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Vol. 10(35), pp. 3562-3569, 27 August, 2015
DOI: 10.5897/AJAR2015.10088
Article Number: CD9E7F055187
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Full Length Research Paper*

# Effects of water management on growth, irrigation efficiency and initial development of *Aspidosperma polyneuron* seedlings

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Received 30 June, 2015; Accepted 12 August, 2015

**The amount of available water for nursery irrigation is forecasted to decline on this decade and over or deficit watering of seedlings may have adverse consequences. To produce quality seedlings for accelerate the restoration of ecosystems and prevent further environmental damage, nursery water management should be reformed, especially for endangered species, such as *Aspidosperma polyneuron* Müll. Arg. The objective of this work was to evaluate the effect of three gross irrigation depths (8, 11 and 14 mm) applied daily and two irrigation frequencies (two and four times a day) on growth, irrigation efficiency and initial development of *Aspidosperma polyneuron* seedlings. Irrigation efficiency, in *A. polyneuron* seedlings, is related to the shoot part development degree (height and shoot dry mass). Increases in irrigation efficiency do not necessarily produce a greater development of morphological parameters and root system quality in the nursery. The 11 mm irrigation depth produces the same amount of seedlings with able root systems that the 14 mm irrigation depth, and uses 21% less water. The 11 mm irrigation depth applied in two irrigation frequencies produce *A. polyneuron* seedlings with optimum roots system and proper morphological development in the nursery, which continues after planting.**

**Key words:** Peroba-rosa, land degradation, tropical forest, gross irrigation depth, irrigation frequency, runoff, forest nurseries, development after planting.

## INTRODUCTION

The original Brazilian Atlantic Forest has been lost, and only 11.73% of the original vegetation (16,377,472 ha) remains (Ribeiro et al., 2009). In these cases, tree seedling plantings are a potential option to accelerate the restoration of this ecosystem and prevent further environmental damage (Modna et al., 2010).

Due to the reduction of native populations caused by extensive logging, the tropical species *Aspidosperma polyneuron* Müll. Arg. has been included on the Red List of Endangered Species (IUCN, 2015). This species is native of Brazilian Atlantic forest and is recommended to recover ecosystems and restore degraded riparian areas in soils not subject to flooding (Carvalho, 2003).

To optimize plantings, especially under harsh conditions, it has become increasingly obvious that a change of focus towards seedling quality is needed

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(Lindqvist and Ong, 2005), improving the morphological, physiological and genetic quality of seedlings (Wilson and Jacobs, 2006).

In nurseries, the main factors that affect the development and quality of seedlings are the quality of its genetic materials, water management, nutrition, the type of container and the substrates used (Silva et al., 2012). Water management is defined as the process of determining how much to apply (irrigation volume) and timing (when to apply) (Warren and Bilderback, 2005).

Frequently the water management in most Brazilian nurseries is applied by micro-sprinklers (Augusto et al., 2007) and over or deficit watering of seedlings may have adverse consequences. Overwatering may lead to nutrient leaching which may affect environmental quality and increase production costs, while water deficit can deleteriously affect potential growth and cause seedling death (Bauerle et al., 2002; Montague and Kjelgren, 2006). Thus, is necessary to define water management in the nursery to suit environmental laws and improve the quality of the seedlings (Silva et al., 2004).

The objective of this work was to evaluate the effects of gross irrigation depths and irrigation frequencies on growth, irrigation efficiency and initial development of *A. polyneuron* seedlings.

## MATERIALS AND METHODS

### Plant material and experimental conditions

This experiment was conducted between October 2011 and October 2012 in a suspended and sectorized nursery located in Botucatu, São Paulo State, Brazil (22°1'S, 48°25'W). The climate of the region is Cwa according to the Köppen climate classification.

Seeds of *A. polyneuron* were collected in September 2011 with climbing techniques in a forest fragment located in Botucatu, Brazil. The seeds were packed in polyethylene bags and transported to the nursery. In the nursery, the seeds were stored for 30 days at a temperature of 10 ± 2°C and a relative humidity between 8 and 12%, where they remained until sowing. Plastic tubes (92 $cm^3$) were used in seedling production. The plastic tubes were placed in 108 cells of each polypropylene tray and filled with a substrate consisting of *Sphagnum* peat, vermiculite and carbonized rice chaff (2:1:1; volume basis).

Substrate physical analyses were conducted according to methods described by Guerrini and Trigueiro (2004), and chemical analyses were conducted according to methods described by Brasil (2007) (Table 1).

The soluble fertilizers Yoorin® Master 1S and Fosmag® 500B and the controlled release fertilizer Osmocote® with NPK (19:6:10) were added to the substrate. These fertilizers provide macronutrients in dosages of 42.3, 69, 31.3, 25.2, 48.2 and 18 mg per plastic tube of N, P, K, S, Ca and Mg, respectively, and dosages of micronutrients 0.3, 0.1, 0.6, 18.4 and 1 mg per plastic tube of B, Cu, Mn, Si and Zn, respectively.

Sowing was performed manually by placing a seed in each plastic tube. The trays were transferred to an automated greenhouse with temperature control (less than or equal to 30°C) and relative humidity (greater than 80%, maintained through nebulization) with a 7 L $h^{-1}$ flow nozzle, triggered automatically by an electric panel for 10 s, every 15 min, from 9:00 am to 4:00 pm. After sowing, the seedlings remained in this environment for 37 days after which they were transferred to a shade house (with 50% light reduction) where they were irrigated with micro-sprinklers with a 200 L $h^{-1}$ flow nozzle, triggered automatically by an electric panel for 20 s, every 30 min, from 9:00 am to 4:00 pm, and where they remained for 42 days.

### Irrigation treatments

The experiment was laid out in completely randomized design with a factorial scheme that consisted of three daily gross irrigation depths (8, 11 and 14 mm), split into two and four irrigation frequencies by micro-sprinklers (Table 2).

Each treatment consisted of 4 replicates (trays). In each tray, the percentage occupancy of the seedlings was 25%. In each repetition, the 12 central seedlings were the useful seedlings, and the 18 other surrounding seedlings constituted the boundary, totaling 48 useful seedlings per treatment.

Before starting the treatments, seedlings were selected in which to homogenize the repeats, ensuring that height and stem diameter averages did not statistically differ ($p < 0.05$). The mean values and standard deviations of height and stem diameter were 5.3 ± 0.8 cm and 1.33 ± 0.16 mm, respectively.

To begin the treatments, the repetitions were distributed in a completely randomized design in three outdoor beds, covered with a plastic light diffuser, in the sunlit area of the nursery. Each outdoor bed received the two treatment repetitions, which were automatically applied by the electric panel-powered irrigation system.

The side dressing fertilization was performed twice a week for 85 days after the start of the treatment application. In each fertilization, the 4 mm irrigation depth of nutrient solution was applied *via* fertigation in all treatments. The solution comprised the fertilizers according to described by Silva and Silva (2015). The hardening fertilization was performed twice a week from 85 until 120 days after the beginning of treatments. In each fertilization, the 4 mm irrigation depth of nutrient solution was applied *via* fertigation in all treatments. The fertilizer solution was composed according to described by Silva and Silva (2015).

### Nursery plant and irrigation analysis

To evaluate the quality of the seedlings in the nursery, the following morphological parameters were measured 120 days after the start of treatments: Height (cm) and stem diameter (mm) (these two parameters were evaluated in the 12 useful seedlings per replication), as well as, shoot, root and total dry mass (g). The roots and shoots measurement was conducted on 6 useful seedlings per repetition. From the combination of morphological parameters, the total dry mass (g) and the Dickson quality index (DQI) was determined using the following equation:

$$DQI = \frac{\text{Total dry mass (g)}}{\left(\frac{\text{Height (cm)}}{\text{Stem diameter (mm)}}\right) + \left(\frac{\text{Shoot dry mass (g)}}{\text{Root dry mass (g)}}\right)}$$

The quality of the root system was evaluated according to Silva et al. (2013), in the same seedlings.

The irrigation efficiency (IE) of each treatment was assessed at 120 days after the start of the treatment application, in two useful seedlings per replication, totaling eight seedlings per treatment, from the equation of Fain et al. (1998):

**Table 1.** Physical and chemical properties of substrate used in this experiment.

| | Porosity (%) | | | Water retention (ml per plastic tube) |
|---|---|---|---|---|
| **Physical properties** | **Macro** | **Micro** | **Total** | |
| | 24.2 | 59.3 | 83.4 | 54.6 |
| **Chemical properties** | **Electrical conductivity (mS cm$^{-1}$)** | | | **pH** |
| | 0.5 | | | 6.5 |

**Table 2.** Irrigation treatments.

| Treatment | Compositions |
|---|---|
| ID8F2 | 4 mm 10:00 am and 4 mm 2:00 pm |
| ID8F4 | 2 mm 9:00 am, 2 mm 11:00 am, 2 mm 1:00 pm and 2 mm 3:00 pm |
| ID11F2 | 5.5 mm 10:00 am and 5.5 mm 2:00 pm |
| ID11F4 | 2.75 mm 9:00 am 2.75 mm 11:00 am, 2.75 mm 1:00 pm and 2.75 mm 3:00 pm |
| ID14F2 | 7 mm 10:00 am and 7 mm 2:00 pm |
| ID14F4 | 3.5 mm 9:00 am, 3.5 mm 11:00 am, 3.5 mm 1:00 pm and 3.5 mm 3:00 pm |

*ID,* irrigation depth; *F,* irrigation frequency.

$$IE = \frac{\text{Water applied (mL) - Water drained (mL)}}{\text{Water applied (mL)}} \times 100$$

#### Initial development conditions and analysis

After the end of nursery phase, the seedlings were kept in their treatments for more 20 days, when six seedlings from each treatment were planted in pots of 7 L, containing 8 kg of soil each. The soil was collected from the surface layer (0-20 cm), corresponding a dystrophic Red Latosol, medium texture. The fertilizer NPK (4:14:8) in dosages 2 kg of fertilizer per cubic meter and limestone, in the same dose, were added to the soil and mixed for 5 min in mixer. Before and immediately after planting, each pot was irrigated, respectively, with 2 and 1 L of water. The plants were kept in a completely randomized design in the greenhouse covered with transparent plastic for 120 days and also irrigated with 0.5 L every nine days. The height (cm) and stem diameter (mm) of plants were evaluated immediately after planting and thereafter at intervals of 30 days. At 120 days after planting, shoot and root dry mass of plants (g) were evaluated.

#### Statistical analysis

An analysis of variance was performed to compare the effect of irrigation depths and irrigation frequency on the parameters analyzed in the nursery. When the value of the F test indicated a significant effect, we used the Tukey's test ($p < 0.05$) to compare differences between means of treatments. In the analysis of initial development, when the value of the F test indicated a significant effect, we used regression analysis over time (height and stem diameter) and Tukey's test ($p < 0.05$) (shoot and root dry mass).

## RESULTS AND DISCUSSION

### Nursery and irrigation results

The 11 and 14 mm irrigation depths applied in two irrigation frequencies formed seedlings with greater height, stem diameter and shoot and total dry mass compared to the same irrigation depths applied in four irrigation frequencies. In the root dry mass and DQI, only the 14 mm irrigation depth applied in two irrigation frequencies overcome the four irrigation frequencies (Table 3).

These results are in agreement with those obtained by Warren and Bilderback (2005), who stated that the cycles may vary from two to twelve per day, but about two at an appropriate time application, as is appropriate.

In two irrigation frequencies, the 11 mm irrigation depth overcome 8 mm the irrigation depth in all morphological parameters and compared to the 14 mm irrigation depth provided equal development. This indicated that the seedlings irrigated with 8 mm irrigation depth showed this behavior because they were likely saturated just a few inches below the surface layer of the substrate, causing water deficits during seedling production in the nursery and the 14 mm irrigation depth was excessive during the treatment application, which may have lead to the nutrient leaching. The purpose of irrigation is to artificially supply water to meet plant water needs for economical crop production. As population and industrial development increase, water supply will become a major constraint to future irrigation development. Therefore, future irrigation systems must utilize water resources more efficiently (Irmak et al., 2001).

The 8 mm irrigation depth produced a greater and smaller amount of seedlings with "poor" and "able" root systems, respectively, showing that the 8 mm irrigation depth is insufficient to produce seedlings with root system quality (Figure 1).

According to Taiz and Zeiger (2004), the proliferation of

**Table 3.** Effects of the interaction between irrigation depths and the irrigation frequencies on some morphological parameters in *A. polyneuron* seedlings 120 days after the beginning of treatments.

| Irrigation depths (mm) | Height | | | Stem diameter | | |
|---|---|---|---|---|---|---|
| | Frequencies | | CV (%) | Frequencies | | CV (%) |
| | 2x | 4x | | 2x | 4x | |
| 8 | $14.1^{Bb}$ | $19.1^{Aa}$ | 15.4 | $4.01^{Bb}$ | $4.78^{Aa}$ | 9.21 |
| 11 | $24.3^{Aa}$ | $18.9^{Ab}$ | 15.3 | $5.18^{Aa}$ | $4.77^{Ab}$ | 9.8 |
| 14 | $23.5^{Aa}$ | $17.0^{Bb}$ | 19.3 | $5.36^{Aa}$ | $4.52^{Bb}$ | 12.4 |
| CV (%) | 15.1 | 19 | | 9 | 12.2 | |
| | **Shoot dry mass** | | | **Root dry mass** | | |
| **Irrigation depths (mm)** | **Frequencies** | | | **Frequencies** | | |
| | **2x** | **4x** | **CV (%)** | **2x** | **4x** | **CV (%)** |
| 8 | $1.67^{Bb}$ | $2.59^{Aa}$ | 13.9 | $0.86^{Bb}$ | $1.07^{Aa}$ | 17.2 |
| 11 | $3.58^{Aa}$ | $2.57^{Ab}$ | 17.8 | $1.17^{Aa}$ | $1.11^{Aa}$ | 19.6 |
| 14 | $3.54^{Aa}$ | $2.23^{Bb}$ | 20.8 | $1.33^{Aa}$ | $0.99^{Ab}$ | 21.6 |
| CV (%) | 20.3 | 15.4 | | 21.3 | 18.1 | |
| | **Total dry mass** | | | **DQI** | | |
| **Irrigation depths (mm)** | **Frequencies** | | | **Frequencies** | | |
| | **2x** | **4x** | **CV (%)** | **2x** | **4x** | **CV (%)** |
| 8 | $2.53^{Bb}$ | $3.66^{Aa}$ | 14.2 | $0.46^{Bb}$ | $0.58^{Aa}$ | 18.7 |
| 11 | $4.75^{Aa}$ | $3.68^{Ab}$ | 17.7 | $0.63^{Aa}$ | $0.59^{Aa}$ | 22.1 |
| 14 | $4.87^{Aa}$ | $3.22^{Bb}$ | 20.5 | $0.70^{Aa}$ | $0.53^{Ab}$ | 23.2 |
| CV (%) | 20.1 | 15.5 | | 23.5 | 19.7 | |

Means followed by the same capital letter in the column and the same lowercase letter across the row are not significantly different according to the Tukey's test ($p < 0.05$).

roots depends on the availability of water and nutrients in the microenvironment surrounding the root, called the rhizosphere. If the rhizosphere is nutrient-poor or too dry, root growth is slow.

The 11 mm irrigation depth, that did not differ the 14 mm irrigation depth, produced a smaller and greater amount of seedlings with "poor" and "able" root systems, respectively. This indicated that the 14 mm irrigation depth was excessive and unnecessary during the treatment application. The highest plant growth is not always associated with the highest rates of irrigation (Fox and Montague, 2009). The application of water and fertilizers during plant production places an onus on container nurseries to minimize the potentially harmful effects of nutrient contamination of runoff water. Experiments that quantify runoff volume and nutrient content during production provide insight as to the relative roles various production practices play in utilizing water and nutrients most efficiently (Million et al., 2007).

The water managements showed no significant effects on the category "good" of root system quality. The 11 and 14 mm irrigation depths applied in two irrigation frequencies formed the same amount of seedlings with optimum root systems, showing the possibility of saving water in irrigation of this species in the nursery. According to Montague and Kjelgren (2006), excess watering can lead to the nutrient leaching, causing damage to the environment, low plant growth and increased maintenance costs (Table 4).

Only the irrigation depths influenced the irrigation efficiency (Table 5).

The 8 mm irrigation depth had increased the irrigation efficiency. This may be because they were likely saturated just a few inches below the surface layer of the substrate. According to Warren and Bilderback (2005), the key to increased irrigation efficiency is in control the application rate, application duration, and interval between applications and if low water volumes are used without taking into account the maintenance of adequate water in the container, stomatal closure may occur, reducing photosynthesis and consequently reducing plant growth.

The 11 and 14 mm irrigation depths did not differ in irrigation efficiency. This result was possible because the seedlings produced in the 14 mm irrigation depth had less amount of shoot part (height and shoot dry mass), reducing water capitation and consequently reducing runoff.

According to Lea-Cox et al. (2001) and Million et al. (2007), the size of the seedlings and the capitation of water is an important factor that may influence irrigation efficiency.

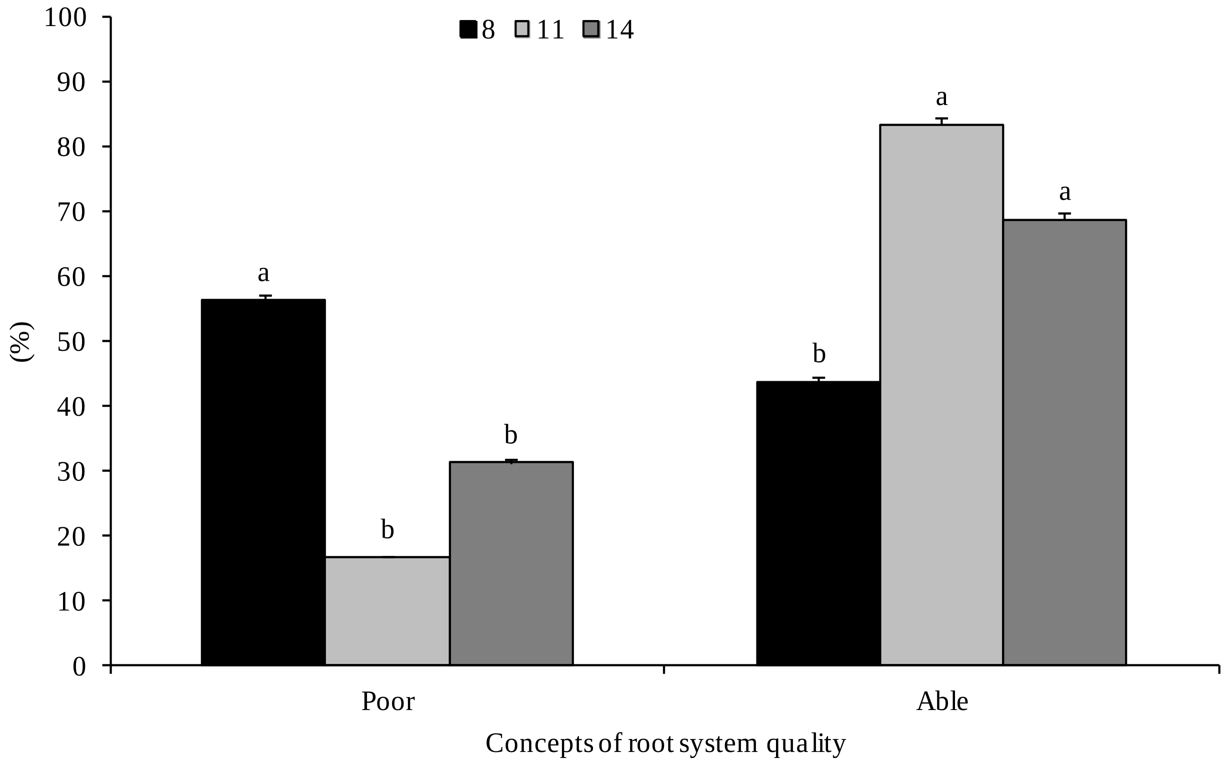


**Figure 1.** Effect of irrigation depths (mm) on the categories "poor" and "able" of root system quality of *A. polyneuron* seedlings at 120 days after the beginning of treatment. *Bars* represent mean ± standard error. The same letter in the same category is not significantly different according to the Tukey's test ($p < 0.05$).

**Table 4.** Effects of the interaction between the irrigation depths and the irrigation frequencies on the category "optimum" of root system quality of *A. polyneuron* seedlings 120 days after the beginning of treatments.

| Irrigation depths (mm) | Optimum (%) | | |
|---|---|---|---|
| | Frequencies | | |
| | 2x | 4x | CV (%) |
| 8 | $8.3^{Ba}$ | $25^{Aa}$ | 2.2 |
| 11 | $58.3^{Aa}$ | $29.2^{Ab}$ | 1.1 |
| 14 | $62.5^{Aa}$ | $12.5^{Ab}$ | 1.1 |
| CV (%) | 1 | 1.9 | |

Means followed by the same capital letter in the column and the same lowercase letter across the row are not significantly different according to the Tukey's test ($p < 0.05$).

## Initial development results

The effect of all treatments on height and stem diameter of the seedlings after planting showed linear behavior (Figure 2). The 11 mm irrigation depth applied in two irrigation frequencies, which produced greater seedlings at nursery phase, continued providing greater heights and stem diameters after planting, showing the influence of seedlings quality in the initial development. With the greater development of the seedlings in the subsequent months after planting, there has been a decrease in the need for cleaning of plantations, which implies a considerable reduction of implementation costs (Carneiro, 1995).

The 8 mm irrigation depth applied in two irrigation frequencies, which produced smaller seedlings at nursery phase, continued providing smaller heights and stem diameters after planting. Before any deficit irrigation regime is applied on nurseries, it is essential that irrigation uniformity is optimized, that the water use of

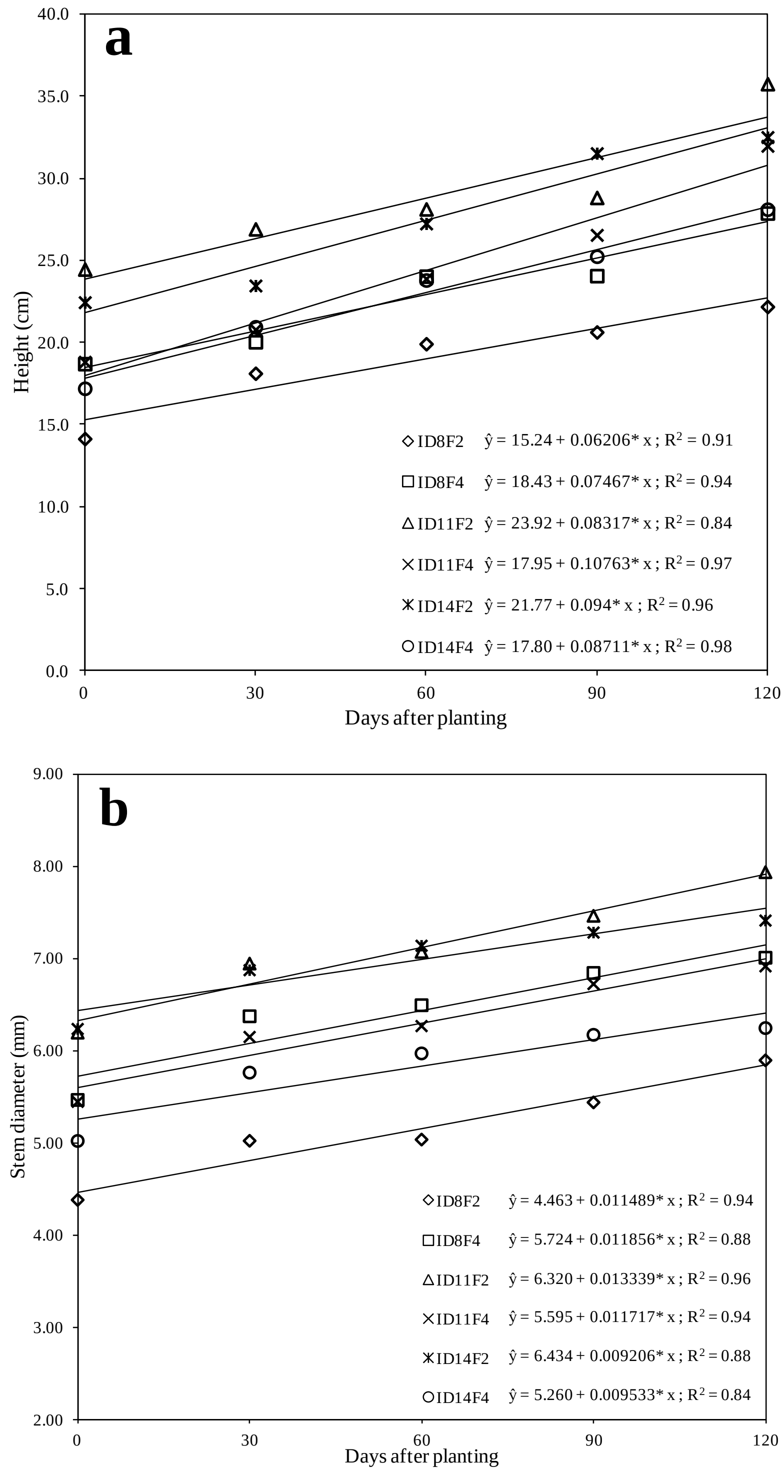


**Figure 2.** Effect of irrigation depths and irrigation frequencies applied in the *A. polyneuron* seedlings in the nursery phase on the height (**a**) and stem diameter (**b**) 120 days after planting. *Significant according to the F test ($p < 0.05$). *ID,* irrigation depth; *F,* frequency.

container crops is well understood, and that the effective methods exist for determining irrigation requirements (Grant et al., 2009).

The seedlings produced with 14 mm irrigation depth applied in two irrigation frequencies showed greater stem diameters until day 30$^{th}$ day, however, from that period,

**Table 5.** Effect of irrigation depths on irrigation efficiency when applied to *A. polyneuron* seedlings 120 days after the beginning of treatments.

| Irrigation depths (mm) | Irrigation efficiency (%) | CV (%) |
|---|---|---|
| 8 | 62.2[a] | 8.2 |
| 11 | 59.2[b] | 8.7 |
| 14 | 57.2[b] | 9.0 |

Means followed by the same letter are not significantly different according to the Tukey's test ($p < 0.05$).

**Table 6.** Effects of the interaction between irrigation depths and the irrigation frequencies applied in the *A. polyneuron* seedlings in the nursery phase on the shoot and root dry mass (g) at 120 days after the planting.

| Irrigation depths (mm) | Shoot dry mass | | | Root dry mass | | |
|---|---|---|---|---|---|---|
| | Frequencies | | CV (%) | Frequencies | | CV (%) |
| | 2x | 4x | | 2x | 4x | |
| 8 | 3.98[Ba] | 4.64[Aa] | 10.8 | 1.13[Bb] | 1.73[Aa] | 16.4 |
| 11 | 7.09[Aa] | 3.56[Ab] | 29.6 | 2.72[Aa] | 1.79[Ab] | 18.2 |
| 14 | 6.84[Aa] | 3.97[Aa] | 13.4 | 2.57[Aa] | 1.90[Ab] | 8.9 |
| CV (%) | 21 | 17.4 | | 14.9 | 15 | |

Means followed by the same capital letter in the column and the same lowercase letter across the row in the same parameter are not significantly different according to the Tukey's test ($p < 0.05$).

were overcome by the seedlings produced with 11 mm irrigation depth applied in this same irrigation frequency, showing the possibility of saving water in irrigation of this species in the nursery. Because there is a lack of scientific information regarding irrigation requirements of landscape and nursery tree species, nursery and landscape trees are frequently irrigated in excess (which may result in water logged soil, poor plant growth, increased runoff, leached nutrients, increased water bills, and misuse of irrigation water) amounts (Montague and Kjelgren, 2006).

In root and shoot dry mass parameters, the 11 mm irrigation depth applied in two irrigation frequencies in the nursery resulted in greater growth after planting compared to the same irrigation depth applied in four irrigation frequencies (Table 6).

The success of planting is largely dependent to the ability of plants quickly generate new roots to maximize the absorption of water and compete with the local vegetation (Burdett, 1990; Haase and Rose, 1993; Grossnickle, 2005; Riley and Steinfeld, 2005; Mañas et al., 2009).

After planting, the shoot dry mass of seedlings produced in the 14 mm irrigation depth did not differ with respect irrigation frequency. Furthermore, there was no difference between the irrigation depths applied in four irrigation frequencies in shoot and root dry mass.

The 11 and 14 mm irrigation depths applied in two irrigation frequencies overcome 8 mm irrigation depth and formed the same root and shoot dry mass, showing the possibility of saving water in irrigation of this species in the nursery. Thus, the 11 mm irrigation depth applied in two irrigation frequencies produce *A. polyneuron* seedlings with proper morphological development in the nursery and after planting. This result is in accordance with those obtained by Silva and Silva (2015) that worked with water management in *Piptadenia gonoacantha*, other tropical species of Brazilian Atlantic forest.

## Conclusions

The following conclusions were supported by the present study:

1. Irrigation efficiency, in *A. polyneuron* seedlings, is related to the shoot part development degree (height and shoot dry mass).
2. Increases in irrigation efficiency do not necessarily produce a greater development of morphological parameters and root system quality in the nursery.
3. The 11 mm irrigation depth produces the same amount of seedlings with able root systems that the 14 mm irrigation depth, and uses 21% less water.
4. The 11 mm irrigation depth applied in two irrigation frequencies produces *A. polyneuron* seedlings with optimum roots system and proper morphological development, which continues after planting.

## Conflict of Interest

The authors have not declared any conflict of interest.

## ACKNOWLEDGMENT

This research received financial support from Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) - Brazil (Process: 2011/03422-8).

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