Short-term influence of fire in a semi-arid grassland on (5): seedling establishment

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Introduction

Fire can be seen as one of the largest anthropogenic influences on terrestrial ecosystems after urban and agricultural activities (Van de Vijver 1999). Whether lightning or man caused these unforeseen fires in both arid and mesic grasslands, they not only have a short-term influence on the functioning of the grassland ecosystem, but may also have a residual effect on the following growing seasons, depending on successive climatic conditions and post-fire management (Scott 1971; Tainton and Mentis 1984; Snyman 2003a, b, 2004). The drier the grassland, the less important fire becomes as an ecological process (Everson 1999).

Though only limited information exists on the influence of fire on seed germination and seedling establishment in the higher rainfall areas (Zacharias *et al*. 1988; Adams 1996) this information is totally lacking for the drier areas (Booysen and Tainton 1984). Some workers have indicated that fire in mesic grasslands may enhance the germination of, for example, *Themeda triandra* (West 1951; Trollope 1984) as a result of modification to the environment. In contrast, fire alone could depress the germination of this species and stimulate it in *Heteropogon contortus* (Zacharias *et al*. 1988). Seed longevity of grass and dicotyledonous weeds of arable lands has been relatively well investigated (Froud-Williams *et al*. 1984; Roberts and Boddrell 1984; Colosi *et al*. 1988), but unfortunately there are fewer studies on natural vegetation (O'Connor 1997). The aim of this study was therefore to quantify the short-term (two years) influence of a one-time fire (head and back) on the seedling establishment of sweet grassland in a semi-arid climate

Procedure

The research was conducted in Bloemfontein (28°50'S; 26°15'E, altitude 1350 m), which is situated in the semi-arid (summer annual average 560 mm) region of South Africa. The study area is situated in the Dry Sandy Highveld Grassland (Grassland Biome) with a slope of 3.5%. Soil in the study area is mostly fine sandy loams of the Bloemdal Form (Roodepoort family – 3 200). Clay content increases with soil depth from 10% in the A-horizon (0 to 300 mm), to 24% in the B1-horizon (300 to 600 mm) and 42% in the B2-horizon (600 to 1200mm).

The research was conducted on 18 plots of 10m x 10m each, with an edge effect of 5m around every plot. The three treatments included fire burning against the wind (back fire), with the wind (head fire) (Trollope 1978), and a control with no burning taking place. The layout was a fully randomised design with three replications for each treatment. Half of the burn plots were burnt on 30 August 2000 and the other half on 23 August 2001. Every plot was therefore burnt only once during the trial period. The head and back fire treatments were applied on the same day to ensure that the two types of fires were comparable over a similar range of environmental variables. The burn treatments were applied when the soil and grass fuels were initially very dry and then spring rainfall thoroughly wetted the soil causing the grass sward to become relatively green. Burning took place in the morning with a light wind blowing. To limit the fire to every burnt plot, the plants surrounding each plot were cut short and soaked before burning. The plots were excluded from any grazing over the two-year trial period.

The fuel load was estimated by cutting 10 quadrats (0.5m x 0.5m each) in the control plots adjacent to the burnt plots (Snyman 2000), which only comprised the growing season's production. The fuel-water content was estimated by harvesting ten grass samples at random from tufts of the dormant grass species in the plots. The fuel water was expressed as a percentage on a dry matter basis.

The mean length of the flames was estimated visually once the fire was burning uniformly. The rates at which the head and back fires moved over the plots were measured by a stopwatch. The wind velocity was recorded at the start, during and at the end of the fire with a hand anemometer held at a height of approximately 1.7m. Wind velocities recorded during the fire were assessed to be most representative for that time of the year. Air temperature and relative humidity were measured immediately prior to burning with a whirling psychrometer.

The fire behaviour model of Trollope (1999) was used to predict the fire intensities to which the treatment blocks were subjected for each season's burning. Fire intensities were estimated and classified into one of the categories proposed by Trollope and Potgieter (1985). The procedure for recording fire intensity

(10mm under the soil, at ground level, grass canopy height and one meter above ground level) by chrome-alumel thermocouples connected to a portable electronic temperature recorder, is fully discussed by Snyman (2003a) and Snyman (2005). The mean grass canopy height was 230 ± 25mm on average for the August 2000 and 2001 fires. Basal cover and botanical composition were determined with a bridge-point apparatus, where 500 points (nearest plant and strikes) were recorded per plot before the fire as well as 1, 4, 8 and 20 months after the fire.

Thirty tufts of the dominant grass species per treatment were randomly selected and permanently marked with steel pins. The total number of flowering tillers in each of these tufts were noted every second month as it was difficult to identify only the shoots of a specific month which turned reproductive. A tiller was only noted when the inflorescence had already appeared. For the species *Cymbopogon plurinodis*, *Digitaria eriantha*, *Eragrostis superba*, *Sporobolus fimbriatus* and *Triraphus andropogonoides*, only 15 tufts were selected per species as there were not a sufficient number of tufts per treatment.

My definition of successful seedling recruitment is that a seedling must survive to at least one growing season or to flowering (if this occurs within 12 months of germination). Seed germination and seedling survival in the field are closely linked to seasonal climatic conditions. Therefore it is important that observations should take place almost daily in the field, to accurately determine the survival percentage of seedlings over a season. If not regularly monitored, it may happen that some seedlings surviving only for a few days, due to variable climatic conditions, will not be monitored. For the above practical reasons it was therefore decided to only note the survived seedlings at the end of a growing season in this study. It was also attempted, as far as possible, to classify seedlings in month of initial germination. The problem occurring with this was that it was very difficult to identify some of the seedlings germinating during the different months, per species. To obviate this problem, seedlings of the 20 most dominant species germinating over that period were randomly chosen and tagged with steel pins, painted in different colours and inserted into the soil nearby, at the end of every second month (middle October – before seed set, December – after first seed production and February – after second seed production). These marked plants were used to classify the seedlings per species, which were identifiable and survived at the end of the growing season, into groups based on month of initial germination. Only the number of survived seedlings per species over a season were obtained and not the percentage survival of the already germinated seeds. This was obtained by counting the seedlings in 30 randomly distributed quadrats (1m^2 each) per treatment at the end of every growing season (March) for that specific season. Seedlings germinating up to and in the respective month over the season were differentiated. The distance between seedling and closest mature plant (regardless of species) was also noted every time. The distance was measured from the edges of tufts.

Results and discussion

Fire behaviour – head and back fires

The environmental conditions during the August 2000 and 2001 fires were very similar. If these environmental parameters obtained with this study for the August 2000 and August 2001 fires respectively of aboveground phytomass production (1453 and 1200 kg/ha); fuel-water content (18 and 21%); wind speed (2.44 and 2.33 m/s) and relative humidity (43 and 41%) were built into the fire behaviour model of Trollope (1999) the predicted fire intensity should have been 1145 and 766kJ/s/m respectively. Therefore, the fire intensities of the two seasons ranged between a moderately hot and cool fire (Trollope and Potgieter 1985).

The head fire was on average 6.7 times faster than the back fire. The flames of the head fires reached heights of twice those of back fires. The intensity of the fire 10mm under the soil in case of both the back and head fires did not vary much, with a respective range of temperature increase of only 9°C to 15°C and 9°C to 21°C. At ground level and canopy height the back fire exceeded 100°C and 400°C respectively. In contrast the head fire had temperatures of less than 100°C at ground level, but exceeded 500°C at 1m above the ground. The reason for the higher intensity of the head fire at 1m above ground lies in the greater flame length of head fire (1.0m vs. 0.5m) which ensures that this stratum above the ground still forms part of or is immediately adjacent to the zone of flaming combustion. The overall conclusion is that back fires are more intense than head fires at ground level, whereas head fires are hotter than back fires at levels above the canopy of the grass sward. Head fires have a greater potential for developing higher temperatures than back fires at all levels given the appropriate environmental conditions.

Botanical composition

The experimental plots were in good condition before the fire with a grassland condition score of only 13% lower than that of the benchmark site. The benchmark site was especially dominated by *Themeda triandra*, which caused this difference in grassland condition to that of the experimental sites. The grassland condition score (expressed as a percentage of that in a benchmark site) decreased by only 3.3% due to the fire.

The botanical composition did not differ much between head and back fires. Where the grassland was dominated by Decreaser species before the fire, the composition after the fire was dominated by a larger percentage of Increaser IIa species. The most conspicuous decrease in frequency due to the fire was the species *T. triandra* (30%); *Cymbopogon plurinodis* (81%); *Elionurus muticus* (72%) and *Digitaria eriantha* (11%). The species increasing with fire were *D. argyrograpta* (97%); *Eragrostis chloromelas* (149%) and *Tragus koelerioides* (124%). The fact that these species split up into many smaller tufts after the fire, could have caused an overestimation of its frequency.

Basal cover

The basal cover significantly ($P<0.05$) decreased in both the head and back fires, to such an extent that it was still 11% lower (average for head and back fires) than the unburnt grassland after two growing seasons (Table 1). One month after the fire the basal cover already decreased by 66% ($P<0.05$) due to the fire (for head and back fires). As expected, the back fire had a greater influence on basal cover, though not significant ($P<0.05$), than the head fire. The first month following the fire, the impact of the back fire on the decrease in basal cover was 18.18% greater ($P>0.05$) than that of the head fire and after two years only 1.48%. Only the cover of the living plant parts was noted and not the dead parts still present in the tufts.

Flowering over the season

The plants in the study area normally follow two growth cycles, namely in the pre-season, peaking about the end of October and a second period peaking middle of February in the post-season. During these two periods the grasses turn reproductive. Due to

Table 1 Basal cover (%) for the burnt and unburnt grassland, measured 1; 4; 8 and 20 months after burning. Least significance (LSD) is calculated at the 1% level. Data are means and standard errors.

Time after burning **(months)**	Unburnt	Head fire	Back fire	t-value
1 LSD = 2.06	7.25 ± 0.51	2.75 ± 0.30	2.25 ± 0.31	0.91
4 LSD = 2.01	7.20 ± 0.62	3.85 ± 0.21	3.50 ± 0.32	0.86
8 LSD = 0.89	7.25 ± 0.61	5.25 ± 0.56	5.20 ± 0.51	0.77
20 LSD = 0.70	7.50 ± 0.51	6.75 ± 0.43	6.65 ± 0.42	0.56

Table 2: Cumulative number of tillers (average per tuft) for the burnt (first and second season after burning) and unburnt grassland for each species, measured every second month. Flw = Flowering tillers; Veg = Vegetative tillers

Species	**Month**											
	October				December				February			
	Unburnt		Burnt		Unburnt		Burnt		Unburnt		Burnt	
	Flw	Veg	Flw	Veg	Flw	Veg	Flw	Veg	Flw	Veg	Flw	Veg
Aristida congesta	7	3	7	3	9	4	9	4	12	5	12	5
Cymbopogon plurinodis	2	11	4	4	3	13	4	6	5	20	9	11
Digitaria eriantha	0	16	0	6	4	21	3	12	7	30	6	22
Eragrostis chloromelas	6	22	7	10	6	28	8	16	18	32	17	26
E. lehmanniana	5	9	6	10	5	14	6	10	12	14	10	12
E. superba	7	8	8	8	7	10	8	10	10	13	12	13
Elionurus muticus	5	19	13	20	7	28	16	32	9	42	19	32
Panicum stapfianum	2	2	0	2	5	4	0	4	6	7	4	4
Sporobolus fimbriatus	8	16	8	16	10	20	9	18	15	30	12	28
Themeda triandra	8	24	6	20	9	32	6	24	17	40	11	32
Triraphus andropogonoïdes	9	7	8	6	10	7	9	6	10	7	9	6

the average and well-distributed rainfall for the 2000/01 and 2001/02 growing seasons, most grasses could also produce seed twice per growing season, during this study period. The 2000/01 and 2001/02 growing seasons respectively received 573 and 811mm rain versus the long-term average of 560mm per annum for this area. As the head and back fires did not have a large impact on seed formation, also for the first and second season following burning, the average numbers of flowering tillers per tuft of every species and for the 2000/01 and 2001/02 seasons are presented in Table 2.

The species forming most seed culms per tuft over the growing season was *Elionurus muticus* (burnt), *Eragrostis chloromelas* (regardless of burning) and *Themeda triandra* (unburnt) with 19, 18 and 17 seed culms per tuft respectively (Table 2). *Cymbopogon plurinodis* and *Digitaria eriantha* formed the fewest seed culms per tuft over the growing season with an average of only 5 and 7 culms per tuft in unburnt grassland. More tufts of the pioneer species *Aristida congesta*, which is more poorly perennial, turned reproductive than those remaining vegetative. *Themeda triandra* and *D. eriantha* were the two climax species of which very few shoots turned reproductive at the end of the growing season, compared to the available vegetative shoots. *Elionurus muticus* was the species most stimulated for seed formation due to the fire and to a lesser extent *C. plurinodis*, while *T. triandra* was not much influenced by fire. When the total number of reproductive shoots formed over a season for both burnt and unburnt grassland is compared, they are precisely the same. On average for all the grass species, fire had therefore no influence on seed formation.

It was almost impossible to differentiate *Tragus koelerioides* tufts from each other due to the stolon growth characteristic of this species. Therefore the seed formation of this species was not noted. The *Eragrostis* species would always seed first regardless of burning.

Seedling recruitment into gaps and their survival in the field

The density of the survived seedlings for the head and back fires differed non-significantly ($P>0.05$) from each other for both growing seasons (Figure 1). Unfortunately, the percentage survival of the grass species which did germinate per month, was not monitored, but only the number surviving at the end of the growing season. The unburnt grassland had more or less the same seedling density for the two seasons in all months. The second season following the fire had an immense increase in seedling survival over all months compared with the first year following the fire. In both seasons, burning influenced seedling survival negatively ($P<0.05$). Also clearly shown in Figure 1 is that regardless of fire, most seedlings occurred during the second half of the season. This trend may possibly relate to the lifting of dormancy by certain grass species (Simpson 1990; Cavers 1995) or possibly the production of more seed.

The seedling establishing closest to the mature plant was not necessarily of the same species. The distance between seedling (regardless of species) and mature plants varied between 25mm and 85mm in unburnt grassland. In case of the established seedlings, 68% were closer than 50mm from the mature plants and the rest further away. In burnt grassland, the average distance between seedlings (also regardless of species) and the mature plants varied from 20mm to 55mm. In this case, 71% of the seedlings were closer than 40mm from the mature plants, with the rest establishing further away. The seedling establishment of burnt grassland in general happened closer to the mature plants than in unburnt grassland. The surviving seedlings, regardless of burning, generally established more successfully closer to the larger mature plants and fewer further away from existing tufts. The better protection and shading of these seedlings by the larger tufts against the onslaught of climatic elements may be the most important reason for this better survival (Pugnaire and Lazaro 2000). No specific grass species in any treatment exclusively established further or closer to the mature plants.

A total average of 0.86, 0.53 and 0.43 seedlings/m^2 (Figure 1) of 8, 12 and 12 species respectively for unburnt, head fire and back fire survived in the gaps over the first season after burning (Table 3). During the second season following the fire, the seedling survival due to fire was higher (average 0.7 plants/m^2), but the species diversity generally decreased to 10. Species richness grows more with fire and again decreases the second season following the fire.

The only grass species occurring only in the burnt plots were *Aristida congesta*, *Tragus koelerioides,* as well as the forb, *Geigeria aspera*. It was very difficult to identify *T. koelerioides* as seedling for a specific month because of its creeping growth form. In relation to the rest of the species within a treatment, the first-mentioned two grass species initially produced many seedlings, but with a sharp decline the second year following the burning. Although expressed in relation to the rest of the species within a treatment (Table 3), the seedling establishment of *Eragrostis chloromelas*, *Themeda triandra* and *Elionurus muticus* were heavily decreased by the fire. *Cymbopogon plurinodis* only had seedlings surviving in the unburnt grassland, though unfortunately the percentage of seedlings which did germinate and not survive, is not known. The trend was that species *Digitaria argyrograpta*, *E. superba*, *E. muticus*, *Sporobolus fimbriatus* and *Triraphus andropogonoides* all better survived

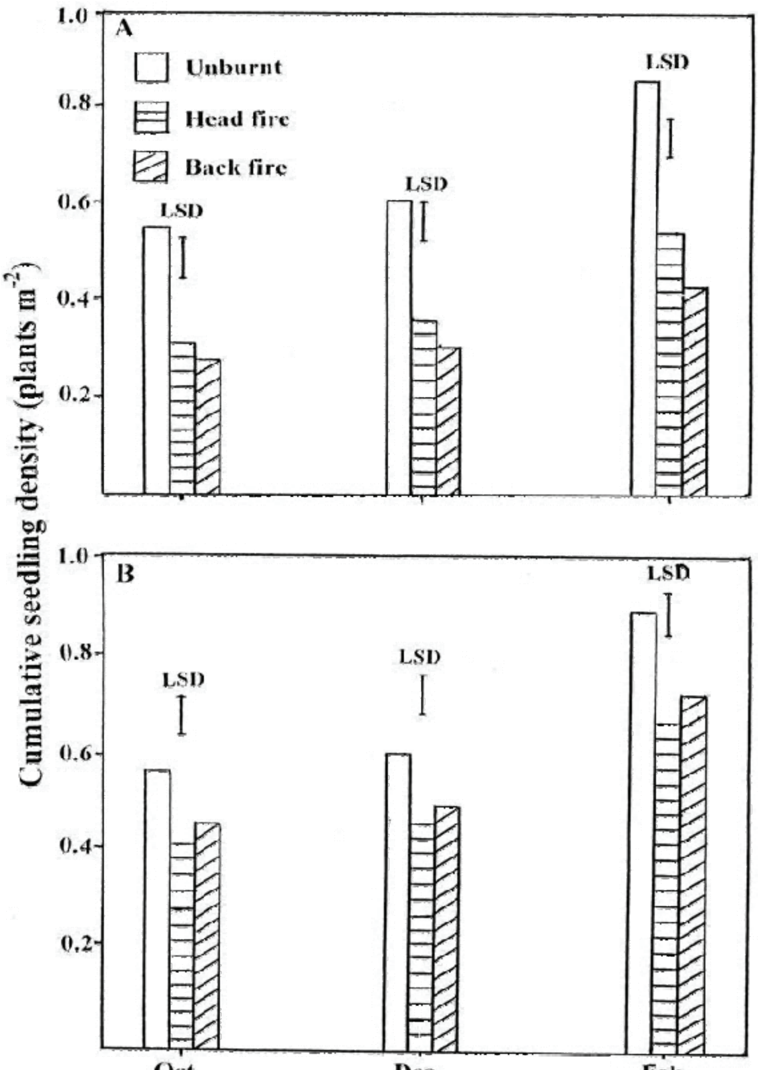

Figure 1: Cumulative seedling density (mean number of survived seedlings/m^2) for unburnt and burnt (first = A and second = B season after burning) grassland, measured at the end of the growing season (March), which germinated respectively up to October, December or February each growing season. Least significant differences (LSD) are calculated at the 1% level.

Table 3: Relative species frequency (%) of survived seedlings for the burnt (first [1] and second [2] season after burning) and unburnt grassland, measured in the field in April of the 2000/01 and 2001/02 growing seasons

Species and ecological status	October					December				
	Un-burnt	Burnt				Un-burnt	Burnt			
		1		2			1		2	
		H	B	H	B		H	B	H	B
Decreaser:										
Digitaria eriantha	12.6	9.4	9.1	10.5	12.2	5.2	14.4	1.0	6.2	13.1
Sporobolus fimbriatus	3.0	3.2	6.2			2.9				
Themeda triandra	51.1	11.4	11.2	42.4	31.3	38.7	15.0	18.6	30.0	21.4
DECREASER TOTAL	**66.7**	**24.0**	**26.5**	**52.9**	**43.5**	**46.8**	**29.4**	**19.6**	**36.2**	**34.5**
Increaser II(a)										
Cymbopogon plurinodis	1.7									
Digitaria argyrograpta		3.1	2.2	1.0	2.1		2.4			1.2
Eragrostis chloro-melas	12.7	3.7	4.7	6.8	9.2	16.7	10.7	10.3	11.1	10.4
E. lehmanniana	1.1	3.6	3.2	2.1	3.1		3.2	3.0	2.4	3.9
E. superba	4.0	2.3	3.9			6.7				
Increaser II(b)										
Elionurus muticus	13.8	3.1	4.0	19.2	17.4	29.8	3.2	5.1	20.0	14.3
Triraphus andro-pogonoïdes		5.5	11.7		7.2					
Increaser II(c)										
Aristida congesta		14.2	12.0	6.5	6.8		16.1	19.1	6.1	7.1
Tragus koele-rioides		40.5	31.8	11.5	10.7		35.0	42.9		
Geigeria aspera									24.2	28.6
INCREASER II TOTAL	**33.3**	**76.0**	**73.5**	**47.1**	**56.5**	**53.2**	**70.6**	**80.4**	**63.8**	**65.5**

and which germinated during Sept/Oct, Nov/Dec, Jan/Feb of each season. (H = head fire and B = back fire).

February					Total for season				
Un-burnt	Burnt				Un-burnt	Burnt			
	1		2			1		2	
	H	B	H	B		H	B	H	B
21.5	7.3		20.0	22.2	11.0	6.1	3.8	5.6	6.5
					1.7	2.9	3.1		
40.0	14.3	20.0	30.0	22.2	47.4	11.7	7.6	32.2	31.2
61.5	**21.6**	**20.0**	**50.0**	**44.4**	**60.1**	**20.7**	**14.5**	**37.8**	**37.7**
					2.1				
	2.0					2.2	1.8	0.9	1.3
17.6	9.6	12.7	17.5	15.6	16.2	9.9	9.8	10.6	10.6
	1.6	4.0	6.3	2.4	0.2	2.0	3.4	5.2	5.7
4.2					3.1	1.2	2.0		
16.7	6.2	4.1	2.2	2.1	18.3	4.0	3.1	18.5	12.0
						2.0	6.9		1.8
	13.1	18.1	4.0	2.1		15.8	17.5	7.0	7.2
	32.7	30.0	20.0	33.4		31.0	26.0	10.9	5.9
	13.2	11.1				9.2	8.1	9.1	13.7
38.5	**78.4**	**80.0**	**50.0**	**55.6**	**39.9**	**79.3**	**85.5**	**62.2**	**62.3**

with germination in the pre-season, while *T. triandra* throughout maintained a good survival regardless of time of germination. The seedlings of the species *A. congesta* and *T. koelerioides* were the only ones that seeded in to the same year of germination.

Conclusions

The fire responses are particularly interesting in this semi-arid grassland type in comparison with the mesic, fire dependent *Themeda* grasslands of the eastern seaboard of the country. In contrast to the rapid decline in *T. triandra* cover in the absence of fire in the KwaZulu-Natal grasslands for example, it seems to persist without burning for decades in the more arid grasslands. This suggests climate control of arid central grasslands and fire control of eastern mesic grasslands.

The study shows fire-stimulated flowering in some species (*E. muticus*), but apparently none in *T. triandra* and most of the other grasses. It is also shown in the study whether seedling recruitment is fire-stimulated or not. Short-lived species (*A. congesta, T. koelerioides*) are fire-stimulated, as is *G. aspera*, but most of the dominant perennial grasses are not. Although *T. koelerioides* often comes up after a prolonged drought, it is not certain whether fire acts in a manner equivalent to drought in reducing grass cover and stimulating germination of plants with dormant seeds or whether there is a specific fire cue for these species (such as smoke-stimulated germination). Therefore, a question to be addressed in future, is if the fire-stimulated species are also drought-stimulated species.

Unlike many studies of post-burn soil conditions, the study also showed clear evidence for hotter, drier soils after burning. Often, the reduction of plant cover and therefore evaporation results in drier surface soils but moister deeper soils than unburnt vegetation.

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11th Agrisson Congress: Report-back

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The 11th congress of the Agricultural Scientific Society of Namibia (Agrisson) was held recently in the auditorium of the Geological Survey of Namibia, in Windhoek. Twelve very interesting reports, varying from the theory of determining land cover to practical issues such as how to reduce the number of cattle in overgrazed communal areas were presented to an audience of about 50 people.

The guest speaker, Dr. Scott Turner of the State University of New York, started off the proceedings by giving a talk on “Termites, Water and Soils”. Dr. Turner has been investigating termites of the fungus-growing genus *Macrotermes* for a couple of years now in Namibia, trying to resolve the question whether they are pests in rangeland management, or not. There are 500 kg of termites for every person on earth and termites account for two-thirds of the macro-fauna biomass in soils. *Macrotermes* collect 1½ tons of