Optimal agronomical practices package for wheat modelized cultivation management in Beijing area

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Summary Based on the principles of system engineering, economics theory and local condition of production, studies carried out by taking "quadratic-regression-orthogonal-rotational" and randomized complete block designs to determine the Optimal Agronomical Practices Package (OAPP) for Wheat Modelized Cultivation Management (WMCM) by system decision-making analysis. The OAPP was expected to meet various goals of different levels of yield and economic benefit of middle and high fertility land in Beijing area. Taking cultivar JINGDONG-1("JD-1")as an example, the OAPP for grain yield ≥6750 kg/ha and net benefit≥360 US $ /ha was consisted as follows: density = 195 plants/m^2; spring irrigation times = 4 (stem elongation, booting, flowering, and 20 days after anthesis); fertilization=150—188 kg N/ha, 113—128 kg P_2O_5/ha.

Key words wheat, agronomical practices package, modelized cultivation management, system decision-making analysis

Introduction

Wheat (*Triticum aestivum* L.) production is influenced by a complex array of factors combining cultivar, plant, soil, water, climate, and cultivation management practices. Wheat Modelized Cultivation Management (WMCM) takes optimal cultivation management practices based on the local production and ecological conditions to help farmers to obtain steady high yield and economical benefit. Although researchers conducted many WMCM studies, WMCM is so far confined to rigid combination of experience models, optimization of separate disciplines, and lack of system coordination and synthesis. System analysis provides us the technique to determine optimal cultivation management practices of WMCM systematically to overcome the limitations above. Trigus(1955) studied the possibility of linear programme application to agriculture. Heady (1975) studied the optimal combinations of production elements and agricultural structures by production function models. Riche (1988) reported the crops simulation models-CERES. The objective of this paper is to approach some WMCM problems based on Production Function Model (PFM) and Economic Benefit Model (EBM) by system decision-making analysis.

Materials and methods

Design and programme

In 1986—1987, designed experiment "quadratic-regression-orthogonal-rotational" of 5 factors and 5 levels was used to construct models (Table 1, Table 2 and Table 4). According to the experimental results of the first year, further experiment was carried out in 1987—1988 to verify and modify the optimal agronomical practices. A randomized-block design with three blocks was used. The experimental treatments comprised cultivars ("JD-1", "7563"),density and spring irrigation (Table 3). Experiments were conducted in the experimental farm of the Crops Institute. The soil fertility was as follows: organic matter = 2.8%; all N = 0.158%; alkali hydrolysis N = 62.9×10^{-6}; available P = 26.16×10^{-6}; exchangeable K = 149.50×10^{-6}. The amount of optimal fertilizer applications was calculated according to the first year experiments results. N was applied in the form of ammonium sulfate and splited into two equal applications, during tillage and the stem elongation period respectively; P was applied in the form of 10% calcium superphosphate. The yield and benefit were calculated after harvest of strip plots.

Analysis methods

The models were established by analysis method of "quadratic-regression-orthogonal-rotational" design; the optimal solutions of models were determined by three methods of gradient-extreme value analysis, computer-based simulation and frequency distribution of different levels of variables for a certain goal.

Table 1. The code value of various experimental factors (1986—1987)

Code value	Cultivar (x_1) weight of 1000 grains(g)	Density(x_2) (ps/m^2)	SI(x_3)* (times)	N(x_4) (kg/ha)	P(x_5)(P_2O_5) (kg/ha)
-r	34(175)	60	2	75.0	0.0
-1	37(7563)	113	3	112.5	37.5
0	40(JD-1)	165	4	150.0	75.0
1	43(ND-142)	218	5	187.5	105.0
r	45(JH-3)	270	6	225.0	150.0

* SI refers to spring irrigation frequancy; irrigation amount per time was 45m^3; ps refers to plants

Table 2. The distribution program of spring irrigation(SI) in different growth periods (1986—1987)

Distribution of SI among growing periods	Turn green	Stem elongation	Booting	Flowering	12 days after anthesis	20 days after anthesis
2(-r)		#		#		
3(-1)		#	#			#
4(0)	#	#	#			#
5(1)	#	#	#	#		#
6(r)	#	#	#	#	#	#

Refers to irrigation

Table 3. The randomized block arrangement of field experiment (1987—1988)

Block	Factors	1	2	3	4	5	6	7	8
I	Cultivar	7563	7563	JD-1	JD-1	7563	7563	JD-1	JD-1
	Density(ps/m^2)	120	195	120	195	120	195	120	195
	SI(times)	4	4	4	4	5	5	5	5
II	Cultivar	JD-1	JD-1	7563	7563	JD-1	JD-1	7563	7563
	Density(ps/m^2)	195	120	195	120	195	120	195	120
	SI(times)	5	5	5	5	4	4	4	4
III	Cultivar	7563	JD-1	7563	JD-1	7563	JD-1	7563	JD-1
	Density(ps/m^2)	120	120	195	195	120	120	195	195
	SI(times)	4	4	4	4	5	5	5	5

Results and analysis

Results of experiments

Table 4. The implement scheme and the yield, benefit results (1986—1987)

Block No.	Strip plot No.	Cultivar X_1	Density (ps/m²) X_2	SI (times) X_3	N (kg/ha) X_4	$P(P_2O_5)$ (kg/ha) X_5	Yield (kg/ha) Y	Benefit ($ /ha) E
I	1	7563	113	5	187.5	112.5	5890.5	330.6
	2	JD-1	166	4	150.0	75.0	6042.0	372.3
	3	ND-142	113	3	187.5	112.5	5626.5	318.0
	4	ND-142	219	3	187.5	37.5	4549.5	255.6
	5	JD-1	166	4	150.0	75.0	5727.0	347.1
	6	7563	219	5	187.5	37.5	4362.0	233.1
II	7	JD-1	166	4	150.0	75.0	6105.0	377.4
	8	JD-1	166	4	150.0	75.0	6048.0	373.2
	9	ND-142	113	5	187.5	37.5	4441.5	245.4
	10	7563	113	3	187.5	37.5	5152.5	326.1
	11	ND-142	219	5	187.5	112.5	5317.5	277.8
	12	7563	219	3	187.5	112.5	4921.5	277.8
III	13	ND-142	113	5	112.5	112.5	5329.5	311.4
	14	7563	113	3	112.5	112.5	6214.5	542.7
	15	ND-142	219	5	112.5	37.5	4839.0	295.8
	16	7563	219	3	112.5	37.5	4581.0	286.5
	17	JD-1	166	4	150.0	75.0	6141.0	380.4
	18	JD-1	166	4	150.0	75.0	5797.5	352.8
IV	19	7563	113	5	112.5	37.5	5088.0	323.1
	20	ND-142	113	3	112.5	37.5	4621.5	294.0
	21	JD-1	166	4	150.0	75.0	5983.5	367.2
	22	ND-142	219	3	112.5	112.5	5250.0	362.1
	23	7563	219	5	112.5	112.5	4578.0	246.9
	24	JD-1	166	4	150.0	75.0	6276.0	392.1
V	25	JD-1	166	4	150.0	0.0	5028.0	323.1
	26	JD-1	166	4	150.0	75.0	6271.5	390.9
	27	JD-1	166	2	150.0	75.0	6160.5	391.2
	28	JH-3	166	4	150.0	75.0	3919.5	201.3
	29	JD-1	166	4	75.0	75.0	5808.0	380.1
	30	JD-1	166	4	150.0	150.0	6402.0	371.1
	31	175	166	4	150.0	75.0	4900.5	282.6
	32	JD-1	166	4	150.0	75.0	5851.5	357.3
	33	JD-1	166	4	225.0	75.0	5446.5	300.0
	34	JD-1	60	4	150.0	75.0	5326.0	321.3
	35	JD-1	166	6	150.0	75.0	6307.5	384.3
	36	JD-1	272	4	150.0	75.0	4932.0	277.8

Model results

According to Table 4, the Production Function Model (PFM) and the Economic Benefit Model (EBM) were constructed as follows:
Production Function Model (PFM):

Table 5. The main results of experiment (1987—1988)

Treatment	Cultivar	Density (ps/m^2)	SI	Yield of blocks (kg/ha)			Order	Significance		F value
				I	II	III		0.05	0.01	
1	7563	120	4	5089.5	4900.5	5034.0	8	a	A	Fw=62.0 **
2	7563	195	4	5578.5	5566.5	5767.5	7	b	B	Fv=126.4 **
3	JD-1	120	4	5358.0	5868.0	5385.0	6	b	BC	Fd=83.4 **
4	JD-1	195	4	5881.5	5778.0	5809.5	4	cd	CD	Fwv=14.2 *
5	7563	120	5	5361.0	5292.0	5292.0	2	de	DE	Fwd=0.1
6	7563	195	5	6019.5	5929.5	6073.5	3	ef	DE	Fvd=0.1
7	JD-1	120	5	6108.0	6352.5	6069.0	5	f	EF	Fwvd=1.1
8	JD-1	195	5	6888.0	6646.5	6759.0	1	g	F	

Fw, Fv, Fd refer to F value of spring irrigation, cultivar, density respectively;
Fwv, Fwd, Fvd, Fwvd refer to the F value of interaction of factors respectively;
Significance was tested by Duncan's multiple rang method;
** and * refer to significance at $P=0.01$ and $P=0.05$ respectively

$$Y = 6056.60 - 15.395x_1 - 26.414x_2 - 4.311x_3 - 5.242x_4 + 45.774x_5 + 31.985x_1x_2 + 6.932x_1x_3 + 0.257x_1x_4 + 5.445x_1x_5 + 5.517x_2x_3 + 0.389x_2x_4 - 16.849x_2x_5 + 4.929x_3x_4 - 6.027x_3x_5 + 8.680x_4x_5 - 59.111x_1^2 - 35.149x_2^2 + 1.685x_3^2 - 18.351x_4^2 - 15.648x_5^2 \quad (F = 13.69 > F_{0.01(20,15)} = 3.36)$$

Economic Benefit Model (EBM):

$$E = 303.052 - 3.317x_1 - 6.266x_2 - 2.422x_3 - 5.458x_4 + 4.155x_5 + 0.078x_1x_2 - 3.369x_1x_3 + 0.986x_1x_4 - 1.206x_1x_5 + 1.676x_2x_3 - 11.810x_2x_4 - 7.013x_2x_5 + 0.353x_3x_4 - 3.114x_4x_5 + 6.320x_1^2 + 1.386x_2^2 + 0.0514x_3^2 + 1.0889x_4^2 + 1.103x_5^2 \quad (F = 12.55 > F_{0.01(20,15)} = 3.36)$$

Decision-making analysis for optimal agronomical practices by PFM

1. Gradient-extreme value analysis The solutions, among $-2 \leqslant X_i \leqslant 2$, were found:

$Y_{max_1} = f$ (Cultivar, Density, SI, N, P) $= f(0,-1,-2,2,2)$
$= f$ ("JD-1", 112.5 ps/m^2, 2, 225kg N/ha, 150 kg P_2O_5/ha) = 6909kg/ha
$Y_{max_2} = f$ (Cultivar, Density, SI, N, P) $= f(-1,-1.39,-2,2,2)$
$= f$ ("7563", 93 ps/m^2, 2, 225 kg N/ha, 150 kg P_2O_5/ha) = 6894 kg/ha)

The practices of Y_{max_1}, Y_{max_2} had characters of low density and high inputs. It would limit its popularization in practice of production because of high risk and high cost.
2. Computer-based simulation Two highest yield agronomical practices combinations were found:

$Y_{max_3} = f$ (Cultivar, Density, SI, N, P) $= f(0,-1,-2,0,2)$
$= f$ ("JD-1", 112.5 ps/m^2, 2, 150 kg N/ha, 150kgP_2O_5/ha) = 6838 kg/ha
$Y_{max_4} = f$ (Cultivar, Density, SI, N, P) $= f(-1,-1,-2,0,2)$
$= f$ ("7563", 112.5 ps/m^2, 2, 150 kg N/ha, 150kgP_2O_5/ha) = 6774 kg/ha

Comparing Y_{max_3} and Y_{max_4} with Y_{max_1} and Y_{max_2}, although the inputs of Y_{max_3} and Y_{max_4} were lower than that of Y_{max_1} and Y_{max_2}, and seemed to be reasonable, its less probability of appearance in simulation resulted in the less reliability and confidence, and the practices were only suitable to skillfully technical farmers.

3. Frequency distribution analysis When PFM was run at $x_i = -2, -1, 0, 1, 2$ ($x_i = 1, 2, 3, 4, 5$)in computer, the frequency distribution of different levels of variables for a certain yield level and the confidence interval at $P = 0.01$ could be calculated out based on principles of statistics (Table 6).

Table 6 The optimal practices of cultivars for high yield by frequency analysis

Cultivar	Test level P=0.01	den. (ps/m²)		SI(times)		N(kg/ha)		P(kg/ha)	
		Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
JD-1	Intl	117—137	134—155	3.1—3.8	3.9—4.4	144—164	140—159	119—134	89—104
	AP	126	144	3.5	4.1	153	150	126	96
	N:P	for Y_1	N:P=1:0.82			for Y_2	N:P=1:0.64		
A5CVS	Intl	108—126	131—143	2.9—3.4	3.8—4.1	143—159	131—156	123—134	102—111
	AP	117	137	3.7	3.9	152	150	128	107
	N:P	for Y_1	N:P=1:0.85			for Y_2	N:P=1:0.71		

AP refers to average point; Intl refers to interval at $P = 0.01$; Y_1 refers to yield ≥6000kg /ha;
Y_2 refers to yield between 5250 and 6000 kg/ha; A5CVS refers to average of 5 cultivars

The practices determined by frequency analysis were more reliable due to the high replication and significance test ($P = 0.01$). The agronomical practices (Table 6) of 5 cultivars for yield more than 6000 kg/ha were: density=117 plants/m²; spring irrigation =4 times; N=152 kg/ha and P=128 kg/ha. The fact that different cultivars needed different agronomical practices to obtain high yield, revealed that agronomical practices must fit rational distribution of cultivars in production. The P applied for yield≥ 6000 kg/ha (N:P=1:0.85) was higher than that of yields between 5250 and 6000 kg/ha (N:P=1:0.71), which indicated that higher level yield required higher level of P. In Table 6, density and irrigation times were less than normal. The reasons were that the treatments of higher density and more irrigation caused serious lodging and yield reduction compared with the lower density and less irrigation treatment due to more rainfall with strong wind during later growth period. So the density and irrigation were considered as the main experimental factors in experiments of 1987 and 1988.

Economic technology decision-making analysis

Fertilizer application is a prime concern associated with the intensive management of wheat. The reasonable strategies of fertilizer applications are important to obtain best effects. This research took cultivar "JD-1" as an example ($x_1 = 0$) to demonstrate the economic technology decision-making analysis.

1. The distribution of N,P fertilizers for the best benefit Based on the principles of economics, when the marginal variable cost is equal to the marginal benefit, the return of cost is the greatest. From the PFM, the following equations were derived:

$$\partial y/\partial x_2 = -26.41 + 5.52x_3 + 0.39x_4 - 16.85x_5 - 70.30x_2 = (R+1)Px_2/Py \quad [1]$$
$$\partial y/\partial x_3 = -4.31 + 5.52x_2 + 4.93x_4 - 6.03x_5 - 3.37x_3 = (R+1)Px_3/Py \quad [2]$$
$$\partial y/\partial x_4 = -5.24 + 0.39x_2 + 4.93x_3 - 36.70x_4 + 8.38x_5 = (R+1)Px_4/Py \quad [3]$$
$$\partial y/\partial x_5 = 45.77 - 16.85x_2 - 6.03x_3 + 8.38x_4 - 31.30x_5 = (R+1)Px_5/Py \quad [4]$$

R was the marginal benefit, the $Px_2, Px_3, Px_4, Px_5, Py$ were the costs ($) per 10 thousand plants, per irrigation time, the prices ($/kg) of N-fertilizer (N), P-fertilizer (P_2O_5),wheat grain, and taking values of 0.156, 0.624, 0.704, 0.8, 0.16 respectively. When the $Px_2, Px_3, Px_4, Px_5, Py$ of equation [1], [2], [3], [4] were replaced by their values, equation[5],[6],[7],[8] were obtained as follows:

$$\partial y/\partial x_2 = -26.41 + 5.52x_3 + 0.39x_4 - 16.85x_5 - 70.30x_2 = 1.95(R+1) \quad [5]$$
$$\partial y/\partial x_3 = -4.31 + 5.52x_2 + 4.93x_4 - 6.03x_5 - 3.37x_3 = 7.80(R+1) \quad [6]$$
$$\partial y/\partial x_4 = -5.24 + 0.39x_2 + 4.93x_3 - 36.70x_4 + 8.38x_5 = 4.41(R+1) \quad [7]$$
$$\partial y/\partial x_5 = 45.77 - 16.85x_2 - 6.03x_3 + 8.38x_4 - 31.30x_5 = 5.00(R+1) \quad [8]$$

If $R=0$, then $\bar{x}=(0,-0.216, 4.465, 0.492, 0.69)^{\tau}$. To take $\bar{x}$ as a begin point to simulate in computer, the optimal point $x=(0,-1.02,-2, 0.132, 1.73)$ = ("JD-1", 113 plants/m^2, spring irrigation 2 times, 162 kg N/ha, 140 kg P_2O_5/ha) was turned out, at which point, the net benefit (deducted only the technology costs) was the highest by $ 419/ha.

2. The distribution of N, P for best return ratio of all fertilizers When the marginal variable cost is equal to the marginal benefit ($R=0$), although the benefit of fertilizers per unit area is the highest, the benefit per unit fertilizer is distinct to be low. In order to obtain higher and stable benefit of fertilizers, especially under the situation of short supplication of fertilizers, the operational research for fertilizers becomes necessary to balance the all fertilizers distribution. In that case, the R value was often assigned larger than zero on the basis of the amount and stability of fertilizers (generally was assigned 4). From Table 6, the optimal density (x_2) and spring irrigation (x_3) with cultivar "JD-1" for yield ≥6000 kg/ha were 126 plants/m^2, 4 times respectively, replaced x_2, x_3 of equation [3][4] with their values, then deduced:

$$x_4 = 0.133 - 0.15R, \qquad x_5 = 1.73 - 0.20R$$

If $R=4$, the N(x_4) and P(x_5) were 132 kg/ha and 110 kg/ha respectively for best return ratio of fertilizers.

3. The reasonable distribution line of N, P fertilizers Only reasonable fertilizer application led to high yield and desirable benefit, and the application of N, P must follow the rule that a certain amount of N must be coordinated by a certain amount of P based on a scientific ratio. This relation of N, P can be described by a line equation. From equation [7],[8],[7]/[8]= $Px_4/Px_5=(-5.53-36.7x_4+8.38x_5)/(58.20+8.38x_4-31.3x_5)=0.704/0.8=0.882$, then x_5 (P)$=1.225x_4$ (N)-1.587.

The line told out the ratio (direction) of N,P coordination application.

Decision-making analysis by EBM

The non-rational input will result in the considerable waste in high level of yield. By the same way of frequency analysis for PFM, Table 7 presented the results of frequency analysis of EBM.

Table 7. The optimal practices of different cultivars for high benefit by frequency analysis

Cultivar	Test level $P=0.01$	Den. (ps/m^2) E_1	Den. E_2	SI(times) E_1	SI E_2	N(kg/ha) E_1	N E_2	P(kg/ha) E_1	P E_2
JD-1	Intl	134—149	122—161	3.6—4.0	4.3—5.0	129—143	141—174	81—95	50—86
	AP	141	141	3.8	4.6	135	158	89	68
	N:P	for E_1	N:P=1:0.65			for E_2	N:P=1:0.43		
A5CVS	Intl	87—117	108—131	3.1—4.0	4.0—4.7	123—150	137—159	119—137	93—111
	AP	101	120	3.6	4.3	137	147	128	102
	N:P	for E_1	N:P=1:0.93			for E_2	N:P=1:0.69		

E_1: Benefit ≥ $ 300/ha; E_2: $ 270/ha ≤ Benefit < $ 300/ha

The practices of cultivars for net benefit≥ \$ 300/ha (Table 7) were different from that for 270≤benefit< \$ 300/ha; the former took lower density, higher P level than the latter, N level was near the same. The trend was same with the one of high yield analysis of PFM. In this experimental conditions, N-fertilizer had less effect in yield and benefit, but if N applied more than reasonable amount, it would reduce the benefit due to in-cereased costs. P-fertilizer got good effects in increasing yield and benefit, which showed that more benefit still returned from increasing application of P-fertilizer. The fact that different cultivars needed different practices in same benefit level showed the characteristic differences among cultivars. Different goals needed different practices (Table 6, Table 7), for example (cultivar "JD-1"), the practices for yield ≥6000 kg/ha were density = 120 plants/m², irrigation times = 3.5, N = 153 kg/ha, P = 126 kg/ha; for benefit≥ \$ 300/ha were 141 plants/m², 3.8 times, 135 kg/ha, 90 kg/ha, respectively.

The synthetic goals decision-making analysis

Suppose Yi is the value of Goal (i) function, x, as one of a multi-dimensional vectors, multi goals are limited by the express formula: $Ai \geqslant Yi \geqslant Bi$, Ai and Bi are the upper limit and lower limit value of Goal (i) which are determined by practical purpose. To consider two goals:
(yield≥6000 kg/ha) and (benefit≥ \$ 360/ha) for goal$_1$, B_1 = 6000 kg/ha, B_2 = \$ 360/ha; (6000>yield≥5250, 360>benefit≥ \$ 300/ha) for goal$_2$, A_1 = 6000kg/ha, B_1 = 5250 kg/ha, A_2 = \$ 360/ha, B_2 = \$ 300/ha. The optimal practices from synthetic goals analysis (Table 8) were not equal to the mechanical combination of single goal (high yield, high benefit), which considered the interaction of various factors. Although some sub-goal's value of synthetic goals was lower than that of the same single goal, the whole goals were better than that of mechanical combinations of single goals. In the practices of synthetical analysis, the N, P inputs were lower than that for high yield and higher than that for high benefit respectively, which were more available to actual production.

Table 8. The optimal practices of different cultivars by frequency analysis under the limitations of goalt and goal$_2$ (synthetic goals)

Cultivar	Test level P = 0.01	Den. (ps/m²)		SI(times)		N(kg/ha)		P(kg/ha)	
		GOAL$_1$	GOAL$_2$	GOAL$_1$	GOAL$_2$	GOAL$_1$	GOAL$_2$	GOAL$_1$	GOAL$_2$
JD-1	Intl	113—137	134—159	2.7—3.4	3.9—4.6	129—150	138—159	111—129	89—101
	AP	125	146	3.0	4.0	140	149	120	96
	N:P	for GOAL$_1$ N:P = 1:0.86				for GOAL$_2$ N:P = 1:0.65			
A5CVS	Intl	99—126	120—144	2.9—3.7	3.9—4.6	125—150	137—159	119—137	93—111
	AP	113	132	3.3	4.0	138	147	122	99
	N:P	for GOAL$_1$ N:P = 1:0.90				for GOAL$_2$ N:P = 1:0.69			

Discussion and conclusion

Experiments were conducted from 1986 to 1988. In the first year, the PFM and the EBM were established based on the experiment results. And the practices for high yield and high benefit were determined which mainly focused on two cultivars ("JD-1", "7563"). Decision-making took three ways of analysis in which the frequency distribution analysis was better than the others.

Different practices needed to fit different goals (Table 9). There was a same trend in practices for various goals, that the density and irrigaton times were lower than normal. The reasons were that too much rainfall with strong wind in later wheat growth period of 1987 resulted in serious lodging and yield reduction of high density treatment and the effects of spring irrigation was canceled too. Therefore the testing and verifying experiments in 1988 were necessary to modify the optimal practices of first year, which was proved to be correct (Table 3).

Table 9. The optimal agronomical practices package for different goals ("JD-1")

Goals	Density (ps/m^2) X_2	SI (times) X_3	N (kg/ha) X_4	P (kg/ha) X_5	Yield (kg/ha) Y	Benefit ($/ha) E
Yield≥6000 kg/ha	127	4	153	126		
Best benefit	112	2	155	140	6546	418
Best return ratio	127	4	132	111	6359	389
High yield and benefit	124	3	140	120	6624	411
Distribution line of N and P for best benefit	$x_5 = 1.227 x_4 - 1.587$					

Summarizing all analyses, taking "JD-1" as an example, some conclusions were deduced that the agronomical practices package for high yield and high economic benefit was as follows: cultivar "JD-1"; density=195 plants/m^2; spring irrigation times=4(stem elongation, booting, flowering, 20 days after anthesis); N-fertilizer=150—188 kg N/ha (split into 2 equal amounts applied during tillage as the fertilizer of seed bed, and elongation stage); P-fertilizer=113—128 kg P_2O_5/ha(applied during tillage before sowing at one time), N:P=1:0.75—0.85, (lower limit was 1:0.5), yield ≥6750 kg/ha, net benefit ≥ $ 360/ha.

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