Short-term influence of fire in a semi-arid grassland on (4): soil characteristics

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Introduction

The habitat of plants growing in arid and semi-arid regions of the world is characterized, at least during part of the season, by low and variable rainfall (Oesterheld *et al*. 2001, Wiegand *et al*. 2004), low humidity and high soil temperatures (Du Preez and Snyman 1993, 2003, Snyman 2002). All these factors combine to decrease the storage or availability of soil-water (Snyman 2000), which often becomes a dominant factor in controlling the growth and root distribution of plant species (Shackleton *et al*. 1988, Schenk and Jackson 2002). The direct effect of fire on belowground systems is a result of the burning severity, which integrates aboveground fuel loading (live and dead), soil water (Snyman 2003) and subsequent soil temperature (Snyman 2002), and duration of the burn (Neary *et al*. 1999). Poor root development accompanying fire (Snyman 2005), will increase the plant's susceptibility to drought and will reduce its capacity to extract mineral nutrients from the soil (Matarechera *et al*. 1998). 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.

As with many other biological processes in arid systems, like plant uptake of nutrients and growth, decomposition and mineralization are closely related to climate and many such systems can be characterized as producing "pulses" or "flushes" of nutrients from mineralization during wet periods. Understanding changes in hydrological characteristics of the ecosystem under different fire regimes is therefore essential when making grass management decisions in these areas to ensure sustainable animal production. Therefore, short- and long-term studies are required to test interactions between fire, climate and vegetation change as affecting soil characteristics. The objective of this study was therefore to determine the short-term effect of fire on different soil characteristics in a semi-arid climate.

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 (Grassland Biome) with a slope of 3.5%. 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 the study area are 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 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 each 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. The experimental layout was a fully randomized design with three replications for each treatment. Two-way analysis of variance at 95% confidence level (burning x soil layer) was computed for soil-water content. The application of the different treatments on 30 August 2000 and on 23 August 2001 as well as the fire behaviour are fully discussed in the previous volume of Grassroots (Snyman 2005).

The soil-water content was determined gravimetrically by means of a Veihmeyer tube (Snyman *et al*. 1987) at 50mm depth intervals in all treatments (5 samples per treatment), 2, 8 and 20 months after burning.

Soil temperature was recorded with mercury thermometers once a week in each plot at 14:00 at 50, 100 and 200mm soil depths for all treatments (burning and defoliation). Although the thermometers were not properly ventilated, they were shielded. An estimate of soil compaction or soil penetration resistance was obtained from 30-point measurements per plot with a simple rod penetrometer (ELE pocket penetrometer) (Friedel 1987). Compaction readings were taken to a depth of 6mm. Points were placed 1m apart on three parallel lines in each plot. Soil compaction from an undisturbed bare soil surface nearby (Snyman 1999, 2000), against the potential was also measured. These measurements were taken three months (beginning of November), one year (at the end of April) and two years after burning (end of April), at about 18 hours after at least 25mm of rain had fallen (Donaldson *et al*. 1984, Donaldson 1986). Data on soil compaction and soil temperature were analysed using a one-way analysis of variance technique.

Results and discussion

Soil compaction

Fire caused the soil to be more compacted ($P \leq 0.01$), even two years after the fire, than the case without fire (Figure. 1). Euckert *et al*. (1978) found a decrease in soil aggregate sizes after a burn, where these effects persisted longer than five years. Raindrop energy from post-burn events can destroy soil aggregates at the soil surface and clog soil pores or form a crust that would restrict infiltration and enhance runoff and erosion (Sykora *et al*. 1990). Soil compaction differed non-significantly ($P > 0.05$) between head and back fires. Only two months after the fire, soil compaction was already higher ($P \leq 0.01$) than that of unburnt grassland (Figure 1). An important contributing factor towards higher compaction with burning can be a decrease in basal cover and litter after the burning (Broersma *et al.* 1999, Snyman 2003, 2004). The loss of vegetative and litter cover (Hoffman and Ashwell 2001, Holm *et al*. 2002) allows a direct impact of raindrops on soils (Russell *et al.* 2001), and may also produce hydrophobic substances that can reduce infiltration (Emmerich and Cox 1992, Snyman 1999). Thurow *et al*. (1988) also argued that the function of aboveground biomass is to protect the surface soil from the disaggregating effect of direct raindrop impact.

The lower soil compaction with the inception of the growing season in all treatments (Figure 1) can be ascribed to its slight lifting by the severe frost characterising the study area during winter. The initial increase in soil compaction as the season progresses, regardless of fire treatment, can be ascribed to greater exposure of the soil to natural elements, while the decrease at the end of the season can be due to an increase in aboveground production (Snyman 2005), affording better protection to the soil. The slow recoveries of plant cover due to fire (Snyman 2005) lead to a decrease in soil compaction during the second season following the fire. The average soil compaction of a bare uncultivated soil surface was an average of 21.60 kg/cm over the two growing seasons, which is not much higher than that of burnt grassland over the first year following the fire. The average soil compaction of unburnt grassland of 7.91 kg/cm obtained in this study is more or less the same as the 8.75 kg/cm obtained by Snyman (2001) also on rangeland in good condition and the same soil form.

Soil temperature

The mean monthly soil temperature at depths of 50mm and 100mm is graphically presented in Figure 2 for the burnt (first year after burning) and unburnt grassland. At these depths, soil temperature did not differ much ($P > 0.05$) between the head and back fires and were therefore presented as an average in Figure 2. Two seasons following burning, soil temperature at all depths did not differ much ($P > 0.05$)

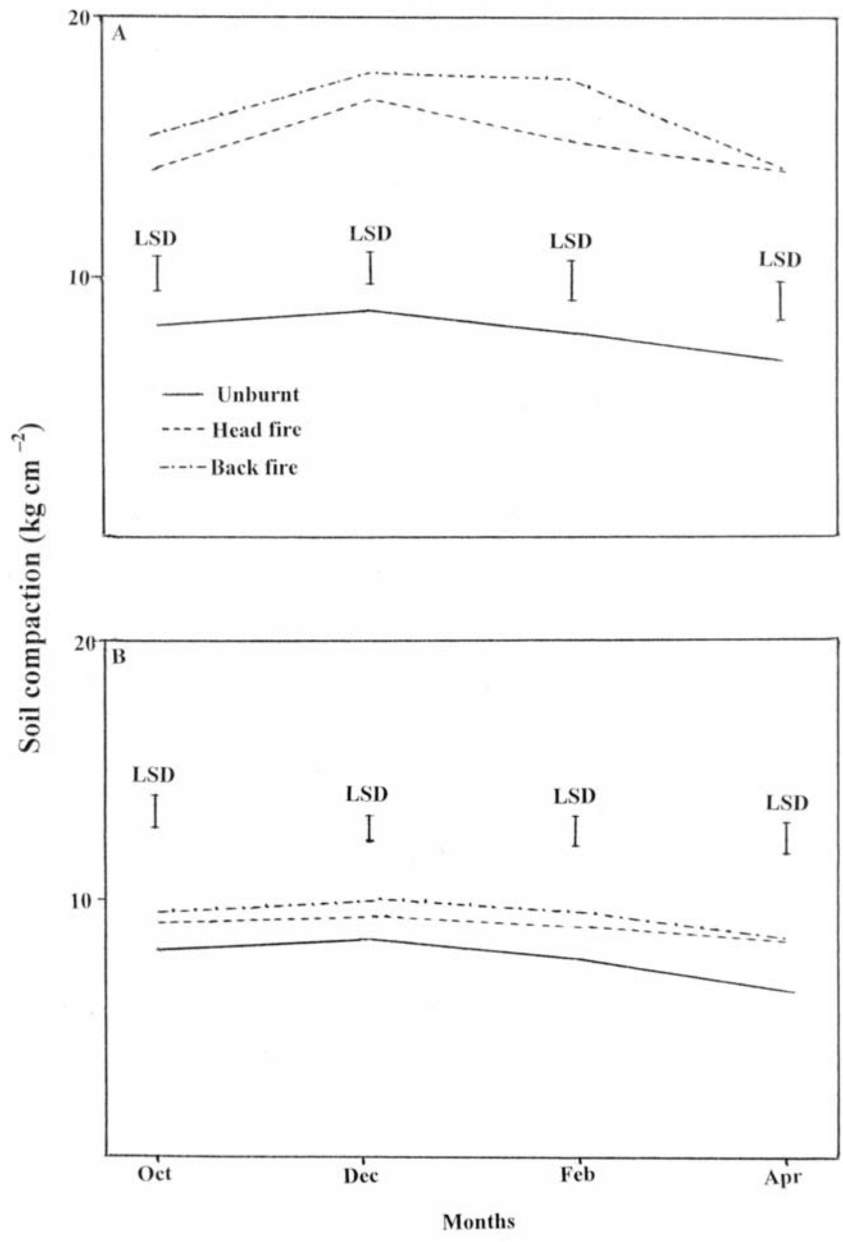

Figure 1: Soil compaction (kg/cm) for the burnt (first = A and second = B season after burning) and unburnt grassland, measured every second month. Least significant differences (LSD) are calculated at the 1% level.

between the burnt and unburnt grassland (data not shown).

Minimum soil temperatures are almost the same (P>0.05) regardless of depth and fire treatment. This low temperature may contribute to the much poorer root mass obtained in both unburnt and burnt grassland over the colder months. Unfortunately, little is known about the way in which root systems integrate the effects of wide ranges of temperature between different zones (Drew 1979, Distel and Fernandez 1988).

For the months of September to April, due to the lower cover (Snyman 2005) and litter, increase (P≤0.01) in soil temperature occurred for both depths with grassland burning (Figure 2). The highest soil temperatures, regardless of depth and burning occurred during January, where burnt grassland reached temperatures of as high as 40°C up to a depth of 50mm. The greatest difference in temperature between

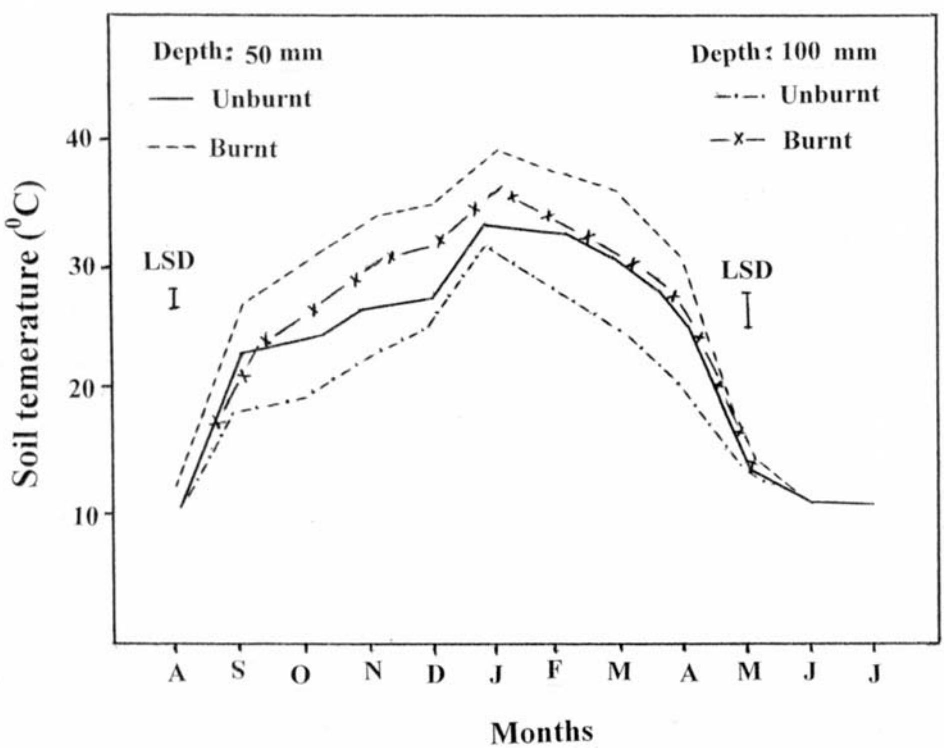

Figure 2: Monthly average soil temperature (°C) taken at ± 14:00 at 50 mm and 100 mm depths for the unburnt and burnt (first season after burning) grassland. Least significant differences (LSD) are calculated at 1% level.

burnt and unburnt grassland, was 7°C during December at a depth of 50mm. The higher soil temperatures recorded from burnt grassland at all depths could potentially restrict root growth (Snyman 2005). Although temperature as high as 40°C could decrease root extension rate in burnt grassland, there is considerable variation between species and genera (Bowen 1991) and it is likely that all of these species have roots adapted to high soil temperatures. In contrast, in the North American prairies, root growth was found to be associated with an increase in soil temperature (in areas where winter snow occurs) and moisture in spring and summer (Bartos and Sims 1974).

Further notable from Figure 2, is that the impact of fire over the first half of the growing season was more than that in the second half, in both soil depths. The most important reason for this difference may be the lower plant cover (Snyman 2005) and litter increasing or improving as the season progressed. For most months, soil temperature did not differ significantly (P>0.05) between treatments for the 200 mm depths (data not shown). The soil temperatures also did not vary much at 200 mm depth during the seasons in all treatments. Two years following burning, soil temperatures at all depths did not differ much between the burnt and

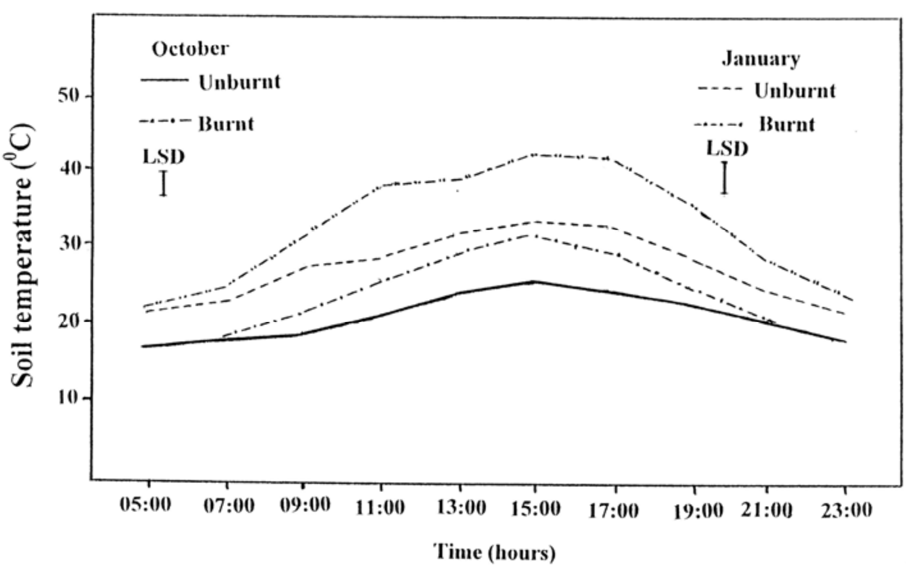

Figure 3: Average soil temperature (°C) for unburnt and burnt (first season after burning) grassland, measured every second hour at 50 mm depth, during the week of 4 October 2001 and week of 4 January 2002. Least significant differences (LSD) are calculated at the 1% level

unburnt plots.

Burning increased (P<0.05) soil temperatures from 09h00 for both October and January (Figure 3).

With the October observations the soil temperature in case of fire was higher (P<0.05) up to 17h00 than that of the unburnt grassland while in January it was higher (P<0.05) still at 21h00. Later in the season when soil temperatures generally increase, the impact of fire on the heating of the soil surface generally increased to almost a full day. The soil temperatures during January increased more rapidly during the day and remained high for longer than the October temperatures regardless of burning. With the January observations, the soil temperature difference due to fire at 15h00 and 17h00 was as high as 9°C.

The highest temperature on top of the soil of 59°C, 49°C and 46°C respectively for one year after burning, two years after burning and unburnt grassland respectively, occurred during January. The higher soil temperatures observed with grassland burning accorded with previous research (Snyman 2002, 2003, 2004, 2005).

Soil-water content

Fire had a considerable impact on the soil-water content, especially over the first year following the fire (Figure 3). The influence of the head and back fires on soil-water content did not differ much (P>0.05) from each other and therefore the average is presented in Figure 4. The lower soil-water content after 20 months over the first 300mm soil layer, in unburnt grassland, resulted from the low rainfall characterising the second half of the 2001/02 growing season.

Figure 4 clearly shows that after only two months the soil-water content decreased by 23% over the first 900 mm depth due to the fire. This difference can largely be due to the lower plant cover and removal of litter due to the fire, which can be ascribed to an increased loss of water through greater runoff (Snyman 2000) and evaporation (Van de Vijver 1999, Snyman 2005). Over the first year following the fire, the soil-water decreased by 42mm to a depth of 900mm due to the burn treatment. Twenty months after the fire the soil-water was still 21mm lower than that of unburnt grassland. The curtailing of growth due to water limitations depends not only on climatic conditions and soil properties but also on species differences, e.g. rooting depth (Drew 1979, Distel and Fernandez 1988).

The soil layer of 300-600mm depth maintained a relatively constant soil-water content for the three periods of monitoring, regardless of fire. The reason for this may be found in the lesser concentration of roots in this layer (Snyman 2005), regardless of the fire, and also the small difference in root decrease due to the fire (Snyman 2005). The soil water in the soil layer of 150-300mm, was the one mostly decreased by fire and also with most roots occurring here. The considerable (P≤0.01) decrease in root mass due to burning was responsible for this great variation.

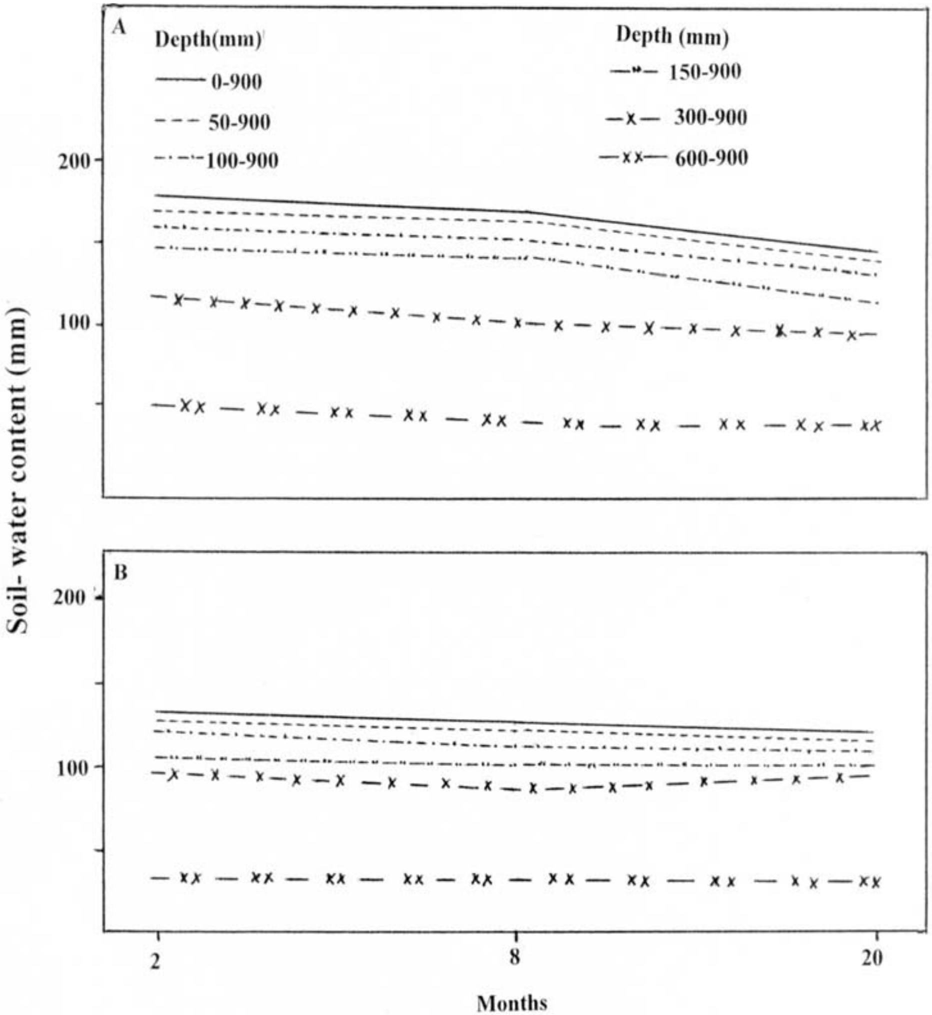

Figure 4: Soil-water content (mm) measured two, eight and 20 months after burning for the unburnt (A) and burnt (B) grassland, over different depths.

Root production in response to increased soil-water has also been recorded for African grasslands (Shackleton *et al*. 1988, 1989, McNaughton *et al*. 1998), Australian rangelands (Mott *et al*. 1992, Ingram 2003) and Argentina grasslands (Distel and Fernandez 1988).

The deep rooting patterns, regardless of fire (Snyman 2005), enable grasses to utilise surface as well as deeper soil-water. The large percentage of roots over the first 300mm depth is largely responsible for aboveground production as they benefit from the lightest rains (Snyman 2005). In contrast, the deeper roots, being thicker, are largely responsible for survival during times of water stress. Roots close to the soil surface produce fine rootlets that are maintained under moist conditions, but die as the soil dries out. The depth of water penetration does not exceed the rooting zone in these semi-arid areas (Bennie *et al*. 1994, Snyman and Oosthuizen 1999).

Conclusions

Although this study did not address basic concepts surrounding indicators of belowground sustainability, it rather focused on how fire affected specific components of belowground systems that, in turn, may affect overall ecosystem sustainability. The considerable increase in soil temperature and soil compaction, leading to a decrease in soil-water content as shown in this study, again emphasise the importance of burning with a specific purpose. The actual impact of fire on the hydrological cycle as determined in this study is not always considered. With water being the prime determinant of plant growth in semi-arid grasslands, reduced vegetation production after burning can be explained by the reduction of soil-water content as result of vegetation litter removal, which increases loss of water through evaporation. The effect of aboveground biomass removal through fire on vegetation production and nutrient content in the semi-arid areas, via changes in soil-water content, is greater than the effect of aboveground biomass removal through herbivores.

Throughout this study the soil-water content in unburnt grassland was higher, especially over the top soil layers, comparing with the much drier soil condition in the burnt grassland. This aspect has therefore a great influence on production and decomposition in roots and litter in arid and semi-arid areas, which are closely related to soil-water content. According to most researchers, nitrogen mineralisation, immobilisation and turnover are restricted both spatially and temporally to the soil layer wetted by rain and its amplitude in the heterotrophic cycle may be determined largely by the availability of water to soil microflora. Therefore it can be concluded that where soil-water may be the most limiting factor in burnt grassland over the first two years in semi-arid areas, it is nitrogen in case of burnt grassland when soil-water content is high. The rate of soil organic matter decomposition can increase to a maximum at about 37°C and then declines (Jenkinson 1981). Therefore, decomposition of litter and roots in burnt grassland, with the higher soil temperatures, may take faster than in unburnt grasslands.

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The effect of large area burns on nutrients and herbivore distribution in the north of the Kruger National Park

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This study was done in the Mooiplaas region on the northern basalt plains of the Kruger National Park, after an area of 113.38 km^2 around the Capricorn roan camp burnt down in April 2002. Within a week after the fire there was a rainfall event of about 20 mm. Soon after, zebra that had been almost absent from the area, were seen on the burnt patch. To determine the effect of a burnt patch on the concentration of herbivores, the animals on the burnt patch and an unburnt control area of 228.87 km^2 was counted in May, using a fixed wing aircraft. These counts were repeated in September of 2002 (Figure 1). The density of animals was much higher on the burnt area within the first month after the burn, but animals were distributed almost evenly by September. However, most of the zebra that moved on to the burn in May were still there in September.

Grass samples were collected to test whether the nutrient content of grass in the burnt and unburnt areas differed. Ten samples of the young