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RESEARCH PAPER

Establishing *Acacia salicina* under dry Mediterranean conditions: The effects of nursery fertilization and tree shelters on a mid-term experiment with saline irrigation

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Abstract

J.A. Oliet, R. Planelles, F. Artero, and J.M. Domingo-Santos. 2016. Establishing *Acacia salicina* under dry Mediterranean conditions: The effects of nursery fertilization and tree shelters on a mid-term experiment with saline irrigation. Cien. Inv. Agr. 43(1):69-84. The restoration of dry lands in the Mediterranean is a challenging task because harsh abiotic conditions hamper the counteraction of feed-back degradation processes. Active restoration through planting must be performed to deter this process. In this study, we tested the influence of mineral nutrition in the nursery (two formulations of controlled release fertilizer at two rates each) and tree protection after planting (by using tube shelters) on the nine-year performance of *Acacia salicina* irrigated with low-quality (saline) water. The overall survival at the end of the study period was 58.2%, with the electrical conductivity of the soil saturation extract reaching 5.4 $dS \cdot m^{-1}$ after nine years. The survival and growth (in height) were greater for seedlings fertilized with more than 1.5 $g \cdot L^{-1}$ of 9-13-18, although the survival differences became significant only after the seventh year. The basal stem diameter (BSD) of seedlings that were fertilized at higher rates was significantly greater than those that were fertilized at lower rates during the first two years of planting; the differences were no longer present thereafter. The seedlings in shelters had marginally superior survival, faster growth during the first four years, and smaller BSD values after the third year compared to those of the unprotected seedlings. In comparison with a parallel study that was conducted under drought conditions, irrigation reduced some differences among treatments, but it increased others. These results emphasize the importance of the size and mineral nutrient status of nursery stock in irrigated plantations under dry Mediterranean conditions, with highly fertilized seedlings showing superior performance. Long-term planting studies are crucial for gaining a greater understanding of seedling performance and for providing a better rationale for treatment recommendations.

Key words: Plantation, restoration, seedling nutrition, seedling quality, tube shelters

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Introduction

The rehabilitation of lands under arid conditions is one of the most challenging restoration tasks because not only does degradation itself preclude the recovery of the ecosystem, but abiotic factors such as intense droughts also reduce the productivity and the ability of the ecosystem to restart succession (Vallejo *et al.,* 2012). Under high levels of degradation (croplands with intensive farming, surface mining, or highly eroded soils), soil systems lose most of their structural elements, resulting in limited microsite diversity (Cortina *et al.*, 2011). In addition, many restoration projects require plant densities and spatial distribution that do not match the site's capabilities. Under these circumstances, ecotechnologies for active restoration at reasonable costs that can ameliorate microsites and reduce predation must be applied to ensure restoration (Vallejo *et al.,* 2012). In addition, choosing species that are adapted to the site conditions (Padilla *et al.,* 2009) and targeting quality seedlings (Villar-Salvador *et al.,* 2012) are among the most common techniques for improving restoration success in degraded Mediterranean areas.

Plant mineral nutrition is among the most important seedling quality attribute for planting temperate forests. A growing body of research that is specific to Mediterranean areas has reemphasized the importance of plant mineral nutrition to survival and growth, supporting the ecophysiological relations between seedling traits and planting responses (Villar-Salvador *et al.,* 2012). Those relations indicate the importance of producing large and nutrient-loaded nursery seedlings for planting success in Mediterranean and dry areas, especially with respect to N (Oliet *et al.,* 2013 and references therein), although a question has been raised in recent years about the importance of accounting for the influence of environmental specificities in drylands to match the seedling quality and fertilization to optimize survival (Cortina *et al.,* 2013). Incorporating controlled release fertilizer (CRF) into the growing media provides an efficient means of nutrient loading in the nursery as well as continued fertilization after outplanting (Haase *et al.,* 2006; Oliet *et al.,* 2013).

One of the most widespread cultural practices in Mediterranean restoration programs over the past 20 years has been the use of tube shelters (Piñeiro *et al.,* 2013). Along with protecting seedlings from animal predation, these shelters can increase seedling survival (Oliet *et al.,* 2003; Padilla *et al.*, 2011). A recent meta-analysis of the use of ecotechnologies for dryland restoration emphasizes tube shelters as one of the most effective methods for improving survival (Piñeiro *et al.,* 2013). These results suggest a positive effect of tube shelters that is related to light reduction (also Puértolas *et al.,* 2012). However, these shelters have also been shown to reduce root growth after planting, especially in shade-intolerant species (Vázquez de Castro *et al.,* 2014), providing a rationale for the observed survival reduction of these species (Oliet *et al.,* 2003; Jiménez *et al.,* 2005). New experiments with other Mediterranean species can help to create a better understanding of the seedling-shelter system and the related response on the basis of specific functional traits to improve prescriptions for use in forestation.

Irrigation of forest plantations can be necessary in Mediterranean dry areas to assure survival when the summer drought is long and severe (Padilla *et al.,* 2011; Pardos *et al.,* 2015). Low precipitation and the salinization of groundwater require the use of additional water resources (wastewater, desalinized water, etc.). Therefore, more information is needed to improve water management in plantations, specifically when using low-quality water resources such as those that are usually found in arid zones (Dawalibi *et al.,* 2015). Because of the interactions between experimental treatments and time, it is important to monitor plantations for more than one season. In particular, the effects of tree shelters or the combination of nursery mineral nutrition and tree shelters may be prolonged for several seasons after planting

(Jacobs, 2011; Oliet *et al.*, 2000; Oliet *et al.*, 2005). In addition, target seedling characteristics can change under Mediterranean dry conditions if irrigation is applied after outplanting. However, few studies consider more than the first year response, especially when examining the effects associated with nursery fertilization treatments.

Acacia salicina Lindl. is an N-fixing leguminous shrub or tree that is native to the arid zone of South Australia, but it has been introduced to other regions as a multipurpose species (Le Houérou, 2000; Rehman *et al.,* 1999). It has been successfully established in degraded areas (Grigg and Mulligan, 1999), and it is highly salt and drought-tolerant (Le Houérou, 2000; Yokota, 2003). In Spain, *A. salicina* has been introduced in some Mediterranean areas to serve as a source of fodder for livestock (Correal *et al.,* 1988), for ornamental uses, and to rehabilitate disturbed areas (Tilstone *et al.,* 1998). In addition, in comparison with the other native and non-native species of arid Mediterranean lands, this species ranked highest as a soil modifier, improving the physical and chemical properties as well as the richness of vascular species under its canopy (Jeddi *et al.,* 2009). This species is not considered invasive in the Iberian Peninsula (Ministerio de Agricultura, Alimentación y Medio Ambiente, 2013). Because of its ability to quickly modify surface properties and foster succession, this species is considered an interesting non-native candidate for the restoration of very degraded Mediterranean areas if some management prescriptions such as reducing the rotation period and controlling its spread are undertaken (Jeddi *et al.,* 2009).

The objective of this study was to evaluate the effects of nursery fertilization and tree shelters in an irrigated experiment on mid- to long-timescale responses of planted *A. salicina* seedlings on degraded land in a semiarid Mediterranean region of Spain. This trial was conducted in parallel to another experiment performed without irrigation in the same plot area (Oliet *et al.,* 2005), and we believe that a comparison of treatments with and without irrigation will provide some interesting clues about the importance of drought stress on the effects of the tested treatments.

Materials and methods

Nursery production and field planting

A. salicina seedlings were grown at the Boticario Centre (2º24'W, 36º52'N, elevation 60 m) in Almeria, Spain. The plants were sown in May 1992 in individual 230 mL cell containers filled with a 4:1 (v/v) sphagnum peat moss:vermiculite growth medium in which the fertilizer treatments were mixed. The fertilizer treatments consisted of two rates of two different controlled-release Osmocote ® (Scotts Co., Marysville, OH, USA) formulations plus a non-fertilized treatment for comparison. The tested formulations and rates were as follows: 9-13-18: 9N (6.1% NH_4-N and 2.9% NO_3-N)-5.7P-14.9K, at rates of 1.5 and 3.25 g L^{-1} substrate; and 16-8-9 + 3Mg: 16N (6.6% NH_4-N and 9.4% NO_3-N)-3.5P-7.5K, at rates of 3.25 and 7.0 g L^{-1} substrate. Each formulation had a nutrient release period of 12–14 months at 21 ºC. Micromax ® (Scotts Co.), which is a solid mixture of microelements, was added to all the treatments at a rate of 0.15 g L^{-1}. The fertilizer treatments were designed to supply an increasing amount of N per plant (from deficiency to luxury consumption, Oliet *et al*. 2004) while maintaining two different N-P-K balances by increasing the amounts of P and K within a formulation (Table 1). The treatments in the nursery were arranged in a completely randomized design. The heights and basal stem diameters were measured in 30 randomly selected 9-month-old seedlings per treatment, and they were sampled directly from the nursery containers. More details about the experimental layout and the results of the nursery study can be found in Oliet *et al.* (2005).

Table 1. N, P and K amounts per plant as supplied by fertilizer treatments (the rates of each formulation per litre of substrate) and the heights and basal stem diameters of *Acacia salicina* seedlings after 9 months as affected by fertilization treatments.

Formulation	No fertilizer	9-13-18		16-8-9	
Rate (g L^{-1})	0.0	1.5	3.25	3.25	7.0
Nutrient amounts per fertilizer treatment					
N (mg $seedling^{-1}$)	-	31.0	67.2	119.6	257.6
P (mg $seedling^{-1}$)	-	19.6	42.3	26.0	56.1
K (mg $seedling^{-1}$)	-	51.5	111.6	55.9	120.3
Seedling morphology					
Height (cm)	19.3c	34.3b	40.2ab	44.5ab	49.7a
Diameter (mm)	2.3c	3.1b	3.6ab	4.1a	4.4a

For seedling morphology, means with different letters within a row indicate significant differences (n=30).

On March 3, 1993, *A. salicina* seedlings were planted on a degraded plain (2º20'W, 36º51'N, elevation 30 m) of Almeria, Spain that was previously devoted to marginal croplands. According to FAO taxonomy, this soil belongs to a cambic arenosol group formed on calcareous parent material (Perez, 1989), with the first sandy horizon (95% sand) at a 30 cm depth on a sandy-loamy horizon (66% sand, 29% loam). The carbon (0.5%) and the fertility of the profile are very low (0.05% total N, 0.75 ppm P and 0.13 mg g^{-1} K) and the pH is basic (pH_{H2O} up to 8.5) (Pérez, 1989). The mean annual rainfall and temperature of the area are 200.2 mm and 18.5 ºC, respectively, with frequent strong southwest winds (Spanish National Institute of Meteorology reports, from data averaged from 1969 to 2001). The precipitation that fell during the study period was collected and measured by a pluviograph that was installed at the planting site. The annual rainfall from 1993 to 2001 averaged 160.5 mm, with an average of 30 mm from May to September (Figure 1). The experimental site was fenced to restrict access to rodents and herbivores. Cross-plowing to a depth of 80 cm was performed prior to planting. The seedlings were planted in manually opened pits (0.3 m × 0.3 m × 0.3 m) with a spacing of 1.5 m × 1.5 m. The 10 factorial treatments (five nursery fertilization treatments × two shelter treatments, with or without shelters at planting) were arranged in a randomized complete block design with four replications. The tree shelters were made of unventilated Tubex Standard ® tubes (Tubex Ltd., Aberdare, UK) which were constructed from twin solid-walled polypropylene with a light transmission coefficient of 45% (Oliet *et al.,* 2003), and they were 0.6 m tall × 0.11 m wide. The experimental unit consisted of a row of 7 seedlings, and each block contained 10 rows. Manual weeding was conducted annually starting from 1993 and continuing through the whole period. Irrigation was applied via drip irrigation system with one drip line of 4.5 $L{\cdot}h^{-1}$ single emitters per seedling, which were installed close to the basal stem of the plant. The irrigation rate and frequency varied over the study period and over the season within a year, according to the water demand and developmental stage. During the first two years, the irrigation was aimed at optimizing survival by supplying adequate water for root growth; in subsequent years, water was applied to maintain soil moisture at stressing but non-lethal values, according to the soil texture and technical guidance (see the following section and www.irrometer.com). The water used here was taken from an adjacent well. A portable electrical conductivity (EC) meter was used to monitor the water salinity for every irrigation session. The EC in the irrigation water (EC_w) ranged from 4.2 to 6.4 $dS{\cdot}m^{-1}$, and the pH was between 7.5 and 8.0 during the nine-year study. According to the two sample analyses that were conducted during 2001, the average cation concentrations (mg·L^{-1} ±EE) were as follows: K, 45.3±2.7; Na, 916.6±52.9; Ca, 269.0±17.2; and Mg, 194.6±8.8. These values indicate a high Sodium-Absorption Ratio (SAR), rising up to 10.38. This value leads to severe restrictions in plant growth because of sodium toxicity (Ayers and Wescott, 1985). In addition, EC_w values above 3 dS·m^{-1} indicate a severe risk of adverse salinity effects on crops, which are only suitable for tolerant species (Ayers and Wescott, 1985).

Measurements

To measure the soil moisture to guide irrigation, tensiometers (R model, Irrometer Company, Riverside, CA, USA) were set up at two depths (45 and 90 cm) at 15 cm from each tree. Four replicates were installed in randomly selected trees. Tensiometer readings (soil suction) indicate the matric potential of the soil (Muñoz-Carpena et al., 2005). The irrigation rate and frequency varied in accordance with the plantation stage and a specified threshold of soil suction. During the first two years after planting, the threshold was 15-25 kPa at 45 cm and 30-40 kPa at 90 cm, which was maintained to avoid soil moisture levels that would induce highly stressful conditions (Migliaccio and Li, 2012). After two years, the threshold was changed to 60-70 kPa at 90 cm for the rest of the experiment. These settings were the primary guidelines used to account for changes in tree water demands. In addition, the irrigation amount was

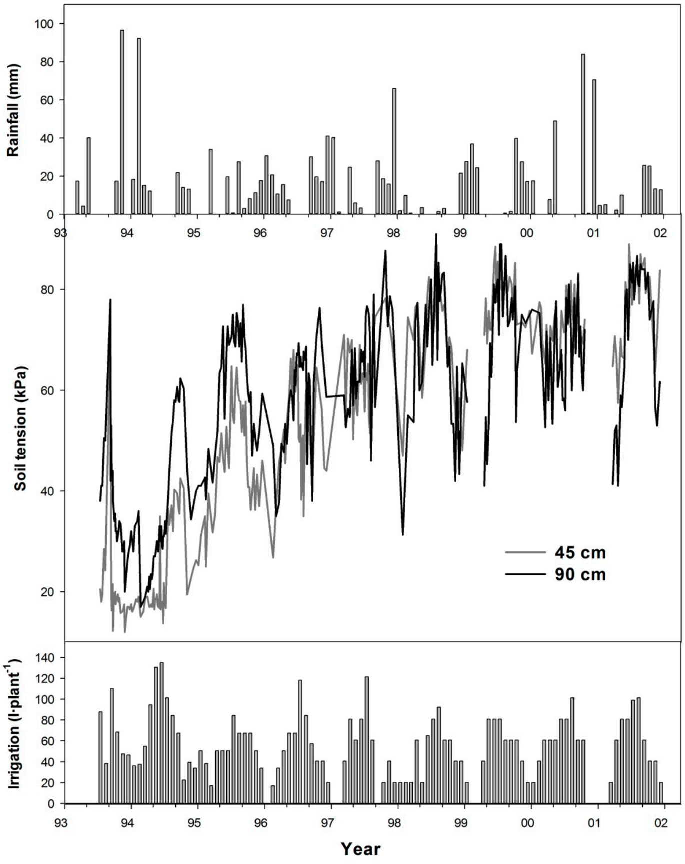

Figure 1. Monthly rainfall (top figure), maximum soil tension prior to irrigation at two soil depths (middle figure) and monthly irrigation rates on a per-plant basis (bottom figure) in an *Acacia salicina* plantation over nine years.

controlled by varying the duration of the session. During the first year, frequent irrigation (every three to seven days, depending on the season) was conducted at 9 L·tree^{-1}. Thereafter, irrigation was applied at rates of 17 to 20.2 L·tree^{-1} per session at longer intervals. This regimen was intended to promote deep rooting (Burman et al., 1991).

The seedling heights and basal stem diameters (BSD) of all the living plants were measured in June and October of 1993 and 1994, November 1995, January 1997, February 1999, December 2000, and January 2002. The survival percentage in each treatment replication was also assessed at the same time. The sturdiness quotient (height: BSD) was also calculated.

To characterize the soil salinity evolution over time, the depths, and distances from drip emitters soil samples were taken prior to planting (March 1993) and on three subsequent dates (October 1995, April 1999, and July 2001). The samples were taken with a 7.5 cm diameter auger that was 10 and 30 cm from the emitters near four trees (the same trees were used for each sampling date). Two 90-cm-deep auger holes were created at each distance from the emitter, and cores were collected at 0-30, 30-60 and 60-90 cm. A composite sample was made from the two sampling points at the same depth. A total of 24 samples (4 replicates x 2 distances x 3 depths) were analyzed for the EC on each of the three sampling dates. Prior to the analysis, the coarse elements (> 2 mm) were separated. Aqueous extracts of soil samples at a 1:5 soil-to-water ratio were prepared by adding 50 mL of deionized water to 10 g of soil in 200-mL screw-cap containers and then shaking the samples in a reciprocal shaker for one hour. Afterwards, each suspension was decanted and filtered. One drop of sodium hexametaphosphate 0.1% was added to prevent $CaCO_3$ precipitation. The electrical conductivity at 25 ºC (EC_{25}) was measured using a conductivity meter that was equipped for automatic temperature compensation. The instrument was tested with a KCl conductivity standard solution of 1.413 dS m^{-1}. Providing that the electrical conductivity in the saturation extract (EC_{se}) is the closest measurement to the plant's conditions in the soil (Richards, 1954), an approximate conversion from the EC in the 1:5 suspension ($EC_{1:5}$) to EC_{se} for $EC_{1:5}$<1.0 dS m^{-1} was calculated on the basis of the equation given by Visconti *et al.* (2010). For $EC_{1:5}$ values above 1.0 dS·m^{-1}, the quoted conversion equation loses accuracy and saturation extract measurements should be performed. However, in noting that only a few samples had $EC_{1:5}$ values that were slightly above that threshold, this operation was not performed.

Statistical analyses

For the nursery experiment, morphological analyses were conducted by one-way ANOVA (additional details in Oliet *et al.*, 2005). Analyses of the survival and growth for the planting experiment were performed by two-way ANOVA with a general lineal model (the primary fixed factors consisted of nursery fertilization and a tree shelter at planting), with the treatment mean for each block comprising the experimental unit (each row consisted of 7 plants). For plantation survival percentages, the data were arcsine-transformed. The height, BSD, and sturdiness quotient data were log-transformed when ANOVA assumptions of normality and homoscedasticity were not met. A Kruskal-Wallis non-parametric test (K-W) was conducted on the data if their variances were not stabilized after log transformation. In any case, the data were reported as back-transformed means with standard errors. When the ANOVA statistics were significant, the differences between means were identified using Fisher's protected least significant differences test. The soil EC was analyzed using a repeated measure two-way ANOVA, with the depth and distance to the emitter as the primary fixed factors and the measurement date as the repeated factor. The effects were considered significant when $P \leq 0.05$. SPSS Version 15.00 was used for all statistical tests.

Results

The shoot sizes of nursery seedlings increased steadily as greater N amounts were applied (Table 1). A more detailed explanation of the primary differences in nursery stock types among fertilization treatments can be found in Oliet *et al.* (2005).

Irrigation, soil moisture and soil conductivity

The soil tension followed a seasonal pattern prior to irrigation, with the maximum values being reached during the summer and the minimum values being reached in midwinter (Figure 1). During the first two years (1993-94), the maximum soil tension was kept low throughout the year, with pre-irrigation values below 20 kPa (with the exception of August 1993, when a mishandled low rate of only 38.2 L was applied during this month) at 45 cm (Figure 1). November 1993 and February 1994 were the wettest months in terms of rainfall during the whole study period, which also contributed to reduced soil tension during the following months (Figure 1). After 1995, the maximum soil tension increased prior to irrigation and stabilized at approximately 70 - 80 kPa in the summer at both depths (Figure 1). On average, 78.1 L·plant^{-1} per month was applied from June to September, with values ranging from 65.8 L·plant^{-1} per month (1997) to 97.0 L·plant^{-1} per month (1994) (Figure 1).

The soil EC was not affected by the distance to the emitter or the depth (ANOVA data not shown). However, the soil conductivity was influenced significantly by time (the P-value for the repeated date factor was ≤0.001) with increases from an overall mean of 1.2±0.1 dS·m^{-1} (across depths and distances to drip emitters) to 5.4±0.4 dS·m^{-1} (Figure 2). Despite the lack of significant differences among the depths (P=0.172), the soil conductance was always greater at the 60-90 cm depth, and the average values at the intermediate depth (30-60 cm) were the lowest.

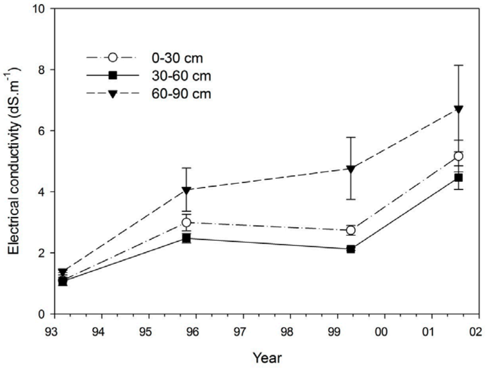

Figure 2. The soil electrical conductivity (±SE. n = 8) evolution during the planting experiment as affected by the soil depth.

Seedling response after planting

Despite the fact that marginal differences were found prior to the seventh year, plant survival was not significantly affected by nursery fertilization until this amount of time had passed after planting (Table 2). By this time, the seedlings that were fertilized with 7 g·L^{-1} of Osmocote 16-8-9 showed significantly higher survival than the non-fertilized seedlings (P=0.05). Non-fertilized seedlings and those fertilized with 9-13-18 exhibited a notable drop in survival during the first two years after planting (Figure 3). By January 2002, the survival rate among the fertilized treatments ranged from 42.9±7.6 % (non-fertilized seedlings) to 75.0±6.5 % (7 g L^{-1} of 16-8-9, Figure 3). The tree shelters did not have a significant effect on survival at any date, although the seedlings that were protected with shelters tended to have higher survival and reached marginally significant differences during some years (Table 2 and Figure 3).

The height responses were significantly affected by nursery fertilization over the entire study (except in 1997, as shown in Table 2, Figure 3). At the ninth year after planting, non-fertilized trees or those that were fertilized at the lowest rate of 9-13-18 were 1.48 m tall on average, while those with the maximum rate of this formulation

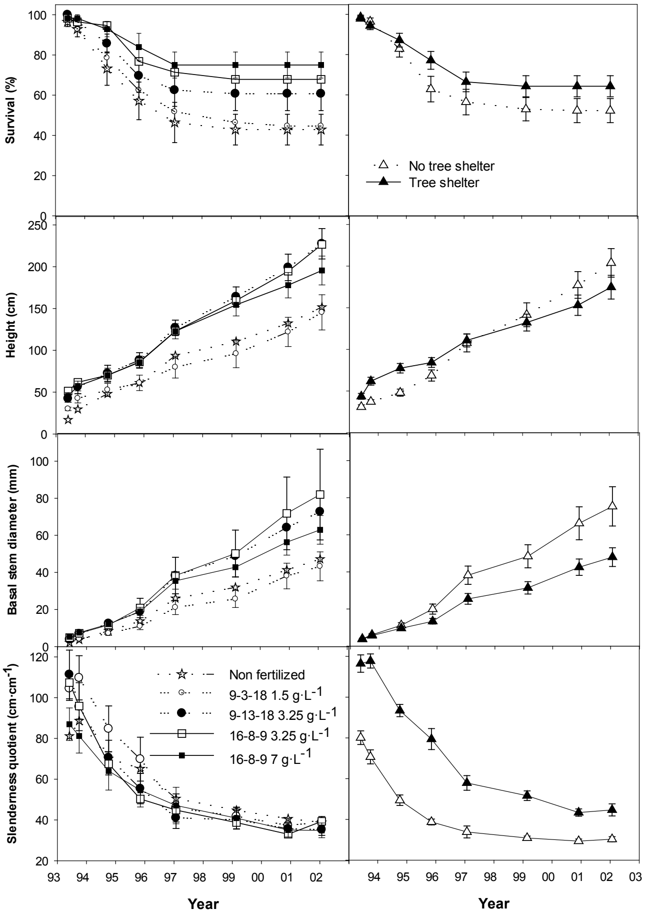

Figure 3. Post-planting survival, height, basal stem diameter and sturdiness quotient of *Acacia salicina* over nine years as affected by nursery fertilization (n = 8) and tree shelters at planting (n = 20). For clarity, only the SE of the maximum, minimum and intermediate fertilizer treatments are shown. In some cases, the SE bars are hidden by the symbol.

were 0.8 m taller (Figure 3). The tree shelters also had a significant and positive effect on the heights during the first three to four years (Table 2, Figure 3).

The basal stem diameter was significantly affected by nursery fertilization during the first two years after planting (Table 2). Thereafter, the results were non-significant, although non-fertilized trees and those that were fertilized at the lowest rate of 9-13-18 tended to have smaller BSDs than the trees in the other treatments (Figure 3). Tree shelter protection did not affect the BSD until the third year after planting (Table 1). Thereafter, non-protected seedlings had larger BSDs than protected seedlings, with differences that increased over time (Figure 3).

Nursery fertilization affected the sturdiness quotient only during the first two years, whereas shelter protection affected the sturdiness quotient during the entire study period (Table 2). The trees that were kept in shelters had higher quotient values than unsheltered ones, although the differences were reduced with time until year eight, when the differences vanished (Figure 3).

Table 2. F values and the statistical significance (*P*) for the effects of shelter and nursery fertilization (Fert) on the post-planting survival, height, basal stem diameter (SD) and slenderness quotient over the nine-year monitoring period (June 1993-January 2002). Significant values are highlighted in bold.

		Survival		Height		Basal SD		Slenderness	
Date	Effect	F	P>F	F	P>F	F	P>F	F	P>F
Jun 93	Shelter (S)	0.36	0.554	136.21	≤0.001	2.94	0.098	107.60	≤0.001[2]
	Fert (F)	0.90	0.478	127.92	≤0.001	91.81	≤0.001	11.72	≤0.001[2]
	F×S	0.31	0.310	7.07	≤0.001	0.68	0.612	1.38	0.266[2]
Oct 93	Shelter (S)	1.18	0.286	81.74	≤0.001	0.90	0.352	174.08	≤0.001
	Fert (F)	0.74	0.573	18.92	≤0.001	14.42	≤0.001	7.014	0.001
	F×S	2.53	0.063	1.67	0.185	0.22	0.925	0.72	0.584
Oct 94	Shelter (S)	0.71	0.406	49.30	≤0.001	2.08	0.161	205.08	≤0.001
	Fert (F)	2.66	0.055	6.01	0.001	3.74	0.015	5.28	0.003
	F×S	0.72	0.582	1.27	0.305	0.34	0.848	0.73	0.578
Nov 95	Shelter (S)	4.13	0.052	4.88	0.036	5.49	0.027	100.61	≤0.001[2]
	Fert (F)	2.68	0.053	3.18	0.029	1.76	0.167	2.29	0.086[2]
	F×S	0.63	0.644	0.67	0.615	0.59	0.676	0.67	0.62[2]
Jan 97	Shelter (S)	1.04	0.316	0.06	0.813	5.08	0.032	20.41[1]	≤0.001[1]
	Fert (F)	1.92	0.136	2.23	0.093	1.53	0.22	0.86[1]	0.931[1]
	F×S	0.45	0.767	0.65	0.629	0.63	0.643		
Feb 99	Shelter (S)	2.93	0.098	0.35	0.558	5.16[1]	0.023[1]	73.11	≤0.001[2]
	Fert (F)	3.43	0.022	3.17	0.029	7.85[1]	0.097[1]	0.58	0.679[2]
	FxS	0.44	0.782	0.99	0.431			0.13	0.971[2]
Dec 00	Shelter (S)	3.27	0.082	1.74	0.198	4.80[1]	0.028[1]	53.12	≤0.001
	Fert (Fe)	3.60	0.020	3.01	0.036	7.66[1]	0.105[1]	1.73	0.172
	F×S	0.40	0.809	0.99	0.43			0.67	0.616
Jan 02	Shelter (S)	3.27	0.082	2.05	0.163	5.16[1]	0.023[1]	23.11	≤0.001[2]
	Fert (F)	3.59	0.020	3.00	0.036	6.95[1]	0.139[1]	0.42	0.793[2]
	F×S	0.40	0.809	0.92	0.466			0.50	0.737[2]

[1] Chi-square and Kruskal-Wallis significant degree values.

[2] ANOVA conducted with log-transformed data.

Discussion

Irrigation management and soil conditions during the study period. Analyzing potential effects on seedling survival

During the first two years after planting, the irrigation threshold was lowered to reduce the planting check and to increase survival. Thereafter, the higher threshold still resulted in an annual irrigation of approximately 630 L·plant^{-1} because of the increasing evapo-transpiration associated with canopy growth. In addition, yearly changes in evaporative demand and rainfall are also important sources of variation (Figure 1). An average of 312 L of water was applied during the summer, which was lower than that of other experimental plantations in the Mediterranean (Pardos *et al.,* 2015), but considerably higher than that of some experiments under arid conditions in which water was supplied manually at the root level through a pipe (Padilla *et al.,* 2011). During the rest of the year, a considerable amount of water (approximately 50% of the yearly irrigation) was still applied during our experiment because of the low rainfall rates (Figure 1). The soil suction values that were registered three years after planting were often over 60 kPa, which can be considered highly stressful, but still not close to the wilting point (Irrometer Co. 2015).

Over time, there was an increase in the soil conductivity from negligible salinity values at planting (less than 2 dS·m^{-1}) to average values of over 5 dS·m^{-1} at the end of the study, which could cause severe restrictions in crop yields (Richards, 1954). In performing observations by depth, the intermediate layer (30 to 60 cm) had the lowest variation because in arid climates, the saline elements are washed down to deeper horizons or are dragged to the surface by capillary rise. This trend could change if the root system of the trees colonize this area of soil and stop most of the water from leaching. The surface horizon (0-30 cm) had the greatest changes in conductivity, which was attributable to the combined action of irrigation, capillary rise, and rainfall. The deep horizon (60-90 cm) showed a continuous increase in conductivity with time; the total amount of salt in the soil was increased by irrigation; therefore, the salinization in this horizon may be accelerated by irrigating with saline water. This tendency could be significant for *A. salicina* because its roots colonize this deep horizon. If irrigation can be stopped once the plantation is well-established, the salinization of that deeper horizon should not be a problem for tolerant plants. However, when the water supply must be maintained, the irrigation volumes should ensure salt leaching (Ayers and Wescott, 1985) to maintain good soil conditions.

The overall survival of *A. salicina* after nine years was 58.2 ± 4.0%, which was not much higher than the survival from a similar experiment without irrigation (52.1 ± 3.2%, Oliet *et al.,* 2005). Because the soil suction values during these periods were below stressing conditions, we hypothesize that the negative effects of water salinity could also be expressed as the mean values of EC_{se} that rapidly increased to over 3 dS·m^{-1} (Figure 2). According to estimations from the literature (Santa Olalla-Mañas *et al*., 2005), under our soil conditions, values of EC_{se} = 0.5 dS m^{-1} (such as those reached right after planting) corresponded to osmotic tension that was approximately equal to the soil suction (matric) tension; for extreme values of $EC_{se} \geq 3$ dS m^{-1}, the osmotic potential reached values above 220 kPa, which is much higher than those registered by the tensiometers (soil tension, Figure 1).

Planting response: effects of nursery fertilization

The survival of non or lowly fertilized (1.5 g L^{-1} 9-13-18) plants was significantly lower than that of plants receiving higher nursery fertilization rates, reflecting the superior performance of nutrient-loaded seedlings (Oliet *et al.,* 2013). Under Mediterranean conditions, N-loaded seedlings develop deeper root systems and frequently survive better after planting (Villar-Salvador *et al.,* 2012). This rooting could explain the superior survival that was found at a 16-8-9 formulation for both rates, despite the fact that the P and K contents are lower than that of the 9-13-18 formulation (Table 1). Significant differences among the fertilization treatments in our study despite irrigation reduced the planting check, indicating that certain levels of saline stress discriminate among nursery stock types with regards to survival. The similarities in certain mechanisms of saline stress resistance with drought stress resistance (Dawalibi *et al.,* 2015) could explain common patterns of nursery fertilization responses to survival under irrigated and non-irrigated conditions (Oliet *et al.,* 2005). In addition, high nutrient tissue concentrations can affect plant tolerance to salinity because of the important role of essential nutrients in adapting the osmotic potential of cells, the synthesis of protective proteins (Schulze *et al*., 2005) or even reducing oxidative stress caused by salt (Cakmak, 2005). Moreover, the primary differences are related to the non-fertilized treatment, in which only 18.2 ± 4.5 % survived when it was not irrigated (Oliet *et al.,* 2005) in comparison with 42.9±7.6 % survival when irrigated (current study). This result underscores the importance of nutrient reserves for survival under harsh conditions.

The growth rate of seedlings that were fertilized with 1.5 g L^{-1} of 9-13-18 formulation was as low as that of non-fertilized seedlings (when raised in the nursery with no nutrient supply), revealing the nutritional insufficiency of the former treatment. Under no irrigation, the differences in the post-planting heights between low or non-fertilized and highly fertilized *A. salicina* seedlings in the nursery vanished after nine years (Oliet *et al.,* 2005). In many studies, larger seedlings tend to maintain a size advantage over time in comparison with smaller seedlings (Rose and Ketchum 2003; Haase *et al.,* 2006), and others have reported that the differences faded after a few years (Oliet *et al.,* 2009). The lack of consistency between these results, apart from the differences in study duration, are associated with variability in the height growth response to a complex interaction between seedling attributes (size and nutritional status) and site characteristics such as soil fertility, drought, and competition (South *et al.,* 2001; South *et al.,* 2005; Oliet *et al.,* 2009; Puértolas *et al.,* 2012). It is particularly interesting to emphasize how, under our conditions, a small increase in fertilizer applications in the nursery (from 1.5 to 3.25 g·L^{-1} of 9-13-18) provoked a 0.82 m difference in height after nine years in a plantation, and it seemed to increase or at least be maintained throughout the years in an anamorphic pattern (Logan and Shiver, 2006).

Planting response: effects of tree shelters

Tree shelters marginally improved the survival of *A. salicina* at the third year after planting and also towards the end of the trial (Table 2), suggesting that this species could benefit from protection. A similar result was found for non-irrigated seedlings in a simultaneous experiment under drought (Oliet *et al.,* 2005). Although *A. salicina* is considered a pioneer species that is able to establish itself in harsh areas (Grigg and Mulligan, 1999; Jeddi *et al.,* 2009), in our experiment, the shelters may have provided some continuous benefits by minimizing the transpirational demand of protected foliage associated with intense drying winds in the area (Bergez and Dupraz, 1997), especially after the third year when both the soil salinity and water tension was increased (Figures 1 and 2).

Most significant differences in the heights occurred when the mean lengths of protected shoots were below or starting to exceed the lengths of the shelters. During this time (around the first two years), the height was positively influenced by light reductions within the tubes that did not affect the growth in terms of diameter. Therefore, the light reduction within this shelter is not limiting the shoot growth during the first three-four years of planting because no allocation tradeoff between height and diameter growth was found. This response can be considered as a phototropic stimulus during the first seasons after planting rather than a reduction of resources (Devine and Harrington, 2008), and it is consistent with the marginal improvement in the survival of sheltered seedlings. Furthermore, the reduced height development in non-protected seedlings during the first year may be associated with transplanting stress as caused by desiccation in the very windy conditions of the experimental field. The reduction in the height growth rate of sheltered seedlings once the plant reached the top of the shelter can be explained by a new stress that was provoked by the transition between sheltered and unsheltered conditions, as was also observed in other studies (Oliet *et al.,* 2000) and during the simultaneous non-irrigation experiment (Oliet *et al.,* 2005). Interestingly, the height differences subsided in the fourth-fifth year, and under the non-irrigated conditions for a simultaneous experiment, the heights of both treatments never converged (Oliet *et al.,* 2005). As often occurs with fast-growing species (Ponder, 2003), the size convergence of sheltered and unsheltered trees can be hastened by accelerating growth treatments such as irrigation. In our case, after the height gains of sheltered trees had vanished, the trend seemed to be shifting, with sheltered seedlings falling below those of the control. This pattern of null or negative gain responses in the height to silvicultural treatments at mid-term has been described by other authors (Logan and Shiver, 2006), and it is the opposite of that found for some nursery fertilization treatments in our study. By contrast, differences in stem diameters between protected and non-protected trees increased with time (especially after the third year of planting), which also occurred under non-irrigated conditions (Oliet *et al.,* 2005). Because the shelters were not removed during our study, the continuous dynamic pressure on the basal stem provoked by the strong winds in the area enhanced the diameter growth of non-protected seedlings in comparison with protected seedlings (Coutand *et al.,* 2008). The sturdiness quotient is an important morphological indicator of tree stability, and it is of interest when evaluating differences between sheltered and non-sheltered plants (Johansson, 2004). As a consequence, differences in the sturdiness quotient were high in comparison with other long-term studies (Oliet *et al.,* 2000; Johansson, 2004). However, after nine years, the trunk development of trees in shelters was sufficient to support the canopy weight and could be removed (personal observation).

Conclusions and management implications for future plantations

Our results from nine years of experiments emphasize the importance of nursery fertilization in the medium-to-long-term development of *A. salicina* under dry conditions with saline irrigation. Nursery fertilization is a highly cost-effective approach, given that a relatively small increase in the rate multiplies during post-planting growth. A minimum of 83.7 mg N per seedling, which was applied as CRF and formulated as (N-P-K) 9-13-18 or 16-8-9, is needed to optimize survival and growth. Despite the windy conditions of the area, the use of tree shelters marginally improves survival under irrigation, but it does not affect the height growth and reduces the diameter in comparison with non-protected plants. The tree shelters seem to be more effective at promoting survival and growth under non-irrigated conditions. Therefore, if irrigation is planned, the use of tree shelters could be omitted to improve operational efficiency.

In comparison with the results of non-irrigated plantations, the use of saline water under the conditions in this experiment did not considerably improve the survival of the species, but it had a positive impact on the growth of surviving *A. salicina* trees. Given the ability of this species to improve microhabitats and soil conditions, the use of low-quality irrigation water can accelerate this restoration process (Jeddi *et al.,* 2009), although increases in soil salinity associated with irrigation must be kept under maximum thresholds.

Our results suggest that monitoring plantations at mid-term provides extremely useful information regarding the effects of nursery practices and stock quality variables. It also provides information about cultural treatments that are applied in the field, or responses following planting, and should therefore be emphasized in experimental afforestation and reforestation trials.

The marked influence of strong winds in this area affects plant responses to treatments, and it emphasizes the fact that no general rules can be set for the application of postplanting treatments. However, a previous study of environmental conditions and the functional characteristics of the species must be conducted instead.

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Resumen

J.A. Oliet, R. Planelles, F. Artero y J.M. Domingo-Santos. 2016. Establecimiento de *Acacia salicina* bajo condiciones mediterráneas secas: efectos a medio plazo de la fertilización en vivero y de los protectores de árboles en un experimento con riego salino. Cien. Inv. Agr. 43(1):69-84. La restauración de áreas secas del área mediterránea es una tarea desafiante, ya que las duras condiciones abióticas impiden corregir el proceso retroalimentado de la degradación. La restauración activa mediante plantación es necesaria para detener dicho proceso. En esta trabajo se examina la influencia de la fertilización en vivero (dos formulaciones de fertilizante de liberación controlada aplicadas en dos dosis cada una) y de la protección de los árboles tras la plantación (empleando tubos protectores) sobre la respuesta a nueve años de *Acacia salicina*, aplicando riego con agua salina de baja calidad. La supervivencia global al final del periodo de estudio fue del 58,2%, con valores de la conductividad eléctrica del extracto de saturación del suelo después de nueve años de 5.4 $dS{\cdot}m^{-1}$. La supervivencia y el crecimiento en altura fue superior para los árboles fertilizados con dosis mayores de 1,5 $g{\cdot}L^{-1}$ de 9-13-18, aunque las diferencias en supervivencia se tornaron significativas sólo a partir del séptimo año. El diámetro basal del tallo (DBT) de las plantas fertilizadas con las dosis más altas en vivero fue significativamente mayor que el de las fertilizadas a dosis menores durante los dos primeros años, aunque las diferencias se desvanecieron posteriormente. Las plantas protegidas con tubo protector tuvieron una supervivencia marginalmente superior, un crecimiento más rápido durante los cuatro primeros años y un menor DBT después del tercer año de plantación que las plantas no protegidas. En comparación con un estudio paralelo, realizado bajo condiciones de no riego, dicho factor redujo algunas diferencias entre tratamientos, pero incrementó otras. Estos resultados ponen de manifiesto la importancia del tamaño de la planta y de su estado nutricional de las plantas producidas en vivero, siendo las plantas altamente fertilizadas las que manifestaron una respuesta superior. Los estudios a largo plazo son cruciales para incrementar nuestra comprensión del comportamiento de las plantas y suministrar así mejores fundamentos para la recomendación de tratamientos.

Palabras clave: Calidad de planta, nutrición en plantas de vivero, plantación, restauración, tubos protectores.

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