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# The "Pot-in-Pot" System Enhances the Water Stress Tolerance Compared with Above-Ground Pot

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## 1. Introduction

In the nursery, plant cultivation in pots or containers is a very common practice. On the one hand, this is to satisfy market demands for herbal plants and shrubs, and on the other because of its many advantages compared with ground cultivation. These advantages include lower stress for plants during transport and manipulation, space reduction in the nursery, the increased possibility of mechanization, a longer supply period, and greater transplantation success (Davidson et al., 1988). However, container cultivation is more affected by environmental conditions in the substrate-root complex, where extreme temperatures can negatively influence root development. The climatic season (winter or summer) will determine thermal stress through cold or heat. Container characteristics (material, color, form, drainage holes, etc.) also influence temperature in the root system, and many studies have looked at the use of different container types (Franco et al., 2006).

In contrast to traditional cultivation in above-ground pots (AGP), pot-in-pot (PIP) production, introduced around 1990 in the USA (Parkerson, 1990), is a nursery production method that combines some of the benefits of both field and container production. In a PIP system, a holder or socket pot is permanently placed in the ground with the top rim remaining above. The container-grown plant is then placed within the holder pot for the production cycle (Ruter, 1998a). Previous research into PIP compared with above ground potting (AGP) determined that PIP improves biomass production (Ruter, 1998b), reduces root zone temperature stress (Young and Bachman, 1996) and enhances efficient water use by decreasing container evapotranspiration (Martin et al., 1999). An additional advantage over AGP is the elimination of extensive staking and blowover and a more easy mechanization. Recent studies by Neal (2010) reported that crabapple and lilac root or shoot mass were greater in PIP compared with another four production systems: field-grown, plastic container, bag-in-pot and above ground system.

The disadvantages of the PIP system include high initial cost of pots and installation, potential drainage problems of socket pots in poorly drained soils, and the possibility of root elongation into the socket pot and surrounding soil. In PIP production, containers may stick together; the bottom of the insert pot may sag, causing an uneven base; and there is little or no spacing flexibility once the socket pots are established (Adrian et al., 1998). So, careful

planning of the layout should be undertaken because of the large initial outlay for production and the cost of changing the system (Tilt et al., 1994). The economic analysis reported by Adrian et al. (1998) concluded that the PIP system had the highest total capital outlay and fixed cost compared with AGP, which related primarily to higher costs associated with purchasing and installing socket pots. The PIP system, however, was least costly on a per harvested plant basis due to less intensive, labor-saving cultural practices and the ability to grow larger plants quickly.

The avoidance of extreme temperatures in the root sphere was stressed as one of the most advantages of PIP system (Zinati, 2005). The importance of avoiding extreme temperatures in the substrate is well documented, especially because of their effect on root development. Ruter and Ingram (1992) observed that the normal growth of holly trees stopped when temperature exceeded 35°C, whereas in other species this value was lower, at 32°C (Levitt, 1980). Other authors, such as Kuroyanagi and Paulsen (1988), described how wheat plants that receive high temperatures in the root sphere suffer chlorophyll loss and show lower protein production in shoots. Mathers (2003) observed that roots on the west sides of pots are usually injured or destroyed by high temperatures. Zhu et al. (2004) suggested that the moderating of root temperature by PIP prevents the death of *Acer rubrum* roots in contact with the pot wall, whether in winter or summer.

Moderation of the substrate temperature influences the crop water balance, reducing evapotranspiration in the substrate-plant system (Ruter, 1998b) and, as a consequence, maintaining higher substrate moisture content (Fain et al., 1998; Ruter, 1997). Less extreme temperatures at root level as well as good water availability in the substrate can accelerate and improve plant growth and development. Indeed, one of the most interesting and practical aspects of PIP for nursery growers is plant growth magnification (Ruter, 1997; Martin et al., 1999). Ruter (1995) related the moderation of temperature with increased root biomass, although the extent of the effect varied according to the species (Ruter, 1993). Zinati (2005) observed root biomass increases of 50% in PIP grown plants compared with 20% in plants grown in AGP.

It is well known that one of the most important aspects for improving water irrigation efficiency is the correct choice of cultivation technique. Techniques that improve root function and minimize water consumption are considered key factors for improving pot cultivation (Mathers, 2003), and are especially important in landscape and gardening projects to ensure success in transplanting and establishment. In this example, a PIP system may help improve water management efficiency in nursery production, which is especially important in drought conditions and where the water is of low quality, such as in arid and semiarid areas of the planet.

The objective of this research was to determine, during eight months, differences in substrate temperature and water content in native *Rhamnus alaternus* cultivated in two systems: PIP and AGP. We also studied how each system affected growth and development, and water status and gas exchange parameters and we compared the results with a previous study with *Myrtus communis* (Miralles et al., 2009).

## 2. Material and methods

### 2.1 Plant material and growing conditions

Seedlings of two year old *Rhamnus alaternus* L. grown in 45 multi-pot forest trays (Plasnor S.A., Gipuzkoa, Spain) were used. The seeds were from natural populations growing in

southeast Spain; they were collected in November 2005 and stored dry at 5 °C. The pots were arranged in a 9 × 5 configuration, had an inverted pyramid form, and measured 60 × 30 × 17 cm (240 cm<sup>3</sup> volume). The plants were transplanted to black PVC pots (cultivation pot) of 2.5 L volume, 16 cm upper external diameter, and 15 cm height. The pots were filled with a mixture of white peat (40%), clay loam soil (30%), and sand (30%). After transplantation, all the plants where cut back to approximately 20 cm height. The experiment was performed in an open-air plot of 70 m<sup>2</sup> at the Tomás Ferro Experimental Agro-Food Station of the Polytechnic University of Cartagena (UPCT) (37° 35' N, 0° 59' W). Transplantation of seedlings to cultivation pots was performed on 15 March 2009, and the experiment took placed from 1 April 2009 to 4 December 2009. Weather conditions were taken from a meteorological station sited 100 m from the experimental plot. The mean hourly values of temperature, relative humidity, and solar radiation were registered (Fig. 1).

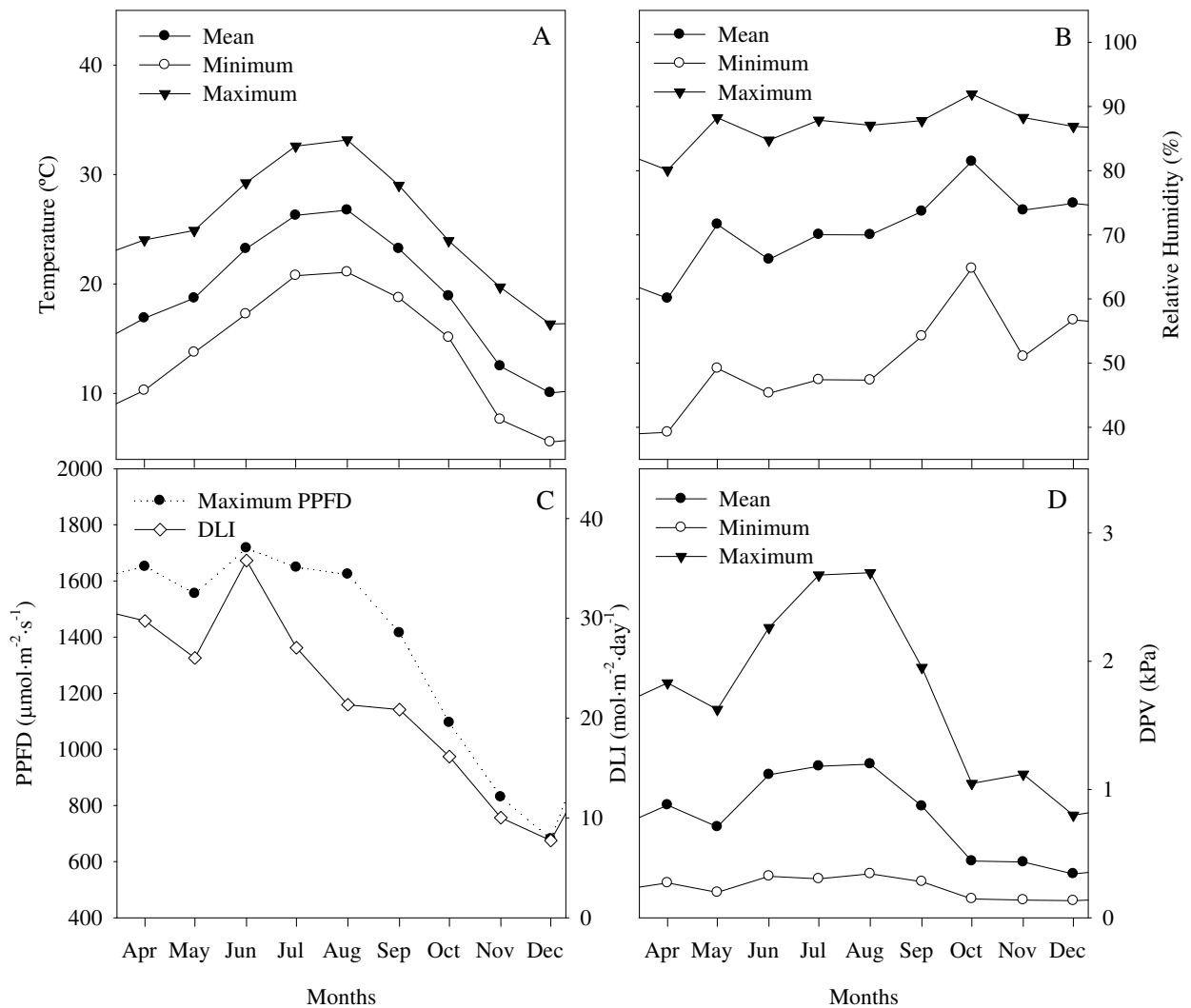


Fig. 1. Mean, minimum and maximum monthly environmental temperature (A), relative humidity (B) and vapor pressure deficit (DPV) (D), and maximum photosynthetic photon flux density (PPFD) and daily light integral (DLI) (C).

A drip irrigation system was installed, with one dripper per plant ( $2 \text{ L h}^{-1}$ ) connected to two spaghetti tubes (one each side of every pot). Local irrigation water ( $\text{pH } 7.2$ ; electric conductivity  $1.7 \text{ dS m}^{-1}$ ) was used, containing  $\text{Ca}^{2+}$  ( $95 \text{ mg L}^{-1}$ ),  $\text{Mg}^{2+}$  ( $69 \text{ mg L}^{-1}$ ),  $\text{Na}^{+}$  ( $145 \text{ mg L}^{-1}$ ),  $\text{Cl}^{-}$  ( $232 \text{ mg L}^{-1}$ ), and  $\text{HCO}_3^{-}$  ( $110 \text{ mg L}^{-1}$ ). Both treatments were irrigated between 12:00 and 14:00 h with the same frequency and volume of water. Irrigation frequency was set so that soil matric potential (SMP) reached values of  $-60$  and  $-80 \text{ kPa}$  in AGP. To meet this criterion, irrigation frequency varied according to the season: two irrigations per week in spring and autumn, and three irrigations per week in summer. Irrigation amounts were programmed to obtain leaching of 15% to 20% in AGP, which produced irrigation water volumes between 400 and 700 mL per pot. Greater volumes of water were applied in summer and when the time between irrigations was greater (e.g., after the weekend). The leachate in PIP was not collected.

## 2.2 Experimental design and statistical analysis

The PIP system consisted of placing cultivation pots in pots already buried in the ground. The buried pots were made of black PVC and contained many small drainage holes to ensure drainage (5.5 L volume, 17 cm upper exterior diameter, and 30 cm height). An air chamber of 15 cm separated the bases of both pots. Once the pots were buried in the ground, the plot was covered with a plastic permeable mulch (Horsol  $140 \text{ g m}^{-2}$ ; Projar S.A., Valencia, Spain), which was covered with a 4 cm layer of gravel ( $\sim 2 \text{ cm}$  dia.) (Fig. 2).

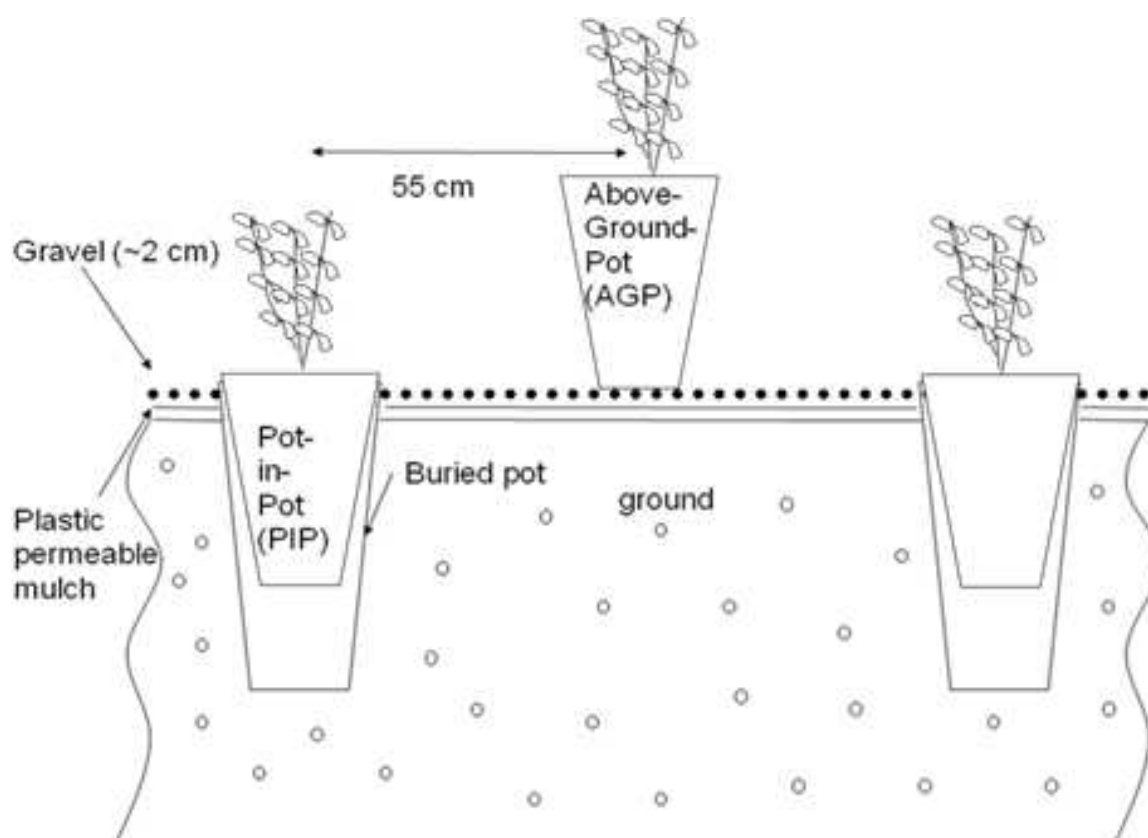


Fig. 2. Pot-in-Pot general design.

A total of 220 cultivation pots were placed in 10 rows, 60 cm apart, so that each row had 22 cultivation pots (Picture 1). These were placed 55 cm apart, buried pots (PIP) alternating



with above-ground pots (AGP). A CR1000 datalogger and an AM16/32 multiplexer (Campbell Scientific, Logan, UT) were installed in the center of the plot connected to eight temperature probes (Termistor 107, Campbell Scientific S.L., Barcelona, Spain) and 16 watermark probes (model 253 Irrrometer Company, Riverside, CA). The data were analyzed using a one-way ANOVA. A significance level of  $\leq 5\%$  was accepted. The statistical analysis was performed using Statgraphics Plus 5.1 software (StatPoint Technologies, Warrenton, VA).



Picture 1. Experimental plot, pot-in-pot (PIP) and above ground pot (AGP) and datalogger in the center of the plot.

### 2.3 Growth and development

On four occasions during the experiment (March, June, September, and December), the main stem base diameter, plant height and length of main shoots were measured. At the end of the experiment, leaf area and dry weight (DW) of root and shoot was determined in six plants per treatment. The leaf area was determined with a LI-3100C (LI-COR Biosciences, Lincoln, NE). To calculate the DW, shoot and root were introduced in clearly identified envelopes and placed in a natural convection bacteriological stove (model 2002471, JP Selecta SA, Barcelona, Spain) at  $60^{\circ}\text{C}$  until constant weight was reached. Before introducing the roots in the stove, roots were washed with pressurized water using a hose with flat tip before being introduced in a dryer. Finally, the DW was determined by weighing with a GRAM ST series precision balance (sensitivity of 10 mg and up to 1200 g, Gram Precision SL, Barcelona, Spain). The index shoot DW/root DW (S/R) was determined, separating shoots and roots.

## 2.4 Soil matric potential (SMP) and temperature

The soil matric potential (SMP) was registered using eight watermark probes and four substrate temperature probes per treatment to perform the SMP corrections due to temperature (Thompson et al., 2006). The devices were connected to the datalogger and multiplexer, which were programmed to register data every minute and to save the hourly mean value. The watermark and temperature probes were installed in random pots, in a southerly orientation and 5 cm deep. SMP was estimated using the equation of Shock et al. (1998), which is the best way of fitting the studied interval, as described by Thompson et al. (2006).

## 2.5 Leaf water potential and gas exchange

Leaf water potential ( $\Psi_1$ ) was determined using a pressure chamber (Soil Moisture Equipment Corp; Santa Barbara, Cal.) according to Scholander et al. (1965). The stomatal conductance ( $g_s$ ) and net photosynthesis ( $P_n$ ) were measured using a portable photosynthesis system (LI-6200, Licor, Inc., Lincoln, Neb.). All measurements were taken at midday in six plants per treatment the following months: March, June, September, and December.

## 2.6 Measurements of leaf color and SPAD

The color and SPAD measurements were made for 12 plants of each treatment at the end of experiment. For the determination of both, representative plant leaves were chosen, taken from south-facing mid-height and mature. The color was determined with a shot in the middle of the leaf blade with a Minolta CR10 colorimeter (Konica Minolta Sensing, Inc., Osaka, Japan) that calculated the color coordinates (CIELAB): lightness (L), tone (hue angle, H) and saturation (chrome, C). The SPAD was measured using the same criteria as for color but with a SPAD-502 chlorophyll meter (Konica Minolta Sensing, Inc., Osaka, Japan). For each measurement the average of three shots was determined.

# 3. Results and discussion

## 3.1 SMP and plant water relations

The mean monthly environmental temperatures during the experimental period ranged between 10 °C and 27 °C, and DLI ranged between 7 and 38 mol m<sup>-2</sup>day<sup>-1</sup> (Fig. 1A and 1C). Mean monthly maximum values were 16 °C to 33 °C and maximum PPFD 680 to 1717 μmol m<sup>-2</sup> s<sup>-1</sup>, respectively (Fig. 1A and 1C), and mean monthly minimum temperatures varied between 6 °C and 21 °C (Fig. 1A). The registries were nearly the same reported by Miralles et al. (2009).

The mean monthly substrate temperatures in all the experimental months were similar in PIP and AGP, ranging between 17 °C and 31 °C. The AGP system showed higher mean monthly maximum substrate temperatures than PIP (Fig. 3B), with the thermal differences between both systems around 8 °C. Young and Bachman (1996) and Ruter (1993) described how, on the hottest days of summer, PIP substrates for different species were 2.3 °C and 6 °C lower, respectively, than AGP temperatures. As shown in figure 3B, PIP moderated substrate temperature increases from June to September, preventing mean monthly maximum temperatures >34 °C, unlike in AGP, where 43 °C was reached.

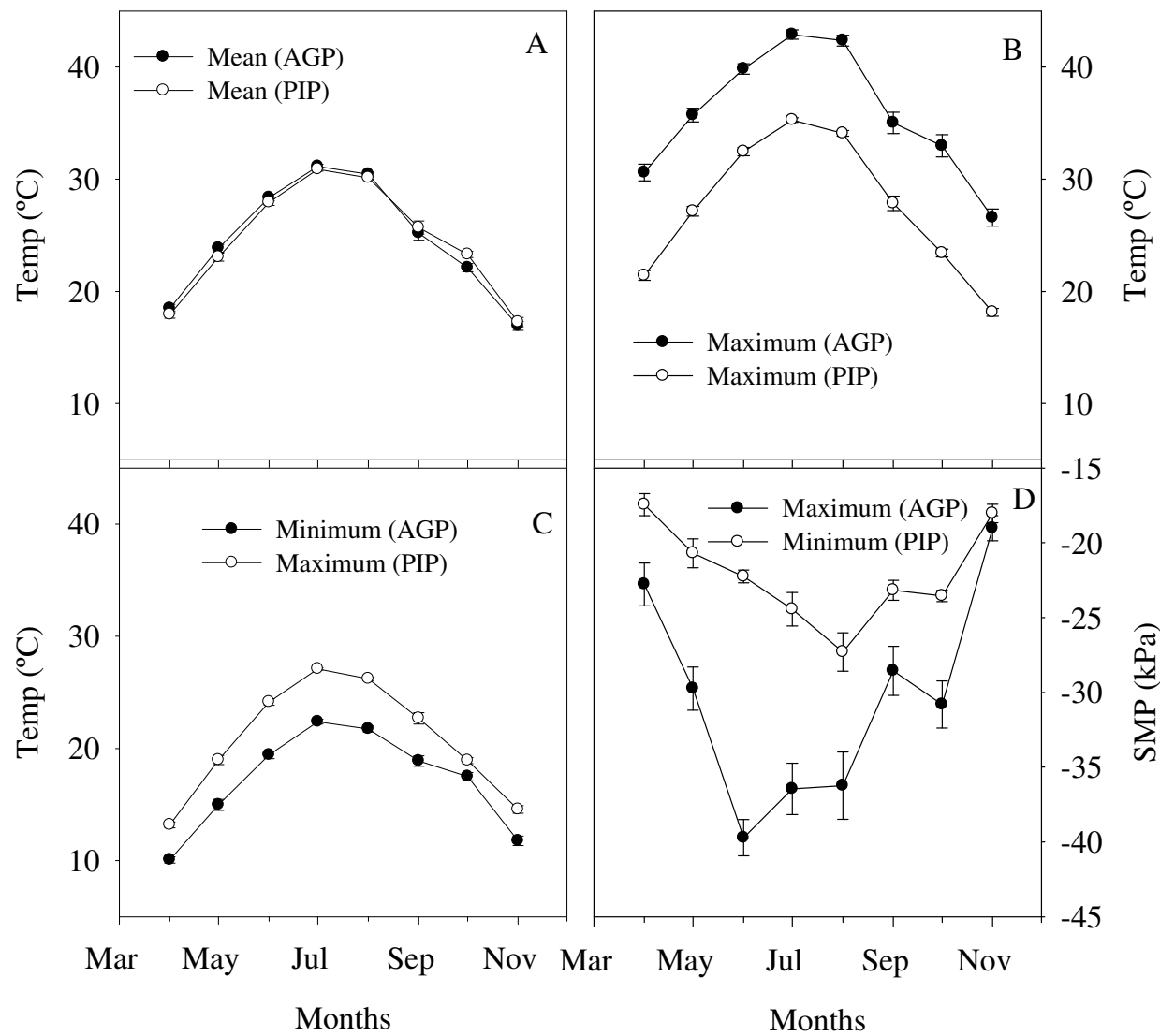


Fig. 3. Mean monthly temperature (A), mean monthly maximum temperature (B), mean monthly minimum temperature (C), and mean monthly minimum soil matric potential (SMP) (D) evolution in substrate of PIP and AGP treatments. Error bars are standard errors ( $n = 4$  for temperature and  $n=8$  for SMP).

Mean monthly minimum substrate temperatures showed the opposite behavior to maximum temperatures (Fig. 3C), with PIP reaching higher temperatures than AGP. The thermal differences between both systems ranged from 1 °C to 5 °C, although the temperature differences between both systems were lower than the corresponding maximum values. Young and Bachman (1996) and Ruter (1993) found that, on the coolest winter days, PIP substrates were 1.1 °C and 3 °C warmer, respectively, than the corresponding AGP values. This behavior can be explained by the ground effect, which slowed the temperature loss at night. Miralles et al. (2009) confirmed during a one year experiment that PIP significantly moderated low and high substrate temperatures, particularly when temperatures were at their most extreme, as well as London et al. (1998).



Mean monthly temperatures were similar in both systems (Fig. 3A) because AGP reached higher daily temperatures than PIP but lower temperatures at night the one compensating the other.

Mean monthly minimum soil matric potential (SMP) was greater in PIP compared with AGP except in December which became similar (Fig. 3D). The greater differences were found in summer. The greater water demanding conditions increased water demands in summer in *R. alaternus*, while in winter due to plant growth stop, these differences in SMP disappeared. Mean monthly maximum SMP were not significantly different between treatments and mean monthly SMP had intermediate values between the minimum and the maximum (data not shown). Miralles et al. (2009) on its previous study with *M. communis* found a different behavior. In this case no differences were found from the beginning of the experiment (March) to August. In September and October, the mean monthly minimum SMP values were more negative in AGP and no more differences were found until February where PIP showed again higher mean monthly minimum SMP until the end of the experiment in May. The absence of differences the first months were related to low plant growth, and the SMP differences at the end of the experiment were related to the higher water consumption of plants in AGP following growth activation during the winter-spring transition. This may have been caused by higher maximum substrate temperature, together with more developed *M. communis* in the AGP system. In our experiment, *R. alaternus* plants grew more than *M. communis* plants and plants cropped in PIP grew more than AGP plants (Table 1). However,  $g_s$  was greater in AGP plants after summer (Fig. 4B) what would explain a greater water consumption in the pot, what produced lower SMP registries than PIP plants. Besides, substrate evaporation in *R. alaternus* was also greater than *M. communis* due to its plant architecture, which opposite to *M. communis*, it has a main shoot what leave the substrate surface expose to wind and with low shading level.

Miralles et al. (2009) described four periods of ten representative days (one per season) for *M. communis*. For the summer (Fig. 5), the high number of oscillations in daily minimum SMP is due to greater substrate drying; however, the differences between both systems were barely significant. These low differences in summer SMP between PIP and AGP were explained by greater evaporation because of the higher radiation that the AGP pots received, and the higher transpiration in PIP influenced by higher stomatal conductance.

In autumn (Fig. 6), when the irrigation frequency was lower, AGP reached more negative SMP values than PIP, possibly because transpiration rates leveled out due to similar stomatal conductance levels. Moreover, after summer, some roots from PIP plants entered the air chamber between the two pots of the PIP system, which may mean that transpired water did not come totally from the substrate, as occurred in AGP (Miralles et al., 2009). These differences between PIP and AGP agree with experiments performed by Martin et al. (1999) using *Acacia smallii* and *Cercidium floridum* in which AGP needed extra irrigation, as well as programmed irrigation, to keep moisture tensions for all rooting substrates between -0.005 and -0.01 MPa; AGP needed 5.3 L weekly per pot, and PIP needed 3.2 L per pot.

In November, December, and January, the mean monthly minimum SMP was similar in both systems, which could be a consequence of lower plant growth due to a decrease in temperature and solar radiation. Daily minimum SMP during a representative winter period (Fig. 7) showed less negative values, which were very similar in both systems, reflecting very low irrigation frequency. These registers showed that AGP reached more negative SMP before PIP, which suggests that PIP has lower irrigation requirements (Miralles et al., 2009).

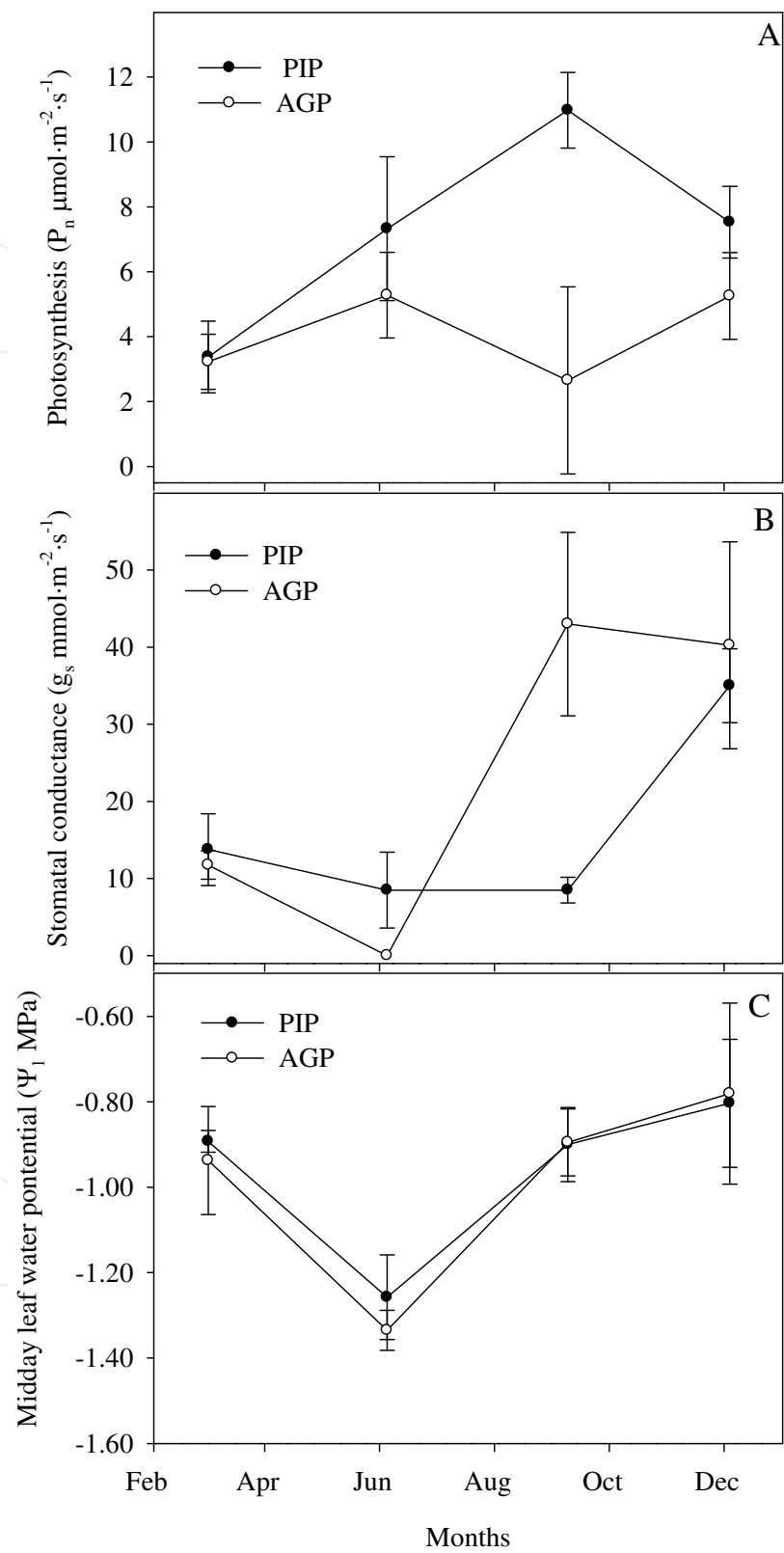


Fig. 4. Net photosynthesis ( $P_n$ ) (A), stomatal conductance ( $g_s$ ) (B) and leaf water potential ( $\Psi_1$ ) (C). Error bars are standard errors ( $n = 6$ )

In February, as the temperature began to increase, the mean monthly minimum SMP in AGP became more negative than the corresponding values in PIP, and in spring, with this season's better environmental conditions for plants, these differences increased. This is reflected in the results shown in figure 8 (spring), where a greater number of SMP variations as a result of increasing water needs can be appreciated. Furthermore, AGP clearly reached more negative values than PIP, whose substrate conditions remained better. Some records in AGP reached  $SMP < -100$  kPa (Fig. 8), which could have caused water stress. Nevertheless, such values were isolated, and the average leaf water potential, in general terms, pointed to no water stress (Miralles et al, 2009). Indeed, in well developed plants, no leaf water potentials under  $-1.0$  MPa were recorded in either system, the values being greater than those recorded for leaf water potential registered in other experiments with *M. communis* plants subjected to moderate water stress (Vicente et al., 2006).

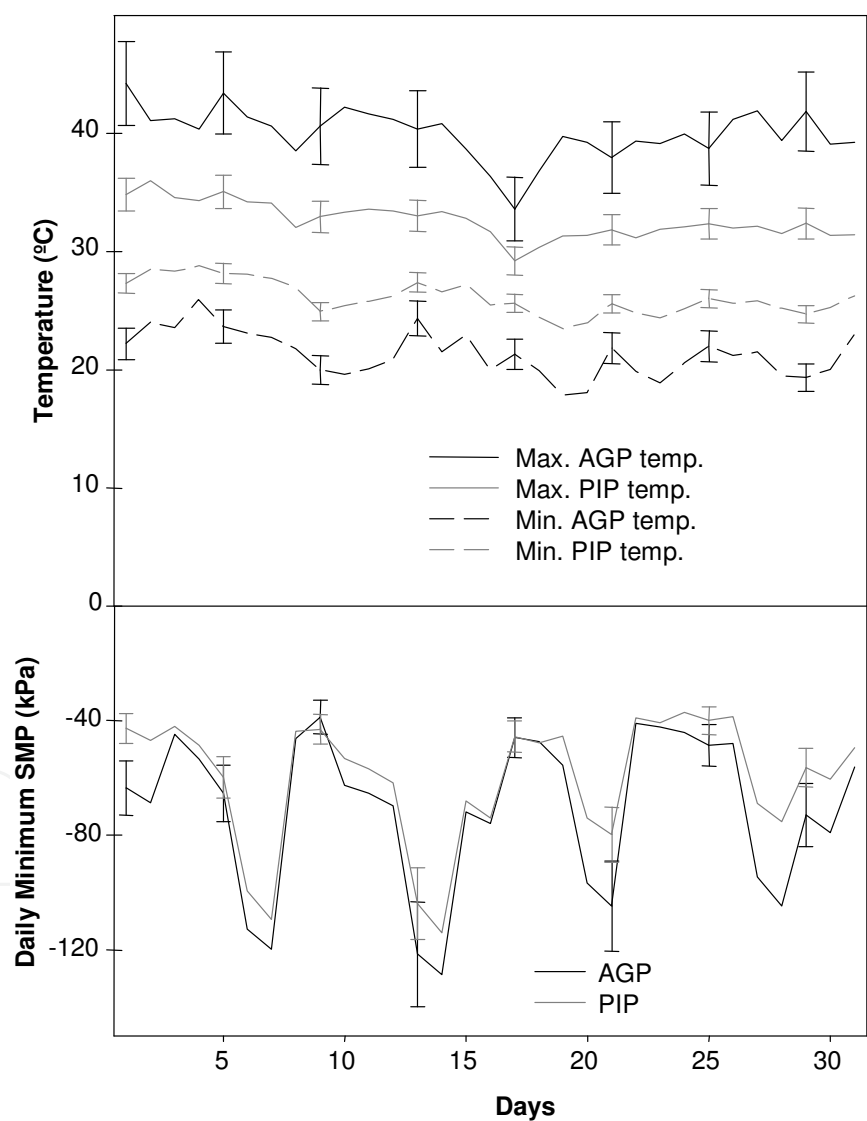


Fig. 5. Representative 31-day period for summer, showing daily maximum and minimum substrate temperature in PIP and AGP systems and daily minimum substrate SMP registers in PIP and AGP systems. Error bars are standard errors ( $n = 4$  in temperature, and  $n = 6$  in SMP). For clarity, only every fifth standard error value is shown. (Miralles et al., 2009)

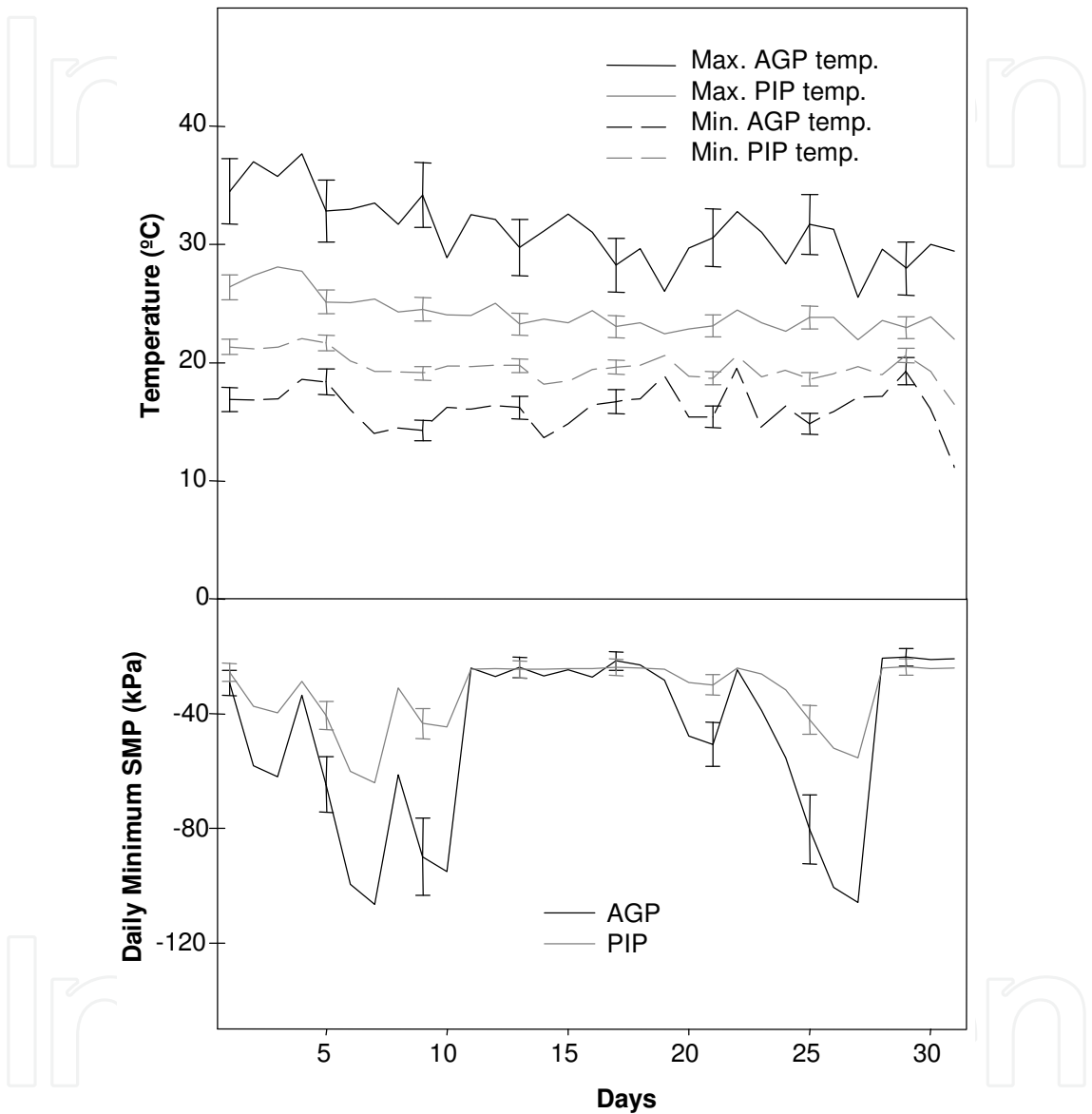


Fig. 6. Representative 31-day period for autumn, showing daily maximum and minimum substrate temperature in PIP and AGP systems and daily minimum substrate SMP registers in PIP and AGP systems. Error bars are standard errors (n = 4 in temperature, and n = 6 in SMP). For clarity, only every fifth standard error value is shown. (Miralles et al., 2009)



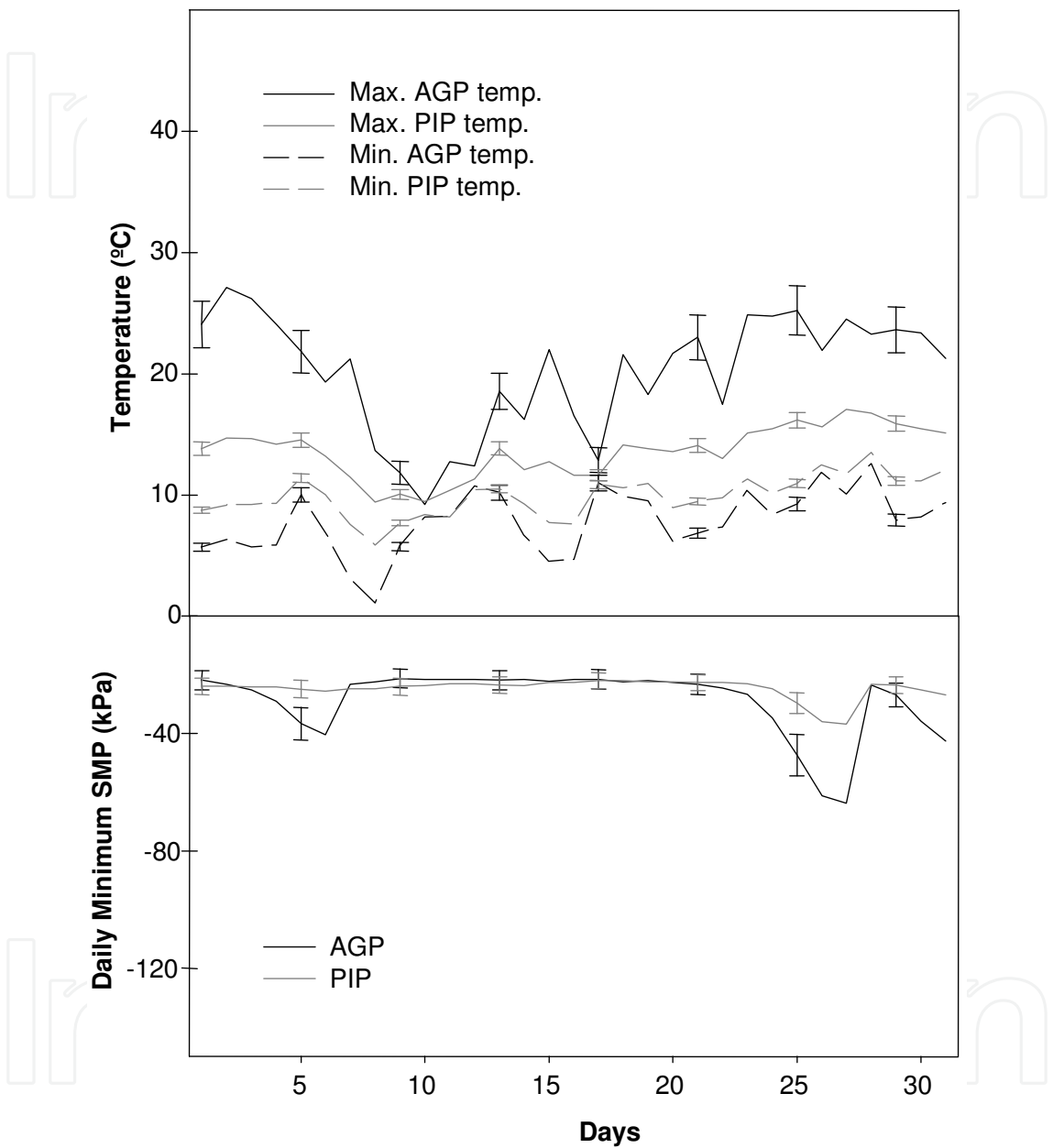


Fig. 7. Representative 31-day period for winter, showing daily maximum and minimum substrate temperature in PIP and AGP systems and daily minimum substrate SMP registers in PIP and AGP systems. Error bars are standard errors ( $n = 4$  in temperature, and  $n = 6$  in SMP). For clarity, only every fifth standard error value is shown. (Miralles et al., 2009)

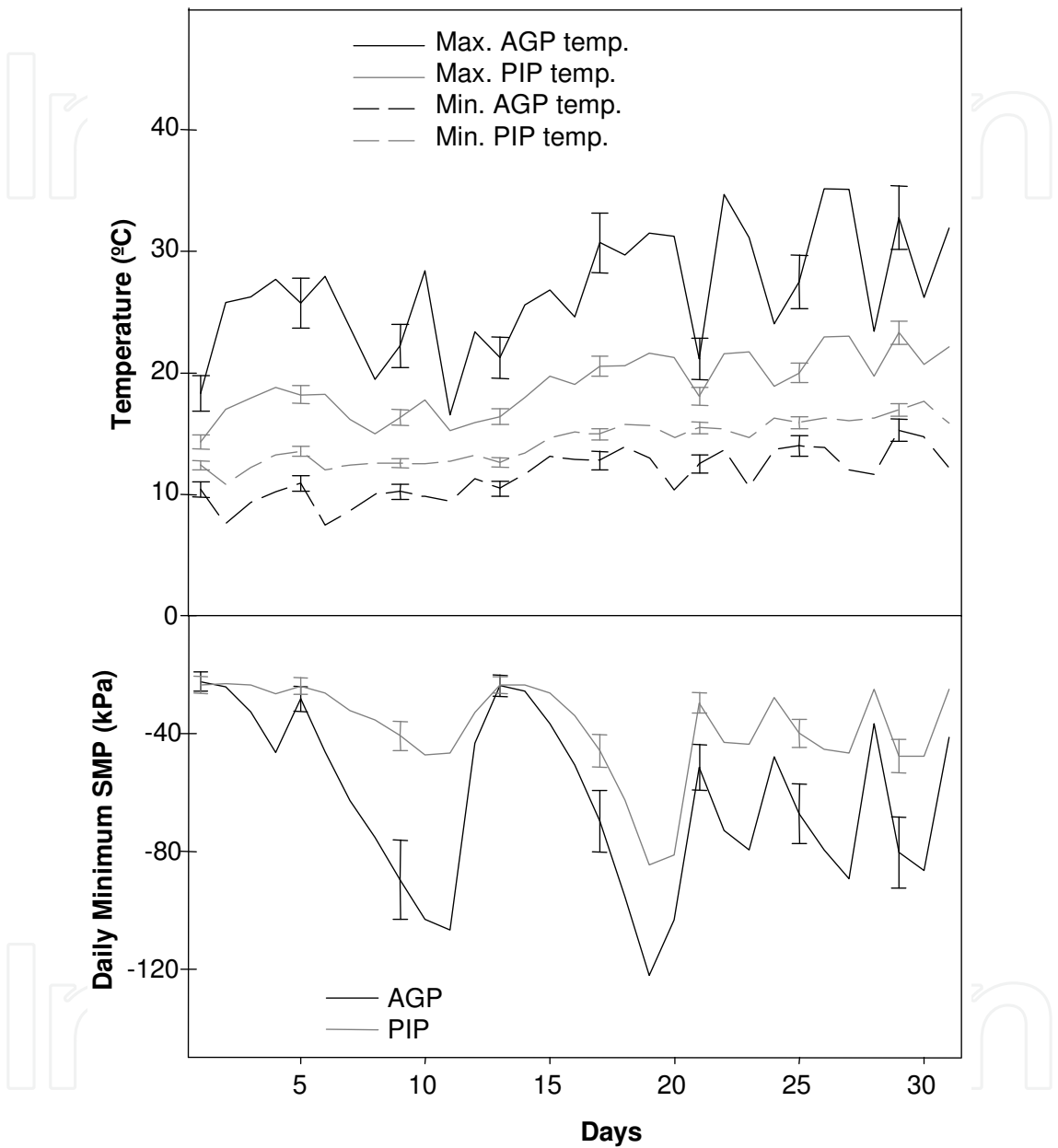


Fig. 8. Representative 31-day period for spring, showing daily maximum and minimum substrate temperature in PIP and AGP systems and daily minimum substrate SMP registers in PIP and AGP systems. Error bars are standard errors ( $n = 4$  in temperature, and  $n = 6$  in SMP). For clarity, only every fifth standard error value is shown. (Miralles et al., 2009)

At the beginning of cultivation (April) until the beginning of the summer, plants in PIP and AGP showed similar gas exchange values (Fig. 4A and 4B), which can explain the lack of difference in growth (Fig. 9). In autumn,  $P_n$  was greater in PIP plants and  $g_s$  in AGP plants (Fig. 4A and 4B), while in winter the differences disappeared. The  $\Psi_1$  was not different between both treatments, but lower at the beginning of summer for all plants (Fig. 4C), so the differences observed in SMP (Fig. 3D) had no effect on  $\Psi_1$ , perhaps due to SMP were not too negative to produce water stress. Miralles et al. (2009) did not found  $\Psi_1$  differences either, however, they registered SMP < -80 kPa in summer in AGP, so they explained that *M. communis* could have activated the messages sent by roots, perhaps of a chemical kind, which might have lowered stomatal conductance rates and, as a consequence, led to lower photosynthetic activity. Such behavior probably helped leaf water potential not to fall in these plants. Mendes et al. (2001) found a high sensitivity to stomatic closure in *M. communis* affected by water deficit. This fact, linked to high solar radiation in this period, could also influence this stomatal conductance behavior. Niinemets et al. (1999) described how stomatic sensitivity was intensified by high solar radiation.

### 3.2 Growth and development

Plant diameter evolution was greater in PIP plants than AGP plants since autumn, but both treatments had the greater diameter growth in summer (Fig. 9A). This greater diameter produced a final plant DW in this species in PIP (Table 1). Plant height and length of main shoots evolution in PIP and AGP was similar during the experimental period, increasing from 20 to 70 cm and 20 to 250 cm, respectively (Fig. 9B and 9C). Both, reduced their growth rate in autumn. Ruter (1993) observed no differences in shoot production in *Lagerstroemia indica* x *fauriei*. However, in *Magnolia* x *soulangiana*, the same author found that PIP plants had more shoots than their AGP counterparts. This effect in plant height was also found by Ruter (1993), although Miralles et al. (2009) reported that the height of PIP *M. communis* plants grew the same in both crop systems from transplantation in March to January, after which the AGP plants grew in height more than PIP plants until the end of the experiment, when they were 16% taller.

In our experiment, due to environmental conditions characterized by hot summers and mild winters (Fig. 1), it might be expected that, in summer, PIP plants would present higher growth because of the moderating effect on substrate temperature (Fig. 3B and 3C). Such behavior only occurred in plant diameter (Fig. 9A), while no differences were found in plant height or main shoot length (Fig. 9B and 9C). However, Miralles et al. (2009) did not have such effect, perhaps due to the physiological characteristics of *M. communis*, which rests at high temperatures (Brosse, 1979). Whatever the case, the influence of PIP on summer growth may depend on the species. For example, during the summer cultivation of *A. smallii*, Martin et al. (1999) observed that PIP increased plant height by 80% in contrast with AGP, but had no effect on *C. floridum*.

Table 1 shows a greater plant growth in PIP (shoot and root), which resulted in a 39% and 181% extra growth in shoot and roots, respectively, compared with AGP. In *L. indica* x *fauriei* and *Magnolia* x *soulangiana*, Ruter (1993) observed greater root dry weight (47% and 70%, respectively) when the plants were cultivated in PIP. Later works by the same author showed similar behavior in *Magnolia grandiflora* (Ruter, 1995). In *A. smallii*, Martin et al.

(1999) found a higher root dry weight in PIP (167 g) compared with AGP (97 g), although no differences for *C. floridum*. Furthermore, Young and Bachman (1996) recorded an increase of 26% in root dry weight when *Ilex x attenuate* was cultivated in PIP. The greater root growth was especially important inside the air chamber between pots what contributed to so high extra growth. Miralles et al. (2009) also reported greater root development in PIP (extra 14%), however, *M. communis* plants in PIP presented 11% less shoot dry weight compared with AGP shoot dry weight.

Parameter	AGP	PIP	Significance <sup>[a]</sup>
Root dry weight (g)	6.67	18.73	***
Shoot dry weight (g)	28.83	39.99	*
Plant dry weight (g)	35.50	58.72	**
Shoot DW/Root DW (S/R)	5.58	2.23	**
Leaf area (cm <sup>2</sup> )	607.37	965.28	*
SPAD	66.41	67.27	ns
Lightness (L)	31.73	32.42	ns
Chrome (C)	21.27	21.98	ns
Hue angle (H)	107.98	107.78	ns

<sup>[a]</sup>Asterisk indicate statistically significant between means at \*P < 0.05, \*\*<0.005, \*\*\*<0.0005. ns = Not significant.

Table 1. Final measurements of plant growth and biomass distribuitin, SPAD and Color.

The greater root growth in PIP reduced its S/R ratio compared with AGP, an effect also reported by Miralles et al. (2009). In contrast, Ruter (1993) described that *L. indica* x *fauriei* cultivation in PIP caused a substantial increase in the S/R ratio, although Martin et al. (1999) did not observe this difference in *A. smalli* or *C. floridum*. It has been suggested that a diminishing shoot/root ratio lowers the relative transpiration capacity, unlike water and nutrient absorption (Bernier et al., 1995). Mathers (2000) described that slight reductions in the shoot/root ratio gives plants greater water stress resistance during nursery production and transplantation, which accelerates plant establishment in the field (Owings, 2005). As mentioned by Guarnaschelli et al. (2006), these effects are more patent in drought conditions, so this change in biomass distribution in plants could improve survival after transplantation. In this study, the greater SMP of PIP plants along the experiment indicate that PIP plants water consumption in the pot was lower than AGP plants, so PIP plants should have lost less water from substrate evaporation, but they must have taken some water from the air chamber between pots, what would justify the large development of roots in it. Miralles et al. (2009) reported that, after two weeks without irrigation at the end of the experiment with *M. communis*, the PIP system led to 90% plant survival, compared with 62% for AGP (Picture 2), and he pointed that the presence of roots in the air chamber between the two pots could have affected the survival, because relative humidity was very high in this chamber (Fig. 2).



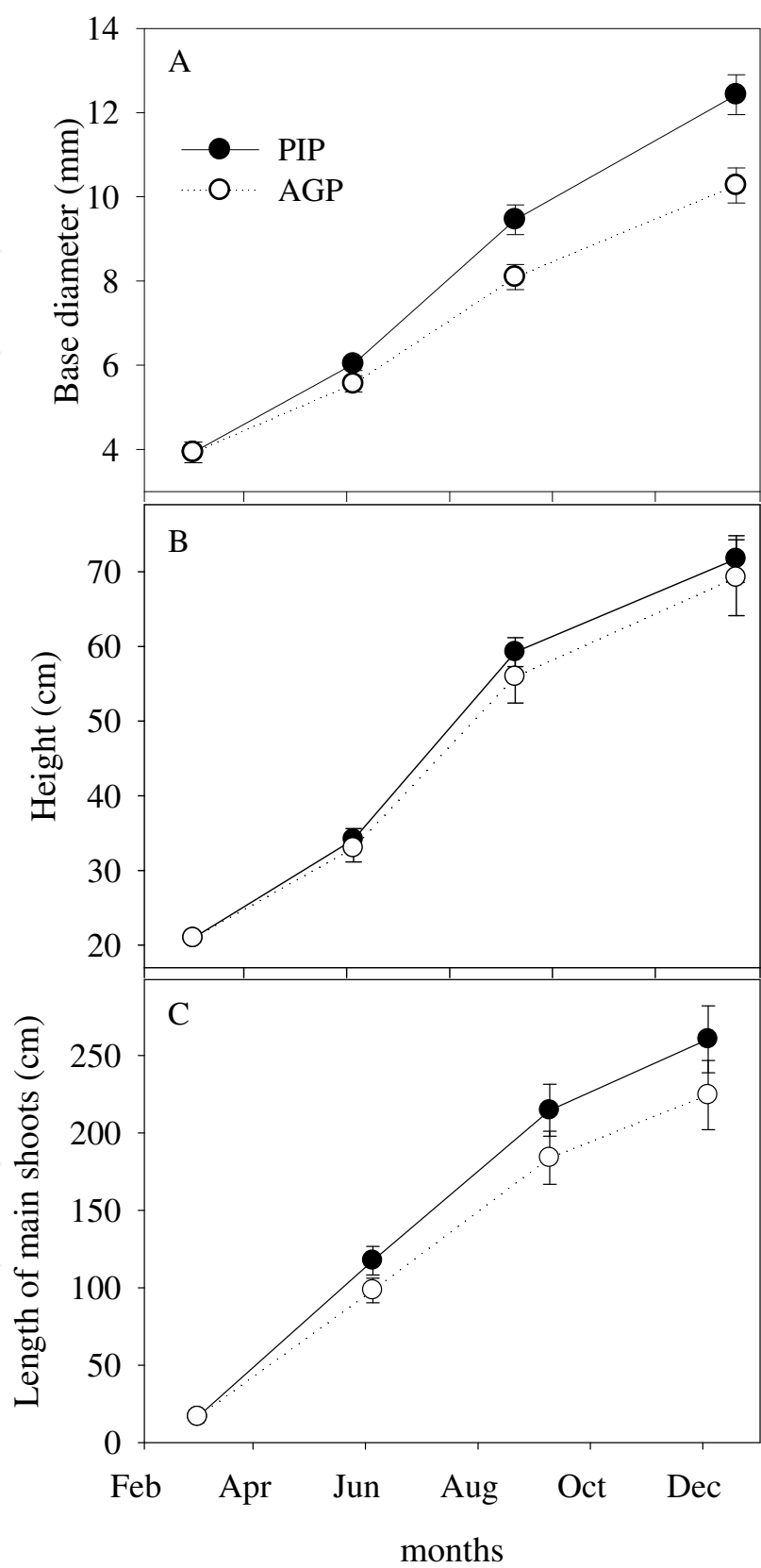


Fig. 9. Base diameter (A), plant height (B) and length of main shoots (C) evolution in PIP and AGP systems. Error bars are standard errors ( $n = 110$ ).

The crop system did not affected leaf color and leaf SPAD, however, leaf area was greater in PIP (Table 1). So, since an aesthetic point of view, plants were quite similar, however those cropped in PIP had more foliage what supposed an advantage in this field.



Picture 2. Experimental plot after two weeks without irrigation at the end of the experiment.

#### 4. Conclusion

The most relevant conclusions of this experiment are four. Firstly, the PIP system used in *R. alaternus* moderated extreme substrate temperatures. Secondly, PIP maintained a higher substrate SMP, which suggests lower irrigation needs than in AGP. Thirdly, PIP increased plant growth in terms of dry weight (more plant diameter) and also in leaf area (plant height, main shoot length and leaf color were not affected) what increased its aesthetic value. Lastly, the PIP system favored greater root development inside the air chamber between pots, which was translated into a lower shoot/root ratio, favoring taking some water from this chamber what maintained greater SMP in the pot substrate.

#### 5. Acknowledgements

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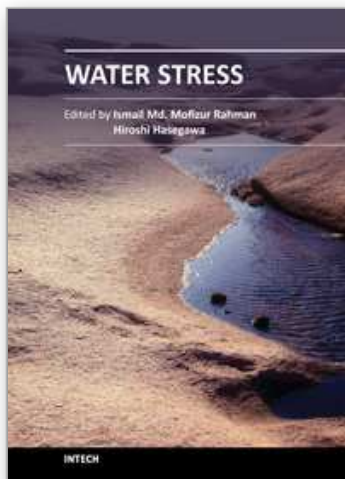
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## **Water Stress**

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Plants experience water stress either when the water supply to their roots becomes limiting, or when the transpiration rate becomes intense. Water stress is primarily caused by a water deficit, such as a drought or high soil salinity. Each year, water stress on arable plants in different parts of the world disrupts agriculture and food supply with the final consequence: famine. Hence, the ability to withstand such stress is of immense economic importance. Plants try to adapt to the stress conditions with an array of biochemical and physiological interventions. This multi-authored edited compilation puts forth an all-inclusive picture on the mechanism and adaptation aspects of water stress. The prime objective of the book is to deliver a thoughtful mixture of viewpoints which will be useful to workers in all areas of plant sciences. We trust that the material covered in this book will be valuable in building strategies to counter water stress in plants.

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