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ARLY FIELD PERFORMANCE OF DROUGHT-STRESSED SCOTS PINE (*PİNUS SYLVESTRİS* L.) SEEDLINGS

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Abstract

Scots pine (*Pinus sylvestris*) has a large natural distribution throughout the world, including semi-arid areas of Turkey, where it is being used for afforestation. Determining the drought resistance of Scots pine provenances can increase the success of afforestation efforts in semi-arid regions. In the first stage of this study, water-stress treatments were applied to ten provenances of one-year-old Scots pine seedlings in their second vegetation period (between April and November). The diameter and height of the seedlings were evaluated in the nursery in order to determine their morphology. The four drought-stress treatments consisted of once-weekly irrigation (IR1), twice-weekly irrigation (IR2-Control), biweekly irrigation (IR3) and open field conditions (IR4). Later, the water-stressed seedlings were planted in a semi-arid district in Bayburt, Turkey, and their survival and growth performances were evaluated over a five-year period. The nursery study showed that drought stress and provenance as well as the interaction of the two significantly affected the morphological characteristics of the seedlings. Under water-stress conditions, the best growth performance was found in the Dokurcun, Degirmendere and Dirgine provenance seedlings. Water-stress and provenance factors and their interaction also affected the open field performance of the seedlings, where the Degirmendere, Dirgine and Dokurcun provenances again exhibited the best performance. Consequently, these Scots pine provenances can be recommended for afforestation sites having conditions similar to those of the study site.

Key words: Provenance, Survival, Morphology, Afforestation.

Abbreviations

IR1: irrigation once a week
IR2: irrigation twice a week (control)
IR3: irrigation biweekly
IR4: open field
RCD: root-collar
SH: seedling height
S1: survival percent at the end of the first growing season (six months after planting)
S2: survival percent one year after planting,
S3: survival percent five years after planting
DI: diameter increment
HI: height increment

Introduction

Afforestation success in semi-arid regions depends mainly on the usage of drought-resistant species and provenances. Drought is a significant limiting factor for afforestation (Garau *et al.,* 2008). Understanding seedling responses to drought is essential for successful afforestation in semi-arid regions (Elfeel & Mohamed, 2011). Drought stress is a significant cause of seedling mortality in both natural and artificial regeneration applications. Lack of water causes a decrease in height and diameter growth by negatively affecting bud formation, leaf and shoot growth, diameter increment, early leaf fall and branching (Kozlowski & Pallardy, 2002; Kulac *et al*., 2012).

Success cannot be achieved in semi-arid land afforestation unless seedling physiology allows it. For this reason, seedlings must be resistant to stress conditions (Genc *et al*., 2005). There are many environmental stress factors affecting seedlings planted in arid land. These factors reduce seedling survival and growth. The morphological and physiological characteristics of seedlings play crucial roles in seedling resistance to environmental stress factors (Hobbs *et al*., 1987; Grosnickle & Folk, 1993).

Many studies have been carried out on the morphological, physiological and genetic variations of Scots pine, including isoenzyme analyses (Prus-Glowacki & Stephan, 1994; Turna, 2003), geographical variations (Shutyaev & Giertych, 2000), phenotype and genetic variations (Harju *et al*., 1996), drought stress (Sonesson & Eriksson, 2000) and cold stress (Nilsson & Walfridsson, 1995). However there have been no studies to date dealing with the development of drought-stressed Scots pine seedlings in semi-arid regions.

For the present study, it was hypothesised that Scots pine seedlings subjected to drought stress would have high survival rates and growth performance in semi-arid and arid land conditions. In addition, the regions of provenance might significantly affect seedling responses to drought. Moreover, an interactive effect on seedling survival might exist between provenance and pre-treatment. Thus, in order to investigate their growth performance, Scots pine seedlings from ten provenances were first subjected to stress treatment in the nursery. They were then planted in semi-arid land in the Aydıntepe district of Bayburt Province, Turkey, and the five-year field performance of the seedlings was evaluated. The aim of this study was to determine the effects of drought stress on the seedling morphology of the Scots pine provenances as well as on their subsequent field performance in semi-arid afforestation land conditions.

Materials and Methods

Seed supply: In rich seed years previous to the study, Scots pine seeds were collected from ten different seed stands representing the natural distribution of Scots pine in Turkey (Table 1, Fig. 1). The seeds were stored in a refrigerator at +4°C until the beginning of the study.

Table 1. Information about seed stands where seeds were collected (10-years data).

Number	Provenance	Latitude	Longitude	Altitude (m)	Max. Temp.	Min. Temp.	Av. Rainfall
1.*	Vezirköpru	41° 10' 00"	35° 01' 45"	1200	38.1	-10.1	536.1
2.	Dirgine	41° 02' 00"	31° 57' 38"	900	35.3	-10.5	550.4
3.	Kastamonu-Daday	41° 22' 18"	33° 28' 54"	1250	37.4	-14.2	524.1
4.	Aladag	40° 38' 00"	31° 41' 30"	1400	36.3	-12.4	557.6
5.	Kartalkaya	40° 35' 40"	31° 42' 30"	1500	35	-14.1	560.5
6.	Akyazı-Dokurcun	40° 37' 30"	30° 50' 00"	1450	36.1	-10.4	450.3
7.	Degirmendere	39° 58' 20"	31° 07' 18"	1550	36.7	-14.3	401.4
8.	Kars-Sarıkamıs	40° 18' 00"	42° 37' 30"	2350	35	-31.4	582
9.	Mesudiye-Arpaalan	40° 22' 45"	37° 52' 30"	1650	31.9	-11.8	748.5
10.	Artvin-Kılıckaya	40° 31' 40"	32° 08' 00"	2050	32.2	-3.7	1387.7

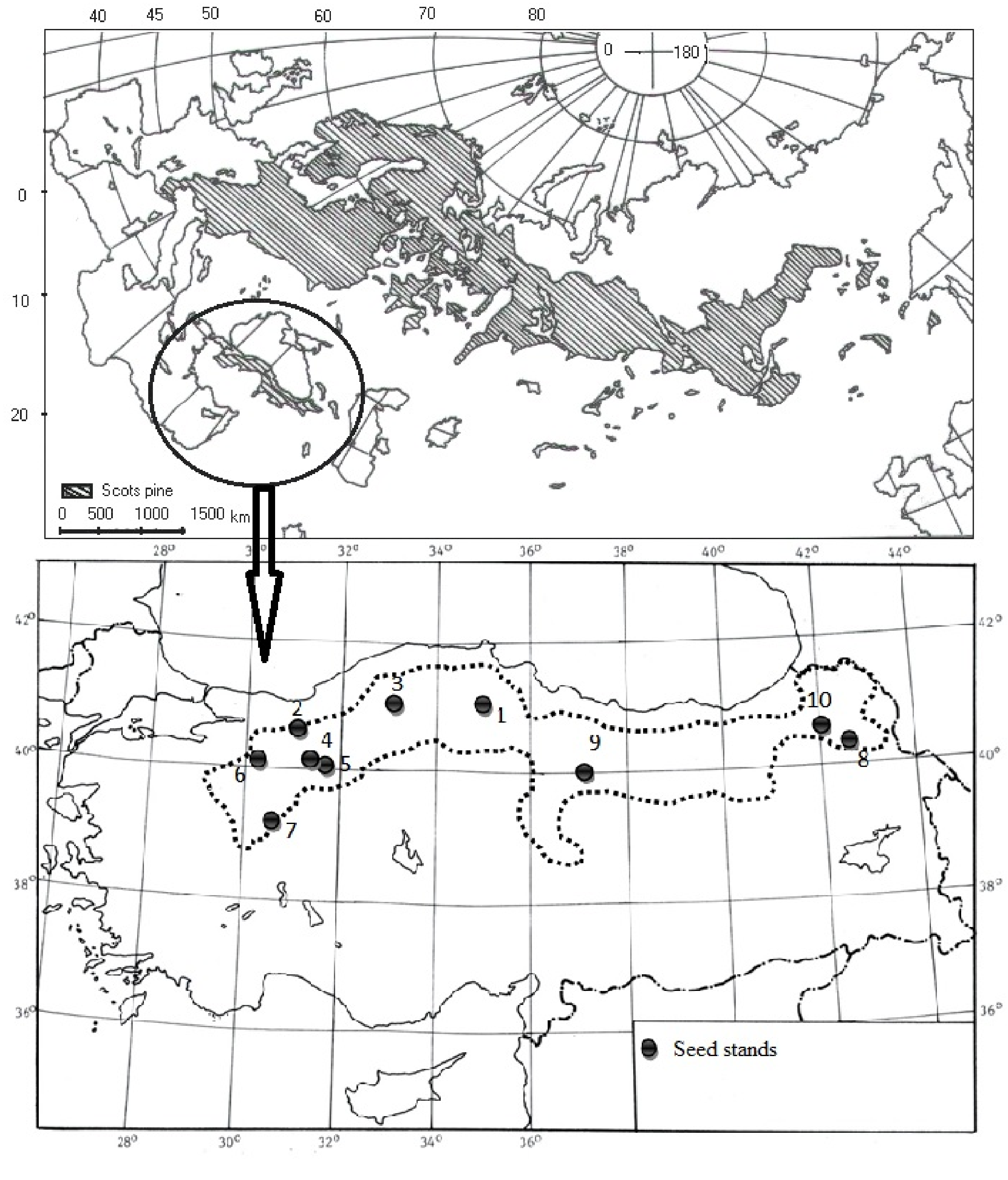

Fig. 1. The location of seed collection stands in Turkey.

Seedling materials: The seeds were sown in 10 × 20 cm polyethylene tubes at the Research Nursery in Trabzon in April 2006. The growth media consisted of 40% forest soil, 40% Finland peat, and 20% Styrofoam mix. A total of 8000 one-year-old seedlings were produced in the 2006 growing season. According to climate data from the Turkish State Meteorological Service, Trabzon, where the nursery experiment took place, is a semi-humid, mesothermal area which experiences a moderate water deficit during the summer and has a climate influenced by the sea. The annual rainfall, temperature, and humidity values of the growth environment over the ten-year period prior to the experiment were 808 mm, 14.5°C, and 75%, respectively. In addition, the mean temperature of Trabzon during the vegetation period was 17.3°C with a water deficit occurring in July. The annual rainfall, temperature, and humidity values of the growth environment in 2006 were 739 mm, 15.8°C, and 71%, respectively.

Nursery study: In the second vegetation period (2007), water-stress treatments were applied on one-year-old seedlings of ten different provenances. A split-split-plot design with three blocks was used in the nursery study. In each block, the main plot was the water-stress treatment and the subplot was the provenance. The three main plots were covered with plastic greenhouse tenting (2.5 m above ground level) and one plot in each block was left open. Gravel was spread under the covered blocks in order to prevent the seedling tubes from coming in contact with the ground. Forty seedlings from each provenance were placed in each subplot. A total of 4800 seedlings (3 blocks × 4 main/ drought-stress plots × 10 subplots/provenances × 40 seedlings) were used in the nursery study. Drought-stress treatments included four different irrigation levels: once-weekly (IR1), twice-weekly (IR2-Control), biweekly (IR3), and open field (IR4). Half of the seedlings, 2400, were used for the measurements (water potential, etc.). The other 2400 were planted in the field after drought-stress treatments. No fertilizer supplements were used. Weed control was done once a week.

All the seedlings were irrigated with 50 ml of water, with up to75 ml given in hot periods. Annually, the IR1, IR2 and IR3 seedlings received 300 to 450, 600 to 700, and 125 to 200 mm of irrigation water, respectively. The IR4 seedlings received 800 mm of natural rainfall annually. Water potential was determined by a pressure chamber (PMS Instruments, Model 1000) immediately prior to irrigations. According to predawn water-potential measurements of stems during the vegetation period, the water potential of the IR2, IR1, and IR3 seedlings ranged from -1 to -8, -8 to -12, and -12 bar and above, respectively. The water potential was kept within the desired range by adjusting the amount of water (0 to 75 mm range) given to the seedlings, whereas for the IR4 seedlings, the water potential varied from -9 to -29 bar during the vegetation period in summer.

At the end of the second vegetation period, measurements of root-collar diameter (RCD) and seedling height (SH) were determined for a total of 2400 seedlings (20 seedlings from each subplot in all blocks). The diameter and height of the seedlings were measured with a digital calliper (0.1 mm) and a rule (0.1 cm), respectively. These measurements were accepted as the starting values of the field study.

Field study: In May 2008, the water-stressed seedlings were planted in a semi-arid site (Aydıntepe District in Bayburt Province, 40° 23' N, 40° 07' E, 1600 m), having a northeast aspect and a 15% slope. The soil had a sandy-loam texture and a depth of 150 cm. Based on long-term climate data obtained from the Bayburt Meteorology Station (40° 15' N, 40° 14' E, 1584 m), the mean annual temperature, rainfall, and relative humidity were 10.5°C, 364 mm and 52%, respectively. According to climate data from the Turkish State Meteorological Service, Bayburt is a semi-arid, low-humid, microthermal location with a moderate level of water excess during winter and under the effects of an inland climate. In addition, the mean temperature of Bayburt during the vegetation period was 19.1°C, with the water deficit occurring between July and September. The mean rainfall and temperature values of the vegetation period (daytime temperature > 10°C, April to October) were 246 mm and 17.6°C, respectively. The lowest mean temperature value was -12.9°C in January, while the highest mean temperature value was 29.7°C in July. The study site is semi-arid with a water deficit lasting approximately four months, between mid-May and mid-September (Fig. 2).

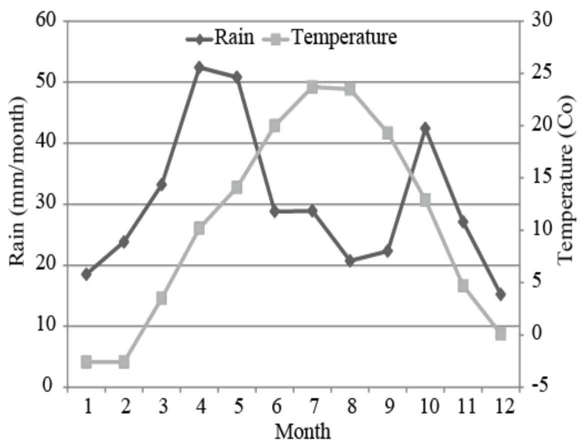

Fig. 2. Walter climatic diagram for Bayburt Meteorological Station (40° 15' N, 40° 14' E, 1584 m).

Terraces were prepared parallel to contour lines, with a 2-metre distance between terraces. A plough attached to a tractor was used for terrace building. A split-split-plot design with three blocks was used in the field study. The main plot and the subplots were drought stress and provenance, respectively. In this study, in March 2008, 20 seedlings were planted in each subplot in all blocks, a total of 2400 seedlings. The seedlings were planted by hand hoe with 2 × 2 m spacing.

The survival of the seedlings was determined one and five years after planting. The RCD and SH were measured in all seedlings after five years of growth. The diameter and height measurements of the seedlings were measured with a digital calliper (0.1 mm) and a rule (0.1 cm), respectively. The nursery measurements of the water-stressed seedlings were accepted as the initial RCD and SH values for the field study. The diameter and height increments were determined by deducting the initial values from the values at the end of the four following years.

Statistical analyses: Analyses of variance (ANOVA) (p<0.05) were performed to determine the effects of drought stress, provenance and their interactions on the morphological characteristics of the seedlings (RCD, SH, RCD increment, SH increment) and their survival (p<0.05). The Duncan test was used to compare variable means (α = 0.05). Arcsin conversions were made for survival before variance analysis. Furthermore, normality and homogeneity of the variances were checked before ANOVA (Ozdamar, 1999).

Results

Nursery study (stress treatments): The analyses of variance showed that drought stress, provenance and the interaction of the two had significant effects on the RCD and SH of the seedlings at the end of the second vegetation period (p<0.05). Mean values for each factor are shown in Table 2.

As seen in Table 2, the highest mean RCD value of the one-year-old seedlings was found in the control (IR2) seedlings (5.7 mm) in the nursery site, while the IR3 seedlings had the lowest diameter values (3.3 mm). The increment in diameter of the IR3 seedlings was 40% less due to the drought stress.

The Dokurcun provenance seedlings had the largest RCD (4.8 mm) while those of Daday and Sarikamis provenances exhibited the smallest RCD (3.7 mm). In addition, Dokurcun provenance seedlings were nearly 20% greater in diameter than those of Daday, Sarikamis and Kılıckaya provenances (Table 2).

The IR2 seedlings showed the greatest SH (20.2 cm), in contrast to the lowest SH of the IR3 seedlings (12.8 cm). Due to water stress, the IR3 seedlings showed a 37% decrease in SH. Dokurcun provenance seedlings had the highest SH (20.2 cm), while those of Sarikamis and Daday provenances had the lowest SH. In other words, the SH for the Dokurcun provenance seedlings was 35% greater than that of Sarikamis and Daday provenance seedlings (Table 2).

The effects of *drought stress* × *provenance* interactions on RCD and SH are shown in Fig. 3. The highest RCD increments were observed for the Dirgine, Kartalkaya, Dokurcun and Degirmendere provenance seedlings in IR2, while the lowest RCD increments were found for the Sarikamis seedlings in IR3, and for those of the Sarikamis and Daday provenances in IR4. The highest SH values were found in the Dirgine, Dokurcun and Degirmendere provenance seedlings in IR2, while the lowest values were found in those of the Daday, Sarikamis and Kartalkaya provenances in IR4 (Fig. 3).

Field study: The analysis of variance results revealed that factors and factor interactions had significant effects on seedling diameter and height at the end of the 5th vegetation period.

At the end of the first vegetation period, the IR4 seedlings had the highest survival percentage (87.8%), while the IR1 group had the lowest (80.7%). Following the first and fifth year of afforestation, the IR3 group had the highest survival percentage (80.4% and 71.4%) and IR4 had the lowest (70.3% and 62.4%), as shown in Table 3.

The results of a combination of factor interactions at the end of the first vegetation period were as follows: Kartalkaya, Degirmendere and Arpalan provenance and IR4 seedlings had the highest survival percentage, while Aladag provenance and IR1 seedlings had the lowest survival percentage; first- and five-year results post-afforestation showed that Degirmendere provenance and IR2 seedlings exhibited the highest survival; Aladag provenance and IR4 seedlings had the lowest survival (Table 4). After stress treatments, the highest survival rate was observed in seedlings of Dirgine provenance.

According to five-year results, the IR2 seedlings had the highest overall mean diameter and height values (18.3 mm), while the IR4 seedlings had the lowest diameter (12.5 mm). The IR2 seedling mean diameter and height values were 32% and 26% higher, respectively, than those of the IR4 group (Table 3). The five-year diameter increments of IR1, IR2 and IR3 showed values similar to or higher than those of IR4. Seedlings that were subjected to drought stress had a greater diameter increment than seedlings that had not been subjected to drought stress. After five years of growth, the IR2 seedlings had the highest mean height values, whereas the IR4 group had the lowest. At the end of the 5th year, Dirgine, Vezirkopru and Degirmendere provenance seedlings had the highest diameter values, while those of Dirgine, Vezirkopru and Kartalkaya had the highest height values. Sarikamis and Arpaalan provenance seedlings had lower diameters and height values than those of the other provenances (Table 3). In the current study, similar results were observed for SH values.

Based on the mean differences between provenances at the end of five years, Vezirkopru provenance exhibited the maximum SH and HI values, whereas Sarikamis provenance showed the lowest height and height increment values. Differences in the DI among Dirgine, Degirmendere, and Sarikamis were insignificant, and there was no difference in the HI of Dirgiri and that of Kartalkaya (Table 3). According to combinations of factor interactions at the end of five years in IR2, statistically, all provenances showed maximum diameter increments except for Sarikamis and Kılıckaya. All provenances apart from those of Dirgine, Degirmendere and Dokurcun showed minimum diameter increments in IR4. Moreover, Arpaalan provenance showed similar diameter development and increments in IR1 (Table 4). After stress treatments, in IR3, Dokurcun, Degirmendere, and Dirgine provenances showed maximum diameter development and diameter increments, while Sarikamis and Kartalkaya had the lowest values. The DI observed after water regime IR3 may be related to drought acclimatisation of the Dokurcun, Degirmendere and Dirginine provenance seedlings.

Table 2. Effects of drought stress and provenance on seedling characteristics (standard errors in parentheses).

Factor	Level	Root collar diameter(mm)	Seedling height (cm)
Drought stress	IR1	4.1 b[1] (0.08)	16.2 b (0.37)
	IR2	5.7 a (0.12)	20.2 c (0.75)
	IR3	3.3 d (0.09)	12.8 a (0.43)
	IR4	3.6 c (0.10)	15.9 b (0.53)
Provenance	Vezirkopru	4.0 bcd (0.33)	16.4 c (0.89)
	Dirgine	4.3 ef (0.34)	18.3 d (1.63)
	Daday	3.7 a (0.27)	13.5 a (0.6)
	Aladag	3.9 abc (0.24)	15.8 c (0.66)
	Kartalkaya	4.3 def (0.36)	16.3 c (1.32)
	Dokurcun	4.8 g (0.28)	20.2 e (1.07)
	Degirmendere	4.5 f (0.3)	19.0 d (0.93)
	Sarikamis	3.7 ab (0.28)	13.2 a (0.68)
	Arpaalan	4.1 cde (0.26)	14.7 b (0.82)
	Kılıckaya	3.9 abc (0.24)	15.5 bc (0.71)

Table 3. Comparison of various seedling characteristics (S1: at the end of the first growing season, S2: one year after planting, S3: five years after planting, DI: diameter increment, HI: height increment).

Factor	Level	Survival (%)			Diameter (mm)	DI (mm)	Height (cm)	HI (cm)
		S1	S2	S3				
Drought stress	IR1	80.7 a[1]	72.9 b	66.0 c	16.1 ab	12.1a	54.5b	38.3b
	IR2	82.4 b	75.0 c	64.4 b	18.3 a	12.8a	58.0c	37.8b
	IR3	85.2 c	80.4 d	71.4 d	16.0 ab	12.7a	54.1b	41.3b
	IR4	87.8 d	70.3 a	62.1 a	12.5 c	8.9b	42.8a	26.8a
Provenance	Vezirkopru	83.1 d	78.1 f	70.0 f	16.4cd	11.7bc	49.4bc	29.2ab
	Dirgine	89.2 e	84.8 e	80.3 g	18.4 e	14.1d	59.1ef	40.8def
	Daday	91.4 g	73.2 d	64.8 d	15.4 c	11.7bc	50.9bc	37.4cde
	Aladag	64.2 a	52.8 a	44.6 a	15.2 bc	11.3b	51.1bc	35.3cde
	Kartalkaya	87.4 e	77.6 ef	67.2 e	15.0 bc	10.8b	57.5def	41.2ef
	Dokurcun	85.3 d	76.7 e	70.0 a	17.2 de	13.2cd	62.2f	45.8f
	Degirmendere	93.2 h	89.3 h	85.9 h	17.8 de	13.3cd	53.8cde	34.8bcd
	Sarikamis	77.5 b	70.2 c	50.7 b	12.8 a	9.1a	41.1a	27.9a
	Arpaalan	90.6 g	66.3 b	63.2 c	14.4 b	10.2ab	46.0ab	31.3abc
	Kılıckaya	83.2 c	77.5 ef	63.1cd	14.9 bc	10.9b	52.4cd	36.9cde

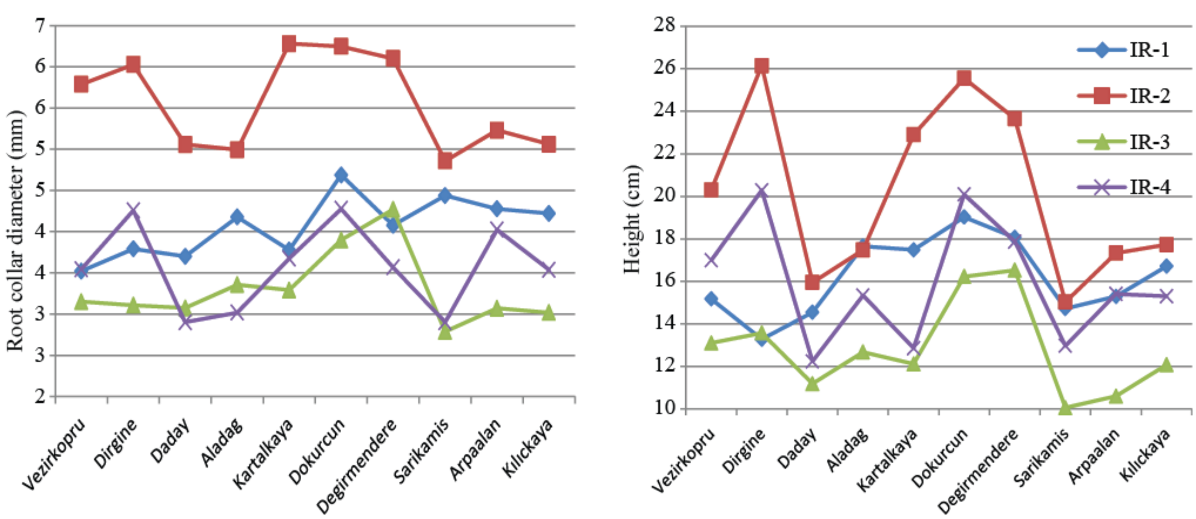

Fig. 3. Effects of drought stress × provenance interaction on SH and RCD.

Table 4. Effects of *drought stress x provenance* interaction on survival and growth (S1: six months after planting, S2: one year after planting, S3: five years after planting, DI: diameter increment, HI: height increment)

Factor		Survival (%)			Diameter and Height			
Irrigation	Provenance	S1	S2	S3	Diameter (mm)	DI (mm)	Height (cm)	HI (cm)
IR1	Vezirkopru	70.0 cd	63.3ef	50.0fg	13.5 b-f	8.8 a-f	45.1 b-g	26.0 a-e
	Dirgine	88.5jk	88.5 s	84.6rs	16.2 e-l	12.4 f-m	61.5 i-n	48.3nop
	Daday	96.7 p	90.0s	86.7stu	20.2 m-o	16.5 o	68.5 m-n	53.9 op
	Aladag	40.0 a	40.0 b	30.0 b	15.1 c-j	10.9 c-j	46.0 b-h	28.4 a-h
	Kartalkaya	80.0ef	70.0ijk	56.6 h	15.7 d-j	11.9 d-m	54.9 d-l	37.4 e-n
	Dokurcun	86.2hıl	86.2r	82.7pr	19.1 k-o	15.5m-o	63.2 j-n	48.0 m-p
	Degirmendere	84.6 h	84.6pr	80.8 op	17.2 g-n	13.2 g-o	54.0 d-l	35.9 d-n
	Sarikamis	93.8mn	64.6fg	53.1 g	14.3 b-g	9.9 b-h	48.4 c-i	33.6 c-l
	Arpaalan	80.6 f	58.0 d	58.0hi	12.7 a-e	8.4 a-e	38.7abc	23.4 a-d
	Kılıckaya	87.1ij	83.9 p	77.4 n	17.4 g-n	13.2 g-o	64.7 k-n	48.0 m-p
IR2	Vezirkopru	92.0 l	72.0jk	64.0 j	19.3 l-o	13.5 h-o	67.2lmn	46.9 l-p
	Dirgine	80.0ef	80.0no	80.0nop	20.8 n-o	14.8 k-o	67.0lmn	40.9 h-o
	Daday	84.6 h	61.5 e	38.4 c	14.7 k-o	9.6 b-g	45.6 b-g	29.6 a-i
	Aladag	68.0bc	68.0hi	64.0 j	18.8 k-o	13.8 i-o	59.6 i-n	42.1 i-o
	Kartalkaya	83.9gh	75.9 m	63.9 j	18.4 h-o	12.1 e-m	61.3 i-n	38.4 e-n
	Dokurcun	72.0 d	72.0jk	68.0 k	21.6 o	15.4 l-o	54.5 d-k	27.0 a-f
	Degirmendere	96.0 op	96.0 t	96.0 v	20.7 n-o	14.6 j-o	69.0 n	45.3 k-p
	Sarikamis	72.0 d	72.0jk	47.9ef	14.0 b-g	9.1 a-f	42.3 a-d	27.2 a-g
	Arpaalan	96.1 op	80.7 o	78.3no	18.4 i-o	13.2 g-o	58.0 g-n	40.6 g-h
	Kılıckaya	79.9ef	71.9jk	43.8 d	16.8 f-m	11.7 d-l	57.7 f-n	40.0 f-n
IR3	Vezirkopru	82.1fg	76.1 m	60.7ij	15.5 d-k	11.6 d-l	54.4 d-l	38.1 e-n
	Dirgine	95.8 op	95.8**t**	87.5 tu	19.2 l-o	16.1 n-o	59.3 h-n	45.7 k-p
	Daday	89.2 k	71.3jk	64.2 j	15.5 d-k	12.4 f-n	45.8 b-g	34.6 c-m
	Aladag	82.1fg	75.0lm	60.7ij	14.9 c-i	11.6 d-k	54.4 d-l	41.7 h-o
	Kartalkaya	85.7hı	75.0lm	64.3 j	14.0 b-g	10.7 c-i	57.4 f-n	45.3 k-p
	Dokurcun	96.2 op	88.5 s	73.1 m	18.6 j-o	15.5 m-o	68.8 mn	55.6 p
	Degirmendere	92.3lm	88.5 s	84.6rs	18.5 i-o	14.2 i-o	55.6 d-m	39.1 e-n
	Sarikamis	77.8 e	77.8mn	62.9 j	13.3 b-f	10.5 c-i	42.7 a-d	32.6 c-k
	Arpaalan	85.7hi	71.4jk	71.4klm	14.8 c-h	11.7 d-l	52.6 d-k	42.0 i-o
	Kılıckaya	85.2hi	85.2pr	85.2rst	15.9 e-j	12.9 g-o	50.1 c-j	38.1 e-n
IR4	Vezirkopru	81.8fg	72.7kl	72.7lm	11.7abc	8.2 a-d	49.5 c-i	32.5 c-k
	Dirgine	92.5lm	75.1lm	69.3kl	17.4 g-n	13.2 g-o	48.6 c-i	28.3 a-h
	Daday	95.0no	70.0ijk	70.0klm	11.1 ab	8.3 a-d	43.7 a-e	31.4 b-j
	Aladag	66.6 b	28.5 a	23.7 a	12.1 a-d	9.1 a-f	44.3 b-f	29.0 a-i
	Kartalkaya	100 r	89.5 s	84.2rs	12.2 a-d	8.5 a-e	56.5 e-n	43.7j-p
	Dokurcun	94.4 n	88.9 s	88.9 u	15.1 c-j	10.8 c-j	45.7 b-g	25.7 a-e
	Degirmendere	100 r	88.2 s	82.3pr	14.8 c-i	11.3 c-k	36.8abc	19.0 ab
	Sarikamis	66.6 b	66.6gh	38.8 c	9.7 a	6.8 ab	31.0 a	18.0 a
	Arpaalan	100 r	54.9 c	44.9 de	11.6abc	7.6abc	34.7 ab	19.3 ab
	Kılıckaya	80.7 f	69.2hij	46.1 de	9.4 a	5.8 a	36.9abc	21.6abc

According to factor interactions at the end of five years, maximum SH and height increments were observed in IR2 for seedlings of all provenances, except for those of Sarikamis, Daday and Dokurcun. Similar results were found in IR1 for the seedlings of Vezirkopru, Dirgine, Daday, and Kılıckaya provenances. After stress treatments, Vezirkopru, Dirgine and Kartalkaya seedlings showed similar results in IR3 (Table 4). The lowest SH values were observed in Sarikamis, Degirmendere, Arpaalan, Kılıckaya and Daday provenances in IR4, while the lowest SH value was determined in Sarikamis seedlings in IR3 and IR1. Based on height and SH, the Sarikamis provenance group showed the lowest development; in contrast, seedlings of Vezirkopru and Dirgine provenances showed the greatest SH. The widest diameter and tallest height development were observed in the Dirgine provenance seedlings, whereas those of Sarikamis provenance exhibited the least development.

Discussion

According to nursery studies, drought stress causes some reductions in height, diameter, and total biomass of seedlings. Various studies have shown that summer drought decreases growth in Norway spruce and Scots pine by up to 35% (Pikler & Oberhuber, 2007; Sudachkova *et al*., 2009). Moreover, in Scots pine, drought stress decreases growth and increases mortality (Eilmann *et al*., 2010), and in red pine (*Pinus brutia*) seedlings, drought stress decreases the SH of the seedlings (Akca & Yazıcı, 1999). Similar results have also been found with three semi-arid plants (*Acacia tortilis* subsp. *raddiana, Salvadora persica* and *Leptadenia pyrotechnica*) and with fava bean (*Vicia faba* L.) plants showing that drought stress affects seedling growth negatively (Elfeel & Mohamed, 2011; Hayssam *at al*., 2013). These results are in agreement with the present findings that the growth in diameter and height of Scots pine decreased with increasing stress. These findings were similar to those of Kandemir *et al*. (2010) and Shafi *et al.* (2013) with red pine and sunflower, respectively.

Survival at the end of the first vegetation period was higher than for the five years after planting. Although survival percentages after five years were generally lower, the seedlings which had been exposed to more stress (IR3) had a higher adaption ability to field conditions. Previous studies have shown that seedlings exposed to drought stress have increased drought resistance (Abrams, 1988) and a higher survival percentage (Kozlowski & Pallardy, 2002; Elfeel & Mohamed, 2011).

Aladag provenance seedlings showed poor performance as a result of the cold winters and cool summers; thus, low adaptation was observed under the study site conditions, which may be attributed to differences in their genetic structure and the difference between environmental conditions of the provenance and the study site. Among all the provenances, Degirmendere provenance seedlings had the highest survival percentage, while the lowest was that of the Aladag provenance seedlings. Degirmendere provenance seedlings could easily adapt to a dry climate. The high performance of this group might result from the similarity of the study site to the natural growth conditions of the provenance.

The high diameter increments of the drought-stressed seedlings under field condition showed the higher adaptation abilities of the seedlings due to drought acclimatisation. Drought preconditioning helps seedlings to improve their performance, competitiveness and productivity under field conditions. Several conifer species deliberately exposed to water deficit have displayed greater survival after plantation compared to non-conditioned plants (Van den Driessche, 1992), showing that drought pre-treatment induces the morphological and physiological adjustments associated with an increase in drought tolerance. Similarly, Guarnaschelli *et al*. (2006) evaluated the effect of drought pre-treatment after transplanting. Three provenances of *Eucalyptus globulus* subsp. *bicostata* were subjected to moderate water deficit conditions. They demonstrated that the drought acclimatised plants showed higher levels of survival than well-irrigated plants.

Morphological and anatomical adaptations in plants include reductions in shoot height and/or leaf area, rises in root-collar diameter and root growth potential. These occur as a result of hardening and acclimatisation processes (pre-conditioning) during the nursery period, and are correlated with the ability to withstand the shock of transplantation and to increase survival and plant growth following transplantation in semi-arid landscapes (Franco *et al*., 2006). Differences in provenance performances might be assumed to result from genetic variations among provenances. Another consideration might be the genetic inheritance of resistance to lack of water acquired by the seedlings from their parents. Drought resistance has been associated with low annual rainfall at seed origin, and the distribution of the species of *Pinus* is influenced by drought resistance (Li *et al*., 2000).

Under nursery conditions, Degirmendere, Dirgine and Dokurcun seedlings were better adapted to drought than those of the other provenances. These three provenances are located in the western part of Turkey. Survival rates of these seedlings subjected to drought were high under field conditions. Degirmendere provenance seedlings exhibited the highest survival rate. Furthermore, this provenance is located in the southern part of Turkey. The present results may not indicate clearly that the adaptation of provenances to drought was related to genetic variation; however, this increased adaptation capability of the seedlings might be due to their provenances. Similar results according to survival rates have also been reported in Austrian pine (*Pinus nigra* Arnold) by Mataruga *et al*. (2012). Dirgine, Degirmendere and Dokurcun localities have a dry climate; therefore, the increased adaptation to drought of those provenances may be higher than for other provenances. Similarly, Cregg & Zhang (2001) reported that *P. sylvestris* L. provenances from drier central Asia had higher survival rates compared to coastal and mesic European provenances.

Dirgine and Degirmendere seedlings exhibited higher diameter increases compared to those of the other provenances at the end of the 5th year. Dirgine and Vezirkopru seedlings had higher increases in seedling height than those of the other provenances. In conclusion, seedlings developed from Degirmendere and Dirgine provenances would be a better choice for afforestation applications of the semi-arid Bayburt-Aydıntepe region. Successful afforestation establishment is characterised by high rates of survival and growth (Folk & Grossnickle, 1997). Preconditioning had a positive effect on survival level. The present results are similar to those described by Villar Salvador *et al*. (2004) with oak seedlings.

Conclusion

The survival rate of Scots pine seedlings subjected to drought stress was higher than that of others. Therefore, the drought-stress treatment of seedlings (biweekly irrigation) is recommended in order to increase the survival rate of the plants in semi-arid conditions. It is also proposed that Scots pıne seedlings of Degirmendere, Dirgine and Dokurcun provenances would be appropriate for afforestation of semi-arid regions.

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