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Research on the Water-saving and Yield-increasing Effect of Polyacrylamide

Wei Xindong[1], Yuan Xuefeng[1], Li Yumei[2], Wang Youke[2], Yuan Xuefeng[2], Wei Xindong[3], Li Yumei[3]

[1] *The College of Geoscience and National Territory Resources Chang'an University Xi'an 710054, Shaanxi Province, China*
[2]*National Engineering Research Center for Water Saving Irrigation at Yangling Yangling 712100, Shaanxi Province, China*
[3]*Northwest A&F University Yangling 712100, Shaanxi Province, China*
E-mail: shanxitudi@126.com ,E-mail: liyumei2917@163.com ,E-mail: shanxitudi@126.com

Abstract

The water-saving and yield-increasing effect of PAM was studied through a plot experiment. Results showed that soil water content increased with the increase of the application concentration of PAM. During the whole growth period of maize, soil water content increased by 5.62%~10.96% in comparison with control. After the application of PAM, as for all the treatments the average plant heights of maize were higher than control; ear height, ear length and ear diameter had little change; a great effect on the bald length of maize. Meanwhile, PAM did not have an adverse effect on photosynthesis of maize leaves, transpiration, leaf temperature and crop water use efficiency. This study also showed that with the application concentration of 0.5~2.0 g/m2 of PAM the maize yield increased by the percentages of 5.54%~14.13%.

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Keywords: Polyacrylamide(PAM); Water-saving; Yield-increasing; Crop traits; Yield

1. Introduction

One of the important factors contributing to the low utilization of irrigation water and natural precipitation is that the good structure of soil surface is easy to destroy, soil infiltration capacity decreases rapidly as the irrigation and precipitation time goes, and irrigation water and precipitation forms water accumulation or the runoff generation over infiltration on the soil surface,which leads to the meaningless loss of water or evaporation loss[1]. Researches show that [2~4] 50% of the irrigation water is consumed in the field and so the strengthening of the study and development of the field water-saving technologies has become particularly important. In recent years the research and development of the soil moisture conservation technologies concerning the control of soil water evaporation(mulching and chemical

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regulation and etc.) has got more and more attetion. Of them the application researches on polymer(PAM) have got an extensive attention.

As a sort of soil conditioner, PAM has the effects of strengthening the cohesion between particles of the surface soil, establishing and stablizing water stable aggregate[5],maintaining good soil structure, preventing soil crust, increasing soil infiltration, decreasing surface runoff, preventing soil erosion, inhibiting soil water evaporation and increasing fertilizer utilization rate[6]. PAM has no toxic effect on plant[7].Currently researches on the effect of the application of PAM and other polymers of the same kind on soil infiltration and the laws of runoff yield and sediment yield are hot, while there are less researches on soil moisture preservation, fertilizer conservation and crop yield increase. Therefore, the carrying out of this research is of great significance for the popularization and application of PAM in the arid and semi-arid regions and increasing the utilization of irrigation water and natural precipitation.

2. Materials and methods

2.1 Experimental soil and materials

In this experiment Yangling clay loam was selected as the experimental soil and the experimental materials were PAM produced and provided by the SNF company of France.

2.1.1 Basic conditions of the test area

In this experiment Yangling Lou soil was selected as the experimental soil, whose physical clay content is as high as 63.3%. This area is a warm temperate zone, semi-humid and monsoon area, where the mean annual temperature is 12.9 ℃, the extreme maximum temperature is 42 ℃, the minimum temperature is -19.4 ℃, the annual frostless period is 221 days, the average annual evaporation capacity is 884.0 mm, the average annual precipitation is 637.6 mm and the annual rainfall distribution is uneven. 60% of the annual rainfall is centralized in the four months (July to October), the annual variation is large, the ratio of plentiness to driness is 3.0, and the coefficient of variation is 0.25. In this area the temperature can satisfy the requirement of the two crops a year of maize and wheat, and the rainfall is relatively large. But the drought in the early summer affects the sowing of maize, and the drought in the summer of dog days occurs frequently, which affects the production of maize. The frequent continuous rain in the autumn affects the maturation of maize.

2.1.2 Experimental design

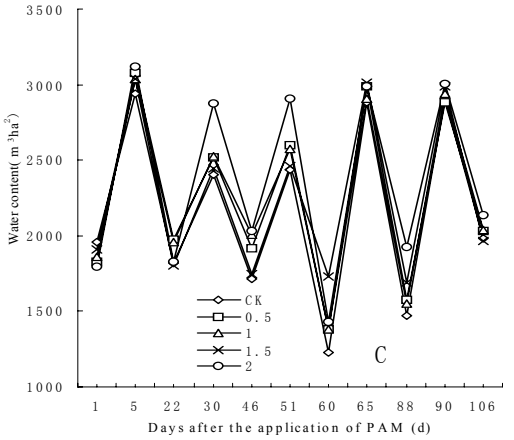

Fig. 1 Effect of PAM on the change of soil moisture

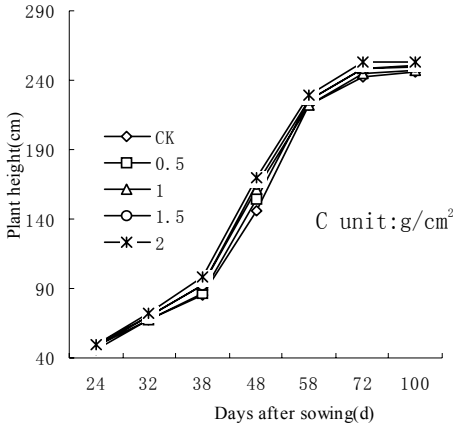

Fig. 2 Effect of PAM on the plant height of maize

The area of the experimental plot was 1.8 m by 4 m.. The row spacing of maize was 60 cm and the plant spacing was 60 cm. Point opening and dibbling was adopted, and three grains was sowed in each point. When maize grows until the trileaf stage, the seedling was established, one plant in each point. The experimental crop was maize and the variety was Nongda 108. As for all the treatments PAM and fertilizer were well mixed and then broad casted while the maize was sowed and the application rate of urea per mu was 15 kg. The application concentrations of PAM were 0 g/m2, 0.5 g/m2, 1.0g/m2, 1.5g/m2 and 2.0 g/m2 respectively. After the first application 600m^3/hm2 was irrigated instantly. The determination indexes were as follows:

1)The determination of the indexes of character and physiology of maize: at the beginning of the jointing stage of maize, the indexes of character and physiology of the fixed 10 plants in the middle position of each plot were determined. A ruler was used to measure the plant height of maize regularly: before the tasseling stage the measurement standards included the height from the soil surface to the highest leaf apex; after the tasseling stage the height from the soil surface to the tassel apex was measured. During the growth process of maize a ruler was used to measure the leaf area of the inverted four leaves regularly and the product of the length and width was multiplied by coefficient of 0.75 for calculation. A vernier was used to measure the stem diameter of maize 10cm from the ground. As the maize caudex is not a regular circular(approximate to an ellipse), based on the experience， the measurement data of the long axis and short axis of stem caudex during different growth periods were converted to the circular diameter to stand for the stem diameter of maize. Meanwhile, in a sunny weather, the Lci photosynthesis system was used from 8 am to determine the physiological indexes of photosynthetic rate, transpiration intensity, stomatal conductance and etc. of the inverted four leaves of the 10 maize sample plants for each treatment.

2)The determination of soil water content: the drying method was used to determine the change of moisture content of different soil layers of 0~10 cm, 10~20 cm, 20~30 cm, 30~40 cm, 40~50 cm, 50~60 cm, 60~80 cm, 80~100 cm respectively before and after irrigation.

3)Harvest and counting: harvest by plot. Random sampling of 10 plants from each plot to determine the indexes of ear length, stem diameter, bald sharpness and etc. of maize.

3. Experimental results and analysis

Through the plot experiment of maize, the change of soil moisture was studied after the application of PAM and from the angles of plant height, stem diameter, leaf area and foliar photosynthesis and etc. the effect of different PAM concentrations on maize growth condition was studied.

3.1 Effect of PAM on the change of soil moisture

With an obvious moisture conservation effect, PAM can decrease soil water evaporation effectively. The soil water dynamics after the application of PAM was shown in fig.1. Experimental results showed that during the whole growth process of maize the water contents of 0~100 cm soil treated with PAM were all higher than control, and with the increase of the application concentration of PAM the soil water content had an increasing trend. During the whole growth period, the water content of soil treated with PAM increased by 5.62%~10.96% compared with control.

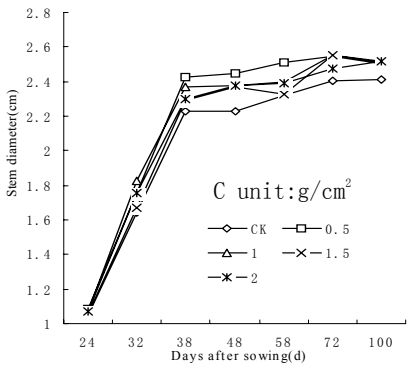

Fig. 3 Effect of PAM on the stem diameter of maize

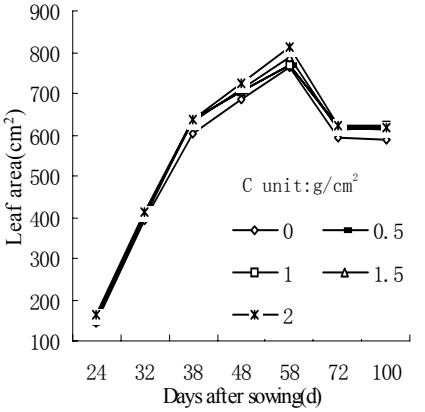

Fig.4 Effect of PAM on the leaf area of maize

Through the observation by the magnifier and vernier it was found that after the application of PAM into soil, the micro-structure of soil changed. A period of time after the application of PAM into soil, because of the intensive evaporation, the water content of the surface soil 3~5cm decreased rapidly and a relatively dry layer was formed, whose volumetric water content was less than 10%. It was also found that the surface and profile of soil treated with PAM was like the honeycomb structure and the soil surface was coarser than control r and had many holes on it.With the increase of PAM concentration the honeycomb structure became more obvious and the thickness became larger, which was 1~5 cm. Soil treated with PAM had a looser texture, and 5 cm~30 cm of top soil was relatively humid.

3.2 Effect of PAM on the plant height of maize

During the growth period of maize, the change of plant height of maize under different concentrations of PAM was shown in fig. 2. As the figure showed the plant heights of maize under the treatments of PAM all increased to different extents compared with control. The plant heights of maize during the stages of jointing and earing had an increasing trend with the increase of PAM concentrations; during the stages of grouting and wax ripeness, when the concentrations of PAM were larger than 1.0 g/m2, there was also an

increasing trend. During the whole growth period of maize, the plant heights under the PAM concentrations of 0.5 g/m2, 1.0 g/m2, 1.5 g/m2 and 2.0 g/m2 averagely increased by 3.51%, 4.58%, 6.64% and 10.16% respectively compared with control. During the growing process of maize, PAM improved soil water and nutrition conditions and decreased the invalid evaporation of soil water, which slowed down the crop water stress, ensured the water supply for crop and had a promoting effect on the plant heights of maize.

3.3 Effect of PAM on the stem diameter of maize

After the application of PAM, the soil water content increased greatly. During the whole growth period of maize, the water contents of 0~100 cm soil treated with PAM were all higher than control with the increasing percentages of 5.62%~10.96%. The improvement of soil water promoted the growth and development of maize and further effectively increased the stem diameter of maize. The changing curve of the effect of PAM on the stem diameter of maize was given as fig.3. It can be seen from this figure that the stem diameters under the treatment of PAM all increased to different extents compared with control. During the whole growth period of maize, when the concentration of PAM was smaller than 1.50 g/m2, there was a generally declining trend in terms of the stem diameter with the increase of the concentrations of PAM; when the concentration of PAM was larger than 1.5 g/m2, the stem diameters had an increasing trend. During the growth period of maize, the stem diameters under the PAM concentrations of 0.5 g/m2, 1.0 g/m2, 1.5 g/m2 and 2.0 g/m2 averagely increased by 6.73%, 5.74%, 3.07% and 4.08% respectively compared with control. To unveil the cause of this phenomenon the further and deeper analysis of the effect of the application of PAM on crop physiology is still needed.

3.4 Effect of PAM on the leaf area of maize

The measured data of the leaf length and leaf width of maize of different growth periods were uesd for calculation to get the mean leaf area under all the treatments. The change of leaf area with time was shown as fig.4.

Researches show that after the application of PAM, the leaf area of maize all increased to different extents, and with the increase of the application amount of PAM the leaf area increased, which showed that PAM had a certain promoting effect on the increase of the leaf area of maize. The measured data showed that the leaf areas of maize were all the largest approximately 58 days after the sowing,when the leaves under the treatment of PAM were deep green and hypertrophy compared with control and the growth was more vigorous. PAM had an especially significantly effect during the jointing stage of maize, when the leaf areas under the concentrations of 0.5 g/m2, 1.0 g/m2, 1.5 g/m2 and 2.0 g/m2 averagely increased by 8.23%, 10.70%, 16.14% and 21.93% respectively compared with control. During the whole growth period of maize, the leaf areas under the concentrations of 0.5 g/m2, 1.0 g/m2, 1.5 g/m2 and 2.0 g/m2 averagely increased by 4.77%,5.84%,7.46% and 10.23% respectively compared with control.

3.5 Effect of PAM on leaf photosynthesis, transpiration, water use efficiency and leaf temperature

In terms of the observed values of the photosynthetic rate of maize there was not an obvious difference between control and the treatments of PAM. The average photosynthetic rates underr all the treatments had a change range of -2.05~1.19% compared with control. But the leaf transpiration rate of maize under the treatments of PAM all decreased compared with control with an obvious diference. The average transpiration rate under all the treatments decreased by 8.76%~13.69% compared with control. The average water use efficiency under all the treatments increased by 11.91%~18.54% compared with control. Meanwhile, PAM had a certain effect on the decrease of the leaf surface temperature. After the application of PAM the average leaf surface temperature decreased by 0.7%~1.56% compared with control, which was

not of the significant level by the test. In general, PAM had little effect on the photosynthetic rate of maize, but it could effectively decrease crop transpiration, which increased the water use efficiency. This study showed that PAM could hold the water and did not have an adverse effect on the photosynthesis, transpiration, temperature and water use efficiency of the maize leaf.

3.6 Effect of different PAM concentrations on the yield and characters of maize

Apart from the water absorbing property of PAM, the increase of soil aggregation and soil water content by PAM and the inhibition of the water evaporation of surface soil by PAM, it also increased the air permeability and permeability, promoted crop root development and enhanced the drought resistance of crop.Meanwhile, the transpiration rate of maize leaf under the treatments of PAM all decreased with an obvious difference.The average water use efficiency under all the treatments all increased compared with control, which provided the advantageous conditions for the yield increase of crop. With the treatment of PAM, the seedling rate of maize increased by 1.2%~3.0%. Also, PAM had a certain effect both on improving economic characters and increasing yield.

It can be seen from table 1 that in the time of harvest the plant heights under the treatments of PAM were all higher than control.When the application concentrations of PAM were more than 1.0 g/m^2, the plant heights of maize had an increasing trend with the increase of the PAM concentrations.The application of PAM did not have a great effect on the stem diameter of maize, and as for the ear diameters the control had smaller ones compared with all the treatments.This study also showed that PAM did not have a great effect on ear height, ear length and ear diameter, but there was a great effect on the length of the baldness of maize, and with the increase of the application concentrations of PAM, baldness length decreased with the percentages of 9.44%~19.51%.

Experimental results showed that with the PAM concentrations of 0.5~2.5 g/m^2 the yield of maize increased by 5.54%~14.13%; when the concentrations were smaller than 0.5 g/m^2, the maize yield increased with the increase of PAM concentrations;with the concentrations of 0.5~1.0 g/m^2 the maize yield decreased with the increase of the PAM concentrations, which was in agreement with the field experimental results basically. But when the concentrations were more than 1.0 g/m^2, the maize yield increased as the PAM concentrations increased. PAM did not have a complete agreement in the effects on maize characters and the final yield of maize, which showed that in terms of the effect on crop yield PAM had something to do with the utilization efficiency of soil nutrient. Therefore, it is necessary to carry out a further study on soil nutrient dynamics after the application of PAM.

It can be concluded from the above analysis that the application of PAM can increase the crop yield; when the concentrations increased to a certain value the maize yield decreased or increased slowly.Therefore, on the economic level, during the application process of PAM the principles of suitable amount should be observed.

3.7 Analysis of water-saving and yield-increasing effects of PAM

Through the above determination an analysis of the effect of PAM on the physiological indexes of photosynthetic rate, transpiration intensity, stomatal conductance and etc.of the maize leaf and the characters of plant height, stem diameter, leaf area, ear length, ear diameter and etc. of maize was made, and finally it came to the effect of PAM on the yield of maize. Through the determination and calculation of the effect of PAM on the yield, water consumption and water use efficiency and etc. of maize, an analysis of its water-saving and yield-increasing effect was made, and the results were given in table 2.

The experimental results showed that the application of PAM can obviously increased crop yield, decreased the total water consumption and increased the water use efficiency. When the concentrations were smaller than 0.5 g/m^2, with the increase of the PAM concentrations, the water consumption had a declining trend, while there was an increasing trend for the yield.In comparison with control, the water

consumption decreased by 175.7 m3/hm^2 and the yield increased by 7.02%. With the PAM concentrations of 0.5~1.5 g/m^2, as the PAM concentrations increased, the water consumption had a declining trend, while there was not a great change for the yield. As for the three treatments of 0.5 g/m^2, 1.0 g/m^2 and 1.5g/m^2 the water consumption decreased by 175.7 m^3/hm^2, 146.1m3/hm^2 and 26.9 m3/hm^2 respectively compared with control, and the yield increased by 7.02%, 5.54% and 6.36% respectively compared with control. When the PAM concentration was 2.0g/m^2, the water-saving and yield-increasing effect was very significant.Compared with control, as for this treatment the water consumption decreased by 306.2m3/hm^2 and the yield increased by 14.13%. With the treatment of PAM the

Table 1 Effect of PAM on the characters of maize

Treatment/g.m^{-2}	Plant height/cm	Stem diameter/cm	Ear height/cm	Ear length/cm	Ear diameter/cm	Baldness length/cm	Mean value/kg.hm^{-2}
CK	244.7	2.402	112.8	23.7	5.155	3.295	5601.85
0.5	251.3	2.414	111.7	24.1	5.204	2.984	5995.37
1.0	247.8	2.496	113.9	24.2	5.221	2.897	5912.04
1.5	248.5	2.478	115.2	23.6	5.196	2.875	5958.33
2.0	252.1	2.503	114.1	24.6	5.198	2.652	6393.52

Table 2 Water use efficiency after the application of PAM

PAM concentration g/m^2	Maize yield kg/hm^2	Water consumption m^3/hm^2	WUEET (kg/m^3)	WUEI (kg/m^3)
CK	5601.85	7389.8	0.76	1.56
0.5	5995.37	7213.3	0.83	1.67
1.0	5912.04	7242.9	0.82	1.64
1.5	5958.33	7362.1	0.81	1.66
2.0	6393.52	7082.8	0.90	1.78

Annotation[1]: Water use efficiency(WUE)=yield/transpiration, irrigation water use efficiency(WUEI)=yield/irrigation amount, transpiration＝rainfall+irrigation amount－△W, where △W is the soil water content, which is obtained by the calculation of the soil water variation.

Table 3 Analysis of the comprehensive economic benefits of maize after the application of PAM

PAM concentration g/m^2	Gross product yuan/hm^2	Increase over control/%	Product per cubic meter water yuan/m^3	Seed,fertilizer,PAM yuan/hm^2	Gross input yuan/hm^2	Benefits yuan/hm^2
CK	4761.6		0.644	225	1998.6	2763
0.5	5096.1	7.02	0.706	425	2156.2	2939.9
1.0	5025.2	5.54	0.694	625	2363.3	2661.9
1.5	5064.6	6.36	0.688	825	2591.9	2472.7
2.0	5434.5	14.13	0.767	1025	2724.9	2709.6

Annotation[2]: the price of maize was 0.85 yuan/kg, water and electricity charge were 0.24 yuan/m3, urea was 2 yuan/kg. The application amount of urea was 225 kg/hm2 (equivalent to 15 kg per mu).The calculation in the table did not involve the employment cost in the field.

water use efficiency and the irrigation water use efficiency both increased compared with control with the average percentages of 10.53% and 8.17% respectively. When the PAM concentrations were of the range of 0.5~1.5 g/m^2, the change of both with the concentrations was not significant.

The factor of the prices of local food, water and fertilizer and etc. taken into consideration the preliminary appraisal of the economic benefits after the application of PAM into the maize field was made and the results were given in table 4.

After the application of PAM the gross product and the product per cubic meter water both increased to different extents. But an analysis with the consideration of the relevant input obviously showed that when the PAM concentrations were larger than 1.0g/m^2, the benefits were relatively low,which was caused by the high price of PAM and the low price of crop, which leads to the fact that the benefits brought by the increase of yield were not more than the input of PAM. Although the benefits increased when the PAM concentration was 2.0 g/m^2, they were still lower than control.These facts showed that although the application of PAM can increase the benefits, the too high price of PAM and the lower additional value of crop leads to diseconomy. Therefore, it is suggested that PAM should be applied on the economic crops with a higher additional value.

4. Conclusions

Through the above research results and the relevant analysis, the preliminary conclusions were drawn:

1） The application of PAM into soil had a certain effect of water conservation. During the whole growing process of maize, the water contents of the 0~100 cm soil treated with PAM were all higher than control.The soil water content had an increasing trend as the PAM concentrations increased. During the whole growth period, soil water content increased by 5.62%~10.96% compared with control.

2） PAM can effectively improve the characters of maize.The research results showed that PAM had little effect on the ear height, ear length and ear diameter, but it affected the baldness length of maize greatly. With the increase of the application concentrations of PAM, the lengths of the baldness of maize decreased by 9.44%~19.51% compared with control.

3） PAM had a certain promoting effect on the leaf area of maize, but it did not affect the photosynthetic rate of maize greatly.The increase of soil water content contributed to the increase of the available water for crop, which effectively decreased the temperature and the transpiration of the leaf surface of crop and increased the water use efficiency. This study also showed that PAM did not have an adverse effect on the photosynthesis, transpiration, temperature of the maize leaf and water use efficiency. With the PAM concentrations of 0.5~2.0 g/m2, the yield increased by 5.54%~14.13% compared with control.

4）The mechanism of saving water and increasing yield of PAM still needs a further experimental study.

5) The too high price of PAM and the lower additional value of crop lead to the disagreement of the output with the input. Therefore，it is suggested that PAM should be applied on the economic crops with higher additional value.

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