Short-term effect of oil-mulch on vegetation dynamic; Integration of ecological and remote sensing-based approaches

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Abstract

Wind erosion is one of the desertification results and is among the natural processes that mostly occur under dry conditions and high wind velocity. Using oil-mulches is one of the common methods to stabilize sand dunes. The current study aimed to investigate the short-term effects of oil-mulch on vegetation attributes (i.e., cover and diversity) and rangeland condition score (RCS) using integrated ecological and remote sensing-based approaches in arid regions of Southwestern Iran. A vegetation survey was carried out in 2019 in the oil-mulched and control area, and a remotely sensed vegetation index (MSAVI) was calculated for 2017 and 2019. The results indicate that one year after treatment, compared to the control area, vegetation cover (30 ± 17.11 vs. 17 ± 5.44 %) and litter (4.6 ± 2.18 vs. 0.94 ± 1.55 %) increased significantly in the oil-mulched area, while bare soil (65.20 ± 17.34 vs. 82.31 ± 5.84 %) decreased. Further, diversity indices (Species evenness, Shannon, and Simpson indices) declined by applying oil-mulch (88%, 63%, and 71%, respectively). The rangeland condition score was significantly higher in the oil-mulched area than in the control area (22 ± 1.86 vs. 12 ± 0.88; $P < 0.001$). Comparing MSAVI between 2017 and 2019 showed that vegetation cover increased 44.8%. Based on the results, it can be suggested that planting native palatable species in an oil-mulched area with the exclusion of livestock grazing is likely to increase the benefits of oil-mulch treatment and will lead to better rangeland condition score.

Introduction

Wind erosion, the movement of course and fine particles by wind, is among natural process that mostly occurs under dry conditions and high wind velocity (Mirhasani et al., 2019; Jarrah et al., 2020), and degrade more than one-third of the 'Earth's land surface (Fattahi et al., 2020). The wind erosion may be accelerated by anthropogenic pressures such as overgrazing rangelands, excessive clearances of native vegetation, deforestation, abandoning farmland, monoculture systems, over-harvesting vegetation, or leaving cultivated lands fallow for a long time (He et al., 2006; Chen et al., 2013), resulting in an increase in the rates of soil loss. Wind erosion decreases water quality and negatively impacts biodiversity and climate changes (Lal, 1994; Fattahi et al., 2020). In addition, the negative effects of wind erosion on soil nutrients have been reported; wind erosion may negatively affect nutrients such as nitrogen by blowing off the most fertile topsoil (Lei et al., 2019). Wind erosion may also damage young plant tissues (Zheng et al., 2020) and accelerate shrub expansion, resulting in alteration of plant community composition (Alvarez et al., 2012). Therefore, wind erosion is categorized as one of the most critical global environmental issues in recent decades.

Mulching is a common method among several methods and materials that have been evaluated to find suitable stabilizers for controlling wind erosion (Tibke, 1988; Manorama et al., 2021). Mulches are natural or artificial materials and are used to protect the soil from the damage of various factors such as wind and rain (Refahi, 2009). Oil (petroleum) mulch (hereafter oil-mulch) is one of the high-cost chemical mulches which can be sprayed over sand dunes to assist with re-vegetation (Amiraslani and Dragovich, 2011) and referes to oil products which are made of hydrocarbon mixtures and are used to cement sand particles (more details in Shojaei et al., 2020). Application or spraying of oil-mulches on the degraded and exposed soil to erosion reduces water evaporation (Chen et al., 2007), resulting in soil moisture manitenance and preventing sudden temperature changes (Ramakrishna et al., 2006). Also, oil-mulches facilitate plant establishment and growth conditions and, therefore, increase fertilization and soil productivity (Shojaei et al., 2020). For example, Jafarian (2006) reported that in the oil-mulched area in the central part of Iran in Kermen province, the germination of*Haloxylon persicum* was nearly three times greater than that found in untreated surfaces. Also, further effects of oil-mulch treatments in stabilizing sand and encouraging seed germination have been reported (Farahpour et al., 2005). In this regard, the positive effects of oil-mulches application have been reported in terms of soil organic matter, soil water holding capacity, and soil organisms' amount and activity (Pouyafar and Asgari Moghadam, 2006). However, the relative contributions of the oil-mulch treatment to vegetation diversity and condition have not received a great deal of attention, especially in arid regions.

Although the oil-mulche effects reduce by time, their application's main goals are to increase soil stability and provide an opportunity for the establishment of other biological activities such as planting and seeding (Refahi, 2009). Generally, the Iranian Ministry of oil provides the oil-mulches at no cost for the purpose of sand stabilization. The first attempt to stabilizing shifting sand dunes and combating desertification was conducted using oil-mulch on 40 ha of dunes at Hamidieh, Albaravayeh, and Albaji in Khuzestan Province in September 1959 (Amiraslani and Dragovich, 2011). Following this project's successful results, nearly 190,000 hectares of sand dunes were stabilized using oil-mulch over the 30 years, and this combat with desertification continues.

Satellite imagery and remote sensing (RS) techniques are among the popular methods to investigate vegetation cover and dynamic across extent areas such as mulched areas (i.e., Hashemimanesh and Matinfar, 2012). however, few studies have been done using RS to evaluate the effectiveness of oil-mulches treatment, especially in Iran's arid regions. Ilam province in western Iran approximately contains 2000 ha dunes area; known as the Abougovair region; 40% of this region speared using oil-mulch in 2018. While, to continue this process, there is no information about the results of oil-mulch treatment on vegetation diversity and condition yet. Therefore, the current study tried to answer these following equations:

(1): Does short-term (one-year) oil-mulch treatment increase plant diversity (richness, evenness, and diversity) and vegetation components (percent of vegetation cover, litter, and bare soil)?

(2): Does short-term (one-year) oil-mulch treatment significantly increase vegetation conditions and RCS?

(3): Do RS tools (i.e., vegetation indices) have the potential for revealing vegetation change pre- and post-oil-mulch treatments?

Materials and Methods

Study area

The study was carried out in 2658 ha of desertic arid area in the Abougovair region (extended form 32° 13' 17" to 32° 16' 56" N and 47° 43' 16" to 47° 48' 30" E), located in Dasht-Abbas town, in southern part of Ilam province, Iran (Fig. 1). In this region, sand dune (1018.6 ha), poor rangeland (1307 ha), non-rain fed (182.9 ha), and rain-fed (149.6 ha) are the main land uses, and agriculture and animal husbandry are the main occupations of the people. The mean annual precipitation, potential evapotranspiration, and temperature were 210 mm, 3857.5 mm, and 26.2 °C, respectively. The altitude in the studied area varied between 60 to 220 m above sea level, and the slope is less than 8%. The soil type in the study area is Inceptisols, based on USA classification.

The desertification in this arid region is mainly due to climatic conditions, improper extraction of groundwater, population growth, degradation of pastures and rangeland, increase in the number of livestock, and expansion of agricultural lands. To combat desertification, with the approval of the Forests, Range and Watershed Management Organization of Iran, it was decided to stabilize an area (about 400 ha) of this region using excess petroleum materials (i.e., oil-mulch). Therefore, in 2018, 8.2 ton/ha oil-mulch was sprayed to stabilize sand dunes and facilitate plant establishment.

Field vegetation sampling

The vegetation cover field data were collected using systematic-random design at the maximum growing season, April 2019. In each site, four randomly selected 200 m transects were placed, then 5 quadrates (2 × 2 m) systematically placed at 50-m intervals along the transect lines, with a total of 20 quadrates in each site. Within each quadrat, vegetation characteristics such as total percentage of canopy cover (%), bare soil (%), litter (%) and stone cover (%) were recorded. Above-ground vegetation biomass also was determined by plant cutting (1 cm above soil surface). In addition, to calculate the species diversity indices, the cover of each plant species was recorded separately.

Figure 1. The geographical location of the study area in Iran and Ilam province.

Vegetation condition

Vegetation condition referrs to the practical representation of the major successional stages of broad plant communities (Parker, 1954) and is mostly used to determine and assess the management practices and improvements (Bashari & Smith, 2010). Although, there are several approaches to determine vegetation condition such as the four-factor method (Parker, 1954), six-factor method (Dnubenmire, 1959), climax method (Parker, 1954), frequency method (Fox, 1984), and the Australian method (DPIF, 2004), the four-factor method is used frequently/repeatedly in Iran, to determine vegetation condition, compared to other mentioned methods. However, to overcome the problems of the four-factor method in arid and semi-arid regions, it was modified to the six-factor (Mesdaghi, 1998). In the current study, we use a modified six-factor method that is developed for arid and semi-arid regions of Western Iran by Faramarzi et al. (2010). This method is based on four factors including litter frequency (LF), percentage of weighted palatability classes (WPC), percentage of potential biomass production (ratio of actual biomass to potential biomass), and percentage of bare soil (as a measure of soil conservation) (Table 1).

Table 1. The score of different factors for range condition and classes of range condition scores (adapted from Faramarzi et al., 2010). BS: bare soil, LF: litter frequency, WPC: weighted palatability classes, BP: biomass production, RCS: rangeland condition score.

Species diversity measurement

To ecologically assess the mulching effects, species diversity indices were used, including species richness, species evenness, Shannon, and Simpson diversity indices based (Table 2).

Table 2. The species diversity indices used

S: number of species; H: Shannon diversity index; p_i: relative frequency; D: dominance

Remote sensing approach

Remotely sensed vegetation indices are among the main tools used in vegetation surveys (Mirzaei et al., 2015; Abdolalizadeh et al., 2020; Zarei et al., 2020). In arid and semi-arid regions, the soil brightness may accelerate the surface reflectance and causes exaggeration in vegetation cover condition; therefore, some Vegetation Indices (VIs) are developed to be used in such regions by considering the soil line parameters (slope and intercept) that are produced by regression between red and near-infrared bands in bare soil patches. In the current study, we used the Modified Soil-Adjusted Vegetation Index (MSAVI) suggested by Qi et al. (1994). The MSAVI is based on a modification of the L factor (soil adjustment factor) of the SAVI index (Soil-Adjusted Vegetation Index) that tended to make a better correction of the soil background brightness in different vegetation cover conditions. Previously, in the SAVI index, the L factor defined according to the density of the vegetation and the climatic conditions of an area (Qi et al., 1994), which replaced by its calculation based on the slope of the background soil line and other vegetation indices (NDVI and WDVI). The MSAVI vegetation index expressed as the following formula (Qi et al., 1994):

$$\frac{NIR - Red}{(NIR + Red + L)} \times (1 + L); \quad L = 1 - 2\gamma\ (NDVI \times WDVI)$$

Where;

NIR= reflectance in the near-infrared band (expressed as reflectance)

RED= reflectance in the visible red band (expressed as reflectance)

NDVI = Normalized Difference Vegetation Index ((NIR-RED)/(NIR+RED))

WDVI = Weighted Difference Vegetation Index (NIR- γRED)

γ = Slope of the background soil line

In this formula, the soil adjust factor is selected as an empirical equation to decrease with decreasing vegetation cover, as in the case in semi-arid regions (Qi et al., 1994). In addition, the L factor ranges from 0 to 1 and multiplied by two (2L) to increase the L dynamic range (Eastman, 2016).

The differencing method was used to detect spatio-temporal trend changes (increasing, decreasing and no changes) between pre- and post-mulch treatment (Singh, 1989). In this method, the digital value of the second map (i.e., MSAVI map of 2017) is subtracted from the first map (i.e., MSAVI map of 2019), pixel by pixel (Mirzaei et al., 2015). This method's results include positive, negative and zero pixels, indicating increasing, decreasing, and no changes in vegetation cover, respectively. However, this method needs to determine the change threshold, to distinguish the changing area (increasing and decreasing) from the no-change area (Fung and Ledrew, 1988). In the current study, we employed a statistical method (Mirzaei et al., 2015) based on the following equation:

$$Z = \frac{X_i - X}{S}$$

Where Xi is the numerical value of each pixel,X is the mean score of the pixels, and S is standard deviations.

Finally, to statistically compare the control and mulch treated area, we design a network of random points including 100 points in both the control and the mulch treated area (Fig. 1). The MSAVI values are extracted and analyzed (see statistical analysis section).

Statistical Analysis

The normal distribution and homoscedasticity were assessed using the Shapiro-Wilk Test and Levene's Test, respectively. To compare the vegetation characteristics (Total cover, bare soil, litter and stone cover), vegetation condition scores (BS, LF, WPC, Prod and RCS) and species diversity indices (species richness, species evenness, Shannon and Simpson diversity indices), independent Student's t-Test was used. To assess the significant difference between pre and post mulching and between the control and the mulch treatments, we used a two-way ANOVA. In this model, year (pre vs. post mulching; 2017 and 2019), treatment (control vs. mulch) and their interaction were introduced as independent variables, and vegetation cover extracted by MSAVI was introduced as the dependent variable to the model. In addition, a t-student test was conducted to detect significant differences between pre and post mulching and between control and mulch treatments. All statistical tests were performed using the SPSS var. 21.0 software.

3. Results

The results showed that gathered data satisfy assumptions of normal distribution (all $P > 0.05$) and homogeneity of variance (all $P > 0.05$) (Table 3). Based on the results, vegetation components significantly varied between control and mulch treated sites (all $P < 0.05$), in which total cover and litter increased both about 76% while bare soil decreased about 26% under mulch treated (Fig. 2). Species richness was not varied between control and mulch treated sites (t -value= -0.067 and$P$ =0.947). In contrast, species evenness, Shannon, and Simpson diversity indices were negatively affected by mulch treatment (Table 3 and Fig. 2). For example, applying mulch treatment resulted in a decline in species evenness, Shannon, and Simpson diversity indices about 88%, 63%, and 71%, respectively (Fig. 2).

Table 3. Results of normal distribution (Shapiro-Wilk Test), homoscedasticity (Levene's Test), and independent t-test between vegetation and diversity component in control and mulch treated sites. significant values are shown by bold numbers. The non-significant values in Shapiro-Wilk and Levene's tests indicate normal distribution and homogeneity in variance, respectively.

Figure 2. Mean ± SE comparison of vegetation and diversity components in control and mulch treated sites. significant differences are indicated by different letters.

All RCS parameters (BS, LF and BP) and total RCS significantly differed between control and mulch treated sites (all $P < 0.001$) while WPC was not significantly different between control and mulch treated sites (t -value= 1.226 and $P = 0.236$) (Table 4). In addition, RCS class in control and mulch treated areas were very poor and poor, respectively.

Table 4. The comparison results of RCS and their components. BS: bare soil, LF: litter frequency, WPC: weighted palatability classes, BP: biomass production, RCS: rangeland condition score. Significant values are shown by bold numbers.

Before calculating MSAVI maps of 2017 and 2019, the slope and intercept of soil lines regression were calculated by fitting a linear regression between the red and infrared bands (Table 5).

Table 5. The soil line parameters (slope and intercept) are based on a linear regression between the red (as the dependent variable) and infrared bands (as an independent variable) and good of fitness indices.

Then, the MSAVI maps of 2017 and 2019 were produced and reclassified (Fig. 3). As shown in Fig. 4, the vegetation cover significantly increased in 2019 compared to those found in 2017.

Figure 3. The vegetation cover maps based on remotely sensed MSAVI index

The results of map differencing showed that vegetation cover of extent area of studied regions was not varied (52.4%) or increased (44.8%) between 2017 and 2019; however, vegetation cover in some small areas (northwest) was decreased (2.8%) (Fig. 4).

Figure 4. Vegetation cover change monitoring using the differencing method

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Finally, two-way ANOVA results showed that years (2017 vs. 2019), treats (control vs. mulch), and their interaction had significant effects on vegetation cover value extracted by the MSAVI index (Fig. 5). Based on the results, vegetation cover was greater in 2019 than that of 2017 and also greater in the mulched site in 2019 than the controls site, while there was no difference between vegetation cover in controls and mulch sites in 2017 (Fig. 5).

Figure 5. Results of two-way ANOVA of vegetation cover extracted by MSAVI index for pre and post applying mulching. The significant differences are shown by different letters. ***, indicate significant effects at P < 0.001.

Discussion

Spraying oil-mulch significantly increases vegetation cover and litter percents while it simultaneously decreases the percent of bare soil (Table 3 and Fig. 2). These positive effects of oil-mulch treatment have probably resulted from three mechanisms include 1) stabilizing effects on sand dunes (Wuddivira et al., 2013), 2) decreasing water evaporation and preserving available soil moisture (Kowsar et al., 1969; Mulumba and Lal, 2008; Liu et al., 2020) and 3) increasing the rate of seedling survival (Akbarian and Mosavi, 2006) and germination (Farahpour et al., 2005; Jafarian, 2006). Arid and semi-arid regions are known as water-limited areas (Shojaei et al., 2020), and thereby, soil moisture is an important factor that controls the seedling germination, survival, and growth (Zhenghu et al., 2004). It has been reported that oil-mulch treatment could provide more benefits in encouraging seed germination than other tested sand stabilizers (Farahpour et al., 2005), mainly due to the presence of more soil moisture and temperature. In addition, the positive effects associated with the use of oil-mulch were reported in terms of soil organic matter, soil water holding capacity, and the amount and activity of soil organisms (Pouyafar and Asgari Moghadam, 2006; Hashemimanesh and Matinfar, 2012).

Although it is not expected that after short-term oil-mulch treatment, an increase occurrs in amount of plant litter, our finding may even indicate negative effects (i.e., drying effects on the plants) of oil-mulch treatment on the initial vegetation. On the other hand, however, the increase in litter accumulation may increase along time after oil-mulch treatment, resulting in an increase in soil fertility, infiltration, and stability as well as a decline in soil erosion (Shojaei et al., 2020). The positive effects of plant litter in increasing soil water holding capacity, water retention, and moisture loss reduction from evaporation were also reported (El-Kader et al., 2010; Simmons et al., 2010; Rodrigo-Comino et al., 2020). Similarly, a positive linear effect of mulch application rate on soil organic matter concentration was reported by Duiker and Lal (1999). In addition, an increase in litter accumulation may increase the hydraulic conductivity of soil stability (Moazzemi et al., 2013) and improve the specific mass and soil porosity (Shojaei et al., 2020), increasing the strength of the soil surface and reduction of the soil erosion (Singh and Agrawal, 2008; Mulumba and Lal, 2008).

Our results indicate that the short-term application of oil-mulch significantly decreases bare soil percent (Table 3 and Fig. 2). In line with this result, Hashemimanesh and Matinfar (2012) reported that the petroleum mulch project in southwestern Iran decreased sand dune areas from 66.4% in 1991 to 56% in 2002. Similarly, Azoogh et al. (2018) results indicated that petroleum mulching-biological fixation practices promoted the restoration of vegetation cover in the sand dunes. Therefore, this result is likely explained by the positive effects of oil-mulch treatment on vegetation cover and litter.

Also, results indicate that species diversity and evenness are negatively, and species richness is neutrally related to oil-mulch treatment. Generally, in a short-term oil-mulch application, negative (Karami khaniki, 2009; Adeli, 2012; Gholami Tabasi et al., 2015) and neutral (Jafari et al., 2017) effects on vegetation diversity are reported. In addition, Gholami Tabasi et al. (2014) found that applying the plantation and oil-mulching negatively and neutrally affects vegetation attributes (i.e., cover and density) of *Astragalus squarrosus* and *Convolvolus hamadae* , respectively. In contrast, Tabasi (2014) indicated that oil-mulch did not negatively affect plants; however, it may increase vigor and biomass in the plant's stands. Therefore, it seems that these negative effects of oil-mulch treatment are likely related to the drying effects of oil-mulch on the plants, especially in the early period after the application of oil-mulches. While, by the passage of time since mulching, plant diversity could increase in the mulch-treated area even more than the control area. For example, Khalilimoghadam and Bodaghabadi (2020) reported that 'Shannon's diversity index increased over the time period of 30–40 years compared to the initial years of sand dunes stabilization (< 5 years).

The current study was designed to fill the gap in our knowledge about oil-mulching effects on RCS. The results showed that RCS increased one year after the oil-mulch treatment, i.e., it changes from very poor class (RCS = 12) to poor class (RCS = 22) in control and oil-mulch treated. In this study, RCS was determined based on four parameters, including BS: bare soil, LF: litter frequency, WPC: weighted palatability classes, BP: biomass production (Table 1). As shown previously, results demonstrate that short term oil-mulching increase vegetation cover and litter and decrease bare soil percent. In addition, a strong positive association between vegetation cover and biomass production was reported (Flombaum and Sala, 2007; Pordel et al., 2018; Louhaichi et al., 2018). Therefore, it can be said that oil-mulch treatment leads to better RCS by affecting vegetation attributes (i.e., cover, biomass). On the other hand, however, among all RCS parameters, only WPC was not significantly different between control and mulch treated sites. This difference mainly related to non- or low-palatable plants that reintroduced and planted with mulching such as*Citrullus colocynthis* L., *Prosopis juliflora* (Sw.) DC.,*Eucalyptus camaldulensis* and *Ziziphus spina-christi* (L.) Desf. Considering that native species had a greater chance to survive, establish and grow in such arid condition (Jafari et al., 2018; Bazgir et al., 2020), the management practices after oil-mulch treatment (i.e., selection of suitable plants) had a vital role in achieving successful results.

To compare the vegetation cover pre and post oil-mulch treatment (one year before (2017) and one year after (2019), we used the remotely sensed vegetation index extracted based on Landsat 8 OLI imagery (i.e., MSAVI). Results demonstrated that vegetation cover greatly increased in 2019 compared to those found in 2017, indicating positive effects of oil-mulching and confirmed our previous results. This increase in vegetation cover compared to the control area mainly resulted from two reasons, including 1) positive effects of oil-mulch treatment and 2) increased amount of precipitation in 2019 compared to 2017 (210.7 and 638.8 mm, respectively). As previously noted, soil moisture and instability are the main limitations in an arid area, and any factor like oil-mulch treatment which increases the soil moisture will lead to an increase in vegetation cover (Akbarian and Mosavi, 2006; Mulumba and Lal, 2008; Wuddivira et al., 2013; Shojaei et al., 2020). This conclusion could be confirmed by the two-way ANOVA results that revealed that vegetation cover was greater for 2019 than 2017 and in the oil-mulch treated site in 2019 compared to the correspondence control site (Fig. 5). In addition, no significant difference was observed between controls and mulch sites in 2017, highlighting the importance of oil-mulch treatment. Therefore, the greater vegetation cover in 2019 synergically responded to the joint effects of oil-mulching and an increase in precipitation.

Conclusion

The increase in soil moisture and stabilizing sand dunes is the primary need/requisite to establish vegetation in arid regions, and short- and long-term monitoring of management practices could provide better insight into choosing the method. In the current study, an integration of ecological and remotely sensed approaches was used to monitor the short-term vegetation attributes and diversity and RCS.

Our results highlight the positive short-term effects of oil-mulch treatment on vegetation cover and RCS, while it is challenged by the negative effects of oil-mulch treatment on diversity. In addition, using the native palatable species to planting in an oil-mulched area with the exclusion of livestock grazing is likely to increase the benefits of oil-mulch treatment resulted in better RCS. Finally, we indicate the high potential of remotely sensed vegetation index in order to extend the monitoring of rehabilitation schemes.

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Conflict of Interest

The authors have no conflict of interest to declare.

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Table 1. The score of different factors for range condition and classes of range condition scores (adapted from Faramarzi et al., 2010). BS: bare soil, LF: litter frequency, WPC: weighted palatability classes, BP: biomass production, RCS: rangeland condition score.

Rangeland condition factors

	BS (%)	BS (%)	LF (%)	WPC (%)
Min-Max	0 - 100	0 - 100	0 - 100	100 – 300

Score	0 - 20	0 - 20	0 - 10	0 – 20
Sum score of RCS and rangeland condition	Sum score of RCS and rangeland condition	56-65	56-65	56-65
		46-55	46-55	46-55
		34-45	34-45	34-45
		22-33	22-33	22-33
		11-21	11-21	11-21
		0-10	0-10	0-10

Table 2. The species diversity indices used

Diversity components	Equation	References
Richness	S = Number of species	Magurran, 2013
Evenness	e^H/S	Buzas and Gibson, 1969
Shannon diversity	H = $p_i . ln . p_i$	Shannon and Weaner, 1963
Simpson diversity	1-*D*	Simpson, 1949

S: number of species; H: Shannon diversity index; p_i: relative frequency; D: dominance

Table 3. Results of normal distribution (Shapiro-Wilk Test), homoscedasticity (Levene's Test), and independent t-test between vegetation and diversity component in control and mulch treated sites. significant values are shown by bold numbers. The non-significant values in Shapiro-Wilk and Levene's tests indicate normal distribution and homogeneity in variance, respectively.

Category	Components	Shapiro-Wilk Test	Shapiro-Wilk Test	Levene's Test	Levene's Test	t-Test	t-Test
		Statistic	*P-valve*	*F-value*	*P-valve*	*t-value*	*P-valve*
Vegetation	Total cover (%)	0.937	0.225	3.126	0.10	2.342	**0.039**
	Bare soil (%)	0.937	0.256	3.126	0.10	-2.919	**0.013**
	Litter (%)	0.910	0.085	2.398	0.141	4.16	**0.001**
Diversity	Richness	0.923	0.092	0.282	0.603	-0.067	0.947
	Evenness	0.950	0.424	1.152	0.299	-4.307	**0.001**
	Shannon	0.963	0.658	0.008	0.929	-4.775	$>$ **0.001**
	Simpson	0.957	0.536	1.033	0.324	-4.913	$>$ **0.001**

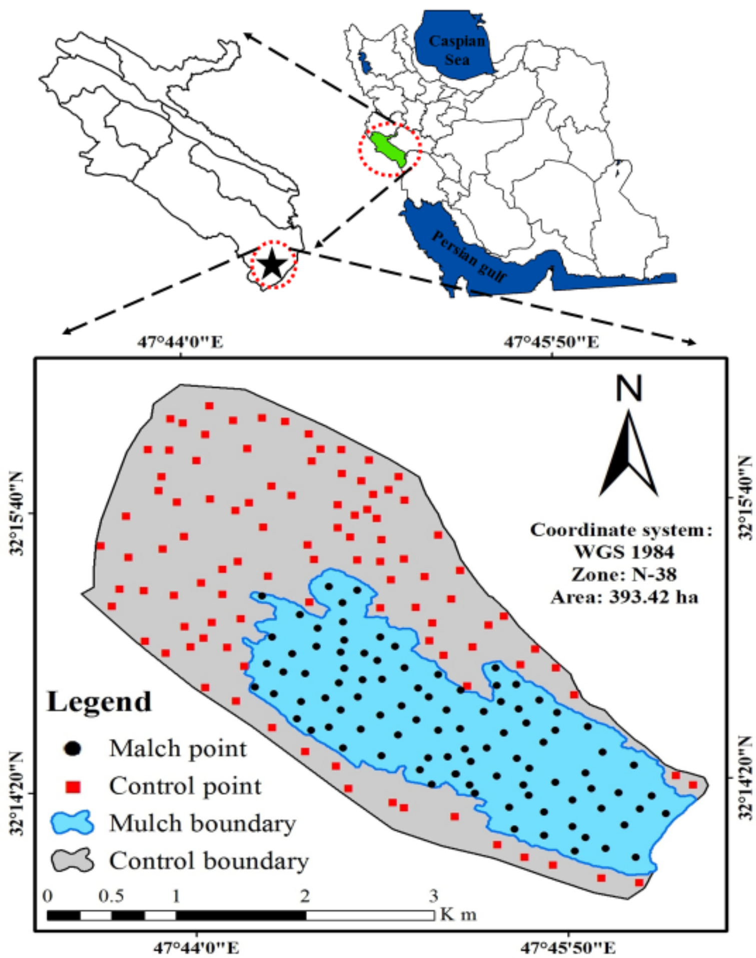
Table 4. The comparison results of RCS and their components. BS: bare soil, LF: litter frequency, WPC: weighted palatability classes, BP: biomass production, RCS: rangeland condition score. Significant values are shown by bold numbers.

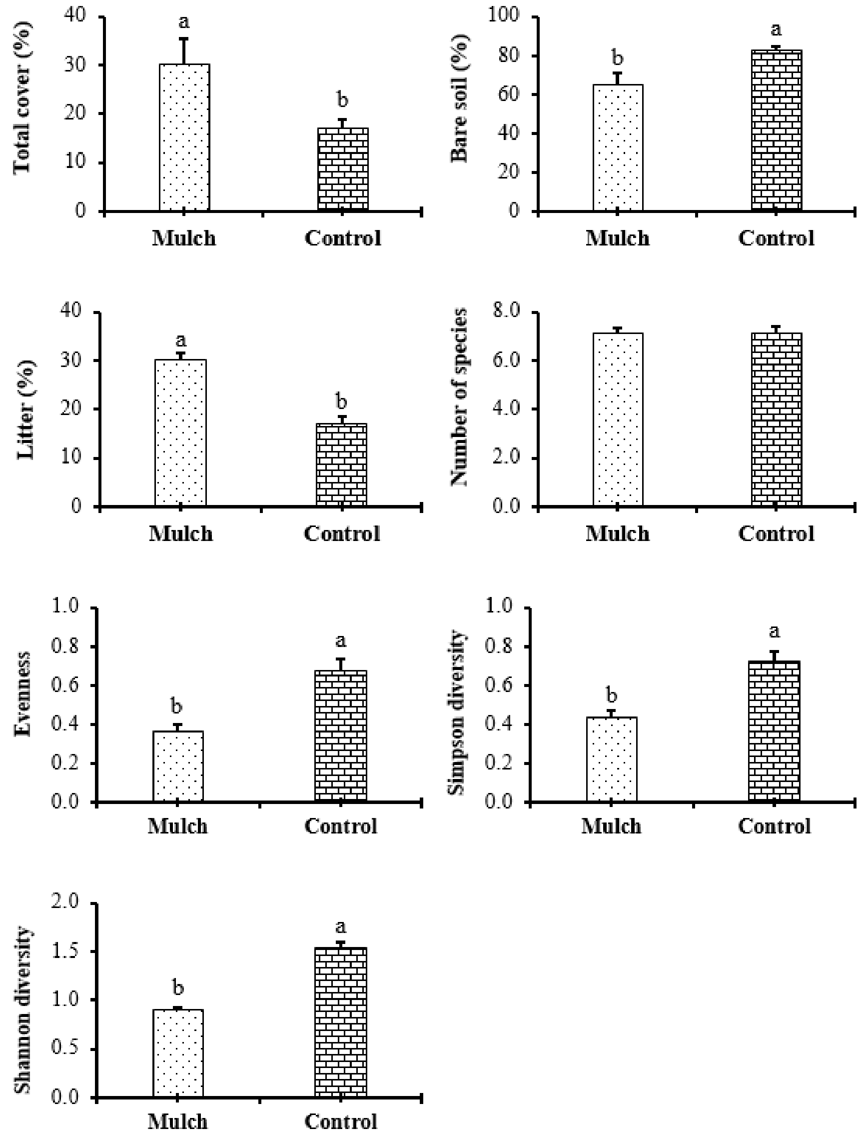
Parameters	Mulch	Mulch	Control	Control	t-value	P
	Value	Score	Value	Score		
BS (%)	55.2	8.69	77.15	4.5	3.414	$>$ **0.001**
LF (%)	4.6	0.92	0.75	0.15	4.676	$>$ **0.001**
WPC (%)	86.17	0.67	38.31	0.00	1.226	0.236
BP (%)	71.0	11.70	44.3	7.30	5.359	$>$ **0.001**
RCS score		22		12	5.351	$>$ **0.001**
RCS class	Poor	Poor	Very poor	Very poor		

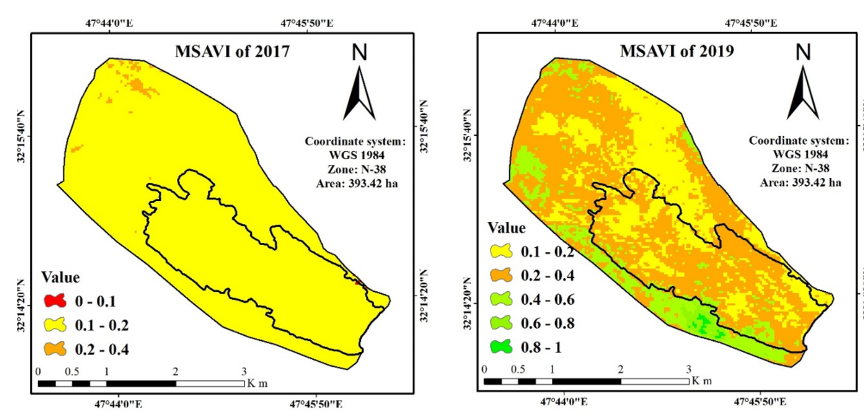
Table 5. The soil line parameters (slope and intercept) are based on a linear regression between the red (as

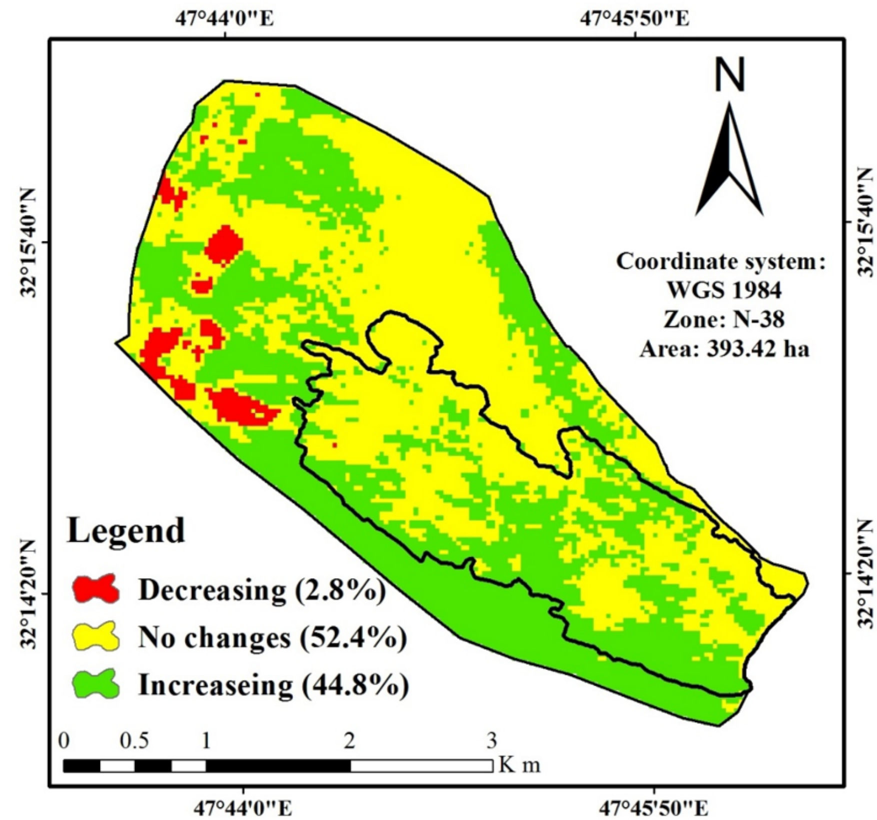
the dependent variable) and infrared bands (as an independent variable) and good of fitness indices.

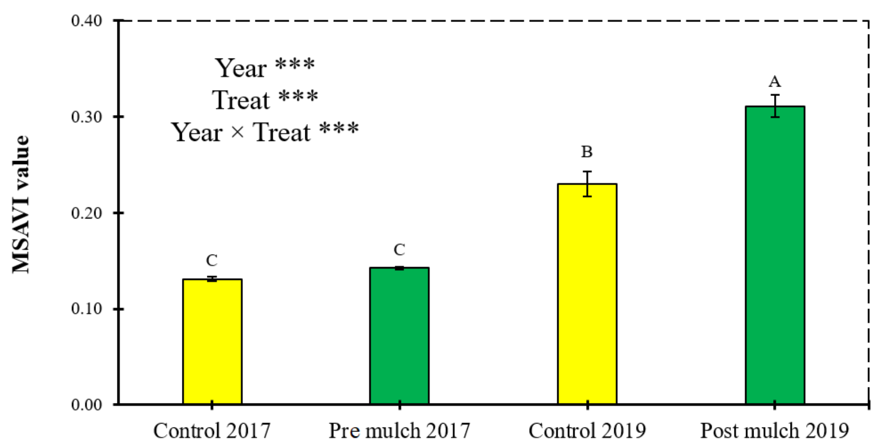
Image year	Slope (γ)	Intercept	R^2	S.E. of estimate
2017	0.882236	-0.037544	0.994	0.006
2019	0.796376	-0.038196	0.962	0.012




Total cover (%)
Bare soil (%)
Litter (%)
Number of species
Evenness
Simpson diversity
Shannon diversity
Mulch
Control
a
b


MSAVI of 2017
MSAVI of 2019
N
Coordinate system:
WGS 1984
Zone: N-38
Area: 393.42 ha
Value
0 - 0.1
0.1 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1
47°44'0"E
47°45'50"E
32°15'40"N
32°14'20"N
K m


47°44'0"E
47°45'50"E
32°15'40"N
32°14'20"N
N
Coordinate system:
WGS 1984
Zone: N-38
Area: 393.42 ha
Legend
Decreasing (2.8%)
No changes (52.4%)
Increaseing (44.8%)
0 0.5 1 2 3
K m


Year ***
Treat ***
Year × Treat ***
MSAVI value
0.40
0.30
0.20
0.10
0.00
C
C
B
A
Control 2017
Pre mulch 2017
Control 2019
Post mulch 2019