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Growth of woody perennials in relation to habitat conditions in north-western Rajasthan

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Abstract: Growth and survival of *Acacia tortilis, Calligonum polygonoides* and *Prosopis juliflora* were studied in relation to habitat conditions and competitive effect of *Dactyloctenium sindicum*. Six different habitats viz. bare dune plantation (BP), semistabilized dune plantation (SP), flat land plantation (FL), flat land with *Dactyloctenium sindicum* grass (FG), flatland without vegetation (FW) and bare dune (BD) were identified on the basis of microtopography and abundance of *D. sindicum*. Total plant biomass (above ground and root) and soil water content was recorded. Absolute and relative growth reductions of tree seedlings were calculated for two successive years during 1996-97 and 1997-98. The grass biomass was 438 g m^{-2} in FG but decreased to 369 g m^{-2} in SP habitat. The soil water content varied from 10.2 to 23.7 mm across the habitats. *D. sindicum* utilised soil water efficiently through its exhaustive root system (56% of total grass biomass). The reduction in height and crown diameter of tree seedlings was 18% to 58% due to varying density of *D. sindicum*. Growth of tree seedlings varied due to habitat conditions and tree species. *A. tortilis* seems to tolerate the competitive effect of the *D. sindicum* on all the habitats. *P. juliflora* showed optimum growth on the bare dune.

Resumen: El crecimiento y la supervivencia de *Acacia tortilis*, *Calligonum polygonoides* y *Prosopis juliflora* fueron estudiados en relación con las condiciones de hábitat y el efecto competitivo de *Dactyloctenium sindicum*. Con base en la microtopografía y la abundancia de *D. sindicum* fueron identificados seis diferentes hábitats: plantación en duna desnuda (BP), plantación en duna semiestabilizada (SP), plantación en terreno plano (FL), terreno plano con el pasto *Dactyloctenium sindicum* (FG), terreno plano sin vegetación (FW) y duna desnuda (BD). Se registraron la biomasa vegetal total (aérea y subterránea) y el contenido de agua en el suelo. Las reducciones en el crecimiento absoluto y relativo de las plántulas de árboles fueron calculadas para dos años sucesivos durante 1996-97 y 1997-98. La biomasa de pasto fue 438 g m^{-2} en FG pero disminuyó a 369 g m^{-2} en el hábitat SP. El contenido de agua en el suelo varió de 10.2 a 23.7 mm entre los hábitats. *D. sindicum* utilizó el agua del suelo eficientemente por medio de su sistema radicular exhaustivo (56% de la biomasa total del pasto). La reducción en la altura y el diámetro de la copa de las plántulas de especies arbóreas fue de entre 18% y 58% debido a las diferentes densidades de *D. sindicum*. El crecimiento de plántulas arbóreas varió debido a las condiciones de hábitat y las especies de árboles. *A. tortilis* parece tolerar el efecto competitivo de *D. sindicum* en todos los hábitats. *P. juliflora* mostró su mayor crecimiento sobre la duna desnuda.

Resumo: O crescimento e a sobrevivência da *Acacia tortilis*, *Calligonum polygonoides* e *Prosopis juliflora* foram estudados em relação às condições do habitat e aos efeitos competitivos da *Dactyloctenium sindicum*. Seis habitates diferentes, plantação em duna nua (BP), plantação em duma semi-estabilizada (SP), plantação em terra plana (FL), terra plana com vegetação de *Dactyloctenium sindicum* (FG), terra plana sem vegetação (FW) e duna nua (BD) foram

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identificadas numa base microtopográfica e de abundância de *D. sindicum*. A biomassa total (aérea e radicular) e o teor em água no solo foram registados. As reduções no crescimento relativo e absoluto nas plântulas, foram calculadas durante dois anos sucessivos, 1996-97 e 1997-98. A biomassa herbácea foi de 438 $g.m^{-2}$ em FG mas diminuiu para 369 $g.m^{-2}$ num habitat SP. O teor em água no solo variou de 10,2 a 23,7 mm ao longo dos diferentes habitates. A *D. sindicum* utilizou a água de forma mais eficiente através do seu sistema radicular extensivo (56% da biomassa herbácea total). A redução em altura e no diâmetro da copa das plântulas situou-se entre os 18% e os 58% devido à variação de densidade da *D. sindicum*. O crescimento das plântulas das árvores variou devido às condições de habitat e das espécies arbóreas. A A tortilis parece tolerar o efeito competitivo da *D. sindicum* em todos os habitates. A *P. juliflora* mostrou um crescimento óptimo na duna nua.

Key words: Arid region, dune area, habitat conditions, interspecific competition, plant growth, soil water.

Introduction

Success of afforestation programmes depends largely upon the environmental conditions and the site characteristics. The survival and growth rate of woody plants get reduced due to the competition of the plants and grasses for water and mineral resources (Richardson 1993). The magnitude of reduction in plant productivity depends on the intensity of competitive interactions (Inchousti 1995; Wilson & Tilman 1993). Biotic factors play an important role in resource limited habitats due to plant competition (Chapin & Shaver 1985; Tilman 1988). However, abiotic factors become important in the nutrient poor habitats (Campbell *et al.* 1991; Grime 1977; Keddy 1989). Plant communities of arid regions are of special interest because water is the major constraint for plant growth and their survival. The arid region of western Rajasthan receives rainfall for a very short period, during the rainy season that induces the growth of surface vegetation, which in turn, compete with the planted seedlings of the forestry plantations.

Dactyloctenium sindicum (Boiss) is a common perennial grass of arid regions that grows on sandy plain, semistabilized dune as well as on interdunal plain and suspected to compete with the introduced woody perennial for soil water and the nutrients. Therefore, the present study was carried out to ascertain the growth and establishment of *Acacia tortilis, Calligonum polygonoides* and *Prosopis juliflora* in relation to the habitat conditions with varying density of *Dactyloctenium sindicum*. *Calligonum polygonoides* (L.) is widely occurring shrub species of sand dune and sandy plains. *Acacia tortilis* and *Prosopis juliflora* are the exotic species widely used in sand dune stabilisation and forest plantations. The objective of the present study was aimed to analyse the effect of *Dactyloctenium sindicum* on soil water content as well as the seedling establishment of woody perennials on flatland and semistabilized dune in northwestern Rajasthan.

Materials and methods

Site conditions

The study was conducted at the experimental centre Bikaner of Arid Forest Research Institute, Jodhpur 28° 00′ N - 73° 18′E) in north-western part of Indian desert. Mean annual rainfall is 286 mm (Rao 1996), with very high variation in the rainfall. The maximum temperature ranges between 48°C to 52°C and minimum being 0 to 4°C. Microtopographically, there are two distinct types of habitats: the dune and the flatland with an average height difference 2-3 m. On the basis of growth of *Dactyloctenium sindicum* grass and plantation, the habitats were categorised as bare dune (BD), bare dune plantation (BP), semistabilized dune plantations (SP) flatland plantation (FL), flatland with *Dactyloctenium sindicum* grass only (FG) and flatland without vegetation (FW). The soil of the site is loamy sand with very low water holding capacity. Among the soil nutrient content, during September 1996, the soil organic matter ranged from 0.14% in FG to 0.10% in semistabilized dune plantation (SP) and 0.09% in BD. The NH_4-N ranged from 0.60 mg kg^{-1} in SP to 0.17 mg kg^{-1} in BD habitats on the other hand. FG and FW habitats had 0.44 and 0.30 mg kg^{-1} NH_4-N, respectively. NO_3-N was higher in SP (2.15 mg kg^{-1}) followed by BD (2.12 mg kg^{-1}), FW (1.89 mg kg^{-1}) and FG (1.48 mg kg^{-1}). The available PO_4-P was also high (3.03 mg kg^{-1}) in SP, followed by FG (3.01 mg kg^{-1}), BD (2.68 mg kg^{-1}) and FW (2.68 mg kg^{-1}).

Experimental design

The area covering bare dune, semistabilized dune and the flatland in foot of the dune covered with *D. sindicum* were selected and the seedlings of *Acacia tortilis, Calligonum polygonoides* and *P. juliflora* were planted in September 1996. The plantation was carried out in a 60 x 60 x 60 cm^3 pit size in randomized block design after removal of the prevailing shrubs like *Aerva pseudotomentosa* and *Leptadenia pyrotechnica*. A total number of 27 plots were laid out randomly from the plantation area such as BP, SP and FL habitats (three habitats x three species x three observation plots). The observation plots were marked for recording observations on plant growth and soil water content. There were 25 plants in each observation plot at the spacing of 5 x 5 m^2, giving rise to 75 plants per species per habitat. Similarly, 9 plots from the non-planted area (without plantation) viz., FG, FW and BD were also marked to compare them with planted area for soil resources. FW and BD habitats were maintained without any vegetation and taken as control for BP, FL and FG habitats. Thus, there were 36 observation plots covering six habitat types. For recording aboveground and root biomass, 12 random sample plots of one square meter area were laid in BP, SP, FL and FG habitats (three sample plots in each habitat).

Field sampling and measurements of growth parameters

The height and crown diameter of the planted seedling of *A. tortilis, C. polygonoides* and *P. juliflora* along with their survival rate were recorded annually in the month of November. Soil samples were collected from each observation plot at a depth of 75 cm and divided into three layers of 0-25, 25-50 and 50-75 cm. To observe the differences in soil water availability with distance, soil samples from the plantation area were collected from root zone (15 cm) as well as from the unplanted area. Soil water was estimated gravimetrically according to methodology adopted by Gupta (1995) by oven drying of the samples at 110°C till constant weight. The percent soil water was converted to mm water using the following equation:

$$\text{Soil water (mm)} = \frac{\text{soil water (\%)} \times \text{soil depth (mm)} \times \text{bulk density}}{100}$$

The aboveground biomass of *Dactyloctenium sindicum* grass was recorded in SP, FL and FG habitats during October 1998 at the end of monsoon period. Root biomass was estimated upto 0-90 cm of soil depth from the same sample plots of BP, SP, FL and FG habitats and dried at 80°C and weighed.

Absolute growth reduction (GR_A) of tree seedlings was calculated using the formula

$GR_A = Y_w - Y_c$; where, Y_w denotes the mean growth parameters viz., height and crown diameter of the plants in BP habitat and Y_c is the mean growth parameters of the plants of SP and FL habitats. Relative growth reduction determined as $GR_R = (Y_w - Y_c)/Y_w$.GR_A express the absolute growth reduction due to *D. sindicum*, while GR_R express the corresponding reduction standardised by mean growth parameters in BP habitat without *D. sindicum*.

Statistical analysis

The data on growth, absolute and relative growth reduction, grass biomass in different habitats and soil water content were statistically analysed using two way ANOVA model. For this, the soil water (recorded in % w/w) was transformed to root mean square value and plant survival data to arcsine value before analysis of variance (Sokal & Rohlf 1981). Pearson correlation coefficients (r) was used to observe the relationship between plant growth (height and crown diameter) with soil water as well as grass biomass and grass biomass alone with soil water in different habitats.

Results and discussion

Grass biomass

The flatland with grass (FG) had significantly (Table 1) higher biomass (above ground grass + root biomass to a depth of 90 cm) (F = 25.01, P<0.001) compared to FL and SP habitat, which

Table 1. Above and below ground root biomass of *D. sindicum* in relations to different habitat types. Values are mean ± SEm. BP: bare dune plantation, SP: semistabilized dune plantation, FL: flatland plantation, FG: flatland with *D. sindicum*. *P<0.05 and **P<0.01.

Habitat	Clumps (no. m-2)	Shoot Biomass (g m-2)	Root biomass (g m-2)			Total
			0-30 cm	30-60 cm	60-90 cm	
BP	-	-	14 ± 1.1	53 ± 2.0	39 ± 1.4	106 ± 3.6
SP	57 ± 2.6	159 ± 1.4	152 ± 3.1	34 ± 1.7	24 ± 2.13	210 ± 5.6
FL	63 ± 2.3	162 ± 4.8	165 ± 4.1	39 ± 1.6	32 ± 2.0	236 ± 5.2
FG	70 ± 2.2	191 ± 5.6	172 ± 3.3	44 ± 1.3	31 ± 1.70	247 ± 5.5
F values						
Habitats (H)	6.77**	25.01**a	262.88**b			
Layers (L)	-	228.76**a	2011.9**b			
H x L	-	3.17a	410.92**b			

a-ANOVA between shoot biomass and root biomass; b- ANOVA among the root biomass in different soil layers.

might be due to higher number of grass clumps as supported by positive correlation with grass clump density (r = 0.776, P = 0.014, n = 9). Root biomass was significantly higher (57%, P<0.001) than the above ground grasses biomass (43%) probably due to the greater carbon allocation in roots. These observations are in conformity to those reported by Givnish (1986). The root biomass was significantly (F = 2011.9, P<0.001) greater in 0-30 cm layer which decreased in accordance with soil depth and reaching lowest in 60-90 cm layer. The interaction between habitat x soil layer indicated variation in root density among the habitats and soil depth (F = 410.9, P<0.001). Hyder *et al.* (1971) have also reported similar variations in the root biomass due to soil depth in a semiarid short grass steppe dominated by *Boutelocia gracilis*.

Soil water content in relation to grass biomass

In plantation area, the soil water content in *C. polygonoides* plots (13.5 mm) was significantly (P<0.001) higher compared to *A. tortilis* plots (12.7

Table 2. Soil water content (% w/w and total in mm) in relation to habitat condition, plant species, and distance from the plants and soil depth. BP: bare dune plantation, SP: semistabilized dune plantation and FL: flatland plantation. Centre: 350 cm, near root: 15 cm.

Habitats	Soil depth (mm)	*Acacia tortilis*		*Calligonum polygonoides*		*Prosopis juliflora*	
		Centre	Near root	Centre	Near root	Centre	Near root
	0-25	0.96 ± 0.02	1.04 ± 0.03	1.17 ± 0.03	1.07 ± 0.03	1.06 ± 0.03	0.96 ± 0.02
BP	25-50	1.24 ± 0.04	1.25 ± 0.03	1.56 ± 0.02	1.07 ± 0.06	1.06 ± 0.06	1.09 ± 0.04
	50-75	1.29 ± 0.01	1.30 ± 0.04	1.69 ± 0.04	1.33 ± 0.03	1.50 ± 0.05	1.21 ± 0.03
Total		13.70	14.09	17.35	13.61	14.21	12.80
	0-25	1.35 ± 0.02	1.25 ± 0.03	1.24 ± 0.04	1.38 ± 0.02	1.42 ± 0.02	1.35 ± 0.02
SP	25-50	1.48 ± 0.06	1.37 ± 0.02	1.42 ± 0.02	1.45 ± 0.02	1.28 ± 0.01	1.51 ± 0.03
	50-75	1.04 ± 0.03	0.87 ± 0.05	1.32 ± 0.03	1.02 ± 0.04	1.10 ± 0.02	0.92 ± 0.02
Total		15.19	13.70	15.62	15.11	14.92	14.84
	0-25	0.74 ± 0.03	0.71 ± 0.03	0.70 ± 0.01	0.81 ± 0.02	0.87 ± 0.05	0.91 ± 0.93
FL	25-50	0.77 ± 0.02	0.76 ± 0.03	0.75 ± 0.01	0.68 ± 0.02	0.94 ± 0.03	0.92 ± 0.04
	50-75	1.15 ± 0.07	0.89 ± 0.04	1.16 ± 0.04	0.82 ± 0.04	0.97 ± 0.05	1.00 ± 0.05
Total		10.44	9.26	10.24	9.07	10.91	11.11

F values of the ANOVA: Habitat (H) - 682.61**; Species (S) - 15.76**; Distance (D) - 76.90**; Soil layer (L) - 39.02**; H x S - 23.83; H x D - 6.41**; H x L - 177.22**; H x S x D x L - 10.36**. Significant at **P<0.01.

mm) and *P. juliflora* (13.1 mm) (Table 2). Depletion of soil water was significantly more from the root zone compared to the centre of four plants (P<0.001). The significant variation in species to distance and species to soil depth interaction (P<0.05) indicate that soil water content changed depending upon the concentration and length of seedling roots. Highest soil water content in the centre of bare dune plantation of *C. polygonoides* has been attributed to the significant three way interactions (habitat x species x distance, P<0.01). Soil water depletion in BP habitat was 6.2 mm, which includes the evaporation losses from the soil surface and the transpiration losses from the tree/shrub species followed by 5.6 and 13.5 mm in SP and FL habitats. Therefore, the differences in the soil water content of habitats may be due to soil water depletion/loss owing to transpiration of seedlings and surface evaporation.

The variations in mean soil water content indicated that habitat had significant impact on soil water content (Fig. 1A-1D), which might be due to planted seedlings and the density of *D. sindicum* grass. Highest soil water in FW (23.7 mm) followed by BD habitat (20.5 mm) has been attributed to the sand cover because it acts as a mulch and reduces the water loss due to evapotranspiration (Kaul 1996). Significantly low water content in FG and FL indicated that *Dactyloctenium sindicum* extracted greater amount of soil water. The negative correlation between soil water content with above ground grass and root biomass also supports the inference drawn. Non-significant (P>0.05) differences in soil water content of FG, BP and SP habitats indicated that deep rooted *D. sindicum* was equivalent/or even more efficient than *A. tortilis* and *P. juliflora* of two year age in utilisation of top 0-75 cm soil water. In a similar study, Knoop & Walker (1985) found that the *Cenchrus ciliaris* dominated herb layers extracted soil water more efficiently than the mature woody plant of *Acacia tortilis* and *A. nilotica*, in wetter year.

Survival and growth of tree seedlings

Percentage survival (Table 3) of the tree seedlings differed significantly due to habitat and species both (P<0.01). Low survival in SP and FL habitats might be due to competitive effect of *D. sindicum* grass for soil water utilisation. Increased survival of *P. juliflora* seedlings in southern Arizona desert grassland has also been reported after removal of *Bouteloua eriopoda, Trichachne californica* and *Muhlenbergia porteri* grasses (Fowler 1986).

In the initial phase of seedling establishment,

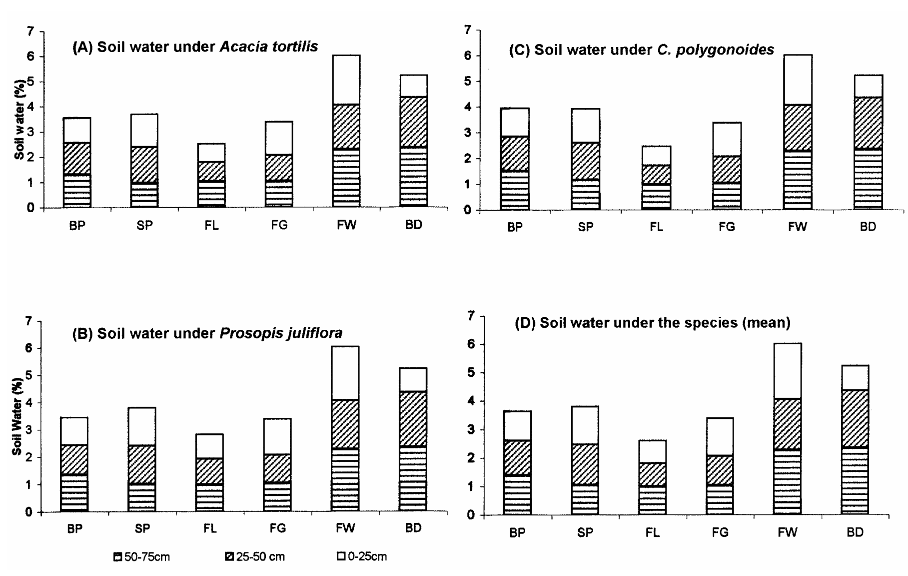

Fig. 1. Soil water status under different tree species in different habitat types; habitat code: BP-bare dune plantation; SP-semistabilized dune plantation; FL-flatland plantation; FG-flatland with *D. sindicum* grass; FW-flatland without vegetation and BD-bare dune.

Table 3. Growth of woody plant species under the influence of different habitat types during three year of study. Values are mean ± SEm. BP: bare dune plantation, SP: semistabilized dune plantation, FL: flatland plantation and H x S: habitats species interaction. *P<0.05 and **P<0.01.

Habitats	Species	Survival (%)	November 1996 Height (cm)	November 1997		November 1998	
				Height (cm)	Crown diameter (cm)	Height (cm)	Crown diameter (cm)
BP	*A. tortilis*	92 ± 4.9	37 ± 0.9	92 ± 7.6	86 ± 5.0	187 ± 8.7	143 ± 6.0
	C. polygonoides	79 ± 7.7	13 ± 0.6	90 ± 8.4	99 ± 2.0	169 ± 8.8	211 ± 16.8
	P. juliflora	85 ± 7.8	44 ± 1.2	152 ± 13.3	152 ± 4.7	256 ± 25.5	293 ± 18.3
SP	*A. tortilis*	99 ± 1.3	33 ± 1.7	76 ± 3.1	67 ± 2.1	152 ± 2.6	132 ± 3.3
	C. polygonoides	68 ± 4.5	15 ± 0.9	62 ± 4.4	62 ± 3.0	137 ± 6.8	144 ± 6.4
	P. juliflora	77 ± 7.3	15 ± 0.9	69 ± 5.2	117 ± 4.6	123 ± 7.6	127 ± 7.2
FL	*A. tortilis*	93 ± 1.7	35 ± 1.5	69 ± 3.9	55 ± 2.1	112 ± 5.5	119 ± 2.3
	C. polygonoides	59 ± 2.2	17 ± 0.9	27 ± 1.5	32 ± 2.0	71 ± 5.9	73 ± 6.0
	P. juliflora	47 ± 3.8	36 ± 1.5	49 ± 0.9	50 ± 2.3	61 ± 4.4	58 ± 4.2
F values	Habitat	7.52**	2.79	74.02**	299.75**	102.1**	47.37**
	Species	23.35**	379.1**	16.86**	143.06**	4.38*	6.52**
	H x S	2.09	8.48**	12.12**	32.33**	12.3**	33.86**

P = 0.028 for height and P = 0.007 for crown diameter

there were no significant differences (P>0.05) in the seedling height of the tree species (Table 3). With increase in the age of he seedlings, the habitat effect became more significant (P<0.001) due to changes in soil water, nutrient and light. After one year, growth of tree seedlings differed with species. The F value for the interaction between habitat x species indicated that *P. juliflora* showed best growth on bare dune (256 cm height and 292 cm crown diameter). *Acacia tortilis* attained maximum growth on SP and FL habitats. Its comparatively less growth in SP and FL habitats was probably be due to the presence of *D. sindicum* grass which competed for soil water with the planted seedlings. It was also supported by significant (P<0.05) negative correlation of growth parameters with above ground and root biomass of *D. sindicum* grass. The results are in conformity to the report that monospecific stand of *Enclia farinosa* showed higher water status and plant size after removing all the neighbouring plants (Ehleringer 1984). Such positive effect of removal of neighbouring plants on derived species has also been observed of other systems by Kadman (1995) and Aarssen & Epp (1990). Likewise, the absence of vegetation or weeds has also been found to increase the soil water availability and enhance the growth of woody plants (Gupta 1995; Clinton & Mead 1990).

Soil water utilisation and growth reduction

Out of 13.5 mm soil water content in FL habitat, 10.4 mm (77%) was utilised by *D. sindicum* sparing 3.1 mm (23%) for the woody plants, suggests greater proportion of soil water utilisation by *D. sindicum*. The competitive effect of *D. sindicum* (Table 2) for soil water probably reduced the height and crown diameter of the planted seedlings by 18% and 32% in SP and 58% and 54% in FL habitat, respectively (Table 4). The differences in soil water content between FW and FG habitats and those between BD and BP habitats indicate that *D. sindicum* utilised more soil water than *P. juliflora* and *A. tortilis* at two years of age. On the basis of such observation it is suggested that the increased absolute and relative reduction in FL over SP habitat compared to BP habitat were due to competitive effect of *D. sindicum* for soil water. There was positive correlation of absolute and relative reduction in growth with above ground grass biomass (r = 0.825 and 0.842, respectively, P<0.01) and the root biomass (r = 0.886 and 0.902, respectively, P<0.01) and non-significant negative correlation (r = -0.637 and -0.648, respectively, P>0.05) with total soil water (total water up to 75 cm soil depth) suggests competition induced growth reduction. The data in Table 4 suggests

less variations in absolute and relative reduction in growth for *A. tortilis*, intermediate for *C. polygonoides* and highest for *P. juliflora* indicating that *A. tortilis* performed better in all three habitats whereas *P. juliflora* was the best in BP habitat only. The results of the study suggest that competitive effect of plants need better understanding for the successful afforestation in arid areas.

Conclusion and recommendation

The presence of *Dactyloctenium sindicum* grass in SP and FL habitats reduced the soil water content. *D. sindicum* competed for soil water availability with *P. juliflora, A. tortilis* and *C. polygonoides* in different types of habitats and reduced the growth of woody plants. The density of grass and the habitat conditions influenced bioavailability of water to the planted seedlings. It has been concluded that water is a limiting factor to plant production in arid and semiarid areas. Presence of *D. sindicum* affects the growth and survival of planted seedlings through competitive effect for soil water utilisation. The physiographic conditions and soil water availability are important factors influencing seedling establishment. The removal of grass from the plantation area during the seedling establishment phase seems to be an important management strategy for successful afforestation.

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