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Research article

Using mulching to reduce soil surface temperature to facilitate grass production

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ABSTRACT

Ecosystems in semi-arid and arid Southern Africa experience high temperatures which translate to extremely hot soil surface temperatures. High soil surface temperatures lead to a decrease in seed germination and consequently less plant cover in these areas. To facilitate maintenance of optimum plant cover, soil surface temperature should be moderated with appropriate mitigation techniques. Temperature variations in low (kg.0.5 m^{-3}) and high density (1 kg m^{-3}) brush packing treatments were compared to bare soil. We also measured the grass productivity (g.m^{-2}) against the effect of temperature in the three treatments. iButtons® were used to log soil surface temperature every hour for seven months. Daily and nightly temperatures of the hottest months were compared amongst the three treatments. Mid-day temperatures, corresponding to peak heat stress were also compared between the three treatments. There was a significant difference ($p < 0.01$) in soil surface temperature between the three treatments. The high density treatment was the most buffered against temperature variation, when compared to the bare soil. Grass production was generally higher in the high density treatment. Productivity can be increased by mulching the soil with brush packing as this will improve soil surface conditions such as moderating abrupt changes in temperatures to assist plant growth.

1. Introduction

One of the important environmental changes that will occur with global warming is rising temperatures (Raza et al., 2019; Ahmad et al., 2021). Climate change predict increases in temperature, changes in precipitation patterns and longer drought periods, with semi-arid and arid regions mostly affected (Miranda et al., 2011). Due to extreme sunlight, soil surface temperatures in semi-arid and arid regions are often elevated. Soil surface temperature is an important factor controlling seed germination and plant growth and development (Leon-Garcia and Lasso, 2019). Higher soil surface temperatures lead to a decrease in seed germination and consequently less plant cover (Hampton et al., 2013). To conserve plants and seed development in semi-arid and arid rangelands, soil surface temperature should be moderated by using appropriate mitigation techniques.

The natural vegetation in certain rangeland areas of South Africa are severely degraded such that the application of management practices will not have the wishful effect on plant recovery and density (Hoffman and Ashwell, 2001). In these cases, drastic restoration measures must be applied to help the re-establishment of vegetation. The measures should aim towards creating a better microclimate and sustainable water balance for the plant cover and density (O'Connor et al., 2001; Snyman, 2000) and eventually control soil erosion. Soil cover is an important factor determining the vulnerability of an ecosystem. Changes in land surface resulting from soil cover can have an extensive influence by decreasing the surface temperatures (Jansen, 2008; Raza et al., 2019). Studies have also reported that a decrease in vegetation cover and the compaction of soils has caused less rain infiltration, more rapid runoff, a significant decrease in soil moisture levels, and an increase in local soil temperatures (Cavalho et al., 2004). Rainfall and temperature determine the potential distribution of vegetation and forms the factors in the genesis and evolution of the soil (Sivakumar, 2007). When soil temperatures increase because of lack of vegetation cover, this affects surface albedo to increase, thus contributing to the tenacity of drought (Hampton et al., 2013).

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The combination of higher surface and near-surface temperatures, increased wind speeds, and lower near-surface atmospheric moisture levels increases the local potential evapotranspiration rates (Ramakrishna et al., 2006). High soil temperatures (above 31 °C) and low precipitation in semi-arid and arid areas lead to low organic matter production (Throop and Archer, 2007). Low organic matter leads to poor soil aggregation, and this results in high potential for wind and water erosion. Soil processes including organic matter decomposition, leaching of minerals and soil moisture patterns are influenced by soil temperature (Throop and Archer, 2007). The rise of temperature eventually accelerates the harmful effects of soil erosion and degradation. Increase in soil temperature will have negative effects on the natural revegetation of plants in semi-arid and arid regions. This means that, in the absence of appropriate mitigation techniques, plants that have surface root systems that mostly use precipitation moisture will be most vulnerable (Leon--Garcia and Lasso, 2019).

Brush packing as a mulch is a commonly used technique in veld conservation to improve grass production (Mangani et al., 2022). The microclimate beneath the brush packing modifies the balance between the absorbed and reflected radiation transmitted through the branches (Ruíz-Machuca et al., 2015). Studies have reported that mulch materials improve soil physicochemical properties, suppress soil temperature, reduce evaporation and increase the soil moisture content, thereby, creating soil microclimatic condition to enable plant growth (Agbede et al., 2013; Gbadebor, 2006; Inyang, 2005). Mulching also improves production quality by reducing weed growth, improving soil structure and enhancing organic matter content (Okoh, 2004).

Different plants have different growing conditions and have different temperature requirements for optimal growth and for normal development (Jansen, 2008). However, increased or rapidly changing temperatures can destroy plants growth faster than gradually changing soil temperatures (Barnes et al., 2015). Plants close their stomata when temperatures are too high. This forbids them from receiving the necessary energy that aids them to grow. In addition, when temperatures are too cold, plants respiration is reduced, leading to dormancy and eventual death (Atkin et al., 2000). The use of brush packing, as a veld management technique, has not been scientifically quantified. Studies have not reported to what extent soil surface properties such as temperature are changed when brush packing is used. Therefore, the objective of this study was to assess 1. the effect of brush packing mulching and its impacts on maximum temperature and minimum temperature changes, 2. to evaluate the diurnal temperature range and, 3. to evaluate plant growth of selected subtropical grasses under the different soil temperature conditions.

2. Materials and methods

2.1. Study area

The study was carried out at the Hatfield Experimental Farm, of the University of Pretoria in Pretoria, South Africa. Pretoria has a mean average rainfall of 573 mm and average minimum and maximum temperature varying between 10.3-15.0 °C and 24.3–29.40 °C respectively (Engelbrecht and Engelbrecht, 2016). The period of the trial was September 2015 to March 2016.

The soil at the study area was a Shorrock series of the Hutton form, red in colour (Soil Classification Working Group, 1991) with 28% clay in the topsoil (top 30 cm). The average air temperature readings at the experimental site during the experiment were T_{min} of 16.10 °C and T_{max} of 30.66 °C with an average rainfall of 2.5 mm (Hatfield automatic weather station).

2.2. Experimental layout and treatments

The experimental area was ninety-one (91) square meters in size. This was then divided into five blocks with 0.5 m spacing in between. Each block was divided into nine, one square meter (1 m^2) plots, and the treatments were allocated randomly. This resulted in forty-five plots (5 replicates by 9 plots- Table 1).

Two brush packing density treatments were used and bare soil (no cover) as a control, this making up the different temperature domains. Branches of *Dichrostachys cinerea* (Sickle bush) collected at Groenkloof, Pretoria (25/47′36″S, 28/12′14″E) were used for the brush packing. The dimensions of the two brush pack densities ($kg.m^{-3}$) were an average of 7.37 $kg.1m^{-3}$ for the high density (HD) and an average of 1.98 $kg.0.5m^{-3}$ for the low density (LD) brush packing amongst all plots. The height was determined by creating fence enclosures of 1.0 m for the HD treatments and 0.5 m for the LD treatments. The brush packing height followed recommendations from studies done by Kellner and van den Berg (2005) which used a knee height (approximately 0.5 m) height to mulch the branches in bare soil patches. However, because the brush pack is irregular in pattern, the surface cover can be uneven. Thus, the study used a more quantifiable method to determine difference between the two different density treatments.

2.3. Measurements

2.3.1. Temperature

Two methods were used to collect data namely an infrared thermometer and thermochron iButtons. The iButton (Fabridge Technologies CC, Cold Chain, 1 wire -40–85 °C, Midrand) has an accuracy of 0.5 °C (iButton, 2017). This instrument yielded better results as it was more consistent and could capture data throughout the day (24 h) per plot. The iButtons were buried at a 3 cm depth in the soil at the centre of the plots using water resistant plastic capsules. Each iButton was programmed to take readings on an hourly basis per day cycle. Added to that, average soil temperatures were taken daily for each month between 11h59-13h59 as this is the critical time of the day where heat stress occurs and plants loose moisture. A comparison was made between the two brush packing treatments and the bare soil.

An infrared thermometer (ARB Electrical Wholesalers, IR thermometer -50–700 °C, Pretoria) was used from September to November to take the daily soil surface temperature between 12h00–14h00, similar to the iButton time. The instrument has an accuracy of 0.3 °C. The infrared thermometer was mainly used to calibrate and compare the results with the iButton method, that is not commonly used. It also yields accurate results since there is no contact between the sensor and the soil surface.

2.3.2. Temperature and dry matter correlation

Three different grasses *Cenchrus ciliaris* (S1), *Chloris gayana* (S2) and *Panicum maximum* (S3) were hand sown randomly in plots underneath brush pack and bare soil treatments. Dry matter yield ($g.m^{-2}$) was a parameter used to assess grass growth under the different temperatures created by the different soil covers. During the growth periods, no fertilisers were added to the soil and the grasses were rainfed. Dry matter yield ($g.m^{-2}$) was harvested at the end of November, January and March to assess growth of each species in the treatments. Each of the plots were cut using a 0.09 m2 square quadrant. The samples were cut at 50 mm above the soil surface and then dried in an oven at 67 °C for 3 days. The dry weight was determined.

2.4. Data analysis

To compare if brush packing lowers soil surface temperature better than bare soils over time, temperature data was analysed using linear mixed model repeated measurements analysis, (REML) (Payne, 2014). This was applied to the average mid-day temperatures over 28 weeks and the brush packing effects, as well as the week by brush packing and bare soil, and grass species interaction. Mid-day temperatures were also compared, as this is an indication of critical day temperatures where evaporation and moisture loss are at the highest. Weekly temperatures were tested individually for significances amongst the brush packing

Table 1. Description of treatments.

Treatment number	Treatment combinations (replicated five times)	
	Brush packing density	Grass species
1	High density (HD)- T1	S1-*Cenchrus ciliaris* (Blue buffalo grass)
2	High density (HD)- T1	S2-*Chloris gayana* (Rhodes grass)
3	High density (HD)- T1	S3-*Panicum maximum* (Guinea grass)
4	Low density (LD)- T2	S1-*Cenchrus ciliaris* (Blue buffalo grass)
5	Low density (LD)- T2	S2-*Chloris gayana* (Rhodes grass)
6	Low density (LD)- T2	S3-*Panicum maximum* (Guinea grass)
7	Bare soil (NC)- T3	S1-*Cenchrus ciliaris* (Blue buffalo grass)
8	Bare soil (NC)- T3	S2-*Chloris gayana* (Rhodes grass)
9	Bare soil (NC)- T3	S3-*Panicum maximum* (Guinea grass)

treatments. Means were separated using Tukey's LSD at the 1% level. This was then used to compare means as the treatment variances were not homogeneous. To test the strength of the linear relationship between temperature and dry matter of each grass species, Pearson's correlation coefficients were used. Data were analysed using the statistical program GenStat® (Payne, 2014).

3. Results

3.1. Mid-day soil surface temperature comparison amongst three different soil covers

The differences in mid-day soil surface temperature amongst three treatments were assessed and illustrated in Figure 1. The different soil covers influenced the soil surface temperature ($p < 0.001$) (Table 2) over the 28 weeks period. The high density brush packing (HD) treatment resulted in lowest temperatures (<30 °C) throughout the 28 weeks. The low density brush packing (LD) treatment has a 6 °C temperature higher than that of the HD (<36 °C) and the bare soil (NC) treatment the having

Table 2. Tests for fixed effects. Sequentially adding terms to fixed model Fixed term.

	Wald statistic	n.d.f.	*F* statistic	d.d.f.	F Pr
Week	45085.43	27	1669.83	168.0	<0.001
Treatment	38422.40	2	19211.20	168.0	<0.001
Week. Treatment	2504.70	54	46.38	168.0	<0.001

Table 3. Average monthly temperatures (T) in °C, of high density, low density brush packing and bare soil.

Month	High Density	Low Density	No Cover
September	24.33^{NOP}	25.17^{JKLMNO}	32.51^{MNO}
October	31.27^{qrs}	33.09^{nop}	43.29^{a}
November	33.44^{fgh}	35.29^{de}	47.25^{b}
December	30.73^{ijk}	32.34^{def}	43.84^{a}
January	27.98^{EFGHIJ}	29.53^{ABCDEF}	38.43^{mn}
February	28.02^{MNOP}	29.14^{KLMNO}	38.95^{rstu}
March	26.67^{LMNOP}	27.93^{HIJKL}	37.25^{mn}
SEM		**0.23**	

*Means followed by a different superscript letter differed significantly ($P < 0.01$). LSD (0.01) compares over treatment means for the whole table.

the highest temperatures (>45 °C). The highest temperatures were recorded in the weeks 8, 12 and 17. In these weeks, the HD treatment recorded temperatures of 29, 35 and 39 °C respectively, the LD treatment recorded temperatures of 35, 42 and 43 °C and the NC treatment recorded temperatures 48, 56 and 58 °C. The HD treatment recorded the lowest temperatures with a difference of almost 20 °C to the NC treatment. Differences in temperature between the HD and the LD treatment ranged between 2–3 °C in these weeks however >19 °C between the HD and the NC treatment. The NC treatment yielded higher temperatures

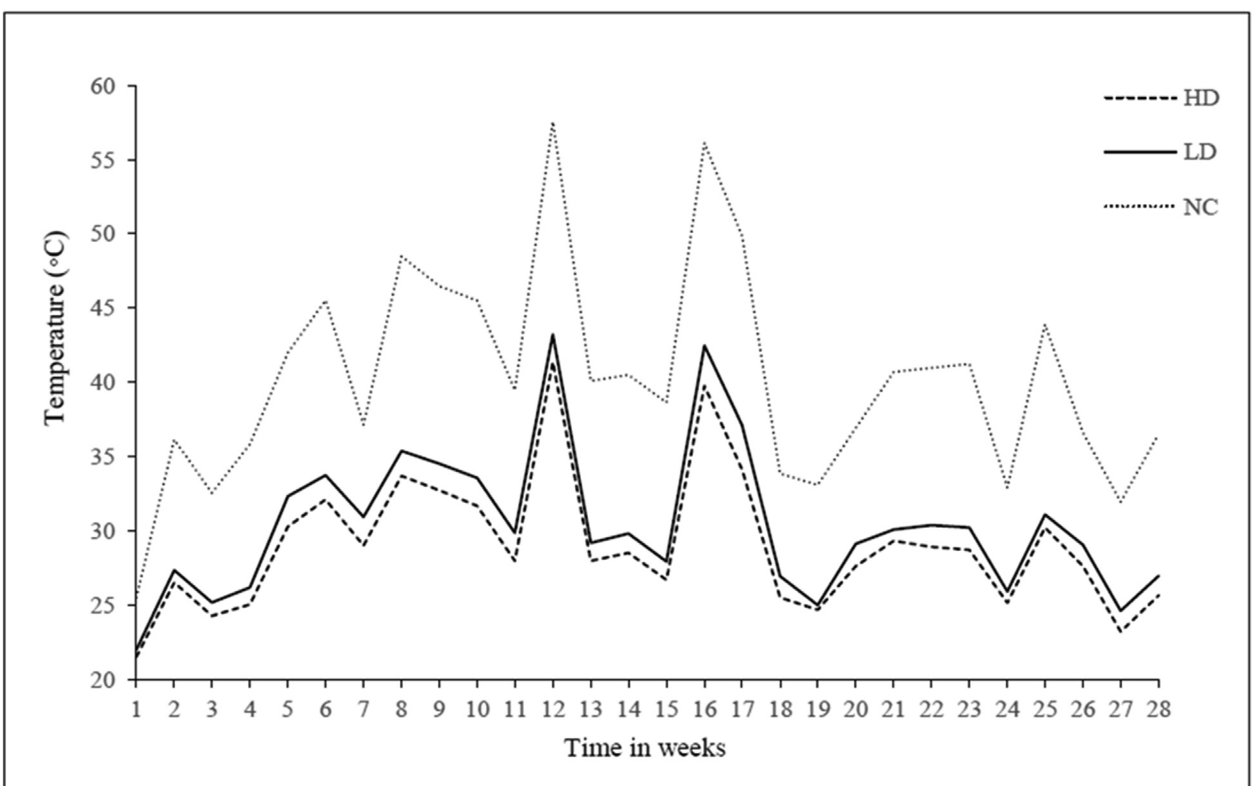

Figure 1. Average mid-day temperatures over 28 weeks in the high density (HD), low density (LD) brush packing and bare soil (NC) treatments.

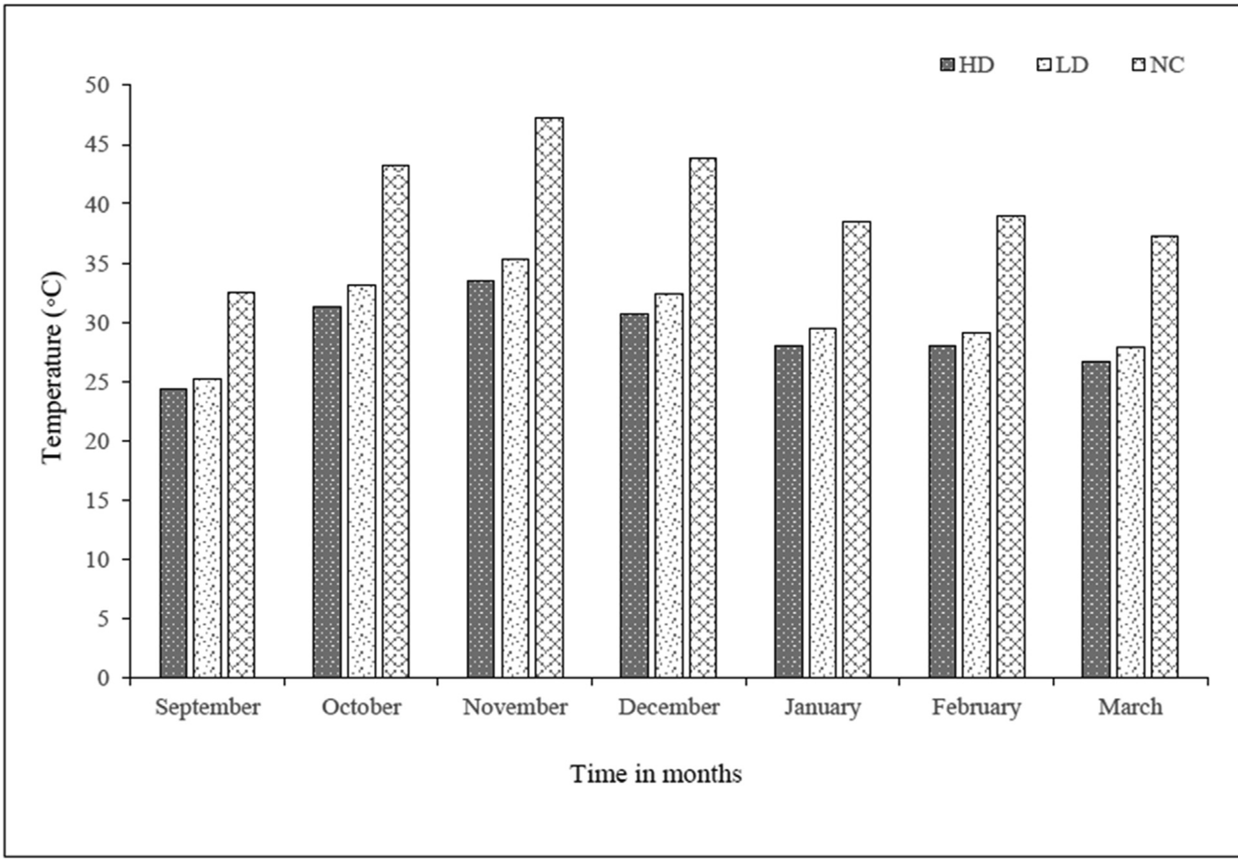

Figure 2. Average monthly temperature (T) in °C, of high density brush packing (HD), low density brush (LD) packing and bare soil (NC). (LSD at 0.01 = 0.66).

over the 28 weeks with temperatures of 10–15 °C above the HD and LD treatments. Even though the HD and LD treatments did not show high differences in temperature over the 28 weeks (<3 °C), the temperature were significantly different ($p < 0.01$) (see Table 2).

The months October, November and December (2015) were the warmest as compared to the other months (Figure 2). The HD treatment recorded the lowest the temperatures (<32 °C), followed by the LD treatment with lower temperatures (>33 °C) and the NC with highest temperatures (>40 °C). November was the hottest month amongst all the seven months, with temperatures of 47.25 °C recorded from the NC treatment, 33.4 °C for the HD treatment and 35.3 °C for the HD treatment. The temperature differences between the NC treatment and the HD treatment were 14 °C in this month. The average temperatures over the months were significantly different ($p < 0.01$) (Table 3). amongst all the treatments. There was approximately a 12 °C temperature difference between the NC treatment and the HD and LD treatments during the warmest months. Generally, the HD and LD treatments yielded lower temperatures over the months as compared to the NC treatment.

The average day and night temperatures during October, November and December (hottest months) are illustrated in Figure 3 for the high and low density brush packing (A and B), and for the bare soil (C) treatments. The day and night temperatures have a critical influence on growth and survival of grasses. The results indicated that the temperatures dropped and increased more gradual and was more stable on the HD and LD treatments as compared to the NC treatment. Both the HD and the LD treatments had similar temperature trends. The HD and LD treatments recorded lower temperatures, ranging between 19–31 °C during the day as compared to the high day temperatures recorded from the NC treatment, ranging between 32–47 °C. The night temperatures for the HD and LD treatments ranged between 15–26 °C as compared to the NC night temperature ranging between 17–24 °C. On average, temperature dropped and increased by approximately 4 °C between day and night on both the HD and LD treatments. The NC treatment had the highest variation, with temperatures dropping and increasing by approximately 18 °C between day and night. The results show that where the day temperature was hotter, the temperature deviation would be less in the in the HD treatment during the night, while higher in the NC treatment This day-to-night temperature difference of 26 °C in the NC treatment was much higher than the 6.7 °C in the HD treatment. Generally, the HD and the LD treatments resulted in lower temperatures during the day as compared to the NC treatment and higher temperatures during the night as compared to the NC treatment.

3.2. Temperature and grass dry matter relationship

Figure 4 illustrates how the grass' yield was affected under lower temperatures from the brush packing treatments vs higher temperatures from the bare soil treatment. The grasses were harvested at three different periods: November 2015, January and March 2016. November was the first harvest with yields just below 41 g m^{-2} amongst all the grasses. In that period, *Cenchrus ciliaris* (S1), produced higher dry matter (40.18 g m^{-2}) in the lowest temperature (33.44 °C, HD treatment) as compared to the other two grasses, *Chloris gayana* (S2) and *Panicum maximum* (S3).

During the January harvest, dry matter yield increased for all the grasses. S3 and S2 produced higher dry matter (49.22 g m^{-2} and 51.52 g m^{-2}) in the lowest temperature of 27.98 °C (HD treatment). S3 yielded the lowest dry matter (48.17 g m^{-2}) in higher temperatures (38.43 °C, NC treatment) compared to S1 (62.8 g m^{-2}) in the higher temperature (38.43 °C, NC treatment). S1 had lower dry matter (53.68 g m^{-2} and 55.05 g m^{-2}) in the HD and LD treatments that have lower temperatures (29.53 °C and 27.98 °C).

In March, (seven months after planting), S3 outperformed S1 and S2 grasses at lower temperatures (26.67 °C) with dry matter yield of 126.37

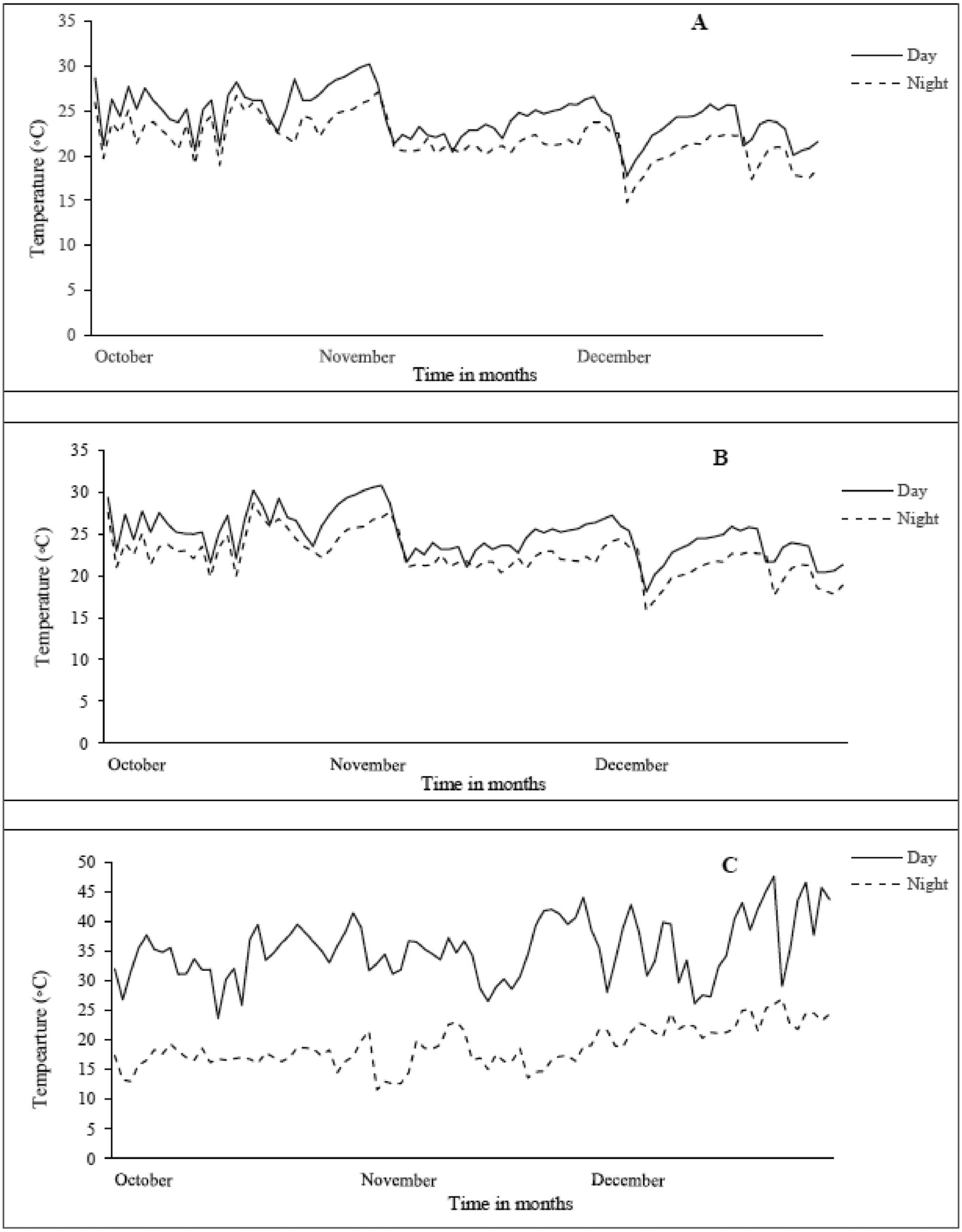

Figure 3. Day and night temperatures (°C) of hottest months during the experiment, comparison of high density brush packing (A), low density bush pack (B) and bare soil (C).

g m^{-2} in the HD treatment. Less dry matter (94.2 g m^{-2}) was produced in higher temperatures (37.25 °C) in the NC treatment for S3 and S2. S1 produced higher dry matter (119.61 g m^{-2}) in the NC treatment with a temperature of 37.25 °C.

S3 and S2 growth was improved at lower temperatures (HD and LD treatment) compared to growth in high temperatures (NC treatment). S1 grew better in high temperatures (NC treatment), however still manages to grow steadily even under low temperatures (HD and LD treatment).

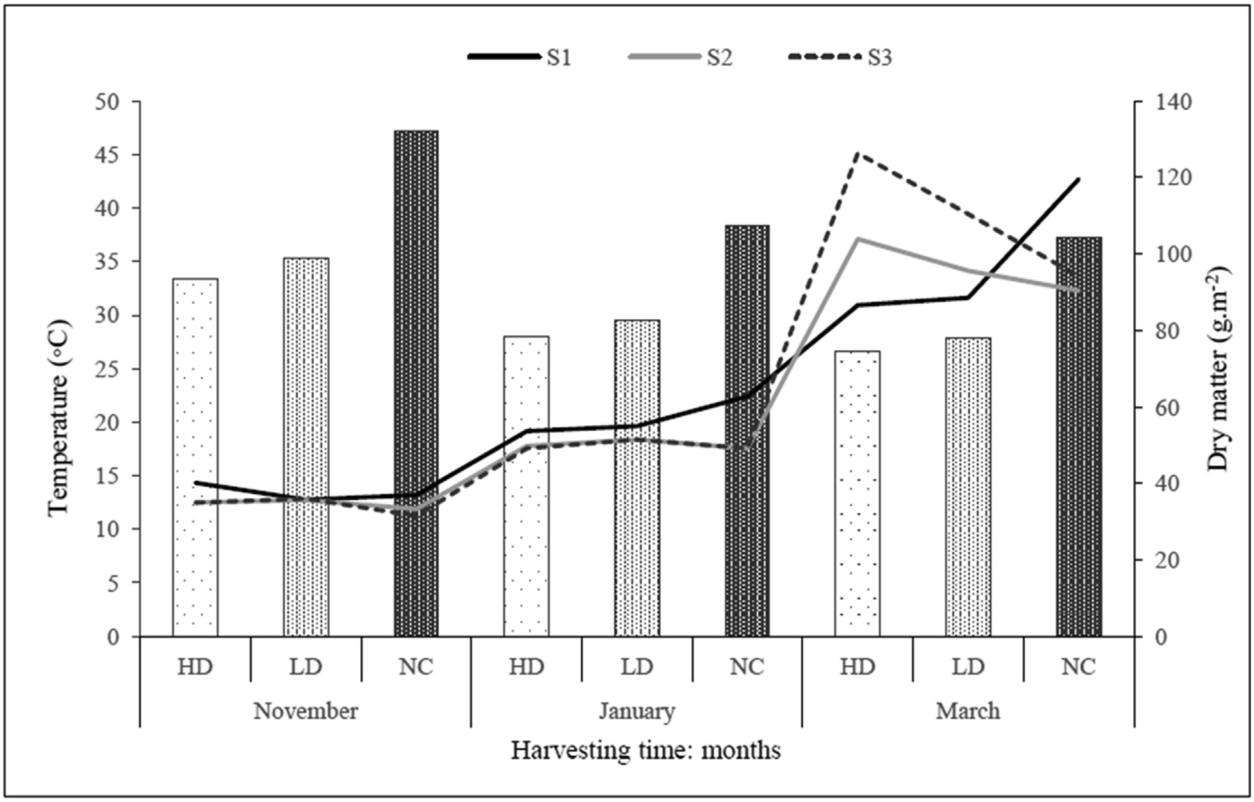

Figure 4. Dry matter yield over different temperature domains for *Cenchrus ciliaris* (S1), *Chloris gayana* (S2) and *Panicum maximum* (S3) at different harvest times (rainy season) under two brush packing densities (HD and LD) and bare soil (NC).

4. Discussion

The brush packing created a microclimate that lowered soil surface temperatures which influenced plant growth. The brush packing also mediated the day and night temperatures consequently creating a favourable micro-environment for plant emergence and growth. The use of brush pack mulching to lower the soil surface temperature in this study was supported by similar work by (Sandholt et al., 2002; Ramakrishna et al., 2005). Soil surface temperature reflects the constant change and different effects of the soil properties and the incoming and outgoing energies (Zhang et al., 2014).

Temperature is an important element for plant growth and development (Agbede et al., 2013). Temperature is a primarily influenced by radiation which affects plant germination and emergence. The lowering of radiation is positively correlated with soil surface temperature. As reported by Barnes et al., (2012), the higher the radiation, the higher the soil surface temperature thus getting more difficult for seedlings to grow. In the first week, the lower temperatures recorded were attributed by the early summer rain received. This rain resulted in the soil surface to be cooler under the brush pack treatments. The high density and low density brush packing treatments did not have a high temperature difference throughout the experiment. This could be because the brush packing irregular covering creates a similar effect on the soil surface temperatures. However, when temperatures were higher, especially in the month of October, November and December, the high density (HD) brush packing recorded the lowest soil surface temperatures. This was because the HD treatment, which used more branches to cover the soil, created an intense shade as compared to the low density (LD) brush packing. Also, because there are more branches in the HD brush pack, there was not much sunlight penetrating in-between the branches through into the soil surface. It was observed that the temperature drops and increase under the brush packing treatments were more stable and gradual as compared to the rapid and unstable sharp changes on the bare soil. A rapid drop and increase in temperature kill grasses more frequently than does a slow change (Ahmad et al., 2021). The brush packing created a blanket effect on the soil surface, making it cooler when it was hot and warmer when it was cold. The bare soil exposed the grasses to higher temperatures when it was hot and lower temperatures when it was cold.

There was a good relationship between temperature and dry matter yield of three subtropical grasses. The growth of particular grasses varied mainly due to the temperature domain. In this study higher temperatures led to a lower yield of *Chloris gayana* (S2) and *Panicum maximum* (S3) (understory species), *Cenchrus ciliaris* (S1) on the other hand produced higher dry matter. This therefore means that under lower temperatures, *Cenchrus ciliaris* had better emergence and vigour in the initial growth stages as compared to *Chloris gayana* and *Panicum maximum*. Dry matter yield was highest in March, with brush packing having more grass production. The brush pack covered soil moderates' temperature effects (Barnes et al., 2015), and creates a gradual and stable change in temperatures, which help grasses against frosting or drying, yielding better plant growth (Nicholson, 2011). The results in this study concur with similar studies done by (Kimiti et al., 2017; Agbede et al., 2013; Gbadebor, 2006; Inyang, 2005) which have reported that the use of mulching using plant material creates a microclimate to improve the soil surface condition, thus assisting plant growth. Although brush packing produced higher yields in the third harvest, *Cenchrus ciliaris* produced the highest yield at higher temperatures, these results are also supported by Esmaili & Salehi (2012) and Van Oudtshoorn (2016). Choosing the right species for rehabilitation is important to implement effective methods of establishment (Zingel, 2005).

5. Conclusion

The temperature results indicated that the brush packing treatments allowed for gradual and stable drops in soil surface temperatures as compared to the bare soil that produced much higher temperature variations. The decrease in soil temperature was due to the reduction in the loss of radiant heat under the brush packing covers as compared to the bare soil. The species adaptation in the results corresponded with their natural habitats. *Panicum maximum*as an understory species was well adapted to the shady brush packing environments with lower temperatures hence it yielded higher dry matter. *Cenchrus ciliaris* produced optimal yields in hotter temperatures, and it was intolerant of shade (Esmaili and Salehi, 2012; Van Oudtshoorn, 2016).

A good plant response can be produced by creating good environmental conditions (Sivakumar, 2007). Higher soil temperatures are known to have caused a remarkable decrease in seed yields. This means that efficiency and productivity can be increased by mulching the soil with brush packs, as this will improve soil conditions for plant growth of selected grasses.

Declaration

Author contribution statement

Tshepiso Mangani; Wayne Frederick Truter: Conceived and designed the experiments; Wrote the paper.

Tshepiso Mangani; Robert Mangani: Performed the experiment; Wrote the paper.

Tshepiso Mangani; Robert Mangani; Lesego Khomo: Analyzed and interpreted the data; Wrote the paper.

Wayne Frederick Truter; George Chirima: Contributed materials, analysis tools or data and supervised; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no competing interests.

Additional information

No additional information is available for this paper.

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