Short-term influence of fire in a semi-arid grassland on (7): defoliation

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Introduction

Fire not only has a short-term influence on productivity of the ecosystem, but may also have a major residual effect on the next growing season, depending on successive climatic conditions and post-fire management (Zacharias and Danckwerts 1999; Snyman 2004a). Unfortunately, unplanned or accidental fires in the drier sweetveld areas cause large-scale fodder flow problems resulting in mismanagement of the grassland. Therefore, fire can seldom be isolated from its association with grazing. This association is responsible for much of the controversy surrounding the use of fire in southern Africa. In spite of this, there is very little quantitative information on the effects of post-fire grazing on the recovery of fodder plants (Everson 1999, Snyman 2003; 2004b). Although grazing management following burning can clearly have a major impact on the stability of the grassland ecosystem (Everson 1999, Hardy *et al*. 1999, Zacharias and Danckwerts 1999) it is unfortunately poorly documented with still a paucity of knowledge on certain principles on which it is based (Scott 1984, Trollope 1984, 1989 and 1999). Two decades ago, for example, results obtained by Barnes and Dempsey (1992) showed that there is a need for drastic revision of current post-fire recommendations specifically for southern Africa, which is still a current problem. The period allotted for grassland recovery after burning in the drier areas specifically, is an aspect requiring urgent in-depth research. Information on the impact of fire on productivity, phenology and survival of vegetation is also important for adjusting stocking rate and ensuring sustainable utilization of the grassland ecosystem. This knowledge will contribute towards the prevention of further grassland degradation (Snyman 1998), especially in the ecologically sensitive arid and semi-arid areas, where accidental or unplanned fires are more the rule than the exception. The purpose with this study was therefore to investigate the short-term influence of different times of defoliation after burning, on the productivity and survival of grasslands in a semi-arid climate.

Procedure

The research was conducted in Bloemfontein (28°50'S; 26°15'E, altitude 1 350m), which is situated in the semi-arid (summer annual average 560mm) region of South Africa. The study area is situated in the Dry Sandy Highveld Grassland (Grassland Biome) with a slope of 3.5%. At the start of this study the grassland was in good condition (veld condition score was 92% of that of the benchmark site) and dominated by the climax species *Themeda triandra*, with *Eragrostis chloromelas* and *Elionurus muticus* also occurring relatively abundantly. The soil is a fine sandy loam soil of the Bloemdal Form (Roodepoort family – 3 200). Clay percentage increases down the profile from 10% in the A-horizon (0 to 300mm depth), to 24% in the B1-horizon (300 to 600mm) and 42% in the B2-horizon (600 to 1200mm depth).

The research was conducted on 18 plots of 100m^2 each, with an edge effect of 5m around every plot. The five treatments included fire burning against the wind (back fire), with the wind (head fire) (Trollope 1978), a control with no burning taking place, as well as two years of defoliation (first and second years following the fire). Within each year there were also four different defoliation times (October, December, February and April). The layout was a 3x4x2 (burning x defoliation x years) factorial experimental design (using a split plot with sub-samples per plot) with three replications for each burning treatment and four for defoliation months. The treatments were allocated randomly to and within the plots. The experimental design for the defoliation treatments is illustrated in Figure 1. Half of the burn plots were burnt on 30 August 2000 and the other half on 23 August 2001. Every plot was therefore only burnt once during the trial period. The control has only been cut simultaneously with the burning treatments to a height of 30mm. 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 burning treatments were applied when the soil and grass fuel 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 three year trial period. At the end of each grow-

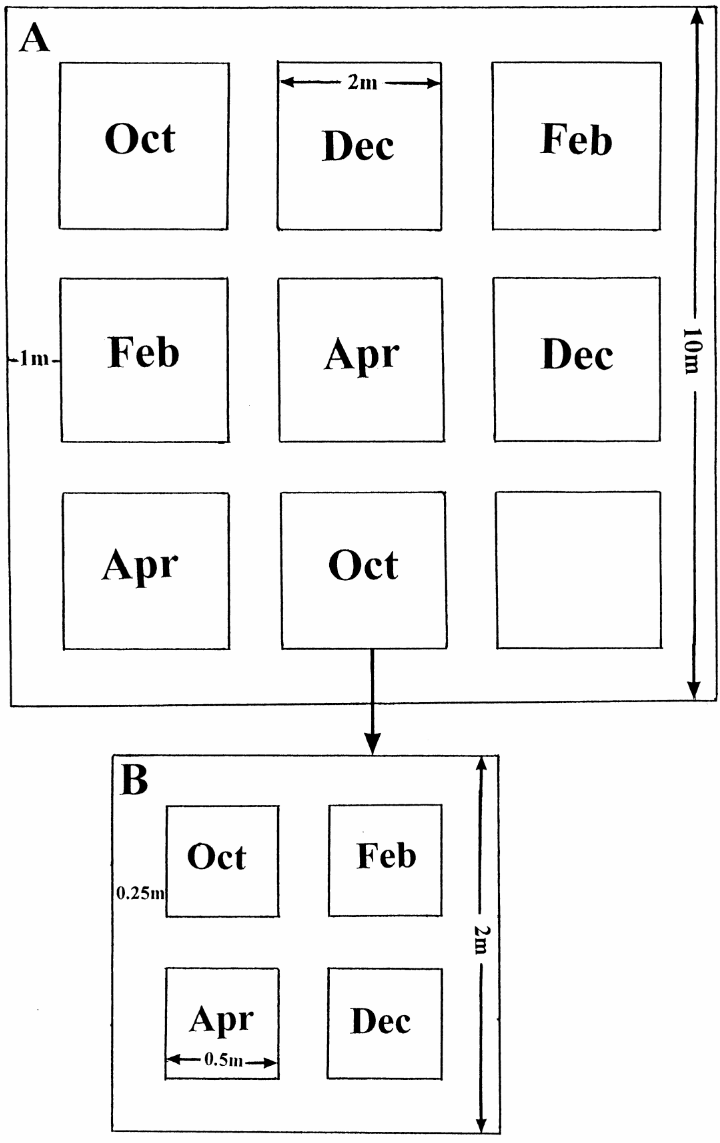

Figure 1: Layout of the defoliation treatments as carried out during the 2002/03 growing season. A = First defoliation (2001/02 growing season) and B = Second defoli-ation (2002/03 growing season).

ing season, every treatment was harvested to a height of 30mm.

The grassland was defoliated to a height of 30 mm every second month over the growing season (October, December, February and April) in nine ($4m^2$) quadrats randomly selected within every plot ($100m^2$ each), during the 2001/02 growing season. It is important to bear in mind that, although half of the grassland was burnt during August 2000 and the other half in August 2001, the defoliation treatments were applied during the same season (2001/02) for the first time. The plots which were burnt in August 2000 were therefore defoliated for the first time during the 2001/02 growing season, after a full growing season's rest. In contrast, the grasses for the August 2001 burn were defoliated the same growing season following the fire (2001/02). As the plants in the fire treatments of the two separate burning years (August 2000 and August 2001) were defoliated the same year for the first time after the fire, variation of climate on productivity was therefore eliminated. In order to determine the carryover effect of defoliation on productivity, the plants in the nine quadrats ($4m^2$ each), which were defoliated one and two years after the fire during the 2001/02 growing season, were defoliated again the following growing season (2002/03) for the second time, also at the end of the above mentioned four months. This was done by defoliating the plants in four randomly placed quadrats ($0.25m^2$) within the defoliation quadrats ($4m^2$) of the pre-

Table 1 Tuft mortality (%) for the head and back fire two months after burning. Data are means and standard errors of 60 plants for each species.

Species	Tuft mortality (%)	
	Head fire	Back fire
Cymbopogon plurinodis	71.87 ± 5.121	78.84 ± 4.353
Digitaria eriantha	58.82 ± 3.142	59.99 ± 3.122
Eragrostis chloromelas	60.22 ± 3.263	58.62 ± 3.100
Eragrostis superba	61.13 ± 3.312	63.06 ± 3.421
Elionurus muticus	69.88 ± 3.451	69.47 ± 3.264
Panicum stapfianum	71.60 ± 3.662	65.17 ± 3.543
Sporobolus fimbriatus	60.51 ± 3.291	61.42 ± 3.412
Themeda triandra	73.47 ± 4.016	79.10 ± 5.665
Triraphus andropogonoides	55.03 ± 2.961	56.73 ± 3.041
Average	**64.72**	**65.82**

vious year (Figure 1). The production of the burnt grassland during April, when all grasses were dormant and killed by frost was taken as the control in determining the production loss due to defoliation regardless of burning. The fire behaviour during this trial was described in detail in previous publications of Grassroots.

Two months after the fire, 20 tufts of the dominant grass species per plot were monitored for die-back due to fire. This was accomplished by separately copying the dead and living parts of every grass tuft on a transparency, after which the area per species was determined by means of a leaf area meter. The dead parts were expressed as percentage of the living parts. To accurately determine the living and dead parts, the tufts were cut just before monitoring.

Water-use efficiency (WUE) is defined as the quantity of aboveground phytomass production per unit of water evapotranspired. Evapotranspiration (Et) was quantified by the soil-water balance equation (Hillel 1971). Rainfall (P) was measured daily with rain gauges. The change in soil-water (DW) was calculated following Moore *et al*. (1988), where (+) indicated an increase and (-) a decrease in the amount of water within the root zone. The soil-water content was determined gravimetrically by means of a Veihmeyer tube at 50 mm depth intervals in all treatments (5 samples per treatment) with each defoliation. Due to the fact that deep drainage (D) only occurs under extremely high rainfall conditions (Snyman 1998) in the semi-arid grasslands, it was excluded for the purposes of this study. Runoff values (R) obtained from grassland in different condition classes adjacent to the burning plots (Snyman 1999) on the same slope, were used for the unburnt and burnt grassland. The basal cover of the unburnt and burnt grassland was on average the same as that of the good and moderate rangeland condition classes respectively (Snyman 1999). Evapotranspiration was therefore calculated as follows:

$$Et = P - R + DW$$

where P is precipitation, DW is the change in soil-water content and R = surface runoff.

In each treatment soil temperature was recorded two weeks after defoliation at approximately 14:00 and during the week of 4 November 2001 on an hourly basis up to a depth of 50mm with mercury thermometers. Two thermometers were placed in every fire treatment plot and unburnt grassland. These two thermometers within a plot were further divided into the defoliation and non-defoliation treatments.

Results and discussion

Tuft die-back

The head and back fires did not influence the tuft die-back much differently for all the species (Table 1). Notably, those grass species forming large tufts like *Cymbopogon plurinodis* and *Themeda triandra* had the highest percentage die-back per tuft. With the back fire treatment, these two species exhibited still higher die-back. The higher fire intensity accompanying more combustible material and also the slower movement of the back fire, is a possible explanation (Snyman 2004b). *Panicum stapfianum* was also very sensitive towards fire especially in case of the back fire.

The least tuft die-back occurred in grasses with smaller tufts, like *Digitaria eriantha* and *Eragrostis chloromelas*. Even the back fire which was supposed to have a higher fire intensity close to the soil surface (Snyman 2004b), caused lower tuft die-back in *E. chloromelas* than the head fire which is cooler close to the soil. *Triraphus andropogonoides* with its visibly hard appearance was the least sensitive towards fire. Many seed culms of this species were not totally destroyed by fire, especially the back fire.

Aboveground phytomass production

The rainfall for the defoliation season (2002/03) was 504mm, with that of the preceding two seasons, 573 and 611mm. The rainfall of all the seasons following burning did not differ much from the long-term annual rainfall of 560mm for the study area.

The main aim of this study was quantifying the impact of defoliation on burnt grassland and therefore the production data on the unburnt grassland was not presented in detail, which is available in the publication of Snyman (2003). The productions of the head and back fires which differed non-significantly ($P > 0.05$) from each other for all the defoliation months and over seasons, are therefore presented as averages for the head and back fires in Figure 2. All grasses were dormant (killed by frost and no further growth took place) with the April defoliation and therefore these production data was taken as control in determining the production loss due to defoliation regardless of burning (Figure 3). The grassland which was defoliated the same growing season (2001/02) after the fire during October, December and February, still had a lower ($P < 0.01$) production than the April (control) defoliation, as measured during the subsequent season (2002/03) for all the defoliation intervals applied (Figure 2A). Defoliation during October right after the fire, decreased production from October to April of the subsequent growing season with as much as 48% to 28% (Figure 3A). The later during the growing season the grassland has been defoliated right after burning, the smaller the influence of defoliation on the subsequent productions within and between seasons. As expected, for every defoliation month following right after burning, production cumulatively increased during the subsequent growing season (2002/03) (Figure 2 A and B).

The production of the October defoliation, after the grassland has rested for a full growing season following the fire, was for October, De-

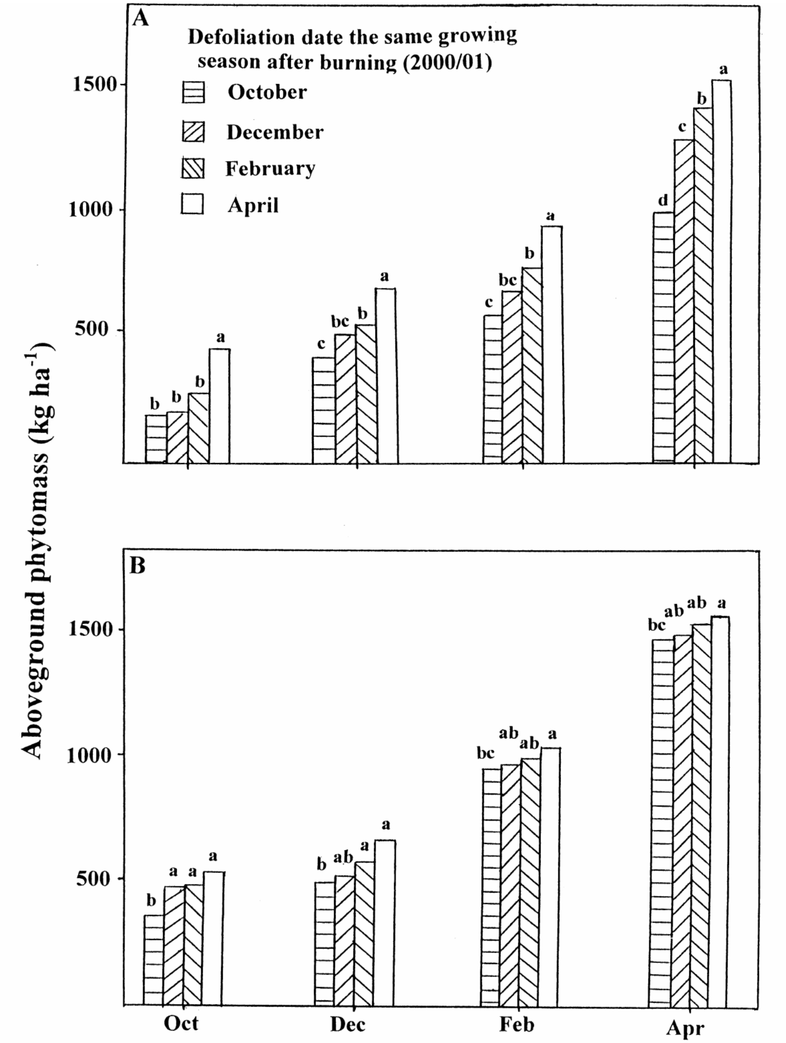

Figure 2: Aboveground phytomass production (kg/ha) of the burnt grassland obtained for various months after burning during the 2002/03 growing season. This included the production of two (A) and three (B) growing seasons after burning, when the grassland was defoliated the subsequent season (2001/02 during the same months. Bars within a month with different superscripts differ significantly (P< 0.01).

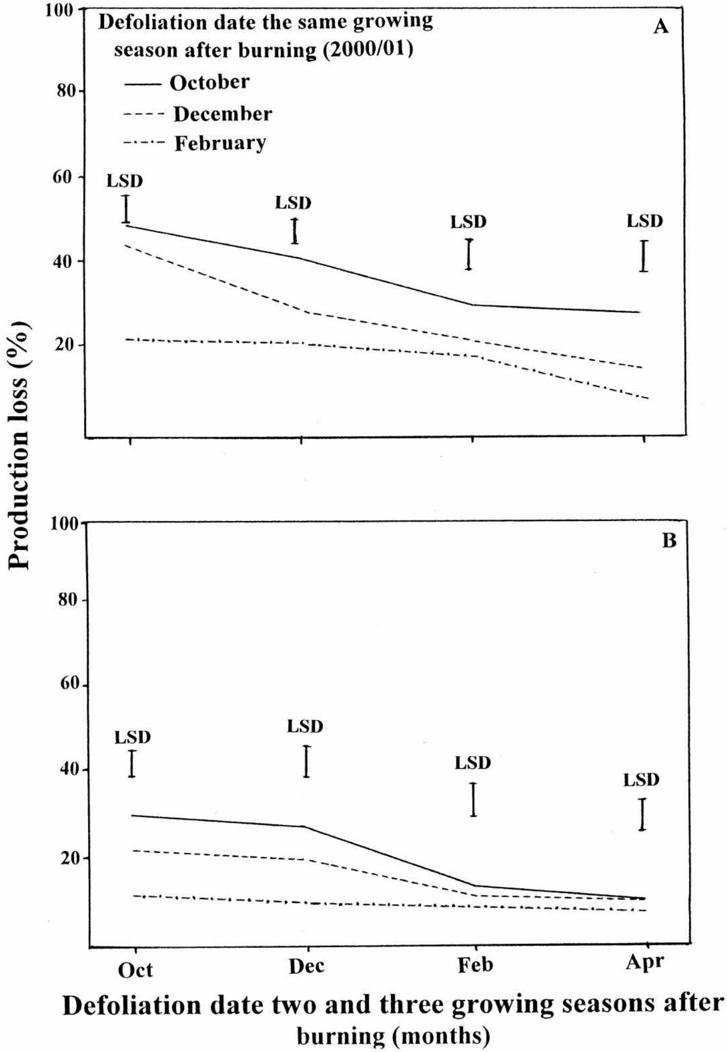

Figure 3: Production loss (%) of the burnt grassland due to defoliation regardless burning, obtained for various months following fire during the 2002/03 growing season. This included the production loss two (A) and three (B) growing seasons after burning, when the grassland was defoliated the subsequent season (2001/02) during the same months. Least significant difference (LSD) is calculated at the 1% level.

cember and February of the subsequent year (2002/03) significantly (P <0.01) lower than that of the April (control) defoliation (Figure 2B). This production loss after a rest of a full season, varied between 32% and 12% for the October to April defoliations the subsequent growing season, due to the October defoliation (Figure 3B). In contrast, the production of the December and February defoliations the subsequent season, which were not defoliated for a year following the fire, differed non-significantly (P > 0.05) from that of the April (control) defoliations. It further seems as if the production loss due to an October and December defoliation of burnt grassland, only started leveling out after the grassland has not at all been defoliated for a full growing season after the fire (Figure 3A and B). In contrast, the February defoliation directly following the fire had the lowest, but also a constant production loss the subsequent growing seasons (Figure 3A and B), regardless of receiving a season's rest or not. The production loss due to defoliation during February after the grassland has rested for a full growing season, varied only 8% to 11% for the September to April defoliations the subsequent season.

Water-use efficiency (WUE)

Regardless of whether the grassland rested for a full growing season after the fire or not, the April defoliation converted water most efficiently (P <0.01) into phytomass than all the other defoliation periods (Figure 4). The grassland which was not defoliated for a full growing season following the fire, for all defoliation periods, used water more (P <0.01) efficiently than when already defoliated the same season after the fire.

The October defoliation, regardless of receiving a seasonal resting period after the fire or not, had the poorest WUE for all the defoliation times. After the grassland rested for a full growing season, the WUE between the different defoliation times started differing less (P > 0.05) from each other. On the other hand, the February and April defoliation right after the fire, used water significantly (P <0.01) more efficiently than the October and December defoliations during the same growing season. The very high WUE occurring after the grassland rested for a growing season and was only defoliated during October for the first time, can be ascribed to the very high rainfall falling over this period during August 2002. For example, the rainfall of this month was nine times that of the long-term average for this month. In contrast the WUE increased as the grassland was defoliated for the first time after the fire later in the season.

Soil temperature

Averages are used in the discussion as soil temperatures differed non-significantly (P > 0.05) between head and back fires over the first 50 mm depth. The hourly soil temperature measurements conducted during the week of 4 November 2001 for the

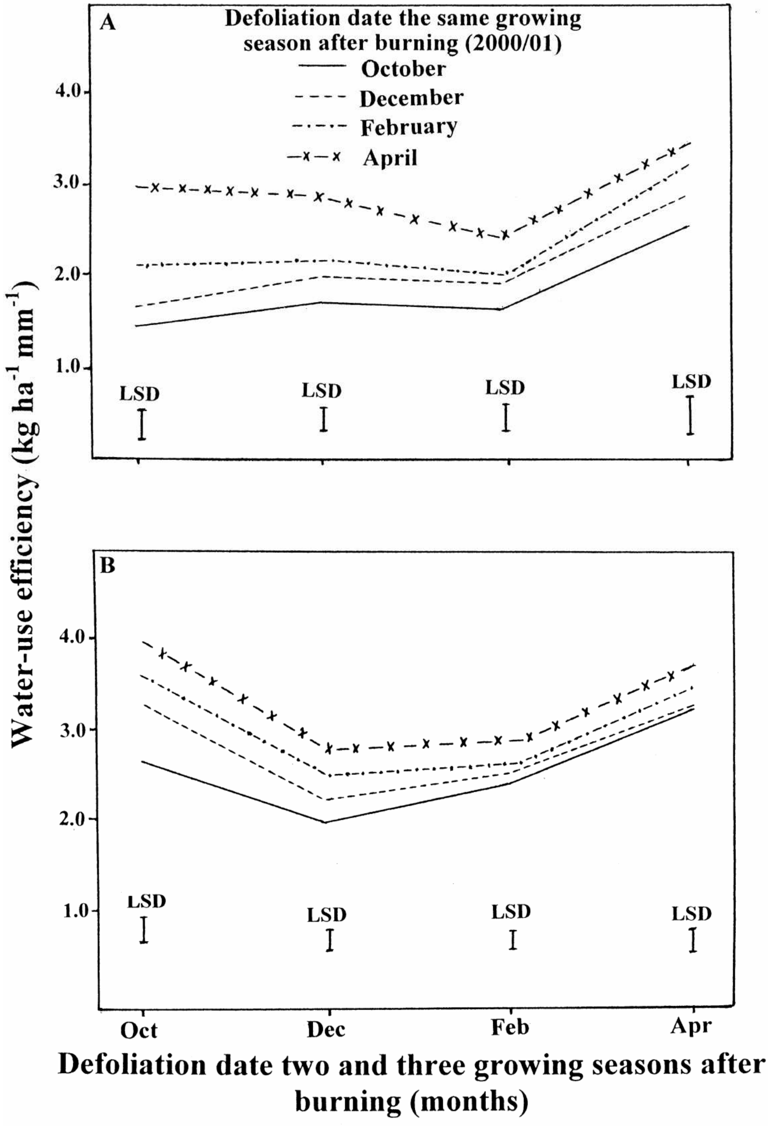

Figure 4: Water-use efficiency (WUE) (kg/ha/mm) of the burnt grassland obtained for various months after burning during the 2002/03 growing season. This included the WUE two (A) and three (B) growing seasons after burning, when the grassland was defoliated the subsequent season (2001/02) during the same months. Least significant difference (LSD) is calculated at the 1% level.

Table 2: Average soil temperature (°C) for burnt (first season after burning) and unburnt grassland measured every second hour at 50 mm depth during the week of 4 November 2001 for the defoliated and undefoliated grassland (n = 3). Significant differences between cut and uncut (P<0.01) indicated by asterisks.

Time (hour)	Unburnt			Burnt			LSD Burnt x Unburnt
	Not cut	Cut	LSD	Not cut	Cut	LSD	
05:00	18.13	18.22		18.15	18.25		0.86
07:00	19.24	20.36		22.44	24.14	*	1.21
09:00	21.12	22.32		29.22	31.13	*	1.06
11:00	23.44	24.44	*	31.13	33.22	*	1.42
13:00	25.26	26.41	*	33.27	34.51	*	1.02
15:00	28.17	30.36	*	36.19	37.47	*	1.42
17:00	26.31	27.12		33.16	34.15	*	0.96
19:00	23.22	32.29	*	31.24	33.24	*	1.12
21:00	20.51	20.14		20.3	20.55		0.98
23:00	19.13	19.26		19.22	19.54		0.88

season directly following the fire, showed that the average soil temperature to a depth of 50mm over the day period from 07:00 to 19:00, increased significantly (P <0.01) due to the fire (Table 2). The second year following the fire, the soil temperature was non-significantly (P > 0.05) influenced by fire (data not shown).

Defoliation increased soil temperature significantly (P <0.01) only from 11:00 to 19:00 in grassland which was not burnt (Table 3). However, due to defoliation, in burnt grassland the soil temperature already increased from 07:00 to 19:00 (P < 0.01).

Defoliation significantly (P <0.01) increased soil temperatures up to a depth of 50 mm, two weeks after the October and December defoliations the same season after the fire (Table 3). Where the grassland has not been burnt, defoliation had no significant (P <0.01) influence on the soil temperature. Regardless of defoliation, fire significantly (P <0.01) increased soil temperature to a depth of 50 mm over the full first season following the fire.

Conclusions

In any defoliation study, the dynamic nature of plant responses to defoliating needs to be considered and in particular the process of compensatory growth, or regrowth of defoliated foliage. This process can lead to biomass production in defoliated treatments being equal to, if not greater than undefoliated biomass. The results from the current study indicate that the carry-over effects of defoliation frequencies from one season to another may have the same, or a greater effect on plant production than the treatment within a specific season. Recommendations based on the results of only one season's research should therefore be handled with circumspection. This data indicates that the impact of defoliation on burnt grassland productivity is not necessarily neutralised after one season of rest.

It is also important to consider defoliation or grazing effects within the context of the physiological status of grasses during the period when they are most likely to be defoliated. In this study it was clear that the impact of defoliation during the first half of the growing season is greater than the last half of the season. The general trend noted in this study was that the longer the grassland rested after burning before defoliation, the lesser the carryover effect should be of a decrease in production after a subsequent growing season. In this way a defoliation during October after resting the rangeland for a full growing season, still produced significantly (P <0.01) lower than October, December and February of the subsequent season. Defoliation during December and February just after a fire, will significantly (P <0.01) lower production over the full subsequent growing season only. Grassland in these semi-arid areas should therefore be rested for a full growing season following a fire and also at least not be defoliated for the first part of the subsequent growing season, to ensure

Table 3: Average soil temperature (°C) for burnt (first year after burning) and unburnt grassland, taken at approximately 14:00 on 50 mm depth, two weeks after the October, December, February and April defoliations. (n = 3). Significant differences between cut and uncut (P<0.01) indicated by asterisks.

Month of defoliation	Unburnt			Burnt			
	Not cut	Cut	LSD	Not cut	Cut	LSD	LSD Burnt x unburnt
October	26.5	28.0		33.5	35.5	*	2.19
December	29.5	30.5		35.0	36.5	*	2.22
February	32.0	33.2		37.8	39.0		2.14
April	24.3	25.3		27.3	28.8		2.37

sustainable utilization of the grassland ecosystem. The importance of the correct time of utilization by grazing after burning, in a semi-arid climate, with respect to sustained high production has again been emphasised. Although drought is a normal phenomenon in the arid and semi-arid grasslands of South Africa and seriously limits the agricultural potential of the region accidental runaway fires further contribute towards its increased intensity and frequency.

This study clearly showed that defoliation after burning, does not only impact on the production of the subsequent seasons, but the soil is also more exposed to the natural elements of the environment. Therefore, defoliation increased soil temperature significantly (P <0.01) up to a depth of 50 mm over the first half of the growing season following the fire. Already from 07:00 in the morning the soil temperature, with defoliation, increased significantly (P <0.01) in the middle of the growing season following the fire. The sparser plant cover and large-scale tuft die-back, as well as the decrease in litter accompanying burning, could have been the main cause for this increase in soil temperature.

.Animals as utilisers of burnt grassland in the semi-arid areas should be considered in a follow-up study, in order to complete a more comprehensive picture on the ideal time of utilisation following a fire. Though obtained from cutting trials, this information contributes towards the scarcity of information quantifying the impact of defoliation following burning in the semi-arid grassland areas.

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