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Analysis of Crop Growth Rhythm in Alfalfa - Wheat Intercropping

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Abstract **Original Research Article**

Logistic equation was used to fit the plant height growth of wheat and alfalfa in different intercropping treatments, and the effects of intercropping on the plant height growth of wheat and alfalfa were analyzed according to the results of fitting curve model parameters. The results showed that the plant height growth of wheat and alfalfa under different intercropping patterns was in line with "S" curve. According to the turning point of the growth curve, the plant height growth can be divided into three stages: gradual growth stage, linear growth stage and slow growth stage. In late March, wheat and alfalfa began to enter linear growth phase, which lasted about one month and one and a half months, respectively. The linear growth of wheat and alfalfa in all treatments accounted for more than 50% of the total growth in growth period. Intercropping alfalfa extended the linear growth period of wheat, but reduced the growth rate and amount of wheat in the linear growth period. While intercropping with wheat shortened the linear growth period of alfalfa, but accelerated its growth rate.

Keywords: Inter-row intercropping, alfalfa, wheat, growth rhythm, logistic model.

INTRODUCTION

Intercropping is the essence of traditional agriculture in China. It has the advantages of increasing yield [1, 2], optimizing resource utilization [3-5], facilitating functional diversity of rhizosphere microbial community [6-8] and increasing farmland biodiversity[9], improving soil fertility [10] or controlling pests and diseases [11, 12]. Legume - cereal intercropping is one of the most widely used planting patterns in agricultural production and plays an important role in grain production in China. In theory, wheat and alfalfa intercropping, in combination with the house feeding technique, can take advantage of the nitrogen fixation advantages of excellent leguminous alfalfa to improve the farmland output capacity and the living standards of farmers in the main wheat producing areas [13]. There are published studies showing that wheat and alfalfa intercropping can not only preserve soil water and improve soil water content [14], but also improve soil water use efficiency [15]. In terms of crop plant nutrients, it can also improve the nitrogen content of wheat plants and grains, and increase the accumulation of other nutrients in crop plants, improve the absorption efficiency of crop nutrients [16]. However, how intercropping affects the growth and development of wheat and alfalfa remains unclear. In this study, the Logistic curve equation was used to fit the plant height of the two crops. And the growth and development rhythm of wheat and alfalfa under intercropping was discussed according to calculated parameters of the curve equation. It was supposed that this study work could provide some reference for refinement and standardized cultivation management of wheat and alfalfa intercropping.

1. MATERIALS AND METHODS

1.1. Test site Overview

The experimental area is located at the National Field Scientific Observation and Research Station of Farmland Ecosystem in Shangqiu, Henan Province (34°35 '13' N, 115°34 '30' E), with an altitude of 52m. The region belongs to the arid, sub-humid warm temperate monsoon climate. The annual average rainfall, which is concentrated in July-September, is 708mm. It has an annual average temperature of 13.9℃. The frost-free period is 206d, the annual evaporation is 1735mm, and the ≥0℃ accumulated temperature is above 4723℃. In April 2017, alfalfa and winter wheat intercropping experiment was carried out. Winter wheat and summer corn were planted twice a

year in the test site for many consecutive years prior to this experiment. The soil type was mainly tidal soil. In 0-40cm layer, soil bulk density was 1.42g/cm^3, and soil mass water content was 17.41~20.30%. Soil bulk density and soil mass water content were 1.34g/cm^3 and 22.24-27.76% respectively in 40~100cm layer.

1.2. Experimental materials and treatments

The alfalfa was MATTWI coated seeds imported from the United States and planted in April 2017. Winter wheat was sown in the autumn of 2017 and the variety was Xinyuan 958. The experiment consisted of three treatments: 1 row of wheat +1 row of alfalfa (XM-1), 2 rows of wheat +1 row of alfalfa (XM-2), 3 rows of wheat +1 row of alfalfa (XM-3) and two controls, unitary wheat (CK-X) and unitary alfalfa (CK-M). Wheat-alfalfa row spacing was 30cm, wheat-wheat row spacing was 20cm, mono-sown alfalfa row spacing was 35cm. Each treatment has three replicates and every plot area was 200m^2.

1.3. Experimental methods

From March 2018, 10 alfalfa and 10 winter wheat plants were randomly selected in each plot for plant height observation, measured every 7-10 days, and repeated 3 times for each plot.

1.4. Data analysis and processing

Excel 2010 was used for regression analysis and logistic growth model was constructed. Derivation of the model was carried out to obtain crop growth parameters. The logistic growth model is expressed as:

$$y = \frac{k}{1+e^{a-bt}} \quad (1)$$

Where, 'y' is plant height (cm), 'k' is the theoretical maximum of plant height growth, 'a' and 'b' are model growth parameters, and 't' is growth time.

Take the first derivative of Formula (1) to obtain the crop growth rate (v):

$$v = \frac{kbe^{(a-bt)}}{\left(1+e^{a-bt}\right)^2} \quad (2)$$

The second derivative of formula (1) is used to obtain the linear growth rate (LGR), and the linear growth period (LGD), the linear growth amount (TLG) are calculated. Formulas are as follows:

$$LGR = \frac{kb}{2\sqrt{3}\ln\left(2+\sqrt{3}\right)} \quad (3)$$

$$LGD = t_2 - t_1 \quad (4)$$

$$TLG = y_2 - y_1 \quad (5)$$

Take third-order derivative of formula (1) to obtain the start and end time (t_1, t_2) and two inflection points (y_1, y_2) of the linear growth period on the crop growth curve.The formulas are as follows:

$$t_1 = \frac{a-\ln\left(2+\sqrt{3}\right)}{b} \quad (6)$$

$$t_2 = \frac{a+\ln\left(2+\sqrt{3}\right)}{b} \quad (7)$$

$$y_1 = \frac{\left(3-\sqrt{3}\right)k}{6} \quad (8)$$

$$y_2 = \frac{\left(3+\sqrt{3}\right)k}{6} \quad (9)$$

2. RESULTS

2.1. Measured plant height of crops under different treatments

The multiple comparison results show that there are both significant differences between the groups in original (March 21) and last (May 7) plant height values. While winter wheat and alfalfa plant height values under different intercropping processing have not been improved obviously than control, but actually gone down (see table 1).

Table-1: Plant height values of crops under different treatments

Treatments	Winter wheat		Alfalfa	
	Initial measurements	Last measurements	Initial measurements	Last measurements
XM-1	（20.90±4.25）ab	（67.40±2.67）b	（9.00±2.05）a	（99.00±5.18）ab
XM-2	（20.00±1.69）a	（65.00±1.88）a	（11.50±2.54）b	（101.00±6.78）ab
XM-3	（22.80±1.68）b	（68.40±3.23）b	（13.00±1.69）b	（97.50±9.73）a
CK	（30.40±1.71）c	（69.10±1.66）b	（12.70±1.88）b	（105.20±8.08）b

Note: Data in brackets represent mean ± standard deviation, and different lowercase letters in the same column represent significant differences between treatments (P<0.05).

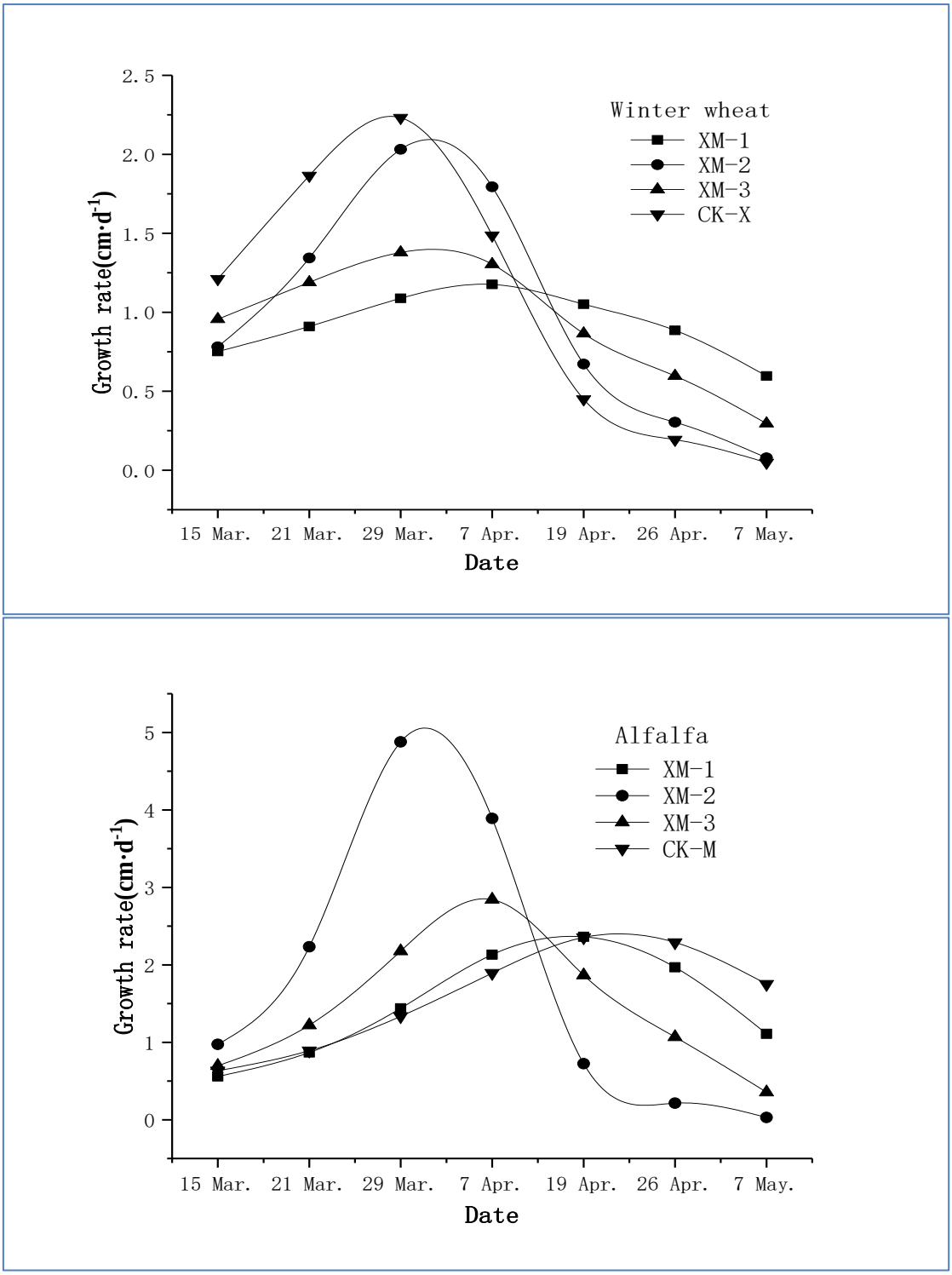

Fig-1: Growth rate curves of plant height under different treatments

The growth rates of the two crops were calculated according to the measured plant heights (figure 1). The growth rate trend of plant heights under different treatments was roughly the same, showing a single-peak trend, but the maximum appeared at different times. The maximum growth rate of unicast wheat appeared on March 29 (2.2314cm·d^{-1}), which was at the stage of standing to jointing. Interplanting with alfalfa made the maximum growth rates of wheat were significantly delayed and their values decreased. Treatment XM-1 delayed the occurrence time of the maximum growth rate of wheat by more than one week than that of the unicast wheat. XM-1 and XM-3 treatments reduced the maximum growth rate of wheat by 38% (1.3784cm·d^{-1}) and 23% (1.7166cm·d^{-1}) compared with single seeding, respectively. While in the later stage the growth rate of wheat was significantly increased by various mixed sowing

treatments, especially the XM-1. The maximum growth rate of unicast alfalfa was 2.3544cm·d^{-1}, which appeared on April 19. XM-2 treatment doubled the maximum growth rate of alfalfa (4.8780cm·d^{-1}), and the date of its occurrence was advanced 20 days (March 29). XM-1 and XM-3 treatments both advanced the date of the occurrence of the maximum growth rate of alfalfa, and increased the maximum growth rate in different degrees, but the effect was far less than that of XM-2. Different from wheat, intercropping significantly reduced the growth rate of alfalfa in the late stage.

2.2. Fitting and construction of crop growth models in different treatments

Logistic fitting was carried out for the plant height data of winter wheat and alfalfa in different intercropping (Fig. 1), and the growth models was established (Table 2). It was found that the coefficient R^2 of fitting equation of wheat and alfalfa in different intercropping was between 0.9540 and 0.9959, indicating that it was feasible to fit the plant height of winter wheat and alfalfa.

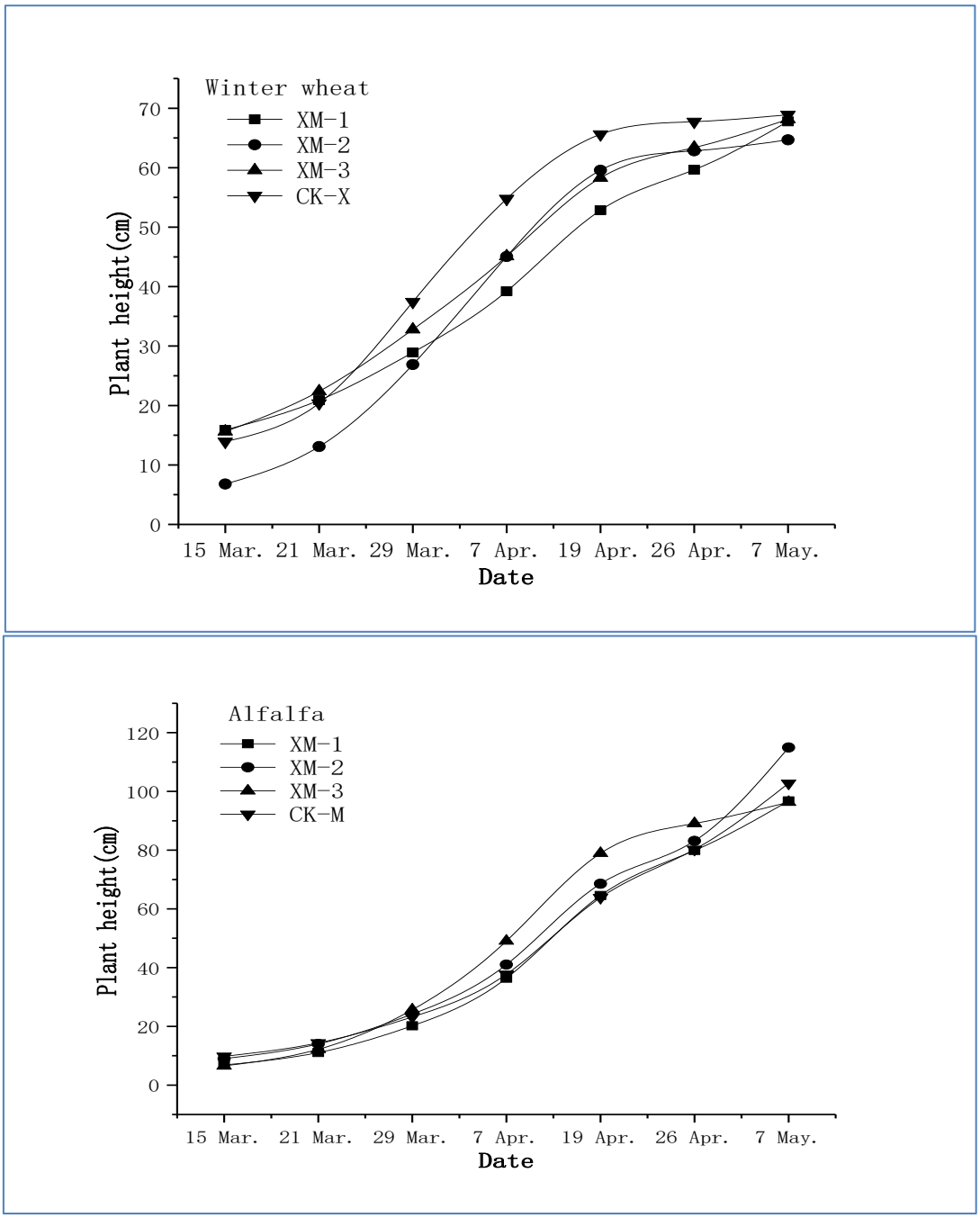

Fig-2: Logistic growth fitting curves of winter wheat and alfalfa under different treatments

The fitting curves of plant height growth model (figure 2) show that winter wheat and alfalfa growth processes in different inter-row interplanting are in accordance with the "slow - fast - slow" growth characteristics. With the growth of crop, the growth curves of plant height of alfalfa in inter-row interplanting are almost all above the unicast alfalfa, while that of winter wheat are below the unicast wheat. This indicated that inter-row intercropping promoted the growth of alfalfa, but inhibited the growth of winter wheat.

表2 不同处理下作物株高生长的logistic模型

Table-2: Logistic model of plant height growth under different treatments

Crops	Treatments	Logistic equation	R2	F	Sig.
Wheat	XM-1	Y=79.65/[1+exp（1.035-0.0591t）]	0.9950	402.0920	0.000
	XM-2	Y=65.31/[1+exp（1.3834-0.1284t）]	0.9608	48.1314	0.002
	XM-3	Y=72.21[1+exp（0.8004-0.0811t）]	0.9959	491.4402	0.000
	CK-X	Y=69.27/[1+exp（0.8756-0.0842t）]	0.9540	40.5145	0.003
Alfalfa	XM-1	Y=111.43/[1+exp（2.2034-0.087t）]	0.9873	155.1370	0.000
	XM-2	Y=115.02/[1+exp（1.975-0.1815t）]	0.9902	201.6291	0.000
	XM-3	Y=99.53/[1+exp（1.9712-0.1143t）]	0.9862	142.3090	0.000
	CK-M	Y=136.24/[1+exp（2.1388-0.0694t）]	0.9936	310.9917	0.000

As seen from the crop growth model (Table 2), except for XM-2, inter-row intercropping increased the growth potential of winter wheat compared with unicast, in which XM-1 had the highest growth potential of 79.65cm, 21.9%, 10.3% and 15.0% higher than that of XM-2, XM-3 and CK(unicast), respectively. Compared with monosown, the growth potential of alfalfa was not increased after interrow intercropping, but decreased gradually with the increase of wheat row number. The growth potential of unicast alfalfa was 136.24cm, which was reduced by 18.2%, 15.6% and 26.9% in XM-1, XM-2 and XM-3 treatments, respectively.

2.3. Division and growth characteristics of different growth stages

The turning points of growth curves and the growth parameters of winter wheat and alfalfa were obtained by logistic equation fitting (Table 3 and Table 4). According to the two inflection points of growth curve, the growth of wheat and alfalfa can be divided into three stages: gradual growth stage (pre-T_1), linear growth stage (T_1-T_2) and slow growth stage (T_2-mature stage). The linear growth period is the most concentrated and rapid period of crop growth, and its starting time and duration represent the time strategy of crop competition for access to light resources, while the linear growth amount and its proportion in the total growth amount represent the effect of crop competition for light resources. It was found that there were significant differences in linear growth period and crop growth parameters of wheat and alfalfa in different intercropping.

Table-3: Linear growth period and parameters of plant in different treatments

Treatments	Winter wheat			Alfalfa		
	Beginning time(T_1/d)	Ending time(T_2/d)	Duration/d	Beginning time(T_1/d)	Ending time(T_2/d)	Duration/d
XM-1	2.48c	37.51d	35.02d	11.74d	38.91c	27.16c
XM-2	1.57a	19.97b	18.41b	4.37b	17.39a	13.02a
XM-3	4.95d	25.74c	20.78c	6.90c	27.58b	20.67b
CK	2.36b	15.86d	13.50a	3.79a	47.84d	44.05d

Note: Different lowercase letters in the same column represent significant differences between treatments ($P< 0.05$).

It can be seen from Table 3 that winter wheat entered the linear growth phase within 3-5 days (March 24, March 23 and March 26) after the plant height measurement, and there is a small difference in the starting time in different treatments. However, inter-row intercropping significantly delayed its ending time and thus extended the linear growth period of winter wheat. The linear growth ending time of winter wheat in XM-1, XM-2 and XM-3 treatments was increased by 21 days, 4 days and 7 days, respectively, and the linear growth period of it was also increased by 159%, 36% and 54%, respectively. Inter-row intercropping had a great effect on alfalfa growth, too. Linear growth starting time of alfalfa was delayed in XM-1, XM-2 and XM-3 treatments. They entered linear growth phase within 4-12 days (April 22, March 25 and March 28) after measurement, respectively. However, the linear growth ending time was advanced, which shortened the

duration of alfalfa, and decreased by 20%, 62% and 39%, respectively, compared with that of unicast alfalfa.

Table-4: plant height growth parameters of crops in different treatments

Treatments	Winter wheat			Alfalfa		
	Linear growth rate(LGR/cm·d^{-1})	Linear growth amount (TLG/cm)	Proportion of TLG(%)	Linear growth rate(LGR/cm·d^{-1})	Linear growth amount (TLG/cm)	Proportion of TLG （%）
XM-1	0.9551a	33.4547d	71.94c	1.7228b	46.8010b	52b
XM-2	1.4901c	27.4276a	60.95a	3.7098d	48.3075c	53.97c
XM-3	1.4589b	30.3303c	66.51b	2.0215c	41.8005a	49.46a
CK	2.1546d	29.0922b	75.17d	1.6801a	57.2181d	61.85d

Note: Different lowercase letters in the same column represent significant differences between treatments (P< 0.05).

During the linear growth period, the average linear growth rate and linear growth amount of winter wheat under different treatments were significantly different and that of single sowing were 2.1546cm·d^{-1} and 29.0922cm, respectively(Table 4). By comparison, the average linear growth rate of the three inter-row intercroppings were 55%, 31% and 32% lower. The linear growth amount of winter wheat in XM-2 was nearly 6% lower than that in unicast, while that in XM-1 and XM-3 was 15% and 4% higher. The proportion of linear growth to total growth of winter wheat in different intercropping treatments decreased by 5-15 percentage points compared with that in monoculture, of which the XM-2 had the greatest effect. The average linear growth rate and linear growth amount of alfalfa in monoculture were 1.6801cm·$d^{-1}$and 57.2181cm, respectively. Compared with its, the average linear growth rate in intercropping treatments were 2%, 121% and 20% higher, but the linear growth amount was 18%, 16% and 27% lower, respectively. The ratio of linear growth to total growth of alfalfa in different interrow intercropping treatments decreased by 7-12 percentage points compared with that in monocropped, and XM-3 had the biggest decrease.

2.4. Validation of crop growth models

Scatter plot was made with measured value as abscissa and predicted value calculated by logistic model as ordinate, and linear regression was conducted to see the correlation coefficient R^2 between them. The results showed that the correlation coefficient between measured value and predicted value of wheat plant height was 0.9115~0.9919, and that of alfalfa was 0.8481~0.9892, both close to 1. The results showed that the predicted and measured values were in good agreement with each other, which verified the reliability of the growth models of winter wheat and alfalfa.

3. CONCLUSIONS

In this study, the logistic equation was used to fit the growth curves and growth parameters of two crops in the wheat/alfalfa intercropping system, and the results were as follows:

(1) From the point of observation result of the plant height, interplanting made the initial and final measurements of wheat and alfalfa were both decreased than that of unicast. But the logistic equation k value of the fitting results showed that interplanting had different effects on growth potential of the two crops that is to increase that of winter wheat and decrease that of alfalfa.

(2) Logistic equation fitting curves showed that interrow intercropping could promote the growth of alfalfa, but significantly inhibit the growth of winter wheat, which seemed to contradict the results of k value above.

(3) Further according to the results of fitting parameters, interrow intercropping significantly delayed the linear growth ending time of winter wheat, and thus extended the linear growth period of winter wheat; The linear growth beginning time of alfalfa was delayed while ending time was advanced, which shortened the linear growth duration of alfalfa.

(4) The growth rate calculated by measured plant height and simulated parameters showed that interrow intercropping decreased the growth rate of winter wheat during the linear growth period, but increased it after. For alfalfa, the linear growth rate was increased and the later growth rate was decreased. The effects of intercropping treatments with different number of wheat rows on the two crops' growth rate were significantly different. The intercropping pattern of two rows wheat-one row alfalfa had the least effect on winter wheat, but the greatest effect on alfalfa; One row wheat-one row alfalfa had the most effect on winter wheat and the least effect on alfalfa. That of three rows of wheat and one row of alfalfa had moderate effects on the growth rates of the two crops.

(5) Interrow intercropping decreased the linear growth rate of wheat, but prolonged its period, which increased the linear growth amount. While the proportions of linear growth amount to total growth amount of wheat plant height were decreased. For

alfalfa, interrow intercropping increased its linear growth rate, but decreased the linear growth period. The proportion of linear amount to total growth amount in plant height was decreased also.

4. DISCUSSION

Alfalfa is a deep-rooted perennial legume forage, which has strong competitiveness for both above-ground and underground resources in the vegetative growth stage [24]. From the Angle of nutrition, the best harvest period of alfalfa is early flowering. While this study did not think in terms of alfalfa forage value of nutrition, and keep it along with wheat growth, to cover the whole growth period of wheat. So the effect and significance of the coexistence of two crops after linear growth period is debatable. And it is necessary to do further study on the planting pattern of wheat/alfalfa interrow intercropping, such as the effects of timely cutting of alfalfa on the above-ground and underground growth of the two crops and their ability to obtain resources.

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