University of São Paulo
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Water and nutrient use efficiency of *Pinus caribaea* var. *hondurensis* and *Pinus taeda*

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Thesis presented to obtain the degree of Doctor in Science. Area: Forest Resources, Option in: Silviculture and Forest Management

Piracicaba
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CONTENTS

RESUMO

Eficiência hídrica e nutricional de *Pinus caribaea* var. *hondurensis* e *Pinus taeda*

O objetivo geral deste estudo foi avaliar a eficiência no uso de água e de nutrientes de *Pinus caribaea* var. *hondurensis* e *Pinus taeda*. Para essa proposta, o presente estudo foi apresentado em três capítulos. Para os capítulos I e II, o estudo utilizou árvores de *Pinus* spp., aos 13 anos, provenientes de uma área experimental do Programa Cooperativo de Pesquisa em Pinus no Brasil (PPPIB), situada no município de Itatinga, São Paulo. Dados de inventário e mensurações de bandas dendrométricas foram utilizados para avaliar o crescimento das árvores de *Pinus* spp. cultivadas sob distintos regimes de fertilização (tratamentos fertilizado e controle). Ademais, quarenta e oito árvores foram selecionadas e quatro amostras por árvore foram coletadas à aproximadamente 1,3 m de altura. No Capítulo I, o crescimento arbóreo, as relações clima-crescimento e a eficiência intrínseca do uso da água (EIUA) foram avaliados através de uma análise combinada do incremento de área seccional transversal (AST), balanço hídrico e razão isotópica de carbono ($\delta^{13}C$). No Capítulo II, a densidade da madeira foi avaliada pela técnica não-destrutiva de densitometria de raios-X. Adicionalmente, foram delimitados os anéis anuais das árvores e realizada a datação cruzada entre as árvores. As cronologias de largura do anel de crescimento e densidade da madeira foram analisadas pelo método dendrocronológico e correlacionadas com com dados de precipitação e temperatura. Para o Capítulo III, foi conduzido um experimento em casa de vegetação com mudas de *Pinus caribaea* var. *hondurensis* e *Pinus taeda*, com duração de três meses, sob duas condições hídricas (bem irrigado e com déficit hídrico) e dois níveis de K do solo (suficiente e alto). Foram obtidos dados de biomassa, estado nutricional, composição isotópica foliar ($\delta^{13}C$‰ $\delta^{15}N$‰), potencial hídrico foliar (Ψw) e fluorescência da clorofila. Diante do exposto, alguns dos principais resultados foram: Capítulo I- a adição de fertilizante às espécies de *Pinus* afetou a abundância natural de ^{13}C, resultando em diferentes respostas de EIUA; Capítulo II- o regime de adubação aumentou a produção de madeira em *Pinus caribaea* var. *hondurensis* e aumentou a densidade da madeira em *Pinus taeda*; Capítulo III- o alto suprimento de K afetou negativamente a fisiologia das mudas de Pinus spp., e inibiu a fotossíntese e o crescimento.

Palavras-chave: Manejo florestal, Dendrocronologia, Estresse hídrico, Abundância isotópica

ABSTRACT

Water and nutrient use efficiency of *Pinus caribaea* var. *hondurensis* and *Pinus taeda*

The overarching purpose of this study was to evaluate the water and nutrient use effectiveness of *Pinus caribaea* var. *hondurensis* and *Pinus taeda*. To achieve this, the present study was presented in three chapters. For chapters I and II, the study used *Pinus* spp. trees, at 13 years, from the Cooperative Program on Pine Research in Brazil (PPPIB) experiment, situated in the municipality of Itatinga, São Paulo. Inventory data and measurements of dendrometer bands were used to assess tree growth of *Pinus* spp. field-grown under distinct fertilized regimes (fertilized and control treatments). Additionally, forty-eight trees were selected, and four cores per tree at approximately 1.3 m height were collected. In Chapter I, the growth, climate-growth relationships, and intrinsic water use efficiency (WUEi) were assessed by a combined analysis of cross-sectional area increment (CSA), water balance and carbon stable isotope ratio ($\delta^{13}C$). In Chapter II, wood density was analyzed by the non-destructive technique of X-ray densitometry. Also, the annual tree-rings were delimitated and the crossdating between trees was performed. Tree ring width and wood density were analyzed by dendrochronological method and correlated with rainfall and temperature. For Chapter III, a greenhouse experiment was conducted with *Pinus caribaea* var. *hondurensis* and *Pinus taeda* seedlings for three months, under two water conditions (well-watered and water deficit) and two soil K levels (sufficient and high). Plant biomass, nutritional status, leaf isotopic composition ($\delta^{13}C$‰ $\delta^{15}N$‰), leaf water potential (Ψw) and chlorophyll fluorescence were measured. In light of the foregoing, some of the key results were: (Chapter I) fertilizer added to *Pinus* species affected the natural abundance of ^{13}C, resulting in different responses of WUEi; (Chapter II) the fertilization regime incresead the wood production in *Pinus caribaea* var. *hondurensis* and increased wood density in *Pinus taeda*; (Chapter III) the K supply negatively affected plant's physiology, and inhibited photosynthesis and growth.

Keywords: Forest managmement, Dendrochronology, Water stress, Isotopic abundance

1. INTRODUCTION

In Brazil, *Pinus* is among the most economically important genus, occupying 1.6 million hectares of planted forests, the equivalent to 28% of total area (IBA, 2020). Brazilian pine forests display some of the world's highest growth rates, with an average productivity of 30 m^3. ha^{-1}. $year^{-1}$ in about 18-year rotation cycles (IBÁ, 2020). Although more extensive plantations are concentrated in South and Southeast regions, the introduction of different species coming from a wide range of ecological conditions in their original distribution has contributed to the expansion of forests planted with pine in other regions of the country (Chaves and Corrêa, 2003). Pine wood has potential for several uses such as production of cellulose, industrial laminated products, plywood for civil construction, furniture manufacturing and resin extraction.

Loblolly pine (*Pinus taeda*), species originated from United States, is the most planted species among pine in Brazil (Oliveira et al., 2018). P. taeda plantations are mostly managed by large-scale forest companies to supply raw material for pulp, paper, and wood-based composite industries (Oliveira et al., 2018). The highlands of South and Southern regions present most favorable growth conditions for that species, with mild temperatures associated with no water deficit (Campoe et al., 2016a; Dobner et al., 2019). Notably, under favorable conditions, *P. taeda* can reaches growth rates higher than 50 m3. ha-1. yr-1, at ages of 16-18 years (Elesbão and Schneider, 2011; Leite et al., 2006), more than twice as much as in its natural United States forests (Albaugh et al., 2018).

Pinus caribaea, native to the Central America, is known by its varieties *caribaea*, *bahamensis* and *hondurensis*, and has been cultivated in Brazil for over 30 years. As a tropical specie, *Pinus caribaea* has a broad adaptation in Brazilian territory, extending to Southeast and Central-west regions (Campoe et al., 2016b; Araújo et al., 2012; Pirovani et al., 2018) and some areas of the North and Northeast regions (Lima et al., 2022; de Oliveira et al., 2018). *P. caribaea* var. *hondurensis* is the most commonly planted variety in Brazil, and its timber has favorable quality for manifold uses (Shimizu & Medrado, 2005). Honduran provenance climates are very variable, range from 700 mm mean annual rainfall with 6 -7 months dry season, to over 3000 mm mean annual rainfall, and 2-3 months dry season (Robbins & Hughes, 1983). Typically, *Pinus caribaea* has excellent productivity and reaches higher growth rates than the *Pinus taeda* (Campoe et al., 2016b).

Much of the *Pinus* representativeness is associated to the genus' tolerance and rusticity, which makes possible its adaptation to low fertility soils, involving low input costs (Dobner Jr., 2013; Oliveira, 2013). However, although Pinus forests have low nutritional demand, studies have pointed to the importance of fertilization practices for the purpose of improving the productivity and to maintain the long-term sustainability of forests (Moro et al., 2014; Samuelson et al., 2008). Additionally, despite the economic importance of *Pinus* plantations in Brazil, not much is known about the management of these on response to the factors such as climate, site, and resources availability, leading to the belief that its potential has not been well explored.

Considering this, further studies directed to the understanding of how the productivity of the main pine species (tropical and subtropical) respond to climate, silvicultural and management practices have been required. This subject is directed towards the interests of the forest managers to create management strategies aimed at increasing productivity and improving competitiveness of *Pinus* forests. The main objective of this study is to evaluate the water and nutrient use effectiveness of *Pinus taeda* and *Pinus caribaea* var. *hondurensis*. Thus, three chapters were developed to achieve the present goal.

1. Climate-growth relationships and isotopic Δ^{13}carbon responses of field-grown *Pinus* spp. to nutrient availability. This chapter characterizes the development of *Pinus caribaea* var. *hondurensis* and *Pinus taeda* trees grown in an experimental site located in Itatinga Municipality, São Paulo state, Brazil, from a factorial design with two level of management, considering fertilization regime. Biomass variations were monthly analyzed over a 7-year period and correlated to local climate variables. Intra-annual $\delta^{13}C$ analysis was applied jointly with biomass and climate data for the in-depth assessing of water use effectiveness of *Pinus caribaea* var. *hondurensis* and *Pinus taeda* trees.

2. Effects of fertilization management on stand development and radial wood density variability of *Pinus caribaea* var. *hondurensis* and *Pinus taeda*. In this chapter, non-destructive X-ray densitometry analysis was applied to assess wood density variability of 13-year-old *Pinus caribaea* var. *hondurensis* trees, considering fertilized and unfertilized treatments. Interrelations of tree-ring width, microdensity and biomass were also assessed and correlated to local climate data.

3. Effect of high potassium supply and soil water regime on the early growth of *Pinus caribaea* var. *hondurensis* and *Pinus taeda*. Here, the objective was to evaluate the

effects of drought stress and K-fertilization on morphological and physiological responses of *Pinus caribaea* var. *hondurensis* and *Pinus taeda* seedlings. To achieve the proposed objectives a greenhouse experiment was conducted for three months. Measurements include growth, plant chemical composition, chlorophyll fluorescence, leaf water potential, and isotopic composition ($\delta^{13}C$ e $\delta^{15}N$).

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2. CLIMATE-GROWTH RELATIONSHIPS AND ISOTOPIC Δ^{13}CARBON RESPONSES OF FIELD-GROWN *PINUS* SPP. TO NUTRIENT AVAILABILITY

2.1. Introduction

Brazilian pine plantations have one of the highest productivity rates in the world, with an average of 30 m^3 ha^{-1} $year^{-1}$ (IBA, 2020), and consists predominantly of subtropical species as opposed to tropical species. Loblolly pine (*Pinus taeda*), native to North America, is the most planted species. The good performance of *Pinus* spp. plantations is to be largely attributed to the more favorable soil and climatic conditions (Sass et al., 2020) as well as the selection of more adapted and productive genotypes (Aspinwall et al., 2011). However, pine forests show wide regional variation in productivity, ranging from 15 to 50 m^3 ha^{-1} $year^{-1}$ (IPEF, 2016), which is ascribable mainly to differences in silvicultural practices management. That is because due to genetic and environmental factors and silvicultural treatments interacts on the capacity of *Pinus* spp. production is still unclear.

Diversified responses of *Pinus* species to climate-edaphic variability are directly connected to phenotypic plasticity and to local adaptation (Corcuera et al., 2010; Richter et al., 2012; Taïbi et al., 2015; Valladares et al., 2007) and therefore are the basis for adoption of best management practices aimed at increasing pine productivity and to maintain the long-term sustainability of forests. *Pinus Caribaea* var. *hondurensis*, a tropical pine, has been drawing some attention among forest managers because it is assumed to be relatively drought resistant (Barret; Golfari, 1962) and able to adapt to various climate conditions and soil types (Chaves and Corrêa, 2003; Shimizu, 2006). In contrast, as a subtropical species, *Pinus taeda* is well established in regions with mild temperatures, where the annual water deficit is less than 50mm (Pirovani et al., 2018).

Most Brazilian pine plantations are on low-fertility and sandy soils where moisture is frequently limiting (Sass et al., 2020). Despite the genus' tolerance and rusticity (Dobner Jr., 2013; Sixel et al., 2015), soil nutrient availability in pine stands is considered one of the most important factors affecting forest yield (Allen et al., 2005; Fox et al., 2007; Maggard et al., 2016). Fertilization increases pine productivity mainly through increases in leaf area index and intercepted radiation (Albaugh et al., 2016). Furthermore, it is known that there are interactive effects of nutrient availability and water stress on the physiological processes and tree growth (Maggard et al., 2016; Ward et al., 2015). In this sense, it has been suggested that the fertilization may be beneficial in *Pinus* spp. plantations experiencing reduced water availability (Faustino et al., 2013; Samuelson et al., 2018; Wightman et al., 2016).

Fractionations of stable carbon isotope ($\delta^{13}C$ ‰) in tree rings of *Pinus* species in sub- and tropical (Brooks and Mitchell, 2011; Fichtler et al., 2010; Ibell et al., 2013; Krepkowski et al., 2013; van der Sleen et al., 2017) zones have been analyzed at inter- and intra-annual resolutions. Linking tree growth, carbon isotopic composition provides integrated measures of both environmental conditions and plant physiological processes, and is related to the plant water use efficiency (Farquhar et al., 1982; Mateus et al., 2019; 2022). Stomatal conductance for CO_2 and the photosynthetic carbon assimilation are regulated by the partial pressure of CO_2 in the leaf intercellular spaces (Farquhar et al., 1989). The CO_2 diffusion through stomata and the carboxylation process mediated by Rubisco are the principal components of photosynthesis influencing carbon discrimination and $^{13}C/^{12}C$ isotopic ratio (O'Leary, 1988, 1993). The primary mechanism for inhibition of photosynthesis under water deficit is the decrease in intercellular CO_2 concentration and a reduced CO_2 supply to Rubisco (Marques et al., 1995). As the water availability cause variations of CO_{2plant} / CO_{2atm} mainly through their effects on stomatal conductance and photosynthetic activity, these effects are measurable as either changes in $\delta^{13}C$ or carbon discrimination (Δ). Overall, water stress condition causes stomata closure, reduces stomatal conductance for CO_2, and leads to increased water use efficiency. It is expected to be recorded in tree-rings as an increase of the ratio between ^{13}C and ^{12}C stable isotopes of carbon fixed in steam wood (McDowell et al., 2003).

The present work evaluated the climate-growth relationships of *Pinus caribaea* var. *hondurensis* and *Pinus taeda* stands grown under fertilized and unfertilized treatments, on an experimental area situated in the Southeast Brazil. These data were linked to the variation in $\delta\ ^{13}C$ of annual rings to assess the water use efficiency of trees. The hypotheses are: (1) the fertilization regime would influence the tree cambial activity and wood production of the two studied *Pinus* species; (2) the natural abundance of ^{13}C may be an effective tool for assessing the effects of fertilization regime on tree WUE (as indicated by wood $\delta^{13}C$) and tree growth.

2.2. Conclusions

The tree growth of *Pinus caribaea* var. *hondurensis* and *Pinus taeda* showed significant relationships to meteorological variables and all tree size classes responded to multiple meteorological variables related to water availability and evapotranspiration. Considering the climate aptitude of studied *Pinus* species, the water balance analysis revealed that the tree growth performance was not significantly impacted by drought stress in most of the years of study.

Differences between treatments were recorded in $\delta^{13}C$ which showed that fertilized *Pinus* spp. trees displayed higher carbon isotope discrimination values. This indicates that the increased of nutrient availability improved the soil water absorption capacity, resulting in higher photosynthetic performance of *Pinus* spp. trees. Unfertilized trees of *Pinus caribaea* var. *hondurensis* presented lower wood productivity associated to higher WUEi. In return, fertilized trees of *P. taeda* showed higher WUEi in some drier periods, without significant changes in growth rates. In general, *P. caribaea* var. *hondurensis* has proved to be more water-use efficient than *P. taeda*, being able to use smaller amounts of water for a higher wood production.

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3. EFFECTS OF FERTILIZATION MANAGEMENT ON STAND DEVELOPMENT AND RADIAL WOOD DENSITY VARIABILITY OF *PINUS CARIBAEA* VAR. *HONDURENSIS* AND *PINUS TAEDA*

3.1. Introduction

Understanding the mechanisms that control growth and wood formation of trees is critical for forecasting forest stands dynamics and to overview best management practices aimed at sustainable development and increased forestry productivity. Genetic and physiological components of plants are intrinsically related to their abilities to absorb and utilize nutrients under distinct environmental and ecological conditions. These traits interact with external factors such as soil moisture and temperature (Baligar et al., 2001), and how this dynamic affects the biomass production is related to the ability of crops to take up and utilize nutrients for maximum yields (Dijkstra et al., 2016; Toca et al., 2019).

Pinus taeda, a subtropical species from southeast United States, is the most cultivated *Pinus* species in Brazil (IBÁ, 2020). Among species of tropical pines, *Pinus caribaea* var *hondurensis* has been increasingly cultivated in Brazil (de Lima et al., 2016; Gonçalez et al., 2018). In general, the *Pinus* genus is seen as exceptionally tolerant and rusticity, based on its satisfactory adaptation to low fertility soils (Kulmann et al., 2021; Pietrzykowski, 2014; Rocha et al., 2020). However, although *Pinus* forests have considerable low nutritional demand, studies have pointed to the importance of fertilization practices aiming to improve the productivity as well as to maintain the long-term sustainability of forest plantations (Campoe et al., 2016; Moro et al., 2014; Samuelson et al., 2008). Besides, despite the economic importance of *Pinus* plantations in Brazil, not much is known about the effects of fertilization management on the growth performance associated to the factors such as climate and wood properties, leading to the belief that the productivity potential of the *Pinus* spp. plantations has not been well explored.

Radial growth of trees greatly depends on the interactions between environmental and competition dynamic (Piutti and Cescatti, 1997). Changing environmental conditions, do not only influence growth rates of the trees (and thus ring width), but can also affect the wood properties, as wood density. To comprehend the role of the fertilization regime on forest dynamics in the context of the nutritional efficiency is facilitated by understanding of tree growth changes into a longer assessment period. Dendrochronological analysis provides tools to explore radial variability of wood stablishing relationships between tree-ring width, and climate data over time (tree age) (Aragão et al., 2019; Fritts, 1976). These relationships can be used in association with radial variation in wood density, for a in depth assessment of trees development (Gao et al., 2017; Jacquin et al., 2017; Tomazello et al., 2008). In this sense, annual tree-rings being a precise tool to assess long-term growth trends and to report accurately information about the effect of fertilization on stand development and their interaction with environmental conditions.

The present work used the Cooperative Program on Pine Research in Brazil (PPPIB) experiment to determine how tree growth of *Pinus taeda* and *Pinus Caribaea* var. *hondurensis* differ in response to fertilization, and how these responses are associated to tree-ring microdensity variability and climate variables.

3.2. Conclusions

In particular for *Pinus caribaea* var. *hondurensis*, fertilized plots varied greatly from the control plots in relation to tree growth and biomass production. Significant changes in the *P. caribaea* var. *hondurensis* tree-volume trends were verified in all years by the fertilization regime, indicating a high level of responsiveness to both fertilizer application periods.

The wood microdensitometry analysis associated to the study of annual rings provided accurate data to understand the impact of fertilization regime on *Pinus* spp. stands development over the years of study, regardless species and tree size class (large, medium, small). Although no significant effect was observed on tree stem volume increment of *Pinus taeda* trees, a small increase in wood density occurred in response to fertilization. Furthermore, the precipitation was a principal climate variable related to tree ring width (positive correlation) and wood density (negative correlation).

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4. EFFECT OF HIGH POTASSIUM SUPPLY AND SOIL WATER REGIME ON THE EARLY GROWTH OF *PINUS CARIBAEA* VAR. *HONDURENSIS* AND *PINUS TAEDA*

4.1. Introduction

Globally, drought stress is one of the main abiotic factors that limits crop growth and its production (Ryan et al., 2010; Booth 2013; Anderegg and Hillerislambers 2016). It is a recognized fact that the water stress adversely impacts many aspects of the physiology of plants, especially photosynthetic capacity (Osakabe et al., 2014). Under water limited conditions, plants promote the closure of stomata to avoid water losses, and although this mechanism prevents the desiccation and xylem cavitation, it also restricts CO_2 supply for photosynthesis, leading to a decrease in the tree productivity (Chaves et al., 2009; Sperry and Love 2015). In addition, due to drought, there is a significant reduction in photochemical efficiency (Mena-Petite et al., 2000; Yang et al., 2006) and different water relation parameters are affected (Cochard et al., 1996 Sergent; et al., 2020). In this sense, efforts to adapt forests to drought stress have been directed at assessment of impacts and genetic variation in traits that may be important for maintaining higher photosynthetic capacity in drought-tolerant plants.

Potassium is essential for plant nutrition and plays a key role optimization of physiological and biochemical processes involved in water content of plants and CO_2 use efficiency during drought periods (Christina et al., 2015; Battie-Laclau et al., 2016; Mateus et al., 2022). Drought tolerance of the plant as a function of K nutrition is based on the fundamental role of K in osmoregulation, enabling the maintenance of turgor and cell expansion necessary to promote root growth in conditions of water deficit (Leigh and Jones 1984; Oddo et al., 2011). Furthermore, K must be intrinsically related to the water use efficiency of plants subjected to drought stress, since it controls stomatal closure, which is the most effective way to retain water in plant tissues (Egilla et al., 2005; Jordan-Meille et al., 2018). Based on this, K supply has been adopted as a nutritional management option to attenuate drought stress in tree species plantations as *Eucalyptus* spp. (Battie-Laclau et al., 2016; Santos et al., 2021; Mateus et al., 2022). However, the results that have been reported about the effect of K in the attenuation of osmotic stress linked to photosynthetic process differ regarding species or genotype, which place high emphasis on genetic factor as source of variability.

Photosynthesis in plants greatly relies upon the photochemical processes including the chlorophyll fluorescence, an important indicator of the photosynthetic energy conversion during light reaction (Schreiber et al., 1994). Chlorophyll fluorescence has been widely used in studies of plant physiology (Murchie and Lawson 2013), and is a very promising method for providing quantitative and non-invasive information. Measuring chlorophyll fluorescence can be provide various information about the photosynthetic activities of plants. The energy dissipated via light-harvesting antenna pigments when excitation energy is not being transferred to the Photosystem II (PSII) reaction centers is termed F_0 (Bresson et al., 2015). After reaching F_0, the application of a brief saturating pulse induces a maximum value of chlorophyll, Fm, which is the level attained when maximal closure of PSII reaction centers is reached (Hsu 2007; Bresson et al., 2015). The difference between Fm and F_0 is defined as the variable fluorescence, Fv. The ratio of Fv/Fm provides an estimate of the maximum quantum efficiency of PSII photochemistry (Butler, 1978), and it has been widely used to assess alterations in the photosynthetic systems induced by stress (Toscano et al. 2016, Marias et al., 2017; Remke et al., 2020; Kunert et al., 2021). In this context, differential $\delta^{13}C$ and $\delta^{15}N$ signatures have been also used to gain insights into the nutritional status and physiological response mechanisms to abiotic stress throughout its whole cycle (Cernusak et al. 2009, Serret et al., 2018; Mateus et al., 2021; 2022).

Although *Pinus* species are widely distributed and most of them display relative drought tolerance (Koralewski et al., 2014; Móricz et al., 2018; Hanene et al., 2021), it has been recognized that the water stress greatly limits the growth efficiency and pine stand production (Albaugh et al., 2004; Fox et al., 2007). *Pinus taeda* and *Pinus caribaea* var. *hondurensis* are important components of Brazilian conifer forests, which represent about 20% of total planted forest areas (IBA, 2019). *Pinus Caribaea* var*. hondurensis*, a tropical pine, is assumed to be relatively drought resistant (Barret and Golfari, 1962), while *P. taeda*, a subtropical species, has been well established in regions without dry season (Campoe et al., 2016; Pirovani et al., 2018). Studies describing the effect of water stress and how K can upregulate drought tolerance of different *Pinus* species are scarce. This information is also useful in choosing the strategic management of the species to fully exploit planted forests.

The research evaluated the K-dynamic nutrition in *Pinus caribaea* var*. hondurensis* and *Pinus taeda* in response to different water availabilities in the soil and stablished relationships among the distinct treatments and nutritional and physiological responses, as well as yield traits. For this, the study was carried out by the following hypotheses: (1) drought induced-stress affects the physiology and K-nutritional status when plants are supplied with K; (2) K supply has the potential to alleviate the drought-induced stress in *Pinus* by up-regulating growth, physiological and biochemical parameters. This research also aims to confirm the efficacy of the methods of natural isotopic abundance ($\delta^{13}C$ ‰ and $\delta^{15}N$ ‰) and chlorophyll fluorescence as a reliable indicator of the effects of K-fertilization throughout plant metabolism cycle.

4.2. Conclusions

Pinus spp. plants showed a negative response to potassium supply, as the increase in K level affected directly the plant's growth and physiology, impairing plant dry matter production and disturbing the photosynthetic activity (Fm, Fv/Fm NDVI, chlorophyll a and anthocyanin indexes). Although this negative effect has been verified for both water regimes, it was higher for *Pinus* seedlings maintained well-watered. In this sense, K supply decreased the plant biomass in well-watered regime and did not alleviate the drought-induced stress in *Pinus* spp. seedlings.

Regardless of the K-fertilization regime, water deficit was related to substantial decrease in leaf water potential (Ψw) and increase in leaf carbon isotope value ($\delta^{13}C$ ‰). Differences in discrimination against ^{15}N between treatments indicated consistent relationship with N cycle processes, suggesting an antagonistic relationship between high K level and N-uptake. The information presented in present study improves our understanding of the toxicity of high potassium for *Pinus* species in detriment of other essential elements and highlights the need for plantation planning to stablish a nutritional balance in order to achieve high nutrient use efficiency.

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