Effect of osmotic stress on germination and radicle growth in five provenances of Abies cephalonica Loud

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Summary

The effect of water stress on germination and radicle growth was studied on five *Abies cephalonica* provenances using polyethylene glycol 600 solutions with osmotic potentials ranging from 0 to −1.5 mega Pascal (MPa) under 4°C conditions. A decrease is osmotic potential from 0 to −0.1 MPa significantly increased total germination and a decrease beyond −0.7 MPa significantly decreased total germination. The decrease in osmotic potentials noticeably delayed radicle emergence. No germination was observed at −1.5 MPa, except for the EVIA provenance. Germination rates and dynamics varied significantly between provenances. Seed transfer from 4 to 20°C markedly increased germination in all provenances, especially under the lowest osmotic potentials (from −0.5 to −1.0 MPa depending on the provenance). EVIA always ranked highest for germination rates and always initiated germination earlier regardless of the osmotic potential. A decrease of osmotic potential from −0.03 to −0.1 MPa significantly lowered overall mean radicle length. However, radicle length showed no significant among-provenance variation for osmotic potentials of −0.1 and −0.5 MPa. The possible use of germination under osmotic stress conditions as an early selection test for drought resistance is discussed.

Keywords: *Abies cephalonica*, osmotic stress, germination, radicle growth, geographic variability.

Résumé

L'effet du stress hydrique sur la germination et la croissance radiculaire a été étudié sur cinq provenances d'*Abies cephalonica* au moyen de solutions de polyéthylène glycol 600 à des potentiels osmotiques variant de 0 à −1,5 méga pascals (MPa) pour une température de 4°C. Une diminution du potentiel osmotique de 0 à −0,1 MPa augmente significativement le nombre total de germinations et le diminue significativement au delà de −0,7 MPa. La diminution du potentiel osmotique conduit à une germination de plus en plus tardive. Aucune germination n'a été observée à des potentiels de −1,5 MPa sauf dans le cas de la provenance EVIA. Le nombre et la dynamique des germinations varient significativement d'une provenance à l'autre. Le fait de changer les conditions de température de 4 à 20°C augmente fortement les taux de germination de toutes les provenances, tout particulièrement sous les conditions de potentiels osmotiques les plus bas (de −0,5 à −1,0 MPa selon les provenances). La provenance EVIA, quelque soit le potentiel osmotique, germe toujours plus tôt et en plus grande quantité. L'abaissement du potentiel osmotique de −0,03 à −0,5 MPa diminue significativement la croissance moyenne des radicules, toutes provenances confondues. Cependant, la variabilité inter-provenances de la croissance radiculaire n'est pas significative pour des potentiels osmotiques de −0.1 et −0.5 MPa. La germination sur milieux déficitaires en eau pourrait être utilisée pour une sélection précoce de la résistance à la sécheresse.

INTRODUCTION

Soil water supply is an important environmental factor controlling germination and seedling establishment (KRAMER & KOZLOWSKI, 1979; CÔME, 1982), particularly in Mediterranean regions. One technique to study the effect of water stress on germination and radicle growth is to simulate stress conditions using artificial solutions to provide variable osmotic potentials (e. g. LARSON & SHUBERT, 1969; SHARMA, 1973; TAYLOR *et al.*, 1982). These experiments have also proven to be reliable to demonstrate the existence of an early geographic variability between provenances and to select those best adapted to water deficits (SAINT-CLAIR, 1976; LAKSHMINARAYANA *et al.*, 1979; CALAMASSI *et al.*, 1980; NGUYEN, 1986).

The purpose of this study was: 1) to evaluate the effects of water deficits on germination and 2) on radicle growth and 3) to determine whether there is significant variability in the effects of water stress on germination and radicle growth among *Abies cephalonica* provenances.

MATERIALS AND METHODS

The seeds used came from five different *Abies cephalonica* seed sources: PRIL, VETI, CEPH, KOLO and EVIA (table I). Cones were harvested in natural stands by the Greek Forest Service during the winter of 1987. Seeds were then shipped, dehydrated and stored at −3°C in the INRA Laboratory of Forest Tree Breeding in Bordeaux, France, until they were used during the summer of 1988. These five provenances were chosen as they are a representative sample of the range of the geographic variation of *Abies cephalonica* for such traits as morphology, height growth, bud break and terpene composition (FADY, 1990 *a*, 1990 *b*, 1991 *a*, 1991 *b*; FADY *et al.*, 1991).

Removal of empty seeds

The Greek Forest Service in charge of seed collection and PANETOS (1976) estimate the percentage of empty seeds to be between 30 and 50% in natural environments depending on the provenance. In fact, this percentage was as high as 60 to 75% in the seed collection used depending on the provenance. In *Abies*, separation of full seeds from empty seeds is difficult, probably due to the high density of empty seeds (LEBRUN, 1967). For simplicity, flotation on ethanol was used to separate empty seeds rather than the air-flow technique. Ethanol (density of 0.785) yielded better results than other compounds tested such as water, pentane, petroleum ether and toluene. Flotation on ethanol increased the detection of the number of full seeds from 35 to 60% in VETI and from 25 to 50% in CEPH. To avoid toxic reactions between the solvent and cellular components, flotation was performed rapidly (5 min). Solvent was then evaporated from the seeds by warm air and the seeds were rinsed twice in water. This technique was used to separate seeds of several conifer species by LEBRUN (1967) who did not observe any significant decrease in germination rates.

Stratification and germination treatments

A four-week stratification at 4°C (International Seed Testing Association standards, 1985) in darkness was used to break dormancy, as has been routinely performed for other *Abies* species (FRANKLIN, 1974; MULLER, 1986). During stratification, seeds were placed in the same osmotic solutions as those used afterwards for germination counts. A 2 ml/l cryptonol solution (140 g/l of double sulfate of hydroxy-8-quinoleine and potassium, La Quinoleine Laboratories, Paris) was used for fungus control.

Experimental media were polyethylene glycol 600 (PEG-600, Merck Laboratories) solutions with known solute potentials (NGUYEN, 1986). The molecular weight of 600 was chosen based on VIEIRA DA SILVA's (1970) and NYGUEN's (1986) results.

TABLE I. — *Ecological characteristics of sampled provenances.*

Provenance code	Location (forest and mountain range) and latitude and longitude	Elevation and aspect	Annual rainfall	Substrate	Bioclimatic zone (Barbero and Quézel 1976 and Quézel personnal communication)
PRIL	Profitis Ilias, Taygetos 37°05 N, 22°16 E	1 450 m north	1 300 mm	Limestone	Supra-Mediterranean
VETI	Vetina, Menalon 37°33 N, 22°15 E	950-1 160 m	1 200 mm	Limestone	Supra-Mediterranean
CEPH	Cephallenia, Cephalonia island 38°14 N, 20°32 E	730-1 480 m	1 100 mm	Limestone	Supra-Mediterranean
EVIA	Evia, Euboea island 38°40 N, 23°30 E	550-700 m	750 mm	Schist	Meso-Mediterranean
KOLO	Kolokithovrissi, Parnassos 38°33 N, 22°29 E	1 250 m north	1 200 mm	Flysch	Supra-Mediterranean

Six treatments with osmotic potentials of 0, −0.1 (17 g/l of PEG), −0.5 (79.5 g/l of PEG), −0.7 (100.5 g/l of PEG), −1.0 (128 g/l of PEG) and −1.5 MPa (166 g/l of PEG) were used. The possible influence of PEG on germination (e.g. blocking water uptake through the seedcoat due to molecular size or entry of solute into the germinating seed) has been discussed by KAUFMANN and ROSS (1970), SHARMA (1973), MCDONOUGH (1976) and NGUYEN (1986) among others. Nevertheless, the osmoticum was left in contact with the seeds because of the seemingly low influence of PEG-600 on germination (VIEIRA DA SILVA, 1970; NGUYEN, 1986).

Germination was tested in Petri dishes on filter paper soaked with solutions (4 ml per dish) containing increasing concentrations of PEG-600. After the end of stratification, seeds were kept in the same osmotic media and germination counts were made every two days for seven weeks. The temperature treatment was performed as follows: four weeks at 4°C followed by three weeks at 20°C. A seed was considered to be germinated when the radicle emerged 2 mm from the seed coat. A total of 4,000 seeds were used as follows: 2,000 seeds in the 0 MPa treatment (400 seeds per provenance) and 400 seeds in each of the five remaining treatments (80 seeds per provenance per treatment). A larger amount of seeds were used in the 0 MPa treatment as expected germination was low and germinated seeds were intended for radicle growth experiments. All germination experiments were performed in total darkness, except for the two hours used every two days for the counts.

Radicle growth treatments

Seeds germinated in control treatments (distilled water, 0 MPa) were placed into −0.03 (control), −0.1, −0.5 and −1.0 MPa PEG-600 solutions and radicle length was measured every two days for two weeks. Germinated seeds were suspended over containers filled with 5 liters of PEG solution on plexiglass sheets pierced with 150 holes (30 seeds for each of the five provenances), which maintained cotyledons above the solution level. Air circulation in the solution was generated by an aquarium pump. Solutions were supplemented with nutrients and trace elements (SEILLAC, 1960), which explains the slight −0.03 MPa potential (NGUYEN, 1986), and changed every six days. Photoperiod was 12 hours of light (1,500 lux) and 12 hours of darkness. Constant temperature (20°C) was controlled by thermostats in a laboratory greenhouse. In addition, radicle growth of seeds germinated under −0.1 and −0.5 MPa treatments was measured on −0.03 MPa Seillac solutions to test possible effects of the germination media on subsequent root growth using the same experimental conditions as mentionned above.

Data analysis

Significance of differences in total germination due to provenance and treatment were tested using Student's one tailed t test. Variations among provenances to changing osmotic potentials was tested using chi-square heterogeneity tests in which the −1.5 MPa treatment was not included as too few seeds germinated (expected frequency below 5). Differences in radicle length due to provenances and treatment were also tested using Student's one tailed t test.

RESULTS

Germination

Variation in total germination in relation to osmotic potentials (table II) showed that all provenances except PRIL has more germinated seeds under −0.1 MPa treatments than under 0 MPa treatments. Data analyses over all treatments showed that three groups of significantly different treatments appear: the high total germination −0.1 MPa group, the medium 0, −0.5 and −0.7 MPa group and the low −1.0 and −1.5 MPa group (table II). Differences between treatments were also shown when early or late radicle emergence was considered: earlier radicle emergence appeared for 0 and −0.1 MPa (fig. 1 *a*) treatments, late

emergence for −0.5 and −0.7 MPa (fig. 1 *b*) treatments and very late emergence for −1.0 MPa treatments (fig. 1 *c*).

TABLE II. – *Germination of five* Abies cephalonica *provenances in relation to osmotic potential and temperature increase.*

Provenances	Osmotic potential in MPa	Total final germination (in %)	% of seeds germinated after transfer from 4 to 20°C
KOLO (a)	0	16.6	11.3
	−0.1	47.1	51.5
	−0.5	18.8	33.3
	−0.7	23.8	89.5
	−1.0	3.8	100
	−1.5	0	–
EVIA (b)	0	26.3	10.5
	−0.1	62.5	10.0
	−0.5	40.0	37.5
	−0.7	31.3	28.0
	−1.0	17.5	57.1
	−1.5	2.5	100
VETI (a)	0	25.6	30.5
	−0.1	38.8	22.6
	−0.5	28.8	60.9
	−0.7	10.0	100
	−1.0	1.3	100
	−1.5	0	–
PRIL (a)	0	23.1	91.4
	−0.1	18.6	100
	−0.5	17.5	100
	−0.7	15.0	100
	−1.0	2.5	100
	−1.5	0	–
CEPH (a)	0	15.9	41.2
	−0.1	22.5	22.2
	−0.5	21.3	41.2
	−0.7	11.3	66.7
	−1.0	3.8	100
	−1.5	0	–
Mean	0 (a)	21.4	38.1
	−0.1 (b)	38.2	31.7
	−0.5 (a)	25.3	51.5
	−0.7 (a)	18.3	68.5
	−1.0 (c)	5.8	73.9
	−1.5 (c)	0.5	100

Provenances followed by the same letter are not significantly different (5% level, one tailed t test) for total germination over all treatments.

Treatments (mean values) followed by the same letter are not significantly different (5% level, one tailed t test) for total germination over all provenances.

When provenances were considered, data analyses over all treatments showed that differences in germination were significant only for EVIA which demonstrates

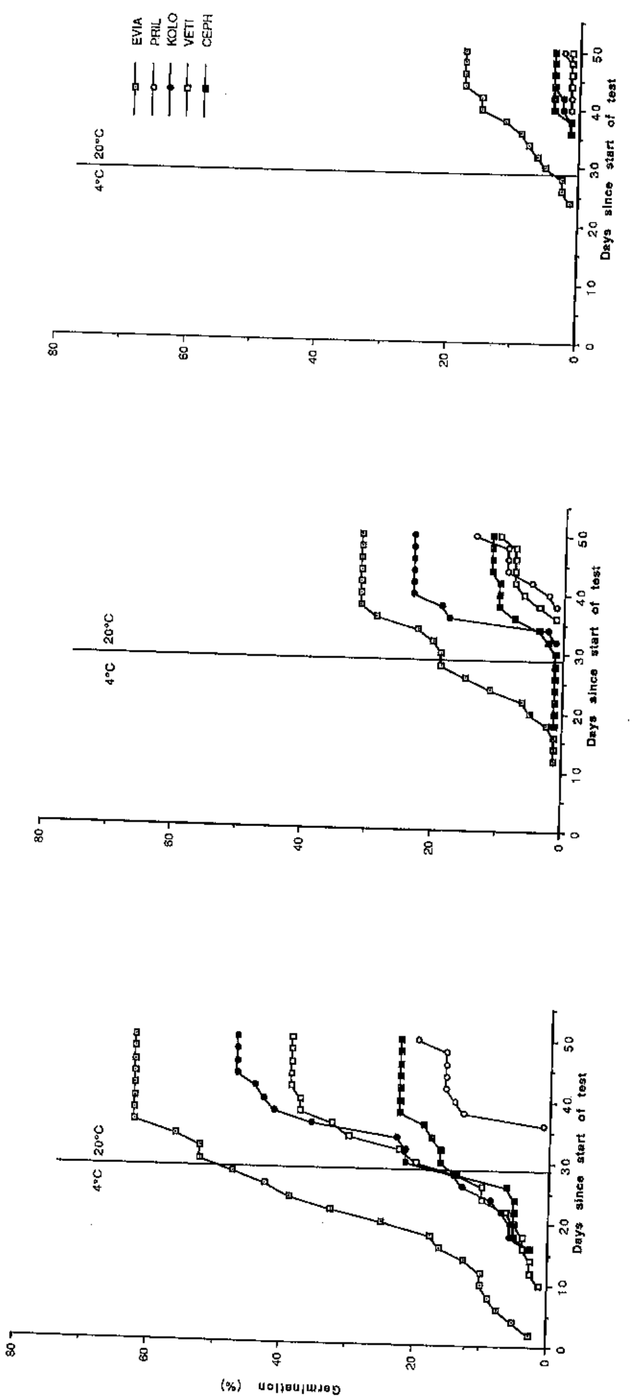

FIG. 1. – Mean germination curves of five *Abies cephalonica* provenances: 1 *a*) for −0.1 MPa, 1 *b*) for −0.7 MPa and 1 *c*) for −1.0 MPa osmotic treatments.

higher germination than the other seed sources. When response of provenances to changing osmotic treatments was considered (table III), EVIA's behavior appeared close to KOLO's although beyond −0.7 MPa EVIA clearly had more germinated seeds than KOLO (heterogeneity chi squares became significant for this osmotic treatment). This group of provenances was opposed to VETI and PRIL whose loss of germination capacity is more rapid when osmotic potential decreases. Some differences were also shown between provenances when early or late radicle emergence was considered. On distilled water (0 MPa), under −0.1 MPa potentials (fig. 1 *a*) and −0.5 MPa treatments, EVIA initiated germination earlier while PRIL initiated later than the other provenances, which remained clustered. Under −0.7 MPa potentials, EVIA and KOLO demonstrated higher germination rates than the other provenances, although radicle emergence in KOLO occurred rather late compared to EVIA (fig. 1 *b*). VETI and PRIL showed the latest radicle emergence. For the −1.0 PMa treatment, radicle emergence occurred much earlier in EVIA than in the other provenances (fig. 1 *c*). In addition, the percentage of germinated seeds was 17.5 % for EVIA compared to a mean of 1.3 to 3.8% for the other provenances in the −1.0 MPa treatment (table II).

TABLE III. – *χ-square heterogeneity tests among provenances.*

		PRIL	EVIA	KOLO	CEPH
EVIA	χ^2	15.98			
	p	0.001			
KOLO	χ^2	15.33	1.34		
	p	0.002	0.719		
CEPH	χ^2	4.78	3.01	5.31	
	p	0.188	0.389	0.150	
VETI	χ^2	6.79	7.60	10.36	1.66
	p	0.079	0.055	0.016	0.647

Transfer from 4 to 20°C made it possible for seeds under osmotic potentials of −0.7 MPa or lower, depending on the provenance, to germinate, although germination had not occurred before (table II). At −1.0 MPa, except for EVIA where 42,9% of total germination had already occurred, germination had not started before the transfer from 4 to 20°C. For PRIL, no germination occurred at −0.1 MPa before the transfer from 4 to 20°C and, at 0 MPa, only 18.6% of the seeds germinated before the transfer as compared to 61.9% on average.

Radicle growth

Radicle growth noticeably increased around 8 to 10 days after germination in all treatments. Cotyledons (5 to 7 per seedling) appeared from the seedcoat at the end of the first week in all treatments. Accelerated radicle growth could then be the result of input of new photosynthetic assimilates.

Overall mean radicle length at two weeks was significantly affected by osmotic potential decrease (table III), although PRIL and KOLO did not show significantly shorter radicles under -0.1 MPa than under -0.03 MPa treatments. A decrease of osmotic potential from -0.1 to -0.5 MPa did not affect radicle growth of the provenances tested (3 out of 5). Due to low total germination, the experiments could not be continued beyond -0.5 MPa. In the -0.03 MPa treatment, KOLO, VETI and PRIL had significantly longer radicles than EVIA and CEPH. In the -0.1 and -0.5 MPa treatments, no significant group appeared. Individual within-provenance variability in radicle length was very high (table III), especially for the -0.1 and -0.5 MPa treatments, and could be responsible for the absence of observable variability among and within provenances for these treatements.

TABLE IV. — *Mean radicle length after two weeks of five* Abies cephalonica *provenances in relation to osmotic potential.*

Provenances	Osmotic potential in MPa	Radicle length (in mm)	Coefficient of variation
KOLO	−0.03 (a)	41.0	39.08
	−0.1 (a)	38.37	53.82
	−0.5 (a)	38.22	59.01
EVIA	−0.03 (b)	31.83	29.44
	−0.1 (c)	22.73	39.46
	−0.5 (c)	19.0	39.95
VETI	−0.03 (a)	44.12	37.39
	−0.1 (c)	21.63	49.26
	−0.5 (ac)	24.67	57.52
PRIL	−0.03 (a)	47.53	37.76
	−0.1 (ac)	27.69	65.59
CEPH	−0.03 (d)	25.59	51.65
	−0.1 (ec)	15.0	47.84
Mean	−0.03 (a)	38.85	43.54
	−0.1 (b)	26.11	63.79
	−0.5 (b)	29.56	64.49

Treatments within provenance and provenances within treatment followed by the same letter are not significantly different (5% level, one tailed *t* test) for mean radicle length.

Treatments (mean values) followed by the same letter are not significantly different (5% level, one tailed *t* test) for mean radicle length over all provenances.

No significant difference in mean radicle lenght over all provenances was observed between seedlings germinated on -0.1 and -0.5 MPa solutions and seedlings germinated on distilled water. However, VETI had significantly longer radicles than the other provenances tested after two weeks when seedlings germinated on distilled water. In addition, a small number of seedlings whose radicle emerged under -0.7 and -1.0 MPa potentials showed dark yellow radicles, as well as a very limited growth on -0.03 MPa solution.

Correlation between germination and radicle growth and between these data and ecological conditions in the natural environment

No significant correlation was found between total final germination and radicle growth for the same osmotic conditions or between radicle growth and ecological conditions. Correlations were found between total final germination and mean annual rainfall in natural environments. Correlations were: $r=-0.96$ ($p=0.012$) for germination under −1.0 MPa potentials and $r=-0.88$ ($p=0.049$) for germination under −0.5 MPa. Although unsurprising from an ecological point

of view, these correlations could be due both to the presence of EVIA, which was the only provenance to show a marked germination capacity under −1.0 MPa, and to the fact that only five pairs of values were analyzed.

DISCUSSION

Germination in *Abies cephalonica* is low. The highest mean germination percentage (−0.1 MPa) after flotation on ethanol was only 38%. Depending on the provenance, from 37.5 to 87.5% of full seeds (cut after the end of the experiment) did not germinate under the most favorable conditions (0 or −0.1 MPa). As no dehydration treatment was used prior to storage (MULLER, 1980), seeds could have undergone a degradation process during storage. Another reason for low seed quality could be the accumulation of lethal or sub-lethal recessive homozygous genes due either to self-pollination, as has been observed in *Abies* (FRANKLIN & RITCHIE, 1970), or more generally to high mean inbreeding (MOREAU, 1989, for *Abies alba*; FADY, 1990 *a*, for *A. cephalonica*). Seeds could also have been collected before their ripening process inside the cone was completed. PANETSOS (1976) has insisted on proper harvest techniques and schedule to improve germination rates in *Abies cephalonica.* It should be noted, however, that *Abies* is known as a genus where total germination rarely exceeds 50% (HICKEL, 1911; FRANKLIN, 1974).

Germination was strongly controlled by temperature under conditions of severe water stress. Except for PRIL, over 60% on average (from 48.5% in KOLO at −0.1 MPa to 90% in EVIA at −0.1 MPa) of total germinations occurred at 4°C when water stress was low (0 and −0.1 MPa solutions). This may indicate that most provenances can initiate germination during the cold season in their natural environment if enough water is available. When water stress increases (from −0.5 to −0.7 MPa depending on the provenance), germination at 4°C was greatly increased by a sudden temperature rise to 20°C. When water uptake is restricted, germination is inhibited (MCDONOUGH, 1976), but a rise in temperature can remove this physiological inhibition (KAUFMANN & ROSS, 1970; KAUFMANN & ECKARD, 1977; CÔME, 1982). However, under more severe water stress (−1.0 to −1.5 MPa depending on the provenance), germination does not occur despite a rise in temperature.

Keeping the seeds under cold conditions (4°C) resulted in a clear separation between provenances and made it possible to observe germination dynamics. Mean total germination was comparable to data presented by PANETSOS (1975) and showed a high geographic variability (from 18 to 62% for −0.1 MPa osmotic potentials). Comparable between-provenance variability on PEG solutions has been shown for other conifers (CALAMASSI *et al.*, 1980; NGUYEN, 1986). Germination dynamics were also highly variable. Geographic variability became increasingly evident with decreasing water potentials. Solutions with −0.7 to −1.0 MPa osmotic potentials seemed best adapted to clearly discriminate between *Abies cephalonica* provenances.

EVIA showed the highest total germination and initiated germination earlier than the other *Abies cephalonica* provenances in all osmotic treatments. However, the difference in germination capacity between EVIA and the other provenances was strongest for low osmotic potentials (−1.0 and −1.5 MPa). As this study did not clearly separate the effects of osmotic water stress between dormancy and germination, these characteristics could be linked both with EVIA's ability to break dormancy earlier (smaller low temperature requirement) and to better resist water deficits than the other provenances. In previous studies, this provenance has appeared to be significantly different from other *Abies cephalonica* provenances grown in experimental sites in southern France due to its small annual shoot increments, its early bud break and its terpene composition (Fady, 1990 *a*, 1990 *b*, 1991 *a*, 1991 *b*).

Higher germination capacity at osmotic potentials lower than 0 MPa has previously been noted for other species, e. g. *Pinus ponderosa* (Larson & Shubert, 1969; Djavanshir & Reid, 1975) and *P. eldarica* (Djavanshir & Reid, 1975) at potentials of −0.2 to −0.4 MPa. The causes for this increased germination were not analyzed in this study but could prove to be linked to seed adaptation to the osmotic potentials existing in soil solutions. PEG solutions with different osmotic potentials are widely used to increase germination (Heydeker *et al.*, 1973, for food crop pretreatment; Muller & Bonnet-Masimbert, 1983, and Hallgren, 1989, for forest tree "priming"). In *Abies cephalonica*, PEG-600 solutions of approximately −0.1 MPa osmotic potentials could probably be used for priming in commercial nurseries.

An important decrease in germination occurred between −0.7 and −1.0 MPa for all provenances except EVIA where it occurred beyond −1.0 MPa. Comparable decreases have been noted, e. g. at approximately −0.7 MPa (Larson & Shubert, 1969) or −0.4 MPa (Djavanshir & Reid, 1975) for *Pinus ponderosa*, −0.6 MPa for *P. eldarica* and −0.8 MPa for *Picea engelmanii* and *Pinus contorta* (Kaufmann & Eckard, 1977). Within its genus and among other conifers, *Abies cephalonica* is considered to be a species particularly well adapted to severe summer droughts (Aussenac, 1980; Guehl *et al.*, 1990) and a decrease in germination occurring at osmotic potentials lower than those of the above-mentioned species could be linked to this capacity. However, *Abies cephalonica* figures should be compared to those of other conifers with known resistance to water stress to confirm the value of this test as a marker for enhanced resistance to water stress.

A decrease in radicle growth (seeds transferred from 0 MPa germination treatments) appeared to be significant over all provenances when osmotic potentials decreased from −0.03 to −0.1 MPa. However, probably because of high individual within-provenance variability, differences were not significant between −0.1 and −0.5 MPa treatments. Also, variability of among-provenance radicle growth was not significant for potentials lower than −0.03 MPa as Calamassi *et al.* (1980) have already shown for several Mediterranean pine species. No correlation was found between germination and radicle growth under severe stress: EVIA did not exhibit significantly higher radicle growth on low osmotic potential media.

Reduced radicle growth due to permanent radicle damage has been noted under control treatments for seedlings germinated on low osmotic potential solutions compared with seedlings germinated on distilled water (Larson & Shubert, 1969; Djavanshir & Reid, 1975). For all but one *Abies cephalonica* provenance, no significant differences in radicle growth under control treatments was found between seeds germinated at 0, −0.1 and −0.5 MPa. In addition, no abnormal radicles were observed for these treatments, which indicated that no permanent damage resulted from these osmotic potentials. However, the few seeds germinated at −0.7 and −1.0 MPa and grown afterwards in control treatments had damaged

radicles suggesting either that germination under lower osmotic potentials influences subsequent radicle growth in *Abies cephalonica* or, more likely, that PEG-600 may have direct deleterious effects on germination and subsequent radicle growth above a certain concentration, or both.

Earlier and higher germination in EVIA for low osmotic conditions could be related to its better adaptation to water deficits than the other provenances. Early and rapid germination is all the more important in areas where soil water availability is limited and where seedlings have a short time to develop. After a study conducted on several herbaceous species, Sharma (1973) suggested that germination on water stressed media was not an accurate index of general drought resistance. Obviously adult plants present a wide range of adaptations to drought resistance outside the root system (Oppenheimer, 1961; Stocker, 1961; Kozlowski, 1976). However, root morphology and physiology play an extremely important role in drought resistance of woody plants (Oppenheimer, 1961; Stocker, 1961; Nguyen & Lamant, 1989). Physiological characteristics of root systems must appear early in juvenile stages and can probably be linked with adult physiological characteristics (*Pinus pinaster*, Nguyen & Lamant, 1989). Several studies have shown significant correlations between germination under osmotic stress and known drought resistance in adult plants (e. g. Saint-Clair, 1976, for several sorghum varieties; Lakshminarayana *et al.*, 1979, for several tobacco varieties). In *Abies cephalonica*, germination under highly concentrated PEG solutions (−1.0 MPa) is also significantly correlated with the low annual rainfall found in the provenances' natural range.

Germination tests on PEG solutions can be adapted to differentiate between drought resistant varieties or species (Johnson & Asay, 1978). Of the provenances studied, EVIA seems to be the best-adapted to high water stress, at least for germination, and might be used for reforestation in areas with more severe drought than those where *Abies cephalonica* is usually planted.

However, future studies would be necessary to more closely define these preliminary results. Even though a large number of seeds were used for germination counts, radicle growth experiments yielded few data as germination was well below expected germination. In addition, a greater number of provenances would yield more significant data for correlations with environmental conditions. A higher amount of germinated seeds would also make it possible to better analyze provenance variation of radicle growth in relation to provenance variation of germination.

On a long term basis, the high germination variability among provenances could be used as an early selection criterium for drought resistance in *Abies cephalonica* if a genetic control over drought resistance can be demonstrated.

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