The effect of cellulose polymer mulch on sand stabilization

Seyyed Morteza Abtahi[1)]

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Abstract: In this study, the effectiveness of cellulose polymer mulch (CPM) on sand stabilization was evaluated in two kinds of experiment: laboratory and field. Erodibility index in wind tunnel, compressive strength, abrasion resistance, impact resistance and the thickness of layers formed using a solution with various CPM content were measured in the laboratory experiment. According to the results obtained in this part of study, the highest impact resistance and the least erodibility index value were achieved when using the solution with a concentration of 30 % (30 % CPM and 70 % water). In the field experiments, the resistance of mulch used in the amount of 10 and 5 t/ha in sand dunes of Kashan deserts (central Iran) and its impact on the survival and establishment of seedlings and cuttings of *Calligonum* were investigated over a year. The results showed that CPM has a positive effect on plant establishment. The highest survival was reported for 10 t/ha of mulch treatment in planting with seedlings method.

Keywords: biological reclamation, cellulose polymer mulch, sand dunes, wind erosion, wind tunnel.

Wpływ polimerowego mulczu celulozowego na stabilizację piasku

Streszczenie: Oceniano skuteczność roztworów polimerowego mulczu celulozowego (CPM) stosowanego do stabilizacji piasku. Przeprowadzono dwa rodzaje badań: w laboratorium i w terenie. W laboratorium mierzono wskaźnik wytrzymałości w tunelu aerodynamicznym, wytrzymałość na ściskanie, odporność na ścieranie, odporność na uderzenia i grubość warstw utworzonych po zastosowaniu roztworów o różnych stężeniach CPM. Najwyższą odporność na uderzenia i najmniejszą wartość wskaźnika erozji uzyskano w przypadku roztworów o stężeniu 30 % (30 % CPM i 70 % wody). W ramach badań terenowych, przez rok badano odporność mulczu dozowanego w ilości 10 i 5 t/ha na wydmach pustyni Kashan (centralny Iran) oraz jego wpływ na przeżycie i rozwój sadzonek *Calligonum*. Wyniki dowiodły, że CPM ma pozytywny wpływ na badane rośliny, a najdłuższe przeżycie sadzonek odnotowano po zastosowaniu mulczu w ilości 10 t/ha.

Słowa kluczowe: rekultywacja biologiczna, polimerowy mulcz celulozowy, wydmy, erozja wiatrowa, tunel aerodynamiczny.

Dry and extra-dry conditions over a large part of Iran with the rainfall less than 150 mm per year have caused that about 80 million hectares of the area of Iran be under desert, sand dunes and areas with low vegetation covering. Moreover, about 12 million hectares are occupied by sand dunes of which about 6 million hectares are active sand dunes, which threaten towns and villages, economic and military centers and roads [1]. The damage dimensions are different depending on the severity of wind damage and durability, as well as the amount and type of particles carried by the wind. The wind blowing the sand causes numerous losses such as severe degradation of crops, buildings, and facilities, and the erosion of the soil hunks and clay materials create dust [2]. Another example of this is how a substantial part of the Qinghai-Tibet' railway was buried under sand in 2006 [3]. Wind erosion is identified as one of the most serious environmental threats in many arid regions [4, 5].

Practically, executive and management activities for wind erosion control in Iran began in 1959, and it involved the implementation of 40 hectares of biological testing operations to control the sands in Albaji region, Ahvaz. It continued until 2005 by implementing 6.46 million hectares of seedling planting, mulching, seeding, constructing the biotic and abiotic windbreakers, exclusion and wastewater management in the desert provinces [6].

Sand stabilization methods are various; however, they are based on the continuity between the sand particles and establishing the vegetation. Various techniques can be used for sand control such as creating the windbreaks, mulching, and using straw and emulsified bitumen mulch, covering the ground surface and vegetation establishment. Generally, these techniques can be used in combination to achieve better and more stable results [1]. Since the oil mulches are bitumen-like, their

1) Research Division of Natural Resources, Isfahan Agricultural and Natural Resources and Education Center, AREEO, Isfahan, Iran.

Author for correspondence; e-mail: m-abtahi@areeo.ac.ir

dark color has high heat absorption coefficient. Extensively, these mulches make the region warmer than the surroundings which in turn affects the energy balance of the region and cause the rise of wind. On the other hand, abraded and damaged mulches disperse in the environment and their dust also leads to environmental pollution and causes problems in the growth and development of plants, and it affects animal and human health. In addition, the mulches entering the groundwater are considered as a major threat to groundwater pollution [7]. The non-oil mulches are all materials or coatings that are used in order to prevent evaporation of water, weeds, and generally to increase soil productivity. Non-oil mulches include a variety of synthetic chemicals' polymers, lime, gypsum, vegetable balsams, and other natural chemicals [1].

Non-petroleum mulches such as bentonite and kaolinite clays [8], grit coatings [9], gravel particles [10], moisture-absorbing materials and a Chinese non-petroleum mulch based on recovered material [11], clay mulch [12], poly-lattice polymer mulches [13] are extensively applied for sand stabilization. Heidari *et al*. [14] examined the effects of grit mulch on soil erosion and its erosion threshold velocity by preparing and placing soil trays in the wind tunnel with grit mulch in four levels: zero (control sample), 25, 50 and 75 %. Ali-Arab *et al*. [15] examined the effect of seed size, fencing and protective treatments (seedlings and mulch protection) on the establishment, growth and survival of seedlings from seed planting of *Quercus castaneifolia* in Lowe degraded forests in Golestan province. Hazirei and Zare Ernani [16] evaluated the effect of clay-calcareous mulch on sand stabilization. Ekhtesasi *et al*. [17] compared the chemical, biological, and mineral mulches for sand stabilization. Maleki *et al*. [18] investigated experimentally the wind erosion of biocemented soil samples in a wind tunnel under the condition of wind velocity of 45 km/h.

The mulch examined in this study is biodegradable cellulose polymer mulch (CPM) obtained from extensive research by scholars of Sciences Department of Maleke Ashtar University in Isfahan.

The hypothesis of this study was that CPM can be replaced with oil mulch. The objectives of this research were to confirm the effect of CPM in reducing wind erosion and sand movement and to investigate the best planting and CPM amount for sand stabilization in Kashan desert of Iran.

EXPERIMENTAL PART

Materials

The mulch used in this study was a white and biodegradable liquid of modified cellulose which is water-soluble having a quotable jellifying ability. The biocompatible stabilizer compounds were prepared through chemical enriching of cellulosic residues and converting them into the compounds with the ability of gelling in water. By dissolving a certain amount of the obtained compound in water, the stabilizing and nutrifying liquid is achieved. The solution quickly turns into an adhesive gel after it is sprayed on the surface of soil or sand dunes, which in turn attaches soil particles together and creates a protective layer tolerating them against movement.

Methods of testing

The soil erodibility parameters, such as impact resistance, compressive strength, crust thickness, abrasion resistance and wind erodibility index (using wind tunnel) were measured on mulched samples. For this purpose, sand samples from sand dunes of the deserts of Kashan (central Iran) were collected from three directions, windward slopes, the top and leeward slopes and a single soil sample was prepared combining the samples. The textural class was sandy (12 % of clay, 2 % of silt and 86 % of sand) with electrical conductivity E_c = 0.42 dS/m and pH = 9. Soils were poured into metal trays according to the wind tunnel dimensions of 4 (depth) x 30 (width) x 100 cm (length) with a smooth and uniform surface. The solutions of 10, 20, 30 or 50 % CPM in distilled water together with pure distilled water as a control sample were selected for testing. The solutions of CPM were evenly sprayed by the sprinkler on the soils within the trays. The treatments became completely dry after seven days after mulching. A completely randomized statistical design with three replications was used to compare the treatments with different CPM concentrations.

The trays were placed inside the wind tunnel so that the tested surface was matched with the bottom of tunnel. The treatment tray was exposed to the wind with 9 m/s speed by the height of 20 cm for 15 min. Finally, the amount of sediment collected from the surface of the treatment (30 x 100 cm^2) was weighed and data were converted to g/m^2 at 1 h.

Normality of the data was analyzed using Kolmogorov--Smirnov test [19]. The Duncan test [20] was employed for comparison of means of the parameters with normal distribution while the Kruskal-Wallis test [20] was used for the parameters with non-normal distribution or having the rating phenomena as non-parametric tests.

The compressive strength of the layer formed on the soil surface of each treatment in 10 points of the tray was measured with the same distribution. A penetrometer with a cylindrical bar with a flat tip to show the amount of force needed to dive the bar into the soil was used.

As a result of mulching, a concrete layer is created on the soil surface. The thickness of the layer was measured from 10 points of the trays using a Kolis. The loose soils attached to the substrate were removed by scrubbing prior to measurement.

The impact resistance of the treatments was measured by dropping vertically a 150 g weight columnar steel bar with a sharp tip from a height of one meter to the trays

T a b l e 1. Impact resistance classification by dropping the indicator bar (according to [16])

Requirements	Class
The soil layer would not crush by dropping the bar	1.00
Dropping the bar will crush the layer and the bar will go down into the soil up to 1 cm of depth	0.75
Dropping the bar will crush the layer and the bar will go down into the soil up to 1–2 cm of depth	0.50
Dropping the bar will crush the layer and the bar will go down into the soil up to 2–4 cm of depth	0.25
Dropping the bar will crush the layer and the bar will go down into the soil ≥4 cm of depth	0

T a b l e 2. Classification of abrasion resistance by sandpaper method (according to [16])

Requirements	Class
More than 30 times rubbing the sandpaper with a roughness of 100 μm cause layer crushed and the particles are separated	1.00
The layer is crushed and the particles are separated by rubbing the sandpaper with a roughness of 100 μm, 15–30 times	0.75
The layer is crushed and the particles are separated by rubbing the sandpaper with a roughness of 100 μm, 5–15 times	0.50
The layer is crushed and the particles are separated by rubbing the sandpaper with a roughness of 100 μm, 2–5 times	0.25
The layer is crushed and the particles are separated by rubbing the sandpaper with a roughness of 100 μm, 1–2 times	0

surface in 10 different locations. The impact resistance of each treatment was classified as shown in Table 1.

Frictional resistance of the formed layers was measured by rubbing a sandpaper with medium roughness (100 μm) and compressive force of 4.9 N on their surface continuously until the layers were abraded and reached the loose soil surface. The number of times of rubbing sandpaper on the soil surface until eroding the layer was counted and recorded at 10 points. The abrasion resistance of each tested sample was also ranked using the criteria listed in Table 2.

Fig. 1. Study area in the desert of Kashan in central Iran

In the field phase, CPM solutions were moved by a tanker near to several active sand dunes exposed to strong winds. The geographical coordinates of the study area in located between longitudes from 51° 25′ to 52° 00′ and latitudes from 33° 45′ to 34° 25′ as it is shown in Fig. 1. In addition, the mean annual precipitation is 124 mm and the annual maximum and minimum absolute temperature are 48 °C and -14 °C, respectively [21].

The project was implemented based on a split plot in the form of the basic randomized complete block design. The treatments were included in the planting procedure (including cuttings and seedlings) using the mulch solution amount 0 t/ha (control), 5 or 10 t/ha. The measured parameters were: temperature (15 cm deep), moisture (15 cm deep) using time domain reflectometry (TDR) device (model ΔAHH2), plant survival and rate of erosion wind (by wood markers installed). The planting distance was 3 x 3 m in 7 rows (repetition) and 7 columns (the number of seedlings per repetition). For example, the number of plants (*Calligonum*) grown in each mulch treatment was equal to 49 bases, with totally 147 bases in different three mulch treatments. In order to create a smooth and balanced surface, all the margins of the region were covered by mulch. The test units were single sand dunes so that a 2000 m^2 dune was considered for each mulch treatment (6000 m^2 total area). The thickness of crust formed on the sand dune surface after the mulch solution treatment in amount of 10 t/ha was equal to 9 mm and after the treatment with 5 t/ha it was equal to 4 mm. Finally, data collected in the SAS environment was analyzed by ANOVA

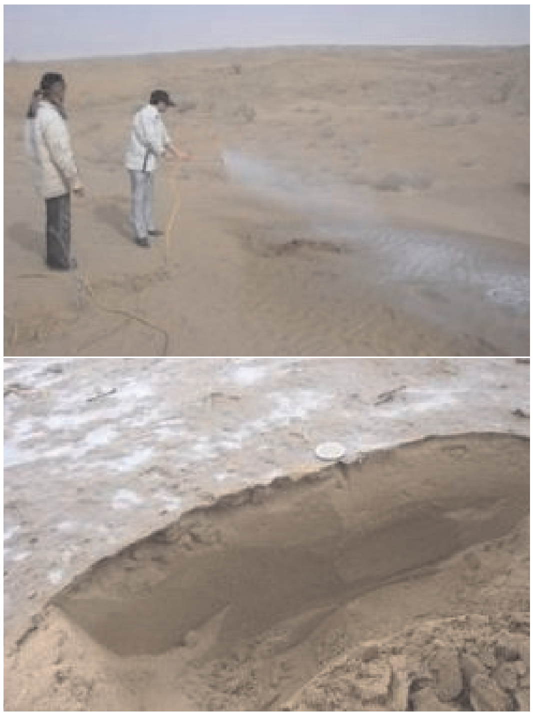

Fig. 2. Mulch spray using a tractor mounted sprayer

(analysis of variance), then the means comparison was performed using Duncan's test at 5 % significance level, and the best planting and mulch solution amounts were specified.

The mulch required was sent to the region by two 5-ton mixers. Then, it was sprayed using a tractor mounted sprayer with 0.8 mm nozzle, as it is shown in Fig. 2.

RESULTS AND DISCUSSION

Laboratory experiments

The results of ANOVA for the compressive strength and crust thickness obtained after the use of solutions with various CPM contents are listed in Table 3. This analysis showed that there was a significant difference at 1 % between mulch treatments in terms of compressive strength and crust thickness.

T a b l e 3. Results of variance analysis (ANOVA) of compressive strength and crust thickness after use of solutions with various CPM content

Source of variation	Degree of freedom	Mean square	
		compressive strength kg/cm²	crust thickness mm
Mulch	3	4.31**)	30.002**)
Error	36	0.032	0.057
Sum	39	–	–

**) – significant at a significance level of 1 %.

The means comparison of the compressive strength, crust thickness, abrasion resistance and impact resistance done after use of solutions with various CPM contents are presented in Table 4.

The Kruskal-Wallis test results showed that there was a significant difference at 5 % between mulch treatments in terms of abrasion resistance and impact resistance. The results of ratings comparison show that the highest abrasion resistance was observed for solution with 50 % of CPM which had not any significant difference with solution with 30 % of CPM. In addition, the lowest abrasion resistance was observed for the samples with CPM content of 10 and 20 %.

The means comparison of impact resistance show that the highest value of this parameter was observed for solutions with 50 % CPM and the lowest impact resistance was determined for the sample with 10 % CPM. However, there was no significant difference between the samples with other CPM percentages.

Based on the results of analysis of variance, listed in Table 5, mulch had a significant effect at 1 % level on wind erodibility index. However, no significant effect of the measured time and interaction between mulch and the time was observed.

The means comparison of wind erodibility index in wind tunnel affected by mulch treatments is shown in Fig. 3. Based on these results, the wind erodibility index for control sample (100 % of water) was significantly higher than that after mulch treatments at all three measurement times. The results also indicate that no significant difference was observed between various contents of CPM in terms of this parameter. In addition, there was no significant impact of various times on the erodibility index in any mulch treatments. The results of Hazirei and Zare Ernani [16] showed that by increasing the mulch to a certain level, the wind erodibility index decreases. In an experimental wind tunnel study on polyacrylamide polymer for wind erosion controlling, He J. *et al*. [22] concluded that applying this polymer on the soil surface had increased the wind erosion resistance capacity of the soil and in this respect, 4 g/m² of added polymer acts more effectively than 2 g/m² of polymer.

Results of the Movahedan *et al*. [23] experiments on wind erosion in a wind tunnel in wind conditions with a speed of 26 m/s showed that there was a significant difference between wind erosion of soil samples treated with

T a b l e 4. Means comparison of the compressive strength, crust thickness, abrasion resistance and impact resistance after use of solutions with various CPM content (means followed by the same letters are not significantly different)

Mulch level, %	Compressive strength, kg/cm²	Crust thickness, mm	Abrasion resistance	Impact resistance
10	0.21c	0.11d	5c	15b
20	0.22c	1.40c	15bc	18ab
30	0.48b	2.81b	25ab	22ab
50	1.60a	3.62a	35a	25a

T a b l e 5. Results of variance analysis (ANOVA) of wind erodibility index for various CPM contents in solution and times of measurements

Source of variation	Degree of freedom	Sum of squares	Mean square	Fisher test
Mulch	4	234 979.689	58 744.92	57.411**)
Time	2	289.184	9.976	0.141ns
Mulch*Time	8	1536.413	2.629	0.188ns
Error	30	30 697.185	0.900	

**) – significant at a significance level of 1 % (0.01), ns – non-significance.

T a b l e 6. Results of variance analysis of survival and establishment of seedlings and cuttings of *Calligonum* for various CPM contents in solution and planting types

Source of variation	Degree of freedom	Sum of squares	Mean square	Fisher test
Rep	6	18.47	1.41	1.41
Mulch	2	15.47	7.73	7.74**)
Error Mulch	12	21.52	1.79	1.79
Planting	1	29.11	29.16	29.17**)
Mulch*Planting	2	6.33	3.17	3.17*)
Error	18	17.9	1	

*), **) – significant at a significance level of 5 and 1 %, respectively.

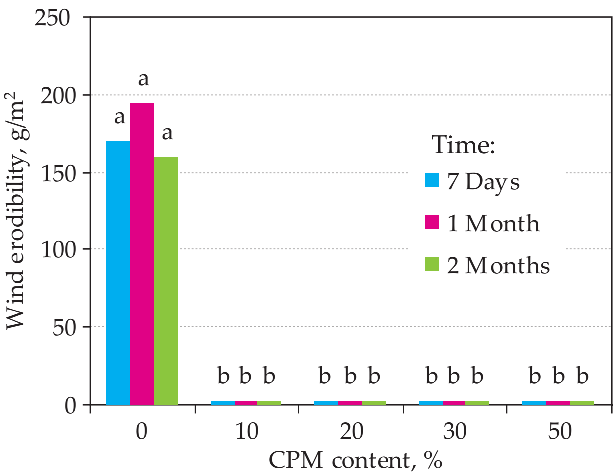

Fig. 3. Means of the wind erodibility index after various times depending on CPM content in solution used for treatment

the polymer material and the samples treated with water. Addition of polyvinyl acetate polymer up to 25 g/m^2 had reduced the wind erosion in the sand samples to zero, and in the medium and heavy-textured soils by at least 90 % compared to samples treated with water. Zhou *et al.* [24] used wind tunnel experiments to test the capacity of sand-cemented bodies (SCB) on mulch beds. The total sand transport rate decreased as the level of SCB coverage increased.

Field experiments

The analysis of variance for survival trait, presented in Table 6, showed that the survival under treatments with various content of CPM in solutions, planting type and interaction is significant at 1 and 5 %, respectively.

The means comparison of the interaction of two mulch treatments and planting type, listed in Table 7, showed that the highest mean was achieved after the treatment with solution amount of 10 t/ha and planting the seedlings and the lowest survival was observed in control treatment and for planting the cuttings. However, Rezaie [13] studied the effect of poly-lattice polymer and petroleum mulches on the establishment of *Haloxylon* seedlings and *Calligonum* cuttings, but none of the treatments showed a significant difference with control treatment.

The soil moisture at a depth of 15 cm was measured after different treatments using TDR device within 1 h after rainfall and 1 week after rainfall. The results of the ANOVA and means comparison are presented in Tables 8 and 9, respectively. The moisture percentage after rainfall is significant within 1 h for the mulch treatment at 1 %, and within 1 week for the 5 % treatment. The highest and lowest percentage of moisture in both harvest times has been recorded for 10 t/ha mulch treatment and for control treatment, respectively.

T a b l e 7. Means comparison of the survival under interaction of different CPM content in solutions and planting types (means followed by the same letters are not significantly different)

Planting	Mulch	Survival Mean
Seedling	10	3.71^a
Cutting	10	1.42^b
Seedling	5	3.28^a
Cutting	5	1.14^b
Seedling	0	1.42^b
Cutting	0	0.85^b

T a b l e 8. Results of variance analysis of soil moisture in different time after rain for various CPM contents in solutions

Source of variation	Degree of freedom	Mean square	
		1 h after rain	1 week after rain
Mulch	2	15.2**)	3.01**)
Error	6	1.18	0.62

**) – significant at a significance level of 1 % (0.01).

T a b l e 9. Means comparison of soil moisture in different time after rain for different CPM levels (means followed by the same letters are not significantly different)

Mulch content, %	Moisture of soil, %	
	1 h after rain	1 week after rain
10	9.27^a	6.33^a
5	7.13^{ab}	5.93^{ab}
0	4.77^b	4.43^b

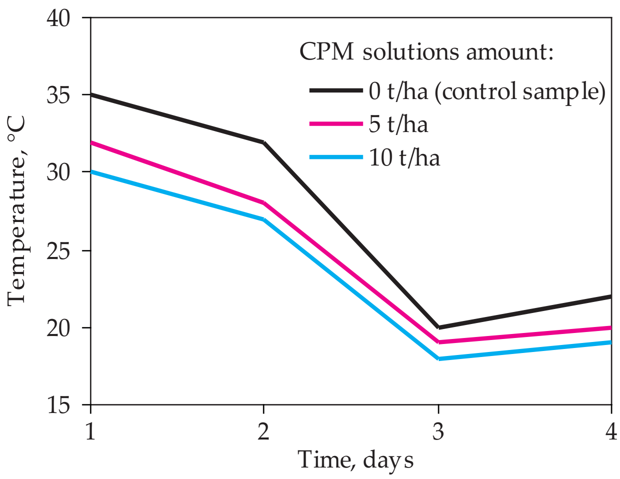

Fig. 4. The trend of soil temperature changes during consecutive days after use of solutions with various CPM content

The trend of soil temperature changes presented in Fig. 4 showed that for all measured times, soil temperatures after 5 and 10 t/ha of mulch treatment were lower than in the control sample, and the lowest temperatures were observed after the use of 10 t/ha treatments.

Furthermore, the measured indices of wind erosion, which were monitored every 15 days, showed that the dunes mulched with up to 10 t/ha were of high resistance and no displacement of sand was observed in them. However, some sands from the adjacent dunes covered the surface of the dunes. On the other hand, erosion and wind drift were observed in control and after 5 t/ha treatments. The indices showed 20 cm and 12 cm movements for the control and 5 t/ha of mulch treatments after 6 months, respectively. The erosion of control treatment was begun in the early days of the study. So that, 5 cm displacement of sand in this treatment was seen during a severe wind blowing in mid-March. But in the case of 5 t/ha treatment, the wind drift was begun in mid-April, that is, about a month and a half after mulching. In previous studies, for controlling sand movement the recommended gravel coverage to form an equilibrated surface ranged from 40 to 80 % [3, 25]. Our results indicate that CPM mulch surface could have an effect similar to gravel mulch.

CONCLUSIONS

According to the results of the laboratory experiments, the layers formed using the solutions with 30 % CPM were characterized by the highest impact resistance and the lowest erodibility index and were recognized as the best solution concentration compared to other ones. In addition, it is economically more effective than solution with 50 % CPM.

Results of the field studies showed that CPM has a positive effect on the plant establishment. The highest survival was observed after the use of mulch solution in amount of 10 t/ha. Among two types of plantings, the seedling followed the cutting planting, showing the highest establishment. The high plant establishment by 10 t/ha of mulch treatment is for two reasons: one, stabilization of running sands and the other, rainfall moisture storage in mulch and more use of it by plants. It should be noted that CPM can be jellified by getting the water from rainfall, and somehow can play a role of absorbent material. The results of evaluation of the moisture changes in the interval between rainfall and one week later also confirmed it. So that, the highest water content was recorded in the case of using 10 t/ha of mulch solution followed by 5 t/ha and the control treatments.

The wind drift and erosion of sand after the treatments using 10 t/ha of mulch solution were zero. However, some sand was deposited in some mulched areas as a result of wind erosion of surrounding sand dunes. Evaluation of the treatments, 5 t/ha of mulch solution and the control suggested 12 and 20 cm of sand movements, respectively.

Thus, according to the results of the study, it can be stated that CPM solution with the spraying rate of 10 t/ha in Kashan climatic conditions will give a relatively good soil strength. This mulch has a positive impact on the plant establishment and consequently on the biological stabilization of the sand dunes. This mulch can partly play a role as absorbent material because of storing the moisture from the rainfall. It should be noted that the mentioned mulch becomes hard and fragile in dry conditions. Upon getting the moisture through rainfall, the mulch becomes soft, and the created fractures will be restored. Following the softening, mulch will fully absorb the moisture from rainfall and will prevent the runoff. Because of the light color of mulch, the temperature rise was not observed in different mulch treatments, which implies the advantage of this mulch over the oil mulch. In general, by changing the composition of mulch in order to increase its flexibility, the mulch can be a good alternative to oil mulch.

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