

Effects of water stress on yield at different wheat development stages and drought diagnostic method

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Received October 6, 1992

Summary Water stress treatment at different developmental stages of a winter wheat variety was made in outdoor pot experiments from 1987 to 1988. It was found that the most sensitive stage was the booting stage and the second most sensitive stage was the flowering stage. Water stress at most development stages affects the number of grains. Wheat water stress can be diagnosed effectively and quickly by means of leaf temperature difference between the drought field and the well watered control plot measured by an infra-red thermometer.

Key words wheat, water stress, drought, leaf temperature

Introduction

There are a lot of references of effects of drought on yield at different stages of wheat development, but the conclusions are quite different. Day et al. (1970) discovered that the most serious yield decrease due to drought was at the elongation stage. Fischer (1973) pointed out that wheat at booting stage was most sensitive to moisture. Bracke drew a conclusion according to his experimental results that drought affected grain yield most seriously at heading and flowering stages. But Luellen (1980) considered that the filling stage was the most critical stage of water stress. On the contrary, Shan Lun et al. (1980) suggested that soil drought at the beginning of filling stage might increase grain weight.

Many methods about examining and predicting crop drought were also suggested such as to determine conductivity of stomata with porometer (Sivakumar et al. 1978; Wang Hong et al. 1987) and to measure leaf temperature with infra-red thermometer (Idso, 1982). However, there are still some different opinions. For example, O'Tools et al. (1978) suggested that other environmental factors affecting stomata openness varied so severely that it was difficult to judge drought by stomata conductivity. Walker et al. (1983) considered that the accuracy to determine crop drought by leaf temperature depended on how big was the independent effect of drought on stomata openness. Therefore, the sensitivity and determination of drought should be further studied. The research work in this paper is a part of experiments to work out the problems combining with the research of water economizing in Beijing area.

Materials and methods

Drought experiments with pots culture at different growth stages were carried out at Beijing Experimental Station of Agroecological System, Academia Sinica, from 1987 to 1988.

There was 11.85 kg soil in each pot ($d=25\text{cm}$, $h=30\text{cm}$) with base fertilizer of 2.0 g N, 1.0 g P_2O_5 and 0.5 g K_2O , and no dressing fertilizer after then. The variety of winter wheat was Fengkang-6. The ear number was kept 40 per pot by discarding plant. Each treatment with 3 repetitions was watered sufficiently at all stages except a certain stage. The following measures were taken to keep the pot culture condition similar with the field environment: (1) The water in wet soil gradually evaporated until wheat plants withered. At the same time, the soil in ck was kept wet continuously by irrigation every day. (2) Damp cinnamon soil, from experimental field undersurface 0–30 cm with 1% organic material and 22.9% of moisture capacity, was put in pots. (3) The pots were put in the meteorological station and moved into a shelter before each rain. Leaf temperature was measured by an ER-2008 Infra-red thermometer, and the value was calibrated with a standard source before and after each measurement. The measure method of stomata resistance (reciprocal of stomata conductivity) and calculation can be seen in articles of Wang Hong et al. (1987a, b).

In order to obtain comparison of results in two years, crop sensitivity (CS) suggested by Hilter et al. was applicated to analyse the yield and biomass:

$$CS_i = \frac{(X - X_i)}{X}$$

where X and X_i is the yield or biomass of ck and of drought treatment at stage i , respectively.

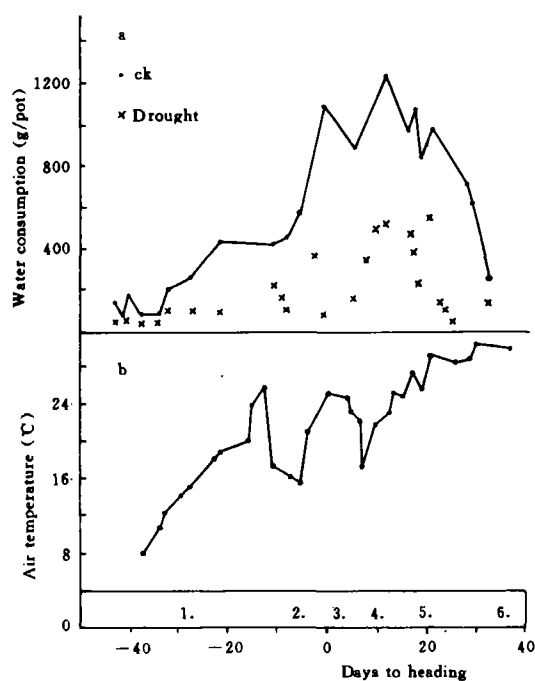
Results and discussion

Sensitivity to drought at different developmental stages

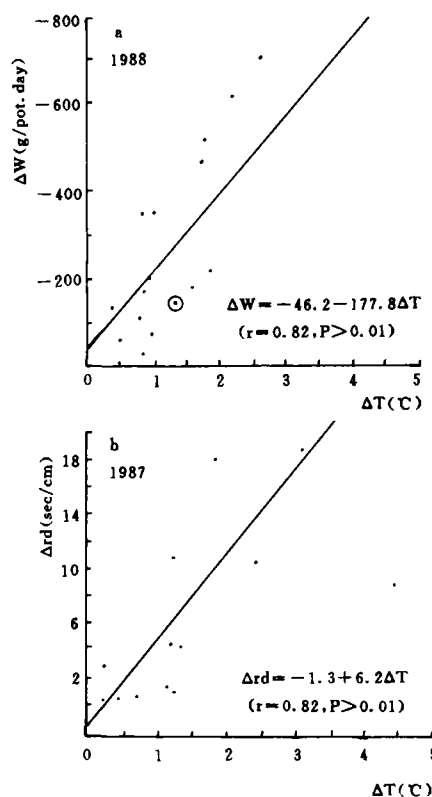
It can be seen from Tab. 1 that the trend is generally same in two years' results of experiments although there are some differences. The biggest effect of drought on yield was at the booting stage with decrease of 43% and 47% compared with ck in 1987 and 1988, respectively. The reason is that this stage is also the tetraspore in spike differentiation, and is very sensitive to water deficit. Particularly the pollens may be sterile due to drought at meiotic stage of pollen mother cell. As a result the grain number reduced as shown in Tab. 1. The average grain number reduced 46% and 50% in two years, respectively. Although grain weight increased, the compensation effect was too little in filling stage. The second most sensitive stage is the flowering stage. The yield in two years reduced 25% and 28%, respectively. Waldlaw and Brocklehurst et al. pointed out that grain sitting percentage and weight might reduce due to water deficit at flowering and insemination stages. The yield decreased 14% to 18% due to drought at erect stage when wheat plant was at vegetative period and differentiation of spikelet rudiment. Drought resulted in decrease of dry weight, short plant, small leaves, short spike, reduction of grain number and yield. But the harvest index of drought treatment was higher than that of ck. This indicated that the nutrient transportation of photosynthetic product in the late stages could compensate part of loss in early stages. Elongation stage is also the stage of anther cell formation, when stems and leaves grow rapidly. Therefore drought can influence both grain number and grain weight. The yield reduction was 13% to 19%. The stem and tiller stop growing basically at heading stage. At this stage the drought effects on yield are much less than that at the booting stage or flowering stage. There is a stronger drought resistance of wheat at filling stage particularly at ear filling stage. Grain weight may reduce due to early maturity caused by water deficit at late filling stage. Wheat is not sensitive to drought at dough stage any more.

Table 1. Crop sensitivity(CS)of yield and different characters to drought

| Stage of drought treatment | Yield | | Grain number per ear | | Thousand grain weight | | Dry weight of stem & leaves | | Harvest index | |
|----------------------------|-------|------|----------------------|-------|-----------------------|-------|-----------------------------|-------|---------------|-------|
| | 1987 | 1988 | 1987 | 1988 | 1987 | 1988 | 1987 | 1988 | 1987 | 1988 |
| Erect | 0.18 | 0.14 | 0.14 | 0.14 | 0.05 | 0.01 | 0.43 | 0.30 | -0.20 | -0.11 |
| Elongation | 0.13 | 0.19 | 0.07 | 0.07 | 0.07 | 0.14 | 0.17 | 0.08 | -0.02 | 0.09 |
| Booting | 0.43 | 0.47 | 0.46 | 0.50 | -0.05 | -0.05 | 0.15 | 0.08 | 0.22 | 0.34 |
| Heading | — | 0.14 | — | 0.09 | — | 0.06 | — | 0.10 | — | 0.03 |
| Flowering | 0.25 | 0.28 | 0.12 | 0.27 | 0.14 | 0.02 | 0.18 | -0.02 | 0.04 | 0.23 |
| Filling | | | | | | | | | | |
| Early | 0.12 | 0.05 | 0.03 | 0.04 | 0.09 | 0.02 | -0.03 | 0.17 | 0.09 | -0.09 |
| Middle | 0.13 | — | 0.00 | — | 0.13 | — | 0.01 | — | 0.07 | — |
| Late | 0.17 | 0.11 | 0.08 | -0.04 | 0.10 | 0.14 | 0.07 | 0.00 | 0.07 | 0.09 |
| Dough | 0.06 | 0.02 | 0.00 | -0.07 | 0.06 | 0.08 | -0.04 | -0.08 | 0.07 | 0.09 |

**Fig. 1** Variation of water consumption(a)and air temperature (b)in treatments of drought and ck (1988)

1. Elongation 4. Flowering
2. Booting 5. Filling
3. Heading 6. Dough

**Fig. 2** Correlation of leaf temperature difference (ΔT) with water consumption difference (ΔW) and stomata resistance difference near axial section (Δrd) between drought treatment and ck at different stages (⊙ is the value before maturity when most leaves withered already)

Physiological index of drought

Because of the linear correlation between water consumption and photosynthesis of wheat, the differences between drought and ck in water consumption are able to reflect the intensity of water deficit. As shown in Fig. 1, the degrees of drought at different developmental stages of wheat are different due to joint effects of soil moisture and atmospheric conditions. Water consumption is less in drought treatment at erect stage than that in ck but the difference is not big. As the leaf area grows bigger, the temperature raises and water consumption increases, the difference becomes more obvious. Except overcast and cloudy days, the difference is the biggest from booting to flowering stages and it becomes small near maturity, when most leaves have become withered and the water consumption reduces rapidly.

Fig. 2a shows the significant linear relation between ΔT and ΔW , where ΔT and ΔW is the difference of leaf temperature and water consumption between drought treatment and ck at different developmental stages respectively. Besides, leaf temperature difference is closely correlated with stomata resistance difference near axial section (Fig. 2b), which is similar with the results we observed in field (Wang Hong et al. 1987b).

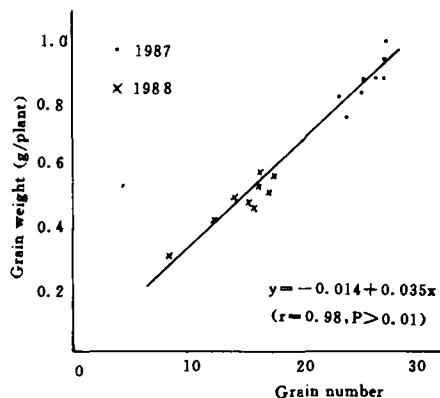


Fig. 3 Relation between grain number and grain weight per plant in drought treatments & ck at different stages

Conclusions

1. The experimental results indicate that drought at different developmental stages of wheat will lead to yield loss but the reduction is different. Booting stage is the most sensitive period to drought but the effect of drought at dough stage is not big. Therefore, the plant should be reasonably irrigated according to the regulation and the actual situation of soil and weather if water resource is limited.
2. The mechanism of drought effects on yield is different at different stages, sometimes the grain number or weight reduces, in other cases both reduce. But as a significant correlation between grain number and weight indicated, drought affects yield mainly by means of reduction of grain number.
3. In order to eliminate the disturbance of such atmosphere conditions to physiological index of drought, as light intensity, air temperature and humidity, it is necessary to measure the environmental factors and to make complex calculation. And it is a simple and convenient method getting rid of disturbance to set control plot of sufficient water.
4. The close relation between leaf temperature and water consumption or stomata resistance indicates that leaf temperature maybe a good physiological index to examine drought. Infra-red Thermometer is characterized by big measured area, accuracy and quickness, therefore, it can make the measurement of leaf temperature more effective and practical than that of other crop physiological index.
5. Pot cultural experiments against background of field environment are closer to practice and of significance bigger than those under complete control conditions. But the results are

still different from that of field crops, for example, the drought process is quicker and intensity is bigger in pots. Therefore, this method should be combined with field experiments.

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