose is to produce the largest volume of biomass per unit area and time (COUTO; MÜLLER, 2008). Moreover, forest energy plantations play an essential role in the carbon (C) storage, from the capture and storage of this gas in the form of forest biomass. According to LACLAU (2003), fast-growing forest plantations are considered highly efficient carbon sinks capable of contributing to the mitigation of the increase of CO_2 levels in the atmosphere. Forest biomass for energy generation is considered nearly carbon neutral (KUMAR et al. 2006; THAKUR et al., 2014) because the amount of CO_2 released during combustion is nearly the same as taken up by the tree during growth.

The use of woody biomass as energy-fuel source provides substantial benefits as far as the environment is concerned (DEMIRBAS, 2004; VASSILEV et al., 2010). Biomass absorbs carbon dioxide during growth and emits it during combustion offering the advantage of a renewable and CO_2-neutral fuel. Therefore, biomass helps the atmospheric carbon dioxide recycling and does not contribute to the greenhouse effect (DEMIRBAS, 2004). The characterization of composition, properties and quality of a given biomass source is the initial and most important step during the study and application of this feedstock for energy generation. For example, data from structural, gross calorific value, proximate and ultimate analyses have been used to characterize biomass sources (VAN LOO; KOPPEJAN, 2008; SAIDUR et al., 2011).

Forest energy plantations can be considered as an important sink of C of the atmosphere. Moreover, forest plantations are capable of storing large amounts of CO_2 in a relatively short period of time. This is related especially with the forest species capacity to store carbon in their structure (wood, branches, leaves, roots). Carbon storage in forest plantations involves numerous components including biomass C and soil C. Management systems that maintain a continuous canopy cover are likely to achieve the best combination of high wood yield and C storage (THORNLEY; CANNELL, 2000; LAL, 2005). In this context, it is important to understand and quantify the carbon stored and partitioned in the system as a whole, i. e., soil stocks and forest biomass, including roots biomass, of the different forest species studied. Moreover, there is a lack of information about the carbon storage and partitioning in forest energy plantations.

In order to meet global energy demand and enhancing sinks for carbon storage to mitigate the climate change, new research is needed to study forest energy plantations, considering different forest species growing on different planting spacings in order to evaluate the potential for carbon storage and forest biomass production. According to COUTO; MÜLLER (2008) and WELFLE (2017), the forest management aimed the production of biomass for energy, basically consists of choosing the appropriate species, managing the tree density and planting spacing and the rotation time of the forest plantations.

The planting spacing is a primary factor in the production of forest biomass. The most used spacing for biomass production for energy are those that provide a useful area varying from 3 m² to 9 m² (COUTO et al., 2002). The use of reduced planting spacing is being extensively studied and disseminated due to the benefits provided (NJAKOU DJOMO et al., 2015; EISENBIES et al., 2017). The tendency of reduce the planting spacings for biomass production is highlighted by the need to reduce the crop cycle, resulting in gains in productivity, time and cost with forest management (GONÇALVES et al., 2004; GUERRA, 2012).

Forest management for wood production is carried out mainly by companies and rural producers. The basically management regime adopted by them is planting with spacing of 3 × 2 m and shallow-cut between the 6^{th} and 8^{th} year (STAPE et al., 2001; GONÇALVES et al., 2013). In this context, the authors proposed in this study to evaluate the feasibility of the use of reduced planting spacings (greater number of trees per unit of area), whereas trees grown in these spacings can maximize the solar radiation interception, carbon storage and increase the biomass production for energy. Forest managers can accelerate growth and increase the production of forest biomass by manipulating available natural resources, especially solar radiation, using adequate planting spacing.

Climate conditions have a great influence on tree growth and yield. There is great interest in how plants interactions in different spacings change along spatial gradients in resource availability, especially in solar radiation interception and radiation use efficiency. In a forest production system, the tree growth happens as a function of accumulated biomass through photosynthesis. The biomass yield in plants depends especially upon the quantity of absorbed radiation by leaves, and the efficiency by which can convert and assimilate the light through photosynthesis (LARCHER, 2003).

Incident solar radiation can be a limiting factor for plant growth and development, which affect photosynthetic biomass accumulation according to the planting spacing. Thus, the conversion of the intercepted photosynthetically active radiation into biomass shows the solar radiation use efficiency of the plant (εb) (MONTEITH; MOSS, 1977). The conversion of solar radiation into biomass is also affected by the leaf area index, which can change according to the plant distribution in the field (SANQUETTA et al., 2014b). Plant biomass accumulation is dependent on the intercepted photosynthetically active radiation and efficiency of the conversion of solar radiation into photoassimilates (BEHLING et al., 2015). Therefore, spacing can affect the ability of trees to acquire available resources, especially the amount of solar radiation intercepted by the plants, determining the forest yield.

In this context, the radiation use efficiency can be assessed by measuring the intercepted photosynthetically active radiation (PARi) that is converted into biomass (MONTEITH; MOSS, 1977). According PRETZSCH and BIBER (2016), little attention has been given to the radiation use efficiency in order to improve forest yields. Recently, there had been increasing focus in obtain ecological information, such as photosynthesis–light relationships in trees, from the meteorological data use, especially solar radiation and forest growth data such as leaf area index. When related the radiation use efficiency with the planting spacing, closer spacing promotes faster development of the leaf area index, which increases light interception and photosynthesis (GONÇALVES et al., 2013), and thus, the radiation use efficiency by plants can be improved.

In this study, we hypothesized that: (i) forest planting spacing affects the biomass yield, carbon storage, properties and radiation use efficiency, which the use of reduced planting spacings can maximize the solar radiation interception and increase the biomass production for energy generation; and (ii) climatic conditions modify the growth and yield of the forest species studied according the planting spacing. Therefore, the objectives of this research were: (i) to evaluate the production of biomass for energy; (ii) to determine carbon storage and partitioning in the forest system (above-belowground biomass + soil); (iii) to determine the radiation use efficiency of *Eucalyptus grandis*; and (iv) to characterize the elemental composition and properties of four forest species *Eucalyptus grandis*, *Mimosa scabrella*, *Ateleia glazioviana*, and *Acacia mearnsii* grown in four planting spacings in Southern Brazil.

CONCLUSIONS

According to the results obtained in this study, and answering the objectives proposed, it is possible to make the following conclusions:

a) The biomass yield and potential energy yield of the forest species studied were affected by the planting spacing. The highest biomass production and potential energy yield was observed for the *Eucalyptus grandis* grown on the 2.0×1.5 m spacing. Among the forest species studied, the *Eucalyptus grandis* was the one that presented the largest potential to produce biomass for energy, followed by *Acacia mearnsii*, *Mimosa scabrella* and *Ateleia glazioviana*. Therefore, the use of reduced planting spacing should be prioritized and recommended for future exploitation of forest energy plantations.

b) The carbon stock of the forest plantations was influenced by the planting spacing. The average amount of above-belowground carbon stored considering the four planting spacing for *Eucalyptus grandis* was 293.2 Mg C ha^{-1}, followed by *Acacia mearnsii* (124.1 Mg C ha^{-1}), *Mimosa scabrella* (109.1 Mg C ha^{-1}), and *Ateleia glazioviana* (31.1 Mg C ha^{-1}). The pattern of carbon stored in the tree compartments were trunk > roots > branches > leaves > litter, being that for *Eucalyptus grandis* it was observed a partition pattern of 69.7% trunk, 3.1% branch, 2.98% leaf, 0.42% litter and 23.8% roots. For the carbon stocks in the soil we observed variations only between soil layers, since for the forest species and planting spacings was not observed differences. The average accumulated soil carbon stock for the forest species was 77.4 Mg C ha^{-1} (0–40 cm).

c) The efficiency of conversion of the intercepted photosynthetically active radiation into biomass of the *Eucalyptus grandis* varied with the planting spacings. The highest radiation use efficiency of (0.0062 kg MJ^{-1}) for *Eucalyptus grandis* trees was obtained in the 2.0×1.5 m planting spacing. We suggest, in future studies, to determine the radiation use efficiency of the other forest species and analyze the climate change effects on these forest species growth and yield.

d) This study reveled that forest species properties and composition were not affected by planting spacing and assessment year, only for the different tree compartments. For instance, the *Eucalyptus grandis* and *Acacia mearnsii* species were characterized to present high levels of carbon and hidrogren and lower percentages of oxygen. Also, these species showed lowers percentages of nitrogen and sulfur in woody biomass which are desirable characteristics to be used as biomass source for energy generation.

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