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Effect of maize irrigation on water use efficiency in the Semiarid region of Northeast China

H.X. Zhao, S.F. Bian*, L.C. Wang, X.Q. Fang, G.B. Tan, L.H. Zhang, W.P. Yan, N. Sun, X.M. Meng

Jilin Academy of Agricultural Sciences, Changchun 130033, China

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In order to popularize and apply technology of the corn regulated deficit irrigation in Northeast Semi-arid Region and achieve efficient use of water resources, the test was carried out to deal with different degrees of water deficit processing of corn in different growth stage, and studied the effects of Regulated Deficit Irrigation on maize's water consumption, yield and water use efficiency (WUE). The results showed that: in terms of the regulated deficit irrigation of each growth stage, the heavy drought will affect the yield greatly during tasseling periods, while the water deficit had little effect on the yield in seedling stage. It showed a downward opening parabola relationship between the yield and water consumption, and if the maize is short of water in the jointing stage, the yield would be significantly decreased. It needs to be dealt with water deficit of maize appropriately, and the best irrigation treatment mode is the moderate water deficit in the seedling stage (the upper limit of water control was 60%).

Keywords: Regulated deficit irrigation, Water saving irrigation, Water use efficiency, Semiarid area of Northeast China

INTRODUCTION

A serious state of imbalance, the efficiency of water use is not high, so that the distribution of water resources and the distribution of productive forces are not matched. There are large reserves of water resources in our country, but due to the large population base, so there is a relatively small amount in per capita use of water, China is one of the world's 13 water-poor countries [1]. Water is the lifeblood of the agricultural production; it has been the basic norms and ethics in our daily life to save water in production and life. Irrigation water use in the country's total water use can reach 73.4%, it can be said that the water consumption is very large, but the irrigation water use efficiency in agriculture is only about 43% of the developed countries [2]. With the accelerated process of urbanization in China, population and economic prosperity involves food problem of basic necessities of life, the most eye-catching is water use and water saving in agriculture. The drought conditions in recent years force us to take water-saving measures and technology to reduce water loss with the maximum extent and improve water use efficiency.

The irrigation system can improve the water use efficiency without reducing the yield, and it is an effective way to solve the problem of water resources irrigation in agriculture in China, which is in line with the current sustainable development strategy.

Northeast region is the most important commodity grain production base in China[3]. The west of Northeast China has a temperate semi humid continental monsoon climate perennially. Due to the monsoon, and it is often windy and the rain is low in spring, the spring drought often occurs in this region, resulting in people's economic burden, waste people's both energy and money, so it constrains social development and brings great influence on agricultural production to some extent. Maize is an important cereal crop, not only can be taken as health food to human and animal feed with rich nutrient, but also has a high industrial value; its straw and maize ear was processed into fuel, to provide raw materials for further solving the energy problem. It is obvious that maize plays a significant role in the grain crop cultivation and production in the world. In recent years, it has been stimulating the cultivation of maize due to its rising prices, the planting area is increasing year by year. In 2011, China's total production of corn continued to rise, accounting for about 24.5% of the world [4]. Especially in recent years, China has increased support for agriculture, the planting area is gradually expanded in the northeast area, and the yield is increased, so there has been a general uptrend in the yield with promising results. As one of the important factors of maize yield, how to maximize the efficiency of water use is extremely important. It will affect corn yield if the irrigation stage is inappropriate and choice is unreasonable, it will make farmers' harvest years into a bad crop years.

To whom all correspondence should be sent:
E-mail: zhaohongxiang1973@163.com

In terms of regulated deficit irrigation and its effects on the quality and physiological indexes of crops, domestic and foreign scholars have carried out a lot of research. The research of relationship between irrigation water and grape growth, yield and wine quality by Intrigliolo[5]. indicated that it does not affect the yield and wine quality under the regulated deficit irrigation conditions. In Liu Xianzhao's study[6] of apple showed that root partition irrigation can effectively improve the water use efficiency and fruit quality. The above studies were focused on the effects of water content in the root zone of the plant or irrigation water on the growth of fruit trees, water use efficiency and fruit yield, quality and so on. Although regulated deficit irrigation technology made a large number of research results in the field of fruit trees, but there are still some problems, first, some of the test results stay in the pot, greenhouse and simulation stage; second, there is a few research of crop, and systematic research is rarer. Especially, there lacks of the study of maize system in the Northeast Semiarid Region, especially in the different stages of fruit development, the different irrigation methods on its water consumption, growth, yield and quality are rarely reported.

In this paper, the effects of water deficit treatment on the growth of maize were obtained through experimental study, so as to select a reasonable crop regulated deficit irrigation growth stage and regulated deficit level. According to the different stages of maize in the black soil region and different regulated deficit irrigation, the water consumption of maize was discussed.

EXPERIMENTAL

Test Conditions

Test area is a comprehensive test base in the west of Jilin Province, its total area is 55 km^2; it has a temperate continental monsoon climate, the annual average temperature is 4.9℃, and frost free period lasts 157 days. The range of average annual rainfall is approximately 400 mm , and June to August is the multiple period of rainfall, it accounts for about 70% of the total rainfall throughout the year. And the multi-year average evaporation is about 796 mm.

The content of nitrogen (N) in soil is 154.4 milligram per kilogram, the content of phosphorus (P_2O_5) and potassium (K_2O) are 40.1 milligram per kilogram and 37.68 milligram per kilogram respectively, the soil pH value is 7.27. The average field water holding rate in the 50cm soil layer is 28.57%, and the soil bulk density is 1.14 gram per cubic centimeter.

Experiments

The pot experiment is used in the test, and variety of maize is Demeiya No. 1, it is carried out in the mobile canopy. The design of the experiment is to set up 16 treatments, and repeat 3 times under the same test condition. Plastic bucket size: the height is 33 cm, and the diameter is 29 cm. Soil needs to be dried, and the soil particles will put into the plastic bucket after the sieve to ensure that the weight of soil in each basin is the same, they are all 15kg. There are 5 grains to be planted in each pot, and keep a full stand of seedlings in the trefoil stage. Using electronic balance to weigh the water content in the basin and record their change. The time to weigh is at 17:00 in the afternoon, and using dosage cup to and water to the standard control until the crop is mature. Through observation and record biological traits of Maize under different water treatment, analyzing the relationship between biological traits and yield of maize under different water treatment and law of water consumption and water use efficiency of Maize under different deficit irrigation.

The test design is based on the growth stage of Maize in the upper limit of different soil moisture, and the maize's growth and development period and yield are studied for the purpose, it will be divided into four growth stages, that is seedling, jointing, tasseling periods and grain filling stage, and there are 4 water level to be designed in each growth stage (to account for the percentage of field water capacity).

Phenological period

Record the growing period of different treatments and the growth situation of each treatment and the control of diseases and insect pests.

Soil moisture

Using the soil drilling method for the determination of drying.

Agronomic traits

①plant height: using meter rule to measure, the starting point of height is from the base of the plant to tassel top; ②the stem diameter: using vernier caliper to measure, the position to be measured is the first section of the above the root of maize plants; ③ root weight: after harvest of maize, removed the root out of the basin, washed them with water, and dried them, then put them into the bag respectively, into oven, drying them at 105℃ for 8 hours, take out to weigh them until the quality does not change, and record the corresponding root weight; ④ the dry weight of aboveground part: after harvest of maize, dry the aboveground part, put it into the bag respectively, then into the oven,

and drying them at 105°Cfor 8 hours, then take out to weigh them until a constant weight, record the corresponding weight of the aboveground part; ⑤ the calculation of water use efficiency of maize: Water utilization efficiency of Maize = yield / water consumption.

Yield

10 ears were selected randomly before harvest of maize from per plot, and test their ear length, bald tip length, ear diameter, ear rows number, grain number, 100 kernel qualities, the yield is the measured results of acquiring harvesting alone and threshing alone.

Statistical analysis method

The test data were analyzed by SPSS22.0, and the 3 repeated values of different treatments was analyzed by the variance. If the difference was significant ($P < 0.05$), multiple comparisons were performed. The average value of each process and the drawing of the graph are processed by Excel 2007.

RESULTS AND DISCUSSION

The effect of irrigation on plant height

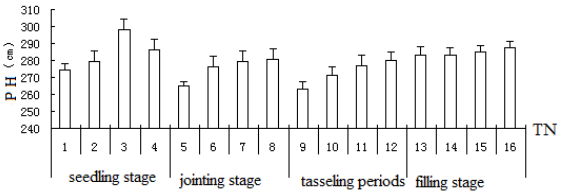

Fig. 1. Plant height in different irrigation levels

It can be seen from the Figure 1, the deficit irrigation in the various growth stages, the measured plant height changes a lot in the seedling stage. The plant height difference is 24.2 cm after deficit irrigation in seedling stage, 15.9 cm in jointing stage, 16.9 cm in tasseling periods, and 4.7 cm in filling stage. The maximum plant height difference reached 35.1 cm in each growing stage of 16 treatments. Except for seedling stage, the plant height showed ladder trend in other growth stages for processing, namely, the height is gradually increasing with the increasing of deficit degree, so it explained that deficit irrigation plays a certain role in promoting the growth stage of the maize in seedling period. In the early stage of seedling, deficient water can promote root growth, and then promote the growth of plant height in the late stage. The plant height of treatment 5 and 9 water deficit degree of 40% in jointing, and tasseling stage was significantly lower than the plant height in other growth stages under the different water deficit treatment ($P < 0.05$). It is not suitable for severe deficit in jointing stage and tasseling stage, otherwise it will affect maize normal growth. The growth stage of maize plant is mainly concentrated in the early time, late time is the formation of maize grain, and so during the grain filling period, the deficit irrigation has little effect on plant height. The above chart shows that the plant height after regulated deficit irrigation in filling stage changes a little ($P > 0.05$). Research shows that water and fertilizer is the main factor affecting the yield of maize, in certain irrigation condition, the yield will be increased with the increase of fertilizer, but reached a certain amount of fertilizer, the yield did not increase or even reduce; also in certain fertilization level, the yield will increase with the increase of irrigation amount, but to achieve a certain amount of irrigation, the yield did not increase or even reduce, thus making reasonable irrigation and fertilization system on maize yield, saving water, improve water and fertilizer utilization rate is very important.

The effect of irrigation on stem diameter

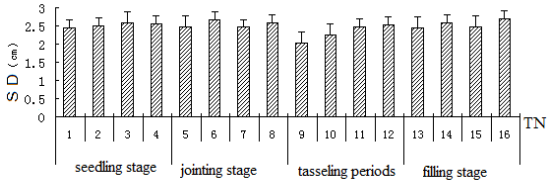

Fig. 2. Stem diameter in different irrigation levels

It can be seen from the Figure 2, after regulated deficit irrigation in the various stages, the measured stem diameter changes a lot in tasseling periods, and it showed a ladder upward trend with the increase of the degree of regulated deficit irrigation. In tasseling stage, the stem diameter of treatment 12 is more 0.5 cm than that of treatment 9, the difference was significant ($P < 0.05$), while in seedling, jointing stage, filling stage grew respectively 5.7%, 8.9% and 9.8%, the whole stem diameter is about 2.45 cm. It can be seen that regulated deficit irrigation on corn stalk diameter impact is relatively large in tasseling stage. Tasseling stage is the key stage of corn growth, is also the accumulation process of the aboveground part, by straw cannot transport nutrients needed for maize growth by absorbing more water, resulting in straw lack of nutrition and contraction, stem diameter is decreased, and therefore there appeared the phenomenon. So under the suitable soil moisture conditions, the growth of stem diameter contributes to improving the lodging resistance and good foundation for improving the yield of Maize in the late.

The effect of irrigation on root weight

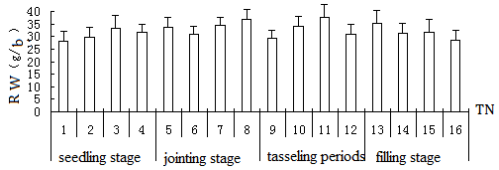

Fig. 3. Root weight in different irrigation levels

It can be seen from the Figure 3, after water deficit treatment in the seedling stage, the root weight of treatment 11 reached 37.6g per basin, followed by the treatment of 8, the root weight is 36.9 g per basin. Overall, all treatments did not follow the law, and the differences between the treatments were not significant ($P > 0.05$), in treatment at seedling stage, root weight of treatment 3 is the largest, is 33.4 g per pot, the jointing stage is treatment 8, tasseling stage is treatment 11, the filling stage is treatment 13, the average root weight is 35.3 g per pot. Water deficit in seedling, water stress will affect the physiological metabolism. During the seed germination, seed vigor and germination rate will be reduced, resulting in their own material conversion rate being decreased. Maize seedlings will absorb enough growth required nutrients under water stress in order to ensure normal growth and development of roots, its root needs to be extended to more distant, and then form larger absorption area to adapt to the arid environment. During the filling stage, the root system has been basically formed, so the treatment of 13, 14, 15, 16 of the root weight is relatively small.

The effects of irrigation on root ratio

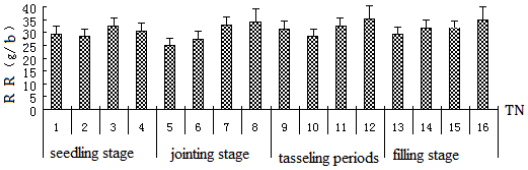

Fig. 4. Root ratio in different irrigation levels

It can be seen from Figure 4, the root ratio changed a little after the water deficit in the seedling stage, the root ratio of treatment 5 after severe water loss in jointing stage was 23.67%, it is significantly higher than that of the treatment for the rest in the jointing stage（$P<0.05$）, the root ratio after deficit water treatment in tasseling stage is larger, its maximum of root ratio is 26.9% than that of treatment 11 after moderate water deficit and root cap after deficit water treatment in grain filling stage exhibits that it will be decreased with the decreased water deficit than the overall, because the water supply is adequate, root ratio of treatment 16 is the minimum of 15.25%. In the growth process of maize, a certain degree of water deficit processing can increase the root ratio of corn plant. To control the assigned amount between the underground part and the aboveground part so that the root system can obtain enough assimilates through their own transformation and inhibit growth of aboveground part and the dry mass increased a little, and the process of maize growth need draw nutrition by root from the soil, use of the internal structure of straw to deliver nutrients to grain, then promote its growth.

The effect of water deficit treatment on water consumption in seedling stage

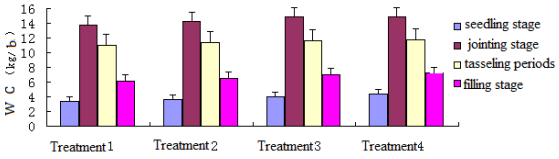

Fig. 5. Water consumption of water deficit treatment in seedling stage

It can be seen from Figure 5, water deficit treatments in seedling, the average water consumption of each treatment in the seedling stage is 3.86kg per basin. As a whole, water consumption of corn seedling has no big difference, but for the late jointing stage, tasseling periods and grain filling stage had little change. After deficient water treatment, the total water consumption of the treatments 1, 3, 4, and 2 were 34.28 kg per basin, 35.78 kg per basin, 37.49 kg per basin, 38.28 kg per basin, respectively. It can be seen from the above chart that water consumption in jointing stage was significantly higher than other stages ($P < 0.05$), followed by tasseling and filling period, and the water consumption in seedling stage was significantly lower than that of other stages ($P < 0.05$), because the seedling stage is the growth stage, the water demand is not so large. A small amount of water on the irrigation and Han Zhanjiang can not only meet the water requirement of crop metabolism, improving the resistance of plants, and because of the characteristics of induced plant compensation of water, the water use efficiency increased significantly, is theoretically consistent.

The effect of water deficit treatment on water consumption in jointing stage

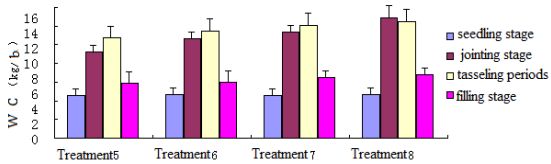

Fig. 6. Water consumption of water deficit treatment in jointing stage

It can be seen from Figure 6, after the water deficit treatment at jointing stage, treatment 8 changes greatly, its water consumption reached the maximum in jointing stage, but water consumption of treatments 5, 6, 7 reached the maximum in tasseling stage, indicating that if the deficit water is serious in jointing stage, it will increase the water consumption in tasseling stage to provide the required amount of water for corn growth in the later stage. The water consumption was small if it has normal irrigation during the seedling stage, and the water consumption treatment 8 is 3.59kg per basin more than treatment 5 in the jointing stage, which was enough to prove that the water requirement of Maize at the jointing stage was large. Water deficit at jointing stage, with the increase of the degree of loss, the amount of water consumption is also an upward trend, so there is a close relationship between the jointing stage and the tasseling stage. In contrast, the water consumption in the grain filling stage showed stable, there is no big difference（P＞0.05）.

The effect of water deficit treatment on water consumption in tasseling periods

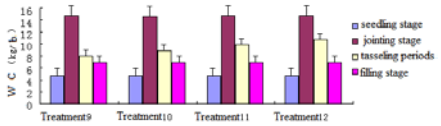

Fig. 7. Water consumption of water deficit treatment in tasseling period

It can be seen from Figure 7, due to normal irrigation treatment in the seedling stage and jointing stage, the water consumption of each treatment changed little. Treatment 9 is to adjust the deficit under 40% of field water capacity, the difference of the water consumption between the jointing stage and tasseling stage can reach the 6.59kg per basin, the minimum difference is 3.95kg per basin, water consumption is significant difference. In the tasseling stage, the water consumption and growth were seriously affected by water deficit treatment. However, the difference of water consumption was not significant when the normal irrigation was resumed at the grain filling stage. The average water consumption between different treatments was 35.55kg per basin. As can be seen, the overall difference of the total water consumption was not significant, but the water consumption difference of the four treatments in the jointing stage and tasseling stage was significant（P＜0.05）.

The effect of water deficit treatment on water consumption in filling stage

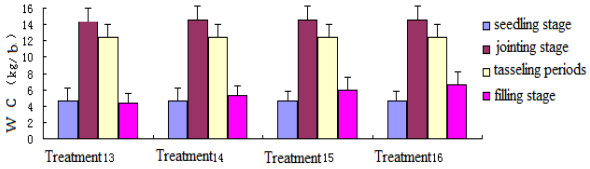

Fig. 8. Water consumption of water deficit treatment in filling stage

It can be seen from Figure 8, due to normal irrigation in seedling, jointing and tasseling stage, little differences are shown in the figure, the overall level is also smooth, so it has not prominent features, and water consumption in jointing stage is still the largest（P＜0.05）. During the filling stage, the water consumption of the treatment 16 is more than 2.16kg per basin to treatment 13. The grain filling stage is formation stage of corn grain, it needs more water to transport sufficient nutrients needed by it, so it is helpful to prevent plant senescence by keeping soil moist state appropriately, also can prolongs the duration of grain filling, improve the degree of filling, and increase grain weight.

The effect of water deficit treatment on water consumption in filling stage

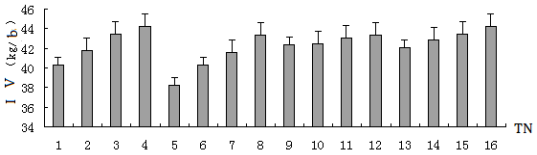

Fig. 9. The effect of irrigation volume in different growth stages

As can be seen from Figure 9, the irrigation amount of each treatment during the growth period showed a stepwise rise, the irrigation amount in the seedling stage and the jointing stage had a larger change, but changed slightly in tasseling stage and filling stage. The irrigation amount of treatment 5 is the minimum in jointing stage under degree of 40% field capacity. In its whole growth period of irrigation, the irrigation amount is 38.27kg per basin, it is significantly less than other treatments ($P < 0.05$), the difference between treatment 5 and 8 is 5.07kg per basin. After regulated deficit treatment in the seedling stage, the difference of irrigation amount between treatment 1 and treatment 4 is 3.98 kg per pot. After regulated deficit treatment in the tasseling stage, irrigation amount difference between treatment 9 and 12 is 1.01 kg per basin. After regulated deficit treatment in the tasseling stage, irrigation amount difference between treatment 13 and 16 is 2.18kg per basin.

After deficient water treatment of maize plants in seedling stage and jointing stage, the water requirement of maize plants changed greatly, which was consistent with the natural growth of the plants.

Yield of water deficit treatment in different growth stages

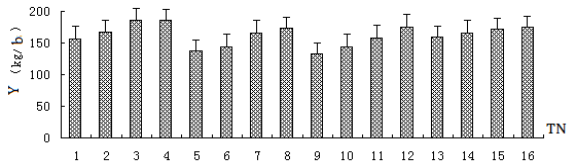

Fig. 10. Yield of water deficit treatment in different growth stages

The output of each treatment present stepped changes. production of treatment 3 is the largest after deficient water treatment in the seedling stage, its output is 186.45g per basin, increased 29.65g per pot than treatment 1（P ＜0.05）, the yield of treatment 4 was less than 1.1 g per pot to the treatment 3（P ＞0.05）, the yield of treatment 5 and 9 are 13.76 g / pot and 132.2 g / pot respectively, the two treatments had the lowest yield in 16 treatments（P ＜0.05）. The average output of treatments 5, 6, 7, 8 in jointing stage is 15.53 g / pot, The average output of treatments 9, 10, 11, 12 is 152.39 g / pot in tasseling stage, and yield average of treatment 1, 2, 3, 4 in seedling is 173.78 g / pot, yield average of treatment 13, 14, 15, 16 in filling stage is 167.68 g / pot. Based on the above analysis, the water deficit treatment in jointing and tasseling stage will affect the yield greatly. Compared to water deficit treatment and in seedling stage and filling stage, the yield difference is 16 g / pot. According to the above shows, the water deficit treatment in the jointing stage and tasseling stage leads to heavy drought of the corn plant; it will have a serious impact on the grain maturing rate and yield of maize in latter time. The moderate water deficit in maize seedling has significant effect on the yield, so moderate drought in the seedling stage can improve crop yield, severe water deficit in tasseling stage increases the corn ear barren tip length, it will has adverse effects on the final yield of corn. Tan Hua[7] thought that water deficit treatment of corn in tasseling stage will lead to bad effect on maize pollination, and the reduction of the seed rate, and even lead to tasseling difficulties and other issues, which is what people often say “card neck drought”. Therefore, it needs sufficient irrigation in the tasseling stage, otherwise it will seriously affect production. Fan [8]believed that due to the reduction of the leaf area in the grain filling period, the daily water consumption is decreased, but due to a longer period of time, the stage of water consumption is still more. Water deficit treatment in filling still can maintain a high yield, is because the growth stage before the grain filling stage has not been influenced by water deficit.

The effect of irrigation level on the water use of Maize

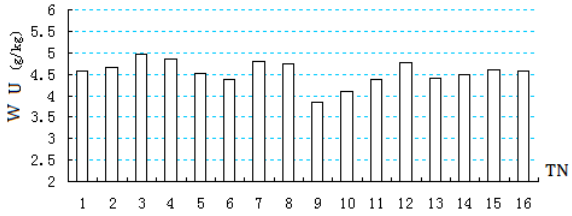

Fig.11 Water utilization efficiency of water deficit treatment in different growth stages

Table 1. Effect of irrigation level on water use of Maize

Treatment number	Water consumption（kg/basin）	Yield（kg/basin）	WUE (g/kg)
1	34.29±6.14	156.8±12.9	4.57±1.13
2	35.78±6.27	166.5±12.5	4.65±1.52
3	37.49±6.56	186.4±12.3	4.97±1.11
4	38.27±6.12	185.3±13.5	4.84±1.12
5	30.47±6.11	137.6±12.8	4.52±1.25
6	32.77±6.25	143.7±12.6	4.38±1.19
7	34.57±6.68	165.8±12.8	4.80±1.28
8	36.84±6.42	174.2±12.4	4.73±1.14
9	34.32±6.32	132.2±11.2	3.85±0.92
10	34.91±5.21	143.2±12.8	4.09±0.89
11	36.72±5.12	158.4±12.9	4.39±1.19
12	36.82±5.58	175.7±12.5	4.77±1.26
13	36.07±6.56	158.6±12.8	4.40±0.93
14	36.91±6.91	165.3±12.5	4.48±1.42
15	37.47±6.45	172.0±12.7	4.59±1.12
16	38.25±6.25	174.8±12.5	4.57±1.14

It can be seen from Table 1 and Figure 11, the degree of water deficit is 60% of the field water holding capacity in the seedling stage, the maximum of water use efficiency of the treatment 3 is 4.97g per kg per basin, it is significantly higher than other treatments ($P < 0.05$). The average value of water utilization efficiency of treatment 1, 2, 3, and 4 after water deficit in seedling is 4.75 g / (kg / basin), it is the maximum value for regulated deficit in four stages, water use efficiency is the highest, so it shows that water deficit treatment in the seedling stage can improve water use efficiency. The water use efficiency in jointing period is 460 g / (kg / basin), water utilization efficiency of treatment 5, 6, 7, 8 float up and down at this value, changes is obvious in tasseling stage, the difference between treatment 9 and 12 is 0.92g/ (kg / basin)（P＜0.05）and water use efficiency in this growth stages changes a lot after regulated deficit irrigation. The regulated deficit degree in tasseling stage is 40% of field water holding capacity, water use efficiency of treatment 9, is 3.85 g / (kg / basin) in minimum, regulated deficit in the period will make soil moisture supply relatively insufficient, and maize plant growth will be affected, so it cannot manufacture organic matter and transport smoothly to the grain plant, it is easily to lead reduction. the water use efficiency value of treatment 13, 14, 15,

16 in filling stage shows smooth in the overall, they have not much difference, water use efficiency value float up and down in 4.51 g/ (kg / basin), change a little. Comprehensively, regulated deficit in seedling stage and jointing stage will have high water use efficiency while regulated water deficit in tasseling stage, its water use efficiency was affected most, and regulated water deficit in filling stage, its water use efficiency was affected least, it is stable.

It can be seen from Figure 12: it showed a downward opening parabola relationship between the yield and water consumption, this is consistent with the conclusion of Kang S Z [9]; when water consumption is 134.0kg / basin, yield is 465.62g / basin, the parabolic value reached the maximum, namely the water utilization efficiency is 3.47g/kg at this moment. When the water consumption is lower than 134kg/ basin, the yield will be decreased with the decrease of water consumption, and the water consumption is higher than 134 kg/ basin, the yield will be increased with the decrease of water consumption. This shows that excessive water deficit will lead to a decline in maize production; moderate water deficit can not only reduce the consumption of water, but also improve the yield of corn, and achieve the effect that save water and increase grain. Corn is a dry crop, the demand for water is not very large, only in the individual growth stage, and water requirement is large. The experimental study showed that moderate water deficit in seedling stage was favorable to the growth of root system and the formation of grain in the later stage. This is the reason why farmers often restrain the growth of seedlings (for root development) in the seedling stage.

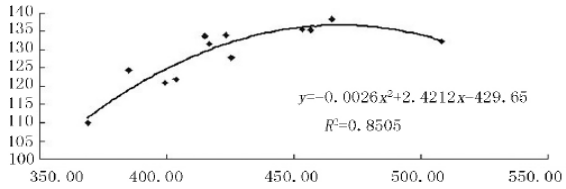

Fig. 12: Relationship between maize yield and water consumption

Through the regression analysis of water consumption and yield in each growth stage, the relationship between the two is drawn, and obtains the corresponding relation type:

$y=-0.0026x^2+2.4212x429.65$ ($R^2=0.8505$)

CONCLUSION

This experiment carried out a pot experiment of maize regulated deficit irrigation, which is aimed at the problem of lack of water resources and the lower crop yield and water use efficiency in the semiarid region of Northeast China. Experiments were used to study the biological characteristics, water consumption and water use efficiency of maize under different regulated deficit period and different water deficit degree. The preliminary results of the study are summarized as follows:

1. After water deficit in each growth stage has normal irrigation, the plant height increase higher under the high level of regulated deficit treatment than under the low level of the regulated deficit treatment, but the effect of regulated deficit treatment in grain filling stage on the plant height was not high.

2. The difference of the water requirement of maize is relatively large in different growth stages.

3. Water deficit in the jointing stage and tasseling stage has great effect on the yield of maize, the yield was decreased obviously.

4. Sufficient irrigation increases water consumption of plant growth, but inhibits the growth of the dry matter on aboveground, and waste water resources, regulated deficit treatment in seedling can increase water use efficiency of maize.

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