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Impacts of different prescribed fire frequencies on selected soil chemical properties in a semi-arid savannah thornveld

C. Parwada^{1*}, M.I. Magomani³ and J.J. van Tol²

Abstract: Effects of fire frequency on soil chemical properties in semi-arid savannahs are still unclear. A study was conducted on a long-term fire research trial in the semi-arid part of Eastern Cape Province, South Africa. The study aimed at determining the impact of outbreak on the soil properties by comparing the effect of different prescribed fire frequencies on pH, C, N, P, Ca, Mg, Cu, Zn, Mn, Na levels and C:N ratios. The treatments were no burn (control), sexennial, quadrennial, triennial, biennial and annual burns randomly laid in uniform blocks. A line intercept sampling technique was used in soil sampling from 0 to 75 mm depth for analysis. Fire burning frequencies had significantly varied effects on soil chemical properties ($P < 0.05$). There was an increase of C, Mg and Ca in the triennial than other frequency treatments. Significant positive correlations were observed between N and P, Ca and Mg and pH and Ca and Mg content and burning frequencies. C and other elements content were reduced in most burning frequencies except triennial. The triennial burning frequency may be an ideal option for veld management. Further studies under different climatic conditions, soil and vegetation types and fractionation analysis of chemical elements are necessary to determine whether different frequencies result in short-or long-term fire-induced changes.

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Professor J.J. van Tol is a renowned researcher in soil science and hydopedology at the University of the Free State formerly with the University of Fort Hare, South Africa. In addition, he is a well renowned researcher in soil science and agronomy.

PUBLIC INTEREST STATEMENT

Unlike the wildfires, prescribed fires are useful tools for veld management. However, fire can be highly destructive to the environment if uncontrolled. The effects of prescribed fires on soil properties and functioning are usually generalized leading to soil degradation. In order to quantify the effects of fire on the soil chemical properties, six different fire burning frequency regimes (no burn, annual, biennial, triennial, quadrennial and sexennial burns) were studied at the University of Fort Hare (UFH) research farm. Effects of the fire burning frequencies on the soil properties were dynamic. Some burning frequencies enhanced the soil properties while others degraded the soil. The triennial burning was the best practice in rangeland management because it had positive effects on the soil chemical properties. It can be recommended to burn the veldt after every three years especially in areas with similar climatic conditions with the UFH research farm.

Keywords: Burning regime; fire outbreak; fractionation; heat; veld fire; veld management

1. Introduction

Fire affects the physical, chemical and biological properties of soil and is an important rangeland management tool. Hence, prescribed fires are crucial in the ecological functioning of many forests, including savannah thornveld and woodlands (Snyman, 2003). The savannah thornveld is characterised by a grass-dominated lower level dotted with a number of trees of varying sizes forming the upper canopy level of the biome. The fire also has prospects of being one of the most destructive agents to soil and vegetation if not monitored although the savanna systems are known to be highly dependent on wildland fires to maintain ecosystem health (Heydari et al., 2012). Therefore, studying fire and its current and future effects on the soil is of great interest (Stoof et al., 2010). Regardless of the numerous studies on the impact of fire on soil properties (Ritsema et al., 1998; Zavala et al., 2014), the impact of recurring fires on soil chemical properties in regions that experience warm and dry weather conditions during the year is still unclear (Ferreira-Leite et al., 2016). Evaluating both short- and long-term fire management regimes on chemical soil properties will give a guide in improving fire management practices and information toward updating fire management policies.

The impacts of fire on soil can be both positive and negative depending much on the inherent soil properties, fire frequency and severity among other factors (Keeley, 2009). Zavala et al. (2014) showed that fire-affected soils are low in soil organic matter (SOM). The SOM is a critical component as it confers soil resistance to erosion, regulates soil temperature promotes soil microbial activity and directly supply plant nutrients upon mineralization (Gundale et al., 2005). In soil ecosystems where above-ground biomass production is limited like in the arid and semiarid, the organic inputs are mostly from below-ground sources. Soil organic matter is also the most important indicator of soil quality as it generally modifies many soil properties including the soil-hydrological properties (Parwada & van Tol, 2018).

Soil organic matter can significantly influence soil nutrient pools and control total cation exchange capacity (organic and clay mineral) of the soil (Parwada & van Tol, 2018). Fire transforms unstable SOM to a relatively stable form, e.g. charcoal that may affect plant nutrient uptake and the competitive balance between plant species (DiCosty et al., 2003). The effects of fire frequency on soil nutrient elements vary. Burning was observed to increase the amount of nitrogen (N) and carbon (C) compared to unburned soils (Doerr & Santin, 2013; Neff et al., 2005) however, Banj Shafiei et al. (2010) did not find a significant difference when comparing nitrogen and carbon content in burned and unburned soils. Stoof et al. (2010) noted a decrease in N and C content in burnt soil. Heydari et al. (2012) also found that edaphic properties varied with the degree of fire severity although no attempt was done on the impact of fire frequency. The chemical properties were shown to be more affected by fire severity than physical soil attributes (Heydari et al., 2012). Rau et al. (2009) concluded that burning increases N, phosphorus (P), calcium (Ca), magnesium (Mg), manganese (Mn), copper (Cu), sodium (Na) and zinc (Zn) in semi-arid ecosystems. This greatly suggests inconsistency in understanding the impact of fire frequency on soil nutrient elements.

Fire transforms chemical minerals at the surfaces due to alkaline compounds from the heated minerals or by organic matter combustion (Nesmitha et al., 2011). Under prescribed fires, solubility and availability of P and potassium (K) can either increase or decrease depending on the chemical compounds formed when the burnt material cools (Doerr & Santin, 2013). Fresh unaltered surfaces could release P and K more rapidly than weathered surfaces. Direct loss of nutrients to the atmosphere is temperature dependent (Erickson & White, 2008) and nitrogen is most prone to this type of loss. Volatilization of nitrogen starts at 200°C and at temperatures >500°C, over half the N in organic matter can be volatilized (Stoof et al., 2010). It is not the case though with elements like K which requires relatively higher temperatures (>760°C) to vaporize, P (>774°C), Na (>880°C), Mg (>1107°C) and Ca (>1240°C) (Vergnoux et al., 2011).

Soil pH was observed to increase when a soil is burnt (Rau et al., 2009). This increase in pH has been attributed to ash accretion (Battle & Gollady, 2003). The response depends on the amount of ash and buffering capacity of the soil (Keeley, 2009) and is considered negligible in grasslands (Shakesby et al., 2007). The fire duration and pre-fire pH level of the existing soil may be important in determining the impact of fire on soil pH. This rise in pH is due to released oxides or carbonates that usually are alkaline to the soil from the burnt organic matter (Vergnoux et al., 2011). This was supported by Ubeda et al. (2009), who have found that ash is dominated by carbonates of alkaline and alkaline earth metals.

The extent and duration of fire-induced changes vary greatly across soil types, fire frequency and severity, and post-fire prevailing climatic conditions. These effects may range from short- to long- term, or permanent changes (Keeley, 2009). This makes it difficult to ascertain the impact of fire on different soils and climatic zones. Thus, studies on the extent of fire-induced changes on soil chemical properties have to be site specific.

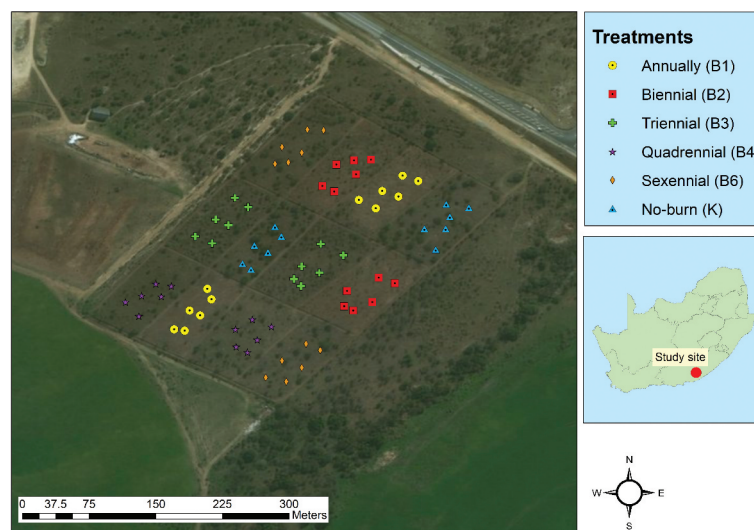
The effects of fire management on soil chemical properties are not yet well documented in South Africa. However, in 1980, an experiment was established at the University of Fort Hare (UFH) Research Farm to investigate the effect of burning frequencies on soil & vegetation (Trollope, 1984). Over the years, studies conducted on this long term the experimental trial was biased toward investigating the effect of fire management on rangeland vegetation but ignoring the fire impact on soil properties (Magomani & Van Tol, 2018). Recently, Magomani and Van Tol (2018) investigated the effects of fire impacts on soil physical properties but did not include chemical properties. We hypothesized that the frequency of fire outbreak had a major effect on the soil properties. Therefore, the objective of this study was to compare the impact of different prescribed fire frequencies on selected soil chemical properties.

2. Materials and methods

2.1. Description of the study site and experimental layout

The study was carried out at the University of Fort Hare (UFH) Research Farm (32° 47' S; 26° 52' E), Eastern Cape Province, South Africa (Figure 1). The area receives an average annual rainfall of 500 mm and more than 70% is received from October to March. The UFH Research Farm experience a maximum temperature range from 26°C to 41°C in January and minimum temperatures range from -5°C to 11°C in July (Agriculture and Rural Development Research Institute (ARDRI), 1989). The farm is characterised by semi-arid savanna of the false thornveld with mostly grasses interspersed with *Vachellia karroo* trees. The area is generally affected by late-dry wildfires once per year that will last for 2–4 days on average if not controlled (Magomani & Van Tol, 2018). The

Figure 1. Experimental layout at the University of Fort Hare Research Farm.



soils are silty loams of the Glenrosa form (Soil Classification Working Group, 1991) or Ochric Cambisol (IUSS Working Group WRB, 2014) that are characteristically shallow and stony on the surface of alluvial parent material origin (Mandiringana et al., 2005).

The long-term burning experimental trial was established in order to investigate the effects of varying fire frequencies on species composition and biomass production. The experiment consisted of six treatments which included: no burn (K), annual burn (B1), biennial burn (B2), triennial burn (B3), quadrennial burn (B4) and sexennial burn (B6) (Figure 1) (Magomani & Van Tol, 2018). The triennial and no burn plots had a higher tree (*Vachellia karroo*) density per unit area than others. Late-dry season prescribed burning is done once per year and fire intensities dependent on the available fuel load per plot. This is to mimic the intensities of wildfires. The treatments were arranged in blocks on plots measuring 50 m x 100 m and replicated three times. Each plot was surrounded by a 5 m buffer to minimise the edge effect (Figure 1).

2.2. Data collection and analysis

2.2.1. Soil sampling

Soil sampling was done using a line intercept sampling technique as described by Warren and Olsen (1964). The sampling procedure started by marking two transects parallel to the longest side of the plots (no burn, sexennial, quadrennial, triennial, biennial and annual burns) and then identifying sampling points that were 25 m apart along the transects. Soil samples in all the fire blocks were taken in April 2015 just before the onset of the dry season in the study area. Eighteen soil samples were collected from each plot with 108 samples in total. The samples were collected from the topsoil (0 to 75 mm) using a graduated auger. Lastly, the samples were air-dried for two weeks and sieved to <2000 µm in size to achieve homogeneity of aggregates.

2.2.2. Laboratory analysis

2.2.2.1. Soil pH. Soil pH was measured in aqueous soil extracts in 1 M KCl solution (1:2.5 soil: KCl solution ratio suspension on a mass basis) using a pH meter (model pH, Crison Instruments, Johannesburg). This method entails that 25 cm³ KCl was added to 10 g of dried soil (≤2000 µm) weighed into a glass beaker (Manson & Roberts, 2011). The contents were stirred for 5 s before and again after 30 minutes. Therefore, the pH of KCl was measured using a gel-filled combination glass electrode while stirring.

2.2.2.2. Total C and N. Total C and N was analysed by combustion method using a LECO CNS 2000 analyser (Leco Corporation, Michigan, USA; Matejovic, 1996). About 1 g of soil sample was weighed into ceramic crucible then 0.5 g vanadium pentoxide was added as combustion catalyst. The crucible was placed into a horizontal furnace and burned in a stream of oxygen at 1350°C. Carbon dioxide (CO₂) and N were determined in infra-red and thermal conductivity cells, respectively.

2.2.2.3. Extractable Ca, Mg and extractable acidity. The Ca and Mg were determined by the atomic spectrometer. Initially, 25 ml of 1 M KCl solution was added to 2.5 g of soil and stirred at 400 r.p.m for 10 min using multiple stirrers. The extracts were filtered using Whatman No.1 paper then 5 ml of filtrate was diluted with 20 ml of 0.0356 M SrCl₂. For determination of extractable acidity, 10 ml of the filtrate was diluted with 10 ml of de-ionized water containing 2–4 drops of phenolphthalein and titrated with 0.005 M NaOH.

2.2.2.4. Extractable P, K, Zn, Cu and Mn. Extractable P, K, Zn, Cu and Mn in the soil were measured using the Ambic-2 extraction solution as described by Manson and Roberts (2011). Firstly, the extracting solution was adjusted to pH 8 using concentrated ammonia solution and consisted of 0.25 M (NH₄)₂CO₃ + 0.01 M Na₂EDTA + 0.01 M NH₄F + 0.05 g L⁻¹ superfloc (N100). Then, 25 ml of ambic-2 solution was added into 2.5 g of soil and stirred at 400 r.p.m for 10 min using a multiple stirrer (Manson & Roberts, 2011). The extracts were filtered using Whatman No.1 paper. P was determined on a 2 ml aliquot of filtrate using a modification of the Murphy and Riley (1962)

molybdenum blue procedure (Hunter, 1975). K was determined by atomic absorption on a 5 ml aliquot of the filtrate after dilution with 20 ml de-ionized water. Zn, Cu and Mn were determined by atomic absorption on the remaining undiluted filtrate (Manson & Roberts, 2011).

2.3. Statistical analyses

An analysis of variance (ANOVA) test was run to compare treatment means of the soil chemical elements. The residuals of each analysis were checked for normality and homoscedasticity. Means were separated using the Tukey's honest significant difference (HSD) at $P \leq 0.05$. Pearson correlation test was performed to establish relationships between the selected soil chemical properties. All data were analysed with Statistix 10.0 statistical software.

3. Results and discussion

Soil C ranged from 1.56% to 2.01% across all treatments, with the lowest on the annual plot and highest C on the quadrennial. N content (%) was significantly ($P < 0.05$) higher (0.21%) in the triennial and no burn plots than in sexennial, quadrennial, biennial and annual fire burning frequencies (Table 1). The C:N ratio was highest (1:10.11) in the quadrennial and significantly lowest (1:8.53) in no burning plots ($P < 0.05$). However, the C:N ratio was significantly higher in quadrennial and biennial than sexennial and annual fire burning. The P content was the highest (6.08 mg L^{-1}) and lowest (3.83 mg L^{-1}) in the triennial and quadrennial burned plots, respectively.

The importance of organic carbon on physical, chemical and biological soil properties is well documented (Granged et al., 2011a; Meira-Castro et al., 2014). In this study the results indicate that repeated annual burning cause a decline in soil C (Table 1) when compared to relatively infrequent burning (biennial, triennial and quadrennial). This is in agreement with findings under prescribed fires from other regions (Nesmitha et al., 2011) and several others (Granged et al., 2011b). Although general consensus regarding the impact of fire on C in mineral soils has not been reached it appears that the intensity and severity of burning have a greater influence on C stocks than the burning frequency (Costa et al., 2014).

Longer periods between fires resulted in more biomass accumulation which influences fire intensity so shorter periods between burns are expected to have lower intensity than longer periods under same weather conditions (Keeley, 2009). High intensity fires caused complete combustion of C (decrease soil C), whereas the low intensity fires promoted the formation and incorporation of ash and slash (increased soil C) (Nesmitha et al., 2011). Basing on the fire intensity, one would expect a low C content in the sexennial and quadrennial; however, we observed a higher C in the quadrennial than annual burning. We had longer time between burns on the quadrennial than annual which would have allowed the rebuilding of the soil C pool lost during fire outbreak. Besides, the low soil C in the annual burning could be as a result of the annual regrowth of vegetation post-fire which was taking up a lot more C than the other plots. In addition, the general increase in soil C with burning compared to the control is likely due to the reduction of bush encroachment associated with burning (Banj Shafiei et al., 2010). Grasslands tend to have higher soil C than thickets in the topsoil due to denser root systems, hence the higher soil C contents (Certini, 2005).

3.1. Effects of burning frequency on the total N

The annual burning treatments showed a lower total N content than triennial burning and no burning (Table 1). High N in the triennial and no burning plots could be due to addition through biological nitrogen fixation as these plots had more trees (*Vachellia karroo*) than other plots. The decrease in total N under more frequent burning may be due to repeated burning that resulted in volatilization of nitrogen and annual post-fire regeneration of vegetation an N uptake. Other studies in regions that experience hot and dry conditions in some parts of the year reported that frequent burning decreases total N in the soil surface horizons (Nesmitha et al., 2011) and Doerr & Cerda, 2005). Certini (2005) however, noted that changes in N were positively correlated with the duration and magnitude of the fire. The impact of fire on N was also dependent on other soil properties, fire frequency and severity and prevailing climatic conditions after the fire (Shakesby

Table 1. Mean values (mg kg⁻¹) of selected micronutrients and C, N, C:N ratio and P in various burning treatments

Treatment	Zn	Mn	Cu	C (%)	N (%)	C:N ratio	P (mg L ⁻¹)
No burn (control)	1.00 (0.59) ^c	44.17 (13.29) ^a	2.31 (0.63) ^b	1.79 (0.27) ^{ab}	0.21 (0.02) ^a	8.53 (0.47) ^c	5.00 (1.13) ^{ab}
Sexennial	4.10 (2.31) ^a	27.10 (24.36) ^a	2.60 (1.20) ^b	1.75 (0.32) ^{ab}	0.20 (0.03) ^b	8.67 (0.63) ^c	4.20 (1.26) ^b
Quadrennial	2.74 (1.92) ^b	43.50 (29.46) ^a	4.23 (1.22) ^a	2.01 (0.26) ^a	0.20 (0.01) ^b	10.11 (1.47) ^a	3.83 (0.83) ^b
Triennial	3.15 (1.84) ^a	36.09 (27.47) ^a	5.06 (1.95) ^a	1.95 (0.20) ^a	0.21 (0.02) ^a	9.54 (0.61) ^{ab}	6.08 (1.31) ^a
Biennial	3.01 (2.49) ^{ab}	41.30 (21.46) ^a	2.33 (0.86) ^b	1.91 (0.20) ^a	0.19 (0.02) ^b	9.81 (0.53) ^b	5.00 (1.54) ^{ab}
Annual	0.67 (0.35) ^c	45.08 (11.40) ^a	2.25 (0.33) ^b	1.56 (0.28) ^b	0.17 (0.02) ^b	8.77 (0.70) ^{bc}	4.64 (1.15) ^{ab}
Pr > F	0.000	0.460	0.000	0.001	0.009	0.000	0.001

Mean values followed by different letters within a column were significantly ($P < 0.05$) different according to Tukey's HSD and ($\pm$ sd).

et al., 2007). The decline of N due to burning may be short-term and that soil is likely to recover from N volatilization after the period of two to three years.

3.2. C:N ratio

The C:N ratios in the soils are relatively low (<10:1) compared to optimum ratios of around 15 (Table 1). The low C:N ratios could be due to the low C content of the soils which are typically associated with semi-arid regions. Generally, the burning led to low (<2.1%) C content in the soils although it resulted in ideal C:N ratios. Soil functioning is highly influenced by microbes that are in-turn affected by soil properties such as clay content (PSD), soil temperature, water content and the C:N ratio. Badia and Marti (2003) observed a C:N ratio of 8:1 as ideal for soil microbes and hence soil functioning. We also observed C:N ratios in the range of 8–10:1 that could be good for the microbial decomposition of SOM and release of N important for ecosystem recovery.

3.3. Extractable P

There is a significant positive correlation between P and C therefore, fire frequencies which result in increased C have higher P content (Table 3). Ubeda et al. (2009) ascribed the increase in P to incorporation of ashes whereas Vergnoux et al. (2011) and Brye and West (2005) attribute P increases to mineralisation of organic P. The observed increase in P could be due to its deposition from the ashes after burning. Other studies (Gundale et al., 2005), did not record any significant changes in P contents after burning.

3.4. Effects of fire burning frequencies on the soil micronutrients (Zn, Mn and Cu)

Zn contents correlated positively with Mg contents (Table 4) which suggest that higher Zn concentrations can be attributed to ash released during combustion of vegetation. Cu contents are positively correlated to C contents, which supports the fact that burning treatments resulting in C accumulation (quadrennial and triennial), have the highest Cu contents as Cu is also chelated or complexed with organic C compounds. Hence, the positive correlation. This could be the reason for Cu deficiency in organic soils. Few studies focussed on the impact of burning on micronutrients, especially on the behaviour of Mn, Cu and Zn during combustion. Brye (2006) found no difference in Zn between burned and unburned plots, decreases in Mn associated with burning and increases in Cu after burning (Brye & West, 2005).

The burning frequency had a significant effect ($P < 0.05$) on soil pH. All burning frequencies had a higher soil pH than in no burn plots (Table 2). Burning frequency did not significantly influence K or

Table 2. Mean values of pH and base cations of various burning treatments

Treatment	pH (KCl)	K (mg kg ⁻¹)	Ca (mg kg ⁻¹)	Mg (mg kg ⁻¹)	Na (mg kg ⁻¹)
No burn (control)	4.77 (0.23) ^b	205.00 (69.50) ^a	836.46 (70.95) ^c	168.67 (18.60) ^b	17.18 (5.46) ^a
Sexennial	5.11 (0.16) ^a	189.86 (94.89) ^a	869.00 (99.35) ^{bc}	181.30 (37.25) ^b	14.13 (2.27) ^a
Quadrennial	5.26 (0.18) ^a	218.09 (98.19) ^a	986.50 (117.03) ^a	194.83 (20.97) ^{ab}	15.19 (4.78) ^a
Triennial	5.12 (0.29) ^a	233.09 (46.99) ^a	949.18 (46.99) ^{ab}	204.08 (30.77) ^a	13.69 (0.94) ^a
Biennial	5.24 (0.11) ^a	211.20 (32.33) ^a	918.00 (70.90) ^b	181.60 (22.00) ^{ab}	13.11 (1.92) ^a
Annual	5.29 (0.12) ^a	192.67(26.68) ^a	907.42 (82.14) ^b	171.67 (16.21) ^b	15.07 (5.74) ^a
Pr > F	0.000	0.633	0.003	0.008	0.181

Mean values followed by different letters are significantly ($P < 0.05$) different according to Tukey's HSD and ($\pm$ sd).

Na contents, but did result in significant differences in Ca and Mg contents ($P < 0.05$, Table 3). The Ca content was highest (986.50 mg kg⁻¹) in the quadrennial and lowest (836.46 mg kg⁻¹) in no burn plots (Table 2). Trends similar to that of Ca content in the soil were observed with Mg. The highest Mg content (204.08 mg kg⁻¹) was noted in triennially burned plots, which were significantly ($P < 0.05$) higher than that of no burn and annually burned plots (Table 2).

The burning frequency significantly ($P < 0.05$) influenced Zn and Cu and insignificantly influenced the Mn content (Table 1). The highest (4.10 mg kg⁻¹) Zn content was observed in the sexennial burn plots followed by the triennial burn plots; both of these were significantly higher than that of the no burn and annually burned plots. Zn in the biennial plots were also significantly higher ($P < 0.05$) than annual burning frequencies. The Cu content was significantly higher in quadrennial and triennial burned plots when compared with all the other treatments.

Significant positive correlations exist between the C content and the N, P, Ca, Mg and Cu contents of the soils (Table 3). Similarly, positive correlations were observed between N and P, Ca and Mg. pH was positively correlated to Ca and Mg. Other positive correlations exist between Ca and Mg, Mg and Zn, Zn and Mn and Mn and Cu.

3.5. Effects of prescribed fire burning on soil pH

Burning experiments, regardless of the frequency, increased the soil pH significantly (Table 1). This is in agreement with several other studies done under similar climatic conditions (Brye & West, 2005; Costa et al., 2014; Materechera et al., 1998). The reason is that the basic cations (Ca, Mg, Na, K) become part of ash after burning which are essentially oxides or carbonates or hydrogen carbonates of these basic cations. All these compounds had a liming effect which led to a rise in soil pH after burning of vegetation. Therefore, the observed raise in pH could be related to the fuel load (source of basic cations) and the buffering capacity of the soil. This is supported by significant positive correlations between Ca, Mg and pH.

3.6. Exchangeable cations

The release of Ca and Mg through the combustion of vegetation during burning resulted in significant increases in these cations when compared to the control (Table 1). Again the positive correlation between C and Ca and Mg can be attributed to the elevated levels of Ca and Mg in quadrennially and triennially burned plots. Similar increases of Ca and Mg following burning were observed by *inter alia* Gundale et al. (2005), Costa et al. (2014), and Shakesby et al. (2007).

4. Conclusion

Fires are important drivers in the studied landscape and used as a veld management practice; hence, it is imperative to know the ideal fire frequency needed to maintain this system without negative impact on the soil. The fire-induced changes were dynamic and were either positive or negative depending on the

Table 3. Pearson correlation matrix between various soil chemical properties

Variables	C	N	C:N	P	pH	K	Ca	Mg	Na	Zn	Mn	Cu
C	1											
N	0.75**	1										
C:N	0.71**	0.06	1									
P	0.24*	0.31**	0.01	1								
pH	0.04	-0.15	0.22	-0.11	1							
K	0.107	0.04	0.11	0.15	0.02	1						
Ca	0.49**	0.42**	0.29*	0.36**	0.42**	0.12	1					
Mg	0.44**	0.36**	0.28*	0.33**	0.50**	0.01	0.61**	1				
Na	-0.14	0.06	-0.29*	-0.08	-0.11	0.11	-0.04	0.09	1			
Zn	0.20	0.08	0.22	0.02	0.21	0.16	0.18	0.25*	-0.14	1		
Mn	-0.14	-0.07	-0.12	-0.03	-0.06	0.08	0.13	-0.14	0.08	0.01	1	
Cu	0.23*	0.11	0.25*	0.12	-0.12	0.05	0.22	0.11	-0.10	0.29*	0.32**	1

**Significant at $P < 0.01$; *Significant at $P < 0.05$.

frequency of burning. Soil N was lost in the annual and triennial burning treatments although there were increases in the other measured soil chemical properties.

The triennial burning showed to be the best practice in rangeland management because it positively affected the studied soil chemical properties. In this study, the sampling depth (75 mm) was rather deep and may have diluted fire signals in the soil and the number of samples could be increased hence further studies are needed with shallower (<75 mm) sampling depth. Fractionation analysis of chemical elements is also necessary to determine whether nutrients are lost or redistributed. Furthermore, differences in soil types, climatic conditions, vegetation types, burning frequencies and intensities, the timing of combustion, the period between burning to sampling should be considered when comparing the results between fire studies around the world. Compromising these differences might create misinterpretation and contradictions of results under different fire affected areas.

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Competing Interests

The authors declares no competing interests.

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