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DROUGHT TOLERANCE OF MULTIPURPOSE AGROFORESTRY TREE SPECIES DURING FIRST AND SECOND SUMMER DROUGHTS AFTER TRANSPLANTING

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SUMMARY

The aim of this experiment was to select suitable drought tolerant agroforestry tree species. The findings of this investigation indicated that summer drought from April to June for 25, 50 and 75 days during first and second year after transplanting adversely but differentially affected growth and physiological attributes of five tree species namely, *Grewia optiva, Morus alba, Dalbergia sissoo, Acacia catechu and Populus deltoides.* Plant height, collar diameter and leaf biomass were less in water stressed plants compared to unstressed plants within each tree species and within each drought level. In general, 75 days of drought exerted more pronounced effect on the performance of tree species. The minimum adverse effect of summer drought was seen on *M. alba and D. sissoo,* while the maximum on *G. optiva* and *P. deltoides.* Xylem water potential was significantly higher in unstressed plants compared to water stressed plants of all the five tree species. The water potential (Ψ) in water stressed plants during second summer drought was higher compared to first summer drought. The lowest potential was recorded at 75th day of drought. *M. alba and D. sissoo* maintained relatively high xylem water potential under water stress, whereas *G. optiva and P. deltoides* recorded the lowest values. Reduction in photosynthesis under drought over control was least in *M. alba and D. sissoo,* whereas maximum in stressed plants of *P. deltoides* up to 75th day of drought. Drought injury index was minimum in *M. alba* (40.4%), followed by *D. sissoo* (52.1%) up to 75th day. *P. deltoides* exhibited maximum injury index during the summer drought (83.8%).

***Key words*: Drought injury index, growth, leaf biomass, photosynthetic rate, water potential**

INTRODUCTION

Trees constitute an integral part in any agroforestry system because trees are able to produce more biomass per unit area for longer duration than agricultural crops. The performance and biomass production potential of trees depend on the maintenance of higher physiological status and utilization of resources (Thakur and Sehgal 2003), though drought is reported to cause decrease in water potential, osmotic potential and relative water content in plants (Hennessey and Lorenzi 1988, Thakur *et al.* 1998, Uprety *et al.* 1999, Thakur *et al.* 2000). Water is one of the most important critical resources, which will remain a decisive constraint for suitable production in the 21st century. Drought at any phenophase can affect almost every aspect of growth of above and below ground parts. The need for forestation, especially under rainfed conditions and for stress sites is increasing rapidly world over due to the massive deforestation and decline for fuel wood, fodder and timber. The success of these plantations is closely related to the ability of tree seedlings to establish under water stress conditions

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(Zwiazek and Blake 1990, Thakur *et al.* 2000). Desiccation poses great threats to the survival of newly transplanted seedlings. It is presumed that the first and the second summer droughts after planting are the most critical and decisive for survival and subsequent growth. The faster growing seedlings have an initial comparative advantage but they react differently to varying soil moisture levels. The numerous physiological responses of plant to water deficits generally vary with the severity as well as the duration of water stress (Mathews *et al.* 1984, Weber and Gates 1990, Rose *et al.* 1993, Thakur *et al.* 1998, Li Chunyang 2000, Correia *et al.* 2001, Pane and Goldstein 2001, Pita and Pardes 2001, Weigh 2001). Nursery grown tree seedlings usually experience a great change in environmental conditions when they are out planted; and unless they are adapted to this change, establishment process will be jeopardized. The information, however, is lacking about the ability of degree as well as duration of drought, which various multipurpose tree species can tolerate, especially during the first two summer droughts after transplanting. This study was, therefore, undertaken to reveal relative drought tolerance of five important fuel, fodder and timber agroforestry tree species namely *Grewia optiva, Morus alba, Dalbergia sissoo, Acacia catechu,* and *Populus deltoides* in response to two successive summer droughts.

MATERIALS AND METHODS

The present study was carried out in the experimental farm of Department of Silviculture and Agroforestry, University of Horticulture and Forestry, located at 30º 52'N latitude and 77º 11'E longitude, 14 km east of Solan Town. The experimental site falls in the mid-hill zone of Himachal Pradesh and represents a transitional zone between sub-tropical and warm-temperature region at an elevation of 1250 m above mean sea level. There is considerable variation in the temperature. April, May and June are the hottest months with temperature varying between 29º-35ºC, whereas December and January are the coldest months recording temperature as low as 1ºC. The area receives an average annual rainfall of 1150 mm, most of which is received in the months of July and August. The soil of the experimental site is brown and texture is sandy loam that belongs to Eutrochrept grade group. The soil is medium in available nitrogen (278.4 kg ha^{-1}) and high in available potassium (218.1 kg ha^{-1}) and phosphorus (19.5 kg ha^{-1}) having soil pH of 6.8, organic carbon 0.75 %.

One year old plants of five multipurpose agroforestry tree species, namely *Grewia optiva*; Burret; *Morus alba* Linn; *Dalbergia sissoo* Roxb. Ex DC.; *Acacia catechu* Willd were planted in June and *Populus deltoides* Marsh in January 2001 in the fields as square planting with row x row and plant x plant spacing of 80 cm. Plot size was 20 m x 9 m and design was RBD factorial with three replications (16 plants per replication).

Withholding water for 25, 50 and 75 days from April to June during 2002 and 2003 imposed droughts during summer. The calculated amount of water on the eve of creating drought (0 day) was given by the ridge and furrow method based on cumulative pan evaporation (CPE). Thereafter plants were left un-watered for 75 days, however, the parallel watered plots were maintained to serve as control. Observations for plant height, collar diameter, leaf biomass, water potential, photosynthesis and drought injury index were made on 25, 50 and 75 days after stress treatments.

Plant height of unstressed control as well as stressed plants was measured from the ground level to the top of the main shoot. Diameter was measured at the collar region with the help of digital caliper. Four randomly marked plants within each tree species and within each stress date constituted one replication. Each value is the mean of three replications. The harvesting of foliage biomass in unstressed and stressed plants was done in October. Aboveground portion of the stem was cut and leaves removed. Fresh weight of leaves was taken and expressed as g plant^{-1}. Each value is a mean of three replications (4 plants per replication).

Predawn leaf water potential (MPa) was determined with the Scholander-type pressure chamber. The pressure was increased slowly at 0.5 bar per second till the sap droplets first appeared on the cut surface of the twig. A terminal twig of 10-12 cm containing young leaves was cut with a sharp razor blade diagonally and inserted immediately into the pressure chamber. Photosynthesis (μ mol m^{-2} s^{-1}) was measured with the help of CI-301

Portable Photosynthesis System (CID Inc. USA). Four leaves were randomly selected from each plant for the measurements. Each value is a mean of three replications and each replication a mean of 4 readings. Measurements were taken between 10:00-12:30 hrs. Injury index for stressed and control plants was calculated by adopting the method as described by Gebre and Kuhns (1991). Electrolyte leakage of 20 leaf discs from stressed and unstressed plants within each species was determined using Digital Conductivity Meter at 20 ºC after shaking for 1 h.

Data were statistically tested using the technique of analysis of variance in a randomized block design with the procedure outlined by Gomez and Gomez (1984). This was done in order to divide heterogeneous experimental area into homogeneous sub-groups so that each treatment gets the same environment, which will render the comparison valid. Variables considered for analysis included stressed and unstressed plants within each species and within each duration during two consecutive years.

RESULTS AND DISCUSSION

The difference in plant height between unstressed and stressed plants within each species and within each stress duration was statistically significant at 5 % level during both the experimental years (Table 1). Plants under drought showed lesser height in comparison to those under unstressed condition. During 25th day of drought, the maximum inhibition in plant height was shown by *G. optiva* (4.4 %), followed by *P. deltoides* (3.1 %), whereas the minimum inhibition was observed in *A. catechu* (0.8 %). During 75th day of drought, *A. catechu* plants, followed by *Grewia optiva* (7.1) showed a maximum inhibition of 7.6 per cent. *M. alba* showed lowest inhibition (3.9 %) during 75th day of drought. Plant

Table 1. Comparative plant height (cm) of five agroforestry tree species during summer months in Himachal Pradesh (North Western India).

Treatments (T)	*G. optiva*		*M. alba*		*D. sissoo*		*A. catechu*		*P. deltoides*	
Duration	Unstressed	Stressed	Unstressed	Stressed	Unstressed	Stressed	Unstressed	Stressed	Unstressed	Stressed
First summer drought (2002)										
25th day	31.4	30.0	109.0	106.9	57.8	56.7	57.5	57.0	115.1	111.5
	(4.4)		(1.9)		(1.9)		(0.8)		(3.1)	
50th day	37.2	35.2	113.8	111.0	62.2	60.6	60.2	59.7	118.3	112.7
	(5.3)		(2.4)		(2.5)		(0.8)		(4.7)	
75th day	41.3	38.3	122.8	118.0	66.6	63.9	68.5	63.3	121.7	114.4
	(7.1)		(3.9)		(4.0)		(7.6)		(6.0)	
LSD at 5 %	0.82		1.26		0.42		0.55		0.96	
Second summer drought (2003)										
25th day	122.0	81.6	145.8	131.5	124.0	105.5	88.3	67.7	155.0	110.1
	(33.1)		(9.8)		(14.9)		(23.3)		(28.8)	
50th day	130.0	85.7	153.8	138.2	132.0	110.1	97.5	74.0	163.3	112.8
	(34.0)		(10.0)		(16.5)		(24.1)		(30.9)	
75th day	139.3	89.0	161.5	144.0	142.0	114.0	101.4	76.0	188.3	115.3
	(36.0)		(10.8)		(19.7)		(25.0)		(38.7)	
LSD at 5 %	1.36		1.11		2.26		1.78		1.93	

Values in parenthesis indicate per cent inhibition over control (unstressed) height in all the five tree species appeared more sensitive to second summer drought because reduction was significantly higher in comparison to first summer drought (Table 1). Stressed plants of *P. deltoides* and *G. optiva* showed a greater plant height reduction than the remaining three species during the second summer drought with *M. alba* exhibiting the least inhibition (Table 1).

Results indicate significant (P=0.05) reduction in collar diameter within each tree species as well as each stress duration (Table 2). Adverse effect of drought on collar diameter was evident within each species up to 25th day of stress, which further increased up to 75th day during both the study years. Per cent reduction of collar diameter in stressed plants compared to unstressed plants during both the summer droughts was observed to be maximum in *P. deltoides*, followed by that in *G. optiva*. The minimum reduction was observed in stressed plants of *M. alba*, followed by *D. sissoo* up to 75th day of stress during both the summer droughts (Table 2). Collar diameter reduction was comparatively higher during the second summer drought in comparison to first drought in all the five tree species (Table 2). The critical differences for collar diameter between stressed and unstressed plants within each species and each stress duration were statistically significant at 5 % level.

Statistically significant effect of summer droughts was evident on leaf biomass production ability within each tree species. Stressed plants of all the tree species registered reduction in leaf biomass compared to control up to 75th day of drought during first and second summer drought (Table 3). Reduction in leaf biomass was maximum in *P. deltoides* varying between 41.3 % and 63.0 % during the first drought year. Leaf biomass in stressed plants of *G. optiva* reduced by 54.4 % up to 75th day of drought (Table 3). The minimum leaf biomass reduction during first summer drought was found in *A. catechu* with values between 32.9 to 39.3 % up to 75th day. Stressed plants of *M. alba* and *D. sissoo* showed almost equal leaf biomass reduction at 25th, 50th and 75th day of water stress during first drought (Table 3). A similar

Table 2. Comparative collar diameter (mm) of five agroforestry treee species druing summer months in Himachal Pradesh (North Western India).

Treatments (T)	***G. optiva***		***M. alba***		***D. sissoo***		***A. catechu***		***P. deltoides***	
Duration	**Unstressed**	**Stressed**	**Unstressed**	**Stressed**	**Unstressed**	**Stressed**	**Unstressed**	**Stressed**	**Unstressed**	**Stressed**
First summer drought (2002)										
25th day	11.04	9.09	15.04	14.70	6.68	6.46	7.35	6.81	9.51	7.70
	(17.6)		(2.3)		(3.3)		(7.3)		(19.0)	
50th day	11.48	9.14	15.50	14.76	7.39	7.06	7.98	7.33	9.95	7.90
	(20.3)		(4.7)		(4.4)		(8.1)		(20.6)	
75th day	12.19	9.17	15.85	14.80	9.63	8.09	8.56	7.58	10.94	8.16
	(24.7)		(6.6)		(16.0)		(11.5)		(25.4)	
LSD at 5%	0.08		0.09		0.12		0.25		0.06	
Second summer drought (2003)										
25th day	18.99	13.13	20.27	18.37	13.85	11.95	9.94	8.46	13.80	9.46
	(30.8)		(9.3)		(13.7)		(14.8)		(31.4)	
50th day	19.51	13.44	20.73	18.67	14.30	12.20	10.53	8.90	14.40	9.69
	(31.1)		(9.9)		(14.6)		(15.4)		(32.7)	
75th day	20.06	13.65	20.93	18.71	15.53	13.12	10.83	9.04	15.10	9.96
	(31.9)		(10.6)		(15.5)		(16.5)		(34.0)	
LSD at 5%	1.11		1.03		0.07		1.12		1.01	

Values in parenthesis indicate per cent inhibition over control (unstressed).

Table 3. Comparative leaf biomass (g plant^{-1}) of five agroforestry treee species druing summer months in Himachal Pradesh (north western India).

Treatments (T)	***G. optiva***		***M. alba***		***D. sissoo***		***A. catechu***		***P. deltoides***	
Duration	**Unstressed**	**Stressed**	**Unstressed**	**Stressed**	**Unstressed**	**Stressed**	**Unstressed**	**Stressed**	**Unstressed**	**Stressed**
First summer drought (2002)										
25th day	2.85	1.74	8.50	5.49	5.50	3.48	5.83	3.91	6.30	3.70
	(38.9)		(35.7)		(36.7)		(32.9)		(41.3)	
50th day	4.55	2.56	11.10	7.01	7.75	4.85	7.21	4.10	7.25	3.91
	(43.7)		(36.8)		(37.4)		(43.1)		(46.1)	
75th day	6.10	2.78	14.90	8.25	10.25	5.46	8.10	4.92	10.90	4.03
	(54.4)		(44.6)		(46.7)		(39.3)		(63.0)	
LSD at 5%	0.21		1.15		0.72		0.55		0.16	
Second summer drought (2003)										
25th day	10.83	6.53	30.93	28.31	66.73	46.33	8.55	5.22	39.17	21.29
	(39.7)		(8.4)		(30.5)		(38.9)		(45.6)	
50th day	13.82	7.62	35.89	30.80	69.34	47.06	10.68	5.90	41.70	22.10
	(44.8)		(14.1)		(32.1)		(44.7)		(47.0)	
75th day	17.80	8.58	38.21	31.25	71.65	47.65	12.89	6.60	47.91	22.46
	(51.8)		(18.2)		(33.4)		(48.7)		(53.1)	
LSD at 5%	1.06		1.42		1.80		1.09		0.92	

Values in parenthesis indicate per cent inhibition over control (unstressed).

pattern was followed during the second summer drought where significant reduction was observed in stressed plants within each species and at each duration (Table 3). The maximum reduction in leaf biomass after 75 days of drought was recorded in *P. deltoides* (53.1 %), followed by *G. optiva* (51.8 %), *A. catechu* (48.7 %), *D. sissoo* (33.4 %) and *M. alba* (18.2 %). The reduction was significantly higher on 75th day as compared to 50th and 25th day of drought (Table 3). The trend of leaf biomass reduction indicates maximum sensitivity to drought in *P. deltoides*, followed by *G. optiva*, *A. catechu*, *D. sissoo* and *M. alba* (Table 3).

During the present study, drought (April to June) significantly and adversely affected xylem water potential within each species and within each stress date (Fig. 1). Xylem water potential in unstressed plants of all the five tree species did not change considerably; the values ranged between –0.37 MPa and –0.50 MPa (Fig. 1a). Xylem water potential was, however, significantly lower in stressed plants. *G. optiva* up to 25th day of drought recorded the lowest xylem water potential (-1.32 MPa), which was followed by *P. deltoides* (-1.01 MPa). The values for xylem water potential in *M. alba, D. sissoo* and *A. catechu* were statistically at par. *P. deltoides* recorded the lowest value (-2.98 MPa) during 75th day of drought, which was followed by *G. optiva* (-2.81 MPa). Out of the five tree species tested, stressed plants of *M. alba* followed by *A. catechu* and *D. sissoo* exhibited higher water potential at all the three stress duration (Fig. 1b). Similar was the pattern during second summer drought also where lower xylem water potential (Ψ) was observed in stressed plants compared to control within each species and each stress duration (Fig. 1c). Among the tree species, stressed *D. sissoo* exhibited highest water potential (-0.53 MPa), followed by *M. alba* (0.83 MPa). After 75 days of drought, highest water potential was measured in *M. alba* (-1.10 MPa), followed by *D. sissoo* (-1.13 MPa), whereas the lowest was shown by stressed plants of *G. optiva* (-2.28 MPa) and *P. deltoides* (-1.98 MPa). The critical differences for xylem water potential between stressed and unstressed plants within each tree

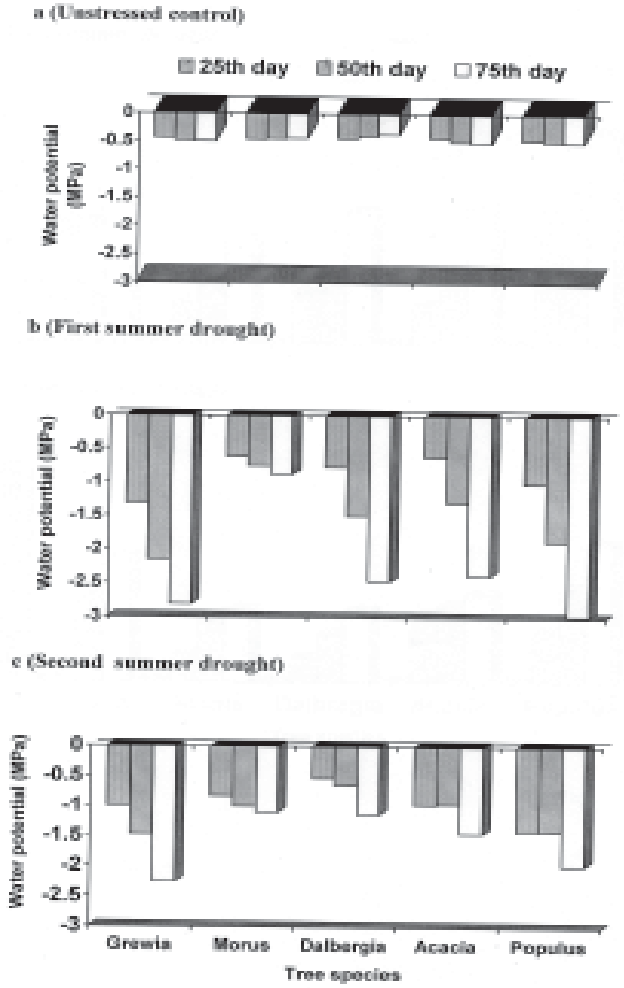

Fig. 1. Xylem water potential (Ψ, - MPa) in stressed and unstressed plants during summer drought. LSD$_{0.05}$ to compare differences between species and stress dates during first summer drought (-0.06); second summer drought (-0.10).

species and within each stress date was statistically highly significant at 5 % level during both the drought years. The stressed plants of all the tree species exhibited higher xylem water potential during second summer drought (Year 2003) compared to first summer drought (Year 2002).

Results in Table 4 indicate much greater reduction in photosynthesis in water stressed plants in all the tree species during 25th, 50th and 75th day of drought. Reduction in photosynthesis in stressed plants compared to control within each species was evident up to 25th day of drought, however, the reduction was significantly higher on 50th and 75th day than that on 25th day (Table 4). Out of the five tree species, *P. deltoides* on 75th day registered maximum reduction in photosynthesis (81.4%) compared to control. The values being 3.82 μ mol m^{-2}s^{-1} for stressed plants against 20.62 μ mol m^{-2}s^{-1} for unstressed plants; minimum inhibition was observed in *M. alba* (26. 6 %) during first summer drought. Twenty five days of second drought had no impact on photosynthesis in *M. alba*, *D. sissoo* and *G. optiva* (Table 4). The photosynthesis in *A. catechu* and *P. deltoides* under drought was 8.42 μmol m^{-2}s^{-1} and 17.00 μmol m^{-2}s^{-1} in contrast to 11.60 μmol m^{-2}s^{-1} and 21.67 μmol m^{-2}s^{-1} under control. A significant decrease in photosynthesis under drought was registered during 50th and 75th day within each species. The critical differences for drought was registered during 50th and 75th day within each species. The critical differences for photosynthesis between stressed and unstressed plants within each species and each stress date were statistically significant at 5 % level of significance. Out of the five tree species, *D. sissoo* and *M. alba* maintained significantly higher rate of photosynthesis under drought, whereas *A. catechu*, *G. optiva* and *P. deltoides* the least (Table 4).

Figure 2 shows comparative drought injury index within each species and within each stress date in all the five agroforestry tree species. During first summer drought, a minimum drought injury index was observed in *M. alba* and the maximum in *P. deltoides* throughout the drought period. For example , drought injury (Id) values of *M. alba* were 15.9, 23.6 and 40.4 per cent at 25th , 50th, and 75th day, respectively , whereas the same were 50.2, 61.5, and 83.8 per cent in *P. deltoides* (Fig. 2a). Id values in *G.optiva* were 48.1, 58.3 and 77.3 per cent on 25th, 50th and 75th day, respectively. Injury index in the remaining tree species i.e. *D.sissoo* and *A. catechu* were 20.2 and 15.1 per cent on 25th day, which increased to 52.1 and 53.4 per cent , respectively up to 75th day of drought. Impact of second summer drought was also significant on injury index within each species and each stress duration. The minimum drought injury index was measured in *D. sissoo* (10.2%), which was statistically at par with *M. alba* (11.2%). During 50th and 75th day of drought, the highest Id was recorded in *P. deltoides* (40.6%, 59.0%) , whereas the minimum was exhibited by

Table 4. Photosynthesis (µmol m^{-2} s^{-1}) in five agroforestry treee species druing summer months (April to June) Himachal Pradesh (North Western India).

Treatments (T)	***G. optiva***		***M. alba***		***D. sissoo***		***A. catechu***		***P. deltoides***	
Duration	**Unstressed**	**Stressed**	**Unstressed**	**Stressed**	**Unstressed**	**Stressed**	**Unstressed**	**Stressed**	**Unstressed**	**Stressed**
First summer drought (2002)										
25th day	17.95	14.51	23.02	20.59	19.43	16.95	14.69	13.29	20.40	11.93
50th day	18.54	9.72	22.22	18.67	20.45	13.97	14.99	8.90	19.60	6.49
75th day	19.18	5.81	22.04	16.16	20.34	9.56	15.28	8.04	20.62	3.82
LSD at 5%	1.50		1.19		1.86		0.89		1.54	
Second summer drought (2003)										
25th day	19.88	18.44	25.98	25.57	22.68	22.67	11.60	8.42	21.67	17.00
50th day	19.82	16.55	25.74	25.03	23.10	22.70	15.11	9.93	23.77	15.98
75th day	19.88	12.21	25.75	20.79	22.68	19.40	17.48	9.91	21.67	13.46
LSD at 5%	1.18		1.04		0.97		0.06		0.44	

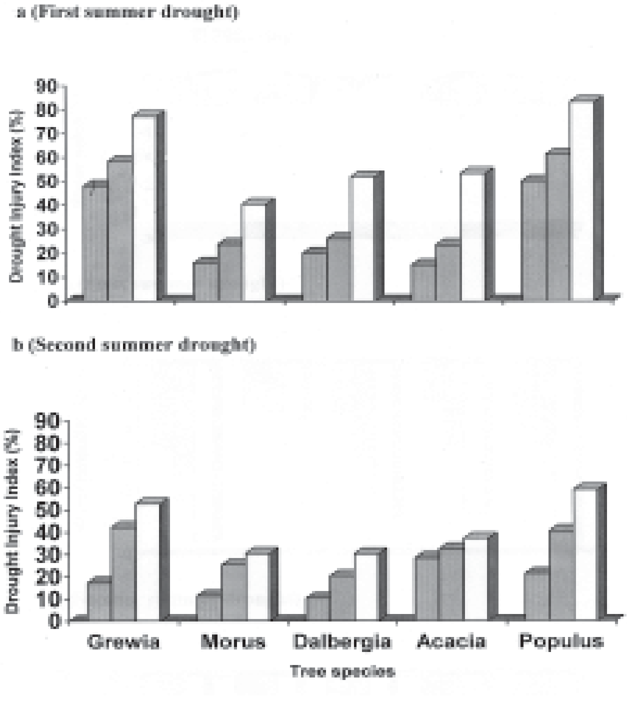

Fig. 2. Drought injury index changes (%) in five tree species during summer drought. $LSD_{0.05}$ to compare differences between species and stress dates during first summer drought (2.15); second summer drought (2.09).

D. sissoo (20.3% and 30.2%). Id in *D. sissoo* was statistically at per with *M. alba* during 75th day of drought (Fig. 2b). Injury was significantly lower during the second drought in comparison within each species (Fig.2).

Out of the five tree species , *D. sissoo* , *M. alba* and *A. catechu* during the present investigation have excelled in growth over *P. deltoides* and *G. optiva*, maintaining significantly higher pace of growth and leaf biomass production ability during the first as well as the second summer drought after transplanting. The better performance and ability of *D. sissoo, M. alba* and *A. catechu* in comparison to *P. deltoides* and *G. optiva* to tolerate summer drought is certainly the cumulative effects of significantly higher water potential, photosynthetic rate and less injury index. The significance of lesser injuries and maintenance of higher pace of physiological processes in tolerating dehydration during drought has been shown earlier for many tree species (Gebre & Kuhns 1991, Thakur et al. 2000). Xylem water potential is a critical indicator to elucidate drought tolerance in different tree species. Drought affected xylem water potential during the present investigation. Xylem water potential was significantly higher in unstressed plants (watered every third day) than plants subjected to 25, 50 and 75 days of drought during summer from April to June. *M . alba* and *D. sissoo* under drought were able to maintain the highest water potential in comparison to rest of the tree species (Fig. 1). The maintenance of significantly higher water potential (Ψ) in case of *M. alba*, *D. sissoo* and *A. catechu* and corresponding better performance, relatively higher drought tolerance and less injury index during the summer droughts hint at the inbuilt ability of these tree species to tolerate drought with least irreversible changes.

Higher water potential in plants will maintain metabolic activities resulting in maintaining higher turgidity through osmoregulation (Martin et al. 1987, Choi 1992, Thakur et al. 1998, Zwiazek & Blake 1999, Thakur et al. 2000). This is substantiated by the physiological status of the tree species during summer drought, where *M. alba* and *D. sissoo* were able to maintain significantly higher photosynthesis compared to *G. optiva*, and *P . deltoides*. Photosynthesis was significantly less in water stressed plants in contrast to higher photosynthesis in unstressed plants, showing poor ability of stressed plants to utilize photosynthetically active radiation. Drought is believed to reduce photosynthesis by increased resistance to diffusion of CO2 to chloroplast and through reduced photosynthetic capacity (Stark 1992; Wan *et al*. 1993; Thakur *et al*. 2000).Higher photosynthetic rate in *M. alba* and *D. sissoo* in comparison to *A. catechu, G. optiva* and *P. deltoides* during two summer droughts reflects least damage to photosynthetic apparatus. Higher water potential (better osmotic adjustment) in *M. alba* and *D. sissoo* appears to be the results of maintenance of higher photosynthetic rate. Injury index (level of leakage of electrolytes) is one of the most important indicators of drought tolerance. *P. deltoides* during the present study had significantly more injury index, followed by *G. optiva.* The minimum injury index was recorded in *M. alba* and *D. sissoo* during summer droughts. So the results have shown differential ability of tree species to sustain internal biological organization, since injury index is the representative of permanent damages at the sub-cellular and metabolic levels. The less injury index in *M. alba* and *D. sissoo* during the summer droughts reflects maintenance of equilibrium in favor of synthetic processes. The plants of these tree species seem to have tolerated drought period with minimum changes at physiological and metabolic levels. This is important and desirable since only those species, which resist alteration and / or irreversible changes at the advent of drought can overcome periods of drought with least adverse effects. *M. alba* and *D. sissoo* , followed by *A. catechu* during the present study have exhibited similar characteristics. *P. deltoides* and *G. optiva*, however, could not maintain proper balance between anabolic and catabolic processes, thus more susceptibility. Intimate relationship between drought tolerance and injury index has earlier been reported in many plants (Zwiazek & Blacke 1990, Gebre & Kuhns 1991, Thakur et al. 2000). It can be concluded that drought tolerance of *M. alba* and *D. sissoo* in response to first and second droughts after out planting is the intrinsic abilities of these tree species to tolerate dehydration. This characteristic was found lacking in *G. optiva* and *P. deltoides*, with the result that these species were affected to greater extent.

Out of the five species, *M. alba* and *D. sissoo* have exhibited relatively higher drought tolerance in comparison to *A. catechu, G.optiva* and *P. deltoides. M . alba* and *D. sissoo* have shown least damage to vital physiological processes at the advent of summer droughts from April to June. Based on the findings the relative drought tolerance of five tree species has been in the order of *M. alba*> *D. sissoo*> *A. catechu*> *G. optiva* and *P. deltoides*. It is recommended that plantation of *M. alba* and *D. sissoo* may be preferred over *G. optiva* and *P. deltoides* at water stress sites for better performance.

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