Journal of Tropical Forest Science 12(2):256–269 (2000)

EFFECT OF BURNING ON SPECIES PERFORMANCE AND SOIL BEHAVIOUR OF ARID LAND PLANTATION

G. Singh

Division of Forest Ecology and Desert Development, Arid Forest Research Institute, Jodhpur - 342005, India

Received July 1997

SINGH, G. 2000. Effect of burning on species performance and soil behaviour of arid land plantation. Observations made after a fire in the experimental field of the Arid Forest Research Institute showed that out of seven species (viz. *Acacia nilotica, A. tortilis, Albizia lebbeck, Azadirachta indica, Eucalyptus camaldulensis, Parkinsonia aculeata* and *Prosopis juliflora*) planted, *A. lebbeck* showed the maximum mortality (45%) and *A. indica* the minimum (5%). In August 1995, three months after the fire, the growth in terms of height, crown diameter (CD) and collar girth was low in the burned area in all the species except for *P. aculeata* and *E. camaldulensis* which showed larger CD, compared to the unburned area. The growth differences were maximum in *P. juliflora* (viz. 22.2% in height, 22.6% in CD and 3.5% in girth) followed by *Albizia lebbeck* (12.5, 17.8 and 18.2%) and *A. tortilis* (8.5, 21 and 16.2% in height, CD and girth respectively). The minimum effect of fire was observed in *A. indica* which showed only 2.1, 4.4 and 1.5% differences in height, crown diameter and girth respectively indicating that *A. indica* was more hardy to fire than the other species. However, in November 1995, the trend was reverse when a recovery was seen in the burned area with generally better growth than in the unburned area. Such increase in growth parameter was believed to be due to the stimulation of new vegetative growth and branching in the species during the first growing season after the fire. The moisture retention varied significantly between the species. The soil water content was higher under the burned area compared to the unburned area and was due to less usage of water in the area. Soil organic matter content and electrical conductivity increased in the burned area while the pH of the soil showed the reverse trend, and was believed to be due to the effect of organic matter and/or due to leaching of salts from the upper to the lower horizons and other mineral nutrients during the burning of ground vegetation.

Key words: Fire - plant growth - soil water and soil properties

SINGH, G. 2000. Kesan kebakaran terhadap prestasi spesies dan sifat-sifat tanah di ladang tanah gersang. Cerapan yang dibuat selepas kebakaran di ladang percubaan di Arid Forest Research Institute menunjukkan bahawa daripada tujuh spesies yang ditanam (iaitu *Acacia nilotica, A. tortilis, Albizia lebbeck, Azadirachta indica, Eucalyptus camaldulensis, Parkinsonia aculeata* dan *Prosopis juliflora*), *A. lebbeck* menunjukkan kematian maksimum (45%) dan *A. indica* menunjukkan kematian minimum (5%). Pada bulan Ogos 1995, tiga bulan selepas kebakaran tersebut, pertumbuhan dari segi ketinggian, garis pusat silara (GS) dan lilit kolar adalah rendah di kawasan terbakar dalam kesemua spesies kecuali bagi *P. aculeata* dan *E. camaldulensis* yang menunjukkan GS yang lebih besar, berbanding dengan kawasan yang tidak terbakar. Perbezaan pertumbuhan adalah maksimum dalam *P. juliflora* (iaitu 22.2% dalam ketinggian, 22.6% dalam GS dan 3.5% dalam lilitan) diikuti dengan *Albizia lebbeck* (12.5, 17.8 dan 18.2%) dan *A. tortilis* (8.5, 21 dan 16.2% masing-masing dalam ketinggian, GS dan lilitan). Kesan kebakaran yang minimum dicerap dalam *A. indica* yang mempamerkan hanya 2.1, 4.4 dan 1.5 % perbezaan masing-masing dalam ketinggian, garis pusat silara dan lilitan menunjukkan bahawa *A.indica* adalah lebih tahan kepada kebakaran berbanding dengan spesies lain. Bagaimanapun, pada bulan November 1995, trend ini berubah apabila didapati berlaku pemulihan di kawasan terbakar dengan pertumbuhan yang lebih baik berbanding kawasan yang tidak terbakar. Pertambahan dalam parameter pertumbuhan ini dipercayai akibat daripada simulasi pertumbuhan tanaman baru serta pendahanan spesies pada musim penanaman yang pertama selepas kebakaran. Ketahanan lembapan berubah-ubah dengan bererti antara spesies. Kandungan air tanah adalah lebih tinggi di bawah kawasan yang terbakar berbanding dengan kawasan yang tidak terbakar. Ini disebabkan oleh penggunaan air yang kurang di kawasan tersebut. Kandungan bahan organik tanah dan konduktiviti elektrik bertambah dalam kawasan terbakar manakala pH tanah menunjukkan trend di sebaliknya, dan dipercayai kesan dari bahan organik dan/atau larut resap garam daripada horizon atas hingga ke bawah dan nutrien galian yang lain semasa pembakaran tanah tumbuh-tumbuhan.

Introduction

Fire is a very important ecological process, mostly as a disturbance element, in nearly all forest and range ecosystems. Its effect can be dramatic and its use or exclusion can be critical. However, responses of plants to a given fire regime vary greatly among species (Gill & Groves 1981, Cowling & Lamont 1987). Fire severity affects the survival and establishment of many shrub species, organic matter consumption, soil heating (Chandler *et al.* 1983) and the biological response of soil flora and fauna. The extent of soil heating depends on the physical characteristics of the fire, in particular to the quantify of fuel consumed (McCaw 1988). Some species survive fire (Hooker & Tisdale 1974) and may become more vigorous when burned. Severe fire may kill the seedlings outright but they may survive in light fire. *Eucalyptus marginata* in the jarrah forest of Australia, with thin juvenile bark, was reported to resprout readily after fire from a subterranean lignotuber and scorched canopy was quickly replaced by epicormic shoots (Abbott & Loneragan 1986, Burrow 1987). In ecosystems like cerrado, fire may be considered as a component of great importance in promoting primary productivity. Fire may also stimulate flowering, increase the branching behaviour, seed production and seedling establishment (Baird 1977, 1984, Hopper *et al.* 1987, Lamont & Runciman 1993). Studies on the effect of surface fire on nutritional and physical properties suggest that fires have a slight detrimental effect on physical properties, viz. decrease in soil water holding capacity (Naidu & Srivasuki 1994) but a slightly beneficial effect on soil nutrition at the same time. The growth rate of *E. regnans* and *Acacia delbata* on soil from mature forest which was heated during burning was many times greater than on unburned soil (Attiwil 1962) and was due to availability of more moisture and favourable climate. Heating the soil changes its chemical, physical and microbial properties. The direct chemical changes during soil heating and combustion of soil organic matter lead to a massive volatilisation of simple nitrogenous compounds, mainly nitrate and ammonium and to some extent S, P and the other ions depending on the fire intensity and temperature. But, at the same time fire transforms soil nitrogen bound in organic substances into ammonium, a form readily available to either plants or subsequent microbial nitrification (De Bano *et al.* 1979, Dunn *et al.* 1979, Waldrop *et al.* 1987). The increase in ammonium and nitrate concentrations in many Californian ecosystems (Polglase *et al.* 1986) has also been reported. The increase in the availability of nutrients (N, P and other mineral nutrients) enhances the growth of the plants.

The study reported here is the postfire observations made on the effect of a wildfire on the growth and hardiness of and the soil properties and soil water retention under the species *Acacia nilotica, A. tortilis, Albizzia lebbeck, Azadirachta indica, Eucalyptus camaldulensis, Parkinsonia aculeata* and *Proposis juliflora.* The genus *Acacia nilotica* is an indigenous species of North Deccan and is distributed throughout the drier part of the country preferring deep clayey soil. *Acacia tortilis* ranges from Southern Israel and Saudi Arabia to Tanzanian Africa. However, it is naturalised in hot arid areas of western India covering sand dunes and sandy plains. *Albizia lebbeck* and *Azadirachta indica* are indigenous species and can stand long hot and dry summers preferring good well-drained soils. *Eucalyptus camaldulensis* is widely distributed in Australia and now naturalised in the Indian region. It is a drought hardy species and most suited for the dry zone of western Rajasthan preferring a wide variety of soil. *Parkinsonia aculeata* is indigenous to tropical America, now naturalised in all the dry regions of India. It grows on a variety of soil including black cotton soil and sandy soil. *Prosopis juliflora* is indigenous to tropical and sub-tropical regions of America (Mexico and Central America), Africa and Asia. It prefers a wide variety of soil, hot dry climate with mild winter, small rainfall and clear atmosphere. However, all the species are naturalised in the arid areas.

Materials and methods

Climate and site conditions

The study was conducted at the Arid Forest Research Institute experimental field, Jodhpur, situated at 26° 45' N and 72° 03' W in the western part of Rajasthan, India. The tract lies in the north tropical zone and in heart of the Thar Desert. The complete year is divided into three seasons, viz. summer, rain and winter. The summer is the most dominant season with encroaching heat reaching up to 48 °C with occasional sand storms, spreading over from March to the middle of July. The period from July to September is the rainy monsoon season and receives maximum rainfall. The mean annual rainfall for the period was 420 mm whereas the mean annual pan evaporation of the period was 2225 mm. October and November are post-rainy months with slight rise in temperature which starts falling from November but real winter months are December and January. However, the lowest temperature recorded during the experimental period was 4.8 °C in the month of February. The mean maximum temperature was 42.6 °C and the mean minimum temperature was 25.3 °C.

The soil of the experimental site is coarse loamy mixed hyperthemic family of Typic Camberthides according to U.S taxonomy. It contains 81% sand and is low in organic matter (0.273%), available N (59 kg ha^{-1}) and phosphorous (P_2O_5, 12 kg ha^{-1}) with pH of 8.90. The electrical conductivity ranging 0.36–0.46 dSm^{-1} has a mean value of 0.44 dSm^{-1}. The depth of the soil is about 80 cm below which is a 'kankar' hard pan of calcium carbonate called murram layer.

Natural vegetation

The vegetation of the area is sparse and consists of scattered thorny trees, shrubs and grasses, classified as tropical thorn forest (Champion & Seth 1968). There are five principal habitats (Satyanarayana 1963, Raheja 1965), each with distinctive vegetation.

Hill and rock outcrop

The hills are of granite, rhyolite, sandstone and limestone, while a few are quartzite, admelit, slate and schists. The common species in these habitats are *Acacia senegal, Anogeissus pendula, Capparis decidua, Euphorbia candicifolia, Cassia auriculata, Grewia tenax* and *Maytenus emarginatus.* Associated tree and shrub species are *Anogeisus rotundifolia, Azadirachta indica, Cordia garaf, Moringa cocanensis, Salvadora oleoides, Prosopis juliflora* and *Wrightia tinctoria.* Common lianas include *Asparagus recemosus, Coculus pendulus* and *Ephedra foliata.* The plants of the field layer are *Aristida funiculata, Achyranthes aspera, Cenchrus biflorus, Indigofera cordifolia* and *Tephrosia purpurea.*

Piedmont plains

The vegetation of the piedmont plains is 'xeromorphic thorn forest'. Common species are *Acacia jacmontii, A. leucophloea, A. nilotica, A. senegal, Azadirachta indica, Balanites aegiptiaca, Capparis decidua, Leptadenia pyrotechnica, Maytenus emarginatus, Prosopis cineraria, Salvadora oleoides, Prosopis juliflora* and *Ziziphus nummularia.* Common grasses include *Aristida funiculata, Cenchrus biflorus, Cymbopogon jwarancusa, Dichanthium annulatum, Eremopogon foveolatus* and *Heteropogon concortus.*

Alluvial plains

The vegetation of the alluvial plains is 'psammophytic scrub desert'. Few scattered trees are *Prosopis cineraria, Salvadora oleoides* and *Tecomella undulata* associated with *Albizia lebbeck* and *Azadirachta indica.* The bushes are *Arva persica, Calotropis procera, Calligonum polygonoides, Clerodendrum phlomoides, Crotolaria burhia, Haloxylon salicornicum, Mimosa hamata, Tamarix aphylla* and *Ziziphus nummularia.*

Sand dunes

Sand dunes are more dominant covering an area of about 60%. The vegetation consists of *Acacia senegal, A. tortilis, Calotropis procera, Calligonum polygonoides, Capparis decidua, Grewia tenax, Haloxylon salicornicum, Leptaddenia pyrotechnica, Prosopis cineraria* and *Tecomella undulata.* The ground flora comprise *Boerhavia diffusa, Citrullus. colocynthis, Corchorus depressus, Indigofera cordifolia* and *Tribulus alatus.* Dominant perennial grasses are *Dactyloctenium sindicum, Eleusssine compressa, Panicum turgidum* and *Lasiurus sindicus.*

Saline flats and depressions

The open scrub community found on saline area is very sparse. Common species are *Cressa cretica, Fagonia cretica, Haloxylon recurvum, Portulaca oleracea,. Salsola baryosma, Sueda fruticosa, Trianthema portulacastrum* and *Zygophylum siplex.* The common grasses are *Aeluropus lagopoides, Chloris virgata, Dichanthium annulatum* and *Sporobolus hevolus.*

Plantation establishment

Observations were made on *Acacia nilotica, A. tortilis, Albizzia lebbeck, Azadirachta indica, Parkinsonia aculeata* and *Prosopis juliflora* which were affected by a wildfire at the age of 23 months and *Eucalyptus camaldulensis* at the age of eleven months. Eight-month-old seedlings of the above species were planted in July 1993, in 60 × 60 × 60 cm size pits in three replications at a spacing of 4 × 4 m, covering an area of 0.70 ha. *Eucalyptus camaldulensis* was infected by termites and was replaced in July 1994. Wild fire which occured in the last week of May 1995 affected about 0.30-ha area of the plot. After the fire, the total area was identified as two blocks, each of 0.23 ha, as burned (fire affected area) and unburned (the area which was not affected by the fire). Each block was again divided into five subplots for recording observations (here called observational subplots) having seven species randomly planted. Thus, there were four plants of each species in each observational subplots making a total of 20 plants in each block of burned and unburned areas. Observations were made on 20 plants per species in the unburned area and 11, 12, 15 and 19 plants in the burned area for *A. lebbeck, P. aculeata, A. nilotica* and the other species respectively.

Observations

The mortality and the growth parameters of each species present in burned and unburned blocks were recorded in August 1995 (monsoon period) and repeated in November 1995 (post-monsoon period) when the plants attained new growth by the resprouted branches, 6 months after the burning. The maximum height attained by the plants, crown diameter (mean of the two maximum spread of the crown recorded perpendicular to each other), collar girth (collar diameter measured using vernier callipers at 10 cm above the ground and converted to circumference) and survival/mortality of the plants were recorded in the month of August 1995. Soil samples for analytical purposes and for determination of soil water content were collected in the upper 75 cm in the 0–25, 25–50 and 50–75 cm layers, 20 cm apart from the randomly selected plants in the first week of October 1995. A total of 210 soil samples (2 blocks × 5 observational subplots × 7 species × 3 depths), each of 200 g, both for moisture content and soil analytical purposes were collected. Percentage soil moisture content (% w/w) was obtained by oven drying the soil samples at 110 °C to constant weight.

Analytical procedure

Soil samples were air dried and passed through a 2-mm mesh sieve and used for subsequent analysis. Organic carbon was determined by the Walkley-Black partial oxidation method following the standard procedure (Jackson 1973), using acidic potassium dichromat as oxidant. Soil pH was determined with a direct-reading pH meter using a combination glass electrode in a suspension of 1:2 soil water solution. All the data obtained were subjected to statistical analysis, i.e. t-test.

Results

The maximum mortality was observed in *Albizia lebbeck* (45%) followed by *Parkinsonia aculeata* (40%), *Acacia nilotica* (25%), *Eucalyptus camaldulensis* (5%), *Acacia tortilis* (5%), *Azadirachta indica* (5%) and *Prosopis juliflora* (5%). The results indicate that *E. camaldulensis, A. tortilis, A. indica* and *P. juliflora* are relatively more tolerant to fire than *A. lebbeck, P. aculeata* and *A. nilotica.*

Effect on plant growth

Plant height, crown diameter and collar girth are presented in Table 1. The data indicate that fire affected the growth of the plants in the burned area compared to the unburned area. In August 1995, the differences in height were observed to be maximum in *P. juliflora* (22.2%) followed by *A. lebbeck* (12.5%) and the least was in *A. indica* (2.1%). The maximum difference in height for *P. juliflora* is believed to be due to the topkilling of the plants in the burned area, instead of picking up growth by resprouted branches. However, the differences in plant height between the burned and unburned areas were not significant. The crown diameter decreased except for *P. aculeata* and *E. camaldulensis* which showed an increase with the former giving a higher increase (15.6%) than the latter (14.8%). The greatest difference in crown diameter was observed in *P. juliflora* (22.6%), followed by *A. tortilis* (21.0%), *A. lebbeck* (17.8%), *A. nilotica* (15.9%) and *A. indica* (4.4%). The crown diameters for *P. juliflora* and *A. tortilis* were

Table 1. Growth data (in cm) of different species affected by the fire

Tree species	Height (cm)		Difference	Crown diameter (cm)		Difference	Collar girth (cm)		Difference
	Burned	Unburned	(%)	Burned	Unburned	%	Burned	Unburned	%
August 1995									
Acacia nilotica	101 ± 12.8	104 ± 17.9	2.9	67 ± 2.6	69 ± 6.4	2.9	5.6 ± 1.6	4.8 ± 1.4	4.2
Acacia tortilis	108 ± 16.8	118 ± 15.7	8.5	98 ± 10.8	124 ± 12.4*	21.0	5.7 ± 1.5	6.8 ± 1.8	16.2
Albizia lebbeck	77 ± 16.0	88 ± 4.2	12.5	37 ± 9.7	45 ± 7.1	17.8	3.6 ± 0.5	4.4 ± 0.5	18.2
Azadirachta indica	137 ± 43.4	140 ± 31.4	2.1	82 ± 19.7	91 ± 23.6	9.9	6.7 ± 2.3	6.8 ± 2.0	1.5
Eucalyptus camaldulensis	110 ± 17.3	122 ± 32.6	9.8	70 ± 22.7	61 ± 14.0	14.8	4.9 ± 1.3	5.2 ± 1.3	5.8
Parkinsonia aculeata	160 ± 49.4	167 ± 10.1	4.2	141 ± 34.6	122 ± 29.6	15.6	6.5 ± 2.2	7.0 ± 1.9	7.2
Prosopis juliflora	137 ± 39.2	176 ± 36.0	22.2	154 ± 31.9	199 ± 22.8*	22.6	8.3 ± 1.4	8.6 ± 1.3	3.5
November 1995									
Acacia nilotica	119 ± 11.3	116 ± 17.2	2.6	80 ± 11.0	85 ± 10.9	5.9	5.5 ± 1.4	5.5 ± 1.5	18.1
Acacia tortilis	141 ± 11.4	135 ± 14.2	4.4	137 ± 15.1	128 ± 20.9	7.0	7.4 ± 1.1	6.5 ± 1.0	13.8
Albizia lebbeck	123 ± 19.7	101 ± 7.6	21.8	71 ± 8.5	67 ± 10.2	5.9	5.5 ± 1.2	5.6 ± 0.7	1.8
Azadirachta indica	161 ± 38.4	167 ± 40.9	3.6	108 ± 12.2	100 ± 18.4	8.0	8.0 ± 1.7	7.8 ± 1.9	2.6
Eucalyptus camaldulensis	131 ± 29.0	124 ± 22.6	5.6	90 ± 20.4	81 ± 20.3	11.1	6.0 ± 1.0	6.1 ± 1.4	1.6
Parkinsonia aculeata	197 ± 7.8	180 ± 46.9	9.4	187 ± 28.8	165 ± 35.2	13.3	8.5 ± 1.3	8.1 ± 1.7	4.9
Prosopis juliflora	189 ± 40.0	189 ± 29.2	-	215 ± 23.4	200 ± 29.3	7.5	10.5 ± 2.0	10.4 ± 2.6	5.8

*Significant at 0.05.

significantly higher in the unburned area in comparison to the burned area. Differences in collar girth of the plants between the burned and unburned areas were not significant. Plants in the burned area were relatively thinner than those in the unburned area. The difference in girth was greatest in *A. lebbeck* (18.2%), followed by *A. tortilis* (16.2%) and *P. aculeata* (7.2%). The minimum difference was in *A. indica* (1.5%).

However, in November 1995, the differences in the growth of the plants between the burned and unburned areas decreased with comparatively greater growth in the burned area during the period from August to November 1995. Most of the species in the burned area showed higher growth data than those in the unburned area, and differences in growth between the burned and unburned areas were not significant.

Effect on soil moisture

The soil moisture content varied greatly between the species and the highest was recorded under *A. tortilis* followed by *P. juliflora* whereas the lowest was recorded under *A. nilotica* (Table 2). There were no significant differences in the soil moisture content between the burned and unburned areas. However, soil moisture levels were comparatively greater under the burned area except for *E. camaldulensis* and *P. juliflora*. Even under the latter species, soil moisture content was distinctly higher in the two top layers in the burned area.

Effect on soil properties

The analytical data on percentage soil organic matter (SOM), soil pH and electrical conductivity are presented in Table 3. SOM was greater in all cases (even in the lowest horizon), and significantly under *A. nilotica, A. tortilis, A. lebbeck, E. camaldulensis* and *P. juliflora* in the burned area compared to the unburned area. Maximum SOM was 0.486% under *A. lebbeck* followed by 0.455% under *E. camaldulensis*, though the difference was not significant.

Soil pH in the burned area was significantly lower under *A. nilotica, A. lebbeck, E. camaldulensis* and *P. aculeata* ($p< 0.05$) than in the unburned area and generally increased with increasing soil depth. The lowest pH was observed under *E. camaldulensis* (8.30) followed by *A. nilotica* and *A. lebbeck* (8.41) in the upper 25-cm layer (Table 3). The electrical conductivity increased with depth in the burned area, with the highest value of 0.87 dSm^{-1} under *A. nilotica* followed by the value of 0.78 dSm^{-1} under *E. camaldulensis*, both at the lowest soil depth. At this level, a higher electrical conductivity was also seen in the burned area than in the unburned area. However, differences among the species were not significant.

Table 2. Effect of fire on soil water content (% w/w) under different species

Tree species	Soil depth	Burned area	Unburned area
Acacia nilotica	0–25	1.494 ± 0.74	1.339 ± 0.16
	25–50	2.071 ± 0.32	2.324 ± 0.50
	50–75	2.473 ± 0.34	2.055 ± 0.30
	Mean	2.013	1.906
Acacia tortilis	0–25	1.648 ± 0.33	1.407 ± 0.24
	25–50	2.480 ± 0.48	2.331 ± 0.26
	50–75	3.158 ± 0.54	3.101 ± 0.13
	Mean	2.429	2.280
Albizia lebbeck	0–25	1.483 ± 0.11	1.353 ± 0.26
	25–50	2.486 ± 0.24	2.547 ± 0.30
	50–75	2.845 ± 0.38	2.800 ± 0.33
	Mean	2.271	2.233
Azadirachta indica	0–25	1.459 ± 0.32	1.400 ± 0.28
	25–50	2.571 ± 0.14	2.280 ± 0.23
	50–75	2.834 ± 0.37	3.000 ± 0.55
	Mean	2.288	2.227
Eucalyptus camaldulensis	0–25	1.412 ± 0.36	1.496 ± 0.49
	25–50	2.330 ± 0.40	2.354 ± 0.14
	50–75	2.644 ± 0.36	2.912 ± 0.30
	Mean	2.129	2.254
Parkinsonia aculeata	0–25	1.624 ± 0.72	1.234 ± 0.22
	25–50	2.433 ± 0.32	2.411 ± 0.31
	50–75	2.743 ± 0.45	3.101 ± 0.33
	Mean	2.267	2.249
Prosopis juliflora	0–25	1.575 ± 0.36	1.468 ± 0.23
	25–50	2.401 ± 0.24	2.367 ± 0.26
	50–75	2.747 ± 0.61	3.018 ± 0.37
	Mean	2.241	2.284

Discussion

Resistance to injury and capacity for recovery together determine the fire tolerance of an individual and the population. Therefore, when considering the response of plants to fire, it is important to distinguish the resistance of the plants to fire damage and the ability of the plants to recover and resume form and function following injury (Gill & Ashton 1968). The variation in mortality was believed to be due to the ecological nature of the species. Bark type and thickness are also an important factor in the resistance of a particular species to damage. McCaw *et al.* (1994) reported that having thicker bark, *E. muellerana* showed better fire resistance than *E. diversicolor*.

Table 3. Effect of fire on soil properties

Tree species	Soil depth	pH		EC(dSm-1)		Soil organic matter (%)	
		Burned	Unburned	Burned	Unburned	Burned	Unburned
Acacia nilotica	0–25	8.41 ± 0.52*	9.14 ± 0.08	0.30 ± 16.1	0.47 ± 16.2	0.452 ± 0.058	0.382 ± 0.019
	25–50	8.57 ± 0.36	8.87 ± 0.17	0.43 ± 10.1	0.50 ± 18.3	0.373 ± 0.047*	0.237 ± 0.101
	50–75	8.49 ± 0.10	8.81 ± 0.31	0.87 ± 17.5	0.45 ± 9.6	0.348 ± 0.034*	0.199 ± 0.037
Acacia tortilis	0–25	8.58 ± 0.53	8.91 ± 0.32	0.39 ± 23.5	0.54 ± 18.9	0.403 ± 0.060*	0.324 ± 0.032
	25–50	8.67 ± 0.76	9.08 ± 0.36	0.62 ± 19.1	0.38 ± 7.4	0.366 ± 0.033*	0.270 ± 0.060
	50–75	8.46 ± 0.48	8.88 ± 0.20	0.55 ± 30.7	0.40 ± 5.9	0.397 ± 0.136	0.261 ± 0.090
Albizia lebbeck	0–25	8.41 ± 0.31*	8.88 ± 0.22	0.51 ± 9.4	0.50 ± 11.6	0.486 ± 0.061*	0.336 ± 0.091
	25–50	8.23 ± 0.47*	9.02 ± 0.11	0.45 ± 23.4	0.39 ± 6.1	0.446 ± 0.063*	0.293 ± 0.042
	50–75	8.51 ± 0.40	8.93 ± 0.28	0.67 ± 16.7	0.37 ± 6.5	0.352 ± 0.050*	0.222 ± 0.036
Azadirachta indica	0–25	8.57 ± 0.46	8.91 ± 0.38	0.41 ± 23.3	0.60 ± 25.7	0.437 ± 0.087	0.384 ± 0.145
	25–50	8.81 ± 0.64	8.88 ± 0.39	0.40 ± 6.4	0.55 ± 16.7	0.359 ± 0.023	0.319 ± 0.076
	50–75	8.78 ± 0.29	8.96 ± 0.24	0.48 ± 7.9	0.49 ± 8.3	0.343 ± 0.066	0.283 ± 0.067
Eucalyptus camaldulensis	0–25	8.30 ± 0.45*	8.91 ± 0.39	0.34 ± 12.2	0.45 ± 22.6	0.455 ± 0.043*	0.302 ± 0.063
	25–50	8.61 ± 0.32	8.87 ± 0.32	0.36 ± 9.3	0.36 ± 17.2	0.382 ± 0.037*	0.300 ± 0.059
	50–75	8.45 ± 0.27	8.89 ± 0.33	0.78 ± 9.8	0.46 ± 34.8	0.317 ± 0.077	0.263 ± 0.050
Parkinsonia aculeata	0–25	8.47 ± 0.37*	9.06 ± 0.18	0.40 ± 36.6	0.46 ± 15.0	0.388 ± 0.056	0.348 ± 0.064
	25–50	8.87 ± 0.54	8.99 ± 0.39	0.41 ± 21.1	0.39 ± 17.5	0.352 ± 0.045	0.272 ± 0.088
	50–75	8.73 ± 0.44	9.11 ± 0.55	0.45 ± 14.7	0.33 ± 9.3	0.318 ± 0.043	0.302 ± 0.039
Prosopis juliflora	0–25	8.73 ± 0.37	9.14 ± 0.28	0.39 ± 16.4	0.44 ± 11.5	0.410 ± 0.016	0.360 ± 0.075
	25–50	8.74 ± 0.68	9.11 ± 0.31	0.31 ± 22.0	0.38 ± 9.0	0.353 ± 0.074*	0.256 ± 0.029
	50–75	8.99 ± 0.66	9.23 ± 0.39	0.47 ± 13.0	0.32 ± 6.4	0.340 ± 0.017*	0.225 ± 0.052

*Significant at 5% level.

The decreased height and collar girth for the plants of the burned area in August were due to the initial slow growth of the defoliated plants. The latter, however, picked up growth after receiving rain (from July to September) and even exceeded the growth of the plants in the unburned area in November 1995. Such accelerated growth was probably due to the increased availability of nutrients resulting from the burning which increased the rate of mineralisation and biological activity. The increase in height, crown diameter and collar girth in November 1995 is attributed to new vegetative growth and increase in branching through resprouting of the protected buds or the epicormic shoots stimulated by the fire after foliage removal (Baird 1977, Lamont & Downs 1979). Attiwill (1992) reported a mean volume increment of 50 m^3 ha^{-1} y^{1} and mean biomass accumulation of 22 t $ha^{-1}y^{1}$ in a 7-y-old *E. regnans* forest which regenerated after a bushfire. An increase in branching in *Macropidea fuliginosa* and *Anigozanthos pulcherrimus* in the year following a fire was observed by Lamont and Runciman (1993).

The comparatively greater amount of soil moisture/water under most of the species except *E. camaldulensis* and *P. juliflora* in the burned area may be attributed to lesser utilisation of soil water and/or the decrease in evapotranspiration by the less number of plants in the burned area. However, the low soil water content under *E. camaldulensis* and *P. juliflora* was due to their higher vegetative growth, as observed through the growth data, which utilises more soil water.

The increase in SOM in the burned area was probably due to incomplete burning of the dry grasses, with the highest amount under *A. lebbeck* due to the greater density of grasses under this species. The broad nature of the leaves and susceptibility of *A. lebbeck* to fire also contribute to the observed increase. The general increase of SOM as a result of burning can also be attributed to the addition of dead and incompletely burned vegetable matter to the soil. The increase in organic matter due to increase in faunal activity on the debris of densely growing grasses during the monsoon period cannot be ruled out, although such a study was not carried out. Wahlenburg (1946) indicated that the surface soil in a burned stand tended to have a higher level of organic matter. The greater amount of SOM in the lower horizon in the unburned area, is attributed to the slow release of SOM from the upper to the lower horizons through rain water.

The decrease in pH was believed to be due to the increase in the organic matter content in the burned area and decomposition of the added organic matter into organic ions and the consequent buffer action, as observed by Nihlagard *et al.* (1988) who explained that the organic acids derived from the decomposition of plant litter cause a decrease in soil pH. A good illustration is afforded by *A. lebbeck* in the burned area where the significant decreases in pH are supported by the corresponding significant increases in SOM, especially in the two top soil horizons. Although the burned area generally gave lower pH values than the unburned area, the pH of the different horizons in the former were almost similar despite the fact that the electrical conductivity (EC) increased with depth. The expected decrease in pH with depth was perhaps counteracted by the lower carbon content of the soil of the lower soil layers. Khanna *et al.* (1994) found that the addition of ash to the soil increased its pH with the increase being inversely dependent on the soil carbon content. In the present study, burning which added ash to the soil did not increase the pH but instead caused a decrease; this was possibly due to the greater effect of the increased SOM with the resultant increase in soil carbon, especially in the top layers. Burning was therefore incomplete in the study.

Hakkila (1989) reported an increase in the electrical conductivity due to the addition of wood ash, and Naidu and Srivasuki (1994) observed the increase immediately after a fire. Table 3 shows a clear increase in the EC in the lowest soil depth of the burned area. This can be explained by the washing down of the dissolved cations from the ash by rain during the monsoon period, leaving the top layer unaffected.

Conclusion

The fire tolerance of a species depends on the fire intensity and temperature. The high mortality of *Albizia lebbeck* (45 %) due to the fire in the study, compared to the much lower values in *Azadirachta indica, Eucalyptus camaldulensis* and *Prosopis juliflora,* is very much related to its fire susceptibility. The growth of the plants was initially affected by fire but it was stimulated after the rains during the monsoon period which increased the soil moisture content and soil nutrient availability such that the growth exceeded that of the plants in the unburned area. *Azadirachta indica* was comparatively less affected due to its greater hardiness to fire. Although the burned area generally had a greater level of soil water due to less water usage/ evapotranspiration, the reverse observation in the soils under *E. camaldulensis* and *P. juliflora* was attributed to their greater vegetative growth which utilised more water. Burning gave rise to an increase in soil organic matter content and, in the lowest horizon, the electrical conductivity, while the pH decreased.

Acknowledgements

The author is grateful to R. N. Mishra, the Director of the Arid Forest Research Institute, for providing the facilities, and G. N. Gupta, Head of the Division of Forest Ecology and Desert Development, for his valuable suggestions. Two reviewers gave valuable comments and criticisms which greatly helped in improving the manuscript. Thanks are due to Thanaram Rathod and R. K. Gupta for their assistance in data recording and statistical analysis respectively.

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