THE RESPONSE OF WINTER WHEAT TO WATER STRESS AND NITROGEN FERTILIZER USE EFFICIENCY

Wang Fujun Qi Mengwen Wang Huaguo Zhou Changjiu
Laboratory for Application of Nuclear Techniques
Beijing Agricultural University
Beijing 100094 P. R. China

1. ABSTRACT

The response of winter wheat to water stress imposed at different crop growth stages by deficit irrigation and fertilizer use efficiency under several schemes of irrigation were evaluated on fine sandy soil and sand loam soil. The results showed that according to grain yield response factor K, the order of sensitive growth stages of winter wheat to water stress in decreasing sequence were booting to flowering (K=0. 90), winter afterward to booting (K=0. 69), flowering to milking (K=0. 44), winter forward (K=0. 40) and milking to ripening (K=0. 25). Field water efficiency would get 16. 7kg/mm·ha when no water stress in growth period, and when water stress has occured in some growth stages, the value of it decreased by 5—20 precent. It was also found that high fertilizer application rate without split application would not significantly influence the yield on fine sandy soil. But schedule of irrigation affected the translocation of nitrogen in the plant. When water stress occured in later growth stage, the ratio of NUE in grain to straw decreased, and fertilizer was available for crop only about one month after fertilizer application, excessive fertilizer rate would result in decrease of NUE by leaching of nitrogen in sandy soil. Total recovery of fertilizer at harvest was less half amount of application.

2. INTRODUCTION

Improper irrigation may waste large amount of water, leach soil nutrients, and decrease productivity . Water for irrigation becomes more and more valuable due to the increase cost of irrigation projects and a limited supply of good quality water. Therefore, we must learn how to prevent an excessive waste of irrigation water to against the degradation of the land and bring about its improvement for maximum crop prduction, especially for sand loam soil.

All these must be based on knowledge of crop, soil and weather. The most important is to know which growth stage of crop is more sensitive to water stress, and according to the crop itself characteristic to establish a reasonable irrigatoin scheme. A lot of works about this aspect have been completed[1,2,3,4].

"Evapotranspiration-Yield" model is a good way to predict yield of crop responds to water stress[5,6] and this model have been become a guidline for irrigation schedule which was suggested and recommended by FAO.

This experiment was conducted to study the yield response to water stress imposed at different plant growth stages of winter wheat by deficit irrigation, evaluate the sensitivity of winter wheat to water stress using "ETa-Yield" model, and assess nitrogen use efficiency

(NUE) under this condition. We, then, designed a reasonable irrigation and fertilization scheme in Hua Bei plain, the biggest plain for wheat production in China.

This study is a part of FAO/IAEA co-ordinated research programme on "The Use of Nuclear and Related Techniques in Assessment of Irrigation Schedules of Field Crops to Increase the Effective Use of Water in Irrigation Projects".

3. MATERIALS AND METHODS

3.1 Experimental site

Experiments was carried out in Da Ming experimental station of Beijing Agricultural University (E 114°30′, N 36°46′, altitude 45m). Located in a semi-humid region with 589mm annual precipication at last 20 year, and only about 20 percent of it occured in the period of winter wheat growth. Mean annual temperature was 13.33℃ and evaporation from water surface was 2079mm.

3.2 Soil characteristic

Experimental plots were different for 1992—1993 and 1993—1994, but location was same, texture of experimental soil was fine sandy and sand loam soil, respectively, soil bulk density and field capacity in different soil layer were listed in Table Ⅰ and soil nutrient content was listed in Table Ⅱ.

TABLE Ⅰ. BULK DENSITY AND FIELD CAPACITY of the SOIL

Soil layer (cm)	1992—1993		1993—1994	
	Bulk density (g/cm^3)	Field capacity (mm)	Bulk density (g/cm^3)	Field capacity (mm)
0—20	1.28	39.0	1.30	25.0
20—40	1.44	49.5	1.41	35.8
40—60	1.45	56.6	1.45	55.6
60—100	1.50	131.9	1.50	120.4

TABLE Ⅱ. NUTRIENT CONTENTS of the SOIL

Soil layer (cm)	1992—1993		1993—1994	
	0—20cm	20—40cm	0—20cm	20—40cm
Organic matter (%)	0.573	0.348	0.823	0.454
Total N (%)	0.032	0.021	0.061	0.028
Available N (mg/kg)*	37.8	25.0	41.2	26.1
Avaliable P (mg/kg)*	5.3	0.9	9.6	3.6
Availble K (mg/kg)*	50.7	39.8	74.6	46.3

* Available N: Alkali-hydrolyzable N, Available P: Olsen P, Available K: Exchangeable K

3.3 Experimental Treatment

3.3.1 Plot experiment.

The experiments of two years were consisted of eight different irrigation treatments, (listed in Table Ⅲ). Each treatment consisted of four repetition attributed to plots of 7.5 by 2 metres each by the radomized completed back design. Each irrigation treatment of

1992—1993 was combined with two level of fertilizer level treatments, the base fertilizer was same for all treatments as 150kg/ha of phosphorus and 120kg/ha nitrogen, two fertilizer level was obtained by top dressing after winter , just at begining of regreening, 90kg/ha nitrogen was assigned as low fertilizer level and 160kg/ha as high fertilizer level. Experiment of 1993—1994 only included irrigation treatment, and base fertilizer for all treatments was as same as 150kg/ha phosphorus, 100kg/ha of potash and 160kg/ha of nitrogen.

TABLE Ⅱ. AMOUNT OF IRRIGATION WATER (mm) OF DIFFERENT TREATMENTS

Year	Treat. *	Seeding to winter forward (60 days)	Winter afterward to booting (35 days)	Booting to flowering (26 days)	Flowering to milking (14 days)	Milking to ripening (16 days)
1992—1993	A(1—1111)	58	60	60	40	50
	B(0—0000)	12	20	20	0	0
	C(0—1111)	12	60	60	40	50
	D(1—0111)	58	15	60	40	50
	E(1—1011)	58	60	20	40	50
	F(1—1101)	58	60	60	0	50
	G(1—1110)	58	60	60	40	0
	TR(0—1110)	0	100	100	100	0
1993—1994	A(1—1111)	55	60	60	40	50
	B(1—0000)	55	0	0	0	0
	C(1—0111)	55	0	60	40	50
	D(1—1011)	55	60	0	40	50
	E(1—1101)	55	60	60	0	50
	F(1—1110)	55	60	60	40	0
	G(1—1001)	55	60	0	0	50
	H(1—1100)	55	60	60	0	0

* "1" ; no water stress in a special growth stage. "0" ; water stress in the growth stage which was gotten by deficit irrigation. "TR" ; traditional methods.

Winter wheat (local variety 87—2) was seeded in October and harvested in June of next year, and the other productive managements, such as insect controlling, were just as same as local practice.

3. 3. 2 N-15 Subplot Experiment.

N-15 fertilizer experiment was only done in 1992—1993. Twenty four subplots by 65cm * 60cm located in the middle of the plot were installed for treatment A, D, E,F, G and TR respectively, each treatment with two repetitions.

The date and amount of N-15 labelled fertilizer applied in subplot were just as in plot. N-15 abundance was 2. 28 percent.

3. 4 Date collection

The soil samples for determining soil water content were taken by a soil anger at 10cm of interval up to one metre depth in the profile once every ten day, before and after irrigation or after rain (>15mm), the data of soil water content was also determined.

Meteorological data, such as temperature, humidity, precipitation, windspeed, sunshine and free water evaporation, elc. were observed by the meteorological station which was only 100m far from the experimental plot. At harvest time, plant samples from 1. 5 square metre and 0. 5 squre metre area in each plot were taken for determining yield and yield components respectively.

Plant samples from one twentieth of plant in each subplot for N-15 analysis were taken at begining of booting (11th, April), flowering (4the, May), milking (21th, May) and ripening (5th, June) respectively. At harvest, soil samples from 0—20cm and 20—40cm soil layer was taken for N-15 analysis.

3. 5 Relevent calculation

"Yield—ETa model" uses formula as follows[1].

$$Ya/Ym = \prod_{i=1}^{n} [1-Ki(1-\sum_{j=1}^{m} ET\ aij / \sum_{j=1}^{m} ETpij)]$$

where

Ya was actual yield for a special treatment,

Ym was maximum attainable yield without water deficit at any time during the growth season, corresponding to the treatment A in this paper,

ETaij was actual ET at jth day in ith stage,

ETpij was maximum potential ET at same time, corresponding to the ETa under treatment A.

Actual evapotranspiration was affected by factors of plant and soil moisture except for climate, and could be estimated as follow formula.

$$ETa = f(p) * f(s) * ETp$$

where

ETa was actual evapotranspiration,

f(p) was crop coefficient, and were 0. 76, 0. 91, 1. 23, 1. 22, and 0. 9 for each given stage,

ETp was potential ET which was calculated by modified Peman formula[4].

f(s) was a adjusted factor related to soil moisture and could be estimated by equation as follows[5].

$$f(s)=1 \quad \text{When} \quad SW>SWC,$$

$$f(s)=SW/SWC \quad \text{When} \quad SW=<SWC$$

where

SW was soil water content,

SWC was critical water content which was estimated to be 70 percent of field capacity.

4. RESULTS AND DISCUSSION

4. 1 Actual evapotranspiration and yield

Actual evapotranspiration for two year' s experiments were listed in Table Ⅳ. The results showed that the lower evapotranspiration occured in the period of deficit irrigation, and the slight soil water deficiency in a former growth stage would not have a significant effect on ETa in the next growth stage when soil water content recovered. The grain yield and dry matter were listed in Table Ⅴ.

TABLE Ⅳ. ACTUAL EVAPOTRANSPIRATION (mm) OF DIFFERENT IRRIGATION TREATMENT IN DIFFERENT GROWTH STAGE OF WINTER WHEAT.

Year	Treat.	Seeding to winter forward (60 days)	Winter afterward to booting (35 days)	Booting to flowering (26 days)	Flowering to milking (14 days)	Milking to ripening (16 days)	Total
1992—1993	A(1—1111)	51.0	72.6	132.1	59.5	81.1	398.3
	B(0—0000)	34.1	64.8	107.6	43.0	57.3	306.8
	C(0—1111)	34.1	79.8	132.1	59.5	83.1	388.6
	D(1—0111)	51.0	50.6	132.1	59.5	83.1	376.3
	E(1—1011)	51.0	72.6	110.3	60.6	83.1	377.6
	F(1—1101)	51.0	72.6	132.1	42.8	84.3	382.8
	G(1—1110)	51.0	72.6	132.1	59.5	62.0	377.2
	TR(0—1110)	34.1	80.8	105.4	65.5	63.3	349.1
1993—1994	A(1—1111)	52.6	73.6	136.1	60.2	82.6	405.1
	B(1—0000)	52.6	49.4	108.4	41.4	58.3	310.1
	C(1—0111)	52.6	49.4	136.1	60.2	82.6	380.9
	D(1—1011)	52.6	73.6	112.5	61.8	82.6	383.1
	E(1—1101)	52.6	73.6	136.1	41.0	83.3	386.6
	F(1—1110)	52.6	73.6	136.1	60.2	60.1	382.6
	G(1—1001)	52.6	73.6	112.5	38.8	80.7	358.2
	H(1—1100)	52.6	73.6	136.1	41.0	58.3	361.6

* ETa in the period of winter was omited.

TABLE Ⅴ. GRAIN YIELD (kg/ha) AND DRY MATTER (ton/ha)

Year	Treat.	Grain yield				Dry matter			
		Low fert.		High fert.		Low fert.		High fert.	
		kg/ha	%	kg/ha	%	ton/ha	%	ton/ha	%
1992—1993	A(1—1111)	6200 a	100	6313 a	100	15.790	100	14.840	100
	B(0—0000)	4367 d	70.4	4525 e	71.7	11.673	73.9	11.601	78.2
	C(0—1111)	5370 b	86.6	5500 b	87.1	13.865	87.7	13.035	87.8
	D(1—0111)	4850 c	78.2	5033 c	79.7	12.335	78.1	11.975	80.7
	E(1—1011)	5300 b	85.5	5433 bc	86.1	13.185	83.5	13.035	87.8
	F(1—1101)	5600 b	90.3	5263 bc	83.4	13.450	85.5	13.065	88.1
	G(1—1110)	5400 b	87.1	5400 bc	85.5	13.285	84.1	13.165	88.7
	TR(0—1110)	4810 c	77.6	4850 d	76.8	13.125	83.1	13.435	90.5
		kg/ha	%			ton/ha	%		
1993—1994	A(1—1111)	6384 a	100			16.852	100		
	B(1—0000)	4053 f	63.5			11.186	66.4		
	C(1—0111)	4878 e	75.9			13.105	77.8		
	D(1—1011)	5285 c	82.8			14.054	83.4		
	E(1—1101)	5463 c	85.6			15.140	89.8		
	F(1—1110)	5939 b	91.6			15.936	94.6		
	G(1—1001)	4969 de	77.8			12.679	75.2		
	H(1—1100)	5062 d	79.3			13.969	82.9		

In the experiment of 1992—1993, the difference of yield between two fertilizer levels was not significant (LSD 5%) and the cross effect between fertilizer and irrigation was also not significant different (LSD 5%), these results would be discussed in Table Ⅸ.

The results of two years showed that when water stress occured in a special growth stage, the yield would decrease 10% to 25% and continuous water stress would decrease yield 20% to 30%.

4.2 Yield response factor

By the different length of growth stage, same percentage of decrease in yield did not mean same sinsitivity of plants to water stress, and the sinsitivity of wheat response to water stress could be evaluated by yield response factor K, which could be calculated out by "Yield—ETa" model. According to the results of treatment which water stress occured only in one stage in whole growth stage, the K value was calculated and listed in Table Ⅳ. The result showed that water sensitive stage was same between the experiment of two years, the most sensitive stage to water stress was in the period from booting to flowering, the K value was ranged form 0.737 to 1, and next was in the period from winter afterward to booting, the K value was ranged form 0.637 to 0.722, the other growth stage was nonsensitive stage.

TABLE Ⅵ. YIELD RESPONSE FACTOR K

Growth stage	1992—1993				1993—1994	
	Low fert.		High fert.			
	G.Y	D.M	G.Y	D.M	G.Y	D.M
Seeding to winter forward	0.403	0.368	0.389	0.367	—	—
Winter afterward to booting	0.719	0.722	0.675	0.637	0.717	0.677
Booting to flowering	0.855	0.999	0.845	0.737	0.993	1.144
Flowering to milking	0.345	0.528	0.590	0.426	0.452	0.319
Milking to ripening	0.488	0.625	0.569	0.446	0.256	0.199

* G.Y: grain yield, D.M: dry matter.

The "Yield—ETa" model can tested by the results of treatment which had continuous water stress. By using the K value in Table Ⅵ and ETa in Table Ⅳ, the calculated yield have been gotten and listed in Table Ⅶ.

TABLE Ⅶ. THE TEST OF "YIELD—ETa" MODEL

		Calculated yield (kg/ha)	Actual yield (kg/ha)	Relative ereor (%)
1992—1993	Low fert.			
	TR(0—1110)	4570	4810	—4.9
	B(0—0000)	3202	4367	—26.7
	High fert.			
	TR(0—1110)	4754	4850	—2.0
	B(0—0000)	3144	4525	—30.6
1993—1994	B((0—0000)	3091	4053	—23.7
	G(0—1001)	4523	4969	—8.98
	H(0—1100)	5083	5062	+0.41

The results showed that calculated value was quite close to actual yield for treatment TR, G and H, the relative error of grain yield did not excess 10 percent, and for treatment exposed to continuous water stress, if included sensitive stage, the relative error between actual yield and calculated yield would increase, such as in treatment G, if continuous water stress occured in no sensitive stage, the relative error would decrease, such as in treatment H. The related error of treatment B which had water stress in whole growth stage was ranged from 20% to 30%, this result maybe caused by accumulative error of all growth stage water stress.

4.3 Water use efficiency

Irrigation water use efficiency (Ef) was definited as yield per unit irrigation (kg/mm·ha) and field water efficiency (Ec) as the yield per unit ETa and calculated results for two years experiments were listed in Table Ⅶ.

TABLE Ⅷ. WATER USE EFFICIENCY

Year	Treat.	Field water use Eff.				Irrig. water use Eff.	
		Low fert.		High fert.		Low fert.	High fert
		kg/mm·ha	%	kg/mm·ha	%	kg/mm·ha	kg/mm·ha
1992—1993	A(1—1111)	15.6	100	15.8	100	23.1	23.6
	B(0—0000)	14.2	91.0	14.7	93.0	87.3	90.3
	C(0—1111)	13.8	88.5	14.2	89.9	23.6	24.1
	D(1—0111)	12.9	82.7	13.4	84.5	21.7	22.6
	E(1—1011)	14.0	89.7	14.4	91.1	24.3	24.9
	F(1—1101)	14.6	93.6	13.7	86.7	24.1	25.7
	G(1—1110)	14.3	91.7	14.3	90.5	24.7	24.7
	TR(0—1110)	13.8	91.0	13.9	87.9	16.0	16.2
		kg/mm·ha		%		kg/mm·ha	
1993—1994	A(1—1111)	15.76		100		24.09	
	B(1—0000)	13.07		83.9		73.69	
	C(1—0111)	12.81		81.3		23.80	
	D(1—1011)	13.80		87.5		25.78	
	E(1—1101)	14.13		89.7		24.28	
	F(1—1110)	15.51		98.4		27.60	
	G(1—1001)	13.87		88.0		30.12	
	H(1—1100)	14.00		88.8		28.93	

The results of Ec and Ef between two fertilizer level were not significant different (LSD 5%). Except treatments B and TR of 1992—1993, Ec of other treatments were also not significant different (LSD 5%). The results of two year's experiments showed that if no water stress in the all growth stage, field water efficiency would get the biggest value, yield of wheat was 15.7 kg/mm per hectare, however, with water stress in one or two stages, the field water efficiency would decrease 5% to 20%, and yield of wheat reduced to 12.9 kg/mm per hectare in treatment D in 1992—1993, and 12.81 kg/mm per hectare in treatment C of 1993—1994. The lower Ef of tradional irrigation (TR) of 1992—1993 showed that irrigation water in each time was over amount which available soil layer could held, and was not used by wheat. The higher value of Ef in treatment B showed that soil water could support some yield, the water was mainly from deep layer or stored in the available layer in the summer, because amount of precipitation in the period of all growth stage of two year was no more than 50mm, and in generally only had several millimeters in one times.

4.4 Fertilizer use efficiency

The nitrogen fertilizer use efficiency under different treatments in 1992—1993 was determined by N-15 labelled fertilizer and the results were listed in Table IX.

TABLE IX. NITROGEN FERTILIZER USE EFFICIENCY

Time	11th, April	4th, May	21th, May	5th, June		
	Dry matter	Dry matter	Dry matter	Grain	Straw	Dry matter
Low fertilizer						
A(1—1111)	41.7[100]	42.4[100]	41.03[100]	32.22[100]	10.23[100]	42.45[100]
D(1—0111)	37.7[90.4]	40.7[96.5]	40.36[98.4]	29.03[90.1]	10.74[105.0]	39.77[93.7]
E(1—1011)	41.7[100]	38.46[91.4]	38.4[93.7]	31.033[96.3]	9.12[89.1]	40.15[94.6]
F(1—1101)	41.7[100]	42.24[100]	39.40[96.0]	29.72[92.2]	12.14[118.7]	41.86[98.6]
G(1—1110)	41.7[100]	42.24[100]	41.03[100]	27.66[85.8]	12.47[121.0]	40.13[94.5]
TR(1—1110)	42.8[102.8]	43.79[103.7]	41.76[101.8]	30.05[93.3]	13.36[130.6]	43.41[102.3]
High fertilizer						
A(1—1111)	25.38[100]	33.6[100]	35.85[100]	26.12[100]	7.76[100]	33.88[100]
D(1—1011)	17.93[70.6]	29.4[87.4]	30.96[86.4]	24.79[94.9]	7.42[95.6]	32.21[95.1]
E(1—1101)	25.38[100]	25.91[77.1]	30.85[86.1]	22.93[87.8]	8.02[103.4]	30.95[91.4]
F(1—0001)	25.38[100]	33.63[100]	34.80[97.1]	23.49[89.9]	8.55[110.2]	32.04[94.6]
G(1—1001)	25.38[100]	33.63[100]	35.85[100]	24.19[92.6]	8.80[113.4]	32.99[97.4]
TR(0—1110)	28.80[113.8]	34.4[102.5]	36.62[102.1]	24.49[93.7]	9.46[121.9]	33.95[102.1]

Where"[]" ; relative nitrongen fertilizer use efficiency compared with treatment A.

The result in table 4.6 showed that if no water stress occured, the fertilizer recovery would attained to maximum in short period after fertilizer application. After one month of application, the fertilizer N recovery under low fertilizer rate would not further increase and only increased 20—25 percent for high fertilizer rate. It was found that for same fertilizer rate, the fertilizer use efficiency basically was same, fertilizer use efficiency of low fertilizer rate was light higher than that of high fertilizer level, they were about 40 percent and 30 percent respectively. When water stress occured just in the stage after fertilizer application, maximum recovery would be attainted in more long time, but final fertilizer use efficiency would not obviously decrease. Water stress in later growth stage would significantly decrese the ratio of fertilizer N recovery in grain to in straw, the results were listed in Table X. With fine sandy soil, because of loss of nitrogen by leaching, application of fertilizer with high rate would results in the decrease of fertilizer use efficiency, such as treatment of high fertilizer level. At harvest fertilizer remained in 0—40 cm of soil layer was not exceeded over 5% of applied fertilizer.

TABLE Ⅹ. RATIO OF NUE IN GRAIN TO STRAW

Fert.	A (1—1111)	D (1—0111)	E (1—1011)	F (1—1101)	G (0—1110)	TR (0—1110)
Low	3.15	2.70	3.40	2.45	2.22	2.25
High	3.37	3.34	2.86	2.75	2.75	2.59

5. CONCLUSION

Experiment of two year on fine sandy soil in semi—humid region obtained results as follows.

(1) The different growth stage of winter wheat have different sensitivity to water stress. According to the "Yield—ETa" model, the most sensitive stage is in the flower form stage, that is from booting to flowering, another sensitive is from winter afterward to booting, the other growth stage are not very sensitive to water stress.

(2) "Yield — ETa" model is suitable for forcast the yield, and the relative error between calculated yield and actual yield can be controlled in 10 percent.

(3) Field water efficiency is better than irrigation water efficiency when they are used to evaluated the water use efficiency. Field water efficiency will get the biggest value when no water stress in the period of growth, in generay, the value of it is 16.7kg/mm·ha, and when water stress has occured in coming growth stage, the value of it will decrease by 20%.

(4) In the top dressing time, if there is not water stress, the N uptake will increase, water stress in later growth stage will significantly decrease the ratio of fertilizer N recovery in grain and in straw. The N fertilizer use efficiency in sand soil is rangbed form 30 to 40 percent, and it decrease when large amount of nitrgen applied increase in one time of top dressing.

REFERENCE

[1] Day, A. D. and Suhawtr Intalap, Some effect of soil moisture stress the growth of wheat, Agron. J. 62, 27—29(1970).

[2] Ras, N. H., Sarma, P. B. S. and Chander, S., Irrigation scheduling under a limited water supply, Agric. Water Management, 15, 165—167(1988).

[3] Reginato, R. J., Hatfield, J. L., etc. Winter wheat response to water and nitrogen in the north american plain, Agric. For. Meteorol., 44, 105—116(1988)

[4] Doorenboos, J. and Kassam, A. S. Yield Response to Water. Irrigation and Drainage Paper. 33, FAO Rome Italy 35—40 (1979).

[5] Lu Jiezhong, Calculation and prediction of the water balance and the drought of the field, Acta Agriculturae Universitatis Pekinensis. 8(2), 69—75 (1982)(in Chinese).

[6] Tao Zhuwen and Pei Buxiang, The calculation method of evapotranspiration and various value of water content in soil body, Acta Meteorological Sinica. 37(4). 79—87 (1979)(in Chinese).