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Winter Wheat Water Use Efficiency in Middle Scale

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Abstract: Winter wheat water use efficiency in the semiarid regions in middle scale was studied in the study, combined with the theory of Water Use Efficiency (WUE) and the reliably officially statistical data. The results indicated that the average WUE for the winter wheat in Hebei province varied from 1.1 to 1.30 kg m^{-3} and it was much higher than other regions in China.Tangshan city was a region of a highest consuming water and much lower winter wheat yield among the eleven cities in the middle scale. Winter wheat WUE in Handan and Cangzhou were much higher among them, while their consuming water and winter wheat yield were both lower. The consuming water in Baoding was the highest in Hebei province but the winter wheat yield was much lower. And the irrigation water in Shijiazhuang was less than the one in Baoding, its yield was highest among the eleven cities. To obtain higher yield and higher water use efficiency with lower irrigation water, we suggested that the irrigation schedules in Shijiazhuang, Qinghuangdao, Handan and Cangzhou should be referenced so as to optimize and adjust the irrigation schedules in other cities.

Key words: Winter wheat, water use efficiency (WUE), middle scale, water balance, yield

INTRODUCTION

Winter wheat water use efficiency is one of the hottest topics in recent years and more researches related with the topic are made. For example, Li *et al*. (2010) studied root growth, available soil water and water-use efficiency of winter wheat under different irrigation regimes applied at different growth stages in North China and draw a conclusion that irrigation at the jointing and heading stages results in high grain yield and WUE. Wu and Bao (2012) studied wheat water use efficiency in drought condition and in semiarid regions and the results showed that photosynthesis rate, stomatal conductance and transpiration rate were the most important leaf WUE parameters under drought condition. Due to climate warming and to a fall in rainfall over the past 50 years, wheat water use efficiency had significantly increased (Xiao *et al*., 2013). And effects of different tillage systems on soil properties, root growth, grain yield and water use efficiency of winter wheat in arid northwest China were also studied by Huang *et al*. (2012) and the results suggested that Chinese farmers should consider adopting conservation tillage practices in arid northwestern China. Ram *et al*. (2013) did also similarly the research. To increase winter wheat yield and water use efficiency in water-limited environments, a research on a mixture of old and modern winter wheat cultivars was done by Fang *et al*. (2014).

However, winter wheat Water Use Efficiency (WUE) in middle scales is very limited. Especially, it is for the main grain production areas in China, in which there exist some problems such as water shortage, water pollution, low precipitation, high evaporation, arid climate, high population density and low per capita water resources etc. So as to reduce the waste of water resources, improve agricultural crop water use efficiency and increase crop yield etc, it is necessary to study WUE of the main food crop such as winter wheat in middle scales in semi-arid regions like most of cities in Hebei province.

EXPERIMENTAL SECTION

Experimental region choosing: The experimental regions in the paper include eleven cities in Hebei province, in which main water supplying for all of industries is from the Haihe river. It is reported officially that the total area in Hebei province accounts for more than 50% of the Haihe river, while the area of other provinces such as Liaoning, Shanxi, Shandong, Inner Mongolian, Henan, Peking and Tianjin etc is 0.5, 18.6, 9.7, 4.0, 4.8, 5.3 and 3.7%, respectively. Considering the proportion of Hebei province accounting the Haihe river, the similar climatic conditions, in which annual mean temperature is 1.5~14°C, annual mean precipitation 539 mm, annual mean sunshine 2500~3000 h, annual mean continent evaporation 470 mm and it is for varieties of crops like winter wheat to grow.

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Finally, the Hebei province in the Haihei river is selected the experimental region and middle scale in the paper. And winter wheat is the main crop.

Methods: Crop WUE can represent the degree of water resources utilizing effectively. Much higher crop WUE is, much more the potential of water saving under other conditions no changing. Generally, WUE can be defined as the crop yield (Y) obtaining from unit of crop actual consuming water (ET) in its growth. And it can be calculated with the following equation:

$$\text{WUE} = \frac{Y}{\text{ET}} \tag{1}$$

where, WUE is the crop water use efficiency and its unit is kg m^{-3}. Y is crop yield, kg. ET is crop actual consuming water in its growing period, m^3 or mm. It is not so easy to get the relative data such as Y and ET in different regions. To ensure winter wheat WUE in the middle scale, Y can be gotten by comparing with the data investigated the representative farmland and officially statistical data, while ET can be done with water balance equation. And all of data are from reliably official source, such as Heibei province water resources assessment, Haihe river water resources report, China yearbook etc. And it can be analyzed below.

RESULTS

Water balance analysis:

Precipitation: By analyzing precipitation data in eleven cities in Hebei province, we can find that the Accumulating Precipitation (AP) varied from 430 to 514 mm from 2004 to 2006 and the total precipitation from Jun to Sep was accounting for more than 77% of the yearly ones and there existed the characteristics such as heavy rainfall, short lasting time, rainstorm. While the total rainfall was much less in other eight months , when it is the winter wheat growth period. And per mu precipitation for winter wheat in eleven cities from 2004 to 2006 (Fig. 1).

The statistical data indicated that precipitation per mu existed a bigger difference in the eleven cities. The reason was that different geographic location has its own precipitation rules and the rainfall in each city kept yearly stable.

Irrigation water: It is in the winter wheat growing period that there is no enough precipitation to satisfy its growth in the semiarid regions such as the eleven cities in Hebei province. And to irrigate winter wheat is a necessary condition to keep the winter wheat surviving in its growth period. And irrigation water included surface water and underground water in the study regions. So the total yearly irrigation (I_t) could be gotten by making the yearly irrigation water in each city from 2004 to 2006 calculating. And it can be shown below:

$$I_t = \sum_{i=1} [\![I_i = \sum_{i=1} (I_{si}]\!] + I_{ui} \Big) \tag{2}$$

where, i is the number of the study regions in the middle scale, 1 is the total yearly underground irrigation water.

And the yearly irrigation water showed that the total irrigation water basically kept about 10 billion m^3 from 2004 to 2006, including more than 8.2 billion m^3 of groundwater irrigation, which indicated that the groundwater irrigation was the main irrigation way in each city in the middle scale. And there were 10 cities among the 11 cities, in which their underground water irrigated accounted for more than 54% of the total irrigation water. And the proportion in Baoding city was the biggest, 90%. The irrigated underground water in Baoding was 1.78 billion m^3, 18.3 billion m^3 and 18.1 billion m^3 from 2004 to 2006, respectively. While the average proportion from 2004 to 2006 in Shijiazhuang and Xingtai were 84 and 81%, respectively.

Furthermore, the irrigation water per mu in Tangshan was biggest, 500 m^3 mu^{-1}. And the second biggest one was in Baoding, 375 m^3 mu^{-1}. While the least one was in Qinghuangdao, 111 m^3 mu^{-1} (Fig. 2). Generally, the average irrigation water per mu in Hebei province was 280 m^3 mu^{-1}. It showed that there existed a bigger difference for the irrigation water in each cities in the middle scale. So we must adjust the irrigation water per mu in each city and make a suitable irrigation schedules so as to utilize fully the limited fresh water resources and accomplish the object of water saving.

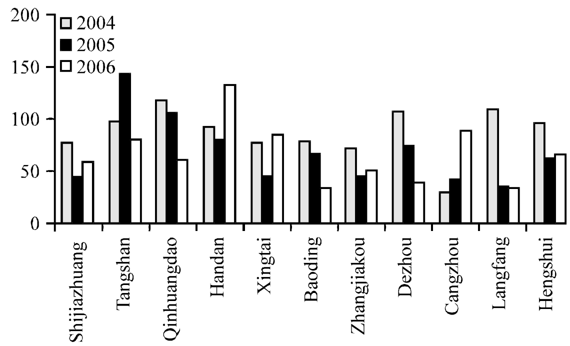

Fig. 1: Per mu precipitation for winter wheat in eleven cities from 2004 to 2006 (m^3 mu^{-1})

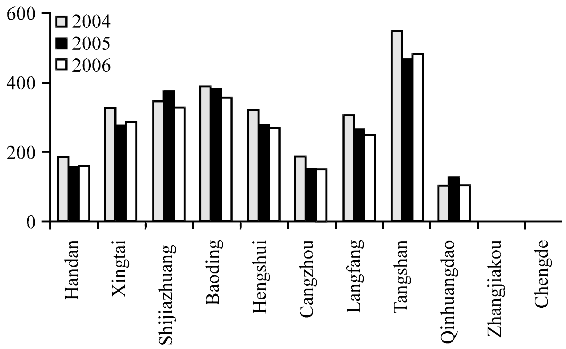

Fig. 2: Per mu irrigation amount in each city from 2004 to 2006 (m^3 mu^{-1})

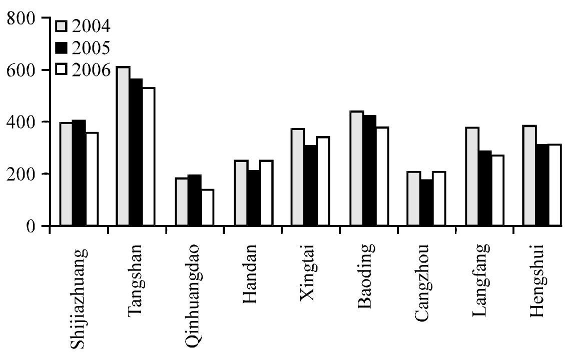

Fig. 3: Consuming water per mu in each city in the middle scale from 2004 to 2006 (m^3 mu^{-1})

Based on the definition of WUE, we can deduce that the irrigation water is a direct and key factor affecting winter wheat WUE, while the precipitation is a relatively minor factor to it.

Soil water and underground water recharging: Winter wheat WUE was studied from the macro-viewpoint in the paper. So an entire research period was the crop's whole growth period. Because water soil content was about 20% before sowing and after harvesting, the inter-annual change of the water soil content could be neglected compared with the change of irrigation amount and precipitation.

Although there existed a certain change for the underground water recharging before and after irrigation, the underground water irrigated were pumped from the deep layer groundwater in which its underground water table was more than 10 m and the longest root of the winter wheat was 2 m. So it was assumed that the underground water irrigated have a minor effect to the normal growth of the winter wheat. Especially, the underground water table would come

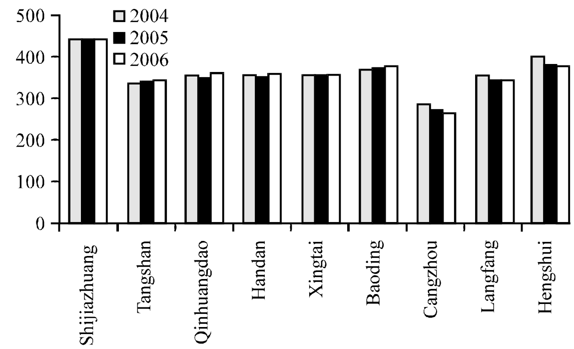

Fig. 4: Winter wheat yield per mu in each city in the middle scale from 2004 to 2006 (kg mu^{-1})

to return to the level before irrigation after the irrigation was stopped. Hence, the underground water recharging to the winter wheat was neglected when water balance was calculated. As a result, the main items in the water balance in the paper included the precipitation and the irrigation water. And it could be shown as follows:

$$P_0+I = ET \quad (3)$$

where. P_0 is the effective precipitation, I is the irrigation water, ET the actual consuming water in the winter wheat growing period.

And the results indicated that the average consuming water per mu in Hebei province was 271 m^3. And the consuming water in Tangshan was highest among the eleven cities, 613, 567 and 534 m^3 from 2004 to 2006, respectively. While the one in Qinghuangdao was lowest, less than 200 m^3. And the one in Cangzhou was much lower and its average consuming water in the three years was 199 m^3. The consuming water in the other cities varied from 213 to 405 m^3 (Fig. 3).

Winter wheat yield: The results showed that the highest winter wheat yield in Shijiazhuang was more than 440 kg mu^{-1} among the eleven cities and the lowest one in Cangzhou was less than 270 kg mu^{-1} (Fig. 4). And the winter wheat yield in the other cities varied from 338 to 404 kg mu^{-1}.

Winter wheat WUE: Based on the above analysis and the method ensuring winter wheat WUE, we could draw a conclusion that the average WUE for the winter wheat in Hebei province was from 1.1 to 1.30 kg m^{-3}, in which winter wheat WUE in most cities were more than the values. And the winter wheat WUE in Qinghuangdao was highest, 1.93~2.55, 1.29~1.67 kg m^{-3} in Cangzhou and

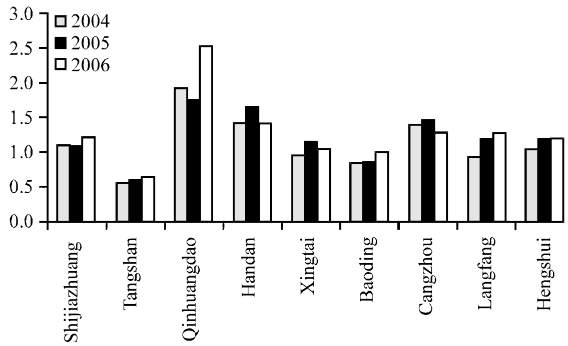

Fig.5: Winter wheat WUE in each city in the middle scale from 2004 to 2006 (kg m^{-3})

Handan, 1.05~1.22 kg m^{-3} in Shijiazhuang and Hengshui. While the one in Tangshan was lowest among the eleven cities, 0.60 kg m^{-3} (Fig. 5).

CONCLUSIONS

The above results indicated that Tangshan city was a region of a highest consuming water and much lower winter wheat yield. Winter wheat WUE in Handan and Cangzhou were much higher among them, their consuming water and winter wheat yield were both lower. The consuming water in Baoding was the highest in Hebei province but the winter wheat yield was much lower. Though the irrigation water in Shijiazhuang was less than the one in Baoding, the yield was highest among the eleven cities. To obtain higher yield and higher water use efficiency with lower irrigation water, we suggested that the irrigation schedules in Shijiazhuang, Qinghuangdao, Handan and Cangzhou should be referenced so as to optimize and adjust the irrigation schedules in other cities.

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