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Impact of different tree species canopy on diversity and productivity of understorey vegetation in Indian desert

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Abstract: Community biomass of understorey vegetation under widely scattered trees of *Prosopis cineraria*, *P. juliflora*, *Azadirachta indica* and *Acacia nilotica* was assessed with the objectives to monitor diversity-productivity relation and to utilize positive interactions in silvopastoral and agroforestry systems. There was 83 to 88% reduction in photosynthetically active radiation (PAR) and 9 to 22% reduction in soil water content (SWC) in plots under tree canopy than in control plots. Species richness and species evenness were highest under *A. nilotica* and *P. juliflora,* respectively, whereas diversity index and species dominance were highest under *A. indica* and *P. cineraria*, respectively. Average population and community biomass was 3.1 and 2.9-fold higher under *P. cineraria* than in the control plots, whereas these variables were lowest under *A. nilotica* plots. Smaller population size and higher community biomass in *P. juliflora* compared to that in the *A. nilotica* and control plots was due to compensatory growth of *Peristrophe paniculata* (50% of total dry biomass) and reduced regeneration and population of species susceptible to *P. juliflora*. Negative value of relative neighbour effects (RNE) for population size and biomass in all the systems indicated facilitative effects of trees on vegetation productivity. Study indicated weak negative correlation between species richness and community biomass indicating interspecies competition. However, the increased productivity in tree canopy zone indicated that tree integration with grass would increase the productivity of pastureland in dry areas. *P. cineraria* is the best tree species for pasturelands with highest biomass of under canopy vegetation.

Resumen: Se evaluó la biomasa de la vegetación del sotobosque bajo árboles muy dispersos de *Prosopis cineraria*, *P. juliflora*, *Azadirachta indica* y *Acacia nilotica* con los objetivos de hacer un seguimiento de la relación diversidad-productividad y de utilizar las interacciones positivas en sistemas silvopastoriles y agroforestales. Hubo una reducción de 83 a 88% en la radiación fotosintéticamente activa (RFA) y una reducción de 9 a 22% en el contenido de agua del suelo (CAS) en parcelas ubicadas bajo el dosel arbóreo que en las parcelas control. La riqueza de especies y la equitatividad de las especies fueron mayores bajo *A. nilotica* y *P. juliflora,* respectivamente, mientras que el índice de diversidad y la dominancia de las especies alcanzaron sus máximos bajo *A. indica* y *P. cineraria*, respectivamente. La biomasa poblacional y la biomasa comunitaria promedios fueron 3.1 y 2.9 veces mayores bajo *P. cineraria* que en las parcelas control, mientras que estas variables tuvieron sus valores mínimos bajo variables bajo *A. nilotica*. El tamaño poblacional más pequeño y la biomasa mayor de la comunidad en *P. juliflora* en comparación con los de *A. nilotica* y las parcelas control se debió a un crecimiento compensatorio de *Peristrophe paniculata* (50% de la biomasa seca total) y a una reducción en la regeneración y en el tamaño poblacional de las especies susceptibles a *P. juliflora*. Un valor negativo de los Efectos Relativos de los Vecinos (ERV) para el tamaño poblacional y la biomasa

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en todos los sistemas indicaron que los árboles tienen efectos facilitadores sobre la productividad de la vegetación. El estudio mostró una correlación negativa débil entre la riqueza de especies y la biomasa de la comunidad, indicando que existe competencia interespecífica. Sin embargo, el aumento en la productividad en la zona del dosel arbóreo indicó que la integración de los árboles con el pasto podría incrementar la productividad del pastizal en sus áreas secas. *P. cineraria* es la mejor especie arbórea para las tierras de pastizal por tener la biomasa más grande bajo la vegetación del dosel.

Resumo: A biomassa da comunidade da vegetação de subcoberto de árvores muito espaçadas de *Prosopis cineraria*, *P. juliflora*, *Azadirachta indica* e *Acacia nilotica* foi avaliada com o objectivo de monitorizar a relação diversidade-produtividade e para utilizar as interacções positivas nos sistemas silvopastorais e agroflorestais. Verificou-se uma redução na radiação fotossintética activa (PAR) de 83 a 88% e 9 a 22% de redução no teor de água do solo (SWC) e de 9 a 22% nas parcelas debaixo da copa das árvores em comparação com as parcelas controlo. A riqueza e a uniformidade específica foi mais elevado debaixo de *A. nilotica* e *P. juliflora,* respectivamente, enquanto que o índice de diversidade e a dominância eram as mais altas debaixo de *A. indica* e *P. cineraria,* respectivamente. A população média e a biomassa da comunidade era de 3.1 e 2.9 vezes mais alta sob *P. cineraria* do que nas parcelas controlo, enquanto que foram as mais baixas sob as parcelas de *A. nilotica.* Menor tamanho da população e maior biomassa da comunidade na *P. juliflora*, comparada com a de *A. nilotica* e das parcelas controlo, ficou a dever-se ao crescimento compensatório da *Peristrophe paniculata* (50% da biomassa total seca) e baixa regeneração e da população de espécies susceptíveis à *P. juliflora.* O valor negativo dos Efeitos Relativos de Vizinhança (RNE) para o tamanho da população e da biomassa em todos os sistemas, indicam os efeitos facilitadores das árvores na produtividade da vegetação. O estudo indicou uma correlação negativa fraca entre a riqueza específica e a biomassa da comunidade indicando competição interespecífica. Contudo, a produtividade acrescida na zona do copado das árvores indica que a integração das árvores com a vegetação herbácea aumenta a produtividade da pastagem nas áreas secas. A *P. cineraria* é a melhor das espécies arbóreas para as pastagens com mais elevada biomassa debaixo do copado da vegetação.

Key words: Community biomass, resource availability, trees, vegetation diversity.

Introduction

Increase in human population, grazing, vegetation exploitation and nutrient deposition results in a decrease in biological diversity in many areas. This has led to decrease in ecological stability and functioning (Elton 1958; Tilman & Downing 1994). The fallout of increasing lack of resources is putting pressure on the existing forest resources for fuel wood and fodder. In most of the cases, annual use of biomass exceeds the sustainable yield of forests and woodlands resulting in gradual decline in these valuable resources. Uncontrolled grazing has completely prevented natural regeneration of vegetation in dry areas (Sinclair & Fryxell 1985). The influence of climate on the dryland vegetation is marked (Meher-Homji 1980; Sharma *et al*. 1980), and high evaporation and low precipitation exacerbate the negative effects of grazing and reduce stocking capacity of the land (Schlesinger *et al.* 1996). These factors cause a loss in diversity. The problem of loss in biodiversity is more in dry region compared to that in humid and in high rainfall region. Almost 80 species from 36 families are under different category of threat in Thar Desert of India (IUCN 2000), which is one of the most populated deserts of the world (Singhvi & Kar 1992). These species need to be conserved, propagated and managed for the benefit of mankind.

Invasion of alien shrubs and trees in these areas is thought to be a serious threat to long-term survival and sustainable production of indigenous species. In absence of proper management, these alien species (i.e., *Acacias* and *Prosopis*) dominate and transform the landscape affecting faunistic and floristic species richness (Chaukiyal *et al.* 2002; Richardson *et al.* 1989). These alien species modify habitats through soil mineral enrichment by increasing litterfall and its decomposition, attenuation of solar radiation and reduced soil water availability under the canopy. Thus, there is need to study the effect of these species on the vegetation diversity and productivity and to define appropriate technical strategies to manage these species not only to increase species diversity but also to maintain sustainable productivity of pastureland in dry areas.

Here we studied aboveground community biomass of vegetation associated with *Prosopis cineraria*, *Prosopis juliflora*, *Azadirachta indica* and *Acacia nilotica* trees in a dry environment of Indian desert. *P. cineraria* and *A. nilotica* are indigenous to the region and are considered useful for their valuable contribution to the local economy. *A. indica* is introduced from a relatively moist area whereas *P. juliflora* is an alien species (Paiecznik *et al.* 2001). Therefore, specific objective was to study tree vegetation interaction in terms of vegetation diversity and community productivity in order to find out suitable tree-vegetation combination that can increase productivity of pasturelands in the region.

Materials and methods

Study conditions

Observations were initiated at the experimental field of Arid Forest Research Institute, Jodhpur (26^0 45′ N latitude and 72^0 03′ E longitude). Mean annual rainfall of the site is 350 mm. However, it showed wide variations between years resulting in four severe droughts in every 10 years (NACPD 2001). The maximum temperature rises to 48^0C in the summer and the minimum temperature drops to 0 ^{0}C in the winter. Average wind velocity in the summer months is 20-30 km h^{-1}.The experimental farm is flat land with loamy sand soil (coarse loamy, mixed hyperthermic, family of Typic Camborthids according to US soil taxonomy) underlain with a thick concretion of calcium carbonate at a depth of 75 cm. The soil pH is 7.8. Soil moisture storage in the upper 75 cm layer varies from 120 mm at -0.01 MPa to 35 mm at -1.5 MPa.

Experimental design and observations

Naturally growing existing rain-fed trees of *Prosopis cineraria*, *Prosopis juliflora*, *Azadirachta indica* and *Acacia nilotica* were identified from an area of about 17 ha. Ten trees of each species were randomly selected in June 2003 for the study purposes. Growth variables like height, crown diameter and diameter at breast height were measured for the selected trees. Quadrats of 1 m^2 area were laid under the canopy of each tree for recording species diversity, population and biomass. Similarly, 10 plots were laid randomly in the area away from the tree canopy to avoid any shading effect. The experiment was laid out in completely randomized design with 10 replicates. The area was protected from biotic interferences. Photosynthetically active radiation (PAR) was measured in each plot in September 2003 using CID, CO_2 analyzer between 10.00 to 11.00 h.

Aboveground vegetation was sampled by clipping at the soil surface from each marked plots during August to September 2003. All living vascular vegetation was sorted by species and population of each species was recorded. Fresh biomass of each species was recorded immediately after harvesting. Dry mass of each species was recorded after oven drying of the samples at 65 ^{0}C. The summed dry mass of all aboveground living vascular plant species from the harvest is called 'community biomass' and was approximately proportional to aboveground primary productivity. Soil samples were collected from 0-30 cm soil layers in September 2003 (immediately after vegetation harvesting) so that soil water content could be determined and utilization of soil water by the vegetation could be assessed. These soil samples were brought to the laboratory and then dried at 110 ^{0}C to constant weight.

Qualitative estimation of species diversity and tree facilitation

Relative density (D), relative frequency (F) and abundance (A) were calculated by the following formulae. D (%) = Number of individuals of a species x 100/ total number of individuals of all species, F (%) = Frequency of a species x 100/ sum of frequency value for all species, and A = total number of individuals of a species in all quadrats/ number of quadrats in which species was present. The index of species diversity (H') and index of species dominance (c) were estimated as described by Shannon & Weaver (1963) and Simpson (1949), respectively. Index of species richness (d) and index of species evenness (e) have been quantified following Margalef (1968) and Pielou (1966), respectively. Effect of tree on vegetation diversity and biomass production was assessed through a relative neighbour effect (RNE) calculation (Markham & Chanway 1996). RNE = $(X_t - X_c)/x$, where, X was the population of target variables in absence (t) and presence (c) of tree and x was the higher of X_t or X_c. Negative values of RNE indicated facilitation and positive values indicated competition effects.

Data processing

Data were statistically analysed using SPSS statistical package (Lindman 1992). Tree growth variables, number of species, species population and community dry biomass were analysed using a one-way ANOVA. Percent soil water was square root transformed before statistical analysis (Sokal & Rohlf 1981). To obtain the relations between vegetation diversity, community dry biomass, photosynthetically active radiation (PAR) and soil water content (SWC) under the trees; a Pearson correlation analysis was performed. The least significant difference test was used to compare treatments at the $p < 0.05$ level.

Results

Environmental factors

Rainfall was 324.6 mm in 27 days during July to September 2003. However, average rainfall and pan evaporation for the last 10 years indicated high soil water deficit at the experimental site (Singh 2005). Potential evapo-transpiration varies between 2.47 mm d^{-1} in December to 8.54 mm d^{-1} in May (Rao *et al.* 1971). Photosynthetically active radiation (PAR) varied significantly between the control and the canopy zone of different tree species. PAR was highest in the control plots (2284.4 µmol m^{-2} s^{-1}) whereas it oscillated between 276.4 µmol m^{-2} s^{-1} in the canopy zone of *A. indica* to 376.8 µmol m^{-2} s^{-1} in the canopy zone of *P. cineraria* (Table 1) with a reduction to a level of 83 to 88% in the canopy zones of the trees.

Soil water content

Soil water content (SWC, %) in 0-30 cm soil layer was significantly higher (P<0.01) in the control plots than in the tree associated plots (Table 1). SWC was lowest in the canopy soil of *P. cineraria* whereas it did not differ (P>0.05) between *P. juliflora* and *A. indica* and those between *A. indica* and *A. nilotica* plots. There was a decrease in SWC by 23% in the canopy zone of *P. cineraria* and that of 9% in the canopy zone of *A. nilotica*.

Table 1. Mean growth variables of scattered trees and their effect on photosynthetically active radiations (PAR) and soil water content (SWC). Values are means of ten replications ±SE.

Parameters	System					ANOVA result	
	P. cineraria	*P. juliflora*	*A. indica*	*A. nilotica*	Control	F value	P value
Height (cm)	556.0	544.0	568.0	434.0	-	62.3	0.000
	±6.2	±7.9	±7.4	±5.5	-		
Crown diameter (cm)	384.0	604.0	464.0	410.0	-	59.3	0.000
	±5.2	±7.9	±18.9	±5.2	-		
Collar girth (cm)	52.4	56.2	50.0	39.6	-	13.3	0.000
	±0.8	±1.5	±2.8	±0.8	-		
PAR (□mol m^{-2} s^{-1})	376.8	277.0	276.4	334.1	2284.4	2877.2	0.000
	±5.4	±2.4	±2.1	±5.0	±35.9		
SWC (%, w/w)	2.14	2.33	2.42	2.52	2.76	40.42	0.000
	±0.02	±0.10	±0.04	±0.06	±0.03		

Table 2. Density (D), frequency (F) and abundance (A) of vegetation in the canopy zone of scattered trees in Indian desert.

Vegetation species	*P. cineraria*			*P. juliflora*			*A. indica*			*A. nilotica*			Control		
	D	F	A	D	F	A	D	F	A	D	F	A	D	F	A
Alysicarpus longifolius (Rottb. & Spreng)	-	-	-	-	-	-	-	-	-	1.4	20	7.0	1.8	30	6.0
Aristida adcensionis Linn.	32.2	90	35.8	-	-	-	53.7	70	76.7	71.6	50	143.5	27.8	90	30.9
Brachiaria ramosa Linn.	9.8	30	32.7	17.0	60	28.3	15.7	40	39.3	9.1	40	22.5	-	-	-
Cassia pumila Lanek	-	-	-	-	-	-	-	-	-	-	-	-	0.6	10	6.0
Cenchrus biflorus Roxb.	23.2	60	38.7	-	-	-	22.3	50	44.6	7.4	70	10.57	8.2	60	13.7
Cenchrus ciliaris Linn.	7.5	20	37.5	-	-	-	0.5	10	5.0	-	-	-	-	-	-
Cenchrus pennisetiformis Hochat.	1.0	20	5.0	8.9	40	22.3	2.5	20	12.5	1.6	30	5.3	5.5	60	9.2
Chloris virgata SW	-	-	-	-	-	-	-	-	-	0.8	10	8.0	-	-	-
Cleome viscosa Linn.	12.3	50	24.6	-	-	-	-	-	-	0.9	20	4.5	-	-	-
Corchorus tridens Linn.	-	-	-	-	-	-	-	-	-	6.6	50	13.2	2.0	40	5.0
Cyperus rotundus Linn.	10.7	30	35.7	8.1	40	20.2	22.0	30	73.3	10.5	30	35.0	10.2	60	17.0
Dactyloctenium aegyptium Linn.	4.3	30	14.3	7.9	20	39.5	1.4	10	14.0	2.3	30	7.7	3.6	10	36.0
Dactyloctenium sindicum Boiss.	-	-	-	3.6	20	18.0	3.4	30	11.3	-	-	-	-	-	-
Digitaria ciliaris Retz.	-	-	-	35.6	50	71.0	-	-	-	6.1	40	15.3	-	-	-
Eragrostis minor Host.	-	-	-	-	-	-	-	-	-	2.1	10	21.0	5.2	20	26.0
Indigofera cordifolia Heyne ex Roth	270.5	70	386.4	-	-	-	28.1	80	35.1	42.5	100	42.5	34.9	100	34.9
Indigofera linifolia (Linn.) Retz	-	-	-	-	-	-	-	-	-	-	-	-	0.4	10	4.0
Peristrophe paniculata Forsk.	-	-	-	45.6	100	456.0	6.6	30	33.0	3.5	30	11.7	-		
Phyllanthus fraternus Webster	-	-	-	15.1	80	18.9	4.4	20	22.0	0.4	10	4.0	-	-	-
Tephrosia purpurea Linn.	5.8	50	11.6	-	-	-	-	-	-	6.2	60	10.3	16.1	80	20.1
Tribulus terrestris Linn.	2.8	20	14.0	-	-	-	1.4	70	2.0	0.6	10	6.0	0.4	20	2.0

Vegetation diversity

Twenty-one vascular plant species were recorded in the area (Table 2). Out of these, 17 species were observed in the *Acacia nilotica* plot, whereas the number of species were 12, 11 and 8 under *A. indica*, *Prosopis cineraria* and *P. juliflora*, respectively. Control plots exhibited 13 species. Among the species, *Cyperus rotundus*, *Dactyloctenium aegyptium* and *Cenchrus pennisetiformis* were recorded in all the plots, *Cassia pumila* and *Indigofera linifolia* were recorded only in the control plots whereas *Chloris virgata* was recorded only in the *A. nilotica* plots. The species with highest relative density were *I. cordifolia* under *P. cineraria*, *Aristida adscensionis* under *A. indica* and *Peristrophe paniculata* under *P. juliflora* plots (Table 2). Lowest relative density was recorded for *C. pennisetiformis* in the *P. cineraria*, *D. sindicum* in the *P. juliflora*, *C. ciliaris* in the *A. indica*, *Phyllanthus fraternus* in the *A. nilotica* and *Tribulus terrestris* in the control plots (Table 2). Relative frequency was highest in the control and *A. nilotica* plots for *I. cordifolia* and in the *P. juliflora* for *P. paniculata* (Table 2). Relative frequency was lowest for *I. linifolia*, *C. pumila* and *D. aegyptium* in the control plot, *C. pennisetiformis*, *C. ciliaris* and *T. terrestris* in the *P. cineraria* plot, *D. aegyptium* and *C. ciliaris* in the *A. indica* and *Eragrostis minor*, *D. sindicum*, *P. fraternus*, *C. virgata* and *T. terrestris* in the *A. nilotica* plots. Species abundance was highest for *I. cordifolia* in the *P. cineraria*, for *P. paniculata* in the *P. juliflora* and for *A. adscensionis* in the *A. nilotica* plots. Variations between lowest and highest values of abundance were greater in the *P. juliflora* plots and smaller in the control plots.

Species diversity index (*H'*) was highest under *A. indica* and lowest under *P. cineraria* (Table 3). Index of species dominance (c) and species richness (d) were highest for *P. cineraria* and *A. nilotica* plots, respectively, whereas the lowest values were for *P. juliflora* plots. However, index of species evenness (e) was highest under *P. juliflora* and lowest under *A. nilotica*.

Population variation and community biomass

Population and biomass of individual species differed significantly ($P<0.05$) between the scattered tree species canopies and control plots. These variables were highest for *I. cordifolia*, *C. biflorus*, *Cleome viscosa*, *C. ciliaris* and *T. terrestris* in the *P. cineraria* plots (Table 4). *Brachiaria ramosa*, *D. aegyptium*, *D. sindicum*, *Digitaria ciliaris*, *P. fraternus* and *P. paniculata* indicated highest population and biomass in *P. juliflora* plots. Population and biomass were highest for *C. rotundus* in the *A. indica* and for *A. adscensionis*, *Corchorus tridens* and *C. virgata* in the *A. nilotica* plots. Control plots indicated highest ($P<0.05$) population and biomass of *T. purpurea*, *Alysicarpus longifolius*, *E. minor* and *C. pennisetiformis*.

Average number of species (per plot) was highest in *A. nilotica* plots whereas population of vascular plant species was highest in *P. cineraria* plots. Lowest population was recorded in the control plots (Table 5). Community biomass (both fresh as well as dry) varied significantly ($P<0.01$) between the treatments (tree species and open plots). When compared with the control plots, dry biomass was 2.9-fold in the *P. cineraria*, 1.6-fold in *A. indica*, 1.4-fold in *P. juliflora* and 1.3-fold in *A. nilotica* plots, whereas the corresponding increase in population was 3.1, 1.3, 1.4 and 1.2-fold. Water content in the vascular plants did not differ between the treatments but it was highest in the species associated with *P. juliflora* and was lowest in the species associated under *P. cineraria*. Relative contribution of individual species in the community dry biomass differed significantly ($P<0.01$) due to scattered tree species. *I. cordifolia* contributed 41, 32 and 37% of community dry biomass in the *P. cineraria*, *A. nilotica* and the

Table 3. Indices of diversity in the vegetation in the canopy zone of scattered trees in Indian desert.

Parameters	Treatment				
	P. cineraria	*P. juliflora*	*A. indica*	*A. nilotica*	Control
Diversity index (*H'*)	1.093	1.815	1.914	1.887	1.863
Species dominance (c)	0.563	0.197	0.188	0.243	0.208
Index of species richness (d)	1.211	0.962	1.486	2.145	1.685
Index of species evenness (e)	0.793	0.873	0.770	0.666	0.726

Table 4. Population (P) and dry biomass B (g m^{-2}) of individual species of vegetation in the canopy zone of isolated trees in Indian desert.

Species	System										ANOVA result			
	P. cineraria		*P. juliflora*		*A. indica*		*A. nilotica*		Control		Population		Dry biomass	
	P	B	P	B	P	B	P	B	P	B	F	Prob.	F	Prob.
A. longifolius (Rottb. & Spreng)	-	-	-	-	-	-	1.4	2.0	1.8	3.4	1.97	>0.05	2.16	>0.05
A. adcensionis Linn.	21.5	48.2	-	-	53.7	53.5	71.6	63.3	27.8	40.4	3.19	0.022	2.69	0.043
B. ramosa Linn.	9.8	13.1	17.0	22.8	15.7	22.2	9.1	12.2	-	-	1.57	>0.05	1.39	>0.05
C. pumila Lanek	-	-	-	-	-	-	-	-	0.6	0.2	-	-	-	-
C. biflorus Roxb.	23.2	52.8	-	-	22.3	25.7	7.4	12.8	8.2	11.5	2.75	0.040	3.52	0.014
C. ciliaris Linn.	7.5	16.0	-	-	0.5	13.6	-	-	-	-	1.19	>0.05	0.93	>0.05
C. pennisetiformis Hochat.	1.0	2.8	8.9	14.7	2.5	11.9	1.6	2.2	5.5	17.0	2.35	>0.05	1.34	>0.05
C. virgata SW	-	-	-	-	-	-	0.8	0.7	-	-	-	-	-	-
C. viscosa Linn.	12.3	19.6	-	-	-	-	0.9	3.6	-	-	1.90	>0.05	2.68	0.044
C. tridens Linn.	-	-	-	-	-	-	6.6	6.0	2.0	4.0	6.02	0.001	4.03	0.007
C. rotundus Linn.	10.7	13.0	8.1	18.0	22.0	25.0	10.5	16.1	10.2	11.2	0.42	>0.05	0.30	>0.05
D. aegyptium Linn.	4.3	5.1	7.9	9.7	1.4	1.5	2.3	4.7	3.6	4.8	0.57	>0.05	0.53	>0.05
D. sindicum Boiss.	-	-	3.6	19.4	3.4	8.7	0.6	1.1	-	-	1.78	>0.05	1.38	>0.05
D. ciliaris Retz.	-	-	35.5	37.5	-	-	-	-	-	-	-	-	-	-
E. minor Host.	-	-	-	-	-	-	2.1	0.5	5.2	2.1	1.55	>0.05	1.83	>0.05
I. cordifolia Heyne ex Roth	270.5	281.5	-	-	28.1	34.1	42.5	71.9	43.7	63.1	4.33	0.005	4.52	0.004
I. linifolia (Linn.) Retz	-	-	-	-	-	-	-	-	0.4	0.2	-	-	-	-
P. paniculata Forsk.	-	-	45.6	120.5	6.6	37.8	6.2	6.1	-	-	18.08	0.000	11.05	0.000
P. fraternus Webster	-	-	15.1	8.6	4.4	5.9	0.4	0.7	-	-	7.74	0.000	3.81	0.009
T. purpurea Linn.	5.8	16.5	-	-	-	-	6.2	7.9	16.1	24.9	2.02	>0.05	3.29	0.019
T. terrestris Linn.	2.8	21.4	-	-	1.4	35.3	0.6	2.7	0.4	2.5	1.32	>0.05	3.52	0.014

control plots. *A. adscensionis* contributed 21% of community dry biomass in *A. indica* whereas *P. paniculata* contributed about 50% of community dry biomass in the *P. juliflora* plots.

Relative neighbour effect

The relative neighbour effect (RNE) for the average number of species ranged from 0.200 in the *P. juliflora* to -0.011 in the *A. nilotica* plots (Table 6). The $RNE_{population}$ was negative with all the tree species except in the *P. juliflora* and it was lowest (more negative) in the *P. cineraria* trees. Relative neighbour effects for community biomass ($RNE_{biomass}$) were negative with all the tree species. The $RNE_{biomass}$ was lowest (P<0.01) in the *P. cineraria* plot, whereas it was higher in the *A. nilotica* plot as compared to the other tree species.

Discussion

Resource availability and vegetation diversity

Tree canopy attenuated solar radiation as evidenced by 83 to 88% a reduction in PAR value as compared to that in the control plots. Greater (P<0.05) interception of light by *A. indica* and *P. juliflora* canopies as compared to those of *P. cineraria* and *A. nilotica* canopies was due to the dense foliage in the former species. However, lesser crown spread and height of the canopy from ground level in *P. cineraria* and *A. nilotica* than in *P. juliflora* and *A. indica* trees might also allow greater PAR to reach in the canopy zone (Table 1). Despite significantly (P<0.01) low PAR reaching to the canopy zone, soil water content was low (P<0.05) in the canopy zone soil. This decrease in SWC was due to increase in herbaceous vegetation

Table 5. Average number of species, their population, community dry biomass and vegetation water status in the canopy zone vegetation influenced by scattered trees in Indian desert. Values are means of ten replications ±SE.

Parameters	Treatment					ANOVA result	
	P. cineraria	*P. juliflora*	*A. indica*	*A. nilotica*	Control	F value	P value
Species	4.9	4.2	4.7	6.1	6.0	5.86	0.001
(no. m-2)	±0.3	±0.4	±0.3	±0.3	±0.4		
Population	386.2	144.7	165.7	170.4	126.7	4.27	0.005
(no m-2)	±105.8	±22.8	±22.7	±28.3	±13.3		
Fresh mass	980.2	553.5	559.9	442.5	368.9	6.89	0.000
(g m-2)	±167.0	±52.6	±72.0	±62.3	±32.9		
Dry mass	521.2	259.4	284.2	227.0	181.5	6.77	0.000
(g m-2)	±98.4	±26.9	±38.4	±28.5	±15.1		
Water content	48.1	53.6	49.5	48.2	50.6	1.82	>0.05
(%)	±2.1	±1.1	±1.1	±2.5	±1.1		

Table 6. Relative neighbour effects (RNE) of scattered trees on average number of species, population and community mass per m² area. Values are means of ten replications ±SE.

Parameters	Treatments				ANOVA result	
	P. cineraria	*P. juliflora*	*A. indica*	*A. nilotica*	F value	P value
$RNE_{Species}$	0.122	0.200	0.144	-0.011	2.80	0.054
	±0.056	±0.064	±0.037	±0.053		
$RNE_{Population}$	-0.206	0.014	-0.031	-0.034	3.92	0.016
	±0.083	±0.021	±0.012	±0.028		
$RNE_{Biomass}$	-0.268	-0.061	-0.081	-0.036	5.14	0.005
	±0.080	±0.024	±0.033	±0.024		

growing under the canopy zone (Belsky *et al.* 1993). Because the vascular plant species grew faster in the tree canopy zone as compared to that in the control plots (open area), canopy zone vegetation extracted increasingly greater amount of water from the soil. As a result, by the later parts (i.e., September) of the growing season (July to September) more water was lost through transpiration from the canopy zone vegetation resulting in relatively low soil water content in the canopy zone soil than in the soil of control plots. This is evidenced by lowest ($P<0.05$) SWC in the canopy zone soil of *P. cineraria*, which was associated with highest community biomass.

Lower diversity under the canopy of *P. cineraria* and *P. juliflora* indicated that natural vegetation less successfully regenerated under tree canopy than in the control plots (Table 3). There was a weak positive correlation ($r = 0.326$, $P<0.05$, $n = 50$) between PAR and average number of species per plot. However, greater species diversity and species richness in the *A. indica* and *A. nilotica* plots (i.e. equal to that in the control plots) indicated that these species did not have a negative effect on the regeneration and survival of local flora as evidenced by negative $RNE_{species}$. However, low population and community biomass in the *A. nilotica* plots as compared to the plots of other tree species suggested that the adverse effect of *A. nilotica* was more on growth and productivity than on regeneration and survival of the natural flora (Table 4). This was similar to observations recorded in Indian desert in which effect of adult neighbour was greater on seedling growth and biomass rather than regeneration and survival of the surface vegetation i.e., *C. angustifolia* (Singh *et al.* 2003). Inouye *et al.* (1980) reported that the competition among annual plant species of the Sonoran Desert reduced growth rate and biomass but did not affect their survival. Variations in species abundance and dominance with the associated tree species indicated adaptability of vegetation species to the modified microclimate like *I. cordifolia* with *P. cineraria* and *P. paniculata* with *P. juliflora.* This is evidenced by higher range of relative frequency in *P. juliflora* and *P. cineraria* (Table 2). However, comparatively less variation in the values of species relative density and abundance in the control plots than in the tree associated plots indicated greater stability in the control plot i.e., having greater number of species and index of species richness. Higher species evenness in the *P. juliflora* plots was associated with low number of species and low species richness.

Community population and biomass

Comparatively greater population and community biomass in the tree-associated plots clearly demonstrated that the tree species had a positive influence on canopy zone vegetation (Holzapfel & Mahall 1999). Both these variables were positively related ($r= 0.905$, $P<0.001$, $n = 50$) to each other. A 3.1 fold and 2.9 fold higher population and community dry biomass in the *P. cineraria* plots suggested that *P. cineraria* had greater ($P<0.01$) facilitative effect on vegetation productivity (Table 5). Highest above ground biomass in vicinity of trees have also been recorded in other studies (Gupta & Saxena 1978; Shankar *et al.* 1976). Gupta & Saxena (1978) recorded 234.4 g m^{-2} dry biomass of ground flora under tree canopy of *P. cineraria* as compared to 167.0 g m^{-2} with *T. undulata*, 132.1 g m^{-2} with *A. lebbeck*, 85.1 g m^{-2} with *P. juliflora* and 78.4 g m^{-2} with *Acacia senegal* in Indian desert. This is also indicated by lowest value of $RNE_{population}$ and $RNE_{biomass}$ in *P. cineraria* plot (Table 6). Negative values of $RNE_{population}$ and $RNE_{biomass}$ were also observed in the *A. nilotica*, *A. indica* and *P. juliflora* plots indicating their facilitative effect on population growth and community biomass production. However, these variables did not differ between the *A. nilotica*, *A. indica* and *P. juliflora* plots as well as the control plot. Relatively higher community biomass (1.4 fold) than population (1.2 fold) in the *P. juliflora* plots as compared to those in the control plots were probably due to greater growth of the individual plants as a function of lower population density. Lesser population and species richness in the *P. juliflora* plots probably reduced the level of competition for soil resources (Tilmann 1996). This was evinced by greater ($P<0.05$) plant water status in the *P. juliflora* plots than in the plots of the other tree species (Table 5). Furthermore, the decrease in shade susceptible species and compensatory increase in the population of the other species (particularly *P. paniculata* in *P. juliflora* plot) would cause increased variability in the biomass of individual species. Lower community biomass in *A. nilotica* plots as compared to the plots of other tree species was probably due to less soil water availability that affected growth and production of the canopy zone vegetation. Inter-species competition because of greater number of species (higher species richness) may also be one of the reasons for low community biomass. Lowest community biomass in the control plots was also due to interspecific competition for the resources as these plots also had greater index of species richness as compared to the other plots (except for the *A. nilotica* plots). Tilman (1996) explained variability in growth as a result of competition at higher diversity and the competition release when drought sensitive plants were harmed by drought. This indicated a decrease in community biomass when species richness increases (Tilmann & Downing 1994).

Conclusions and recommendation

The results of this study suggested that trees modified the microclimate and influenced diversity and productivity of canopy zone vegetation. The trees reduced PAR by 83 to 88% and soil water content by 9 to 22% in the canopy zone than those in the control plot. Highest species dominance and lowest diversity index were recorded for vegetation under *P. cineraria* whereas *P. juliflora* trees were associated with lowest species richness and highest species evenness. Highest average population and community biomass in the *P. cineraria* plots indicated highest facilitative effect of *P. cineraria* tree on the canopy zone vegetation. This indicated that presence of tree canopy promoted regeneration and productivity of the natural vegetation in the dry areas by ameliorating the adverse conditions particularly in dry areas (Frost & Mcdogald 1989; Singh *et al.* 2003). However, highest species richness and lowest community biomass in *A. nilotica* plots indicated a negative relation between these two variables though results of enhancing vegetation productivity under tree canopy emphasized the importance of tree integration in silvipastoral systems. *P. cineraria* was found the best tree species for silvopastoral system with highest biomass of under canopy vegetation.

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