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Modelling the meteorological influence on the yellowing of spring wheat leaves*

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Abstract— The yellowed-leaf rate is one of the important variables in simulation models for the growth of spring wheat. Based on the field experiments (1985–1988), the evolution of yellowed-leaf rate of spring wheat is analyzed. The functional relationship between the yellowing process of green leaves and the development stages of spring wheat is established. Based on modelling and correcting for the yellowing process of green leaves affected by temperature and moisture, the synthetic model for simulating the dynamical evolution of yellowed-leaf rate is constructed. The numerical experiments show that the result of the modelling is satisfactory.

Keywords: simulation model; meteorological influence; spring wheat.

1 Introduction

The leaves play the most important role in the processes of photosynthesis, respiration and transpiration of a plant. The germination, growth and senility of leaves are considered as the law of a life cycle, which is not only closely related to the physiological variations of the plant itself but also depends on the environmental conditions, such as meteorological factors. In fact, the yellowed-leaf rate, the signal showing how the leaves turn withered and yellow, reflects the variations of the relative parameters affecting the plant growth. A lot of studies concerned the meteorological influence on the yellowing of leaves have been taken and the reports in this field have been published at home and abroad. For instance, de Wit *et al.* (Keulen, 1986) assumed the yellowed-leaf rate during a certain phenological growing period as an unchangeable constant in the simulation model for crop growth. Feng

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Dingyuan *et al.* (Feng, 1987) described quantitatively the withering and yellowing processes of leaves with relationship between the yellowed-leaf rate and growing periods of the crop in their numerical modelling on the weather-yield of rice. Based on the four-year field experiments, the functional relationship between the yellowing process of leaves and the development stages of the spring wheat is intended to be realized here using the statistical methods. And the dynamical models have been established for the yellowed leaves caused by the meteorological factors such as temperature and moisture.

2 Field experiments and data

2.1 Field experiments

The four-year (1985 – 1988) experiments were carried out in the field around the town of Bikeqi, Huhehaote area, Inner Mongolia. The wheat of variety Type 7704 was selected as the subject for the experiments.

The experiments were conducted by two treatments: seeding at different dates, and controlling of irrigations.

The experimental seeding was carried out in three different times with a 10-day interval: (1) 10 days earlier than the favorable date; (2) just on the most favorite date; and (3) 10 days later than the timely date. Irrigations for 1 – 3 times were given to the experimental wheat respectively: before jointing, before or after booting, and between blooming and grain filling. The each treatment was repeated in three plots and arranged randomly.

The objects of observation were the leaf area, the weight of green leaves, and the weight of yellowed leaves. The samples were taken every 5 or 10 days in the different experiment-years.

2.2 Source of meteorological data

The meteorological data of radiation, temperature, precipitation and wind velocity etc. are obtained every 10 days from the weather station at the town of Chasuqi, 15 km west to the experimental field.

3 Variation of the yellowed-leaf rate and its relation with the meteorological factors.

3.1 Mathematical expressions of the development stages of crops and the yellowed-leaf rate

3.1.1 In this paper the de Wit's expression is utilized, which is to relate the growing and maturing processes of crops with the accumulated heat and to determine the speed of development, namely development stage (*DVS*). The calculated results of *DVS* are within 0 – 2, in which 0 – 1 means the early growing period (from sprouting to blooming), and 1 – 2 stands the late growing period (from blooming to matured). For instance, tilling stage is about 0.2; jointing is at 0.4; earring, 0.8; blooming, 1.0; yellow matured 1.9 and matured 2.0.

3.1.2 The mathematical expression for the yellowed-leaf rate is given by:

$$DR = \frac{Ly}{Lw} = \frac{Lyi}{Lyi + Lgl}, \tag{1}$$

where *DR* is the yellowed-leaf rate; *Ly* is the yellowed leaves weight and *Lw* is the total leaves weight; *Lg* is the green leaves weight, and $i = 1, 2, 3, \cdots n$ is the time-period sequence.

3.2 Essential relationship between the yellowed-leaf rate and the development stages

From Fig. 1, it can be seen that the variations of the yellowed leaves can be characterized as following: if the $DVS > 0.4$ (about the jointing stage), the yellowed leaves begin taking into place; while *DVS* is getting greater, the yellowed-leaf rate varies with exponential function; and when *DVS* is up to 1.9 or so (the later period of yellow matured stage), the yellowed-leaf rate is the greatest and may reach 1.0. Moreover, the less the irrigations and the later the seedings are taken, the faster the dynamical variation process of *DR* will produce and the earlier the process will come to its end (*DR* reaches 1.0). In a sense, the results indicate that temperature and moisture also affect the dynamical variations of *DR* significantly.

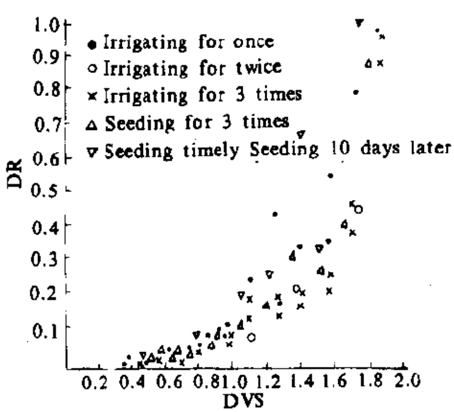

Fig.1 Relationship between the development stages (*DVS*) and the yellowed-leaf rate

Based on the experimental data and pattern of dot distribution in Fig.1, the essential relationship between the yellowed-leaf rate and the development stages of the spring wheat can be expressed as:

$$DR = 0.005231\, e^{2.7525\, DVS} \tag{2}$$

In the statistical verification, $R = 0.9374$; $S^2 = 0.01245$; $F = 570.7183 >> F\,(0.01)$

$=7.17$ and $N=51$. Obviously, it is clear that the Equation (2) can serve as the foundation for establishing the simulation model for dealing with the dynamical variation of the yellowed-leaf rate.

3.3 Effects of temperature on the dynamic variation of the yellowed-leaf rate

It is well known that the temperature environment supporting the growth of wheat will differ if the seedings are taken in different days. Fig. 2 shows that the relationships between *DVS* and *DR* obtained from the different seedings are rather different and the later seeded wheat is accompanied with the greater yellowed rate than the earlier seeded one. It means that the later seeded wheat has got its *DR* up to 1.0 in the earlier *DVS* than earlier seeded one.

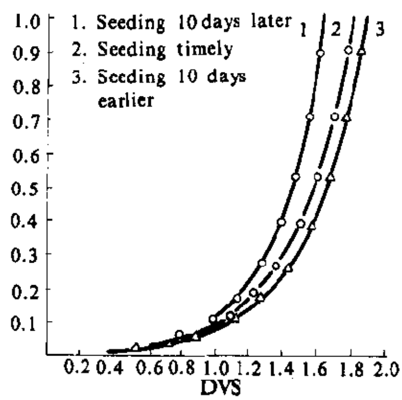

Fig.2 Relationship between *DVS* and *DR* obtained from the seedings on different days
1. seeding 10 days later 2. seeding timely
3. seeding 10 days earlier

Furthermore, through the analysis, it is found that the environment temperature shows a negative correlation with the number of days required for growth ($R=-0.9833$, $N=13$) during the period from three-leave to blooming while the mean temperature almost remains a stable constant during the period from blooming to maturing. In other words, the effects of the unfavorable high- or low-temperatures occurring in the earlier growing period of spring wheat will be reflected in its later growing period: such as its much earlier or later yellowing and withering (called as the ultra-early or delayed effect). In fact, such kind of ultra-early and delayed effects are the results produced by the effects of the unfavorable temperatures on the plant growing process. They can be estimated by the temperature correcting of the development stage under the essential expression:

$$DVS'=DVS-(1-K), \tag{3}$$

where DVS' is the corrected development stage and K is the temperature correcting coefficient:

$$K=T/\bar{T} \qquad (T \geqslant \bar{T});$$

$$K=(T-1)/\bar{T} \qquad (T<\bar{T}).$$

In the expressions above, T is the mean temperature in the period from the sprouting of wheat to its *DVS* getting 0.8. $\bar{T}$ is the mean temperature in the same period of the experiment years.

Thus, the more satisfactory results can be achieved if the above temperature correction is used to simulate the *DR* of wheat leaves.

3.4 Relationship between moisture and dynamic variation of yellowed-leaf rate

As we know that the wheat leaves play not only an important role in photosynthetic processes, but also have got another major physiological function in transpiration-consumption of water. The amount of transpiration depends upon the water content in the soil. If the water content in the soil is sufficient, transpiration will be strong and in adverse, will be weak. If water in the soil is hardly to meet the normal requirements of wheat, the growth of leaves will be slow or even stop, then causing the much earlier yellowing and withering and further bringing the adverse effects on the final yield. Fig.3 shows the relationship between the yellowed-leaf rate and

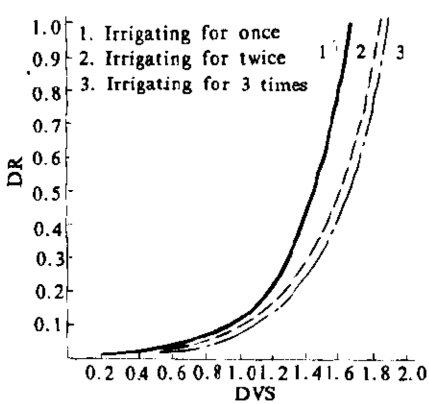

Fig.3 Relationship between *DVS* and *DR* with the different treatments of irrigations
1. irrigating for once 2. irrigating for twice
3. irrigating for 3 times

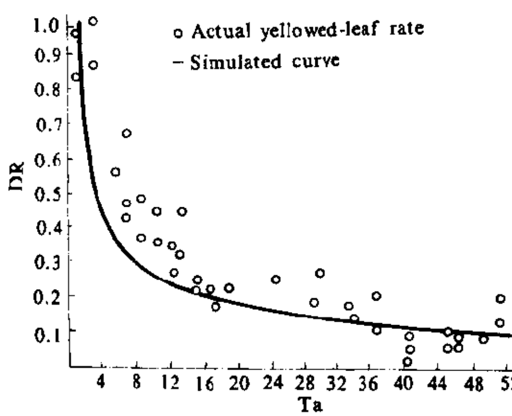

Fig.4 Relationship between actual transpiration (*Ta*) and yellowed-leaf rate (*DR*)
dot(·) actual yellowed-leaf rate; — simulated curve

the development stages measured in the water controlled experiment of 1988. It can be seen from the comparison among the curves when $DVS > 0.8$, the yellowed-leaf rate significantly depends on the times of irrigations. The less the irrigations, the greater *DR* are. This illustrates that the water content in the soil will affect the dynamic variation of *DR* quite significantly.

According to references, firstly the actual transpiration (*Ta*) is estimated by

$$Ta = Tp \ , \tag{4}$$

if $SMr \geqslant SMcr$, and

$$Ta = Tp = \frac{(SMr - SMw)}{(SMcr - SMw)} \ , \tag{5}$$

if $SMr < SMcr$, where *Tp* is the potential transpiration; *SMr* is the soil moisture at the root layer. *SMcr*, the critical moisture can be obtained by

$$SMcr = (1 - p)\ (SMfc - SMw) + SMw, \tag{6}$$

where *SMfc* is the field water capacity of soil (cm^3/cm^3); *SMw* is wilting moisture (cm^3/cm^3); *p* is the soil water depletion fraction which is determined by the plant species and potential transpiration. $(SMr - SMw)$ is maximum soil moisture content at root layer. The potential transpiration can be obtained by the related equation (including the leaf area correction) given in reference (Pei, 1986).

Secondly, the relationship between *Ta* and *DR'* ($DVS \geqslant 0.8$) is showed in Fig.4 and expressed as the following equation:

$$DR' = 0.96155 Ta^{-0.5544}, \tag{7}$$

with $R = 0.5223$, $S^2 = 0.06035$, $F = 139.96 >> F(0.01) = 7.17$, $N = 47$ in terms of statistics.

4 The synthetic model for simulation of yellowed-leaf rate

4.1 Synthetic model

The yellowed-leaf rate can be considered as a factor reflecting the physiological modulation of spring wheat when it is at its early growing period ($DVS \leqslant 0.8$), which can be seen from the relation between *DR* and development stage (*DVS*) simply effected by abnormal (high or low) temperature. However if $DVS > 0.8$, the variation of yellowed-leaf rate becomes more complex, and influenced by both temperature and moisture. In other words, in the ongoing process of *DVS*, dynamic variation of *DR* is not only dependent on the physiological nature of the plant itself but also on the environmental stress influence. That is, either alone the temperature condition or only the water status can not reflect the relation between yellowed-leaf rate at the later development stage and environment meteorological conditions.

In order to consider effects of both the temperature and water status at the same time, a simple integration method as like added-integration, is used to construct. The final synthetic simulation model as following:

$$DR = 0.005231\, e^{2.7525DVS}, \quad 0.4 < DVS < 0.8$$

$$DR = 0.005231\, e^{2.7525(DVS)-(1-k)} + (0.96155Ta^{-0.5544})^2, \; DVS \geqslant 0.8 \qquad (8)$$

Consequently, the better modelling results are obtained (Table 1).

However, it must be pointed out that in the calculation with Equation (8), *DR* will become somewhat false as the measured *Ta* is too lower when spring wheat is entering into the mature stage and leaf area index is near to or lower than 0.1. In order to eliminate the false a control switch should be given. This is the equation:

$$Yk = -(1.2634 \times 10^{-14} e^{1.721T}), \qquad (9)$$

($R = 0.9815$, $S^2 = 0.009111$, $F = 63.5458 >> F(0.01) = 10.0$, $N = 5$). In the Equation (9), *Yk* is the adjustable numerical switch to eliminate the false of *DR*.

4.2 Simulated results

The actually observed yellowed-leaf rate of the wheat seeded timely and irrigated twice in 1987 and 1988 is taken into the comparison with the simulated curve from

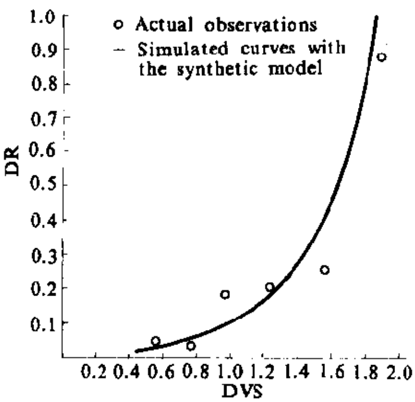

Fig.5 Comparison of the actual observations and the simulated curves with the synthetic model
• actual observations
--- simulated curves with the synthetic model

Table 1 The comparison of simulated *DR* yellowed-leaf rate with different correction of environmental factors

DVS	Measured *DR*	Simulated *DR* with temperature correction	Simulated *DR* with temperature and moisture correction
0.8361	0.0913	0.0395	0.0550
0.9459	0.0903	0.0534	0.0669
1.0945	0.0867	0.0804	0.0928
1.2546	0.1883	0.1249	0.1469
1.4117	0.3478	0.1925	0.2598
1.5689	0.3637	0.2586	0.3474
1.7189	0.4665	0.4486	0.5607
1.8689	0.9798	0.6776	0.9961
Errors sum of squares		0.13495	0.02076

Notes: Irrigated twice in 1988

the synthetic model in Fig.5 and Table 1. Moreover, the error sum of squares of the simulations and observations on the wheat irrigated once, twice and three times are 0.08593, 0.007184 and 0.01257, respectively. So, it can be said that the simulated results are somewhat satisfactory. Obviously, the dynamical modelling for the leaf yellowing process illustrated above can further improve the simulation of wheat growth, as well as more efficiently develop the foundation to the establishment of new dynamical/statistical model for yield prediction and its application.

5 Conclusion

The studies described in this paper show that the modeling of the yellowed-leaf rate of spring wheat could be divided into two stages. In the early growing period, the rate is mainly affected by the greater variations of the ambient temperature. More yellowing of its leaves is the reaction of the spring wheat to the variations of the ambient temperature as a physiological modulation to support its living. In the late growing period, the yellowed-leaf rate differs with the actual transpiration significantly and is also influenced by what happened in the early period, namely by the modulations with the ultra-early and delayed effects. A synthetic model has been established based on the comprehensive studies on the effects of both temperature and moisture. Compared with the actual observations, the simulated results are satisfactory.

The model introduced here belongs to the essential studies on the dynamical modelling of crop growth. It can be applied widely for its establishment on the basis of easily-collected data and its feasible usage and significant physical senses.

The value $\bar{T}$ in the model is obtained from the available data collected in the experiments. It should be further calibrated for its stability due to influences caused by such as too great yellowed leaf rate just before wheat mature.

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