COMPARATIVELY STUDY WATER SENSITIVITY INDEX of the WINTER WHEAT for DIFFERENT GROUNDWATER DEPTH in SHAJIANG BLACK SOIL AREA and YELLOW FLUVO-ACQUIC SOIL AREA

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ABSTRACT: Winter wheat which was a typical dry crop in the Huaibei Plain was studied in the paper through the Wudaogou Hydrology and Water Resources Experimental Station, the long sequence of the lysimeter and the uninterrupted special experimental data. The multilevel water table depth was controlled from 0-5m in the experiments. By modeling the crop-water production function (Jensen Model), the tendency and regularity of the moisture sensitivity index variations of winter wheat cultivated was investigated under the above conditions at different plant developmental stages. The results showed that water deficits have greatly impacted winter wheat yield during key reproductive and seed formation periods, which are in the context of this analysis, the heading - maturation stage. Returning to green - jointing periods, the range of sensitivity to water deficits is 46.1% to 61.3%, which is the period towards maturation and 8.5% - 15.3% for the tillering period and overwintering period in maximum. The water sensitivity indexes reaches the maximum at the 1.0m ground water depth in the Shajiang black soil and Yellow fluvo-acquatic soil, which yields a 1.58 - 2.45 times and 1.16 - 2.08 times increase compared to the minimum in the same growth period. The groundwater depth should therefore be maintained between 0.8m and 1.2m in Shajiang black soil and Yellow fluvo-acquic soil. In comparison to other groundwater depths, this can reduce artificial irrigation and the occurrence of either waterlogging events or requisite drainage measures. Therefore, the findings of this study can optimize irrigation and improve water use efficiency.

1. INTRODUCTION
Huaibei plain is rich in shallow groundwater resources, which is the primary water source for the local agriculture. The average depth of annual groundwater is 2-3m below ground for most areas of this region. Crop water demand is closely linked to groundwater depth because of shallow groundwater table. Soil water is often recharged or supplemented by the aquifer. According to regression analysis, Ozsabuncuoglu I.H. [1] found that the total wheat yield in the Huaibei area related to planting area, fertilizer application and rainfall in wheat irrigation with a multiple-linear, quadratic and Cobb-Douglas function. Morgan et al. [2] proposed a dynamic model of maize yield response to daily available soil moisture. Braud et al. [3] found that water balance model could be applied to a larger
scale or in a region with scarce available data, and model based on potential transpiration could roughly estimate actual transpiration, although it does not consider surface energy balance. Soppe et al. [4] found that, without adjusting irrigation schedule, limiting drainage flow is less effective than a comprehensive approach to irrigation and drainage management. Noory et al. [5] studied the effects of groundwater use on crop yields under different groundwater control burial depths in Iranian semi-arid areas. Mejia et al. [6] conducted experiments to study the effects of groundwater on corn and soybean yields and explored the role of groundwater levels to crop yields by regulating the groundwater level. Nairizi et al. [7] have proposed ways to estimate the water demands of many crops at different stages of growth, including wheat and barley. Kandil et al. [8] found the wheat has different groundwater depth requirements for different regions and ecological conditions. Rana et al. [9] simulated actual crop evapotranspiration of winter wheat under water stress by studying the environmental and soil-plant parameters. Richard. [10] proposed a method for calculating crop evapotranspiration for crop water requirements. Verma et al. [11] carried out a field experiment which was conducted for 2 consecutive years 2008–09 and 2009–10 at Deras, Mendhasal, Odisha, to study the effect of conjunctive use of water sources and fertilizer levels on yield and water use of winter season groundnut. There were also researches about production functions. Igbadun et al. [12] presents a research about the performance evaluation of four selected crop water production functions. The general objective of the study was to test the capability and suitability of the models in predicting grain yield of a maize crop for a study area giving the models’ input parameters. Crop water production functions are closely related to crop’s evapotranspiration. In Karam et al. [13] research, evapotranspiration was measured for a reference crop, rye grass and soybean grown over two seasons in 2000 and 2001 at Tal Amara Research Station, Lebanon, using drainage and weighing lysimeters. Zhang et al. [14] evaluated the simulated comparison between the yield of grain, cotton and potato, grain, cotton and oil, grain and oil and the yield of winter wheat in the north China Plain through field positioning experiment. Guo et al. [15] by comparing different planting modes, found that conventional mode of winter wheat-summer maize double cropping in a year leads to high yield, but has a low water utilization rate and consumes a large amount of ground water, which is not conducive to a sustainable agricultural development. Liu et al. [16] conducted field study at Wuqiao experimental station, comparing the economic benefits and water consumption under different planting modes.

Huaibei Plain is a main crop base of Anhui province, which plays an important role to food security of China. However, water supply is a critical strain to support agriculture development. The main purposes of this study are as follows: (1) reveal the trend and regularity of the water sensitivity index of winter wheat; (2) summarize the appropriate groundwater depths for suitable wheat growth.

2. MATERIALS AND METHODS

2.1 Brief introduction to the experimental area

The Wudaogou Hydrological Water Resources Experiment Station is located in the north of Guzhen Village, Xinmaqiao Town, Anhui Province, which is in north subtropical semi-humid zone and temperate monsoon climate zone. The climate change in this region is dry in winter, and hot and rainy in summer. Due to highly influence of eastern Asian Monsoon climate, inter-decadal variation of annual precipitation is high while spatial distribution of annual precipitation is uneven for this region. Statistical results show that multi-year average of annual rainfall is 892 mm, the annual pan evaporation is 851 mm. The mean annual temperature is 14.7 ℃ with daily temperature ranging from -5℃ to 35℃. The mean of the total sunshine hours is 2200hrs, and the average frost-free period lasts 250 days. The groundwater level depth during perennial fluctuations between 1.5 - 3.5 m. The two test soils include Shajiang Black Soil and Yellow fluvo-aquic soil. Shajiang black soil is a heavy loam soil. A vertical soil crack develops at the beginning of its development at a rate of 150 mm/h. The average soil bulk density is 1.5 g/cm³ at a depth of up to 100 cm. The field water capacity is 24.9%. Yellow fluvo-aquic soil is a sandy loam, the 15cm surface of which is often slightly magnetic, loose and porous. The field water capacity is 27.5%.
2.2 Experiment design and method
In this study, the lysimeter system was used. As shown in Figure 1, the system consisted of nine volumetric lysimeters. The lysimeters were made of 20 cm thick concrete walls. In every lysimeter, the thickness of the soil column was the sum of the constant groundwater level and the depth of 10 cm. The undisturbed soil cores with the same area as the lysimeters were excavated from the field and placed in the lysimeters. Mariotte bottles were used to control the groundwater depths, and each of the nine individual lysimeters remained at different levels (0.2, 0.4, 0.6, 0.8, 1.0, 2.0, 3.0, 4.0 and 5.0 m). The groundwater evaporation, surface runoff and deep drainage of the outflow column were measured by this method.

3. MODEL AND DATA

3.1 Model
In recent years, there has been a number of studies on crop water provision functions. The model can be divided into linear and non-linear components, which attempts to capture the relationship between water input and output. Of particular concern, the context of agricultural pursuits are crop water consumption and its relationship with final yield at various stages of plant development. The Jensen model is widely accepted for the comparison and analysis of model structure and fitting precision.

\[
\frac{Y}{Y_m} = \prod_{i=1}^{n} \left( \frac{ET_i}{ET_m} \right)^{\lambda_i}
\]  

(1)

Where
\( \lambda_i \) = Sensitivity indexes of water shortage to crop yield at different stages;
\( i \) = growing stage division number;
\( Y \) = Actual yield under different treatment conditions;
\( Y_m \) = Yield under full water supply;
\( ET \) = Actual evapotranspiration under different treatment conditions;
\( ET_m \) = Crop evapotranspiration under full water supply;
\( n \) = Total number of model phases.

By solving the following equations one can solve for the value of \( \lambda_i \) in the above model.

By taking the Log of both sides we get:

\[
\ln \frac{Y}{Y_m} = \sum_{i=1}^{n} \lambda_i \ln \left( \frac{ET_i}{ET_m} \right) \quad \text{let } Z = \ln \frac{Y}{Y_m}, \quad X_i = \ln \left( \frac{ET_i}{ET_m} \right)
\]

(2)

Where \( Z \) can be expressed as a linear formula:

\[
Z = \sum_{i=1}^{n} \lambda_i X_i
\]

(3)

Using M processing, you can get \( X_{ij} \), \( Z_{j}(j=1,2,\ldots,m; \ i=1,2,\ldots,n) \) via the least square method,
establishing the target function as fixing:

\[
\min f = \sum_{j=1}^{m} \left( Z_j - \sum_{i=1}^{n} \lambda_i X_{ij} \right)^2, \text{ let } \frac{\partial f}{\partial \lambda_i} = 0
\]

\[
\frac{\partial f}{\partial \lambda_i} = -2 \sum_{j=1}^{m} \left( Z_j - \sum_{i=1}^{n} \lambda_i X_{ij} \right) X_{ij} = 0 \quad (4)
\]

By solving the equation, the first set of linear simultaneous equations are as follows:

\[
\begin{align*}
L_1 \lambda_1 + L_2 \lambda_2 + \cdots + L_n \lambda_n &= L_1 z \\
L_2 \lambda_1 + L_2 \lambda_2 + \cdots + L_n \lambda_n &= L_2 z \\
& \vdots \\
L_n \lambda_1 + L_n \lambda_2 + \cdots + L_n \lambda_n &= L_n z
\end{align*}
\]

\[
L_{ik} = \sum_{j=1}^{m} X_{ij} \cdot X_{kj} \quad (k=1,2, \ldots, n), \quad L_{iM} = \sum_{j=1}^{m} X_{ij} \cdot Z_j \quad (i=1,2,\ldots,n) \quad (5)
\]

Finally the correlation coefficient is calculated as follows:

\[
R = \left[ \frac{\sum_{i=1}^{n} \lambda_i L_{i,n+1}}{L_{n+1,n+1}} \right]^{\frac{1}{2}} \quad (7)
\]

3.2 Data series

From 2008 to 2012, the variety of the experimental winter wheat use at Wudaogou Experimental Station is Yannong19, Sow in late October of each year and harvest in June the following year. The winter wheat crop was divided into 4 growth stages according to key developmental stages in winter wheat growth as well as different sowing and harvest times of each year (table.1).The fertilization level, cultivation and field management of the experimental plot were the same as that of the surrounding farmland. After harvest, the experimental winter wheat plants were cut and shelled manually to measure their mean plant height, ear length, grain number per ear, thousand kernel weight and yield.

| Year      | Emergence - Tillering | Overwintering period | Turning green - Jointing | Heading - Maturation |
|-----------|-----------------------|----------------------|--------------------------|---------------------|
| 2008-2009 | 10.24-11.14           | 11.15-3.5            | 3.6-4.22                 | 4.23-5.30          |
| 2009-2010 | 10.24-11.14           | 11.15-3.5            | 3.6-4.22                 | 4.23-5.30          |
| 2010-2011 | 10.23-11.14           | 11.15-3.5            | 3.6-4.22                 | 4.23-6.2           |
| 2011-2012 | 10.27-11.14           | 11.15-3.5            | 3.6-4.22                 | 4.23-6.5           |

4. RESULT AND DISCUSSION

4.1 Changes of water sensitivity indexes during the whole growth stages

There are several specific parameters of the water production functions in various regions, years and crops. Thus the key to establishing the water production function model is derived by considering the actual local situation when estimating specific parameters. Table 2 illustrates the average plant
characteristics—i.e., ear length, grain number per ear, thousand kernel weight and yield of crops grown in Shajiang black soil and Yellow fluvo-acquatic soil with varying groundwater depths from 2008 to 2012 (Table 2). It is concluded that when the depth of groundwater table is 1.0m, only the mean plant height, thousand kernel weight and yield of winter wheat reach the maximum, as the depth of groundwater table continues to increase, all the characteristic values fall in varying degrees. Among the above indexes, the change of the yield is most sensitive to the change of the depth of the groundwater. However, the same effective changes are not observed in mean plant height and ear length, the grain number per ear tends to increase and then decrease with the increase of groundwater depth.

Table 2 Values for winter wheat growth characteristics at different groundwater depth

| Groundwater Depth (m) | Mean Plant Height (cm) | Ear Length (cm) | Grain Number per Ear | Thousand Kernel Weight (g) | Yield (kg/ha) |
|-----------------------|------------------------|----------------|----------------------|---------------------------|--------------|
| 0.2                   | 45                     | 4.6            | 17.0                 | 36.0                      | 3274         |
| 0.4                   | 64                     | 6.3            | 20.5                 | 35.8                      | 5847         |
| 0.6                   | 68                     | 6.3            | 21.7                 | 37.6                      | 6528         |
| 0.8                   | 66                     | 6.3            | 23.8                 | 37.3                      | 7599         |
| 1.0                   | 75                     | 6.2            | 24.8                 | 40.6                      | 9088         |
| 1.5                   | 72                     | 6.1            | 23.2                 | 34.1                      | 8947         |
| 2.0                   | 71                     | 6.1            | 23.1                 | 33.4                      | 8214         |
| 3.0                   | 68                     | 6.0            | 22.9                 | 33.3                      | 8145         |

Using the Jensen model we further analyzed the relationship between yield and groundwater depth. According to the Jensen model, the evapotranspiration and the corresponding yield in different growth stages were measured. The results obtained by MATLAB are shown in Table 3. Within the experimental plots where the depth of groundwater were 2 and 3 meters the evapotranspiration was minimal, therefore, the contrast was poor and the water sensitivity index was not calculated for these plots.

Table 3 Sensitivity index of winter wheat in different growth stages

| Soils               | Groundwater Depth (m) | Emergence - Tillering | Overwintering period | Turning green - Jointing | Heading - Maturation |
|---------------------|-----------------------|-----------------------|----------------------|--------------------------|----------------------|
| Shajiang black soil | 0.2                   | 0.0486                | 0.0212               | 0.1579                   | 0.342                |
|                     | 0.4                   | 0.0701                | 0.0395               | 0.2767                   | 0.4555               |
|                     | 0.6                   | 0.0713                | 0.0482               | 0.2971                   | 0.5149               |
|                     | 0.8                   | 0.0747                | 0.0494               | 0.3032                   | 0.5261               |
|                     | 1.0                   | 0.0769                | 0.0521               | 0.3068                   | 0.5463               |
|                     | 1.5                   | 0.0679                | 0.0329               | 0.3008                   | 0.4906               |
| Yellow fluvo-acquatic soil | 0.2   | 0.0675                | 0.0321               | 0.1689                   | 0.3423               |
|                     | 0.4                   | 0.0689                | 0.036                | 0.1706                   | 0.429                |
|                     | 0.6                   | 0.0702                | 0.0409               | 0.2298                   | 0.4958               |
|                     | 1.0                   | 0.0789                | 0.0598               | 0.3524                   | 0.5927               |

After seed germination, the water sensitivity indexes of Emergence - Tillering is higher than that of Overwintering period. The water sensitivity indexes were the lowest during Overwintering. Crop water shortage during this period had the least effect on yield. The water sensitivity indexes increased gradually during the period of Turning green - Jointing. Water deficits during this period began to affect crop yield. The water sensitivity indexes reached the maximum level during the period of Heading - Maturation, therefore the winter wheat yield was acutely sensitive to water availability. The water sensitivity index initially decreases, but then increases, presumably because winter wheat has the lowest sensitive degree to water shortage by the end of winter, which can be explained that water demand decline to the lowest and temperature is low. Water is only used to ensure normal growth and
development. As the plant body gradually increases and the product of photosynthesis is mainly used for plant growth, water deficits did not directly affect the yield of winter wheat during this period. During the Heading - Maturation, the root systems of the winter wheat plants were fully developed, and both the length and density of the root system were fully developed. Therefore, in order to form winter wheat seeds, transpiration rates as well as nutrients uptake and production are at their peak. If water deficits occur, this will reduce the final weight winter wheat, thereby directly threatening the formation of Winter Wheat. In conclusion water sensitivity indexes accurately portray and are positive correlated with winter wheat physiological characteristics throughout each growth stage of the winter wheat plant.

4.2 Changes of water sensitivity indexes at varying groundwater depths
In the case of varying groundwater depths, the sensitivity of yield reduction is different and with the increase of the depth of groundwater table, the water sensitivity indexes initially increase but, after reaching a threshold value, then decrease (Fig 2, 3). The water sensitivity indexes increase gradually at groundwater depths of between 0.2m and 1.0m in the Shajiang black soil. It reaches the maximum at the 1.0m ground water depth, which yields a 1.58~2.45 times increase compared to the minimum in the same growth period. At this groundwater depth, the shortage of water has the biggest impact on the production of the crops. The water sensitivity indexes of the Yellow fluvo-acquatic soil also increases gradually at groundwater depths of 0.2 to 1.0m. It reaches the maximum at 1.0m which has a 1.16-2.08 times increase compared to the minimum in the same growth period. From the difference of the water sensitivity indexes we can obtain that the highest water sensitivity indexes, which indicates optimal crop watering regimes for specific groundwater depths.

Fig.2. Water sensitivity indexes for winter wheat in Shajiang black soil at varying groundwater depths

![Fig.2. Water sensitivity indexes for winter wheat in Shajiang black soil at varying groundwater depths](image)

Fig.3. Water sensitivity indexes for winter wheat in the Yellow fluvo-acquatic soil at varying groundwater depths

![Fig.3. Water sensitivity indexes for winter wheat in the Yellow fluvo-acquatic soil at varying groundwater depths](image)

4.3 Changes of water sensitivity indexes for different soil types
Figure 4 illustrates the difference in water sensitivity indexes of the two soil types at varying groundwater depths and winter wheat growth stages, with values above and below the horizontal line signifying greater and lesser water sensitivity indexes in Shajiang black soil, respectively. At a groundwater depth of 0.2m, the water sensitivity indexes of winter wheat plants in Yellow fluvo-acquatic soil were higher than that of Shajiang black soil regardless of the plant growth stage. This is presumably due to the fact that Yellow fluvo-acquatic soil is a sandy loam soil, and at soil depths of 0 to 30cm the maximum water absorption is approximately 5.1%, which is only two-thirds of that of Shajiang black soil. This means that the crops in Yellow fluvo-acquatic soil have a higher demand for water than those in Shajiang black soil. With the continuous increase of groundwater depth, the crop water sensitivity index is greater for Shajiang black soil when a groundwater depth of 1 m is
reached. This may be due to Yellow fluvo-acquic soil being loose, porous and therefore highly permeable. On the other hand, Shajiang black soil has lower water permeability compared to Yellow fluvo-acquic soil, so the water sensitivity indexes of crops in Yellow fluvo-acquic soil is generally lower than that of Shajiang black soil when the groundwater depths are 0.4m and 0.6m.

![Fig.4 Comparison of winter wheat water sensitivity indexes in Shajiang black soil and Yellow fluvo-aquatic soil](image)

4.4 Suitable groundwater depth for winter wheat growth in different soil types

In analyzing the response of each growth stage crop sensitivity index to varying groundwater depths, quadratic polynomials regression equations were used. We deemed these models appropriate given the unimodal response of water sensitivity index to increases in watertable distance from surface, i.e. the indexes generally showed a tendency of initially increasing, followed by decreases at greater distances from the surface (Table.4). According to the inspection of the partial regression coefficient $F > F_{0.05}$, the regression relationship between different groundwater depths and deep water sensitivity indexes were significant for the second order polynomial, meaning that this model can reflect the water demand of crops authentically.

| Soils         | growth stages      | Regression Equation | R Square |
|---------------|--------------------|---------------------|----------|
| Shajiang black soil | Emergence - Tillering | $y = -0.0415x^2 + 0.082x + 0.0375$ | $R^2 = 0.8833$ |
|               | Overwintering period | $y = -0.0582x^2 + 0.1065x + 0.0039$ | $R^2 = 0.9773$ |
|               | Turning green - Jointing | $y = -0.2277x^2 + 0.4913x + 0.0758$ | $R^2 = 0.9681$ |
|               | Heading - Maturation | $y = -0.3117x^2 + 0.6362x + 0.2366$ | $R^2 = 0.9739$ |
| Yellow fluvo-aquic soil | Emergence - Tillering | $y = 0.0169x^2 - 0.0064x + 0.0683$ | $R^2 = 0.9853$ |
|               | Overwintering period | $y = 0.0298x^2 - 0.0014x + 0.0314$ | $R^2 = 0.9893$ |
|               | Turning green - Jointing | $y = 0.1429x^2 + 0.0499x + 0.158$ | $R^2 = 0.9848$ |
|               | Heading - Maturation | $y = -0.1834x^2 + 0.532x + 0.2439$ | $R^2 = 0.9899$ |

According to the sensitivity index curves for the same crop growth stages at different groundwater depths (Fig 5, 6), the fitted curves reach their maxima at groundwater depths of 0.8m - 1.2m. This finding is consistent with the previously mentioned underground water depth. From the analysis of water sensitivity indexes, the groundwater depth range that is suitable for winter wheat grown in Shajiang black soil and Yellow fluvo-aquic soil is approximate 0.8 to 1.2m.
4.5 Water sensitivity index for water saving irrigation

On the one hand, from the perspective of different growth stages of winter wheat (Fig 2, 3), despite the differences in soil types under different groundwater depth regimes the variation of sensitivity indexes of winter wheat in during different growth stages are extraordinarily similar. It can be seen that during the stage of Heading - Maturation, the water sensitivity index is much higher than other stages. This means that water deficits during this stage will have a direct and negative impact on crop yield. Thus, one of the most important things of improving crop yield is to guarantee adequate irrigation of winter wheat during the Heading - Maturation stage of development.

Finally, from the perspective of varying groundwater depths (Fig 5, 6), at the Wudaogou Experimental Station the average groundwater depth is 1.46m with a range from 0.62m to 3.83m. With an increase of groundwater depth, i.e., keeping the groundwater depth in Shajiang black soil and Yellow fluvo-aquic soil between 0.8m and 1.2m, respectively, the water demands for normal growth of winter wheat regardless of the growth stage period can also be adequately met, even under reduced artificial irrigation. Compared to other groundwater depths, 1m may reduce the number of water logging events or requisite drainage measures by maintaining these depths. Furthermore, and possibly most importantly, the increased water efficiency and the benefits of saving water can be achieved.
5. DISCUSSION
The water demand of winter wheat plants is different at different stages of growth. The water sensitivity index reached the maximum value during the Heading - maturation period, which is nearly 6.4~7.3 times that of the Emergence - tillering period and is 1.6~2.1 times that of the Turning green - jointing period. The reason that has such result is mainly due to the interaction between internal factors of winter wheat plant, such as root distribution and factors of soil water balance, including total precipitation and frequency, groundwater depth and phreatic evaporation. The water sensitivity index of the winter wheat plant increases throughout all growth stages, as groundwater depths increase. This is probably due to shallow groundwater providing excessive water supplies within the root zone, thereby creating anaerobic conditions. When the Shajiang black soil groundwater depth is 0.8~1.5m, with the increase of groundwater table depth, the water sensitivity index gradually decreased. The reason for this may be that during the growing season, the moisture content of the anhydrous period is sequestered more rapidly by transpiration while deeper groundwater reserves cannot compensate for the water deficit. In fact, regardless of whether the plants were grown in Shajiang black soil or the Yellow fluvo-acquatic soil, deeper watertables, i.e., groundwater depths in excess of 1.5m, led to the manifestation of different degrees of water stress. Future studies should investigate the effects of groundwater depth variations of more than 1.5m on the growth of winter wheat plants in this area.

In addition, as a result of different precipitation, radiation, temperature and farming methods found throughout the Huaibei Plain, more research should be done on the phreatic evaporation and sensitivity of winter wheat plants under other conditions endogenous to this region via the Jensen's model.

6. SUMMARY AND CONCLUSION
In this work, the effects of groundwater depth on the water sensitivity indexes and yield of winter wheat variety YanNong 19 were investigated by a lysimeter experiment. The experiment was carried out in the transitional zone of northern subtropical and warm temperate climatic conditions in Huaibei Plain. The variation and regularity of water sensitivity indexes of winter wheat plants during various stages of development were analyzed under varying conditions of groundwater depth for two soil types. The conclusions are as follows:

1. With the increase of groundwater depth, the grain number per ear tends to increase up to a certain depth, but then decreases. When the depth of the groundwater table is 1.0m, the mean plant height, thousand kernel weight and yield of winter wheat reaches their maximum value. All the characteristic values fall in varying degrees as the depth of the groundwater table continues to increase. However, the same effective changes are not observed in mean plant height and ear length.

2. Winter wheat plants are the most sensitive to water deficits during the Heading - Maturation stage. During this period fertilizer sequestration may account for the high water demand. In the Turning green - Jointing periods, sensitivity to water deficits are 46.1% - 61.3% that of the Heading - Maturation period. In the Emergence - Tillering period and Overwintering period is 8.5% - 15.3% that of the maximum, therefore the impact of the water deficits on the crop is at its minimal.

3. The water sensitivity index of the crop is affected by not only different growth periods but also by differences in soil types and groundwater depths. The water sensitivity indexes of the winter wheat in the Shajiang black soil primarily increases up to a certain depth, but then decreases, with the maximum - a 1.58-2.45 times increase compared to the minimum in the same growth period – being reached at 1.0m groundwater depth. In the Yellow fluvio-acquatic soil the water sensitivity indexes reaches its maximum – a 1.16-2.08 times increase compared to the minimum in the same growth period – at a groundwater depth of 1.0m. According to the water sensitivity indexes at different depths, the higher the water sensitivity indexes at the maximum depth, the more overall water requirements of the crops.

4. When the groundwater depth is 0.2m and 1.0m, the water sensitivity indexes of winter wheat plants in the Yellow fluvio-acquatic soil are higher than that in the Shajiang black soil throughout all growth periods. On the contrary, when the groundwater depth is between 0.4m and 0.6m, the water
sensitivity indexes of winter wheat in Yellow fluvo-aquatic soil are slightly lower than that in Shajiang black soil.

5. In comparison to other groundwater depths, by maintaining the groundwater depth in Shajiang black soil and Yellow fluvo-aquic soil at depths of between 0.8m and 1.2m, respectively, artificial irrigation can be reduced. So too can the number of water logging events or requisite drainage measures. Meanwhile, one of the most important things of improving crop yield is to guarantee adequate irrigation of winter wheat during the stage of Heading - Maturation. In this way, one can reduce unnecessary irrigation water effectively during other growth stages in order to optimize irrigation and improve water-use efficiency.

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