Effects of Nursery Irrigation on Postplanting Root Dynamics of Lotus creticus in Semiarid Field Conditions

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Additional index words
Postplanting Root Dynamics of Lotus creticus, nursery irrigation, semiarid field conditions, root growth, revegetation

Abstract. The influence of two irrigation treatments during nursery production on the post-transplant development of Lotus creticus subsp. cytisoides was studied. The treatments lasted 96 days and consisted of irrigating 2 days/week with a total of 2.3 L of water per plant over the whole nursery period (T-2) or irrigating six days per week with a total of 7 L of water per plant (T-6). T-2 plants had greater root length: shoot length ratio and higher percentage of brown roots, an indicator of more resistance to post-transplant stress. Minirhizotrons revealed more active root growth in the surface soil of the T-2 plants, although the plants of both treatments rapidly colonized the whole soil depth studied (0–160 cm). T-2 plants had greater stem length growth per unit of soil area covered.

Water shortage, extreme temperatures, and soil salinization are the major limiting factors, in this order of importance, for plant growth in arid and semiarid regions (Zhang et al., 1996).

Use of indigenous Mediterranean species in xeroscaping, landscaping and revegetation projects is of growing interest because of their capacity to adapt to adverse environmental conditions and because of their water-saving potential. Among such species, Lotus creticus L., a member of the Fabaceae and a native of the Mediterranean coast, is considered a good alternative to the species traditionally used for the Mediterranean coast, is considered a good alternative to the species traditionally used for soil cover because of its rapid growth and water-use efficiency (Bañón et al., 2001; Franco et al., 2001; Sánchez-Blanco et al. 1998; Vignolio et al., 2000).

Some species can be made more drought-resistant if they are exposed to periods of controlled drought, low temperatures in the nursery, or both before they are transplanted (van den Driessche 1991a; 1991b). Plant size at the time of transplanting may influence subsequent development, soil-covering capacity and, therefore, ability to protect against soil erosion (Savé et al., 1996). Irrigation regime during nursery production affects the hardening of seedlings and post-transplant growth. The influence of irrigation regimes in the nursery on post-transplant root development in containers has been determined in Lotus creticus (Franco et al., 2001); however, field studies of root system dynamics are especially difficult because they require successive and nondestructive measurements. Minirhizotrons allow direct periodic observation of root systems (Box, 1996; Franco and Abrisqueta, 1997; McMichael and Taylor, 1987).

The objective of this study was to ascertain the extent to which two nursery irrigation treatments influence root and shoot development of Lotus creticus plants after transplanting to semiarid field conditions.

Materials and Methods

Plant material and study site. The experiment was conducted in the southeastern part of Murcia province (SE Spain) on the Mediterranean coast (lat. 37°47’N; long. 0°54’W) and used the autochthonous Lotus creticus L. subsp. cytisoides (L.) Arcang.

The climate of the area is typically Mediterranean with mild winters, low rainfall, and very hot, dry summers. Rainfall is characterized by extreme spatial variation, low overall value and a tendency to fall as storms. Daily measurements of rainfall were made in a field meteorological station located at the site. During the period studied (May 1997 to Aug. 1998) 206 mm of rain fell, none during the summer months (Fig. 1).

The soil was a Typic Haplocalcid, with a silt loam texture (24.4% clay, 35.9% silt, and 34.7% sand), and showed no variation throughout the depth studied (0–160 cm). Water retention properties within the plant root zone appeared to be relatively uniform.

Nursery conditions. The plants were previously exposed in the nursery to two irrigation treatments lasting 96 d right before transplanting. Seedlings of Lotus creticus were pot-grown in a greenhouse covered with 200-μm thick transparent polyethylene. Each plant was potted in early February into a 625-mL plastic pot (10.5 cm diameter, 7.5 cm height) filled with a mixture of silica sand, white peat and black peat (1:0.5:0.5, v/v) amended with Osmocote Plus (The Scotts International B.V., Heerlen, Netherlands) 15N–4.9P–10.8K (3.7 g·kg–1 substrate). Physical characteristics of the medium were: bulk density, 850 kg·m–3; total pore space, 66% by volume; volume of air after irrigation, 18% by volume; waterholding capacity, 4.5 g·g–1 dry weight; easily available water, 23% by volume.

The greenhouse was not heated and the following conditions prevailed: minimum temperature 2 to 9 °C and maximum 18 to 38 °C, minimum relative humidity (RH) 19% to 55%.

Fig. 1. Monthly rainfall in mm during experimental period. The numbers on vertical columns indicate days with rainfall.
and maximum 79% to 95%. The greenhouse had only natural light. The average of the midday photosynthetically active radiation (PAR) inside the greenhouse was 1710 µmol·m⁻²·s⁻¹.

Drip irrigation was used, with a 2 L/h pressure-compensated emitter per plant. (Netatin, Kibbutz Hatzerim, Hanegew, Israel). Two irrigation treatments were utilized: T-6, plants irrigated 6 d a week to container capacity (leaching fraction = 20%); and T-2, plants irrigated twice a week. All plants were irrigated just once a day and received the same volume of water at each irrigation. The total water applied to T-6 and T-2 plants over the whole nursery period (96 d) was 7 and 2.3 L/plnt, respectively.

Each irrigation treatment comprised 120 plants (one plant per pot) divided into three randomly distributed plots of 40 plants, each plot being one replicate.

**Root and shoot growth in nursery.** At the end of the nursery period, six randomly selected plants per replicate were analyzed. Root systems were washed and filtered through a 0.5-mm mesh screen. Total root length was determined using the line-intersect method (Newman, 1966). White and brown roots were measured separately. Shoot extension was measured.

**Transplanting to field.** Prior to their transplanting on 12 May 1997, all plants were watered abundantly in the greenhouse and, after transplanting, received 100 L·m⁻² water distributed over a period of 5 d. One month later, they received another 50 L·m⁻² and then no other irrigation during growth except that derived from natural rainfall (Fig. 1).

A preplant application of herbicide glufosinate (15% by volume) (AgrEvo, Valencia, Spain) at an a.i. rate of 1.2 L/ha following by an early hand weeding was used to controlled weeds throughout the course of the experiment.

**Evaluation with minirhizotrons.** There were three replications, with a row of 10 plants/treatment. The experiment design was totally randomized.

The minirhizotron used for the root growth study was that described by Abrisqueta et al. (1994). One minirhizotron tube was placed just under each plant row. Round acrylic tubes, 2-m long, 80-mm external diameter, and 74-mm internal diameter, were permanently installed at a 66° angle to the soil surface to prevent abnormal growth of the roots at the tube-soil interface (McMichael and Taylor, 1987). The total length of buried tube was 1.75 m, reaching a total depth of 1.6 m. The part of the tube protruding from the soil surface was closed with a rubber stopper and covered with a black plastic sheet and an insulating material to prevent light from entering the tube and to prevent it from becoming hot, both of which would have favored the absence of roots near the tube near the soil surface (Franco and Abrisqueta, 1997; McMichael and Taylor, 1987).

The tubes were installed on 9 May 1997. The plants were transplanted on 12 May 1997 and root counting started on 30 May. Roots were observed by means of a magnifying lens made out of a photographic lens (Will Wetzlar Wilon 1:4.5/50) and a microscope eye-piece (Carl Zeiss, Kpl W 12.5 mm) connected together by sliding PVC tubes for focusing (Franco, 1993).

Fifty-one measurements were made between 30 May 1997 and 22 Aug. 1998, the first 36 with a frequency of once per week and the last 15 at two-week intervals.

Following the method of Upchurch and Ritchie (1983), all the roots were counted in each 5-cm tube section. For each individual root, one count was recorded; branched roots received one count for the primary root and an additional count for each branch. Data were then grouped for each of four sections, corresponding about to seven layers in the soil: 0–23 cm, 23–46 cm, 46–69 cm, 69–92 cm, 92–115 cm, 115–138 cm, and 138–160 cm. The length of root per unit of soil volume was obtained by applying the formula used by Upchurch and Ritchie (1983):

\[
R.L.D. = N \cdot d \cdot A^{-1} \cdot d^{-1}
\]

where R.L.D. = the root length density (cm·cm⁻³ soil), \(N\) = the number of roots observed in each tube section, \(A\) = the area of the tube outer wall in the given section (cm²), and \(d\) = the tube external diameter (cm). The tube diameter is retained in the equation for dimensional consistency.

**Measurement of soil water content.** Changes in soil water content with depth were determined weekly by time domain reflectometry (Moisture Point, model MP-917; Environmental Sensors, Victoria, Canada). The soil water content was monitored every 0.5 cm, 92–115 cm, 115–138 cm, and 138–160 cm. The length of root per unit of soil volume was obtained by applying the formula used by Upchurch and Ritchie (1983):

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**Results and Discussion**

At the end of the nursery period (Table 1), the plants had similar total root lengths regardless of irrigation regime. Nursery irrigation regime had a considerable influence on the percentage of brown roots, which was lower in T-6 plants. The most watered plants (T-6) had the longest shoots and the lowest root length : shoot length ratio. In a study of pine (Pinus contorta Doug. ex Loud.) seedlings, van den Driessche (1991a) observed that an increase in temperature lowered the root : shoot ratio, although, unlike in our experiment, the ratio was not altered by the irrigation rate since a reduction in amount of water provided reduced both shoot and root growth. The hardening of roots, as revealed by the increased percentage of brown roots with lower irrigation rates promoted better resistance to drought and stress conditions following planting of 30 cm, from 0 to 150 cm depth. Three replicates were used.

**Statistical analysis.** Transformations based on Taylor’s power law (Glenn et al., 1987) were used to stabilize the variance of root count data and a trial-and-error approach was used to develop transformations that minimized the correlation of variance and mean (Franco et al., 1995). All sets of data were subjected to analysis of variance (ANOVA) and a least significant difference (LSD) test was used to check significance using Statgraphics version 7.0 (STSC, Rockville, Md.). Standard errors of the means from no transformed data (SE) are represented in the figures.

Table 1. Total root length, brown root length (as percentage of total root length), total shoot length, and root : shoot ratio of Lotus creticus pot-grown seedlings at the end of the nursery period as influenced by two nursery irrigation treatments: T-2, irrigated 2 d/week; T-6, irrigated 6 d/week.

| Irrigation treatment | Total root length (cm) | Brown root length (%) | Total shoot length (cm) | Root : shoot ratio |
|----------------------|------------------------|-----------------------|-------------------------|-------------------|
| T-2                  | 668 a                  | 46 a                  | 72 b                    | 8.2 a             |
| T-6                  | 692 a                  | 5 b                   | 174 a                   | 3.8 b             |

*Mean separation for values in the same column by LSD at P < 0.05.

Fig. 2. Post-transplant evolution of root length density (R.L.D.) for total soil profile (0–160 cm depth) of plants as influenced by two nursery irrigation treatments: T-2, irrigated 2 d/week; T-6, irrigated 6 d/week. Vertical lines indicate se of the means when larger than symbols (n=3).
Lotus creticus in a growth chamber (Franco et al. 2001). Other authors (Leskovar, 1998; Leskovar and Stoffella, 1995) have also shown that irrigation regime provided during the nursery stage affects seedling root characteristics. The onset of browning is associated with suberization of the exodermis or might reflect a metacutization process (Bloomfield et al., 1996), which is a process of lignification and suberization resulting in a resting root that is protected against significant fluctuations in environmental conditions (e.g., drought) and capable of regrowth when conditions are ameliorated.

The post-transplant development of the root system through the whole soil profile (Fig. 2) was similar for the plants of both treatments. Root development at the various depths (Fig. 3) was similar for the plants of both treatments except in the three uppermost soil levels, where two different tendencies could be observed: a first stage (first 7 months) during which the plants of T-6 showed a higher R.L.D. than T-2 plants between 23 and 69 cm depth; and a second stage during which the situation was the reverse, especially between soil surface and 46 cm depth. The existence of these stages was perhaps due to the rainfall regime (Fig. 1) and to the irrigation water the plants received in the middle of May and June 1997 (Fig. 4). The water provided twice after transplanting and the rain, which fell in autumn (an abundant 65.6 mm in September) represented an important contribution to the water content of the soil and might explain why the plants of T-2 did not show their full potential adaptation, after hardening in the nursery, during the first 7 months of the experiment, while the T-6 plants developed without problems.

With the arrival of more adverse conditions (drier and hotter) in March 1998, the T-2 plants responded better, with their roots showing greater development than the roots of T-6 plants. Prior to flowering (spring and summer), R.L.D. fell in both cases, although slightly earlier (March) and reaching lower values in T-6 plants (Fig. 2).

Significant differences in R.L.D. only were observed at 0–23 and 23–46 cm (>0.01 and >0.05, respectively). In the uppermost level, the root development of T-2 plants was greater throughout the experimental period. This was especially so from October onward, when root density was double that of T-6 on several occasions. This level had the lowest water content (Fig. 4), so that the roots of more hardened plants develop better. This is an important observation since it is precisely in this horizon that the development of a strong root system is needed to reduce erosion. Franco et al. (2001) also found that the harsher the conditions after transplantation in a growth chamber (less water in the establishment irrigation), the more evident the positive effect of hardening in the nursery; the most stressed plants in the nursery (less water and no heating) showing greater and more rapid root growth than the less stressed plants.

The maximum R.L.D. values were observed in intermediate levels of the soil profile.
values of around 0.08 cm·cm–3, which is higher
barely 2 months, the plants of both treatments
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the first month in the uppermost levels. After
barely 2 months, the plants of both treatments had
colonised the deepest level with R.L.D. values of
around 0.08 cm·cm–3, which is higher
than other species such as Cynodon dactilon (L.) Pers. (Vignolio et al., 2000) considering
the growth conditions.

T-2 plants had equal or greater post-
transplant stem length than T-6 plants (Fig.
5A). T-2 plants were slightly more luxuriant
(higher number of stems/m2) and therefore
covered the soil better (Fig. 5B).

This paper was not designed to compare the
soil cover surface for the plants as influenced by two
treatments Fig. 2). Vertical lines indicate SE of the means when larger
than symbols (n=3).

between 23 and 92 cm of depth (mean R.L.D.
of 0.15 cm·cm –3). Maximum growth occurred
during Feb.–Apr. 1998 for T-2 plants, while
maximum growth in T-6 plants was in Jan. and

The regime involving the least water in the
nursery period produced the plants best adapted
to post-transplant stress. T-2 plants had a greater
root length : shoot length ratio and higher
percentage of brown roots; however, previous
hardening of the plants in the nursery did not
lead to great differences in postplanting root
growth when abundant water was provided after
transplanting. Only in the uppermost horizon with its lower humidity did the plants
hardened in the nursery show better root de-
velopment.

The rapid above ground growth of Lotus creticus indicates that this species is very
suitable as a soil cover. The low irrigated
plants in the nursery had greater stem growth
for the same soil surface covered than those
plants irrigated 6 d per week and they therefore
provided a denser cover.

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