African Journal of Tropical Agriculture ISSN 2375-091X Vol. 3 (12), pp. 001-007, December, 2015. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Long-term effects of different burning frequencies on the dry savannah grassland in South Africa

Fatunbi Abiodun Oluwole, Johan Mackson Sambo and Dube Sikhalazo

Livestock and Pasture Science Department, Faculty of Science and Agriculture, University of Fort Hare, PB X1314, Alice 5700, South Africa.

Accepted 16 May, 2015

The use of fire in the management of grassland is a common rangeland practice in South Africa. This portends ecological implication for the sustainability of the savannah rangelands as a system. A long term trial was established in August 1980 at the University of Fort Hare, to evaluate the effects of this practice and determine the frequency of burning that yield optimum benefits. The experimental treatments consisted of five different burning frequencies, viz., no burning (K), annual burning (B1), biennial burning (B2), triennial burning (B3), quadrennial burning (B4) and sexennial burning (B6). Surface soil chemical characteristics and macro fauna densities were assessed from each experimental unit after 25 years of treatments implementation. Burning significantly affect the surface soil concentration of total N, organic C, exchangeable K, Mg and Na, but soil pH increased slightly in the short run. The macro fauna density was significantly higher in the annual, biennial and triennial burned plots compared with the unburnt plots. The soil macro fauna density increased by 31.4% in the B1 plots, while longer burning frequencies (B2- B6) ranged between 15.1 – 51.4% which increases with reduced frequency of burning until a peak at B3 and thereafter a reduction. A significant inverse correlation (*r*= -0.56*) was observed between the grass biomass and fauna density. There was also a relative reduction of 23% in grass biomass in the frequently burnt plots (B1). The B3 plots had the highest suitability index of 44, which indicated the frequency of burning at which optimum benefit could be derived based on the measured variables. Frequent burning of savannah grassland led to reduction of surface grass biomass and increase in the soil organic carbon content which we speculated to be due to increase in underground carbon pool from dead roots.

Key words: Fire treatment, rangeland management, soil nutrients, soil macro fauna, grass biomass.

INTRODUCTION

Burning of grass cover is a major cultural practice in the livestock farming system of the South African savannah grassland (Snyman, 2004; Zacharias and Danckwerts, 1999). Farmers often burn to remove moribund and unpalatable grasses from previous growing season; to stimulate the re-growth of fresh herbage with higher nutrient content (Tainton and Mentis, 1984; Snyman, 2003). Burning is also believed to rid the grassland of parasitic insects and to prevent the encroachment of undesirable invasive plant species. The later is subjective since fire is also known to break seed dormancy in some of the common invasive species (Auld and Denham, 2006).

The environmental suitability of grassland burning as a cultural practice has been called into question by may authors (Everson, 1999; Auld and Rozer, 1999; Zacharias and Danckwerts, 1999) for reasons of; (a) the magnitude of heat generated by the fire and its negative effect on soil biota (Badia and Marti, 2003; Flower et al, 2004), (b) The amount of recyclable nutrients that was lost to the atmosphere by volatilization, (c) the destruction of the surface organic mat layer and its effects on the green house gas emission (Badia and Matri, 2003).

Farmers that aim at benefiting from the lush re-growth after burning tend to subject their grassland to fire every season, irrespective of the amount of moribund herbage at the end of the season, thus exposing the surface mat layer to destruction (Booysen and Rowswell, 1983; Snyman, 2002; Snyman 2003b). A balance between the benefits accruing to the farmers from grassland burning

*Corresponding author. E-mail: afatunbi@ufh.ac.za. Phone: +27 40 602 2025, Fax +27 602 2488.

Table 1. Ten years climatic data for the study area (Monthly average).

Year	Rainfall (mm	Temperature (°C)		Relative humidity (%)		Pan Evaporation (mm)	Sunshine hours	Chill Unit	Wind Velocity (Km/day)
		Min	**Max**	**Min**	**Max**				
1997	46.4	10.9	23.9	30.4	85.1	130.9	6.7	-256.8	96.4
1998	49.3	11.3	24.6	33.3	86.4	136.6	7.0	-297.5	108.6
1999	41.3	12.1	25.3	33.6	88.2	121.3	7.0	-337.6	83.9
2000	61.1	11.1	24.0	35.9	88.0	101.7	6.9	-280.8	81.6
2001	53.1	11.5	24.0	40.2	87.4	122.2	7.0	-308.9	94.8
2002	52.2	11.2	24.7	38.3	88.5	135.4	7.2	-276.7	94.9
2003	36.8	11.2	25.0	38.0	91.1	139.7	7.2	-284.0	90.2
2004	51.0	10.9	24.6	37.7	91.0	133.4	7.4	-271.7	86.8
2005	44.4	11.1	24.8	36.3	90.2	135.6	7.3	-296.4	90.2
2006	61.9	11.4	24.0	48.3	96.3	126.1	6.6	-276.0	99.6
2007	47.8	15.9	28.1	48.0	95.7	166.1	7.4	-581.8	117.8
Annual average	**49.6**	**11.7**	**24.8**	**38.2**	**89.8**	**131.7**	**7.1**	**-315.3**	**95.0**

Table 2. Range values of the Initial soil physical and chemical characteristics of the experimental site.

Characteristics	Description
Sand fraction (g kg-^{1})	560 - 600
Silt fraction (g kg-^{1})	260 - 430
Clay fraction (g kg-^{1})	10 - 140
pH	5.60 - 5.67
Organic C (g kg-^{1})	5.1 – 9.6
Available P (mg kg-^{1})	2.57 – 4.33
Exchangeable K (mg kg-^{1})	120.2 – 179.2
Exchangeable Ca (mg kg-^{1})	416.0 – 452.4
Exchangeable Mg (mg kg-^{1})	99.4 – 111.6

burning and the negative implications of such practice on the soil and vegetation properties is important to deriving a sustainable grassland burning system. For burning to be a sustainable rangeland practice, factors to be managed include the; fire intensity, fuel load, season of burning and the frequency of burning (Snyman, 2004). It is also important to determine the optimum range for each of these factors, at which rangeland health is least affected.

This paper reports findings from a long term experiment that was established, with the broad objective of investigating the effects of rangeland burning as a low input cultural practice on the sustainability of rangeland as a system. However, the specific objective of the investigation reported here was to: (i) . Evaluate the medium term (26 years) effect of different frequency of burning on the herbage production potentials of the grassland. (ii). determine the effect of different burning frequency on soil health variables viz., pH, EC, organic carbon, total N, available P, and exchangeable Ca, Mg, K, Na and soil macro fauna density. (iii). Determine the burning frequency with appropriate time lag for optimum recovery of the burnt grassland.

MATERIALS AND METHODS

Site description

This research was conducted at the Honnydale farm (32° 47 S 26° 52 E altitude 518 m), a part of the University of Fort Hare (UFH) research farm and it is at about 3 km outside Alice town. Honnydale farm is situated in the semi arid summer rainfall regions of South Africa. The mean annual rainfall is 500 mm of which 70% occur between October and March. The rainfall distribution pattern is irregular and varies from year to year. The temperature regimes are moderate with cold winter, the maximum ranged between 26 – 41°C and the minimum ranged from 5 - 11°C (ARDRI, 1989) (Table 1).

The vegetation of the study area is the false thornveld of the Eastern Cape, it consisted of grasses interspersed with *Acacia karoo* Hayne shrubs in some part, while most part of the field did not have bush plant. The rangeland was in good condition for livestock production purposes and consisted of dense sward dominated by *Themeda triandra, Panicum maximum* and some invasion of *Digitaria eriantha* and *Sporobolus spp*. The main karroid shrub was *Chrysocoma tenuifolia* (Teague *et al.,* 1981).

The soil at the site is silty loam of the Glenrosa form (Soil Classification Working Group, 1991) or Ochric Cambisol (FAO/UNESCO), which is characteristically shallow with stony surface. Soils were not chemically characterized at inception of the study, however, Materechera et al. (1998), analyzed soil samples from border rows and surrounding plots to give an indication of the initial properties prior to treatment (Table 2).

Treatments

The experiment is a long term trial of the Livestock and Pasture Sci-Science Department, UFH, Alice. It was established in 1980 on a freshly burnt site to ensure relative uniformity in vegetation and soil conditions at the take off point for all treatments. The treatment consisted of annual burning (B1), biennial burning (B2), triennial burning (B3), quadrennial burning (B4), sexennial burning (B6) and no burning (K) (Table1). Each of the treatment was laid out on a

Table 3. Burning history of each treatment since from 1980 - 2005**.**

Treat	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	Total
B1	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	25
B2	#		#		#		#		#		#		#		#		#		#		#		#		#		13
B3	#			#			#			#			#			#			#			#					9
B4	#				#				#				#				#				#				#		7
B6	#						#						#						#						#		5
K																											

Note: **#** = Burnt, B1 = annual burning, B2 = biennial burning, B3 = triennial burning, B4 = Quadrennial, B6 = Sexennial, K = Control

100 x 50 m land that was separated from each other with a border space of five meter. The experiment was laid out in completely randomized design with two replicates. Burning of the plots takes place every August and it is often preceded with a vegetation assessment exercise. The five meter wide boarders of the experimental units are subjected to regular grazing by the cattle, sheep and goats. The current evaluation of the trial was conducted before the implementation of the 26th year treatments in the trial (Table 3).

Soil sampling and analysis

Soil samples (0 - 15 cm) were collected from each treatment plot in July 2006. Ten cores were sampled with a screw auger from each experimental unit to form a single composite. Samples were air dried for two weeks and sieved with a 2 mm mesh before chemical analysis.

Soil pH and EC were measured in 1:2.5 water extract as described by Okalebo et al. (2002). Total N was measured calorimetrically in a digests made with concentrated sulphuric acid, selenium powder and hydrogen peroxide (Okalebo et al., 2002). Organic carbon was determined using the wet dichromate digestion followed by titration with acidified ferrous sulphate (Okalebo et al., 2002). Available P, exchangeable K, Ca, Mg and Na were measured in AMBIC-2 extract (Non-affiliated Soil Analysis Working Committee, 1990). Available P was determined colorimetrically using the modified molybdate blue method, while the exchangeable cations were determined using the atomic absorption spectrophotometer (Model No: Unicam UAA119701) (Non-affiliated Soil Analysis Working Committee, 1990).

Soil macro fauna sampling

Soil macro fauna density was measured using the monolith technique described by Anderson and Ingram (1993). A 50 x 50 cm cavity with 30cm depth was dug out and all the macro fauna species were separated. The fauna were preserved in 10% formalin solution prior to weight determination. Five monoliths were sampled per treatment plot. The mean weight of the fauna was extrapolated to a hectare basis.

Measurements of above ground biomass

The above ground vegetation biomass was measured by using the destructive quadrant method. Herbaceous materials were harvested from five randomly placed 1.0 x 1.0 m quadrant in each experimental unit. The materials were oven dried at 70ºC until constant weight was achieved.

Statistical analysis

All data set were subjected to normality test to ascertain their distribution and conformity to the assumptions of F-test. Furthermore, F-test was conducted using the generalized linear model procedure (Proc GLM of SAS) (SAS Institute, 1999). Means were separated using Duncan multiple range test at 5% (SAS institute, 1999). Correlation analysis was also conducted to determine the level of relationship that existed among the measured variables using "Proc Corr" procedure (SAS Institute, 1999).

An index of suitability was generated with the use of multidimensional analysis technique reported by Shama et al. (2005). To derive an index, four major steps were outlined, (i) define the goal, (ii) select a minimum data set (MDS) of indicators that best represent the rangeland system function (iii) score the MDS indicators based on their importance to the rangeland function and (iv) integrate the indicator scores into a comparative index for rangeland burning frequency.

In our study, the goal of this analysis was to derive an index that integrates the functional variables of a rangeland system, in determining the suitability of a burning frequency. The minimum data set (MDS) in our study comprise of the 11 measured variables viz., soil pH, EC, organic carbon, total N, available P, exchangeable K, Ca, Mg, Na, grass biomass and macro fauna density. We consider the 11 variables in our study to be a modest size; therefore we did not trim down the number of variables in the MDS with the use of principal component analysis and or correlation and regression analysis as reported in other studies (Sharma et al., 2005). The data points for each variable were transformed to have an homogenous unit with other variables. This was achieved by arranging the variables in order, based on theoretical understanding; whether a high value is known to be good or bad for the rangeland function (Sharma et al., 2005). For variables where "higher value was considered better", each observation was divided by the highest observed value, while for "less is better" variables, the lowest observed value was used as the numerator while the values in range are the denominator. This yield a situation where the best point under each variable had a transformed value of one. Observations under each variable were then weighted by multiplying the transformed values with a weight of importance which was allocated to each variable depending on their empirical and or theoretical contribution to rangeland quality. We then sum up the weighted variables score for each treatment using this equation.

$$\text{Suitability Index} = \sum_{i=1}^{n} WiSi$$

Si = Score of variable; *Wi* = weight of importance for the variable.

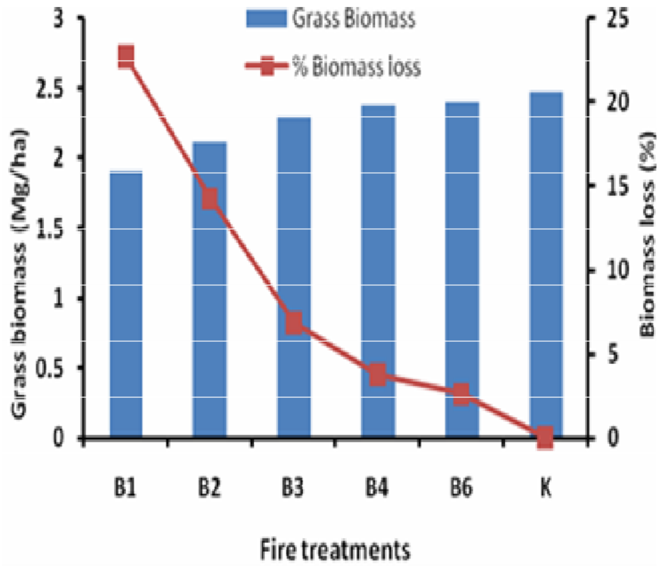

Figure 1. Effects of long term fire treatment on change in grass biomass production over 26 years. B1= annual burning, B2 = biennial burning, B3 = triennial burning, B4= Quadrennial, B6 = Sexenial, K = Control

RESULTS AND DISCUSSION

Long term effect of different burning frequency on grass biomass production

Grass biomass production was not significantly affected by different frequency of bush burning over 25 years of treatment (Figure 1). The grass biomass ranged between 1.91 – 2.64 t ha^{-1} among the treatment means. The grass biomass was reduced with increased burning frequency, while the percentage loss of biomass relative to the control was substantially higher with the annual (22.7%), biennial (14.3%) and triennial (6.8%) burning, while the quadrennial and sexienial are of negligible quantity (Figure 1). Similar observation was reported by Snyman (2004). The observed substantial loss in grass biomass with annual burning could be attributed to reduced plant density, destruction of seed bank and weakened species diversity within the rangeland (Snyman, 1998; 2004; Guevara et al., 1999; Auld and Denham, 2006). Other reports have implicated frequent (annual or biennial) prescribed fire treatment of rangeland with both positive and negative consequences. It has been reported to result in reduction of non palatable grass species and a more balance between grass and shrub species (Guevara et al, 1999) . In turn, high proportion of bare patches often result from frequent burning which predisposes the rangeland to soil erosion and land degradation. Thus a burning frequency with more rapid biomass close up relative to the control could afford the rangeland system the benefits of burning with reduced consequences.

Effects of different burning frequencies on soil chemical properties

Soil chemical properties responded differently to burning of rangelands at different frequencies over 25 years (Table 5). A slight increase was observed in soil pH in all the treatment plots compared with the initial (Table 2). Soil pH was higher in the burned plots compared to the unburned plots; similar observation was reported by other authors (Bird et al., 2000; Snyman, 2004; Badia and Matri, 2003; Chandler et al., 1983) to have resulted from ash deposit from the consumed plant biomass. The resulting ash material is also known to be a rich source of cation. This explains the observed higher content of exchangeable K, Ca, Mg and Na in the burnt plot compared with the unburnt (Clapham and Zibilske, 1992). The differences in exchangeable cations among the different burning frequencies were not statistically significant (P<0.05). We therefore speculated that this could be due to the soluble nature of the basic cation and their susceptibility to leaching, especially in soils with limited colloidal capacity. This observation confirmed an earlier report from this trial after 16 years of establishment (Materechera et al., 1998), where higher concentration of exchangeable cation were found in the lower soil layer as evidence of leaching.

Available P was higher in the annual burnt plots compared to the control, meanwhile, the values obtained in other burning frequency plots were lower compared to the control. This observation was attributed to the supply of P through the more frequent ash from the burnt plants. It has been reported that virtually all the P content of the standing phytomass are added to the soil as ash, since P is a less mobile soil nutrient (Raison et al., 1985; Badia and Marti, 2003).

Soil organic carbon was slightly higher in the burnt plots compared with the unburnt plot; this is in contrast to a previous report from the trial (Materechera et al., 1998). The observed discrepancy in soil organic carbon response could be explained by the dynamics of soil organic carbon in response to surface fire. Often, there is an initial loss of soil organic carbon after fire treatments, due to the combustion of the organic matter fraction in the surface mat layer. Thereafter, soil organic carbon recuperation follows with the decomposition of roots of dead or burnt-off plants, which overtime attains a balance with the unburnt plot. The time lag required for a complete recuperation is not ascertained in this study, yet the time lag between the last fire treatment and soil sampling time in each treatment is important to the stock of soil organic carbon (Table 1). The B3 treatments had a higher soil organic C content, although not statistically significant compared with other burning frequencies and the control. The reason for this is not clear but was attributed to a build up of microbial populations over the period between successive burning (Materechera et al., 1998), which in this case was three years for the B3 treatment before the

Table 4. Effects of long term fire treatments on the soil macro fauna population density

Treatment	Fauna Biomass	Relative effect of treatment
	kg/ha	%
B1	33.7	31.4
B2	33.5	30.5
B3	38.9	51.4
B4	29.6	15.1
B6	20.6	-20.0
K	25.7	0
SED	8.0	

Note: SED = Standard error of difference; B1 = annual burning, B2 = biennial burning, B3 = triennial burning, B4 = Quadrennial, B6 = Sexenial, K = Control

last general burning (Table 3). The total nitrogen concentration had similar trend as soil organic carbon.

The relationship between soil variables and grass biomass is presented in Table 6. The soil organic carbon was significantly correlated with the exchangeable Ca, Mg and available P (r = 0.568*, 0.592* and 0.773**) this further corroborate the observed higher content of basic cation and organic carbon in the burnt plots. The soil organic matter has been described as the source and sinks of most soil nutrient, same applies to rangeland soils. The grass biomass production was negatively correlated with organic C, exchangeable Ca and Mg (r = -0.528*, -0.618 and -0.602).

The effectiveness of ash as liming material has been shown by several authors (Clapman and Zibilke, 1992; Ohno and Erich, 1990; Van Reuler and Janssen, 1996). This explains the significantly ($P < 0.05$) higher pH in the surface layers of burnt plots (B1, B3, B4 and B6) than in the unburnt plots (K). The positive correlations between pH and the basic cations (Ca, and Mg) emphasize the association of pH with the availability of these nutrients for plant use in the rangelands.

Effects of long term burning frequency on soil macro fauna density

Soil fauna affect soil system through their burrowing and feeding behavior, resulting in improved aeration, water infiltration, and incorporation of organic matter (Edwards and Bohlen, 1996). Results from this study showed that fire significantly increased soil fauna population. A 31.4% increase in soil fauna population density was observed in annual burnt plots compared to a 20% reduction in plots burnt every six year (Table 4). This effect is attributed to an increase in the quantity of available litter materials from dead root mass which is a source of food for the macro fauna (Blair, 1997). Reports from other studies on macro fauna density in grasslands have shown the abundance of earthworm species to be higher in the annually burnt grassland relative to grasslands where fire was excluded for 6 years (James, 1982). We speculated that the treatments in our study would have resulted in a gradient of sub-surface litter accumulation from root phytomass; this is known to enhance soil moisture, decrease soil temperature and provide a suitable environment for the proliferation of most soil fauna, particularly at the inception of the growing season (Callaham et al., 2002; Knapp and Seastedt, 1986). Other reports also indicated an increase in the density of *Chironomids spp*. in burned plots than unburned plots (Luxton, 1982). Fire also influences the quality and amount of plant tissue inputs below ground (Blair, 1997), which affects the distribution of macro fauna in the soil. The amount of live root tissue in annual burned soils is significantly greater than in unburned soils and live roots in annually burned soils can have a C:N ratio that nearly double that of unburned soils (Ojima et al., 2001, Johnson and Matchett, 2001).

Optimum frequency of bush burning for sustainable rangeland management

The suitability index for grassland burning frequency was derived from 11 measured variables, using multidimensional analysis techniques (Table 7). The index ranged between 38 and 44, with burnt plot having a higher rating than unburnt plots. The triennial burnt plot had the highest index of 44, which showed the burning frequency at which benefit could be derived from bush burning and optimum recovery of key quality variables will be achieved. Burnt rangelands are susceptible to rapid degradation; as such, post burning management techniques are vital to the sustainability of the rangeland system (Everson, 1999; Auld and Rozer, 1999; Snyman, 2004). It has been recommended that rangelands in the drier part of South Africa (Sweet veld) should not be subjected to fire treatment for increased grass biomass but rather to rid off invasive species and moribund grasses (Snyman, 2004; Trollope, 1999). Our result simply showed the baseline effects of fire treatment and the required time lag for recuperation for the drier savannah grassland (sweet veld) of the Eastern Cape.

Conclusion

The influence of fire on the sustainability of the fragile ecological conditions in the semi arid rangelands in South Africa was not clear prior to this study. More importantly, the long term effects of burning on the communal rangelands, where there is no external inputs or management practices.

The observed long term decline in biomass production and the soil system as well as the required recovery period after successive fire treatment has not been realized in the past. This study showed that the recovery period for optimum productivity of vegetation and soil variables is three years. It is vital to incorporate this information into

Table 5. Effects of different burning frequencies on soil chemical properties after 26 years.

Treatment	B1	B2	B3	B4	B6	K	SED	CV(%)
pH	6.0	5.93	6.27	6.05	6.11	5.89	0.40	2.68
Electric Conductivity (us/cm)	127.45	104.35	142.55	116.2	102.4	115	32.4	15.8
Available P (g/kg)	0.041	0.028	0.024	0.023	0.033	0.035	0.02	0.41
Total N (g/kg)	1.92	1.47	1.58	1.48	1.44	1.24	0.74	29.02
Organic Carbon (g/kg)	12.66	10.93	12.76	12.22	11.64	10.93	4.2	21.06
Exchangeable K (mg/kg)	299.0	373.4	373.5	360.7	397.7	328.6	65.1	10.0
Exchangeable Ca (mg/kg)	1600.1	1348.9	1561.6	1698.3	1742.9	1240.5	407.9	12.9
Exchangeable Mg(mg/kg)	264.4	140.0	232.6	220.3	208.2	126.5	89.7	27.3
Exchangeable Na (mg/kg)	1203.7	1291.4	1182.8	1183.0	1255.4	1117.2	161.4	5.1

Note: B1= annual burning, B2 = biennial burning, B3 = triennial burning, B4 = Quadrennial, B6 = Sexennial, K = Control, SED = standard error of difference.

Table 6. Correlation matrix showing the long term effects of fire treatment on relationship between different soil variables.

	EC	Organic C	Exch K	Exch Ca	Exch Mg	Available P	Biomass
pH	0.643**	0.020	0.229	0.552*	0.376	-0.022	-0.060
EC		0.516*	-0.089	0.367	0.630**	0.577**	-0.277
Organic C			0.185	0.568**	0.592**	0.773***	-0.528**
Exchangeable Ca					0.576**	0.216	-0.616
Exchangeable Mg						0.506*	-0.602

Note *** = significant at P<0.01 ** = Significant at P<0.05 * = Significant at P< 0.10.

Table 7. The weighted values, weight of importance and suitability index for grass burning frequency based on the measured eleven variables.

Treat	pH (3)	EC (2)	Tot N(5)	Org C(5)	Exch. K(2)	Exch. Ca(2)	Exch. Mg(2)	Exch. Na(2)	Avail. P(4)	Fauna PB(4)	Biomass (5)	Suitability Index
B1	3.0	2.5	5.1	4.9	7.5	9.2	2.0	1.9	3.3	4.0	4.2	43
B2	3.0	2.0	3.9	4.3	9.4	7.7	1.1	2.0	2.6	2.9	5.6	41
B3	3.1	2.8	4.2	5.0	9.4	9.0	1.8	1.8	3.9	1.8	5.1	44
B4	3.0	2.3	3.9	4.8	9.1	9.7	1.7	1.8	3.9	1.5	4.2	42
B6	3.1	2.0	3.8	4.5	10.0	10.0	1.6	1.9	2.4	2.7	4.9	43
K	2.9	2.3	3.3	4.3	8.3	7.1	1.0	1.7	3.3	2.0	5.1	38
CV (%)												5.0
SE												0.84

B1 = annual burning, B2 = biennial burning, B3 = triennial burning, B4 = Quadrennial, B6 = Sexenial, K = Control. Value in parethesis represents the apportioned weight of importance for the variable.

the management system for sustainable use of the fragile resource base. Our study did not include the impact of grazing after burning, moreover, if the burnt treatment units were graz- ed as it is practiced in convectional production system, the decrease in soil quality and biomass may be higher and longer recovery period may also be required. Further in-depth research is required to determine the effects of burning and grazing on the ecological sustainbility of the drier savannah grassland of South Africa. It is also important to research the required time lag for vegetation recuperation before grazing and the relative effects of that on the best burning frequency.

REFERENCES

Anderson JM Ingram JSI (1993). Tropical Soil Biology and Fertility, A Hand book of Methods. CAB International, Wallingford, Oxon, UK p. 221.

ARDRI (Agricultural Rural Development Research Institute) (1989). An agricultural guide book for Ciskei. Agricultural and Rural Development Research Institute, University of Fort Hare, Alice.

Auld TD, Rozer MG (1999). How well do post-fire indicators provide insights into the degree of soil heating during the passage of fires? Australian Bushfire Conference Proceedings, Albury, Australia, pp. 1–11.

Auld TD, Denham AJ (2006) How much seed remains in the soil after a fire? Plant Ecol. 187(1): 15–24

Badia D, Marti C (2003). Effect of simulated fire on organic matter and selected micro biological properties of two contrasting soils. Arid Land Res. and Manage. 17: 55 – 70.

Bird MI, Veenendaal EM, Moyo C, Lloyd J, Frost P (2000). Effect of fire and soil texture on soil carbon in a sub-humid savannah (Matopos, Zimbabwe). Geoderma 94: 71–90.

Blair JM (1997). Fire, N availability and plant response in grasslands: a test of the transient maxima hypothesis. Ecol. 78: 2359–2368.

Booysen J, Rowswell DJ (1983). The drought problem of the Karoo areas. Proceedings of the Grassland Society of Southern Africa, pp. 40–45.

Callaham MA, Blaira JM, Toddb TC, Kitchena DJ, Whiles MR (2003). Macro-invertebrates in North American tall-grass prairie soils: effects of fire, mowing, and fertilization on density and biomass. Soil Biol. and Biochem. 35:1079–1093.

Callaham MA Jr, Whiles MR, Blair JM (2002). Annual fire, mowing and fertilization effects on two cicada species (*Homoptera cicadidae*) in tall-grass prairie. American Midland Naturalist 148: 90–101.

Chandler C, Cheney P, Thomas P, Trabaud L, Williams D (1983). Fire in forestry. Vol 1: forest fire behavior and effects. John Willey New York.

Clapham WM, Zibilske LM (1992). Wood ash as a liming amendment. Communication in soil science and plant analysis 23: 1209 – 1227.

Edwards CA, Bohlen PJ (1996). Biology and Ecology of Earthworms, third edition, Chapman and Hall, London.

Everson CS (1999). Veld burning in different vegetation types. In: Tainton, N.M. (Ed.), Veld management in South Africa. University of Natal Press, Pietermaritzburg, South Africa, p 472.

Flower S, Rosenbaum J, Reiersgaard E (2004). The effects of annual burning and mowing on soil fungal richness and abundance. Tillers 5: 13 – 15.

Guevara JC, Stasi CR, Wuilloud CF, Estevez OR (1999). Effects of fire on rangeland vegetation in south-western Mendoza plains Argentina: composition, frequency, biomass, productivity and carrying capacity. J. of Arid Environ. 41: 27-35

James SW (1982). Effects of fire and soil type on earthworm populations in a tall-grass prairie. Pedobiologia 24: 37–40.

Johnson LC, Matchett JR (2001). Fire and grazing regulate belowground processes in tallgrass prairie. Ecol. 82: 3377–3389.

Knapp AK, Seastedt TR (1986). Detritus accumulation limits productivity in tall-grass prairie. Biosci. 36:662–668.

Luxton M (1982). Studies on invertebrate fauna of New Zealand peat soils I. General survey of the sites. Rev. Écol. Biol. Sol 19:535–552.

Materechera SA, Mandriringana OT, Mbokodi PM, Nyamapfene K (1998). Organic matter, pH and nutrient distribution in soil layer of a savannah thornveld subjected to different burning frequencies at Alice, in the Eastern Cape. South Afr. J. of Plant and Soil 15 (3): 109 – 115.

Non-affiliated Soil Analysis Working Committee (1990). Handbook of Standard Soil Testing Methods for Advisory Purposes. Soil Science Society of South Africa, Sunnyside, Pretoria, South Africa.

Ohno T, Erich MS (1990). Effects of wood ash application on soil pH and soil nutrient level. Agric. Ecosystem and Environ. 32: 223 – 239.

Ojima DS, Schimel DS, Parton WJ, Owensby CE (1994). Long and short-term effects of fire on nitrogen cycling in tall-grass prairie. Biogeochem. 24: 67–84.

Okalebo JR, Gathua KW, Woomer PL (2002). Laboratory Methods of Soil and Plant Analysis: A Working Manual. TSBF Program UNESCO – ROSTA Soil Science Society of East Africa technical Publication No. 1. Marvel EPZ Ltd.; Nairobi, Kenya p. 127.

Raison RJ, Khanna PK, Woods PV (1985). Transfer of element to the atmosphere during the low intensity prescribed fire in three Australian subalpine eucalypt forests. Canadian J. of Forest Res. 15: 657 – 664.

SAS Institute (1999). Statistical Analysis System Inc. SAS users guide, Statistical Analysis Institute. Carry NC. 112p.

Sharma KL, Mandal UK, Srinivas K, Vittal, KPR, Mandal B, Grace JK, Ramesh V (2005). Long-term soil management effects on crop yields and soil quality in a dry land Alfisol. Soil and Tillage Res. 83(2): 246-259.

Snyman HA (1998). Dynamics and sustainable utilization of the rangeland ecosystem in arid and semi-arid climates of southern Africa. J of Arid Environ. 39: 645–666.

Snyman HA (2002). Fire and the dynamics of semi-arid grassland: influence on soil characteristics. Africa J. of Range and Forage Sci. 19: 137–145

Snyman HA (2003a) Short-term response in productivity following an unplanned fire in a semi-arid rangeland of South Africa. J. of Arid Environ. 55:160–180.

Snyman HA (2003b). Short-term response of rangeland following unplanned fires in terms of soil characteristics in a semi-arid climate of South Africa. J of Arid Environ. 55: 160–180.

Snyman HA (2004). Short-term response in productivity following an unplanned fire in a semi-arid rangeland of South Africa. J. of Arid Environ. 56: 465–485.

Soil Classification Working Group (1991). Soil classification: A taxonomic system for South Africa. Mem. Agric. Natural Research of South Africa. No 15, Department of Agriculture, Pretoria

Tainton NM, Mentis MT (1984). Fire in grassland. In: P. de V. Booysen , N.M. Tainton (Eds.), Ecological effects of fire in South African ecosystems. Ecological Studies No. 48. Springer, Berlin, p. 510.

Trollope WSW (1999). Fire behavior. In: Tainton, N.M. (Ed.), Veld Management in South Africa. University of Natal Press, Pietermaritzburg, South Africa p. 472.

Teague WR, Trollope WSW, Aucamp AJ (1981). Veld management in the semi- arid bush – grass communities of the Eastern Cape. Proceedings of grassland Society of South Africa 16: 23 – 28.

Auld TD and AJ Denham (2006). How much seed remain in the soil after a fire? Plant Ecol. 187 :15 – 24

Van-Reuler H, Janssen BH (1996). Comparison of fertilizing effects of ash from burnt secondary vegetation and of mineral fertilizer on upland rice in South West Cote d'Ivore. Fertilizer Res. 45:1-11.

Zacharias PJK and Danckwerts JE (1999) Management of humid grasslands after burning in southern Africa. In: Proceedings of the VI International Rangeland Congress, Townsville, Australia, 1: 527–528.