Short-term influence of fire in a semi-arid grassland on (2): root distribution, seasonal root production and root/shoot ratio

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Introduction

Little work has been carried out to investigate the seasonal patterns of root growth and turnover (O'Connor and Bredenkamp 1997) because past plant-ecological studies mainly concentrated on the aboveground parts of the grassland ecosystem. This is especially true in the fragile ecosystems of semi-arid climates where small changes may have long-lasting consequences (Wiegand *et al.* 2004). The fact that roots have no direct economic importance to grazing management systems, the difficulty in sampling because of the inability to distinguish live roots from dead and the high variability of the resultant data, are of the most important reasons for the above problem. This lack further intensifies into the complete lack of data also on the impact of fire on both of the above- (Everson 1999; Snyman 2003, 2004a) and belowground fractions (Trollope 1999; Tainton 1999) in specifically arid and semi-arid grasslands.

Large parts of the semi-arid grasslands of southern Africa are characterised by large-scale accidental, runaway fires driven by August winds. Either lightning or man caused these unplanned events, they not only have a short-term influence on productivity of the grassland ecosystem, but may also have a major residual effect on the next growing season, depending on successive climatic conditions and post-fire management (Snyman 2003, 2004b). This information can serve as guideline in claims arising from unforeseen fires, in which thousands of Rand can be involved and often being based on unscientific evidence. My objective was therefore to quantify short-term (two years) influence of a one-year grassland burning trial, which is a normal event in the semi-arid areas, on above- and belowground productivity for a semi-arid grassland.

Procedure

The research was conducted in Bloemfontein (28°50'S; 26°15'E, altitude 1350m), 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. At the start of this study the veld 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. Soils in my study area are mostly fine sandy loams of the Bloemdal Form (Roodepoort family 3200). Clay content increases with soil depth from 10% in the A-horizon (0 to 300mm) to 24% in the B1-horizon (300 to 600mm) and 42% in the B2-horizon (600 to 1200mm).

The research was conducted on 18 plots of 10 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), and a control with no burning taking place. The experimental 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. Therefore every plot was burnt only once during the trial period. The control was harvested at the same time as 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 fire treatments were applied during the time 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 two year trial period. At the end of each growing season, every treatment was defoliated to a height of 30mm. The detail on fire behaviour was discussed in the previous volume of grass roots.

At the end of every season, as well as two months after burning, plant density was determined by counting all plants within eight quadrats of 0.5 x 0.5m each per plot. The aboveground and belowground phytomass productions for all treatments were determined every second month at the end of October, December, February and April of the 2001/02 growing season. The August 2000 burn treatments were therefore defoliated (30mm height) and root mass determined the first time in 2001, after resting for a full growing season. As the burn treatments of the two separate years were defoliated the first time and root mass determined the same year, variation of climate on phytomass productions was largely excluded. The root mass was also determined during the end of the months of March and June and 15 August (when grass started sprouting) to more clearly identify the possible peak periods of development. Just before the burning (end August) root mass was also determined in the burnt plots.

Root mass was estimated at 50mm intervals to a depth of 900mm together with the aboveground production estimated from a sample of 10 soil cores systematically distributed over each plot. The soil cores were collected with an auger (70mm diameter) during the abovementioned months. Sieving was through two sieves, a 2mm mesh followed by a 0.5mm mesh. After most of the roots had been extracted via successive washings of the core through the 2mm mesh, the remainder of the soil was spread in a shallow tray and water was run continuously through to separate the fine roots by flotation. The outflow from the tray passed through the 0.5mm mesh sieve. No attempt was made to distinguish between live and dead roots. Harvested materials were oven-dried at 90°C for 72 hours before being weighed.

Results and discussion

Plant density

Fire had a drastic influence on the plant density (Table 1). As the plant density did not vary much from season to season for unburnt grassland, only the mean value is given in Table 1. The influence of the back and head fire on plant density did not differ much from each other and is therefore presented as an average in Table 1. It is clear from Table 1 that the densities of *Themeda triandra*, *Cymbopogon plurinodis* and *Elionurus muticus* were influenced most by the fire. The species which only appeared after the fire are *Aristida congesta* and *Tragus koelerioides*. Most species' densities were not influenced by the fire. Various researchers also found a decrease in density on semi-arid grassland due to fire (Everson 1999; West and Yorks 2002), but Tainton and Mentis (1984) could detect no decrease in the higher rainfall areas.

Table 1: *Average plant density (plants/m^2) (± SE) in burnt and unburnt grassland, measured one, four, eight and twenty months after fire*

Species	Unburnt	Burnt			
		Time after burning (months)			
		One	Four	Eight	Twenty
Aristida congesta			1.96± 0.06		
Cymbopogon plurinodis	2.68± 0.21	1.05± 0.09	1.06± 0.08	1.06± 0.09	2.86± 0.28
Digitaria eriantha	5.01± 0.11	4.22± 0.14	5.14± 0.13	4.02± 0.41	4.96± 0.31
Digitaria argyrograpta	1.98± 0.09	1.94± 0.08	1.96± 0.09		
Eragrostis chloromelas	20.31± 4.16	22.14± 3.15	23.01± 0.63	24.06± 0.51	22.21± 0.54
Eragrostis superba	2.65± 0.21	2.96± 0.10	2.97± 0.21	2.92± 0.09	1.86± 0.10
Elionurus muticus	9.21± 0.41	1.82± 0.06	2.86± 0.12	6.12± 0.12	8.14± 0.21
Panicum stapfianum	1.92± 0.09	1.03± 0.02	1.06± 0.09		
Sporobolis fimbriatus	2.86± 0.21	2.94± 0.05	1.96± 0.12	4.41± 0.13	4.10± 0.13
Themeda triandra	24.31± 3.16	14.06± 0.34	15.01± 0.36	19.14± 0.51	19.21± 0.31
Tragus koelerioides		1.96± 0.06	2.03± 0.12		
Triraphus andropogonoides	1.94± 0.09	1.85± 0.06	1.96± 0.11	2.84± 0.09	4.06±0.13
Total	**70.19**	**55.97**	**60.98**	**64.57**	**67.40**

Root distribution with depth

As expected, regardless of the fire treatment, most of the root distribution was concentrated over the top soil layers with a decrease in roots with depth (Table 2). The same root distribution pattern was also noted by various other researchers (Shackleton *et al.* 1988; Moore 1989). Root distribution did not differ much between head and back fires over all depths for both seasons (Table 2). Presumably, in response to increased concentrations of nutrients in the surface layers of the soil, the bulk of root mass for most grass species are located in the top 50 100mm (Table 2). A significant interaction ($P<0.01$) was obtained between root distribution and soil depth deeper than 50mm for both burnt and unburnt grassland. Fire significantly increased root distribution over the first 0 to100mm depth (19%) and decreased it deeper than 100mm (Table 2). The above increase in root distribution due to fire only occurred six months after the fire, while the decrease with depth was already noticeable two months after the fire. A further increase in root distribution by fire occurred during the second season over the 50 to 100 mm layer with the greatest increase the second half of the season. The decrease in root distribution over the top soil layers due to fire can possibly be ascribed to the increase in the concentration of various soil properties.

Table 2: *Percentage root distribution with depth for the unburnt and burnt (head and back fire) grassland*

Depth (mm)	% of total root mass excavated (± SE) Unburnt	First season after burn		Second season after burn	
		Head	Back	Head	Back
0-50	20.68± 1.26	27.83± 1.32	27.28± 2.96	24.25± 1.22	23.85± 0.96
50-100	29.09± 1.33	31.13± 1.22	31.92± 2.41	34.99± 2.22	35.20± 2.12
100-150	22.06± 1.22	16.80± 1.11	17.30± 1.126	18.51± 1.21	17.88± 1.62
150-300	13.07± 1.01	11.76± 0.91	11.43± 0.92	10.08± 0.96	10.37± 0.96
300-600	8.40± 1.00	6.94± 0.86	6.91± 0.86	7.20± 0.99	7.71± 0.92
600-900	6.70± 0.90	5.54± 0.89	5.16± 0.65	4.97± 0.66	4.99± 0.66

Both the burnt and unburnt grassland show a strong concentration of roots in the top 150 mm soil layer where the averages for roots occurring, for the unburnt grassland and one year after the fire for the head and back fires, were 71.83%, 75.76% and 76.50% respectively (Table 2). Typically, more than 85% of roots in unburnt grasses are to be found in the top 300mm of soil (Tainton 1981; Moore 1989; Snyman 1998). There is evidence, however that the deeply penetrating roots are considerably more efficient per unit weight of root than are the surface roots, so the value of these roots

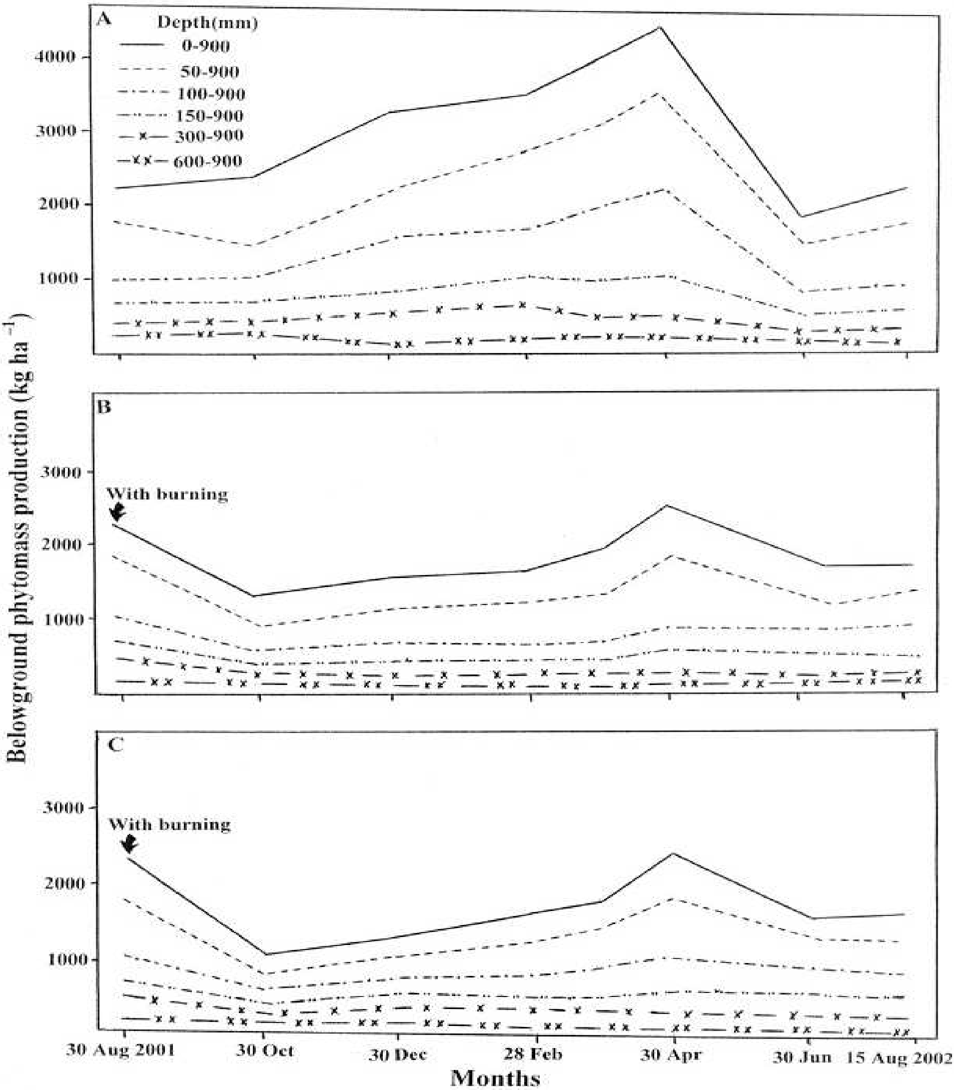

Figure 1:
Monthly root mass (kg/ha) for the unburnt (A) and burnt (B = Head fire and C = back fire) grassland over the first growing season after burning. Horizons (mm): A (0-300), B_1 (300-600) and B_2 (600-900). LSD (0.01) for 0-900 mm depth = 396.

should not be under-estimated (Wolfson and Tainton 1999). In arid and semi-arid environments, many grasses do not have a deep enough root system to access ground-water and are reliant on surface water after rainfall events (Drew 1979), leading to a short growing season which can further be hindered by fire (Table 2).

Two years after the fire the difference in root distribution between burnt and unburnt grassland is still significant with the roots in the burnt part still better distributed over the top 100mm (Table 2).Though no root cores were drawn deeper than 900mm, it should not have made a big difference to total root mass, as most of the roots occur above that.

Belowground phytomass production and seasonal trends

Over the first year following the fire, root mass was lowered ($P \leq 0.01$) by fire (Figure 1). The second season after the fire, the root mass of the burnt parts did not differ much from that of unburnt grassland over almost all depths (Figure 2). Though the back fire had a greater decrease ($P<0.05$) in root mass than the head fire over the first season after the fire, the difference grew smaller as the second season progressed, following the fire.

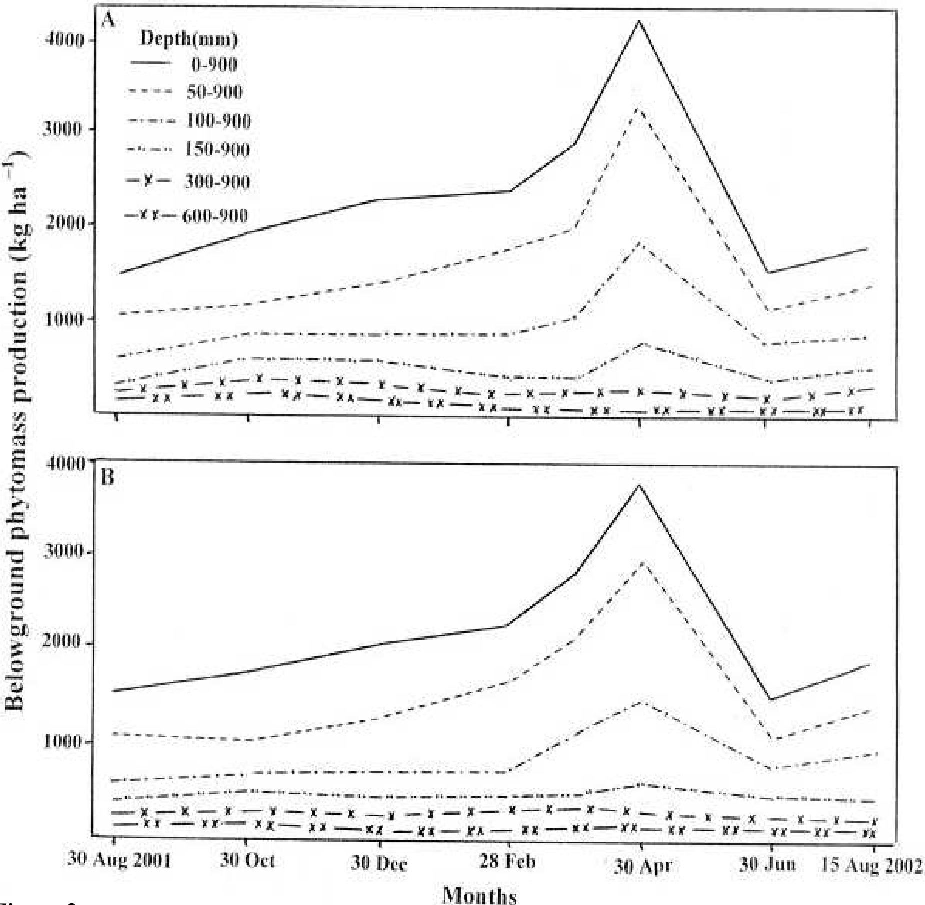

Figure 2:
Monthly root mass (kg/ha) for the burnt (head fire = A and back fire = B) grassland over the second season after burning. Horizon (mm): A (0-300), B_1 (300-600) and B_2 (600-900). LSD (0.01) for 0-900 mm depth = 376.

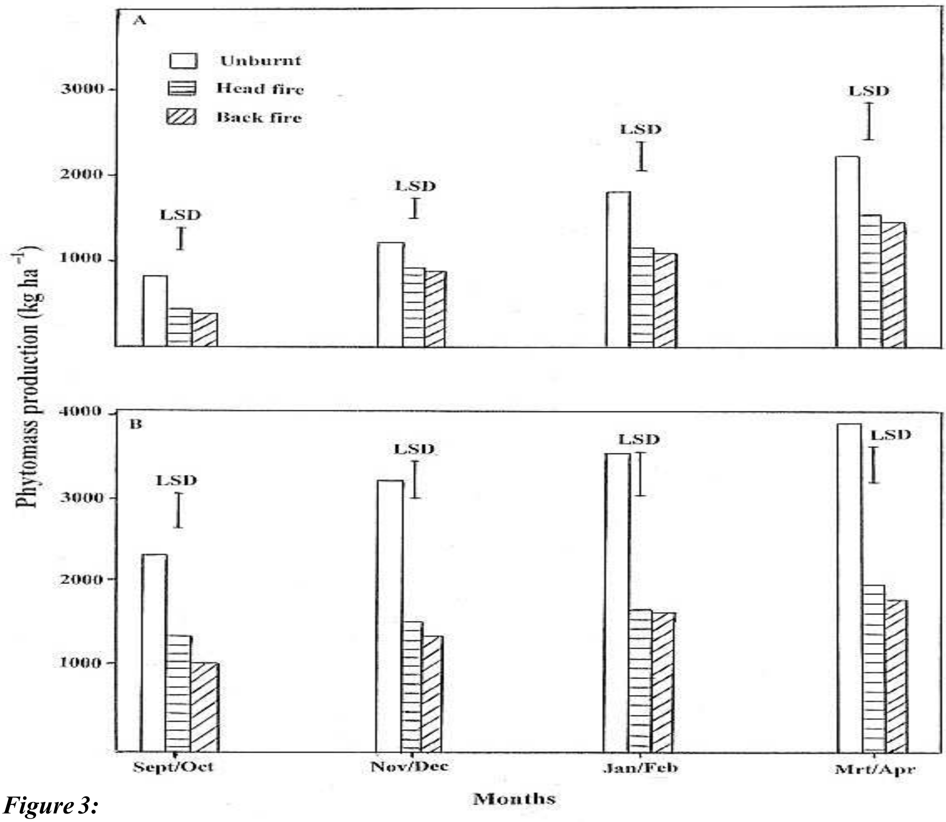

Figure 3:
Cumulative above- (A) and belowground (first 900 mm depth B) phytomass production (kg/ha) for the unburnt and burnt (first season after burning) grassland, measured every second month. Least significance (LSD) is calculated at the 1% level.

The peak root mass (up to 900 mm depth) of the unburnt grassland was 80% and only 11% higher than that of the burnt grassland, one season and two seasons respectively, after the fire (on average for the head and back fires). The peak root mass of 4549 kg/ha for unburnt grassland compared well with other peak values for South African semi-arid grassland of 3100 kg/ha (Weinmann 1943) 2260 kg/ha (Huntley 1977), 4630 kg/ha (Kelly and Walker 1974) and 2327 kg/ha in the Rift Valley province of Kenya (Ekaya *et al.* 2001). Although according to Wolfson and Tainton (1999) and Ingram (2003) root biomasses in semi-arid grasslands are strongly seasonal, the general trend was very similar over the two seasons with this study.

The belowground phytomass production fluctuated considerably over the study period (Figure 1), which is a common problem with root studies (Shackleton *et al.* 1988). Regardless of burn treatment, the grasses grew most active during the months of March to April. Peak autumn values for unburnt grassland were approximately 77% and 84% higher for respectively the head and back fires, one season after burning and 4% and 19% respectively for the second season after burning.

Notable of the considerable decrease in root mass occurring mid-winter, is that root mass was most influenced especially in the top soil layers (0 to 100mm) and also showed the most marked increase in autumn (Figure 1). Also significant in Figures 1 & 2 is that the root mass in unburnt grassland, one and two

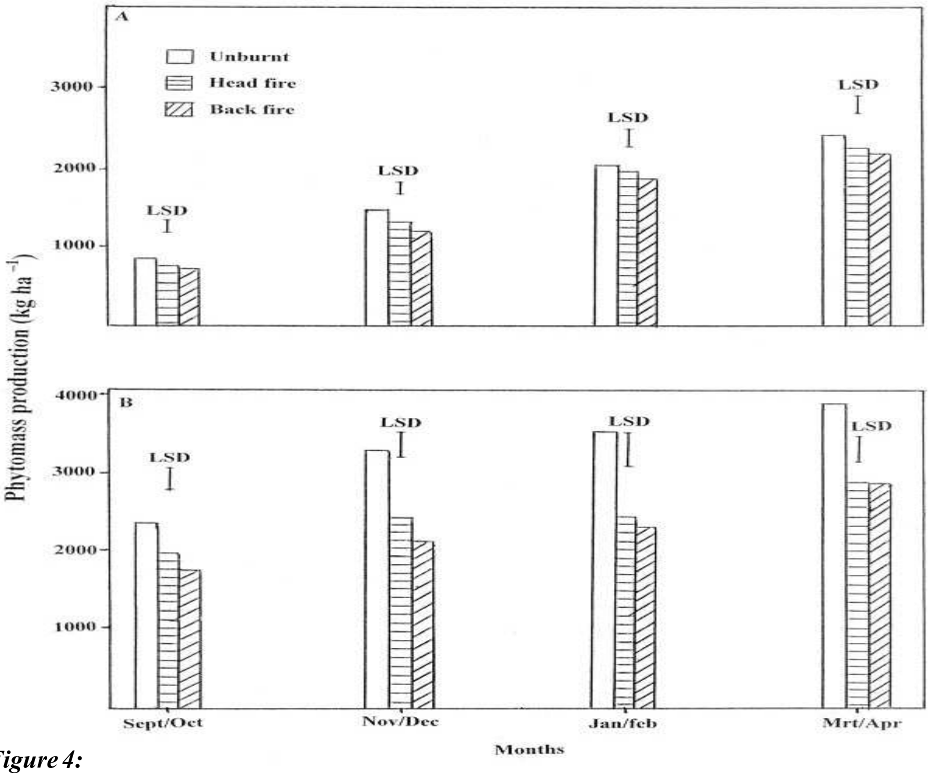

Figure 4:
Cumulative above (A) and belowground (first 900 mm depth B) phytomass production (kg/ha) for the unburnt and burnt (second season after burning) grassland, measured every second month. Least significance (LSD) is calculated at the 1% level.

years after the burning treatments, all declined to almost the same mass during mid-winter over most depths. The increase in root mass occurring with the onset of the growing season, can largely be linked to the increase in tuft sizes (litter production) as the season progresses (Snyman 1998).

Aboveground phytomass production

Fire decreased ($P<0.01$) aboveground phytomass production or regrowth of the burnt grassland over the first season after the fire (Figure 3). For the second season following the fire, the production was still lower than that of unburnt grassland, but statistically significant ($P<0.01$) only at the onset of the season (Figure 4). The production in case of the head and back fires was not significantly ($P<0.05$) different for any month, though the back fire had the lowest production throughout. This lower production could possibly be ascribed to the higher intensity of the back fire, which caused the lower plant density. Over the first season following the fire, the average production for head and back fires was 35% lower than that of unburnt grassland.

Root/shoot ratio

The root/shoot ratios for both one season and two seasons following the fire, as well as for unburnt grassland are presented in Table 3. With the exception of October, the ratios of unburnt grassland were higher ($P<0.01$) than that of the burnt grassland. This phenomenon is valid for both one and two seasons following the fire (Table 3). For almost all months, the head fire had a slightly ($P<0.05$) higher ratio than the back fire. This can possibly be due to the higher intensity of the back fire, which was more detrimental towards the root mass than aboveground production. As the first frost already occurred in the beginning of April in both growing seasons and the plants already then became dormant, the March root masses are used in Table 3 to calculate the root/shoot ratio for April.

For most months, the ratio within a burn treatment following a fire is higher during the first year than in the successive year (Table 3). The reason for this being that the aboveground production was influenced less than the roots by the fire over the first year following the fire. The root masses (over the first 900mm depth), responsible for the aboveground phytomass production for the different months for a growing season following the fire and two seasons thereafter, are graphically presented in Figures 3 and 4 respectively. From Figures 3 and 4 it is clear that in semi-arid areas it seems that root mass is generally greater than aboveground biomass (Shackleton *et al.* 1988). The decrease in aboveground phytomass due to burning for the first (2000/01) and second (2001/02) growing seasons after burning, were respectively 806 and 175 kg/ha compared to the 2002 and 1027 kg/ha decrease of root mass. The conclusion can therefore be made that belowground growth is more sensitive to burning than that of aboveground. The latter is one of the reasons for the decrease in root/shoot ratio with burning.

Conclusions

The time for recovery of belowground systems will not only depend on the burning intensity and its effects on key ecosystems processes and components, but also on the previous land-use practices. Therefore, the impacts of fire on belowground systems can be highly variable and may not be predictable. However from results obtained in this study, it was clear that poor root development accompanying fire, will over the short-term decrease the plant's susceptibility to drought and will reduce its capacity to extract mineral nutrients from the soil. This effect has been strongly implicated in the increasing frequency of man-made drought in the arid and semi-arid regions in southern Africa, in particular. The fact that underground production is more sensitive to fire than the aboveground, further emphasises the importance of a well-distributed root system for sustainable utilisation of the grassland ecosystem in arid areas. As the largest percentage of roots is limited to the top soil layer and responsible for production, the importance of deeper roots contributing towards survival of the plant during water stress, must not be underestimated. Peak root mass is attained during the dormant months when active

Table 3: *Average root/shoot ratios for the burnt (first (A) and second (B) seasons after burning) and unburnt grassland, measured every second month. Least significant differences (LSD) are calculated at the 1% level.*

Month	Unburnt	Head fire	Back fire			
	A	B	A	B	A	B
October LSD: A = 0.42 B = 0.46	2.80	2.79	3.12	2.60	2.96	2.50
December LSD: A = 0.86 B = 0.88	2.60	2.24	1.70	1.83	1.59	1.80
February LSD: A = 0.36 B = 0.38	1.83	1.72	1.42	1.27	1.49	1.24
April LSD: A = 0.22 B = 0.31	1.66	1.62	1.25	1.25	1.20	1.22

growth has ceased, with the storage of photosynthate to promote rapid regrowth at the onset of the growing season.

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