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The effect of arboricides on the vegetation decomposition and influence on the soil property at Neudamm farm, Namibia

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Abstract

This study assessed the effect of arboricides application to control bush encroachment at Neudamm farm. A total of 6 composite soil samples were randomly collected from all three 250 m^2 belt transects in each of the three chemically treated and control sites at a depth of 15 cm using a soil auger. The soil was analysed for pH, organic carbon, organic matter and soil minerals. A General Linear Model (GLM) procedure of SAS was used for data analyses. The soil pH was significantly ($p < 0.05$) higher in chemically treated site of 2015 (6.06), followed by the control (5.61) and the chemically treated site of 2017 (5.5). The organic carbon and organic matter percentages were greater ($p < 0.05$) in the chemically treated site of 2015 than others years in all three sites, due to decomposition of plant materials on treated sites. The chemically treated site of 2016 had the highest soil Ca (551 ppm), K (197.3 ppm), Mg (76 ppm), P (23.3) contents, followed by the site of 2015, than the control site. The study concluded that chemically treated sites had improved soil fertility through controlled bush density. The study recommends that arboricides should be applied as aftercare and long-term monitoring should be carried out routinely to acquire systematic trends of the soil chemical properties.

Keywords: Encroachment, chemical, mineral status, soil fertility

1. Introduction

Bush encroachment, also known as bush thickening, is a serious phenomenon in savanna ecosystems, especially where overgrazing occurs (Van Auken, 2009; Kambatuku *et al*., 2013). According to Ward (2005), some of the key drivers of bush encroachment include the suppression of fire regimes, replacement of mega-browsers with severe grazers and changes associated with rainfall patterns as well as increase in atmospheric carbon dioxide (CO_2). Bush encroachment has many negative effects of rangeland productivity, despite positive effects on the ecosystem to sequestrate carbon into plant biomass photosynthesis, which has been identified as an important aspect in increasing ecosystem services and can help in mitigating effects of climate change (Henry *et al*., 2011). The negative impacts include loss in biological diversity, reduction in rangeland productivity, change of the ecosystem structure, disturbance in

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the functioning of the soil microbes and limitation of the proper functioning of the ecosystem (Francina and Smit, 2006; NNF, 2016; Birch *et al*., 2017). The ecosystem services can have a dynamic shift caused by land use and land cover as a result of bush thickening (Ward and Esler, 2011). The thickening of encroacher bush species can also have a decline in the ability of the biological systems to support human needs, which is an indication of degradation within the ecological system (Kraaij and Ward, 2006).

In Namibia, encroacher bush species have severely affected about 30 to 45 million hectares of the commercial livestock rangelands and close to 15 million hectares of communal land (De Klerk, 2004) significantly decreasing the country's ability to sustain livestock production (De Wet, 2015). The worst affected areas include the Highland savanna and savannas of the north (Adams and Werner, 1990; Wiegand *et al*., 2005; Uchezuba *et al*., 2019). Consequently, land production has been reported to have reduced rapidly, resulting in lower food security, declined nutrition and reduced the overall carrying capacity to half of the original value of the farms (MAWF, 2012; Temmerman, 2016; Charis *et al*., 2019). There are a number of encroacher bush species responsible for bush thickening in Namibia, namely *Senegalia mellifera*, *Dichrostachys cinerea*, *Terminalia sericea*, *Terminalia prunoides*, *Rhigozum trichotomum*, *Vachellia fleckii*, *Vachellia reficiens*, and *Colophospermum mopane*, (De Klerk, 2004; MAWF, 2017; Hauwanga *et al*., 2018). *Senegalia mellifera* and *Dichrostachys cinerea* are the most widely distributed encroacher species in Namibia (De Klerk, 2004; SAIEA, 2015; Shikangalah and Mapani, 2020).

Efforts to combat bush encroachment in Namibian rangelands, particularly in commercial farming systems have long been explored, commonly using Bush-Whacker GG and/ or Tebuthiuron based arboricides in controlling the invasion of encroacher bush species such as *Senegalia mellifera* (De Klerk, 2004). According to Hatzios *et al*. (1980), the use of Bush-Whacker GG and/ or Tebuthiuron in bush control is regarded effective, because it is a non-selective inhibitor of photosynthesis. In low rainfall rangelands of Namibia, Tebuthiuron is reported to have a long half-life and some of the chemicals used have been detected in the soil for more than decades after application (Du Toit and Sekwadi, 2012). Furthermore, the chemical can be lethal to germinating seedlings up to eight years of post-treatment, but this may depend on the factors associated with the edaphic and seed banks that are locally available in areas treated with chemical (Joubert, 2014).

Over the years, Neudamm farm management has been combating bush encroachment using the same arboricides treatment. However, no evaluation has been carried out to determine how the application of arboricides to control encroacher bush has affected the decomposition of the treated bushes and the consequent influence on the levels soil properties on the sites. Hence, the objective of this study was to assess the impact of arboricides (chemical treatment) on the decomposition of the treated bushes and to determine how that might have influenced the levels of soil properties such as (Phosphorus (P), Potassium (K) Calcium (Ca), Magnesium (Mg), Sodium (Na), Organic Matter (OM) and Organic Carbon (OC)). The study focused on treated sites of over a period of three years in comparison to the untreated (control) site.

2. Materials and methods

2.1. Study area description

The study was conducted at Neudamm 63 farm in the Khomas Hochland district of the Khomas Region, located at an altitude of 1856 m above the sea level, and coordinates of 22º27'02″ S and 17º21'38″ E. The Neudamm farm is about 37 km east of Windhoek and it was established in 1904. It covers an area of 10 187 hectares, which are demarcated into nine blocks (A, B, C, D, E, F, G, H and I) and sub-divided into 197 camps.

The climatic conditions of the study area is an arid to semi-arid with the mean annual rainfall ranging from 300 - 360 mm occurring mostly between December to March (Mendelsohn *et al.*, 2002). The mean minimum and maximum temperatures range from 18 °C to 32 °C in summer and from as low as -1 °C to 26°C in winter (Mendelsohn *et al.*, 2002). The soil type in the study area is dominated by homogenous Lithic Leptosols and Eutric Regosols, which are generally shallow and contain very little organic matter, which has been attributed to low organic litter input and rapid mineralization (Bertram and Broman, 1999).

The vegetation type in this area is categorized as Highland savanna and occupies approximately 45 000 km^2 of Namibia's land area (Coetzee, 1998). The Highland savanna is dominated by *Senegalia mellifera* and also characterized by shrubs and low trees, mainly *Acacia* species. The undisturbed rangelands consist of climax grasses such as *Anthephora pubescens*, *Schmidtia pappophoroides*, *Brachiaria nigropedata*, *Heteropogon contortus*, *Cymbopogon species* and *Digitaria eriantha* (Joubert, 1997).

2.2 Site selection and layout

The Neudamm farm was selected for this study, because the farm offers pre-existing ideal conditions, as a result of its previous rangeland manipulation of bush thinning, which is part of the farm management by annually applying a general-purpose arboricide called Bush-Whacker GG (Bromacil 200g/kg) manually in some of the heavily encroached camps on the farm to control bush encroachment. Prior to data collection, a preliminary study of the chemically treated sites was conducted on the farm. Two camps (camp 5 (26 ha) and camp 6 (31 ha) in block D) that had three chemically treated sites in three consecutive years (2015, 2016, 2017) and an untreated camp (control)) were selected for this study. The selected sites were homogeneous, in terms of vegetation structure, soil type as well as topography. These sites were chemically treated with Bush-Whacker GG (Bromacil 200g/kg) which was manually applied at the base of stems of *Senegalia mellifera* woody species. Granules of about 25 grams for small shrubs and 50 grams for big shrubs were applied beneath, around the base (not more than 30 cm) of the encroacher bush species. The selected camps were in the block D, the section, which was used for small stock (sheep and goats) at Neudamm farm. The grazing capacity of each of the chemically treated sites was estimated as follows: 2015 (17 ha SSU^{-1}), 2016 (13 ha SSU^{-1}), 2017 (6 ha SSU^{-1}) and the untreated (8 ha SSU^{-1}). The study was conducted at the end of the rainy season (summer) in April - May 2018, and this was redeemed as the right time to assess rangeland conditions when grass species have fully managed to establish well, blossomed and reached seeding stage (Ward *et al*., 2004).

2.3 Data collection

2.3.1 Soil sampling

Three belt transects of the size of 50 m x 5 m each were randomly laid in each of the study sites. A completely randomized design (CRD) was used for this study and a total of 6 composite soil samples were randomly collected from the 250 m^2 belt transects in each of the three chemically treated sites and the control site, at a depth of 15 cm using a soil auger (Hardy and Walker, 1991). All soil samples were bulked and oven dried at 105^{o}C for 48 hours and milled to pass through a 2 mm sieve before chemical analysis. Fractions measuring more than 2 mm were referred to as stones and gravel, and they were not used in the analysis. The soil properties were analyzed at the Ministry of Agriculture, Water and Land Reform laboratory in Namibia.

2.3.2 Soil chemical analysis

Soil samples were analysed for pH, Organic carbon (OC), Organic matter (OM), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg) and Sodium (Na). Soil pH was determined by using electrodes and based it on $CaCl_2$. Organic carbon and organic matter were determined by the modified wet oxidation method (Walkley and Black, 1934). Soil Potassium was determined by emission spectroscopy, while Calcium, Magnesium and Sodium were determined by atomic absorption spectroscopy (Jackson, 1970). Phosphorus was detected by ultraviolet spectrophotometer (Olsen and Sommers, 1982).

2.4 Data analysis

The soil data were analysed using a General Linear Model (GLM) procedure of SAS (2007). All Soil chemical property data were subjected to a one-way analysis of variance to test variations between different treatment sites. Means were separated following the PDIFF option of the least squares means statement of the GLM procedure of SAS. The Shapiro Wilk test further was used in analyzing the soil property data because the sample sizes were less than 2 000 (Gauch, 1982; Dytham, 1999). The Kruskal-Wallis test was also used to test the null hypothesis that had no significant differences between the median values of the soil chemical properties and the test was done to compare the sites that were treated in 2015, 2016, 2017 and no treatment site (Ashcroft and Pereira, 2003).

3. Results

3.1 Soil pH (H_2O)

The soil pH was significantly different ($p < 0.05$) among the sites and values were 6.06 (2015), 5.37 (2016), 5.50 (2017) and 5.61 (control). The chemically treated site of 2015 had the highest soil pH (6.06), followed by the control (5.61) and the treated site of 2017 (5.50) (Figure 1). The chemically treated site of 2016 had the lowest pH (5.37) value than the other sites. However, the soil pH values in the control (5.61) and the chemical treated site of 2017 (5.50) were not statistically different ($p < 0.05$).

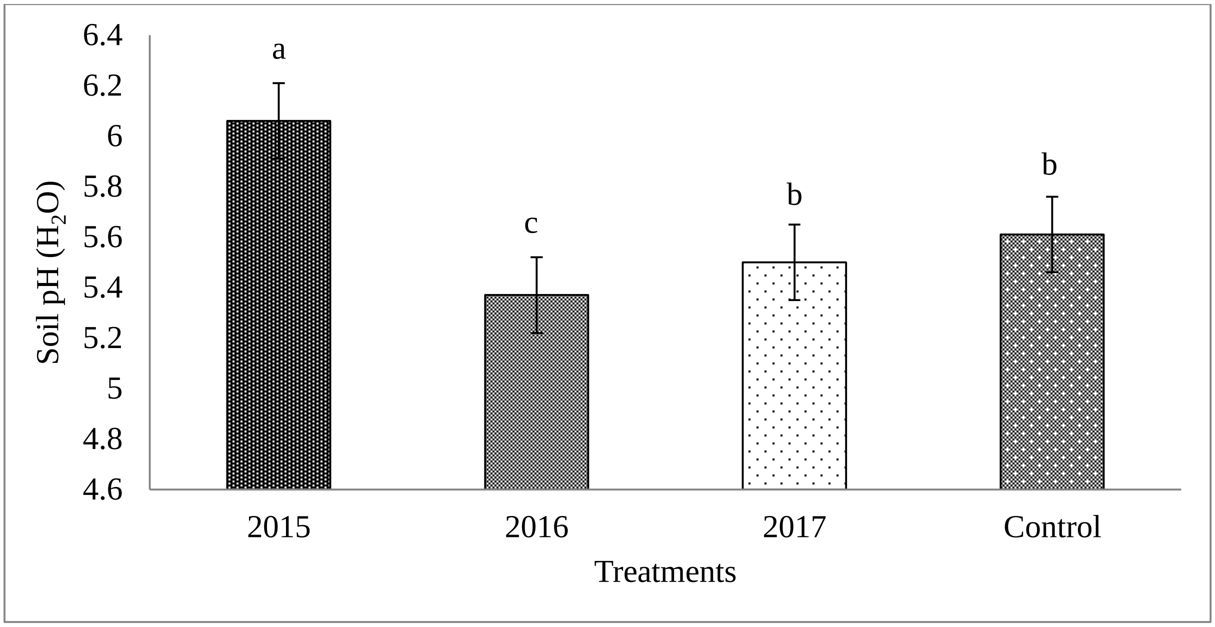

Figure 1. Soil pH of four study sites. Bars indicate standard errors of the means. Means with different superscripts differ significantly ($p < 0.05$) among treatments.

3.2 Organic carbon and organic matter

Organic carbon and organic matter percentages (1.26% and 0.73%, respectively) were significantly higher in the chemically treated site of 2015 than in all the other sites (Figure 2 and Figure 3). The chemically treated site of 2017 had the lowest OC and OM percentages (0.53% and 0.92%), but the OC and OM percentages of the control and the chemical treated site of 2016 were not different (0.62% and 1.07% (control), and 0.67% and 1.16% (2016), respectively.

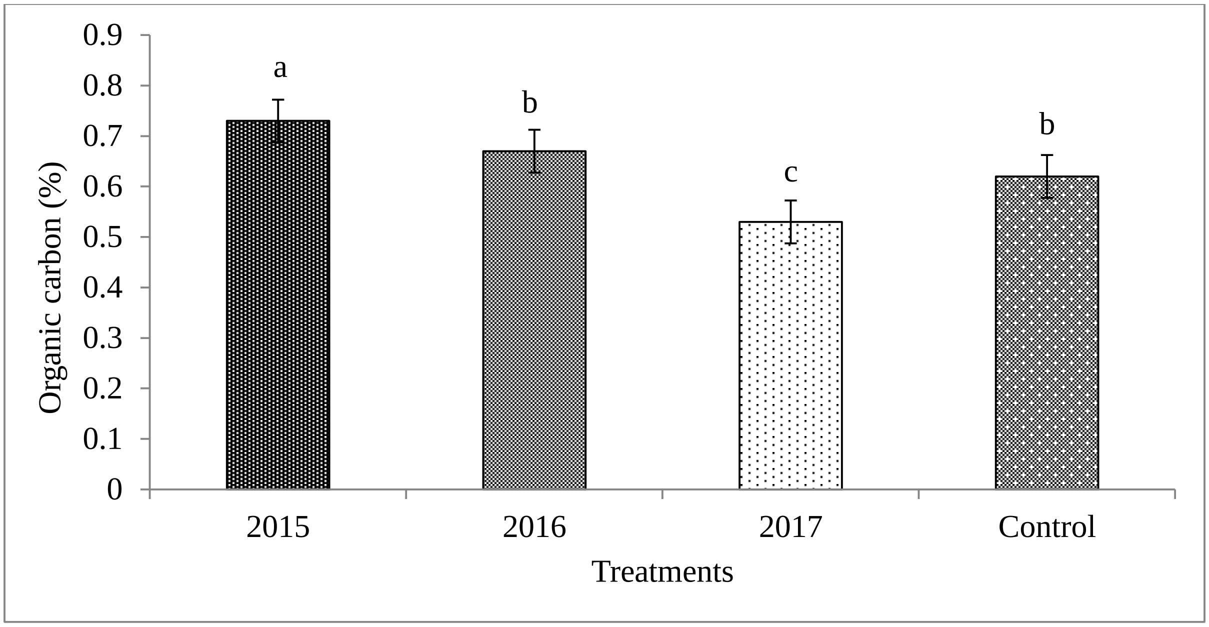

Figure 2. Organic carbon (%) of four study sites. Bars indicate standard errors of the means. Means of OC with different superscripts differ significantly ($p < 0.05$) among treatments.

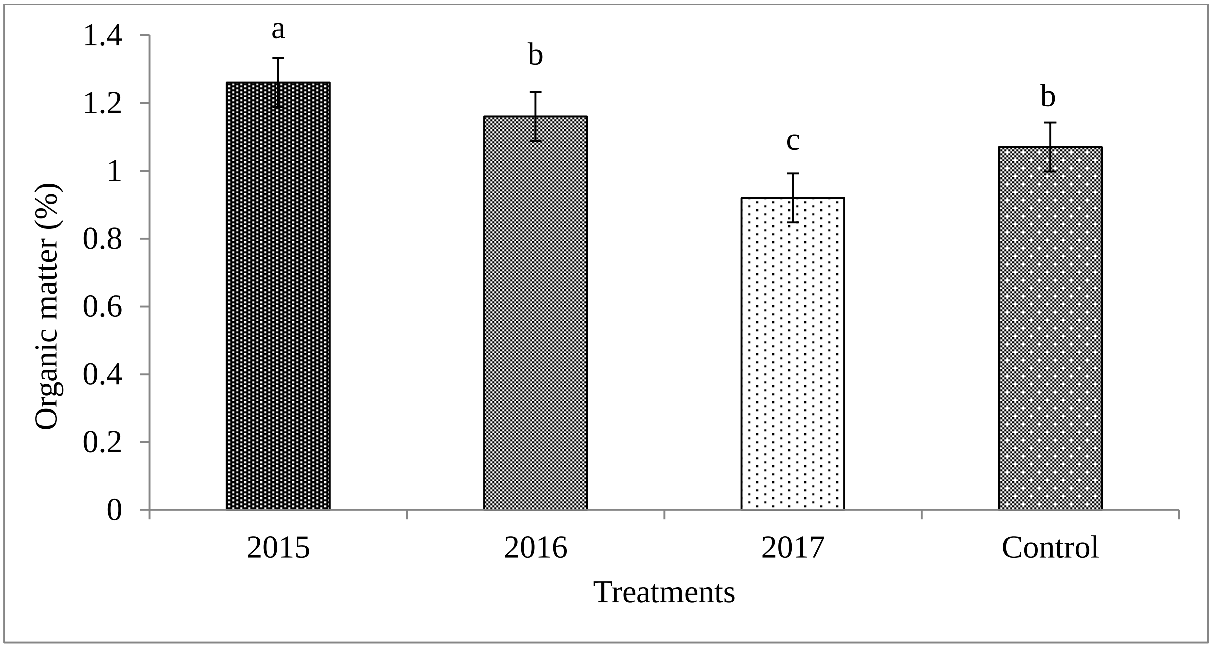

Figure 3. Organic matter (%) of four study sites. Bars indicate standard errors of the means. Means of OM with different superscripts differ significantly ($p < 0.05$) among treatments.

3.3 Soil minerals

The soil Calcium (Ca), Potassium (K), Magnesium (Mg) and Sodium (Na) concentrations were significantly ($p < 0.05$) different among all four different sites (Figure 4). The soil in the chemically treated site of 2016 had the highest Ca (551 ppm), K (199 ppm), Mg (78 ppm), P (23.4) contents, followed by the site of 2015 where the contents were Ca (476 ppm), K (147 ppm), Mg (71 ppm) and P (8.6,) than the soil of other two sites. The soil mineral contents were lowest in the treated site of 2017 and the control (P (11.7 - 2.2 ppm), K (122 - 122 ppm), Ca (300 - 338 ppm) and Mg (30 - 47 ppm)). However, the soil of the treated site of 2015 had Na concentration of 6 ppm than the soil of all other treated sites.

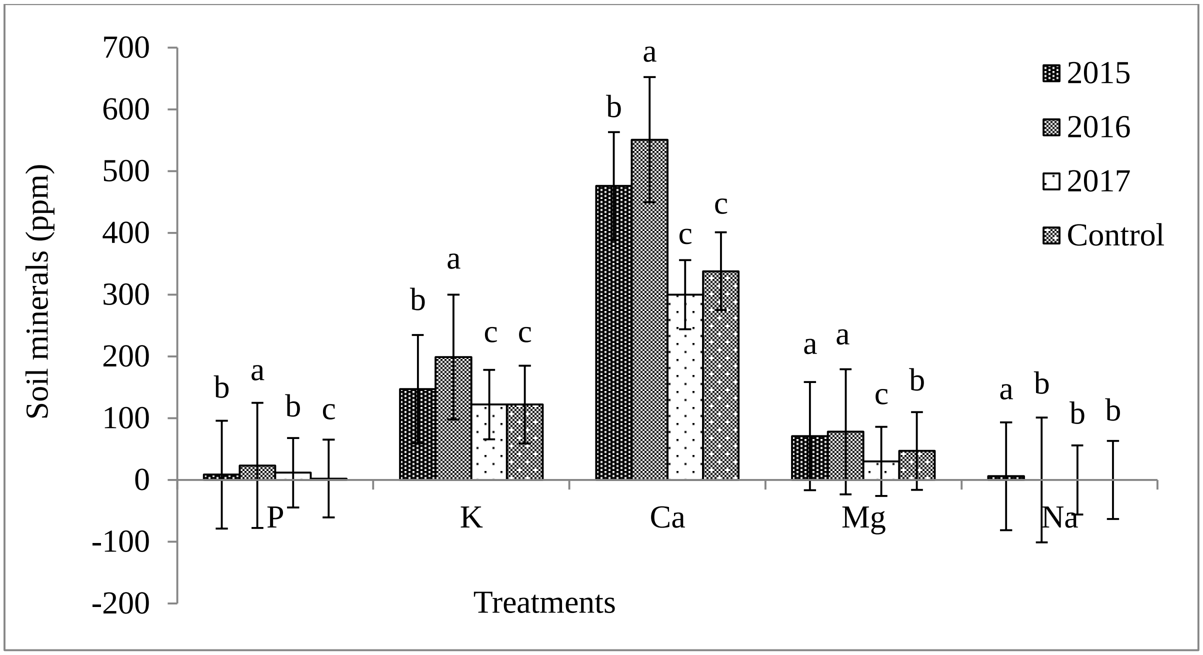

Figure 4. Soil minerals concentration of four study sites. Bars indicate standard errors of the means. Means with different superscripts differ significantly ($P < 0.05$) among treatments.

4. Discussion

4.1 Soil pH (H_2O)

The greater soil pH in the chemically treated site of 2015 could be attributed to mineralization characteristics of the soil, with pH being one of the most important soil factors measured in terms of acidity or alkalinity. The findings of this study were in agreement with the study of Ravhuhali (2017), who recorded the pH values of 6.0-6.4 in the soil of Makgobistadt village in South Africa. The soil pH in the entire study area ranged from 5.37 to 6.06. This was in line with the study of (Lake, 2000), which indicated that the soil pH of 5.2-8.0 is regarded as optimum for most agricultural plants, including grasses, because the soil pH affects the availability of nutrients and how the nutrients react with each other. Correspondingly, the result of the current study was consistent with reports of previous studies (Wang *et al*., 2001; Nsinamwa *et al*., 2005; Solomon *et al*., 2007) that reported complex spatial patterns of soil nutrients in rangelands being commonly supposed to develop over time as a result of interactions of animal activities, parental material, vegetation type and topography. The soil pH variations of the current study could be closely associated with plant density (Gough *et al*., 2000), differences in carbon dynamics of the area and mineral characteristics of the soil (Hobbie and Gough, 2002). Many researchers (Snyman and du Preez, 2005; Smet and Ward, 2005; Solomon *et al*., 2007) indicated that variations in the grazing pressure, history of sites and applied management strategies, effects of grazing on litter cover, and on soil structure and fertility also influence the soil pH of grazing rangelands. The major impact that extremes in pH has on plant growth is also related to the soil concentration of plant-toxic minerals (Londo *et al*., 2006). Garrison (2002) found out that at low soil pH, beneficial elements such as P, Mg and Ca become less available to many plant species and other minerals may become more available, but may reach the level where they can become toxic to plants (Lake, 2000). Certainly, phosphorus is most available for plant uptake at pH 6.0 to 7.0 (Brady and Weil, 1999).

4.2 Organic matter and Organic carbon

The higher organic matter and organic carbon percentages in the chemically treated site of 2015 and 2016 could be attributed to the dense accumulation of dead plant materials (especially woody plant high biomass), which died and decomposed as a result of applied chemical and converted into soil organic carbon and soil organic matter (Smet and Ward, 2005). The latter abundance of plants in the site of 2015, might have contributed to the greater amounts of organic carbon and organic matter in the soil. The results of this study is in line with the report of Bauer *et al*. (1987), who found that grazing reduced soil organic carbon and organic matter. Consistently, Shigwedha *et al*. (2020) showed that the density of the woody plants treated with arboricides reduced dramatically after the treatment, which eventually resulted in the accumulation of decomposed soil organic matters that enhance soil fertility. Heavy grazing may also result in trampling that normally breaks up soil aggregates, exposing organic matter to decomposition and loss through erosion (USDA, 2001). The least soil organic matter and organic carbon levels in the site of 2017, could be attributed to limited input of organic matter (humus), and the reduced physical protection of soil from erosion and compaction. This is comparable to the observation by Franzluebbers (2002), who reported that low soil organic carbon and organic matter levels can be associated with a degraded process (vegetation losses and unsustainable soil management), resulting in continuous impoverishment in the organic matter content, causing low soil productivity. This was supported by Du Preez *et al*. (2011), who indicated that most southern African soils have low organic matter levels because of low rainfall that leads to poor plant growth. Soil organic matter plays an imperative part in maintaining the soil health and its productivity potential as reported by Xie and Witting (2004) and FAO (2017). On contrary, the organic carbon in the current study was lower than the percentages (0.99-1.12%) observed by Ravhahuli (2017) in soil of Makgobistadt, but relatively higher than the organic carbon values (0.20 and 0.30%) reported in the soil of Leporong (0.20-0.30%), South Africa. Normally, significant output of organic carbon can be an indication that the organic matter decreases gradually as grazing intensity and disappearance of plants increase.

4.3 Soil minerals

The highest soil Ca, K and Mg contents in the chemically treated sites of 2016 and 2015 could be associated with the presence of nutrients dissociation from dead woody plant and increase in the concentrations of some soil minerals. The greater concentration of these soil minerals in these sites could also be attributed to the inherent nature of parent materials of savanna soils. The findings of this study were consistent with studies of Vourlitis *et al*. (2015) and Rolo *et al*. (2012), who indicated that vegetation enhances surface P and K ions availability, but not Ca and Mg ions because it contains calcium ions (Ca^{2+}), and this may reveal the reason of greater amounts of Ca, P and K ions concentrations in the sites of 2016 and 2015 soils that had high density of woody vegetation. In contrast, Boyazoglu, (1997) reported that the phosphorus level in soils of most of the semi-arid rangelands are low and this is attributed to the fact that this element is stored in unavailable forms to plants (Juo, 1978). In natural rangeland ecosystems, the phosphorus cycle is virtually closed and most plant phosphorus is recycled by microbial breakdown of litter and organic debris (Berliner and Kioko, 1999).

The high soil contents of Mg in the chemically treated sites of 2015 and 2016 could be attributed to the soil magnesium (Mg^{2+}) cations attracted to the negative exchange sites of organic matter (cation exchange complex of the soil) (Sawyer, 2003). The result of this study is consistent with the results of McDowell (1985) and Tiffany *et al*. (2001), who reported that the soil Mg deficiency results in low rangeland and animal productivity. The lowest soil levels of Na could be related to the high concentration of calcium in the soil. Calcium, just like magnesium, generally competes for the exchange sites occupied by sodium thereby reducing the amount of sodium that will be bound to soil (Hanson *et al*., 1999). Factors such as heavy grazing, deforestation, burning, chemical application and the structure of the soil (texture) can reduce the concentration of minerals in the soils. This was also supported by Blank *et al*. (2007) who stressed that herbaceous vegetation removal increased availability of nitrate, Ca and Mg.

5. Conclusion

The study revealed that there is a difference in the soil chemical properties between the chemically treated sites and untreated (control) site, therefore the study concluded that the overall pH remained acidic, though varied particularly in the soils of 2016, 2017 and control, but decreased slightly in the soil of 2015. The findings showed that the soil health status of the treated sites of 2015 and 2016 improved in the nutrient contents of P, K, Ca and Mg, due to the decomposition of organic matter, which supports the sequestration of the soil organic carbon. The study observed a constant decrease of organic matter and organic carbon in soils from 2015 to 2017 treated sites. However the soil of 2016 site and the control recorded the same contents. Hence, the study concluded that more decomposition might have taken place early on sites that had plant materials (woody plants) from sites that were treated earlier, which could enhance the soil fertility and the treatment might not be very effective in the absence of woody plant as decomposition seemed to be the key to the enhancement of the nutrient concentrations in the soils. The current study only served as a baseline study in the semi-arid savannas, thus further investigations are recommended to monitor and evaluate the effectiveness of the treatment and the trends of the soil properties of the farm over a longer period of at least five years.

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