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Effects of Super-Absorbent Polymer on Soil Remediation and Crop Growth in Arid and Semi-Arid Areas

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Abstract: The water-retaining and yield-increasing capacity of super-absorbent polymer (SAP) are essential for soil remediation in arid and semi-arid areas. Therefore, it is of great significance to investigate the influencing factors and mechanisms of SAP effects on soil environments and crop growth for the precise management of agricultural water-saving irrigation. In this study, we adopted SAP as a soil conditioner and monitored changes in soil temperature, photosynthetic rate, leaf transpiration rate, chlorophyll, crop growth indexes (plant height, stem diameter, leaf area index, dry matter accumulation), and yield under different SAP doses during the growth stage of maize, on the basis of which the improvement mechanism of SAP in arid and semi-arid soil was analyzed. The results demonstrated the following: (1) 45 kg/hm^2 of SAP application could increase the temperature of the soil layer, effectively reduce the diurnal temperature variation of the soil surface, and promote the stable growth of maize; (2) when different SAP doses were applied, the leaf surface temperature of maize increased by 0.95 °C on average. In particular, when 135 kg/hm^2 of SAP was applied, the leaf surface temperature increased by 1.55 °C; (3) SAP could promote the photosynthetic rate of maize. In addition, the plant height, leaf area index, and dry matter accumulation of maize gradually increased with an increasing amount of SAP; (4) the application of SAP not only increased the grain row number, ear row number, and average 100-seed weight, but also increased the crop yield by nearly 6%. The application of SAP demonstrated a comprehensive utility (redistribution of soil water and temperature, synergy between SAPs and plants), which suggests that the most basic goal, to ensure socio-economic and ecological sustainability in dryland systems, was obtained.

Keywords: SAP; soil infiltration rate; soil temperature; photosynthetic rate; semi-arid area; maize

1. Highlights

- SAP was investigated as a soil conditioner in a semi-arid maize crop
- We monitored soil temperature, photosynthetic rate, crop growth indexes, and yield
- SAP-affected soil and leaf surface temperatures and increased photosynthesis
- The SAP dose is very important in maximizing the benefits and reducing negative effects

- SAP increased the grain row number, ear row number, seed weight, and crop yield

2. Introduction

Ensuring grain yield with limited water resources has been the focus of research on agricultural water-saving irrigation [1]. The arid and semi-arid regions in the world are distributed in all climatic zones except the cold zone, covering more than 50 countries and regions. With the exception of Antarctica, the arid and semi-arid areas of all continents together account for 34.9% of the land area [2]. One potential solution is the application of super-absorbent polymers (SAPs), which can alter the physical and chemical properties of soil, and effectively improve its water- and fertilizer-retaining capacity [3–5]. Also referred to as super absorbent resin, SAP is a polymer material that can absorb a large amount of water that is hundreds or even thousands of times its own weight owing to its three-dimensional network structure. In addition, SAP demonstrates good water retention performance and can repeatedly absorb and release water [6–8]. It has been shown that the water absorption capacity of SAP interacts with temperature changes [6,9–11].

After SAP binds to soil, its swell–shrink processes help to control the soil losses, which are due to water absorption, retention, and release, not only changing soil pores, but also altering soil structure and hydrothermal conditions [12,13]. Thus, SAP regulates soil water content [14], reduces the saturation conductivity coefficient of soil [15,16], improves soil biological activity [4], and enhances soil agglomeration and water retention capacity [17]. In particular, SAP demonstrates a substantial improvement in sandy soil [7]. An appropriate amount of SAP can increase the water retention capacity of sandy loam and the effective water utilization of crops, thereby fully exerting the water retention ability of SAP [18]. In addition, SAP also has the potential to save water, resist drought, preserve fertilizer, and increase yield [7,17,19]. In arid regions, the use of SAP may effectively increase the efficiency of water and fertilizer application in crops [20]. Furthermore, SAP exhibits interception and physiological regulation effects on soil nitrate [21]. In acidic soil, SAP can increase the emergence rate, improve soil moisture, and enhance soil microbial community structure [15,21]. Applying SAP evenly to the soil of arid areas prior to irrigation or the rainy season can significantly reduce surface runoff and soil erosion [22,23], prevent soil surface crust, improve irrigation efficiency and the soil infiltration rate of precipitation, and increase water use efficiency [24]. Therefore, SAP has been shown to be advantageous in desertification control, soil erosion control, and crop emergence improvement in semi-arid areas [20].

However, changes in the physical and chemical properties of soil by SAP may also exhibit negative effects on agricultural production if an excessive amount of SAP is applied. Excessive treatment of SAP not only increases the cost but also results in the agent competing with crops for water upon insufficient soil moisture, causing a declining yield [8,15,16]. Therefore, the SAP dosage should be adjusted according to the soil texture, soil particle size, regional climate characteristics, and type of SAP [8]. Although SAP can improve the content of water-stable aggregates and prevent water evaporation from the soil, its evaporation inhibition efficiency is associated with its particle size, i.e., the smaller the particle size, the better the soil water evaporation inhibition efficiency [12].

Owing to the above effects on soil moisture, as well as soil physical and chemical properties in arid and semi-arid areas [25–28], SAP will also influence emergence and survival rates, root development, absorption of nutrient elements, photosynthesis efficiency, and other properties of crops during growth [29]. At present, there are insufficient in-depth studies on the effects of SAP on soil improvement and the physiological characteristics of crops in semi-arid regions [30,31]. Maize is one of the most widely cultivated cereal crops by human beings, more than 100 countries in the world grow maize [20,21,25]. This research focuses on how to achieve high yields of maize in arid and semi-arid regions and how to maximize water and fertilizer conservation in the soil planted with maize. Therefore, systemic research on the influencing mechanism of SAP in the biochemical index and water consumption of maize has great scientific significance for its application in the future.

3. Methods and Materials

3.1. Research Areas

Hetao Irrigation Area, located to the north of the northernmost bend of the Yellow River, is in the alluvial plain on the north bank of the Inner Mongolia section of the middle and upper reaches of the Yellow River. It has a total area of 2354 km^2, multi-year mean annual precipitation of 140-222 mm, an average temperature of 6.8 °C, substantial diurnal temperature variation, and a long sunshine duration of 3229.9 h as a multi-year mean annual sunshine duration all of which contribute to strong soil evaporation. Controlled by the continental arid and semi-arid monsoon climate in the mid-temperate zone [32], local agriculture relies heavily on the Yellow River for irrigation. The irrigation area is 5733 km^2, making it the largest irrigation area in Asia, which is an important production base for commodity grain and oil in China [33]. The main economic crops include maize, wheat, sunflower, coarse cereals, etc. Maize, as a gramineous crop, is more resistant to disease and less prone to disease in arid and rainless areas [34]. Integrated weed, pest, and disease management strategies are used for control in the Hetao area [35,36]. The study area is located in the Linhe District (107°23′12.01″ E, 40°45′58.28″ N) of Bayannur City in northwestern Inner Mongolia (Figure 1). The soil characteristics are shown in Table 1. Due to soil depletion and low organic matter contents caused by the long-term application of inorganic fertilizers, the soil has been seriously salinized and weakly alkalinized in the Hetao irrigation area of Inner Mongolia [32,34,37].

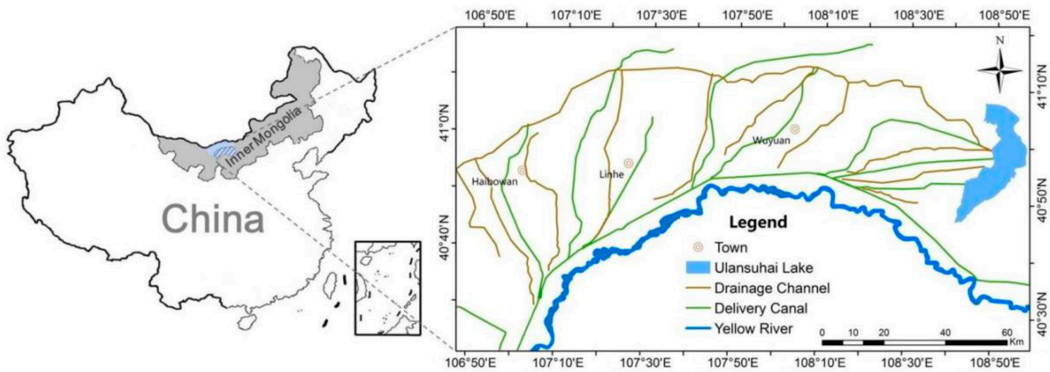

Figure 1. Geographical location of the study area.

Table 1. Physical composition of soil (n = 3).

Texture	Particle Content of Different Treatments (%)					Bulk Density	Conductivity	Organic Matter
	CK	S-3	S-6	S-9	S-12	g/cm^3	μs/cm	g/kg
Sand	50.02	37.05	40.67	37.89	36.15			
Loam	44.41	55.55	52.46	54.67	55.86	1.54	384.50	10.35
Clay	5.57	7.26	6.79	7.45	7.99			

3.2. Experiment Design and Methods

Maize is an important food crop both around the world and in the Hetao Irrigation Area [32]. It has a full growth of 120 days and was sown on 17th April in the experiments. A total of five groups, including a control group were designed in the experiment, which were randomly distributed in the field experiment plots: CK (control), S-3 (45 kg/hm^2 SAP), S-6 (90 kg/hm^2 SAP), S-9 (135 kg/hm^2 SAP), and S-12 (180 kg/hm^2 SAP) (Figure 2).

Super-absorbent polymer (SAP) is a synthetic product, which is a general term for water-absorbing polymers. Its chemical name is polyacrylamide, including amide and carboxyl hydrophilic groups. Model BJ2101XM of SAP was used in the experiment. SAP was purchased from Beijing Hanlimiao New Technology Co., LTD, which was a white powder with a particle size of 0.01–2.00 mm, and a water absorption ratio of 233.9 g/g in deionized water and 124.3 g/g in tap water. SAP was mixed into the top 0-40 cm layer of the soil using a rotary cultivator. Three replicates were prepared in each group, and each replicate plot was 60 m^2 and separated by ground ridges (Figure 2).

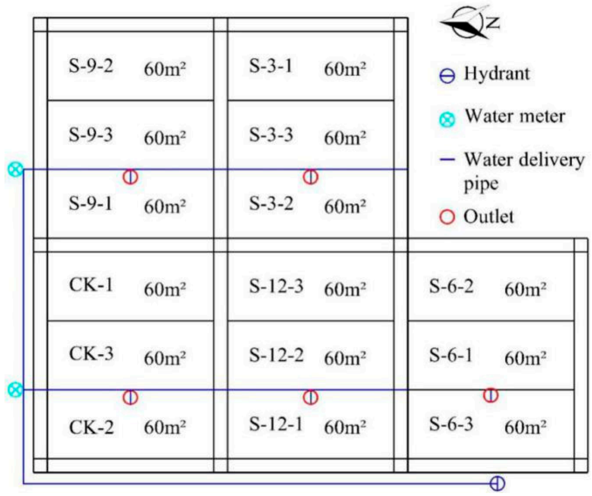

Figure 2. Layout of field experiment plots.

The one-film two-row farming mode was adopted. The row spacing was 60 cm, plant spacing was 25 cm, and the number of plants per mu was approximately 4800. Fertilization was performed as per the local tradition: base fertilizer (compound fertilizer) N: P: K = 48%: 36%: 16% and 50 kg topdressing of nitrogen fertilizer. The topdressing was applied separately prior to irrigations at a ratio of 30%: 50%: 20%, i.e., 15 kg at the jointing stage, 25 kg at the tasseling stage, and 10 kg at the grouting stage. The irrigation mode was tetrahydrate irrigation with a total irrigation volume of 380 m^3/mu, i.e., 80 m^3/mu before sowing, 100 m^3/mu at the jointing stage, 100 m^3/mu at the silking stage, and 100 m^3/mu at the grouting stage, after each irrigation, we recorded the change of soil temperature.

3.3. Monitoring of Crop Physiological Indexes

(a) Determination of morphological and physiological indexes of crops

Growth stage indexes including plant height, stem diameter, leaf area index, dry matter accumulation were determined once every 15 days in each plot.

(b) Determination of crop yield

Three replicates containing 10 consecutive maize strains were taken from each plot. The maize was then air-dried, the grains were scraped down and mixed, and the 100-seed weight was measured with seven replicates for each plot, followed by the calculation of yields per mu and per hectare.

(c) Determination of photosynthetic rate

An LI6400 portable photosynthesis meter was used to measure the three ear leaves in the middle of the maize, and the mean value of three replicates was taken as the result. Alternatively, an SPAD-501 chlorophyll meter was used to measure chlorophyll. Measurement parameters included the photosynthetic rate (*Ph.*), transpiration rate (*Tr.*), and other indicators.

(d) Measurement time points

The experiment was divided into two parts, namely changes of the photosynthetic rate of maize with different growth stages (jointing stage, filling stage, and maturation stage), and daily changes of maize in the filling stage for three consecutive days. Since plants will close their stomas to preserve moisture when exposed to strong sunlight, the observation period of 11:00 to 13:00 was intentionally skipped. Therefore, measurements were conducted at 07:00, 09:00, 11:00, 13:00, 15:00, 17:00, and 19:00.

3.4. Data Analyses

Field experiments were conducted in triplicates. One-way analysis of variance (ANOVA) was conducted using the SPSS statistical software (IBM, SPSS, Statistics 21). The statistical difference was considered significant if $p < 0.05$. Figures were processed using OriginPro 8.0 (OriginLab Corp.).

4. Results and Analyses

4.1. Effects of SAP on Soil Surface Temperature

The soil surface (0-20 cm) temperature affects plant growth, soil formation and properties, and the movement of soil water and soil air [9–11]. Groundwater was used for irrigation in the study area. Due to the low groundwater temperature (mean 4-6 °C), maize growth was slowed down by 5–8 days after each irrigation, indicating that the temperature influenced both the growth and yield of maize. Therefore, stable ground temperature fluctuation plays an important role in improving maize growth. Changes in soil temperature with different amounts of SAP were monitored within 0-20 cm of the surface layer of the soil from 05:00 to 21:00 for three consecutive days during each growth stage (Figure 3).

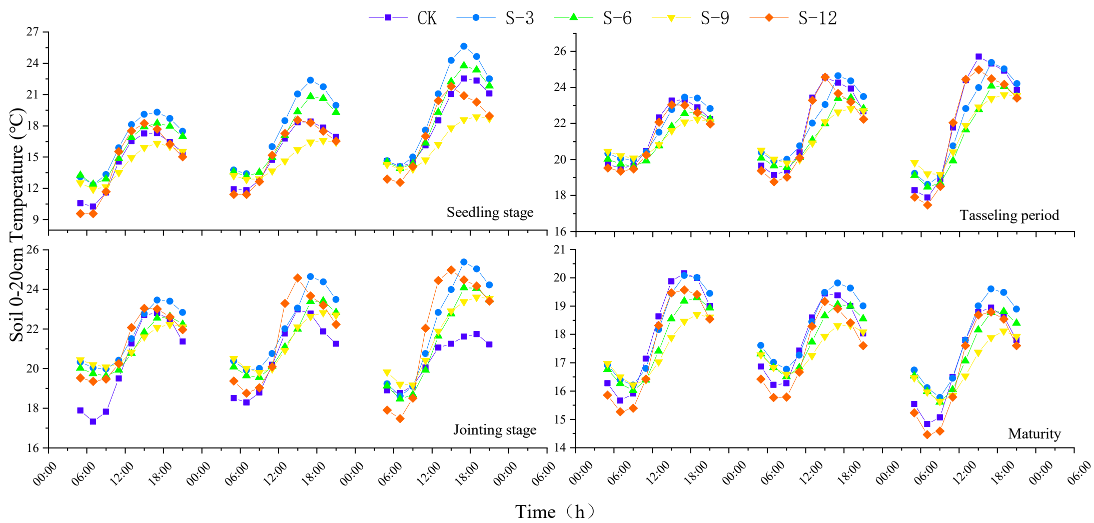

Figure 3. Effect of super-absorbent polymer on the soil surface (0–20 cm).

The mean temperatures of each treatment at different growth stages were calculated (Table 2). The results showed that the application of a certain amount of SAP could increase the soil surface temperature, and the mean temperature increase was 0.95 °C. The overall trend of the soil temperature was in the order of S-3 > S-6 > S-12 > CK > S-9. Treatment S-3 demonstrated a significant influence on the stability of the temperature in the application layer, with the temperature variation ranging from 0.03-2.13 °C ($p < 0.05$). The increase of the ground temperature was significant in the early growth stage. With an increasing amount of applied SAP, the influence of Treatment S-6 on the ground temperature was weakened with the temperature variation ranged from −0.67-1.08 °C ($p < 0.05$). On the contrary, Treatments S-9 and S-12 caused great fluctuations in the temperature of the application layer, introducing substantial ground temperature decreases at the seedling stage and consequently hindering its development at the early growth stage.

After the jointing stage, the surface temperatures of Treatments S-3 and CK were higher than those of other treatments ($p < 0.05$). After the tasseling stage, due to the strengthened evaporation in high-temperature seasons, the moisture content of soil without SAP treatment decreased sharply, resulting in a larger diurnal temperature variation. Subsequently, when maize entered the maturation stage, the diurnal temperature variation of the surface temperature decreased, with S-3 exhibiting the least effect on the temperature of all treatments. The application of 45 kg/hm^2 of SAP could improve the temperature of the treated soil layer and enhance maize growth.

Table 2. Average temperature (°C) of the 0-20 cm soil layer at different growth stages.

Growth Stage	CK	S-3	S-6	S-9	S-12
Seedling stage	16.09	18.22	17.17	15.12	15.88
Jointing stage	21.92	21.95	21.25	21.3	21.59
Tasseling stage	20.49	21.02	20.44	20.81	21.08
Maturation stage	17.7	18.09	17.58	17.25	17.28

4.2. Effects of SAP on Leaf Temperature, Photosynthetic Rate, and Transpiration Rate of Maize

From 07:00, the leaf surface temperature of maize treated by SAP was higher than that of CK, with a mean increase of 0.95 °C, which remained consistently higher over the entire day. Of all the treatment groups, the effect of Treatment S-9 was the most significant with a mean increase of 1.55 °C ($p < 0.05$) (Figure 4a).

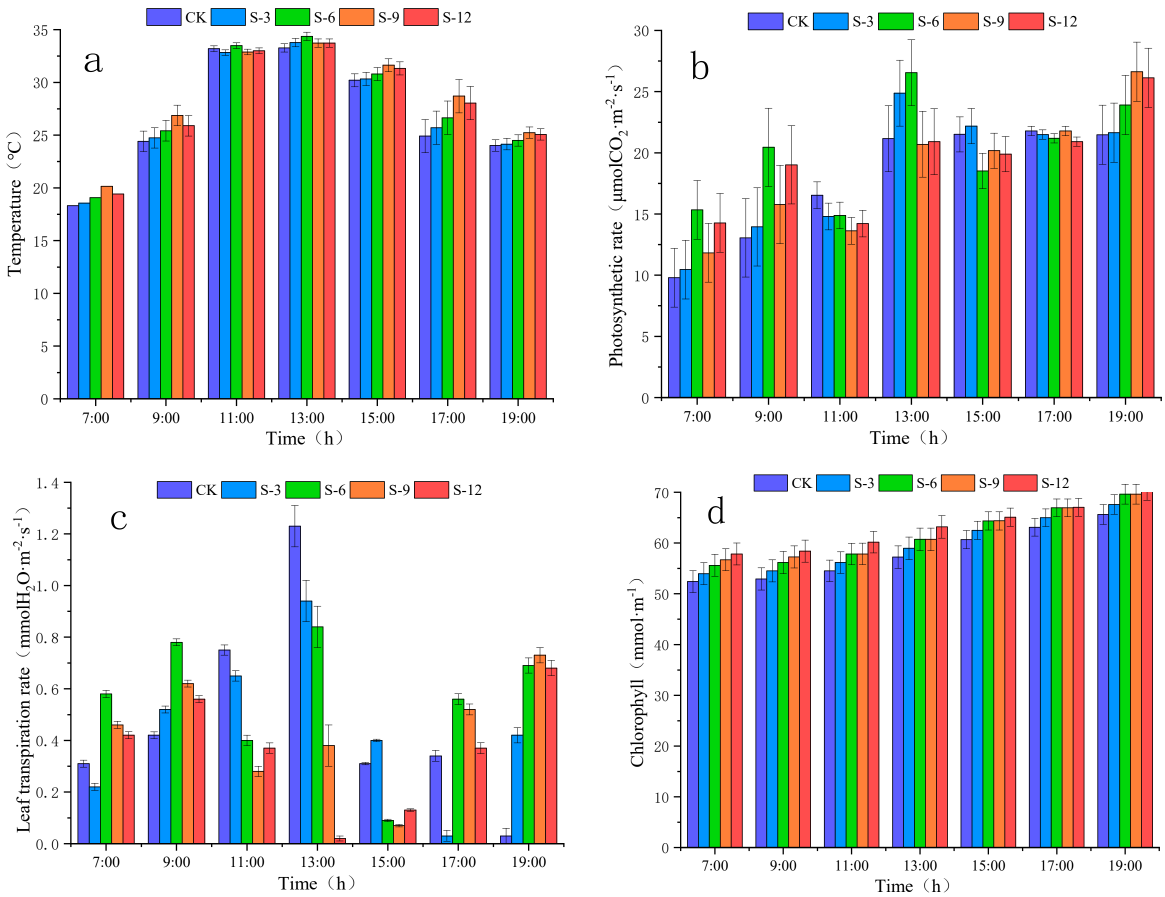

Figure 4. Effect of SAP on crop indicators. (**a**) temperature; (**b**) photosynthetic rate; (**c**) transpiration rate; (**d**) chlorophyll.

The photosynthetic rate represents the CO_2 absorption capacity of plant photosynthesis and was monitored in this study (Figure 4b). The analysis showed that the CO_2 absorption capacities of maize in all the SAP treatment groups were consistently higher than that of CK, with a mean photosynthetic rate increase of 9.75% and Treatment S-3 showed the highest increase of 17.65%. Overall, the increased photosynthetic rate was directly proportional to the amount of SAP applied. In addition, changes in the photosynthetic rate within one day demonstrated a similar parabolic curve in all treatment groups, reaching a peak at 13:00 (mean of 23.26 μmol·CO_2·m^{-2}·s^{-1}) before starting to decline. During the period of 13:00-19:00, as the amount of added SAP increased, the attenuation of the photosynthetic rate gradually weakened, but remained higher than that of CK at 19:00.

As a representation of water metabolism intensity, the transpiration rate is an important indicator for estimating the crop water demand. Analysis of changes in the transpiration rate (Figure 4c) showed that the initial transpiration rate of the SAP treatment was greater than CK at 07:00 ($p < 0.05$). However, from 11:00 to 17:00 the transpiration rate of CK began to increase to be higher than that of the treatment groups, whilst comparison within treatment groups showed that the leaf transpiration rate exhibited a decreasing trend with an increasing SAP application. Subsequently, at 19:00, the leaf transpiration rates of SAP treatments were again higher than that of CK. The chlorophyll concentration in maize leaves increased with the photosynthetic rate (Figure 4d), reaching its peak at 13:00 p.m.

4.3. Effect of SAP on Growth Indexes of Maize

The plant height of maize increased with an increasing amount of SAP, with 5.46% (S-3), 8.83% (S-6), 3.66% (S-9), and 12.40% (S-12) higher than that of the CK group at the maturation stage ($p < 0.05$). In addition, not only did the stem diameter increase with an increasing amount of SAP, but maize with SAP applied also reached a stable stem diameter earlier than those in the CK group. More specifically, maize in the SAP treatment groups reached a stable stem diameter from 26 June to 17 July, whereas the growth of maize in the CK group did not cease until 24 July (Figure 5).

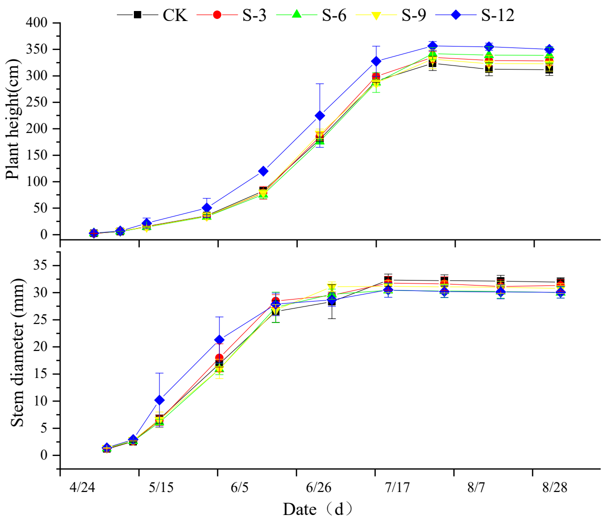

Figure 5. Plant height and stem diameter of maize planted with the super-absorbent polymer.

The maize leaf area index increased rapidly from 6 June (jointing stage) to 5 August (tasseling stage) (Figure 6). During the tasseling stage (from 5 to 20 August), maize leaves showed a linearly increasing trend. Conversely, the leaf area stopped increasing from the tasseling stage to the maturation stage (i.e., as maize in the SAP treatment groups began to form ears). In general, the maize leaf area index increased with increasing applications of SAP from germination to maturity, increasing by 2.84% (S-3), 2.87% (S-6), 8.22% (S-9), and 10.64% (S-12) during the maturation stage compared to that of the CK group ($p < 0.05$).

Dry matter accumulation is an important indicator of crop growth and yield [19]. In general, the accumulation of maize dry matter in the SAP treatment group showed an obvious increasing trend and rose linearly with the growth of maize until maturity (Figure 7). The differences in each group began to appear from the 6th to the 9th leaves of the maize, showing increases of 64.61% (S-3), 42.31% (S-6), 51.02% (S-9), and 88.29% (S-12), respectively, compared with the CK group ($p < 0.05$).

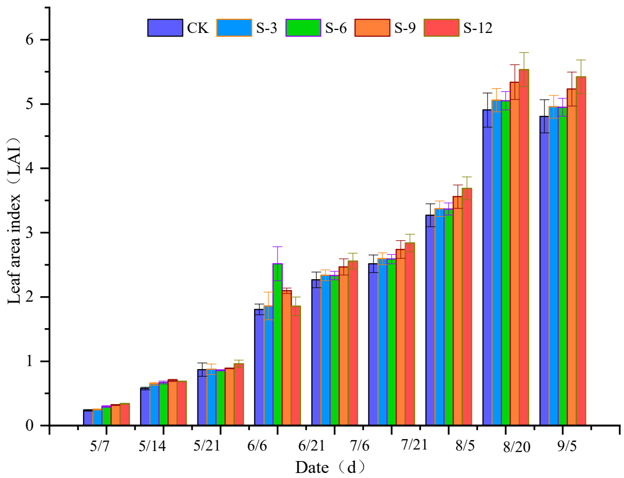

Figure 6. Maize leaf area index with super-absorbent polymer applied.

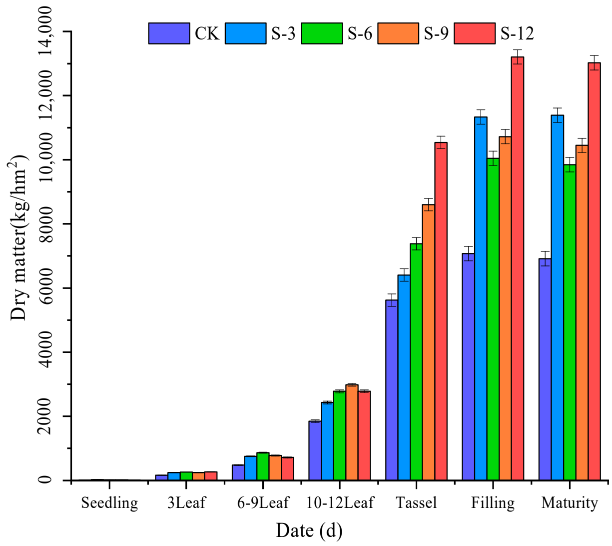

Figure 7. Maize dry matter accumulation by super-absorbent polymer.

4.4. Effects of SAP on Maize Yield

Ten consecutive rows of maize were randomly selected from each treatment plot and harvested separately three times. The ear length, grain number per ear, 100-grain weight of the maize, and the yield per hectare were then determined to analyze the effects of different SAP amounts on these parameters (Table 3). The moisture content of fresh corn is between 20–24%. To ensure the integrity of corn kernels and the accuracy of yield measurement, corn generally needs to be air-dried to 15–17%. Results and analysis showed that the mean grain row numbers increased slightly after SAP treatment by 1.22% (S-3), 3.14% (S-6), 2.18% (S-9), and 2.18% (S-12), respectively, compared to the CK group ($p < 0.05$). The mean ear row number increased by 1.61% (S-3), 4.07% (S-6), 13.53% (S-9), and 13.53% (S-12), respectively, compared to the CK group ($p < 0.05$). The mean 100-seed weight increased by 1.64% (S-3), 0.16% (S-6), 1.44% (S-9), and 3.12% (S-12), respectively, compared to the CK group ($p < 0.05$). Lastly, the yield increased by 4.75% (S-3), 5.98% (S-6), 1.66% (S-9), and 1.19% (S-12), respectively, compared to that of the CK group ($p < 0.05$).

Table 3. Maize yield with super-absorbent polymer applied.

Treatment	Grain Row Number	Ear Row Number	100-Seed Weight			Number of Plants per Mu	Yield per Mu (kg)	Yield per Hectare (kg)
			Replicate 1	Replicate 2	Replicate 3			
	44.0	14.00	38.66	38.36	39.06			
	45.0	14.00	40.90	40.60	41.30			
	46.0	16.00	40.11	39.81	40.51			
CK	48.0	16.00	38.38	38.08	38.78	3700.00	961.22	14,418.27
	43.0	14.00	38.38	38.08	38.78			
	40.0	16.00	39.62	39.32	40.02			
	46.0	16.00	39.12	38.82	39.52			
	48.0	14.00	40.63	40.33	41.03			
	45.0	16.00	39.95	39.65	40.35			
	43.0	16.00	41.36	41.06	41.76			
S-3	43.0	14.00	39.19	38.89	39.59	3700.00	1006.83	15,102.42
	48.0	14.00	40.63	40.33	41.03			
	44.0	16.00	40.37	40.07	40.77			
	45.0	14.00	37.54	37.24	37.94			
	46.0	14.00	40.03	39.73	40.43			
	44.0	16.00	39.45	39.15	39.85			
	45.0	16.00	42.65	42.35	43.05			
S-6	43.0	16.00	40.31	40.01	40.71	3700.00	1018.68	15,280.13
	48.0	16.00	39.66	39.36	40.06			
	49.0	16.00	35.57	35.27	35.97			
	47.0	16.00	37.91	37.61	38.31			
	42.0	20.00	41.12	40.82	41.52			
	47.0	16.00	39.78	39.48	40.18			
	45.0	16.00	39.47	39.17	39.87			
S-9	48.0	16.00	38.69	38.39	39.09	3700.00	977.18	14,657.75
	43.0	16.00	40.05	39.75	40.45			
	47.0	18.00	39.38	39.08	39.78			
	47.0	18.00	40.63	40.33	41.03			
	42.0	20.00	40.71	40.41	41.11			
	47.0	16.00	40.86	40.56	41.26			
	45.0	16.00	41.68	41.38	42.08			
S-12	48.0	16.00	40.54	40.24	40.94	3700.00	972.73	14,590.98
	43.0	16.00	41.24	40.94	41.64			
	47.0	18.00	39.09	38.79	39.49			
	47.0	18.00	39.61	39.31	40.01			

5. Discussion

5.1. Effects of SAP on the Photosynthetic Rate and Yield of Crops

Our results suggest that SAP can improve soil moisture, reduce the diurnal temperature variation of soil [10,11], and prolong the duration suitable for the photosynthesis of maize leaves by providing sufficient soil moisture. For example, whilst the soil temperature of the SAP treatment groups was higher than that of the CK group in the morning and evening, it was lower at 13:00, thereby greatly extending the photosynthesis time by reducing the leaf surface temperature. SAP played an important role in increasing the water absorption capacity and retention during water shortage conditions, and decreasing the negative effects of drought stress [17,38].

In addition, under a sufficient water supply, by raising the leaf transpiration rate, SAP treatment promoted the nutrient transport capacity of individual plants and reduced the damage from free radicals generated by drought stress on chlorophyll and the photosynthetic electron transport system, thereby playing a positive role in dry matter accumulation [17,38]. Variation in the chlorophyll content is one of the most important indicators that reflect changes in leaf physiological activity and also reveals the intensity of leaf photosynthesis, whilst the accumulation of photosynthetic products is closely related to yield [17,20,39]. This study shows that SAP treatment can significantly improve the chlorophyll content, net photosynthetic rate, stomatal conductance, and transpiration rate of maize during tasseling and filling stages. The mean grain row numbers of the SAP treatment group were all elevated slightly compared to that of the CK group, with the largest increase in Treatment S-6 (3.14%). Alternatively, the mean ear row number of Treatment S-9 increased by 13.53% compared to that of the CK group, whereas the average 100-seed weight of Treatment S-12 and the yield of Treatment S-6 increased by 3.12% and 5.98%, respectively, when compared to that of the CK group ($p < 0.05$). Besides, different organic material mulches and the application of the appropriate amount of SAP also have positive effects on soil moisture evaporation and moisture content, the simulated evaporation and barrel control tests were investigated, and it was found that the water retention effects were wood chips, bark, and garden waste in turn [40–43].

5.2. Contribution of SAP to Soil Remediation and Crop Growth

SAP plays an important role in the redistribution of soil water and temperature, soil erosion prevention, maintenance of fertility, and the synergy between SAP and crops [22,44]. According to our results, different SAP doses demonstrated different effects on the soil surface (0–20 cm) temperature, as well as the photosynthetic rate and yield of maize [45]. For example, while all SAP treatments exhibited a certain heat preservation effect on the soil surface temperature at a depth of 0–20 cm, the overall trend was in the order of S-3 > S-6 > S-12 > CK > S-9. Treatment S-3 showed the most significant effect on the stability of the temperature in the application layer, with a variation ranging from 0.03–2.13 °C ($p < 0.05$). SAP could relieve the pressure of water scarcity and increase the soil temperature by 0.72 °C [22], making it beneficial for crops in arid and semi-arid areas [4,17,25,30,38,39].

Abrisham used SAP to improve sandy loam in the Emrani area, which suggested that a low input of SAP could improve the moisture condition, increase the effective water content, and reduce the bulk density and the infiltration rate of the soil, in addition to being the most economic choice [3]. The water retention and salt absorption performance of SAP can promote the emergence and increase the emergence rate of maize in saline soil in semi-arid areas [31,40]. In addition, since SAP can rapidly absorb water when there is insufficient rain or irrigation water [46] and later slowly release it for absorption and utilization by crops [18]. In our study, the research area was mainly composed of clay loam with small porosity. Therefore, after soil irrigation, due to insufficient space for moisture absorption and expansion, excessive SAP application could reduce soil permeability and temperature transmission flux [15,16]. On this basis, it is concluded that the SAP dosage should be carefully adjusted according to the soil texture, soil particle size, regional climate characteristics [7,11,44], and SAP type [6,7,22].

In addition, the soil with an appropriate amount of SAP can improve the germination rate of plant seeds, shorten the budding time, and flowering time, and then promote the plant growth [47]. However, excessive dosage of SAP cannot promote root development, and will inhibit root elongation and the physiological functions of the root, inhibit seed germination, and reduce seedling emergence rate and transplant survival rate [48]. Due to its biocompatibility, it has been reported that it is also used for wastewater purification and seed treatment in agricultural sectors, as well as biological insecticides against fungal infections and as preservatives for winemaking [49].

6. Conclusions

Through monitoring of the main meteorological factors affecting maize growth and the influences of different modifiers on the physiological indexes and yield of maize during its growth stages, the effects of different SAP dosages on soil temperature, photosynthetic rate, maize growth indexes, and other aspects were investigated in detail in this study. The main conclusions of the study include the following:

(1) According to the temperature measurements at 0-20 cm of the soil surface, SAP Treatment S-3 (45 kg/hm^2 SAP) demonstrated a significant effect on the stability of the temperature in application layer, with a variation from 0.03 to 2.13 °C.
(2) Different SAP doses consistently promoted the photosynthetic rate of maize by stimulating CO_2 consumption through the moisture content in all cases.
(3) Although different SAP doses all increased the grain row number, ear row number, 100-seed weight, and yield per hectare of the maize to a certain extent, Treatment S-6 (90 kg/hm^2 SAP) demonstrated the best effect in increasing the grain row number, with an increase of 3.14% compared to that of the CK group; Treatment S-9 (135 kg/hm^2 SAP) demonstrated the best effect in raising the ear row number, achieving an increase of 13.53% compared to that of the CK group; Treatment S-12 (180 kg/hm^2 SAP) demonstrated the best effect in increasing the 100-seed weight, achieving an increase of 3.12% compared to that of the CK group; Treatment S-6 demonstrated the best effect in improving the yield, achieving an increase of 5.98% compared to that of the CK group. It is considered that S-6 is more suitable for promotion.

These results indicate that SAP can be utilized to improve salinized weak alkali soil, thereby improving its effects of water-saving, fertilizer preservation, and yield increase. The application of SAP has made an important contribution to finding a solution for water shortage in arid and semi-arid areas. The economic sustainability of SAP application in the long term and the environmental impacts of this technology on the ecosystem after the end of the crops should be the focus of future research and analysis.

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