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Effects of Different Gravel Mulching on Soil Moisture Status and Regression Model Prediction in Arid Regions

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Abstract

Drought is one of the main factors limiting the agricultural planting and production; gravel mulching is an effective inhibiting evaporation and water-saving planting pattern in the arid regions. In this study, experiments were conducted to study soil moisture effect and regression model with different gravel mulching, the soil moisture content and evaporation were compared that gravel mulched with different particle sizes, different thickness layer and different mulched years. The results showed that: 1) The cumulative soil evaporation of gravel mulched was only 29.3% of that bare fields. Mulching gravel could significantly reduce soil moisture evaporation. 2) The effects of inhibiting soil moisture evaporation are the best when mulch gravel thickness is 10 - 15 cm. 3) The particle size of gravel mulched is smaller, the evaporation inhibition effect will be better. Considering the water holding capacity and material economy, it is the most suitable to mulch gravel with the particle size of 3 - 5 cm. 4) Mulching gravel on the soil surface for 1 - 3 years can improve the soil moisture content. However, the gravel was mulched for more than five years, the soil moisture content decreased significantly. 5) The quadratic polynomial regression fitting model can better simulate and predict the cumulative evaporation on different gravel mulched, and the regression fitting degree R^2 is more than 0.98.

Keywords

Gravel Mulched, Evaporation, Thickness, Particle Size, Mulching Years, Regression Fitting

1. Introduction

Mulching is one of the most effective water management practices to improve soil moisture. Gravel mulched is an agricultural farming technique on the dry land. It is usually used gravel to cover the soil surface, which can inhibit soil water evaporation, soil salinization, and wind erosion. Wang found that mulching gravel in arid areas can improve the soil environment, inhibit evaporation and improve crop quality (Wang et al., 2019). The mixed coverage of sand and gravel is more conducive to maintaining the soil moisture, within a specific range, the thicker mulching and the better maintaining soil moisture (Ma et al., 2011). Yuan studied the evaporation effects of gravel particle size and found that the gravel particle size is closely related to evaporation inhibition, the larger particle size and the lower the ability to inhibit evaporation (Yuan et al., 2009; Cai et al., 2014). Zhou studied the evaporation effects of mulching gravel shape and color, and found that mulching regular gravel is better than irregular gravel on the inhibition evaporation (Zhou et al., 2016). Ma et al. studied the soil water dynamics and consumption law of gravel mulched field, and found some different effects for different mulched years (Ma et al., 2011). Although previous have found that mulching gravel can significantly inhibit soil water evaporation, there is a lack of quantitative analysis on the moisture effect of different gravel mulched in arid areas, there isn't research on the regression fitting model of evaporation with time. In this study, experiments were conducted to study soil moisture effect and regression model with different gravel mulched, the soil moisture content and evaporation were compared that gravel mulched with different particle sizes, different thickness layer and different mulched years, it established a regression fitting model to predict the change of melon field cumulative evaporation with time in the arid area.

2. Materials and Methods

2.1. Study Area

The experimental site is located at EnHe Village (37˚49'N, 105˚76'E), Zhongning County, Ningxia, China. It belongs to temperate continental arid and semi-arid climates, with drought and little rain, long sunshine time, and significant temperature difference between day and night. The annual sunshine length is 2883 - 3019 h, and the summer sunshine length is 13 - 14 h per day. The average daily temperature difference is 13˚C - 14˚C, and the average yearly temperature is 9.5˚C. The precipitation is mainly concentrated from July to September. The yearly rainfall is 220 - 350 mm, and the average yearly evaporation is 2100 - 3200 mm, which is far more than precipitation. The soil belongs to calcareous soil and sandy loam, and the parent material of soil formation is loess. Watermelon is widely planted in this area and usually mulched gravel on the soil surface, which is taken from the river pebbles of the Yellow River and its tributaries. The gravel resources are relatively abundant.

2.2. Experimental Design and Field Management

Experiments of soil moisture effects were conducted in watermelon planting regions. Experiment 1: gravel mulched fields and un-mulched fields treatment, the particle size of gravel mulched is about 2 - 3 cm and mulched the thickness is about 15 cm, then compare the soil moisture evaporation of mulching and un-mulching fields. Experiment 2: the particle size of gravel mulched is 2 - 3 cm, and the thickness of mulching was set with four different thicknesses of 2, 5, 10, and 15 cm, then compare the soil moisture evaporation. Experiment 3: the thickness of gravel mulched is 10 cm, and four different gravel particle sizes of 0.5 - 1 cm, 1 - 2 cm, 2 - 3 cm, and 3 - 5 cm were set to compare the soil water evaporation. Experiment 4: it selected the fields with different mulched years of 1a, 3a, and 5a, to compare the soil water content of watermelon different growth stages. Experiment 5: It carried out regression fitting for the cumulative evaporation of no mulching field, mulch gravel thickness of 15 cm and mulch gravel particle size of 30 - 50 mm field respectively.

The area of experiments is 28.8 m^2, row spacing is 80 cm and plant spacing is 100 cm. Within-group random design and three repetitions. The watermelon variety is "Jincheng No.5". Before mulching gravel, combined with land preparation, apply farmyard fertilizer, 225 $kg \cdot hm^{-2}$ of diamine and 70 $kg \cdot hm^{-2}$ of urea. The experiments were conducted from April 2018 to August 2019 for two growing seasons.

2.3. Sampling and Measurements

Soil evaporation was measured by simulated evaporation, using methods that the soil column was heated and weighed. Load the soil into a column (PVC pipe, inner diameter 20 cm, thickness 0.2 cm, height 50 cm), heating source was a 200 W lamp, above the soil column 30 cm. During each measurement, heated lamp was turned on from 9:00a.m. to 6:00p.m. Taking an electronic scale with a measuring range of 30 kg and an accuracy of 1g was used for weighing. The difference in soil column daily mass was the daily soil evaporation mass E_1 (kg), and the soil evaporation mass E_1 (kg) was transformed into standard soil evaporation E (mm).

$$E = E_1 \times 1000 \times 10 \div \left(10^2 \pi\right) \tag{1}$$

where E is the standard soil evaporation (mm), E_1 is the measured soil evaporation (kg), and 10 is the evaporator radius (cm). The soil moisture content was measured by the RS485 soil moisture sensor (measurement range: 0% - 100%, accuracy: 3%).

2.4. Data Analysis

All data presented are averages of three replicates. The soil moisture content and evaporation data were calculated in Excel 2010. The regression fitting was analyzed by SPSS 19.0 (SPSS Inc., Chicago, USA).

3. Results

Use either SI (MKS) or CGS as primary units. (SI units are encouraged.) English units may be used as secondary units (in parentheses). An exception would be the use of English units as identifiers in trade, such as "3.5-inch disk drive".

3.1. Effects of Gravel Mulched on Soil Evaporation

The cumulative evaporation of un-mulched field increased rapidly from April 10 to August 10, the cumulative evaporation increased from 160 mm to 1150 mm, but the cumulative evaporation of mulched gravel field was relatively flat, increasing from 90 mm to 380 mm (Figure 1). Within 120 days, the soil cumulative evaporation of mulching gravel was only 29.3% of that of un-mulched.

Table 1 shows that mulching gravel significantly impacted on soil moisture content during the growth period of watermelon. In different growth stages of watermelon, the soil moisture content of the un-mulched field is less than 6% at the 0 - 10 cm depth, the soil moisture content of gravel mulched field is more than 10%. From 20 - 60 cm depth of the soil layer, the soil moisture content of gravel mulched field is about 5% - 10% more than that of un-mulched at the same depth. Especially in the expansion stage with significant water demand for watermelon growth, the soil moisture content of each laminated mulching field is about 6% - 13% more than that of un-mulched fields (Table 1). The soil moisture content of mulched gravel watermelon field is significantly more than that of un-mulched. Gravel mulched can significantly inhibit soil water evaporation and has good water storage and drought resistance.

3.2. Effects of Different Mulched Gravel Thickness on Soil Moisture Evaporation

Figure 2 presented results in the different treatments in Experiment 2. When the thickness of mulching gravel is 2 cm, 5 cm, 10 cm, and 15 cm, the maximum cumulative evaporation is about 730 mm, 610 mm, 430 mm, and 340 mm respectively (Figure 2). The cumulative evaporation of soil moisture decreases

Table 1. Soil moisture content in different growth stages of watermelon (%).

Land type	Soil depth (cm)	Watermelon growth period				
		Seedling	vines	Bearing	expanding	mature
Un-mulched	0 - 10 cm	4.89	5.36	5.17	4.63	5.07
	20 - 30 cm	8.15	7.92	8.58	6.91	9.03
	30 - 40 cm	11.82	11.69	12.17	10.97	12.69
	40 - 50 cm	15.68	16.09	15.95	14.39	16.06
	50 - 60 cm	18.80	19.15	18.73	17.45	18.77
Gravel mulched	0 - 10 cm	10.43	10.25	10.98	10.06	10.75
	20 - 30 cm	13.97	14.37	14.86	14.11	14.65
	30 - 40 cm	19.12	19.82	19.19	18.35	19.49
	40 - 50 cm	24.17	23.43	24.76	23.58	25.33
	50 - 60 cm	30.72	32.35	31.87	30.56	32.12

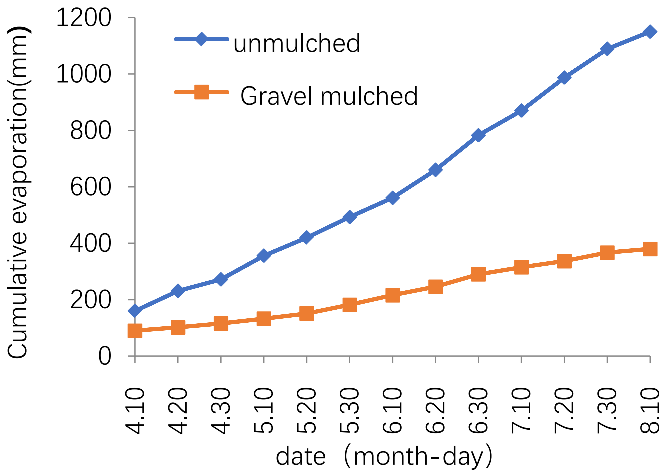

Figure 1. Comparison of soil cumulative evaporation between gravel mulched and unmulched field.

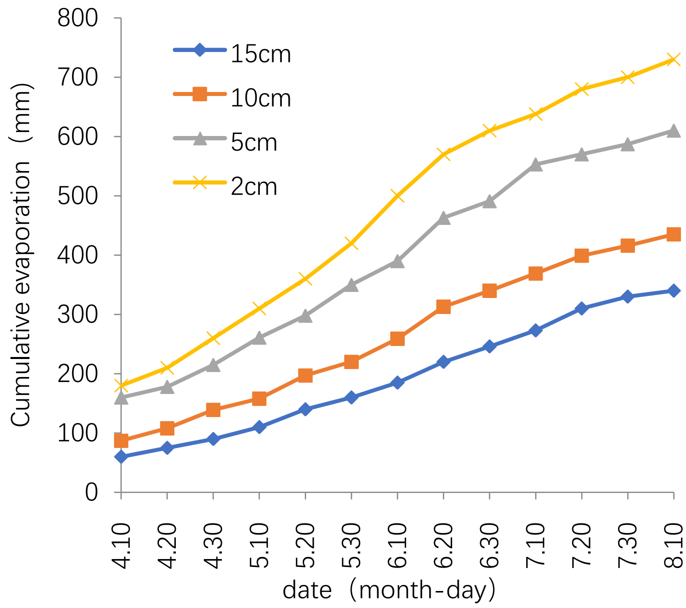

Figure 2. Cumulative evaporation effects of different mulched thickness.

with the increase of mulched gravel thickness, that can effectively inhibit soil water evaporation when gravel was mulched thicker. Especially, it affected by the rise of temperature from June, the cumulative evaporation increases rapidly and the curve was rise obviously when mulched thickness was 2 cm and 5 cm, while the cumulative evaporation increased slowly when the thickness of mulching gravel was 10 cm and 15 cm (Figure 2).

3.3. Effects of Different Mulched Gravel Particle Sizes on Soil Moisture Evaporation

Figure 3 presented results in the different treatments in Experiment 3. When gravel mulched with particle size of 0.5 - 1 cm, 1 - 2 cm, 2 - 3 cm, and 3 - 5 cm

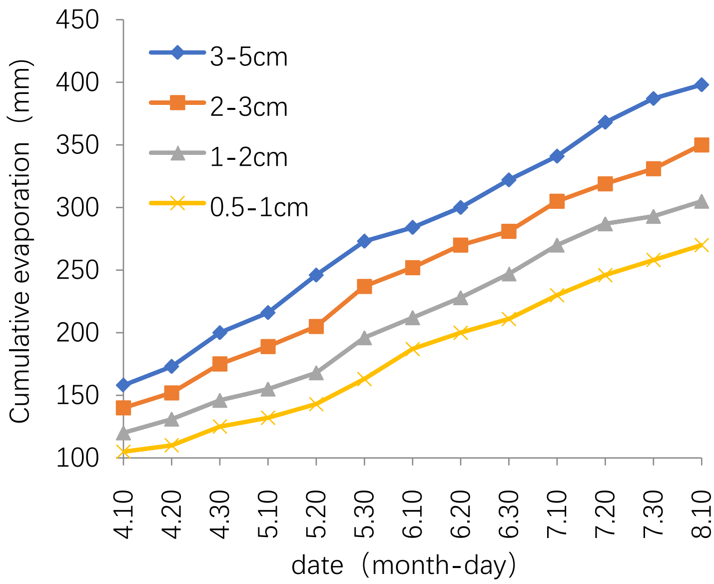

Figure 3. Cumulative evaporation effects of different mulched gravel particle sizes.

on the soil surface, the maximum cumulative evaporation is about 270 mm, 305 mm, 350 mm, and 400 mm respectively (Figure 3). The results of Experiment 3 indicated that the particle size of mulched gravel changes from small to large, the cumulative evaporation is also increased gradually. The different particle sizes of mulching gravel will affect the evaporation of soil moisture, and the water retention effect of soil is also significantly different. The particle size of mulching gravel is the smaller, the evaporation inhibition effects would be better.

3.4. Soil Moisture Content Effect of Gravel Mulching Years

Figure 4 presented results in the different treatments in Experiment 4. In 0 - 60 cm soil depth, the average soil moisture content of un-mulched gravel is about 9%, the soil moisture content of mulched gravel for one year was about 14%, that was about 5% more than that of un-mulched. The soil moisture content of mulched gravel for three years was about 20%, that was about 11% more than that of un-mulched. But the soil moisture content of mulched gravel for five years was only about 6%, that was less than that of un-mulched field (Figure 4). It can be seen that the soil moisture content of mulched gravel for three years was the highest, as gravel mulched increased to more than five years, the soil moisture content decreased significantly.

3.5. Regression Fitting of Soil Cumulative Evaporation on Different Gravel Mulched

Table 2 presented the regression fitting of soil evaporation on different gravel mulched, which have linear regression fitting model, quadratic polynomial regression fitting model, and power regression fitting model. In the models, y (mm) is the cumulative evaporation, t (days) is the cumulative time. According to the principle that the greater the fitting coefficient R^2 of the regression model,

Table 2. Regression fitting of cumulative soil evaporation.

Mulched type	Regression fitting	Mathematical model	Fitting degree R^2
Un-mulched	Linear regression	$y = 8.592t + 100.769$	0.986
	Quadratic polynomial	$y = 0.025t^2 + 5.619t + 156.012$	0.997
	Powers	$y = 105.453t^{0.437}$	0.835
Thickness 15 cm	Linear regression	$y = 2.663t + 41.480$	0.984
	Quadratic polynomial	$y = 0.004t^2 + 2.173t + 50.583$	0.986
	Powers	$y = 42.152t^{0.387}$	0.737
Particle 30 - 50 mm	Linear regression	$y = 2.184t + 143.667$	0.987
	Quadratic polynomial	$y = -0.006t^2 + 2.877t + 130.768$	0.995
	Powers	y = 108.127t0.241	0.851

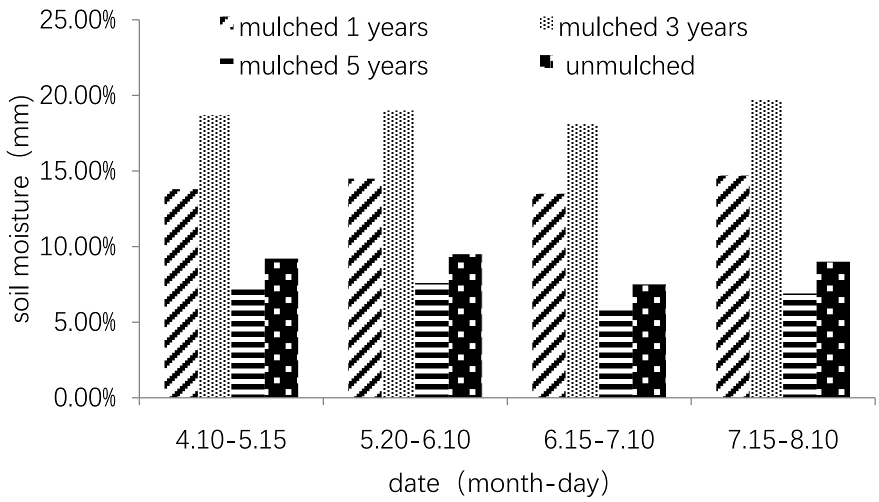

Figure 4. Soil moisture content of gravel mulch different years.

regression fitting value R^2 is closer to 1, the regression model is better to the observed value. By comparing the fitting coefficient R^2, the fitting coefficient of quadratic polynomial is greater than that of the other two models, so the quadratic polynomial regression fitting to the observed values is better, while the fitting coefficient of power model is the smallest, and the power model to the observed values is poor (**Table 2**). **Figures 5-7** presented the regression fitting curves, in which the linear regression curve and quadratic polynomial regression curve can better simulate the observed data values, in contrast the power regression curve deviates from the observed values. By comparing the regression simulation curve and fitting degree R^2, the quadratic polynomial regression model can better simulate and predict the cumulative evaporation of soil water under different gravel covers. The expression of quadratic polynomial is Equation (2). y (mm) is the cumulative evaporation, t (days) is the cumulative time, and a, b, and c are quadratic polynomial coefficients.

$$y = at^2 + bt + c \tag{2}$$

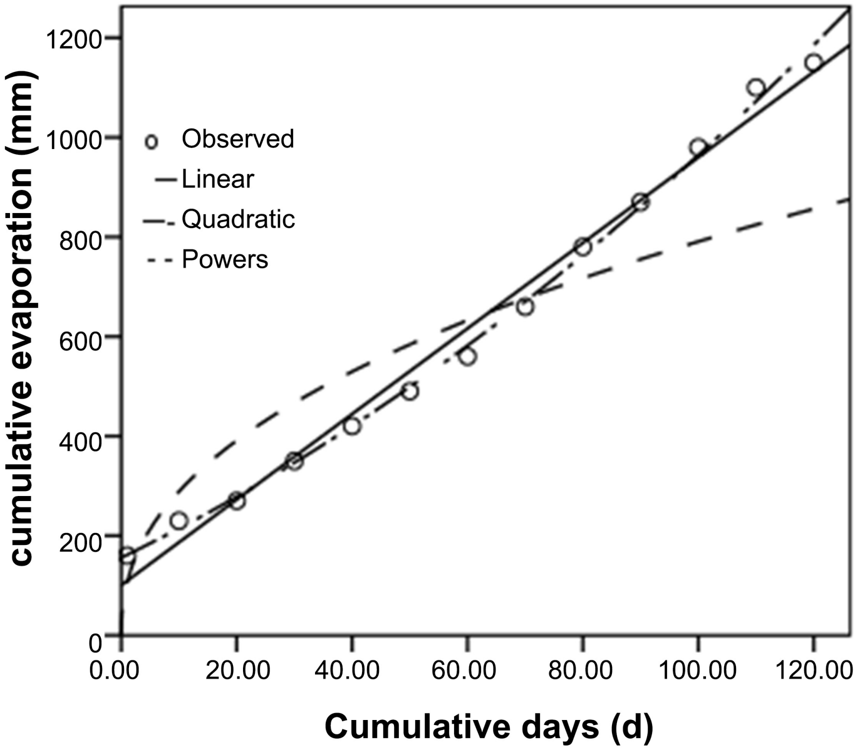

Figure 5. Fitting curve of cumulative evaporation that un-mulched gravel.

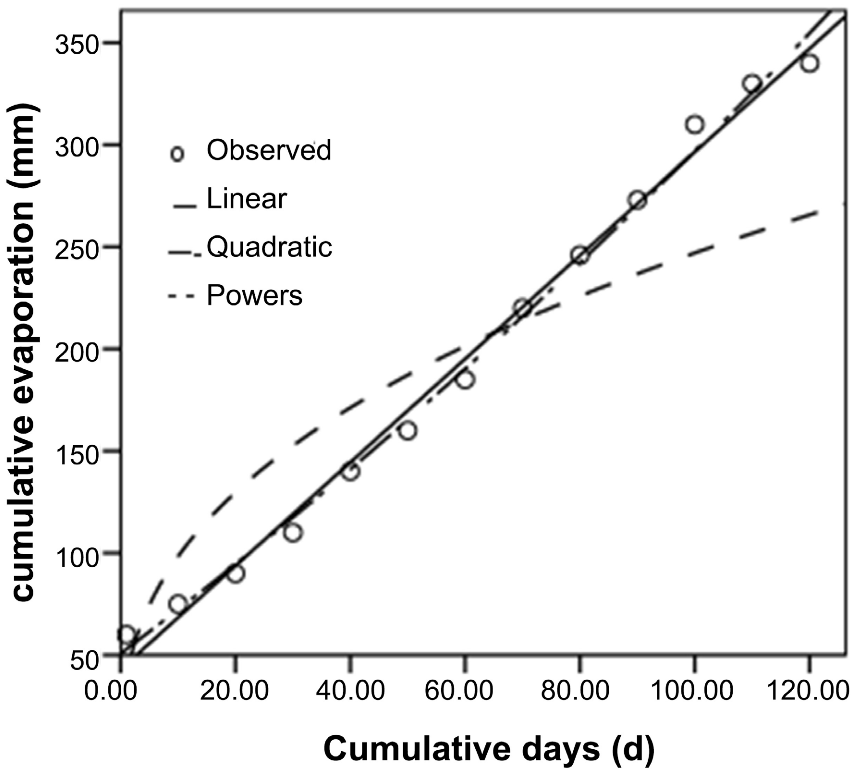

Figure 6. Fitting curve of cumulative evaporation that mulched gravel 15 cm thickness.

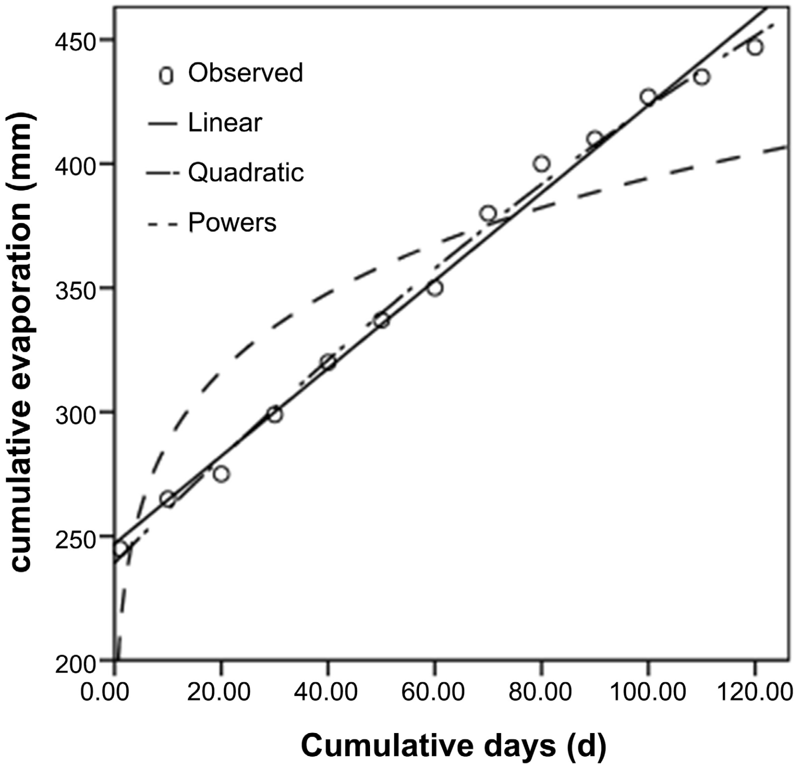

Figure 7. Fitting curve of cumulative evaporation that mulched gravel particle size 3 - 5 cm.

4. Discussion

In the arid area of central Ningxia, the local maximum temperature in April is about 15˚C, the accumulated evaporation difference between the gravel mulched field and un-mulched field is slight, but with the increase of sunshine time and temperature, the evaporation of un-mulched soil increases rapidly. During the growth of watermelon from April to August, the cumulative soil evaporation of gravel mulched fields was only about 30% of that un-mulched.

Especially in the expansion period of watermelon growth, the plant leaves and fruits need to consume a lot of water, and the soil moisture content in gravel mulched field is about 5% - 10% more than that un-mulched. The results of Experiment 1 indicated that the soil moisture evaporation of gravel mulched fields is significantly less than that of bare land, and gravel mulched land has good water storage and drought resistance.

Previous research has shown that soil evaporation decreases with increasing thickness of the gravel mulched layer (Yang et al., 2014; Zhou et al., 2016), however, the cumulative evaporation is not significant between 2 cm to 15 cm mulched thickness. The results of this study show that the thicker gravel mulched and the more soil evaporation can be reduced, which is consistent with the previous research results. When the thickness of gravel mulched is 2 cm - 5 cm, the cumulative evaporation increases rapidly due to the rise of temperature, while the thickness of gravel mulched is 10 - 15 cm, the cumulative evaporation of soil water increases slowly. Considering the economy and utilization rate of mulching gravel thickness, the effects of inhibiting soil water evaporation is the best when the cover thickness is 10 - 15 cm.

The effects of gravel mulched with different particle size on evaporation are also different, previous studied gravel particle size (coarse sand, medium sand, and fine sand) as the influencing factor and found that mulching fine sand has the best effect on inhibiting evaporation (Lyu et al., 2021; Zhao et al., 2016). The results of this study show that with the increase of the particle size of covered gravel, the cumulative evaporation is also increase gradually, which is the same as the previous research results (Chen et al., 2005; Cai et al., 2014). In reality, local farmers prefer to use the particle size 3 - 5 cm gravel mulch because they believe that gravel of the particle size 3 - 5 cm is taken locally without processing, while the gravel of the particle size 0.5 - 1 cm needs reprocessing. In addition, the gravel covered with 3 - 5 cm has stronger impact resistance than the gravel with the small particle size of 0.5 - 1 cm. The rainwater is easy to precipitate and penetrate, which can effectively reduce surface runoff and prevent water and soil loss. Therefore, considering the economy and water stability, the fields was usually mulched gravel of particle size 3 - 5 cm, which can not only inhibit soil water evaporation, but also have good water holding capacity and water stability.

Some studies stated that soil microbial biomass carbon and nitrogen has a large decreasing after replanting five to ten years (Xue et al., 2011). This study shows that gravel mulch for years also affected the soil moisture. The results of Experiment 4 indicated the soil moisture content of gravel mulch 1 - 3 years is more than that of un-mulched fields, and the soil moisture content is relatively higher when gravel mulch for three years, however, with the increase of mulching period to more than five years, the soil moisture content decreased significantly, and it is lower than that of the bare land. The soil environment of gravel mulch will change significantly with the increase of gravel mulch years and natural weathering. That affects the decline of soil moisture content, aggravates land desertification, and destroys the soil micro ecological environment.

The relationship between cumulative evaporation (y) and the time of gravel mulch (t) showed in **Table 2** indicates that this relationship can be described by the equation. Cai stated that the cumulative evaporation is directly proportional to the square root of time, i.e. $E = \alpha t^{0.5}$, where E is the cumulative evaporation (mm), α Is the coefficient related to soil properties, and t is the time of evaporation (days) (Cai et al., 2014).

This study carried out linear regression fitting, quadratic polynomial regression fitting, and power regression fitting for the cumulative evaporation of no mulching land, mulched gravel thickness of 15 cm, and mulched gravel particle size of 30 - 50 mm in melon field respectively. The fitting coefficient R^2 and simulation curve of three regression mathematical models were compared. The results of Experiment 5 indicated that the quadratic polynomial regression fitting R^2 is more excellent than two others regression fitting models. Quadratic polynomial regression model can better simulate and predict cumulative soil evaporation under different gravel mulch. Because the temporal and spatial stability of soil moisture will also be affected by rainfall, organic matter, surface plants, and human activities, the prediction model of cumulative evaporation need more data collection and analysis, which needs to be further studied.

5. Conclusion

Covering gravel has an effect on soil evaporation. In particular, continuous gravel coverage for more than 5 years will reduce the soil water content, lead to an increase in the ground gravel content, and aggravate land desertification in arid areas. To reflect the biological activity of soil quality, it is also necessary to comprehensively analyze it in combination with studies on soil microbial diversity. In the future work, the soil microbial community structure covered with gravel will be studied to explore the ecological effect of soil microorganisms on soil fertility, so as to protect the sustainable development of soil and ecology.

Fund

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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