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RESEARCH PAPER

Examining temperature and soil moisture contents of mulches in the urban landscaping of an arid region

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Abstract
High temperatures, low average rainfall, drought, and high evapotranspiration are limiting factors in arid lands. Therefore, when constructing landscapes (green spaces) in these regions, strategies should be developed to mitigate these climatic influences. One practical strategy is utilizing different types of mulches on the surface of the soil. This study was conducted as a randomized complete block design experiment with four replications during 2014 and 2015 to examine the performance of organic and inorganic mulches as non-living mulches and ground cover plants as living mulches. Ground cover plants were *Carpobrotus* sp., *Potentilla reptans*, *Vinca minor*, *Frankenia* sp. and a mixed turfgrass. Non-living mulches were turfgrass clippings, wood chips, sawdust, gravel, rubble and scoria (volcanic rock). Bare soil was used as the control treatment. The results demonstrated the application of mulches could modify soil temperature at 5 and 15 cm depths in different seasons of the year. The living mulches especially *Carpobrotus* sp. and turfgrass reduced the temperature more than the non-living mulches. The soil covered with sawdust and wood chips preserved soil moisture content over the soil covered with other types of mulches. It would appear the selected mulches could decrease the irrigation intervals through increased water holding capacity of the soil. The outcomes of this research could assist landscape managers operating in extreme climate conditions of arid and semi-arid regions to advance the management of soil moisture and temperatures with the objective to improve sustainability.

Keywords: Mulch, Soil temperature, Organic, Ground cover, Green space.

Introduction

Increasing urbanization and population growth increase the population's need for natural and green environments in urban spaces (Hatami Nejad *et al*., 2011). Green spaces are key elements for maintaining natural life in modern urbanism (Mortezai Nejad and Etemadi, 2006). Green spaces can provide aesthetic and pleasant places (Mortezai Nejad and Etemadi, 2006; Azani *et al*., 2010), clean air (Shaban *et al*., 2009), and sustainable infrastructure for the development of natural life in new urbanism (Mortezai Nejad and Etemadi, 2006; Shaban *et al*., 2009). In urban green space developments, suitable soil and water can be limited resources (Jian Borjaki *et al*., 2007). When bare soil is exposed to heat, the wind and other environmental factors, the soil moisture is reduced through evaporation. Selecting appropriate mulches in green spaces can significantly decrease the frequency of irrigation (Chalker-Scott, 2007). Mulch is defined as any natural or synthetic substance that cover the soil surface in green spaces; that protects and promotes soil quality, and has a thickness between 1 to 4 inches (2.54 - 10.16 cm) (Safari and Kazemi, 2014). Mulches are divided into two important categories; living mulches (ground covers) and non-living which include organic and inorganic materials (Steward *et al*., 2003; Singer and Martin, 2008). Ground cover vegetation is the group of plants with a high species

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diversity, capability for rapid growth in various locations and climates, and have a maximum height of one meter. Ground covers can include creeping woody shrubs through to herbaceous perennials (Safari *et al.*, 2015a). The rate of evaporation from a soil surface covered with mulches is less than that of bare soil (Steward *et al*., 2003; Singer and Martin, 2008). Mulches retain moisture and available water within the root zone (Koshki and Jocobi, 2004). Utilizing stone mulches, animal manure and a range of plant materials as mulches do not hinder the penetration of water into the soil and can improve the ability of the soil to retain water (Chalker-Scott, 2007). Non-living mulches are a beautiful addition to the practical benefits (Chalker-Scott, 2007). In dry regions, water efficiency in landscaping can be increased by utilizing drip irrigation, applying irrigation at night, reducing the level of turfgrass and selecting native plant species within the landscape design. Other methods can include applying treated wastewater (Kazemi and Beechm, 2007). Bunna *et al*., (2011) found that when rice straw was utilized as a mulch, the crop yield increased by 10% and water use efficiency increased up to 100%. Whereas, soil moisture retention when using wheat straw as mulch was 10-20% higher than when black polyethylene was used as the mulch (Ghosh *et al*., 2006). In Litzow and Pellett's experiments (1983) it was identified that the highest amount of soil moisture was recorded in soil covered with wood chips and bark of Giant trees (*Sequoiadendron giganteum*) and the least amount of moisture was recorded in the surface of bare soils. This study was carried out because of the knowledge need on benefits and functionalities of living and non-living mulches in extreme climate conditions including arid and semi-arid climates. The overall object was to achieve temperature and moisture content potential of the most common living and non-living mulches used in green spaces. This was done to achieve guidelines on the use of these materials in the construction and maintenance of urban green spaces.

Materials and Methods

This study was conducted as a randomized complete block design experiment with four replications with different mulches as the treatments. The experiment was conducted in the experimental fields at the Department of Horticultural Science and Landscape at Ferdowsi University of Mashhad during 2014 and 2015. In this experiment, ground cover plants were considered as living mulches, and organic and inorganic mulches were considered as non-living mulches. Ground cover plants included *Carpobrotus* sp., *Potentilla reptans*, *Vinca minor*, *Frankenia* sp. and a sports turfgrass. Non-living mulches selected were wood chips including a mixture of pruning from different tree species (length of particles: 60 mm, bulk density: 0.43 g/cm3), sawdust (length of particles: 5 mm, bulk density: 0.18 g/cm3), turfgrass clippings (length of particles: 4 cm, bulk density: 0.10 g/cm3), gravel (diameter of particles: 0.8 cm, bulk density: 2.51g/cm3), rubble (diameter of particles: 1.97 cm, bulk density: 2.70g/cm3), and scoria (diameter of particles: 2.44 cm, bulk density: 1.64 g/cm3) as a volcanic rock. Bare soil was used as the control treatment. In this study, the temperature was measured by a thermometer from the center of the plots at 5 and 15 cm depths of the soil at monthly intervals. The measurements were made on the 15th day of each month. It is expected that mulches could balance soil temperatures over the year; they are expected to reduce temperatures in warm seasons and increase temperatures in cold seasons. Therefore, the months with maximum temperatures in warm seasons of spring and summer were chosen as the reference months for comparison of the temperature in bare and mulched soils. In addition, in the cooler seasons of autumn and winter, represented months that presented the cooler temperatures at the time of the measurement were selected as the reference months (Fig 1). This selection was made to help to identify the mulches that could increase the temperature in cool seasons of the year to be able to protect plant roots from the risk of frost. Soil moisture measurements were carried out by a moisture sensor model (EXTECH MO750, made in the USA) at soil depths of 5 cm and 15 cm on a monthly basis. Irrigation volume was similar for the plots containing each type of mulches and was conducted every three days during warm seasons and every 12 to 14 days in cooler seasons. Statistical analyses were carried out through the JMP 8.0 software package.

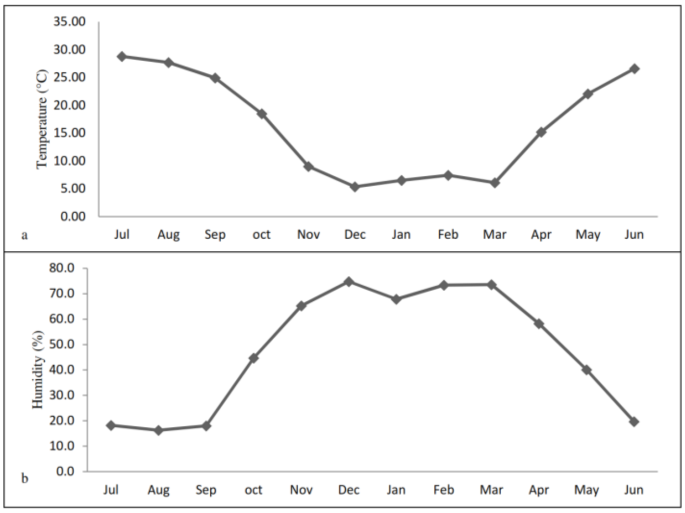

Figure 1. a. Weather temperature; and, b. humidity in different months during the experimental period (source: synoptic weather station of Mashhad)

Results

Soil temperature

Temperature at 5 cm depth of the soil

Analysis of variance related to the temperature at 5 cm soil depth (Table 1) showed that the effect of mulches on soil temperature at 5 cm depth was significantly different ($p < 0.01$). All the twelve types of mulches were available in the first three seasons of the experiment (summer, autumn, and winter). However, the turfgrass clippings had completely decomposed by the end of the winter season. Therefore, the degree of freedom was reduced to 10 (instead of 11 for the other mulches in the other seasons) in the statistical analyses (Table 1).

Table 1. Analysis of variance for the temperature at 5 cm depth of the soil as a function of mulch type in different seasons

Analysis of variance	df	Summer	Autumn	Winter	Analysis of variance	df	Spring
Block	3	26.354 **	10.472 **	2.310 *	Block	3	32.181**
Mulch	11	9.675 *	2.219 *	10.823 **	Mulch	10	35.518**
Error	33	3.717	0.911	0.757	Error	30	3.218

** Significant at 1% level of probability, * Significant at 5% level of probability, ^{ns}: Non-significant

The results of mean comparisons for the soil temperature of summer showed the highest value of temperature was recorded in the bare soil, thus in summer, all the mulches reduced the soil temperature at 5 cm depth. Conversely, there were no significant differences between non-living and living mulches regarding the temperature at 5 cm depth of the soil. The lowest temperature was recorded in the soil covered by *Frankenia* sp. (Fig 2.a). The results of mean comparisons for the soil temperature in autumn showed the highest temperatures were recorded under sawdust and the lowest values were recorded under the lawn and the wood chips (Fig 2.b).

The results of the comparisons of the means of the soil temperature in winter showed that the highest temperature was recorded under *Vinca minor*. The lowest temperature was recorded under turfgrass and *Carpobrotus* sp. (Fig 2.c). Finally, in spring, the maximum soil temperature at 5 cm soil depth was recorded under rubble, and the minimum temperature was recorded under the ground cover *Carpobrotus* sp. (Fig 2.d).

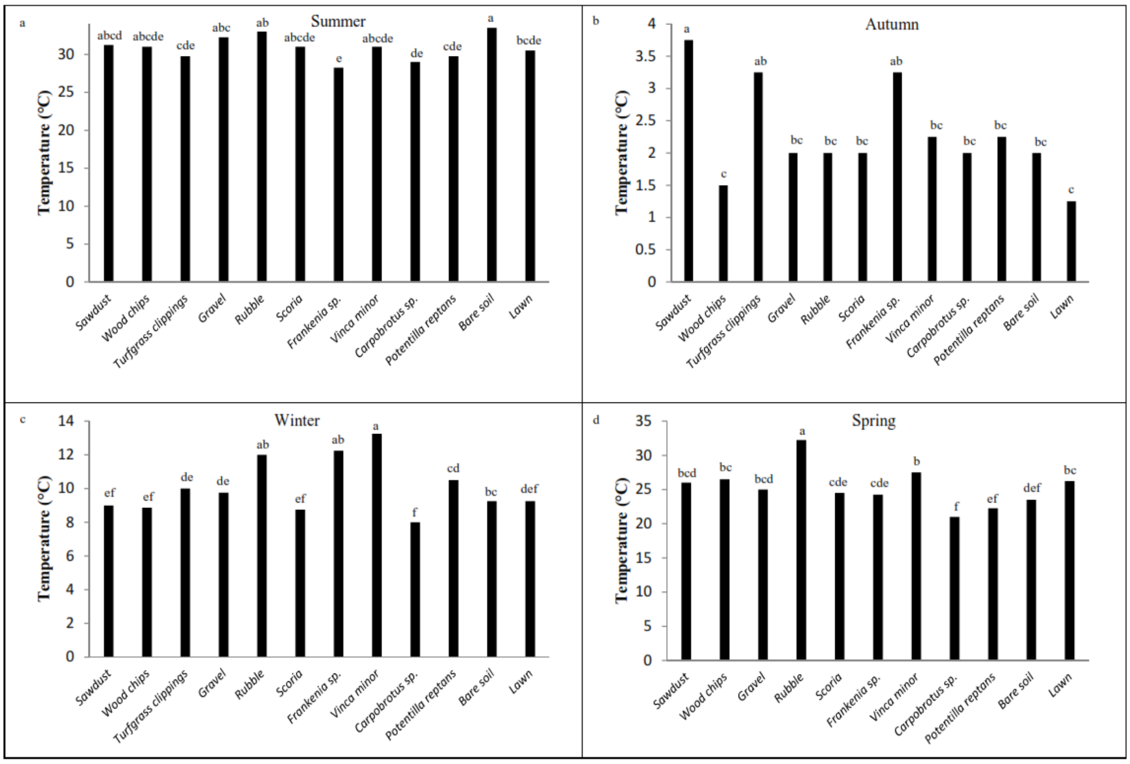

Figure 2. Effect of non-living and living mulches on the temperature at 5 cm soil depth; a. summer, b. autumn, c. winter, d. spring

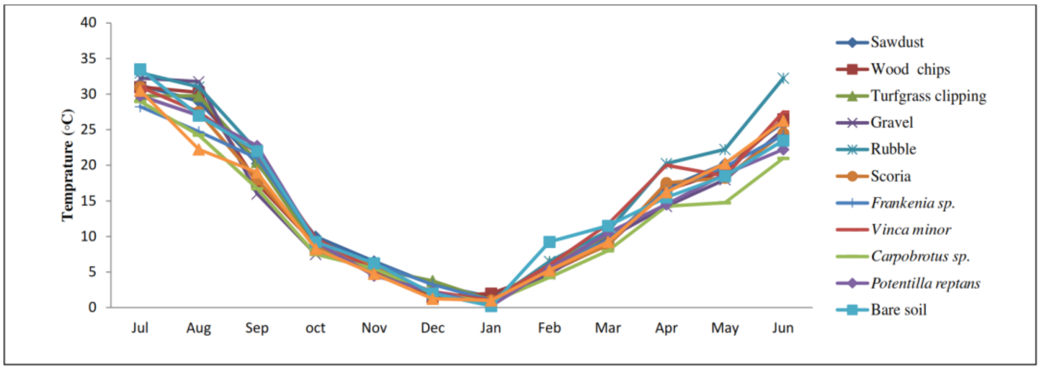

Figure 3. Changes in temperature at 5 cm soil depth affected by living and non-living mulches

Figure 3 illustrates at 5 cm soil depth in summer and spring, different mulch types showed the largest temperature fluctuations. At the beginning of summer (July), the highest temperatures were recorded under bare soil and equally, all the selected mulches reduced soil temperature. Whereas in spring and the subsequent seasonal climatic conditions, all the mulches increased or decreased the soil temperature. In June, the rubble mulch increased soil temperature more than the other types of mulches, whereas living mulches reduced soil temperature in the warmer months.

Temperature at 15 cm depth of the soil

The analysis of variance in all seasons (Table 2) showed that the mulches had significant effects ($P < 0.01$) on the temperature at 15 cm depth of the soil. Turfgrass clippings as one of the mulch types decomposed by the fourth season of the experiment (spring), Result in why the number of degrees of freedom in the experiment was reduced to 10 in this season (Table2).

Table 2. Analysis of variance for temperature at 15 cm depth of the soil as a function of mulch type in different seasons

Analysis of variance	df	Summer	Autumn	Winter	Analysis of variance	df	Spring
Block	3	6.456 ns	14.750 **	7.076 **	Block	3	25.000 **
Mulch	11	52.005 **	5.522 **	1.020 **	Mulch	10	27.504 **
Error	33	2.904	0.704	0.333	Error	30	1.783

** Significant at 1% level of probability, * Significant at 5% level of probability, ns: Non-significant

The results of the comparisons of the means in summer showed that the highest temperatures were recorded under gravel, rubble and wood chips. The lowest temperature was recorded under *Carpobrotus* sp. and turfgrass (Fig 4.a). In autumn, at 15 cm depth of the soil, sawdust and scoria had the highest temperatures compared to the temperature of the bare soil. The lowest temperatures were recorded under the turfgrass and the bare soil although this was not statistically different from the temperature under the other types of the mulches (Fig 4.b).

The results also showed in winter, the soil under rubble at 15 cm depth was associated with the highest temperature. However, the lowest temperature was associated with the soil under *Carpobrotus* sp. although the soil temperature under many other types of mulches was not significantly different from the soil temperature under *Carpobrotus* sp. (Fig 4.c). In autumn, sawdust, scoria and rubble had the largest temperatures, whereas, bare soil and lawn had the lowest temperature although this low temperature was not significantly different with the temperature under the other types of mulches but bare soil and scoria (Fig 4.d).

At 15 cm soil depth in warmer months, demonstrated mulching had a significantly different effect on soil temperature compared to bare soil. Non-living inorganic mulches (rubble, gravel), increased soil temperature while living mulches (*Carpobrotus* sp.) reduced soil temperature. In colder months, mulches increased soil temperature compared to bare soil (Fig. 5).

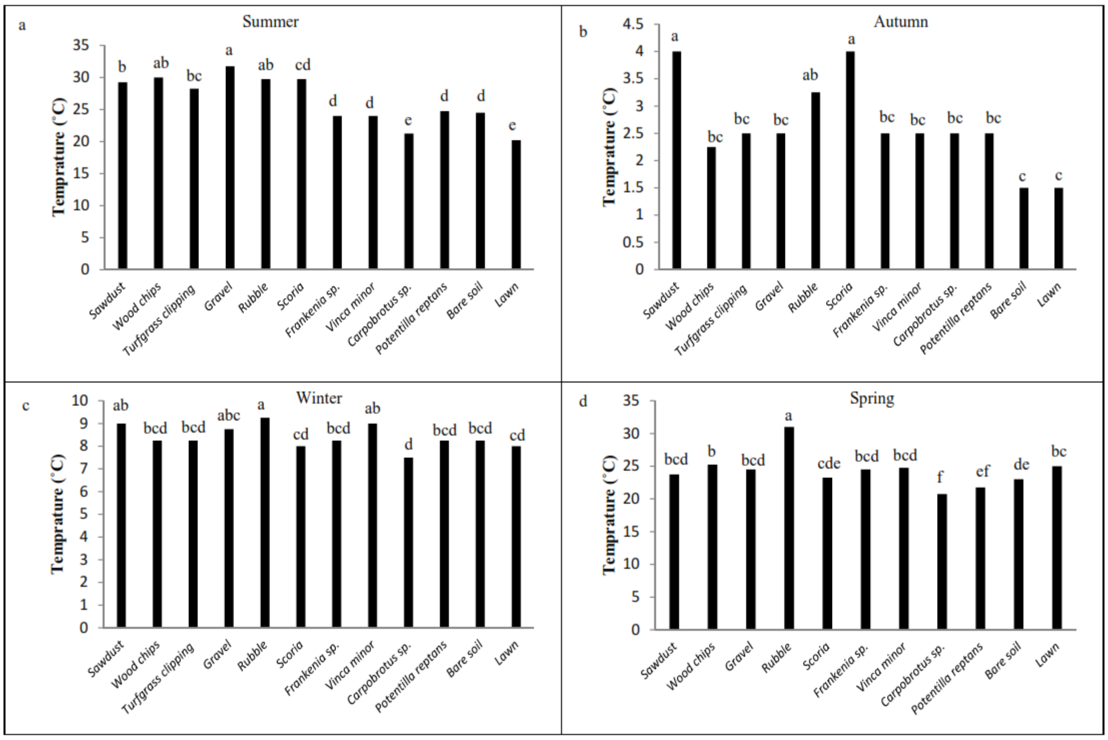

Figure 4. Effect of non-living and living mulches on the temperature at 15 cm depth of the soil; a. summer, b. autumn, c. winter, d. spring

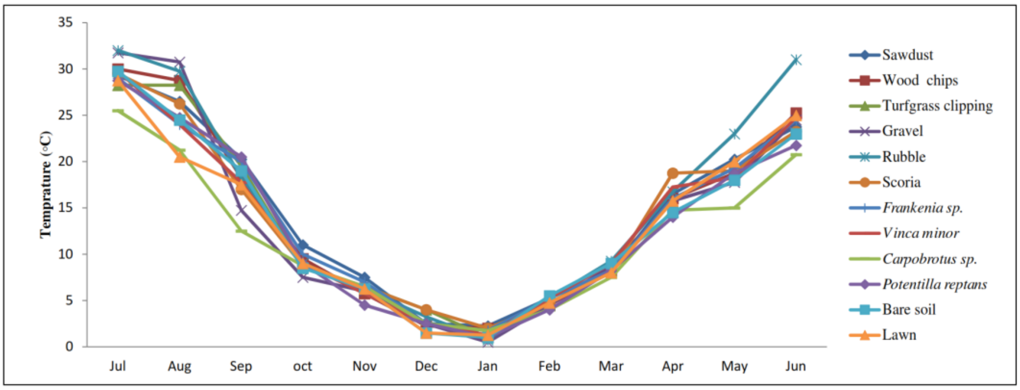

Figure 5. Changes on temperature at 15 cm depth of the soil affected by living and non-living mulches

Soil moisture

Moisture at 5 cm depth of the soil

Analysis of variance (Table 3 and 4) showed that the mulches were significantly different regarding soil moisture at 1% and 5% levels of probability. Turfgrass clipping decomposed by the fourth season of the study, i.e. spring. The degree of freedom was reduced to 5 instead of 6 in this season (Table 3).

Table 3. Analysis of variance of moisture at 5 cm depth of the soil as a function of mulch type (non-living mulches) in different seasons

Analysis of variance	df	Summer	Autumn	Winter	Analysis of variance	df	Spring
Block	3	0.619 ^{ns}	95.666 **	7.050 ^{ns}	Block	3	1.644 ^{ns}
Mulch	6	36.821 **	41.166 **	12.624 *	Mulch	5	51.274 *
Error	18	5.757	4.227	4.438	Error	15	15.979

** Significant at 1% level of probability, * Significant at 5% level of probability, ^{ns}: Non-significant

Table 4. Analysis of variance of moisture at 5 cm depth of the soil as a function of mulch type (living mulches) in different seasons

Analysis of variance	df	Summer	Autumn	Winter	Spring
Block	3	0.703 ^{ns}	91.819 **	4.165 ^{ns}	6.163 ^{ns}
Mulch	5	29.641 **	81.341 **	40.169 **	27.118 **
Error	15	3.841	11.825	7.165	4.093

** Significant at 1% level of probability, * Significant at 5% level of probability, ^{ns}: Non-significant

In the summer season, at 5 cm depth, the soil under sawdust, wood chips, and turfgrass clippings showed the most amount of moisture whereas the bare soil at 5 cm depth presented the least amount of moisture (Fig 6.a). Among the living mulches, the higher soil moisture was recorded under turfgrass, whereas, the lowest soil moisture was recorded under *Frankenia* sp. (Fig 9.a). The autumn season, among non-living mulches, the maximum soil moisture was recorded under sawdust and wood chips and the minimum soil moisture content was recorded under rubble and bare soil (Fig 6.b). Figure 9.b showed that the maximum soil moisture was recorded under turfgrass and the minimum soil moisture content was recorded under *Frankenia* sp. and *Vinca minor*.

In the winter season, among the non-living mulches, the lowest soil moisture was recorded under rubble, and the highest soil moisture was recorded under sawdust and wood chips and scoria (Fig. 6.c). Among the living mulches, the soil moisture under *Vinca minor* was the highest while the soil moisture underneath the other types of mulches was the lowest. The moisture content underneath *Frankenia* sp. was between the moisture underneath these two groups of mulches regarding quantity (Fig 6.c). In the spring season, among the non-living mulches, maximum soil moisture at 5 cm depth was recorded under sawdust and wood chips and the minimum moisture content was recorded under rubble and scoria (Fig 6.d). Among the living mulches, maximum soil moisture was recorded under *Potentilla reptans* and the minimum soil moisture content was recorded under *Frankenia* sp. and *Vinca minor* (Fig 6.d).

In warmer months, soil moisture at 5 cm depth of the soil under living and non-living mulches were significantly different. *Frankenia sp*. had the lowest soil moisture during the year. Sawdust kept high moisture in the soil in warmer months. In the summer, non-living organic mulches retained more moisture in the soil and compared to the bare soil (Fig 8).

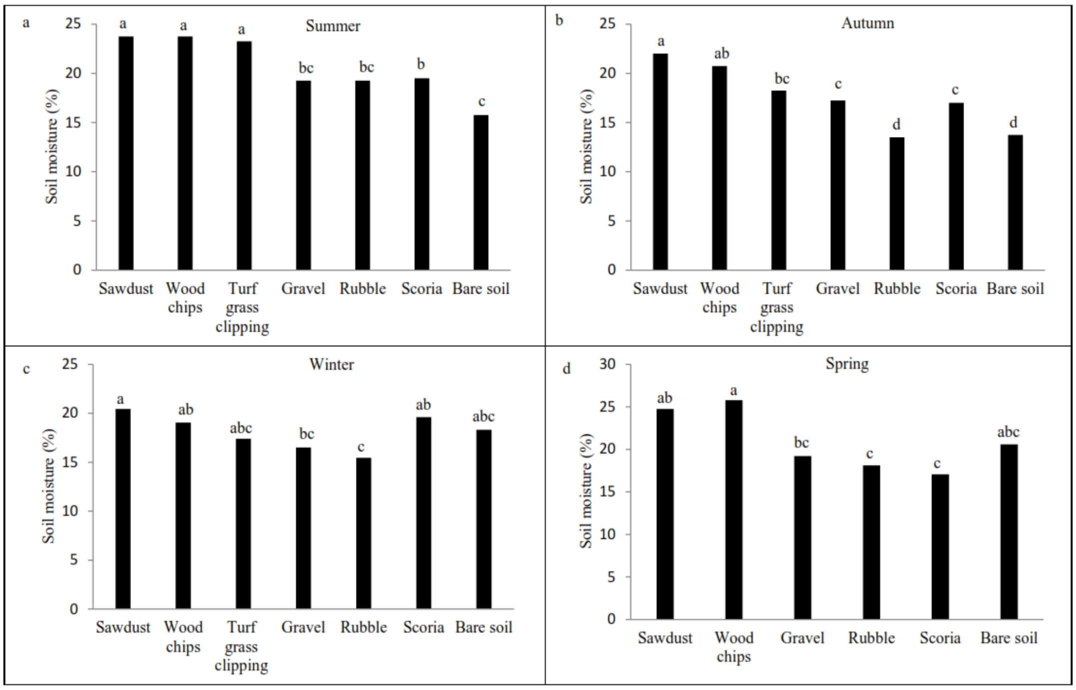

Figure 6. Effect of non-living mulches on soil moisture at 5 cm depth; a: summer, b: autumn, c: winter, d: spring

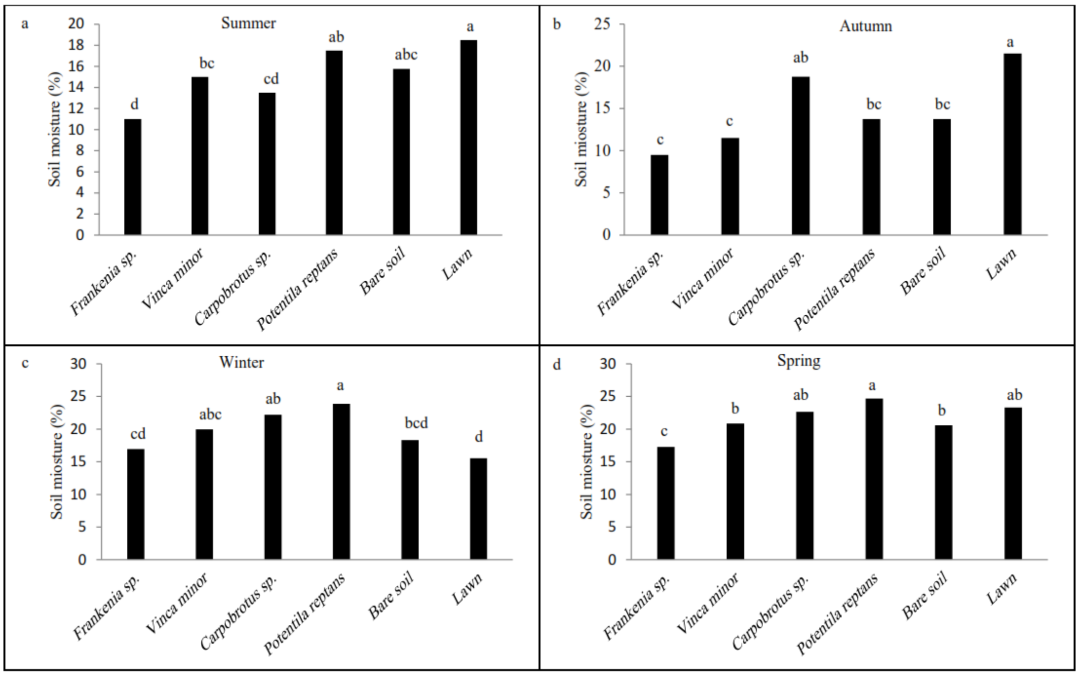

Figure 7. Effect of living mulches on soil moisture at 15 cm depth; a: summer, b: autumn, c: winter, d: spring

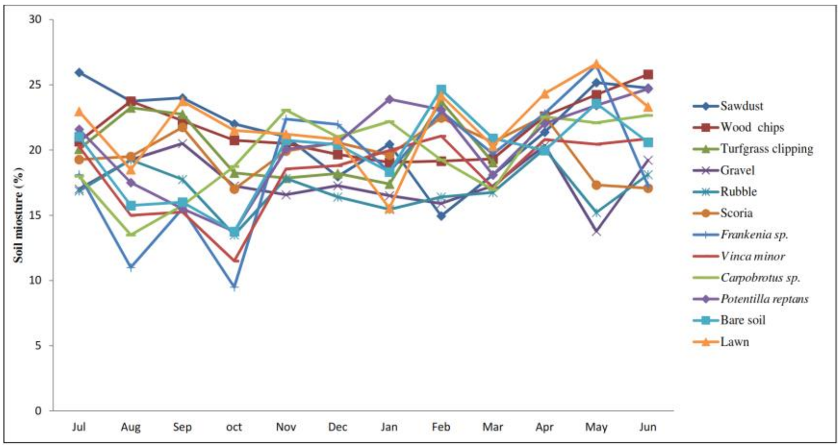

Figure 8. Changes on moisture at 5 cm depth of the soil affected by living and non-living mulches

Moisture at 15 cm depth of the soil

Analysis of variance (Table 5 and 6) showed that there were significant differences ($p<0.01$) in moisture content at 15 cm depth of the soil under different mulches. Turfgrass clipping was disappeared in the fourth season of the study, i.e. spring. That was why degree of freedom was reduced to 5 instead of 6 in this season (Table 5).

Table 5. Analysis of variance of moisture at 15 cm depth of the soil as a function of mulch type (non-living mulches) in different seasons

Analysis of variance	df	Summer	Autumn	Winter	Analysis of variance	df	Spring
Block	3	8.130 ^{ns}	5.464 ^{ns}	23.059 ^{ns}	Block	3	85.497 ^{ns}
Mulch	6	21.166 **	18.821 *	31.090 *	Mulch	5	246.28 **
Error	18	3.436	6.075	9.551	Error	15	46.867

** Significant at 1% level of probability, * Significant at 5% level of probability, ^{ns}: Non-significant

Table 6. Analysis of variance of moisture at 15 cm depth of the soil as a function of mulch type (living mulches) in different seasons

Analysis of variance	df	Summer	Autumn	Winter	Spring
Block	3	3.162 ^{ns}	25.152 *	98.547 ^{ns}	61.007 ^{ns}
Mulch	5	26.275 **	33.441 **	197.887 *	270.374 **
Error	15	2.297	6.552	50.560	41.049

** Significant at 1% level of probability, * Significant at 5% level of probability, ^{ns}: Non-significant

In summer, among non-living mulches, the soil moisture under sawdust was the highest and the soil moisture under bare soil was the lowest (Fig 9.a). Among the living mulches, the soil moisture under the lawn, *Potentilla reptans* and *Vinca minor* were the highest and the soil moisture in the bare soil and under *Carpobrotus* sp. and *Frankenia* sp. was the lowest (Fig 10.a). In autumn, among the non-living mulches, maximum moisture at 15 cm soil depth was recorded under sawdust and woodchips, and the minimum moisture content was recorded under rubble and bare soil (Figure 8.b). Among the living mulches maximum soil moisture was recorded under lawn and *Carpobrotus* sp. and the minimum moisture content was recorded under *Vinca minor* and *Frankenia* sp. (Fig. 10.b).

In winter, among non-living mulches, the maximum soil moisture was under sawdust and the minimum soil moisture was under the rubble (Fig 9.c). Among the living mulches, the soil moisture under *Vinca minor* was the highest, and it was the lowest under bare soil and lawn (Figure 10.c). In spring, at 15 cm depth of the soil, the moisture under wood chips and sawdust were maximum. The lowest soil moisture was also recorded under rubble and scoria (Fig. 9.d). Among living mulches, the highest soil moisture was recorded under *Potentilla reptans* and the lowest soil moisture was recorded under *Carpobrotus* sp. and *Frankenia* sp. and then bare soil (Fig. 10.d).

At 15 cm depth of the soil, in July, mulches had different effects in soil moisture. In most months of the year, rubble and gravel retained little moisture compared to the other mulches, in particular, the non-living organic mulches retained more soil moisture (Fig. 11).

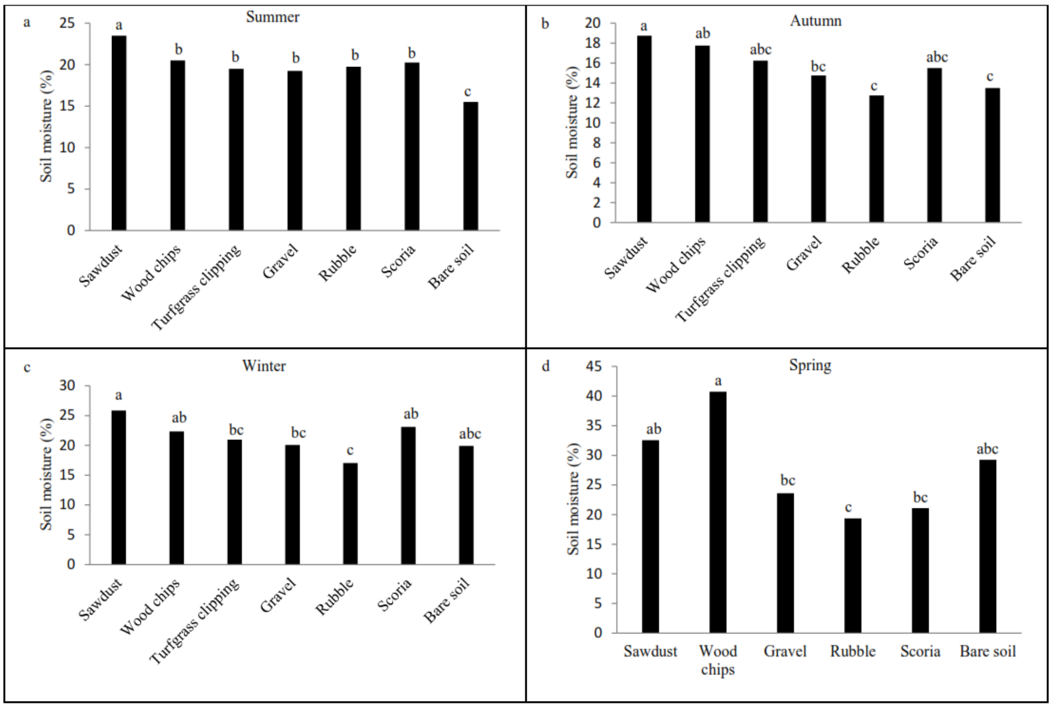

Figure 9. Effect of non-living mulches on soil moisture at 15 cm depth; a: Summer, b: Autumn, c: Winter, d: Spring)

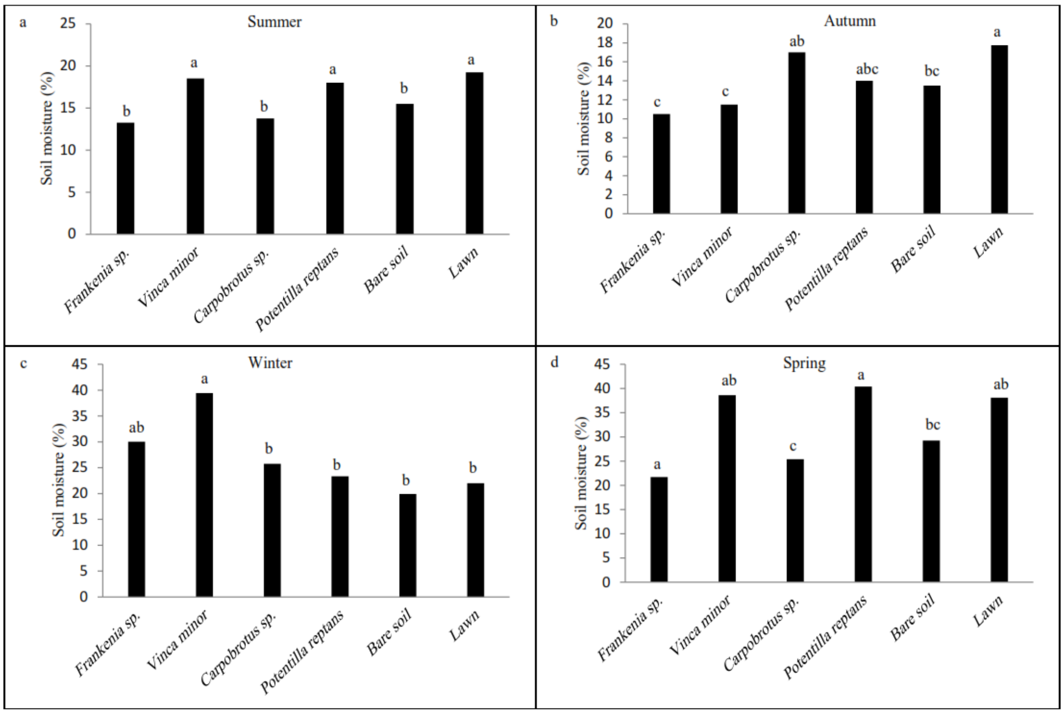

Figure 10. Effect of living mulches on soil moisture at 15 cm depth; a: Summer, b: Autumn, c: Winter, d: Spring)

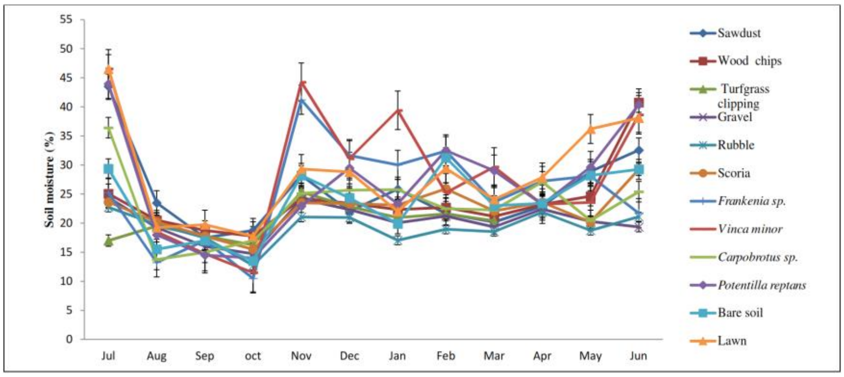

Figure 11. Changes on moisture at 15 cm depth of the soil affected by living and non-living mulches

Discussion

Soil is the main component of the biosphere and the key factor for the life of the plants and microorganisms (Bodagh Jamali, 2003). One of the fundamental factors in the soil which affects the life of the plants, animals, and microorganisms is the soil moisture. This factor performs a major role in the exchange of energy between the air and the ground track (Bodagh Jamali, 2003). The bare soil loses the moisture through evaporation when it is exposed to heat, wind, or compression, and obtain the moisture through irrigation and rainfall (Chalker-scott, 2007). It is mentioned that success in agriculture depends on maintaining enough amounts of water and moisture in the soil (Barker, 1990). At the same time, one of the most important and viable strategies for sustainable water-conserving agriculture especially in arid regions with water shortages is to reduce the amount of water evaporated (Nazemi *et al*, 2019$_{a,\ b}$). Therefore, a practical solution to maintain soil moisture for a longer period and to increase water use efficiency is to use mulches (Islami and Farzamnia, 2009; Safari and Kazemi., 2016; Kazemi and Safari, 2018); and to understand water and moisture potential of different mulches under different mulch types. These results showed that different types of organic and inorganic mulches had different effects on soil moisture retention at 5 and 15 cm soil depths. Among the non-living mulches studied in this experiment, the two mulches of wood chips and sawdust retained more moisture at two depths of 5 and 15 cm than the other mulched and non-mulched treatments. In addition, the three organic non-living mulches including sawdust, wood chips, and turfgrass clippings performed better in terms of moisture retention than the three inorganic non-living mulches of gravel, rubble, and scoria. In all seasons of the year, the rubble, as an inorganic mulch type, showed no statistically significant difference with control bare soil treatments in terms of moisture content at 5 cm soil depth. Other studies have also confirmed the positive effect of mulches on soil moisture retention. In a study by Stelli *et al*. (2018), it was found that pots covered with types of organic and inorganic mulches including bark chips, compost, dry leaves, and white pebble averaged 35% better in water retention than that in non-mulch pots (Stelli *et al*, 2018). In another experiment, using different types of organic and inorganic mulches (viz bajra straw ‹maize straw grasses, brankad (*Adhatoda vasica*), farmyard manure, black polyethylene) increased soil moisture content at a depth of 15 cm about 2% to 5% compared to the control treatment. This increase in moisture was also observed at 15 to 25 cm depth of the soil. Therefore, with a positive effect of mulches on soil moisture retention, the amount of performance significantly increased in Eureka lemon compared to the same plant planted in a control, bare soil treatment (Kumar *et al*., 2015). Mulches prevent evaporation and help return the moisture in the soil (Ramakrishna *et al*., 2006). Using the mulches on the soil surface increases the diffusion of the water under the vapor pressure gradient during the growing season. This factor increases the maximum water absorption under the mulches (Kumar and Dey, 2011). Research works also have demonstrated that the moisture content causes more cohesion in the soil structures, hence, reduces evaporation (Aggarwal and

Goswami, 2003). Direct sunlight on the soil surface increases evaporation from the soil surface and dries out the soil. However, the use of mulches as a protective layer on the soil surface, prevents these events, and also reduces the pressure caused by the direct collision of the raindrops on the soil surface and prevents the production of runoff on the soil surface. As a result, the water absorption and infiltration into the soil increases and then the soil moisture content will increase (Safari and Kazemi, 2016). Mulches can keep the soil moisture by avoiding direct sunlight exposure to the soil surface (Farias-Larios, 1997), preventing water from reaching the soil surface due to removing the capillary rise of the soil through increased water infiltration. This even is mainly because of preventing runoff from the soil surface (Farias-Larios, 1997), and the efficient use of irrigation water and rainfall due to their high absorption capacity (Farias-Larios, 1997). While mulches reduce the water loss, their effects greatly depend on the characteristics of the mulch types (Chalker-scott, 2007; Riaz Hussain *et al*., 2014). The volume of the saved water depends on the soil structure and texture, and also the type of the used mulch (Aggarwal and Goswami, 2003). The results of this study also confirm this opinion. It means that, in this study, the three organic non-living mulches had better performance in soil moisture retention than the three inorganic non-living types of mulches. As mentioned earlier, the highest amount of moisture was recorded in the soil covered with wood chips and sawdust mulches in different seasons of the year. However, the response of inorganic mulches to soil moisture retention varied in different seasons studied in this experiment. In summer, three inorganic mulches including gravel, rubble, and scoria increased the soil moisture compared to the control but this increase in moisture only showed a significant difference with the control when scoria was used on the soil surface. The increase in soil moisture in the other two inorganic mulches was not statistically significant compared with the control treatment. In autumn, scoria and gravel mulch significantly increased the soil moisture compared to the control treatment. In the spring, the soil covered with inorganic mulch retained less moisture in the soil than the control treatment. However, there was no a statistically significant difference between the treatments. These results showed that the moisture content in the soil covered with organic mulches is much less varied than inorganic mulches during different seasons. Other researchers have also confirmed the positive performance of different types of organic mulches in maintaining soil moisture. Chalker-scott (2007) demonstrated that the use of certain organic types of mulches, such as the bark and the jute, leads to the regeneration of some compacted soils and increases the porosity of the soil (Chalker-scott, 2007). Using organic mulches of straw and grass clippings can help to maintain the soil moisture (Chakraborty *et al*., 2008), and temperature (Ramakrishna *et al*., 2006), and increase the crop production (Siczek and Lipec, 2011) by reducing the consumption and loss of water in the soil (Zribi *et al*., 2015). It is important to note that the organic mulches break down with time and become a part of the soil. This decomposition and increase of organic matter in the soil improve the water and nutrient retention in the soil and increases the water retention capacity of the soil, which results in better plant growth. However, these types of mulches need to be replaced frequently (Safari and Kazemi, 2014; Pramanik *et al*., 2015). In this study, three different types of organic non-living mulches were used. Among them, the remaining mulch of turfgrass clippings was able to function as mulch just in three seasons of a year. This mulch type was decomposed before the beginning of the spring. The living mulches examined in this experiment also showed different responses to soil moisture retention. In summer, lawn, bare soil and *Potentilla reptanse* retained the highest amount of moisture in the soil underneath them. In this season, the lowest moisture content was observed in the soil covered with *Ferankenia* sp. The use of lawn at the soil surface was associated with the highest amount of soil moisture in the summer, autumn and spring seasons. *Carpobrotus rossii* in autumn and *Potentilla reptanse* and *Carpobrotus rossii* in spring had higher moisture content than other groundcover plants or the bare soil. In winter, both plants of *Potentilla reptanse* and *Carpobrotus rossii* were able to retain the moisture in the soil. Comparing the findings of the soil moisture under the living mulches in this study, it can be seen that in all seasons of the year except for winter, when the lawn was grown as a living mulch, it was able to retain the soil moisture in different soil depths. Observations in our study showed that this finding appeared to be mainly because of creating a thatch layer under the lawn which could assist in preserving the moisture under the soil surface (Rabbani *et al*., 2019). Thatch is formed by the accumulation of dead leaves, stems, and roots, decomposing above the soil surface and under the green leaves of turfgrasses. The highest percentage of thatch production is from the plant stems. Grass decapitation must be done before thatch formation in plants. The rapid growth and not taking good care of turfgrasses, increases the production of thatch in these plants (Beard, 1972). While it is believed that lawn usually have higher water needs than most other living mulches or ground cover plants (Rabbani *et al*., 2019) and by planting lawns as living mulches an increase in water consumption and a decrease in water use efficiency within urban landscaping may occur, our findings confirmed that if lawns have been managed to produce thatch, they can act as efficient water-conserving living mulches. The results of Liang *et al*. (2017) also confirm the results of our study. Liang *et al*. (2017) found that the presence of thatch in red fescue and Kentucky blue grass was effective in increasing the absorption rate of water and the retention time of water in the soil. Furthermore, the water penetrated more slowly in the thicker thatch. Also, the presence of thatch in these two plant types at the rain time reduces surface runoff, and by allowing more water to be absorbed by the soil, increased water penetration into the soil and water evaporation from the soil surface decreased compared to that in the bare soil. In general, the presence of thatch at the soil surface changes the hydraulic processes near the soil surface, which also influences the management conditions of these cultivated plants and their irrigation schedule (Liang *et al*, 2017). Findings of the current study provided strong evidence that among the living mulches *Frankenia* sp. kept less moisture under the soil almost in all the studied seasons and soil depths. It appears this plant species acted like a sponge in removing the moisture from the soil. However, it kept a high visual aesthetics during the period of this experiment. This finding was less discussed in previous studies and may also require further deeper research investigations in the future. However, previous studies have confirmed very low water needs of *Frankenia* sp. which has made it a suitable plant candidate for water-conserving landscaping. In an experiment conducted by Chegah *et al*. (2014), the growth of the ground cover of *Frankenia* sp. in 70% field capacity humidity conditions was similar to the plant growth of the control treatment (100% FC). The results of this study indicated that this plant had a favorable growth in low moisture conditions (Chaghe *et al*., 2014). Also, a study by Sadeghi (2017) showed that *Ferankenia* sp. tolerates reduced soil humidity down to 50% field capacity and provides acceptable quality and visual quality in the green space (Sadeghi, 2017). Among the groundcover types, this plant, after the turfgrasses, has the highest resilience (Chgahe *et al*, 2014). The low water requirement, low maintenance and cultivation capability in areas and surfaces where cultivation of grass as a groundcover is almost impossible are the reasons to replace the turfgrasses with Frankenia (Chegah *et al*, 2014). Therefore, if Frankenia is planted adjacent to low-water need plants, low moisture content of the soil should not be a major issue. As was previously mentioned, the use of mulches on soil surfaces led to protect the soil from wind and water erosion. Using living mulches in areas with steep slopes is more effective than using non-living mulches (Chalker-Scott, 2007). In general, due to the high diversity among the ground cover plants, obtaining plant species with lower water requirements for application in green space development should not be difficult. In addition to the practical aspects, the groundcover plants have aesthetic features that enable them to create beautiful landscapes. Beautiful contrasts using ground cover plants with turfgrasses and other plants due to the high variety of colors in these plants (ranges from gray to light green to grassy green, tanning to purple, and green and gray or yellow or white), or having a variety of textures (from fine-leaf textures similar to turfgrasses such as the texture in *Sagina subulata* to coarse texture plants such as in *Hedera* sp. or *Host asp*.) offers a unique and incredibly beautiful design with minimal care and low water requirement in the green spaces (Safari and Kazemi, 2015a). If used scarcely and as a background, by establishing the principles of unity, these plants reduce distress and anxiety due to the high diversity of elements; and, they have the ability to connect irrelevant elements, and soften the edges and sharp angles of the objects in green space designs. Ground covering plants are the best options for reductions of ups and downs and remove the uniformity in the green spaces, and at the same time, they can influence the spatial perception of the design, for example, depending on their color and texture, make spaces smaller or larger than reality (Safari and Kazemi, 2016). Even in some cases, some positive plant associations within green spaces may appear, including improved plant performance quality and water use efficiency of other plants due to their positive neighboring effects (Butler and Orians, 2011). The use of other living mulches may help their adjacent ornamental trees and shrubs to develop deeper root systems and their access to the resources may become easier (Mackenzie, 2003). Razzaghmanesh *et al*. (2014) in a green roof study in Australia found that the ground cover plant species of *Carpobrotus rossii* could tolerate high temperatures and dry weather in South Australia; hence, it could efficiently use water compared to the other plant species used in that study. In arid regions, the soil temperature is important to provide a suitable environment for plant establishment in different green space types (Kazemi and Mohorko, 2017). Very high and low temperatures have bad effects on the root growth of the plants (Ghaemi Nia, 2011). Also, higher temperatures in the soil can destroy the plant fibrous roots and may cause tension in the root systems (Nasrollahzade Asl and Dast Parjin, 2015). In general, balancing the soil temperature in extreme temperature regimes can be beneficial for agriculture and urban green space development (Nasrollahzade Asl and Dast Parjin, 2015). Previous studies, mainly on non-living mulches, also have shown that a variety of organic and inorganic mulches can assist in balancing the temperature in root zone of the plants in green spaces in different seasons of the year (Steward *et al*, 2003; Singer and Martin, 2008; Kazemi and Safari, 2018). According to the results of this study, the use of different living and non-living mulch had different effects on soil temperature. In summer, *Ferankenia* sp. significantly reduced soil temperature at 5 cm depth compared to the control treatment. However, in this season, at 15 cm depth, the soil covered with *Carpobrotus rossii* and lawn was recorded to have the lowest temperature compared to the control and other experimental treatments. In the two cold seasons of the year (autumn and winter), the soil covered with *Ferankenia* sp., turfgrass clipping, and wood chips, *Vinca minor* and rubble had higher temperatures at 5 cm depth than the control soil. The use of two inorganic mulches of scoria and rubble and the organic mulch of wood chips and *Vinca minor* at 15 cm depth increased the soil temperature compared to the control bare soil. From an agricultural perspective, the soil temperature has a greater impact on plant growth than ambient temperature (Fan *et al*., 2012; Gan *et al*. 2013). The soil temperature variations are related to the method of the mulch usage and the climatic conditions of the region (Komariah *et al*., 2011). The soil temperature changes are influenced by some various factors when applying the mulches to the soil surface. It should be noted that the cooling or heating effects of mulches depend on their ingredients and the light conditions (Ham *et al*. 1993). The results of this study showed that generally use of inorganic non-living mulches was more effective in increasing the soil temperature than the other treatments. An inorganic mulch such as polyethylene increased the minimum and maximum soil temperature, however, the organic mulches reduce the maximum soil temperature and increase the minimum soil temperature (Pramanik *et al*., 2015). In this study, two mulches of wood chips and sawdust balanced the soil temperature in different seasons of the year in addition to maintaining the soil moisture during the experiment. The straw mulch of different plants kept lower temperatures under the soil than that under the inorganic or synthetic mulches (Fan *et al*., 2012). These results are also in agreement with the results of our study. Two living mulches of *Ferankenia* sp. and *Vinca minor* were also able to raise soil temperature by 2 degrees centigrade in winter compared to the control non-mulched soil. Other researchers have also confirmed the different effects of various types of mulches on soil temperatures. Abdul Kader *et al*. (2017) found that the use of mulches of straw, grass, paper, and plastic at the soil surface reduced the soil temperature at 5 cm depths by 2 degrees compared to the control treatment. This decrease in temperature was also recorded at the depths of 15 and 25 cm to 0.5 °C. The soil under the straw and plastic mulch also retained more moisture content at 5 and 15 cm depths than the other treatments and the bare soil. Also, at 25 cm soil depth, the paper mulch performed better in maintaining soil moisture than the other treatments. In another study, the use of different types of mulches at the soil surface had different effects on soil temperature. The use of polyethylene mulch increased the soil temperature at 5 and 10 cm about 6 and 4 °C, respectively. Plants in the soil covered with polyethylene mulch and rice straw performed better than the other plants in the experiment (Ramakrishna *et al*., 2006). The use of organic and inorganic mulches increased soil temperature in January compared to that in the control treatments. According to the material of each mulch, the intensity of its impact on soil temperature varies. The use of two mulch types of sawdust and rice straw on the soil surface increased the soil temperature compared to the control treatment (Rachel *et al*., 2018). In another study, it was found that among different types of organic mulches such as rice straw, sorghum straw, sesame straw, Sudan grass, the sesame straw mulch retains more soil moisture (Teame *et al*., 2017). Kamal and Singh (2011) confirmed that the use of polyethylene mulch on soil surface increased soil temperature from 2.2 to 3.4 °C. The differences in the results of these studies on soil temperature of different mulches depending on their materials are consistent with the results of our study. In another study, the use of different types of organic and inorganic mulches increased the soil moisture compared to the control treatment. Also, the use of mulch on the soil surface caused a soil temperature balance in different months of the study. It is also noteworthy that the rate of temperature change on the soil differs depending on the mulch type (Acharryya *et al*., 2019). Non-living mulches especially sawdust and woodchips in this study reduced the soil temperature and evaporation from the soil surfaces by creating a barrier at the soil surface and reflection of solar radiation instead of transferring the heat energy into the soil depth; hence, with less evaporation from the soil surface, more moisture could be retained in the soil, which can remove the need for re-watering in shorter intervals; and can cause an improved water use efficiency in landscape and agricultural plantings (Safari *et al*., 2015b). This phenomenon was also evident in the current study. To balance the temperature and maintain the soil moisture throughout the different seasons, the sawdust and wood chips mulch had more effective roles, while the use of gravel mulch increased the soil temperature. Other studies have shown that the use of straw mulch at the soil surface balanced the soil temperature changes. The soil temperature fluctuations are correlated with the soil energy balance mechanisms. This mechanism is affected by solar radiation, the soil temperature, the sensible and latent heat fluxes between the mulched and the bare soil treatments (Komariah *et al*., 2011). This phenomenon occurs due to the interaction of a high reflectance of the solar radiation and a low thermal conductivity between the mulches and the soil surface (Awe *et al*., 2014), and also the low-temperature capacity of the mulches (Awe *et al*, 2014; Abdul Kader *et al*., 2017), which probably causes a balance in the soil temperature after using these types of mulches (Fourie and Freitag, 2010). Soil mulching is an effective way to retain soil water and increase soil temperature in annual and perennial plants (Zegada-Lizarazuand and Berliner, 2011); because the functional activity of the roots is strongly affected by soil temperature changes. The straw mulch improves the root growth of crops, leads to better root growth and provides the carbon and the energy for the use of soil microorganisms by balancing some severe fluctuations in soil humidity and temperature (Ghosh *et al*., 2006; Cai *et al*., 2015). By modifying the hydrothermal regime in the root growth zone, the soil moisture retention increases and finally the weeds will decrease, thereby, the productivity of the soil increases (Singh *et al*., 2011). In addition, mulches provide a combination of the optimum soil temperature and moisture content, resulting in an increased soil microbial activity (Kaschuk *et al*., 2010). An experiment also showed that mulch-covered soil affected the arthropod populations. The population of some arthropods in the soil covered with dried alfalfa mulch increased to almost twice (Dudas *et al*., 2016). The mulch on the soil surface prolongs the process of evaporation from the soil surface, which results in more water remaining in the soil for a longer period of time (Safari *et al*., 2015_b). Due to the existence of sufficient moisture in the soil, the soil surface temperature will also decrease, which illustrates the role of the moisture in balancing the soil temperature (Ngosong *et al*., 2019). Soil moisture also plays a role as a deterrent buffer and prevents soil from rapid temperature changes caused by atmospheric temperature changes. Further, due to the heat of evaporation of water, the presence of water in the soil in summer has a cooling effect on soil temperature (Alizade, 2008). In other experiments, using mulches increased the subsoil moisture (Burt *et al*., 2002). In our experiment, the temperature of the soil covered with wood chips mulch increased during the two cold seasons of the year and decreased in the two warm seasons of the year compared to the control treatment. The results of soil moisture content also showed that the moisture content in the underlying soil covered with this mulch was higher than that in the other treatments during the whole year. Retaining the soil moisture by this mulch in the soil might have played an important role in balancing the temperature in different seasons of the year. It is also noted that *Ferankenia* sp., was able to increase the soil temperature in cold seasons compared to the control treatment despite the low amount of the soil moisture. The high density of the stems of this plant resulted in a dense cover on the soil surface, that possibly caused an increase in the temperature during the cold seasons of the year due to the lack of heat transfer from the underlying soil to the cold air due to this uniform and dense cover. The high amount of moisture in the soil under the mulch is also likely due to reduced erosion and evaporation from the soil surface and suppression of high soil temperature fluctuations (Pande *et al*., 2005). Therefore, mulch usage is classified as an effective method for soil preservation (Smets *et al*., 2008). All in all, mulches protect and enhance the soil quality in the green space by covering the soil surface. Suitable soil temperatures for optimum growth rates of different plants are various (Pramanik *et al*., 2015). By considering different types of organic and inorganic mulches and ground cover plants in this study, considering the influence of these mulches on soil moisture and temperature and the unique properties of these mulch materials, the appropriate mulches can be selected and used for cultivation of different plants in green spaces and under different environmental conditions. Organic non-living mulches balance the soil moisture and temperature, decompose and become part of the soil, increase the soil nutrients, which are effective in improving soil physical and chemical properties, and thereby, improve the plants' growth. However, it should be noted that these mulch types need replacement (Pramanik *et al*., 2015). Also comparing the turfgrass mulch, red pumice and wood chips it was identified that wood chips mulch had better aesthetic performance than the other two types of mulches (Nazemi Rafi *et al*, 2020). Inorganic non-living mulches affect the soil temperature. Light color stones can reflex the heat of sunlight to the plants that cause plant damages. In addition, this mulch type has not a role in increasing soil organic matter (Pramanik *et al*., 2015). As a result, such mulch type can be used in areas in the green spaces that either require increased soil temperatures or can be used in the areas with high-temperature resistant planting designs. Ground cover plants can be planted and used as living mulches on the soil surface and enhance the visual aesthetics of the green space and increase plant diversity and biodiversity in addition to the desired effects on soil moisture and temperature.

Conclusion

This study confirmed that living and non-living mulches affect the soil moisture at different seasons of the year. Therefore, understanding such temperature effects are very important for better management of urban green spaces. Especially the living mulches of *Carpobrotus* sp. and lawn had increased cooling effects compared with non-living mulches. Among the non-living mulches, sawdust and wood chips assisted the soil to retain its moisture content compared with the soil covered with other types of mulches. The mulches could decrease the irrigation intervals by increasing the soil moisture. These outcomes can assist the landscape managers operating in extreme climate conditions of arid and semi-arid regions to advance the management of soil moisture and temperatures to enhance sustainability in urban landscapes.

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