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Effects of Fire on Litter, Forage Dry Matter Production, and Forage Quality in Steppe Vegetation of Eastern Anatolia, Turkey

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ABSTRACT

The effect of fire on vegetation of semi-arid steppe has not been studied extensively. Wildfires are rare in some steppe rangelands because of high levels of large herbivore grazing. However, grazing is sometimes restricted or excluded in areas such as national parks or the areas where afforestation projects are conducted. Therefore, sometimes, wildfires occur during the dormant season when litter (the uppermost layer of organic debris on the soil surface; essentially the freshly fallen or slightly decomposed vegetal material) mass has resulted in peak levels. Our study assessed the effects of a single fire on litter mass, forage production, and forage crude protein, Neutral Detergent Fiber (NDF), and Acid Detergent Fiber (ADF) in high altitude rangelands of Eastern Anatolia. We found significant effects of treatment (fire and no fire), years, and sampling date on all variables. Following the prescribed fire in 2011, litter mass and forage production was less in treated plots compared to untreated control plots during both years. The effect of the fire on litter and forage production was more pronounced in 2012 compared to 2013. The effects of the fire on forage quality variables were also greater in 2012 than in 2013. Forage crude protein levels were consistently higher in treated plots during all 2012 sampling periods. Similarly, NDF and ADF tended to be lower in treated plots relative to the control plots during 2012. All effects we found were more pronounced in the first growing season following the fire compared to the second growing season, suggesting a relatively transient nature of fire effects in the steppe vegetation we studied.

Keywords: ADF, Litter mass, NDF, Organic debris, Semi-arid rangelands.

INTRODUCTION

In the Eastern Anatolia region of Turkey, high altitude rangelands cover large areas and play a crucial role in the agricultural production. The steppe vegetation of this region is comprised of short grasses and forbs with perennial grasses being the dominant life form (Koc *et al*., 2013). These rangelands have experienced heavy grazing pressure for decades; chronically high levels of herbivory reduce fuel loads and hence the probability of fire ignition and fire spread. However, in areas such as national parks or areas where afforestation projects are conducted, grazing is restricted or prohibited with a concomitant increase in the risk of wildfire because of the accumulation of standing biomass and litter. On the other hand, studies conducted in the region have demonstrated that prescribed fire can be used as a range improvement tool, especially for the control of undesired plants (Gokkus, 1987; Erkovan *et al*., 2016).

In addition to the control of undesired plants, prescribed fire can be used to increase forage utilization by livestock and to improve habitat for wildlife (Augustine

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and Derner, 2014; 2015a). While many of the benefits of prescribed fire have been demonstrated in warm temperate rangelands dominated by C_4 grasses, little is known about the effects of wildfire or prescribed fire in arid steppe rangelands, especially where the vegetation is dominated by C_3 grasses. Oesterheld *et al*. (1999) suggested that fire has a negative effect on aboveground biomass production in rangelands where annual precipitation is between 250 and 450 mm. Fire removes standing vegetation biomass and litter, and soil evaporation generally increases after fire due to greater levels of solar radiation at the soil surface. This effect on soil moisture can subsequently affect forage production and forage quality (Redmann, 1978; Emmerich, 1999; Augustine *et al.*, 2010; Erkovan *et al*., 2016). In general, the negative effect of fire on soil moisture is alleviated with increasing soil depth and precipitation level (Certini, 2005; Augustine and Derner, 2012; Shaoquing *et al*., 2010; Erkovan *et al*., 2016). Biomass production can decrease in the years after fire, but this effect can be quite ephemeral depending on climatic conditions (Schacht and Stubbendieck, 1985; Scheintaub *et al*., 2009; Erkovan *et al*., 2016). In addition to the effect of fire on soil moisture, post-fire environments can be characterized by altered competitive relationships between neighbouring plants and altered nutrient dynamics (Knapp and Seastedt, 1986; Emmerich, 1999; Augustine *et al.*, 2010; Erkovan *et al*., 2016).

It is generally accepted that fire improves forage quality by removing dead material, thus increasing forage quality components such as crude protein and digestibility while decreasing forage anti-quality components such as Acid Detergent Fiber (ADF) and Neutral Detergent Fiber (NDF) (Mbatha and Ward, 2010; Dufek *et al*., 2014). Forage quality can be higher on burned areas at the beginning of growing season but converge with that found on unburned areas during the dormant season (Augustine and Milchunas, 2009; Augustine *et al.*, 2010; Augustine and Derner, 2015a, b). This convergence occurs as crude protein content decreases through the growing season (Koc and Gokkus, 1996), accompanied by an increase in the amount of cellulosic deposition of lignin, NDF and ADF (Erkovan *et al*., 2009), These changes can result in forage quality after the summer dormancy period being insufficient for animal maintenance (Koc *et al*., 2000). While this general trend in forage quality through the growing season and in the subsequent dormant season characterizes steppe ecosystems, it can be modified by management actions such as grazing during the growing season, application of fertilizers, or the occurrence of fire (Erkovan *et al*., 2009; Koc *et al*., 2014).

Currently, there is limited information on the effects of fire on forage quantity and quality in semi-arid steppe rangelands (Augustine *et al.,* 2010). The aim of our study was to determine the seasonal effect of dormant season fire on forage dry matter production, litter accumulation and the forage quality variables including crude protein, NDF and ADF in cool season steppe rangelands of the Eastern Anatolia region.

MATERIALS AND METHODS

Our research was conducted in steppe vegetation at a study site administered by Ataturk University (39° 5404" N, 41° 1401" E) during 2012 and 2013. The experimental area was characterized by nearly flat topography at an altitude of 1,860 m on foothills of the Palandoken Mountain, in the Eastern Anatolia region of Turkey. For approximately 20 years, the study site has been excluded from grazing for research and education purposes by Ataturk University, Faculty of Agriculture. Climate of the study site is semi-arid with a mean annual precipitation of 388 mm, the majority of which occurs from September to May. Mean annual temperature is 5.6°C. During 2012 and 2013, total annual precipitations were 313 and 284 mm, and average annual temperatures were 5.5 and 5.3°C, respectively (Figure 1a, b).

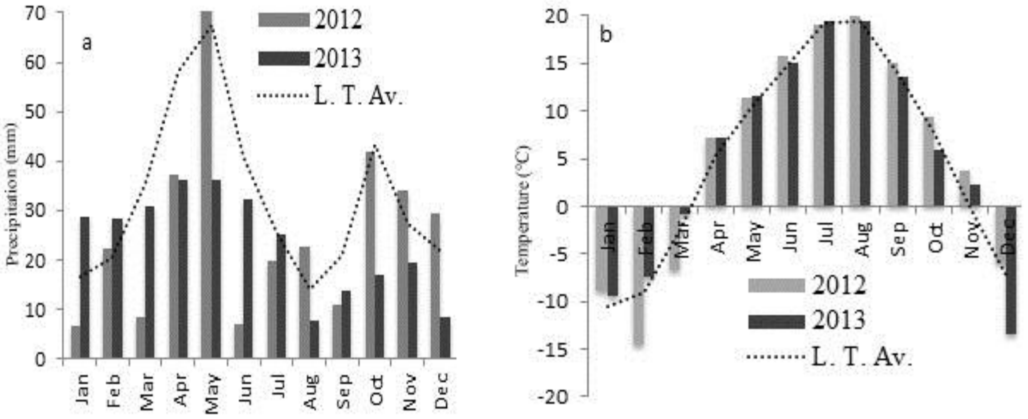

Figure 1. Climatic data for the study site: (a) Monthly precipitation (cm), and (b) Temperature (°C) during 2012 and 2013 and the Long-Term Average (LTA; 1990–2013) of climatic variable.

Vegetation of the study site is considered shortgrass steppe dominated by the grass species *Festuca ovina* with other common grass species being *Agropyron intermedium, Bromus tomentallus*, and *Koeleria cristata*. Common non-grass species include *Medicago* sp., *Onobrychis* sp., *Acontholimon caryophillaceum, Achillae millefolium, Artemisia spisigera, Carex* sp., *Eryngium campestre*, and *Tragopogon* sp.

We established two 1-ha plots for our study to compare the effect of fire on dry matter production, litter accumulation, and forage quality. One of the 1-ha plots was considered as control plot and was not treated with prescribed fire. The other 1-ha plot was considered a treatment plot and the entire 1-ha area of the plot was treated with a prescribed fire on August 26, 2011; no extra fuel material was added to the treatment plot prior to the prescribed fire. Within each 1-ha plot, ten subplots (20×50 m) were established for sampling purposes. We acknowledge this study design does not achieve replication of control and treatment plots and the subplots represent an example of psuedoreplication (Hurlbert, 1984), hence, the ability to infer from our results is limited. However, others have previously argued that a lack of true replication is not a reason to dismiss the informative value of results generated from field experiments where true replication is difficult or impossible due to the constraints of scale or the nature of treatments i.e. disturbance events such as fires (Hargrove and Pickering, 1992; Oksanen, 2001; van Mantgem *et al.*, 2001).

The following soil properties of the study site were determined (Soil Survey Laboratory Staff, 1992) to be: sandy clay loam soil texture; organic matter of 2.73%; $CaCO_3$ of 0.50%; pH of 7.4 in soil saturation extract; and available potassium (K) and Olsen Phosphorus (P) contents of 961.1 and 45.2 kg ha^{-1}, respectively.

During each year of the study (2012 and 2013), forage samples were obtained by clipping vegetation within each sub-plot to the soil surface within a 0.25 m^2 (0.5×0.5 m) sampling frame. During both years, clipping occurred every other week beginning at the period of stem elongation (when forage is appropriately mature for grazing use; approximately May 19th) and continued until the beginning of the summer dormancy period (approximately July 24th). Before clipping of forage, litter mass samples were collected from the soil surface within the sampling frame and kept separate from forage samples. All biomass (litter, forage) samples were dried at 68^{o}C until reaching constant weight, and weight of each sample was recorded. After weighing the live component of forage, samples were ground to pass through 2 mm sieve for forage quality analyses. Total N content of samples was determined by the Kjeldahl method and multiplied by 6.25 to give crude protein content (Jones, 1981). Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF) content were measured using an ANCOM fiber analyzer (ANCOM Technology, Fairport, NY, USA) following the procedure described by Van Soest *et al*. (1991).

Data were analyzed using the general linear model procedure as a completely randomized design using the Statview package program (SAS Institute, 1998).

RESULTS

A significant effect of prescribed fire was observed on forage production (Table 1). In general, prescribed fire substantially decreased forage dry matter production during the growing season. The negative effect of fire on forage dry matter production was more pronounced in 2012 compared with 2013. During 2012, forage dry matter production in the treatment plots was 722.8 kg ha^{-1} at the beginning of sampling (May 19th) and it did not change significantly through June 19th; thereafter, it showed a decreasing trend through the last sampling date on July 24th. During 2013, forage dry matter production in the treatment plot increased from the first sampling date through the June 19th sampling date, then decreased through the last sampling date on July 24th. In contrast to the treatment plot, dry matter production in the control plot increased from the first sampling date during 2012 and 2013, reaching a peak on the July 9th sampling date in 2012 and a peak on the June 19th sampling date in 2013 (Figure 2).

Year, treatment, sampling date, and their dual interactions had a significant effect (P< 0.0001) on litter mass (Table 1). There was no litter present on the treatment plot during any sampling date in 2012, but 89.2 kg ha^{-1} litter was recorded at the beginning of sampling period in 2013 and the amount of litter in the treatment plot increased with successive sampling date in that year (Figure 3). On the control plot in 2012, litter mass was 842.6 kg ha^{-1} on the May 19th sampling date and remained relatively constant through the July 9th sampling date, after which litter mass declined on the July 24th sampling date. During 2013 in the control plot, litter mass increased from the first sampling date through the July 9th sampling date and, thereafter, showed a slight decrease on the July 24th sampling date (Figure 3).

There was a significant effect (P< 0.01) of year, treatment, and sampling date on crude protein content and their two- and three-way interactions were also significant (Table 2). Crude protein content was lower in the first year than the second year. Forage samples from treatment plots had higher crude protein content than samples from control plot during all sampling periods in 2012, but not in 2013 (Figure 4). In most instances, year, treatment. and sampling date had a significant effect (P< 0.0001) on NDF and ADF contents and the two- and three-way interactions (Table 2). The one exception to this was the interaction of

Table 1. Analysis Of Variance table (ANOVA) of forage dry matter production and litter mass.

	df	Dry matter (kg ha^{-1})		Litter mass (kg ha^{-1})	
		F	*P*	*F*	*P*
Fire (F)	1	1157.643	< 0.0001	2853.366	< 0.0001
Sampling Date (D)	4	204.255	< 0.0001	395.295	< 0.0001
F×D	4	16.517	< 0.0001	70.392	< 0.0001
Year (Y)	1	942.606	< 0.0001	844.451	< 0.0001
F×Y	1	36.865	< 0.0001	509.067	< 0.0001
D×Y	4	81.538	< 0.0001	580.216	< 0.0001
F×D×Y	4	55.817	< 0.0001	9.506	0.0537

Table 2. Analysis of variance table (ANOVA) of crude protein, NDF and ADF.

	df	Crude protein (%)		NDF (%)		ADF (%)	
		F	*P*	*F*	*P*	*F*	*P*
Fire (F)	1	290.893	< 0.0001	158.014	< 0.0001	200.811	< 0.0001
Sampling Date (D)	4	325.466	< 0.0001	106.565	< 0.0001	81.255	< 0.0001
F×D	4	122.070	< 0.0001	1.516	0.1985	10.784	< 0.0001
Year (Y)	1	838.966	< 0.0001	874.822	< 0.0001	617.851	< 0.0001
F×Y	1	406.543	< 0.0001	34.602	< 0.0001	66.235	< 0.0001
D×Y	4	274.460	< 0.0001	16.523	< 0.0001	8.653	< 0.0001
F×D×Y	4	134.035	< 0.0001	41.298	< 0.0001	6.353	< 0.0001

treatment and sampling date on NDF, which was not significant (P= 0.1985). Both NDF and ADF contents of the forage samples were lower in the second year than the first year (Figures 5 and 6). Forage from treatment plot had lower NDF and ADF contents than forage from the control plot.

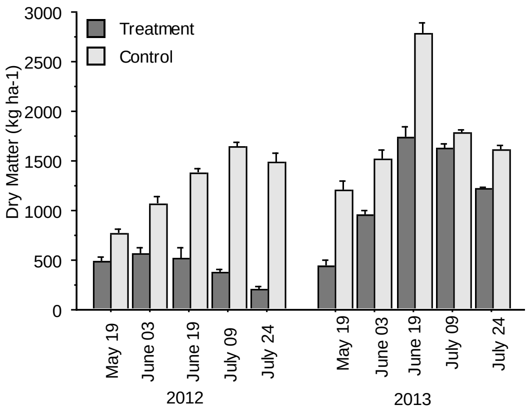

Figure 2. Mean forage dry matter production (±SE) in treatment and control plots during 2012 and 2013 sampling periods.

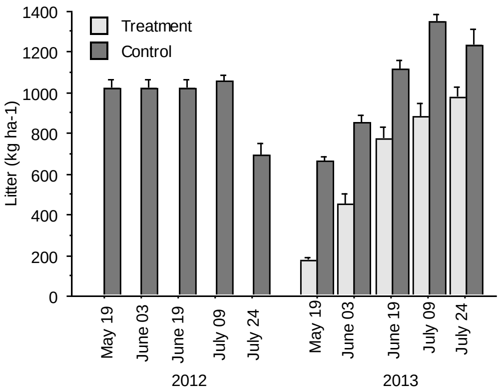

Figure 3. Mean litter mass (±SE) in treatment and control plots during 2012 and 2013 sampling periods.

DISCUSSION

Dry matter production of semi-arid rangelands is affected by a variety of factors including precipitation, temperature, fire, and grazing by large herbivores. Following fire, the loss or reduction of litter on the soil surface may lead to increased evaporation of soil moisture (Augustine *et al.*, 2010); this loss of soil moisture may be exacerbated by summer precipitation that is minimal or absent (Augustine *et al.*, 2010; Vermeire *et al.*, 2011). Fire can have a strong effect on dry matter production in semi-arid rangelands during the year following a fire, but this effect can decrease in subsequent years (Schacht and Stubbendieck, 1985; Scheintaub *et al*., 2009). Oesterheld *et al*. (1999) suggested that fire would have a

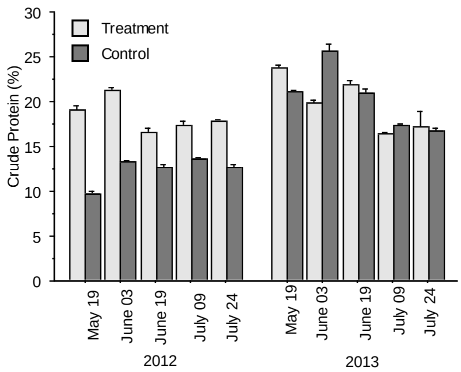

Figure 4. Mean crude protein (±SE) in treatment and control plots during 2012 and 2013 sampling periods.

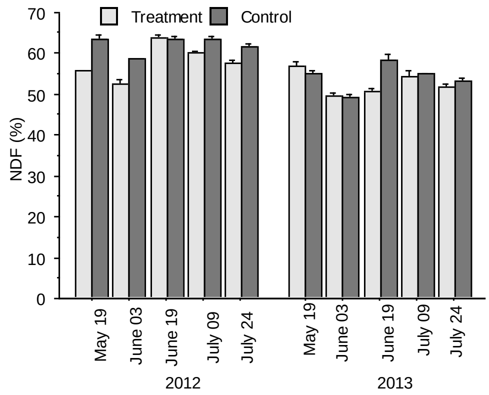

Figure 5. Mean Neutral Detergent Fiber (NDF, ±SE) in treatment and control plots during 2012 and 2013 sampling periods.

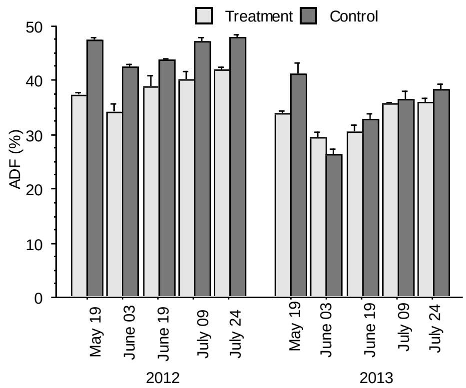

Figure 6. Mean Acid Detergent Fiber (ADF, ± SE) in treatment and control plots during 2012 and 2013 sampling periods.

negative effect on aboveground biomass production in regions where annual precipitation is between 250 and 450 mm. In eastern Anatolia rangelands, dry matter yield generally increases until middle of July, but decreases thereafter due to the effect of summer drought (Koc and Gokkus, 1996; Koc and Gokkus, 1999; Koc *et al*., 2000). General trends in dry matter production within control plot of our study were similar in 2012 compared to 2013 with the exception of a slight difference in the period of peak dry matter production (Figure 2).

Litter accumulation in semi-arid rangelands is influenced by vegetation, soil, and climate properties, but litter rarely accumulates to high levels in semi-arid rangelands because large herbivores typically remove a relatively high amount of standing crop on an annual basis (Augustine and Derner, 2012; Augustine and Derner, 2014). In areas where large grazing herbivores are excluded, however, litter can accumulate to a much greater degree relative to areas where large grazers are present. Fire removes litter (Knapp and Seastedt, 1986; Emmerich, 1999; Erkovan *et al*., 2016), hence, there was no litter present in our treatment plots during any sampling date in 2012. In 2013, litter in our treatment plots steadily increased though most of the growing season, likely as a result of senescing live material (Turner and Long, 1975; Edmonds, 1979), but it was always less than what we found in our control plots. The slight decrease in the amount of litter found in our control plots during the final sampling date of 2012 may have been due to removal of litter due to high winds which can occur in the late growing season (Steinberger and Whitford, 1983).

In general, forage crude protein content decreases with advancing growth stage (Bakoglu *et al*., 1999; Muruz *et al*., 2000), a phenomenon that was apparent in samples from both our control and treatment plots. Crude protein levels in samples from treatment plot during 2012 were consistently higher than crude protein levels in samples from control plot. This was likely due to the absence of dead biomass in samples collected from treatment plot whereas samples from control plot likely contained both live and dead biomass. In 2013, treatment plot had accumulated dead biomass during 2012 and through 2013; relative crude protein levels were more variable that year when treatment plot was compared to control plot.

In both treatment and control plots, NDF and ADF tended to occur at their lowest levels during the June 3rd sampling date but increased thereafter; this was likely due to increased cellulosic content that occurs with advancing stages of plant growth (Messman *et al*., 1991; Erkovan *et al*., 2009). In general, samples obtained from treatment plot were characterized by lower NDF and

ADF compared to samples obtained from control plot. This may have been due in part to the presence of dead biomass in samples collected from control plot, where dead biomass had been able to accumulate for successive years prior to sampling. In treatment plot, the prescribed fire in 2011 consumed all dead biomass and samples collected in 2012 consisted solely of live biomass.

CONCLUSIONS

Prescribed fire has been demonstrated to improve forage quantity and quality in many temperate rangelands dominated by C_4 grasses (Campbell and Smith, 2000), However, in our study, conducted in high elevation steppe rangelands dominated by C_3 grasses, we did not find a positive effect of prescribed burning on forage quantity and a variable, often negligible, effect on forage quality. Therefore, it seems premature at this point to suggest prescribed fire as a range management strategy to improve forage quantity and quality in the rangelands we studied. Our research is useful, though, because it assists rangeland managers in understanding what effects fire may have on forage quantity and quality following an accidental fire, allowing them to make appropriate changes to management to deal with these effects. Additional research on the effect of fire in these rangelands is warranted because of the occurrence of accidental fires, which are more common in areas where grazing by livestock and other large herbivores is excluded such as in national parks or areas where afforestation projects are conducted. Furthermore, there are other reasons why prescribed fire may be appropriate in semi-arid rangelands, such as for the control of undesirable plants (McDaniel *et al.,* 1997; Vermeire and Roth 2011; Augustine and Derner 2015a), the management of wildlife habitat (Augustine and Derner 2012; Augustine and Derner 2015a; Augustine and Derner 2015b), and to alter the distribution of domestic and wild animals across landscapes (Augustine and Derner 2014). Further research on fire in these rangelands will provide a better understanding of when there may be tradeoffs in forage quality and forage quantity (Augustine *et al.,* 2010; Augustine and Derner 2014). Finally, additional research will assist managers in determining how to adjust management practices following accidental fires or utilize prescribed fire to achieve management objectives.

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اثرات آتش سوزی روی لاشبرگ، تولید و کیفیت ماده خشک علوفه ای درپوشش گیاهی استپ در آناتولیای شرقی ترکیه

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چکیده

اثرات آتش سوزی روی پوشش گیاهی مناطق استپ نیمه خشک چندان مطالعه نشده است. آتش سوزی در مراتع استپ به علت چرای سنگین چارپایان گیاهخوار به ندرت رخ می دهد. با این همه، در بعضی موارد، چرا در مناطقی مانند پارک های ملی یا درنقاطی که پروژه جنگلکاری است محدود یا ممنوع می شود. بنا براین، بعضی مواقع، آتش سوزی در دوره خفتگی (dormant season) رخ می دهد که در آن جرم لاشبرگ به حد اکثر رسیده است(منظور از لاشبرگ بالاترین لایه از باقیمانده های

آلی در سطح خاک است که بیشتر شامل مواد گیاهی تازه فرو افتاده از درخت و موادی که کمی پوسیده شده اند می شود) . در این پژوهش، اثر یک آتش سوزی در یک مرتع مرتفع در آناتولیای شرقی روی جرم لاشبرگ، تولید علوفه، و مقدار پروتئین خام علوفه، فیبر شوینده خنثی (NDF)، و فیبر شوینده اسیدی (ADF) ارزیابی شد.نتایج به دست آمده حاکی از اثرات چشمگیر تیمارها (آتش سوزی و بدون آتش سوزی)، سال، و تاریخ نمونه برداری روی همه متغییر های مطالعه شده بود. به دنبال آتش سوزی برنامه ریزی شده(prescribed fire) در سال ۲۰۱۱، جرم لاشبرگ و تولید علوفه در کرت های آتش سوزی درمقایسه با کرت شاهد در هر دو سال مطالعه کمتر بود. اثر آتش سوزی روی لاشبرگ و تولید علوفه در سال ۲۰۱۲ چشمگیر تر از ۲۰۱۳ بود. همچنین، اثر آتش سوزی روی متغییرهای کیفیت علوفه در سال ۲۰۱۲ بیشتر از ۲۰۱۳ بود. مقدار پروتئین خام علوفه در کرت آتش سوزی همواره در همه تاریخ های نمونه برداری در سال ۲۰۱۲ بیشتر بود. نیز، مقدار NDFو ADF در سال ۲۰۱۲ در کرت آتش سوزی گرایشی به کمتر بودن از کرت شاهد نشان داد.همه اثرات مطالعه شده در سال اول بعد از آتش سوزی شدید تر از دو سال بعد از آتش سوزی بود و این اشارت داشت که اثرات آتش سوزی در پوشش گیاهی منطقه استپ این مطالعه سرشتی متغییر و گذرا دارد.