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# Effect of Resource Management on Diversity and Productivity of Vegetation Associated with *Prosopis juliflora* in Indian Arid Zone

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**Abstract:** Diversity and productivity of vegetation associated with *Prosopis juliflora* (Swartz DC) was studied to monitor the impact of this invasive alien species on indigenous flora of the Indian desert. Resource management treatments in the form of canopy removal and trenching around tree root zone were: intact tree without trench ($T_1$), intact tree and trench ($T_2$), lopped tree without trench ($T_3$), lopped tree and trench ($T_4$) and control plots without tree ($T_5$). Photosynthetically active radiations (PAR) reduced by 86-87% under *P. juliflora*. A total of 20 plant species were recorded. Species richness, diversity and evenness were significantly greater ($P<0.05$) in $T_1$ and $T_2$ as compared to $T_3$ and $T_4$ treatments. Treatments with intact canopy produced 2.1-fold greater biomass than the lopped ones. Decrease in relative neighbour effect (RNE) values for diversity variables and community biomass in $T_2$ and $T_4$ than their respective value in $T_1$ and $T_3$ treatments indicates positive effect of trenching. A greater difference in RNE between intact and lopped trees as compared to that between trenched and untrenched treatments showed that the beneficial effect of canopy retention was greater than trenching around tree in this environment. Temporal changes indicated highest biomass in September, thereafter it decreased by 35%, 50% and 70% in December, March and June, respectively. Conclusively, highest diversity and vegetation biomass in $T_2$ treatment indicated beneficial effect of both canopy and trenching, which can be adopted to increase the productivity of rangelands with *P. juliflora*. However, optimization of density is required to increase the production of rangeland grasses.

**Key words:** Arid region, photosynthetically active radiations, species diversity, vegetation dynamics, Indian desert, *Prosopis juliflora*.

Invasive plant species are causing big challenges to global ecosystems and biodiversity (Manchester and Bullock, 2000; D'Antonio and Kark, 2002). *Prosopis juliflora* (Swarz) DC (Family-Mimosaceae) is one of the commonest invasive tree species found in the dry tropics (Pasiecznik *et al.,* 2001). It has been extensively planted to meet fuel and fodder needs in drier climates of the tropics (Pasiecznik *et al.*, 2004). *P. juliflora* improves soil fertility, controls soil erosion, stabilizes sand dunes, provides fuel wood and feed/forage for livestock, live fencing and timber wood (Singh and Rathod, 2002; Zeila *et al.*, 2004; Esther and Brent, 2005). Because of high biomass production even on degraded land, *P. juliflora* provides more and good quality firewood and charcoal than other tree species (Ahmed *et al.*, 1994). However, there are reports, which contrast some of the described benefits (Zainal *et al.*, 1988). *P. juliflora* forms impermeable dense thickets, which reduces grass cover of grazing lands adversely affecting stocking density (Pasiecznik, 1999). The leaves have allelopathic effects inhibiting under canopy growth (Al-Humaid and Warrag, 1998; Nakamo *et al.*, 2003); the pollen causes allergic reactions (Pasiecznik, 1999) and the thorns are poisonous both for humans and animals. In Kachchh region of Gujarat, India, *P. juliflora* has invaded more than half of Bani grassland causing considerable damage on indigenous flora and fauna by reducing the availability of palatable grasses (Gavali *et al.*, 2003).

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Special attention is required to manage this invasive species by adopting suitable technical strategies to maintain its population and production of indigenous flora in the rangelands for the benefits of local people. Therefore, it is utmost necessary to study the changes in vegetation pattern, composition and production of the vegetation associated with *P. juliflora*. This study was carried out to answer if *P. juliflora* influences floral diversity and productivity and if resource management improves diversity and productivity of the associated vegetation. Enhancing productivity of pastureland/rangelands in dry areas without degrading land resources is the ultimate objective.

## Materials and Methods

### *Study area*

The experiment was conducted at AFRI, Jodhpur (26°45′ North latitude and 72°03′ East longitudes) during 2001-2004. The climate of the region is dry tropical. Mean monthly maximum and minimum temperatures varied from 32.41 to 35.31°C and 19.48 to 21.11°C, respectively. Mean maximum and minimum relative humidity varied from 50% to 67% and from 22% to 35%, respectively (Fig. 1). Average annual rainfall during 1995 to 2004 was 318.1 mm with 90% of rainfall between June and September. Rainfall during experimental period indicated wide variation with drought during 2002-2003 (Table 1). The rainfall was 402.0 mm during June 2001 to May 2002, 72.3 mm during June 2002 to May 2003 and 392.0 mm during June 2003 to May 2004. However, rainfall during cropping season of June to September was highest in 2003. The soil of the experimental site was coarse loamy, mixed hyperthermic family of Camborthids according to US soil taxonomy. Soil pH and organic matter in upper 0-30 cm soil were 7.9 and 0.218%, respectively.

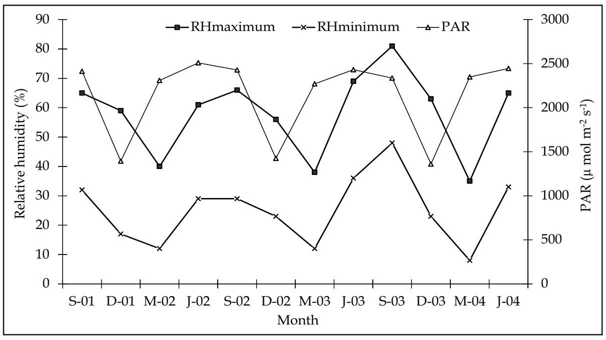


*Fig. 1. Temporal changes in RH and PAR during 2001 to2004. S: September, D: December, M: March, and J: June.*

### *Experimental design and sampling*

About 10-year-old trees of *P. juliflora* were selected in July 2001. Average height, diameter at breast height (dbh) and crown diameter of the selected *P. juliflora* trees were 5.00±0.15 m (mean±SE), 19.20±0.42 cm and 6.11±0.28 m, respectively. Treatments in the form of canopy removal (lopping) and trenching (45 cm deep x 30 cm wide in 2 m diameter) around trees were: trees without trench ($T_1$), tree and trench ($T_2$); lopped tree without trench ($T_3$), and lopped tree and trench ($T_4$). Four permanent quadrates of 1 $m^2$ were laid out under the canopy zone (at 2 m distance from the tree trunk) of the selected trees in all four directions for vegetation studies. Size of the quadrates was finalized following standard procedure (Misra, 1968). In addition, there were 12 control plots (1 $m^2$) without tree ($T_5$) well beyond the canopy zone of the trees. The experiment was in a complete randomized design with three replications. Photosynthetically Active Radiations (PAR) were measured in each plot using portable CI-301, $CO_2$ gas analyzer between 10:00 to 11:00 h. Study was carried out for three years i.e., 2001-2002, 2002-2003 and 2003-2004 including a severe drought in 2002 that affected seed germination and growth. However, there was seed germination after rain in February 2003, but emerged seedlings dried within 15 days.

### *Vegetation harvesting and calculation of diversity variable*

Aboveground live biomass was harvested just above the ground surface from the quadrates and sorted to species. Species were identified using standard literatures (Shetty and Singh, 1993). These species and their population were counted manually. The harvested samples were dried at 80°C in an electric oven to a constant weight and dry mass of individual species was recorded using electronic balance. Summed aboveground dry mass of all living vascular plant species from a harvest is called 'herbage drymass'. Species richness, diversity, dominance and evenness were calculated as per Simpson (1949), Shannon and Wiener (1963) and Pielou (1966). Effect of *P. juliflora* on floral diversity and biomass production was obtained through a RNE (Markham and Chanway, 1996).

### *Statistical analysis*

Data were analyzed using repeated measure ANOVA considering months as tests of within-

*Table 1. Annual and seasonal changes in rainfall at the experimental site during 2001 to 2004*

| Year | Rainfall (mm) | | | | | |
|---|---|---|---|---|---|---|
| | June | July | August | September | Season | Annual |
| 2001 | 53.5 | 203.6 | 113.7 | 10.6 | 381.4 | 407.2 |
| 2002 | 7.7 | 0 | 13.8 | 11.8 | 33.3 | 51.4 |
| 2003 | 64.6 | 260.3 | 65.3 | 1.6 | 391.8 | 418.7 |
| 2004 | 31.5 | 35.1 | 139.5 | 11.1 | 217.2 | 220.4 |

subjects effect and treatments as the tests of between-subjects effects. Pearson correlation coefficient was observed to find out relationship between different parameters. Regression equation was developed for total population through best fits models using PAR and rainfall.

## Results and Discussion

### *Photosynthetically Active Radiation*

Photosynthetically active radiations (PAR) varied (P<0.05) between years, months and treatments. The PAR was 1395.4 μmol $m^{-2}$ $s^{-1}$ in 2001 and 1382.5 μmol $m^{-2}$ $s^{-1}$ in 2003. Existing canopy of *P. juliflora* reduced PAR by 86% to 87% in the canopy zone of $T_1$ and $T_2$ treatments than those in the $T_3$, $T_4$ and the control treatments providing significant shade for the vegetation growing beneath the canopy. 45% to 65% reduction in PAR under the canopy of *Acacia tortilis* and *Adansonia digitata* as compared to open grassland has been recorded in African savanna (Belsky *et al.,* 1993). Singh *et al.* (2008) also reported 83% to 88% reduction in PAR under the canopy of *Prosopis cineraria*, *P. juliflora*, *Azardirachta indica* and *Acacia nilotica* trees. Lowest PAR was recorded during November to January, possibly due to the frost/fog resulting from reduced air temperature and increased relative humidity during winter. An increase in PAR from winter season to summer season was similar to the observation of Wilson *et al.* (1990). A linear relation of PAR and rainfall with total population of the vegetation (Eq. 1) suggests that these variables influence vegetation structure and productivity. This indicated that increase in rainfall positively influenced plant population, whereas increase in intensity of solar radiations negatively affected the population of growing vegetation.

$$TP = 57.0363 + 0.1433\ RF - 0.0199\ PAR \ldots\ldots\ldots(1)$$

($R^2$ = 0.601, SEE = 21.803, F = 88.158, P< 0.01)

where, TP = Total population; RF = Rainfall; PAR = Photosynthetically active radiations

### *Vegetation diversity*

Number of species recorded was 19 in 2001-02 and 20 in 2003-04 belonging to 9 families (Table 2). In September 2001, total number of species was 13 in $T_1$, $T_2$, $T_3$ and $T_4$ treatments, whereas it was 10 in $T_5$. But the numbers of species were 13, 13, 10, 11 and 10 in $T_1$, $T_2$, $T_3$, $T_4$ and $T_5$ treatments, respectively, in September 2003. $T_5$ treatment showed lowest (P<0.01) species richness, total population, diversity and evenness, where increased solar radiations might have influenced germination of seeds of different species available in the soil affecting diversity variables. The variation in diversity variables among different treatments was due to varying microhabitat affinities in annual plants (Tielbörger and Kadmon, 1997).

*Table 2. Species associated with Prosopis juliflora trees during 2001 to 2004*

| Species name | Family | 2001-02 | 2003-04 |
|---|---|---|---|
| *Aristida funiculata* Trin. & Ruper. | Poaceae | + | + |
| *Brachiaria ramosa* (Linn.) Stapf | Poaceae | + | + |
| *Cenchrus biflorus* Roxb. | Poaceae | + | + |
| *Cenchrus pennisetiformis* Hochst. & Steud. | Poaceae | + | + |
| *Cleome viscosa* Linn. | Capparidaceae | + | + |
| *Corchorus tridens* Linn. | Tiliaceae | + | + |
| Crotolaria medicganea Lamk. | Papilionaceae | - | + |
| *Cyperus rotundus* Linn. | Cyperaceae | + | + |
| *Dactyloctenium aegyptium* (Linn.) P. Beauv. | Poaceae | + | + |
| *D. sindicum* Boiss. | Poaceae | + | + |
| *Digera muricata* (Linn.) Mart. | Amaranthaceae | + | + |
| *Digitaria ciliaris* (Retz.) Koeler. | Poaceae | + | + |
| *Eragrostis minor* Host. | Poaceae | + | + |
| *Indigofera cordifolia* Heyne ex Roth | Papilionaceae | + | + |
| *I. hochstetteri* Baker | Papilionaceae | + | + |
| *Peristrophe paniculata* (Forsk.) Brummitt | Acanthaceae | + | + |
| Phyllanthus amarus Schum. & Thonn. | Euphorbiaceae | + | + |
| *Tephrosia purpurea* (Linn.) Pers. | Papilionaceae | + | + |
| *Tragus roxburghii* Panigrahi | Poaceae | + | + |
| *Tribulus terrestris* Linn. | Zygophyllaceae | + | + |

+ Indicate presence; and - absence of a particular species in the year.

However, highest species dominance in $T_5$ was due to lesser number of species. *Peristrophe paniculata* indicated highest dominance and association with *P. juliflora.* Comparatively greater diversity in the tree-associated treatments than in the control showed that *P. juliflora* had a positive influence on population and productivity of canopy zone vegetation (Fig. 2). Beneficial effects by which *P. juliflora* improved vegetation structures were reduced solar radiations, modified microclimate and probably soil resources. Improvement in growth of under canopy vegetation due to improved soil, water and microclimate has also been observed in other studies (Holmgren *et al.*, 1997). Increased population and growth of *Cassia angustifolia* under the canopy of *A. tortilis*, *P. juliflora* and *Calligonum polygonoides* has also been observed in Indian desert, where *C. polygonoides*

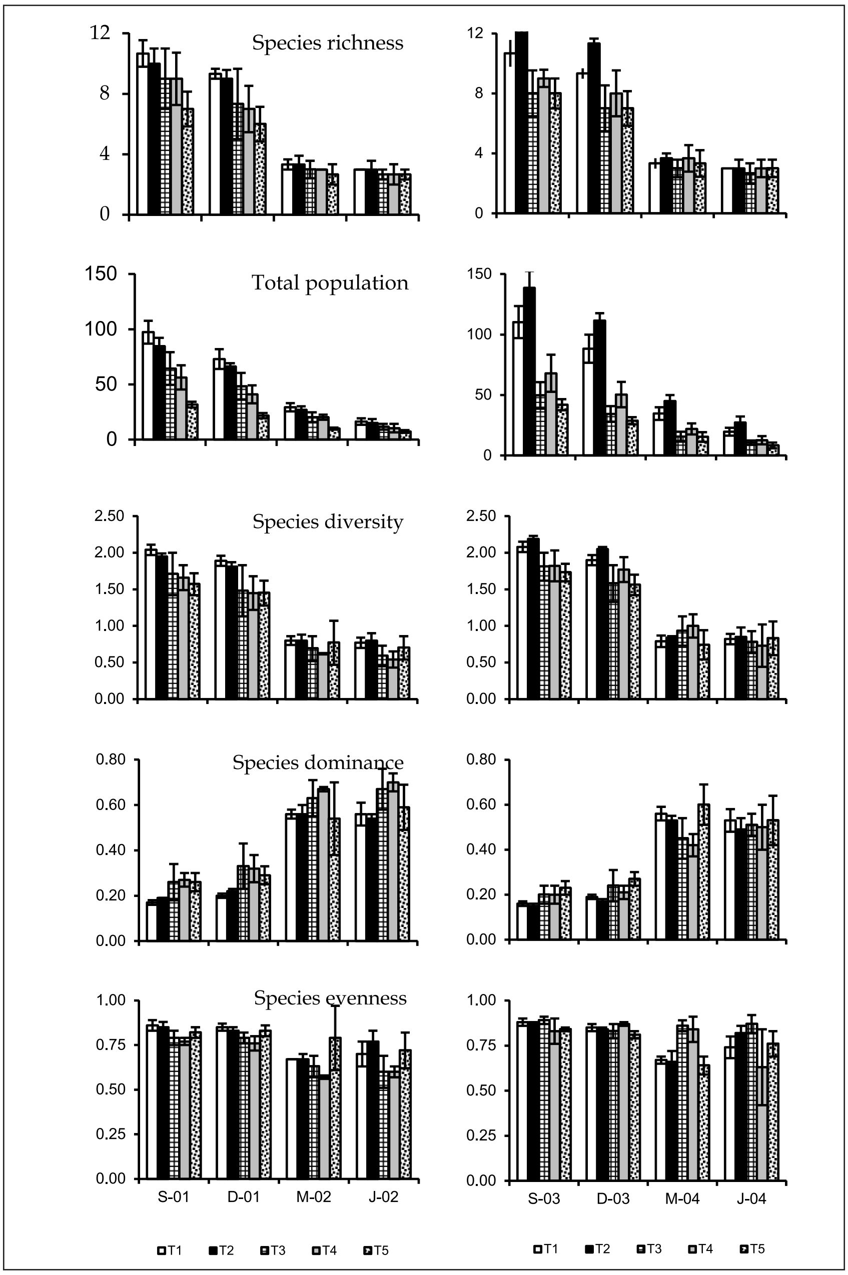


*Fig. 2. Effect of resource management on the diversity varaibles of vegetation associated with P. juliflora tree in 2001-02 (left panels) and 2003-04 (right panels). Error bars are ±SEM of three replications. S: September, D: December, M: March, and J: June. T1: intact trees without trench, T2: intact tree and trench, T3: lopped tree without trench, T4: lopped tree and trench, and T5: control plots without tree.*

showed highest facilitative effect than to the other two species (Singh *et al*., 2003). About 1.2, 1.8, 1.2 and 1.0 fold greater species richness, total population, species diversity and evenness in the tree with canopy treatments (average of $T_1$ and $T_2$) as compared to those in the tree without canopy treatments (average of $T_3$ and $T_4$) showed beneficial effect of canopy possibly through reduced air temperature and solar radiations.

### *Community dry biomass*

Community dry biomass was 2.6 fold greater in the tree-associated treatments than in the control (Table 3). It indicated that the *P. juliflora* had a positive influence on canopy zone productivity. Community biomass was 2.1 fold greater in $T_1$ and $T_2$ as compared to $T_3$ and $T_4$ treatments. It was because of canopy effect, which attenuated solar radiations and possibly soil nutrients influencing species richness and population. Increased incidence of solar radiation negatively affected the community biomass in $T_3$ and $T_4$ treatments as indicated by a negative correlation of PAR with community biomass ($r=-0.468$, $P<0.01$, $n=120$). Lower temperature and PAR beneath tree crown possibly reduced water stress and increased biomass of vegetation (Amundson *et al*., 1995). Mlambo *et al*. (2005) and Jefferson and Pennacchio (2005) observed greater herbaceous biomass under the canopy of *Colophospermum mopane* and *Atriplex bunburyana*, respectively, but lower biomass under tree canopies than in the open areas has also been reported by several workers (Belsky *et al*., 1993; Kahi *et al*., 2009).

About 12.0% and 3.0% greater dry biomass in $T_2$ and $T_4$, as compared to $T_1$ and $T_3$ treatments, suggest the facilitative effect of trenching around trees. It was due to reduction in competition for resources between tree and the associated vegetation. The large difference in dry biomass between $T_2$ and $T_1$ as compared to that between $T_4$ and $T_3$ treatments was due to reduced competition because of lopping and consequent reduction in competitive fine roots development. By minimizing the competitive effect of tree roots through trenching and polythene root barriers, Kumar *et al*. (2001) recorded an increase in the yields of sorghum by 18% and pearl millet by 21%.

### *Vegetation dynamics*

Changes in resource availability through micro-climate modification result in appearance or disappearance of a particular species (Tiedmann *et al*., 1971). *Crotolaria medicagnea* appeared in $T_4$ treatment in 2003-04 suggesting preferential regeneration of this species in fertile full light

*Table 3. Effect of resource management on community biomass (g m$^{-2}$) of herbaceous vegetation associated with P. juliflora trees during 2001 to 2004. Values are mean of three replications±SEM*

| Treatments | 2001-2002 | | | | | 2003-2004 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | S | D | M | J | Mean | S | D | M | J | Mean |
| $T_1$ | 206.17 ±26.81 | 145.33 ±17.40 | 49.00 ±9.54 | 33.83 ±3.49 | 108.58 | 236.17 ±29.64 | 192.17 ±24.55 | 71.00 ±7.81 | 48.00 ±7.77 | 136.83 |
| $T_2$ | 176.50 ±20.82 | 124.67 ±11.26 | 41.17 ±5.89 | 21.00 ±3.82 | 90.83 | 324.17 ±32.47 | 258.50 ±16.86 | 102.33 ±12.03 | 66.83 ±12.33 | 187.96 |
| $T_3$ | 135.83 ±26.73 | 80.83 ±18.04 | 30.33 ±7.38 | 15.50 ±2.36 | 65.63 | 90.67 ±17.37 | 60.17 ±11.72 | 22.83 ±6.30 | 16.17 ±5.85 | 47.46 |
| $T_4$ | 110.83 ±25.10 | 65.67 ±15.18 | 23.50 ±4.07 | 11.00 ±3.55 | 52.75 | 126.67 ±22.99 | 85.00 ±21.05 | 29.67 ±5.89 | 18.50 ±4.50 | 64.96 |
| $T_5$ | 51.17 ±4.11 | 32.33 ±3.77 | 12.67 ±0.17 | 10.33 ±1.09 | 25.94 | 76.50 ±6.11 | 45.67 ±7.26 | 23.00 ±2.65 | 13.17 ±2.20 | 39.58 |
| Mean | 136.10 | 89.77 | 31.33 | 18.23 | 64.74 | 170.60 | 127.63 | 49.40 | 32.47 | 85.70 |
| Repeated measure ANOVA | | | | | | | | | | |
| TWS | df | TSS | MS | F | P | TSS | MS | F | P | |
| Mo | 3.00 | 133944.25 | 44648.08 | 168.44 | < 0.01 | 191551.05 | 63850.35 | 267.40 | < 0.01 | |
| Mo x T | 12.00 | 22076.82 | 1839.73 | 6.94 | < 0.01 | 61177.23 | 5098.10 | 21.35 | < 0.01 | |
| TBS | | | | | | | | | | |
| T | 4.00 | 49501.65 | 12375.41 | 8.44 | < 0.01 | 201749.94 | 50437.49 | 23.01 | < 0.01 | |

S: September, D: December, M: March, J: June, TWS: Tests of within-subjects effects, Mo: Month, T: Treatment, TBS: Tests of between-subjects effects, df: degree of freedom, TSS: Type III sum of square and MS: Mean square.

habitat modified through nutrient enrichment and enhanced solar radiations by trenching and canopy removal, respectively. However, disappearance of *Phyllanthus amarus* and *Tragus roxburghii* from $T_2$, $T_3$ and $T_4$ treatments in 2003-04 indicated their association with adult neighbours. Non-availability of *Datyloctenium aegyptium* and *Digera muricata* in 2003-04 in $T_3$ and $T_4$ treatments might be because of increased solar radiations affecting germination and growth of these species. In contrast, *Cleome viscosa*, *Eragrostis minor* and *Tribulus terrestris* occurred only in the control plots indicating their adaptability to high solar radiations and low soil nutrients, characteristics of the desert. Observation of Veenendaal *et al*. (1993) that seedlings of *Aristida congesta*, *Eragrostis rigidior* and *Tragus berteronianus* emerged in full sunlight, whereas *Panicum maximum* and *Urochloa panicoides* germinated in shady habitats supports the variability and growth in the species resulted from resource management in present study. A predisposition may explain why *Aristida funiculata*, *Cenchrus biflorus*, *Dactyloctenium sindicum*, *Indigofera cordifolia* and *Tephrosia purpurea* are common and able to successfully establish and survive in harsh conditions and found throughout in the Indian desert (Singh, 2007). Disappearance of *Peristrophe paniculata* from $T_4$ treatment showed its strong association with the shaded habitats of *P. juliflora* and indicated its mesic character similar to *Panicum maximum* seedlings established only in a shaded environment (Kennard and Walker, 1973). Changes in relatively mesic environment under the tree canopy to xeric environment after canopy removal and trenching, possibly affected emergence of *P. paniculata* seedlings (Fig. 3c).

Highest values of diversity variables and community biomass in September had resulted from differential accumulation of seeds and their germination or sprouting from perennating organs during the rainy season. Most species flower, fruit, and produce seeds near the end of rainy season and wither away by the beginning of winter, thus the highest value of the aboveground biomass

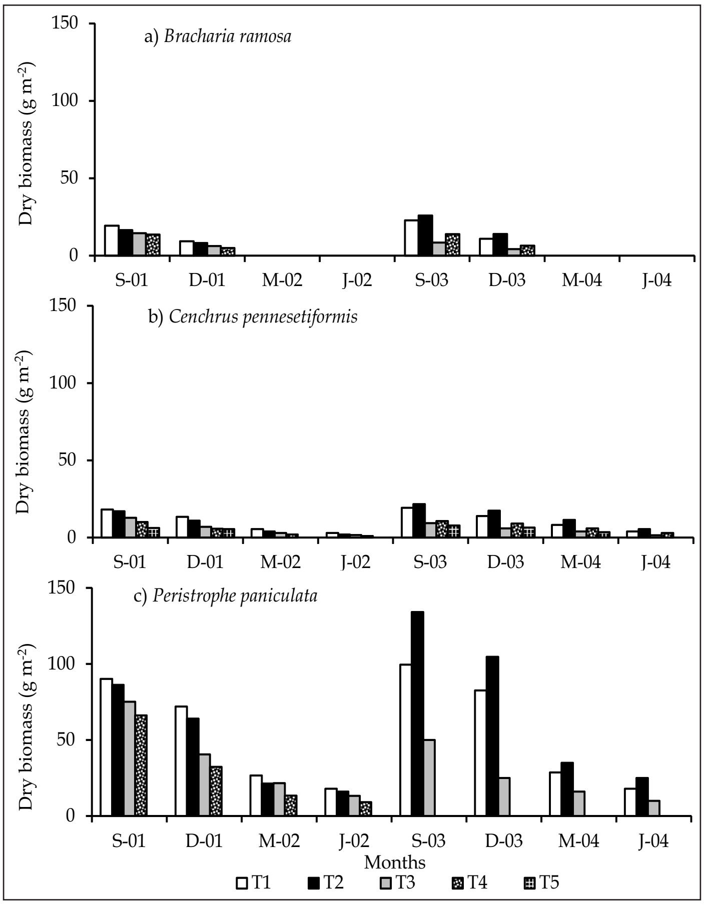


*Fig. 3. Effect of resource management on dry biomass (g $m^{-2}$) of representative herbaceous species associated with P. juliflora tree in September, December, March and June during 2001 to 2004 . T1: intact trees without trench, T2: intact tree and trench, T3: lopped tree without trench, T4: lopped tree and trench, and T5: control plots without tree.*

in September was attributed to the lush growth of various species and increased availability of soil water and soil nutrients (Fig. 3). Saxena *et al.* (1996) reported highest aboveground biomass in *Brachiaria mutica* during rainy season. Diversity variables were relatively greater in 2003 suggesting the role of rainfall and availability of soil water. Brooks (1999) recorded variation in biomass of *Schismus* spp. and *Erodium circutarium* as a result of contrasting rainfall in Mojave Desert. A positive relationship of rainfall with species richness (r=0.583, P<0.01, n=120), total population (r=0.530, P<0.01, n=120) and community biomass (r=0.600, P<0.01, n=120) was similar to that of observed by Singh and Yadava (1974) and Pandey and Singh (1992) in tropical grassland at Kurukshetra and Vindhyan plateau, India, respectively. However, these diversity variables declined with the advent of summer because of decrease in soil water content. *Brachiaria ramosa*, *Corchorus tridens*, *Cyprus rotundus*, *Dactyloctenium aegyptium*, *Digera muricata*, *Digitaria ciliaris*, *Eragrostris minor*, *Indigofera hochstetteri*, *Phyllanthus amarus*, *Tragus roxburghii* and *Tribulus terrestris* almost disappeared after December reducing community biomass by 30% in December (Fig. 3a). The disappearance of these species was faster after December leading to significant (P<0.05) decline in dry mass in June. The bulk of live vegetation converted to standing dead and litter component from December to June through March, whereas mortality and shattering of annuals and tillers of perennial grasses decreased the biomass to the lowest value in June (Fig. 3). Struik and Bray (1970) have also observed that aboveground biomass of herbaceous vegetation tends to decrease with xeric conditions

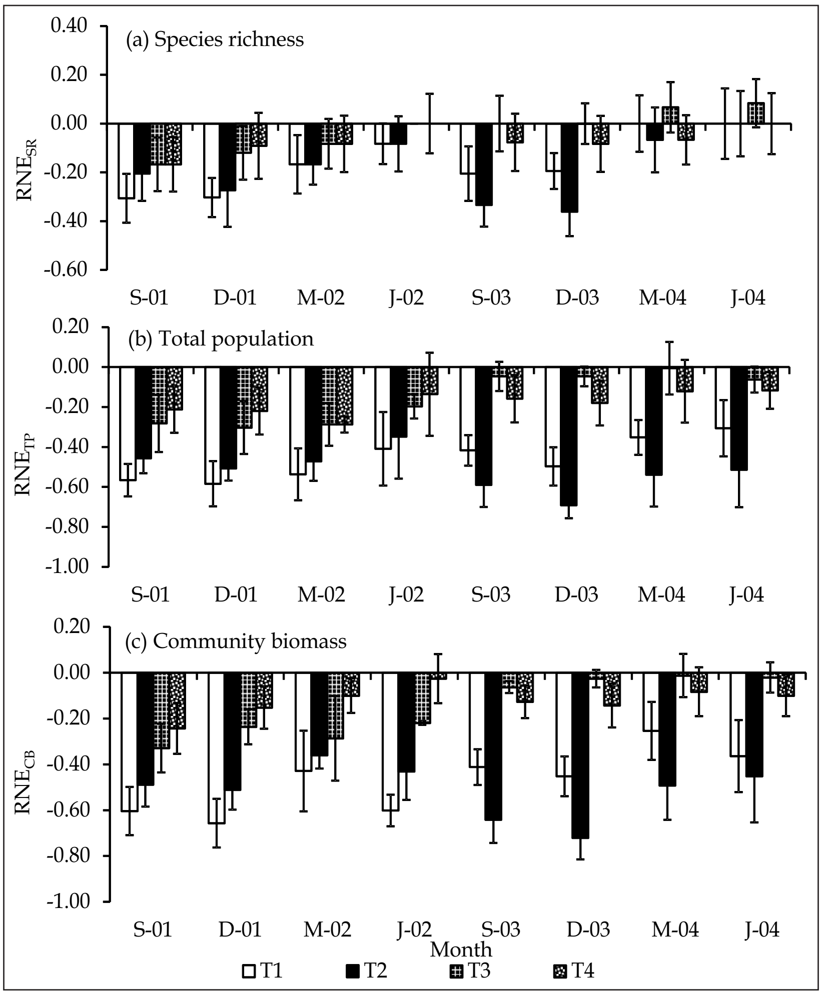


*Fig. 4. Relative Neighbour Effect (RNE) for species richness (a), total population (b) and community dry biomass (c) of the vegetation associated with P. juliflora tree. Error bars are ±SEM of three replications. S: September, D: December, M: March, and J: June. T1: intact trees without trench, T2: intact tree and trench, T3: lopped tree without trench and T4: lopped tree and trench.*

*Relative Neighbour Effect (RNE)*

Negative values of RNE for species richness, total population and dry biomass indicated the facilitative effects of *P. juliflora* on these variables (Fig 4a to c). Lower RNE (more negative) in $T_2$ and $T_4$ (particularly in 2003-04) as compared to $T_1$ and $T_3$ treatments indicated beneficial effect of trenching, whereas lower RNE for intact (average of $T_1$ and $T_2$) as compared to lopped (average of $T_3$ and $T_4$) tree treatments showed the beneficial effect of tree canopy on under canopy vegetation. However, greater difference in RNE between intact and lopped trees than the RNE difference between trenched and untrenched treatments showed stronger effect of canopy retention as compared to the trenching around trees. Positive effects of canopy on vegetation structure and dry biomass have also been observed in other studies (Schlesinger *et al*., 1996).

In conclusion, *P. juliflora* promoted regeneration and productivity of under canopy vegetations by ameliorating the adverse climatic conditions and improved biodiversity. This effect can be further improved by trenching around trees of *P. juliflora*. *Brachiaria ramosa*, *Cenchrus ciliaris*, *Cenchrus pennisetiformis*, *Crotolaria medicagnea*, *Dactyloctenium aegyptium*, *Digitaria ciliaris*, *Indigofera cordifolia*, and *Tragus roxburghii* were abundant under tree canopy indicating highest production, when associated with tree species. Though best associated species with *P. juliflora* was *Peristrophe paniculata,* but fodder species like *B. ramosa*, *I. cordifolia*, *C. pennisetiformis* and *D. ciliaris* and *C. pennisetiformis* also showed better association. Non-palatable *Cleome viscosa* and *Peristrophe paniculata* decreased after canopy removal in terms of population and biomass, so *P. juliflora* canopy may be removed in managing these species in range. However, highest diversity and community biomass with tree having canopy, but without active root (i.e. trenching) suggests beneficial effects of trenching around tree and recommended for adoption to increase production of rangeland. *Brachiaria ramosa*, *Cenchrus pennesetiformis* and *Digitaria ciliaris* may be promoted but density of *P. juliflora* needs optimization.

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