Negative interference on growth and morpho-anatomical modifications in young *Parkia gigantocarpa* plants under waterlogging

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Abstract

The aim of this study was to investigate the responses linked to growth and morphological and anatomical changes in young plants of *Parkia gigantocarpa* subjected to waterlogging conditions. The experimental design was completely randomized with two water conditions (control and waterlogging) combined with five evaluation times (0, 4, 8, 12 and 16-days waterlogging conditions). The parameters evaluated were leaf specific hydraulic conductance, plant height, stem diameter, numbers of leaf and leaflets, as well as shoot dry matter, root dry matter, and total dry matter. The data were subjected to an analysis of variance, and significant differences between the means were determined using the F-test at a probability level of 5 %. Additionally, transversal sections linked to primary and secondary roots were described. The segments from the primary root (removed from region located 4 cm below of the soil surface) and the secondary root (removed from region located 4 cm from the root apex) were fixed, stained and mounted, and subsequently photo-documented. The waterlogging provoked reduction in leaf specific hydraulic conductance, as well as negative interferences on growth. Anatomically, this stress induced the appearance of hypertrophic lenticels in base of the stem, adventitious root and formation of schizogenous aerenchyma located in cortical parenchyma of the secondary root. Therefore, these results reveal the susceptibility of young *Parkia gigantocarpa* plants subjected to waterlogging conditions.

Keywords: hypertrophic lenticels, adventitious roots, air spaces.
Abbreviations: SDM_shoot dry matter, RDM_root dry matter, TDM_total dry matter, K_L_leaf specific hydraulic conductance, g_{smd}_stomatal conductance in midday, Δwmd_variation in water saturation during midday, Ψ_{pd}_leaf water potential in predawn, Ψ_{md}_leaf water potential in midday.

Introduction

The *Parkia gigantocarpa* (Ducke) is a tree found mainly in tropical rainforests, naturally covering land areas, secondary and seasonal floodplain, especially in the North of the Amazon (Hopkins, 1986). In recent years, this species has attracted attention of researchers in relation to breaking dormancy of seeds and seedlings (Oliveira and Joly, 2010), and commercial activities linked to wood of this specie in the Amazon (Carvalho, 2010; Vidal et al., 2002). Furthermore, due to its rapid growth rate, high volume production, uniformity and low mortality, it has been identified as a promising species for reforestation and regeneration of degraded areas (Carvalho, 2010).

Waterlogging is a common abiotic factor in several regions, being able to limit the growth and survival of certain species of plants. This is because the excess water in the soil promotes the reduction of oxygen to the root system, and consequently will affect plant development, due to change from aerobic metabolic pathway to anaerobic, contributing to the reduction of energy and consequently the absorption capacity and transport of water and nutrients to the shoot (Liao and Lin, 2001).

The responses of plants to water saturation in the soil are complex, and it may vary depending on the species, the height of the water depth, duration of waterlogging, and the stage of plant development (Colmer and Voesenek, 2009; Oliveira and Joly, 2010). Studies by Parolin (2002) evaluating species of waterlogging areas from the Amazon suggests that the rapid growth of the stem in early life of the plant would be an adaptation to increase the plant height to survive the effects produced by waterlogging. However, reduced growth of roots and shoots (Medri et al., 2007), epinasty, senescence, abscission of leaves (Katz et al., 2005) and decreased biomass (Chen et al., 2002) have often been shown to reduce survival in tree species subjected to waterlogging. Thus, higher production of dry matter in plants subjected to waterlogging, in principle could indicate a tolerance to this stress.

Some species of higher plants imposed to the stress water aiming to tolerate saturation and maintain metabolism by developing morpho-anatomic modifications, such as hypertrophied lenticels (Katz et al., 2005; Shimamura et al., 2010), the production of adventitious roots (Oliveira and Joly, 2010; Batista et al., 2008; Ezin et al., 2010; Gregório et al., 2008; Kolb and Joly, 2009), and the formation of aerenchyma (Ashraf, 2012; Bouranis et al., 2006; Graffmann et al., 2008; Sairam et al., 2008).

Studies indicate that hypertrophic lenticels and adventitious roots, can interconnect the aerenchyma channels allowing the transport of oxygen from the air to the root system enabling the maintenance of aerobic respiration (Kolb and Joly, 2009), and contribute to the release of potentially toxic compounds such as ethanol, ethylene and acetaldehyde associated with anaerobic conditions (Kozlowski, 1997). Another important contribution of these structures would be the reopening of the stomata and the maintenance of high photosynthetic rates in species tolerant to waterlogging (Mielke et al., 2005).

The aerenchyma is another morpho-anatomical modification that can arise in plants when exposed to waterlogging, and it has large intercellular spaces where air accumulates, which also contributes to the aeration of the roots (Graffmann et al., 2008). The development of a type of schizo-lysigenous aerenchyma arises from separation of cells and intercellular spaces due to the differential arrangement of the cells making up the tissue, without cell death (Evans, 2003). This lysigenous aerenchyma is a result of the hydrolysis of cell wall, and consequent degradation linked to the cell, resulting in possible spaces filled with air between the cells that remains alive (Visser and Voesenek, 2004). However, the mechanisms, by which these structures contribute to the waterlogging tolerance of *P. gigantocarpa* are still mostly unknown.

Currently, there are many reforestation projects using native tree species in young stage of development. However, in many cases a considerable number of individuals are lost due to waterlogging stress. In this sense, the re-vegetation of degraded areas, especially in areas with availability of water resources, using tree species that develop adaptation strategies to waterlogging stress conditions can improve project success. In this context, *P. gigantocarpa* has been recommended to for the regeneration of degraded areas. However, the waterlogging tolerance strategies presented by them are not fully understood, motivating questions of plant behavior in relation to its growth and morphological and anatomical structure, when subjected to waterlogging conditions. Thus, the understanding of how young plants of this species respond to stress will be relevant to subsidize the re-vegetation of degraded areas.

Therefore, the aim of this study was to investigate the responses linked to growth and morphological and anatomical changes in young plants of *Parkia gigantocarpa* plants subjected to waterlogging conditions, researching answers to the following questions: Will young plants of *P. gigantocarpa* tolerate the stress imposed by the waterlogging condition? Is development of young plants of *P. gigantocarpa* influenced by waterlogging condition? Will young plants of *P. gigantocarpa* present morphological and anatomical changes when they are subjected to waterlogging conditions?

Results

Leaf specific hydraulic conductance

There was a significant interaction between treatments (P≤0.001) for leaf specific hydraulic conductance with the

control and flooded plants at 0.29 and 0.02 mmol m^{-2} s^{-2} MPa^{-1}, respectively, with a decrease of 93.1% in flooded plants compared with the control (Fig. 1).

Plant height, stem diameter, leaf number and leaflet number

Waterlogging caused a reduction in plant height, stem diameter, leaf number and leaflets of young *P. gigantocarpa* plants, compared with the control (Fig. 2). There was a significant difference between treatments (P≤0.001) for plant height. At 16 days, the control and waterlogging plant heights were 34.34 and 32.86 cm, respectively, with a reduced growth of 4.30% in waterlogging plants, compared with the control (Fig. 2A). The stem diameter was significantly different between treatments (Fig. 2B). There were significant differences between water regimes for leaf number (P≤0.001). The control plants had 22.4 and 16.8 leaves, respectively, under waterlogging at 16 days with a decrease of 25% in waterlogging plants, compared with the control (Fig. 2C). The waterlogging affected the number of leaflets (Fig. 2D), showing significant differences between treatments (P≤0.001). The control and waterlogging plants had 455.2 and 319.6 leaflets, respectively, at 16 days, with a reduction of 29.78% in the waterlogging treatment compared with the control.

Shoot dry matter, root dry matter and total dry matter

Waterlogging reduced shoot dry matter (SDM), root dry matter (RDM) and total dry matter (TDM). There were significant differences between treatments (P≤0.001) in shoot dry matter of 7.79 and 6.69 g in control and waterlogging treatments, respectively, at 16 days, with a decrease of 14.12% in SDM from waterlogging plants compared with the control (Fig. 3A). The same trend was observed for root dry matter with significant variation between water regimes (P≤0.001). The values were 1.61 and 1.13 g in the control and waterlogging treatments, respectively, at 16 days, representing a decrease of 29.81% in stressed plants compared with the control (Fig. 3B). The total dry matter varied significantly among treatments (P≤0.001). The control and waterlogging plants at 16 days was 9.41 and 7.82 g, respectively, with a reduction of 16.89 % in plants subjected to stress (Fig. 3C).

Hypertrophic lenticels and adventitious roots

After four days of flooding, 60% of the plants of *P. gigantocarpa* showed hypertrophic lenticels of white color at the base of the stem (Fig. 4A), reaching 100% of plants from the eighth day. Another characteristic that observed was the development of adventitious roots on the stem base in 40% of plants under waterlogging, only after 16 days (Fig. 4B).

Transversal sections of the primary and secondary roots

In general, there were no significant structural differences between the anatomy of primary and secondary roots of *P. gigantocarpa*, subject to waterlogging, compared with plants maintained in soil at field capacity during the experimental period. The root primary, secondary growth, has cylindrical contour (Fig. 5A), and displayed a periderm with thick tabular cell layers, turning red when stained with safranin (Figs. 5A and B) as well as the presence of lenticels in both treatments (Fig. 5F). The cortex consisted of parenchyma cells with lignified walls and groups of sclerified cells, located in the periphery and proximity of the phloem (Figs. 5B and D). In this
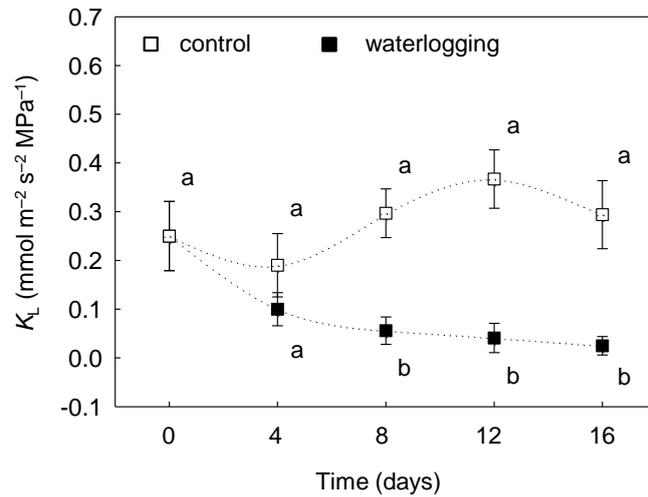
Fig 1. Leaf specific hydraulic conductance in young *Parkia gigantocarpa* plants subjected to waterlogging. Same letters are not significantly difference at F-test (P≤0.05) at each time measured. Squares represent the mean values of five repetitions, and error bars represent the mean standard errors.
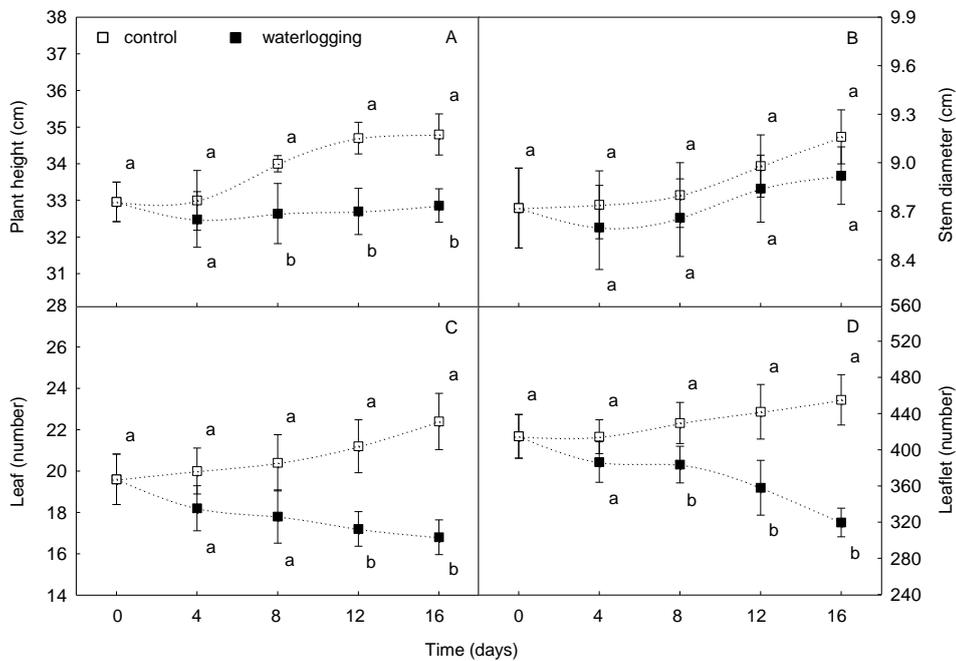

Fig 2. Plant height (A), stem diameter (B), leaf (C), and leaflets (D) in young *Parkia gigantocarpa* plants subjected to waterlogging. Same letters are not significantly difference at F-test (P≤0.05) to each time measured. Squares represent the mean values of five replicates, and error bars represent the mean standard errors.

region, idioblasts occurred with red content together with prismatic crystals (Fig. 5B), which became more evident from the 12th day in both treatments. The cambium is active and bidirectional, with phloem and xylem secondary well developed (Figs. 5A and B), besides abundant starch grains around vessels, which were observed in primary roots subject to waterlogging in polarized light (Fig. 5E). Protoxylem elements were observed in the center (Fig. 5C).

The secondary roots had a circular aspect in primary structure (Fig. 6), with three distinct regions, being the epidermal, cortex and vascular. The epidermal layer is a unit, composed of cells with several dimensions and covered by a thin cuticle. The cortex occurred with about 10-11 layers of parenchyma cells (Fig. 6B). In this region, the parenchyma cells were located near the periphery and the endoderm of the samples showed

waterlogged treatment, at 16 days, the beginning of the schizogenous process with small air spaces (Figs. 6D and F), where the intercellular spaces were visibly conspicuous. The endoderm contents were yellow and turned red when stained with safranin (Fig. 6C) around the vascular cylinder. This structure was clearly differentiated (Fig. 6E). Idioblasts with red content were observed in the phloem and xylem (Fig. 6C).

Discussion

The reduction in leaf specific hydraulic conductance in response to waterlogging was probably due to the loss or death of the root system similar to that found in *Picea mariana* and *Larix laricina* (Islam and MacDonald, 2004). The recuperation
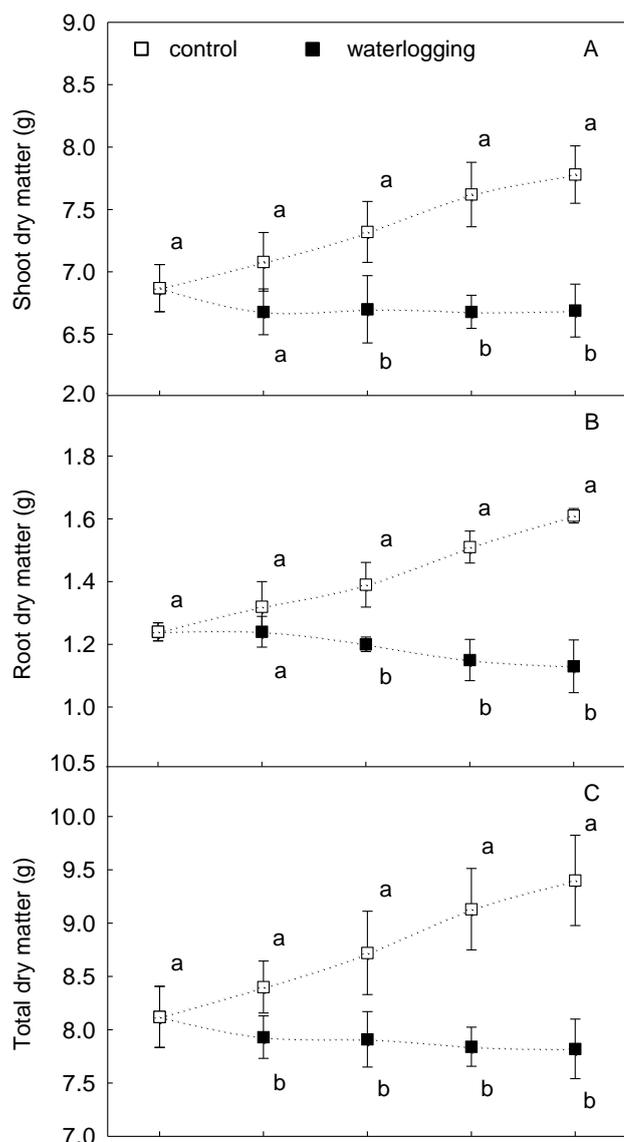
Fig 3. Shoot dry matter (A), root dry matter (B), and total dry matter (C) in young *Parkia gigantocarpa* plants subjected to waterlogging. Same letters are not significantly difference using the F-test (P≤0.05) to each time measured. Squares represent the mean values of five replicates, and error bars represent the mean standard errors.

related to hydraulic conductance in plants of *Larix laricina* under prolonged waterlogging was linked to the emergence of adventitious roots to replace the original roots that were reduced due to necrosis (Islam and MacDonald, 2004; Calvo-Polanco et al., 2012). However, the relative stabilization of the hydraulic conductance in *P. gigantocarpa* under waterlogging was not influenced by adventitious roots. The reduction of hydraulic conductance began in 12th day of waterlogging, and adventitious roots were viewed only at the end of the experiment on the 16th day, in 40% of waterlogged plants. The lower growth of *P. gigantocarpa* was similar to that in other neotropical tree species as *Lithraea molleoides* (Medri et al., 2007), *Pouteria glomerata* (Maurenza et al., 2009), *Hura crepitans* (Martinez et al., 2011), and *Aegiphila sellowiana* (Medri et al., 2012).

The waterlogging conditions generally reduces growth (Lopez and Kursar, 2003; Parolin and Wittmann, 2010) and plant survival (Kabrick et al., 2012) due to the low production of ATP caused by anaerobic soil. Under these conditions, there is a reduction of metabolism and death or low growth of the root system (Glenz et al., 2006). However, the limitation of growth is one of the strategies that plants develop to save energy and survival (Colmer and Voesenek, 2009). Many neotropical species considered as tolerant to water saturation have shown growth decrease, when subjected to waterlogging. Therefore, the reduction of the growth can be considered as a factor of waterlogging tolerance (Parolin and Wittmann, 2010; Parolin et al., 2004). The reduction of growth of *P. gigantocarpa* was not a limiting factor for the survival of this species at least during the period of the experiment. Additionally, stem diameter was unaffected by waterlogging, possibly due to insufficient stress time to promote changes in this structure.

The change from aerobic to anaerobic conditions in roots of plants under waterlogging condition leads to low energy production (Alam et al., 2011), leading to reduced absorption of nutrients (Greenway and Gibbs, 2003), resulting in nutritional deficiency and ATP in shoots, and causing, chlorosis, senescence and abscission of older leaves (Glenz et al., 2006). Normally, the older leaves experience premature senescence due to the re-allocation of phloem mobile elements, such as nitrogen, phosphorus and potassium in direction to younger leaves (Taiz and Zeiger, 2013). The biosynthesis of ethylene in the air, caused by the waterlogging, also induces epinasty, accentuating senescence and leaf abscission (Katz et al., 2005). The reduction of biomass has been observed in many species of trees due to waterlogging, such as *Lithraea molleoides* (Medri et al., 2007), *Pouteria glomerata* (Maurenza et al., 2012), *Alnus subcordata* (Ghanbary et al., 2012), and *Jatropha curcas* (Gimeno et al., 2012). Root growth is significantly inhibited under waterlogging conditions (Sairam et al., 2008). This occurrence is because in waterlogged soils, there is a decrease or lack of oxygen to the roots, resulting in decrease in metabolic activity and ATP production, which restricts the supply of energy for root growth (Liao and Lin, 2001). Excess of Fe^{+2} and Mn^{+2} accumulation of phytotoxic substances, such as carbon dioxide and ethylene, which are common in waterlogged soils (Shabala, 2010), and reduction in translocation of carbohydrates can cause growth inhibition or death of roots (Slewinski and Braun, 2010). This may lead to a decrease in absorption of water, oxygen, macro and micronutrients in plants exposed to stressed conditions, resulting in a large decrease of the root dry matter in *P. gigantocarpa* subjected to waterlogging (Fig. 2). However, the reduction of the dry matter of this organ in this specie is not limiting for their survival during the waterlogging. The data obtained in this work in relation to root dry matter are consistent with those found in *Caesalpinia ferrea* (Lenhard et al., 2010), *Heliocarpus popayanensis* (Pisicchio et al., 2010) and *Alnus subcordata* (Ghanbary et al., 2012) when these species were subjected to waterlogging.

The stomatal closing in plants under waterlogging would be responsible for the reduction of photosynthesis (Mielke et al., 2003), resulting in lower production of assimilates (Lin et al., 2006). This may be attributed to the decrease of the dry mass of the aerial part of *P. gigantocarpa*. Additionally, hypoxia or anoxia in roots may incur changes in the shoot dry matter due to reduced absorption and translocation of nutrients to the leaves (Bertolde et al., 2012). Thus, the survival of the plant under waterlogging condition is dependent on a balance in distribution of photo-assimilates between the various parts of the plant (Batista et al., 2008).
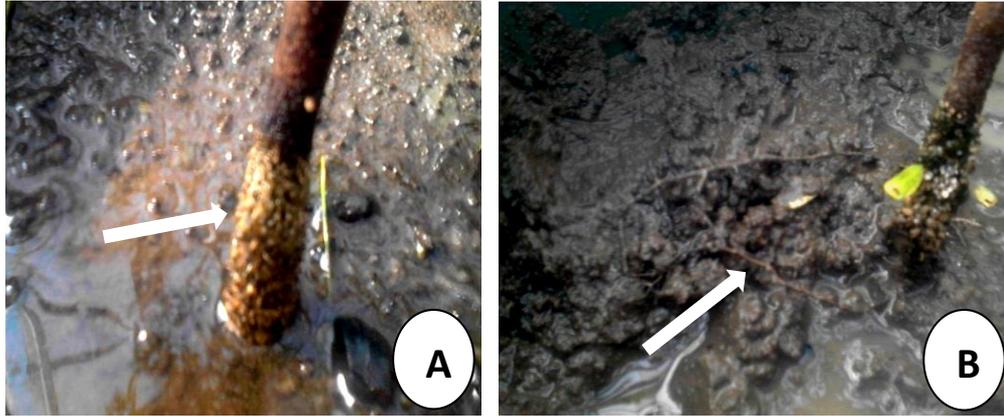
Fig 4. Stem of *P. gigantocarpa* exposed to waterlogging, the arrows indicate the presence of hypertrophic lenticels (A) and adventitious roots (B).
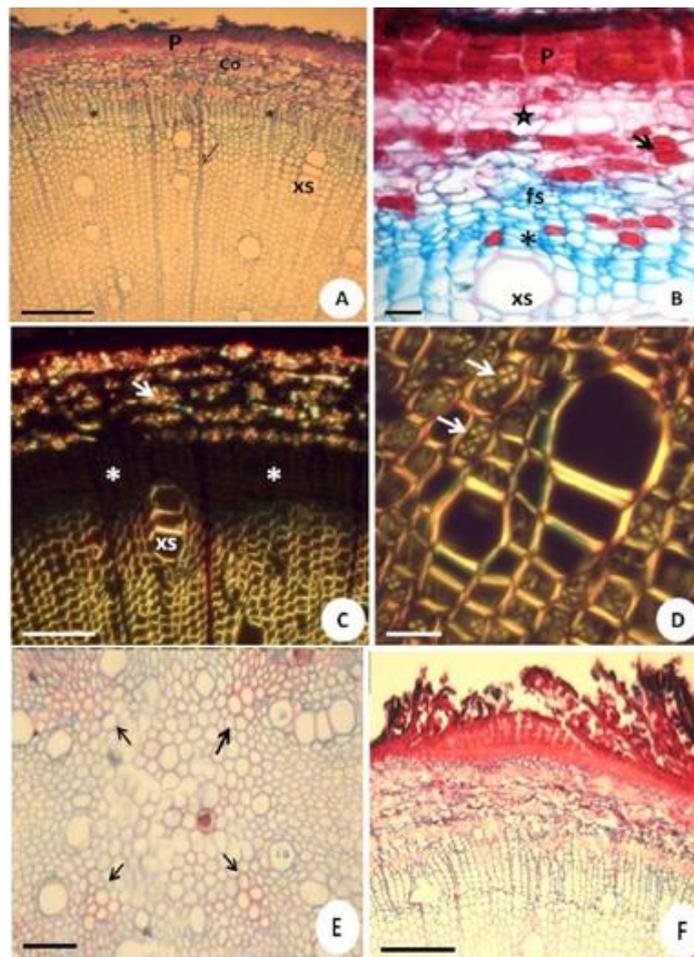

Fig 5. Transversal sections of the primary root of young *P. gigantocarpa* plants exposed to control (A, B and E) and waterlogged (C, D and F) treatments. (A) General aspect, showing the peripheral, cambium, and vascular regions, with the parenchyma cells highlighted (arrow). (B) Detail of the peripheral region with the periderm, cortical region exhibiting sclerified cells (star), vascular cambium (asterisk), and idioblasts with red content (arrow) from 12th day after waterlogging. (C and D) Structures are illuminated in polarized light, revealing lignified walls of the sclerified cortex cells (arrow), and secondary xylem and starch grains around the vessels, indicated by the arrows (D). (E) Medullary region showing the protoxylem (arrow). (F) Detail of the lenticels. Abbreviations: co = cortex, fs: secondary phloem, P: periderm, xs: secondary xylem. Scales: A = 150 μm, B, C and E = 50 μm, D = 20 μm and F = 100 μm.
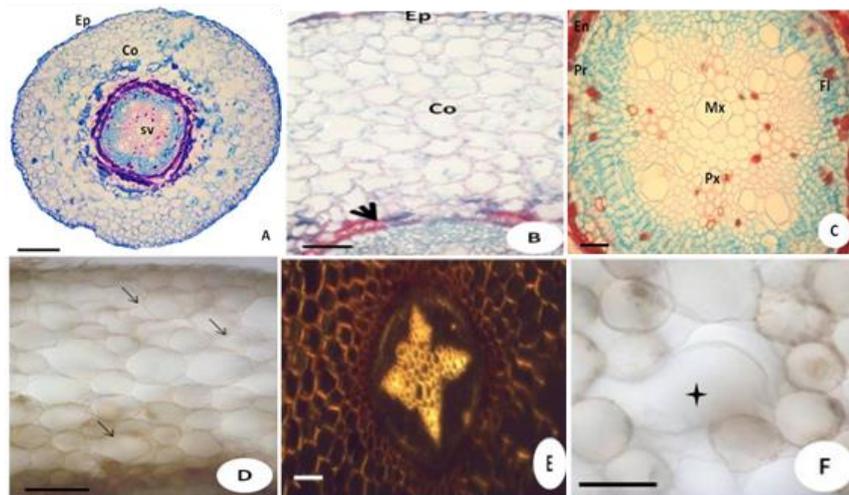
Fig 6. Transversal section of secondary root in young plants of *P. gigantocarpa* plants exposed to control (A, B and C) and waterlogged (D, E and F) treatments. (A) General cross-section. (B) peripheral and cortex regions and vascular system, showing the endoderm (arrowhead). (C) Detail of vascular region, showing lignified walls of the vessels under development. (D) Early formation of spaces in cortex region, after 16 days of waterlogging (arrows). (E) Detail of the vascular system in polarized light. (F) Detail of space formation (star). Abbreviations: Ep: epidermis, co: cortex, Fl: phloem; sv: vascular system, En: endoderm, Pr: pericycle, Mx: metaxylem, Px: protoxylem. Scales: A = 200 μm, B and D = 100 μm, C and E = 50 μm, F = 20 μm.

The reduction of total dry matter in waterlogged plants may have occurred due to the reduction of plant height (Fig. 1A), the number of leaves (Fig. 1C) and root dry mass (Fig. 2B). Mielke et al. (2003) working with young plants of *Genipa americana* in the period of 63 days of waterlogging, attributed the reduction in total dry matter to drop in stomatal conductance and photosynthesis rate of waterlogged plants, compared with well irrigated plants. Maurenza et al. (2012) working with young plants of *Pouteria glomerata* exposed to waterlogging for 180 days, observed a significant reduction of shoot dry matter and total dry matter. Gimeno et al. (2012) also observed a significant reduction in shoot dry matter, root dry matter and total dry matter in young plants of *Jatropha curcas* subjected to waterlogging for 10 days. Ghanbary et al. (2012), working with young plants of *Alnus subcordata*, found that the shoot dry matter, root dry matter and total dry matter were significantly lower in plants subjected to waterlogging than in control plants. The emergence of hypertrophic lenticels at four days of waterlogging in *P. gigantocarpa* may have contributed in plant tolerance during the period, in which they were submitted to stress (16 days) and all waterlogged plants survived. These data demonstrate that hypertrophic lenticels appear not only in tolerant species, but their appearance in initial periods of water saturation may have been an important factor for the survival of plants. This may have occurred because of hypertrophic lenticels make the entry of atmospheric oxygen from the air to the roots possible (Shimamura et al., 2010; Ashraf, 2012; Bracho-Nunez et al., 2012). Furthermore, these structures could eliminate compounds produced as sub products of the anaerobic metabolism, such as ethanol, CO_2, and CH_4 (Ashraf, 2012).

The adventitious root formation is mentioned as a possible strategy of tolerance and survival or recovery of the growth of plants on waterlogging conditions (Ezin et al., 2010). This is because these roots can enhance the absorption of water, oxygen and nutrients in order to compensate the reduction of the original root system (Ezin et al., 2010; Gong et al., 2007). According to Kolb and Joly (2009) and Rätsch and Haase (2007), the adventitious roots are important structures in plants under waterlogging by connecting to parenchymal intercellular spaces, facilitating the transport of oxygen from the air to the root system. Moreover, the formation of these structures have

also been associated with increased tolerance of the plants to waterlogging and ethylene production (Steffens et al., 2006), which were observed in *Pachira aquatica* and *Anacardium excelsum* (Lopez and Kursar, 2003), *Chorisia speciosa* (Povh et al., 2005), *Cecropia pachystachya* (Batista et al., 2008), *Pouteria glomerata* (Maurenza et al., 2009), *Hura crepitans* (Martinez et al., 2011), *Aegiphila sellowiana* (Medri et al., 2011), and *Alnus subcordata* (Ghanbary et al., 2012) during the period, in which the plants were subjected to waterlogging.

In this study, the formation of adventitious roots was viewed only at the end of the experiment in 40% of waterlogged plants. These roots seem to have been important for the survival of young plants, by the period in which they were submitted to waterlogging. The adventitious roots were not observed in most of the waterlogged plants, but survived the 16 days of waterlogging. This fact can be attributed to the formation of other structures such as hypertrophic lenticels at the stem base of flooded plants, as observed in this work.

The young plants of *P. gigantocarpa* did not form aerenchyma in primary and secondary roots during the experiment. However, we observed the beginning of a schizogenous process forming small air gaps in the cortical parenchyma of secondary roots at 16 days (Figs. 5D and F) of soil water saturation, which must be a plant response to reduced oxygen. The development of intercellular spaces in roots of plants under water-saturated soil can increase the aeration of the root tissue (Graffmann et al., 2008) and gas diffusion in the roots, as well as between the root and shoot (Bouranis et al., 2006; Bailey-Serres and Voesenek, 2008), besides of the removal of toxic products produced in the roots during the fermentation (Visser and Voesenek, 2004), and consequently promoting the survival of the plant under conditions of anoxia or hypoxia (Bailey-Serres and Voesenek, 2008).

The formation of intercellular spaces in the cortical parenchyma of roots was also observed at 35 days in *Lithraea molleoides* plants (Medri et al., 2007), in 30 days in *Cecropia pachystachya* (Batista et al., 2008), as well as with 50 and 80 days in *Aegiphila sellowiana* plants (Medri et al., 2011) under water saturation.

Similar data were obtained by Calvo-Polanco et al. (2012) in relation to the accumulation of starch in roots of young *Larix*

laricina plants submitted to waterlogging. According to these authors, large amounts of starch in the root would be needed to provide sufficient energy to these organs to support their growth and basic metabolic functions under waterlogging conditions. According to Gérard et al. (2009) the accumulation of starch would be a metabolic adaptation of tree species tolerant to flooding.

Materials and Methods

Plant materials

The *Parkia gigantocarpa (Ducke)* seeds were collected from location 03°41'07.2"S and 48°38'04.0"W. Seeds were scarified in the lateral region and adjacent to the hilum, and were immediately sown in plastic trays with capacity of 5 L, containing sterile sand. After emergence, the seedlings were transplanted to black opaque polythene bags with dimensions of 25×15 cm in height and diameter, respectively, with perforations in all sides, containing the substrate Plantmax®. The seedlings were grown for 60 days. After this period the young plants were evaluated for height, stem diameter, number of leaves and number of leaflets, and transferred to plastic pots with a capacity of 14 kg, containing the same substrate used in transplanting. The pots with the young plants were taken to the greenhouse to acclimatize for a period of 45 days.

Study location

The experiment was conducted in a greenhouse belonging to Instituto de Ciências Agrárias (ICA) of the Universidade Federal Rural da Amazônia (UFRA) in Belém city, State of Pará, Brazil (01 ° 28'03 "S, 48 ° 29'18" W) during July until November of 2012. Laboratory analyzes were performed in Laboratório de Anatomia Vegetal of the Museu Paraense Emílio Goeldi (MPEG).

Experimental design

The experimental design was completely randomized with two water conditions (control and waterlogging) combined with five evaluation times (0, 4, 8, 12 and 16-days waterlogging conditions), with five replicates, and 50 experimental units in total. Each experimental unit consisted of one plant per pot.

Waterlogging application and plant treatments

After the acclimation period, all the four-month-old *P. gigantocarpa* were subjected to two water conditions and the control plants were irrigated daily with 2.5 L of water to replace the water lost by evaporation, made individually for each pot, and considering the daily weighting set (pot + plant + soil). In the treatment under waterlogging, the plants were placed in pots without holes to avoid water drainage, with the water level maintained 5 cm above the soil surface. Control and waterlogging plants remained for a period of 16 days under these conditions.

Leaf specific hydraulic conductance

The leaf specific hydraulic conductance was calculated in agreement with equation: $K_L = (g_{smd} \times \Delta wmd)/(\Psi_{pd} - \Psi_{md})$, where K_L = leaf specific hydraulic conductance, g_{smd} = stomatal conductance in midday, Δwmd = variation in water saturation during midday, Ψ_{pd} = leaf water potential in predawn and Ψ_{md} = leaf water potential in midday. The measurements were carried out during 0, 4, 8, 12 and 16-days of waterlogging conditions.

Growth characteristics

The measurements related to growth were made at 0, 4, 8, 12 and 16-days of waterlogging conditions, with the plant height, being measured from soil surface to the apex of the plant (cm). Stem diameter measured at 4 cm above the soil surface, using a digital paquimeter (cm). The leaf and leaflets numbers were obtained by counting. For the determination of the dry matter, the plants were removed, divided into shoot (stem, leaf and leaflet) and root and placed in an oven with air forced ventilation at 65 °C to obtain constant mass. Each plant part was weighed on an analytical balance to determine the shoot dry matter (SDM), root dry matter (RDM), and the total dry matter (TDM) determined by the sum of SDM and RDM.

Anatomical characteristics

For the analysis of anatomical characteristics, in each evaluation period (0, 4, 8, 12 and 16-days waterlogging conditions) each individual was cut with a blade, a segment of 0.5 cm from the primary root (removed from region located 4 cm below of the soil surface) and the secondary root (removed from region located 4 cm from the root apex) with five samples of each treatment (Herschbach et al., 2005). The segments were fixed in FAA (formaldehyde, acetic acid and 50% ethanol) for 24 hours (Johansen, 1940) under vacuum dehydrated in a series tertiary butyl (Johansen, 1940) and embedded in paraffin. Transversal sections were made 12 mm thick, in auto-advance microtome Leica®, stained with astra blue and safranin (Gerlach, 1969) and mounted in synthetic resin Permount®, with 50 blades in total for the control treatment and 50 blades for the flooded treatment. The images were obtained with *Olympus* digital camera with eight megapixels and photomicrographs by digital camera *Cannon Power shop* A640, coupled to a light microscope Zeiss, model Axiolab and polarized light microscope coupled to Motic camera, megapixel 5000 both in different magnitudes and allocated in Laboratório de Microscopia da Coordenação de Botânica do Museu Paraense Emílio Goeldi. The methodology used in the anatomical description is according to Medri et al. (2007) and Davanso-Fabro et al. (1998).

Data analysis

The data were subjected to an analysis of variance, and significant differences between the means were determined using the F-test at a probability level of 5 %. Standard deviations were calculated for each treatment at all the evaluation points. All tests were conducted using the statistical program SAS version 8.02 (SAS Institute, 2001).

Conclusions

The young *Parkia gigantocarpa* plants are promising species for re-vegetation of degraded areas due to high survivability after 16 days of waterlogging conditions. During the experimental period the plants subjected to waterlogging conditions had negative interference on vegetative growth, reducing their leaf specific hydraulic conductance (0.02 mmol m^{-2} s^{-2} MPa^{-1}), plant height (32.86 cm), number of leaves (16.8 of leaves) and leaflets (319.6 of leaflets), compared to control plants that showed average of 0.29 mmol m^{-2} s^{-2} MPa^{-1} for leaf specific hydraulic conductance, 34.34 cm for plant height, 22.4 for leaves and 455.2 for leaflets. The waterlogging conditions changed the morphoanatomy of young plants of *P. gigantocarpa* and induced the appearance of hypertrophic lenticels in the base of the stem, adventitious root formation and

schizogenous aerenchyma located in cortical parenchyma of the secondary root. The experimental results suggest that the young plants of *Parkia gigantocarpa* reduced the allocation and redistribution of photosynthate for vegetative growth and invested in morphological changes in order to maintain aerobic respiration and enable survival during the period of waterlogging conditions.

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