RESEARCH ARTICLE

Analysis on water requirement and water-saving amount of wheat and corn in typical regions of the North China Plain

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Abstract This paper studied the variation characters on wheat and corn water consumption and irrigation water-saving amount under different water conditions (ample irrigation level, farmers conventional irrigation level and optimizing irrigation level). The water use efficiency and water saving potential of optimizing treatment and farmers' conventional irrigation treatment were analyzed respectively. The objective of this study was to provide theoretical supporting for popularization and application of optimizing irrigation measures. Crop water requirement under sufficient water supply was calculated by Penman equation. We obtained crop water consumption under conventional treatment and optimizing treatment by field experiment. The main results showed that the irrigation amount of wheat and corn was too much under farmers' conventional irrigation level and basically satisfied their water requirement, therefore, the water-saving amount was smaller while water-saving potential was bigger compared with the optimizing irrigation treatment. The grain yield under optimizing irrigation treatment was improved or appreciably reduced compared with that under conventional irrigation treatment, while the water consumption and irrigation amount of optimizing irrigation treatment was lower, with a higher water use efficiency. Therefore, the optimizing irrigation treatment could achieve a stable yield and high water efficiency at the same time. Moreover, when the optimizing irrigation measure was adopted, the grain yield reached 5940 kg/hm², water-saving amount reached 91mm for winter wheat, and the grain yield reached 7743 kg/hm², with water-saving amount of 49 mm for summer corn in the piedmont region of Taihang Mount. The grain yield got 7710 kg/hm², with water-saving amount of 20 mm for winter wheat in Heilonggang Plain. Therefore, the water-saving amount in the piedmont region of Taihang Mountain was obviously higher than that in Heilonggang Plain. Thus, the piedmont region of Taihang Mountain in the North China Plain is viewed as the key district for water-saving.

Keywords winter wheat, summer corn, water requirement, water-saving amount

Introduction

Winter wheat and summer corn are two most important crops in North China Plain (NCP), where 70% of the arable land is under double cropping system of winter wheat and summer corn. Wheat and corn are also high water-demonding crops, especially for wheat. In Hebei Province of NCP, the irrigation amount was about 3000 m³/hm² for winter wheat and about 1200 m³/hm² for summer corn (Liu et al., 2004), and water use efficiency (WUE) was only 1.38 kg/m³ for wheat and corn

(Wang, 2010). The NCP highly depends on over exploitation of groundwater to satisfy the water use of agricultural and economic development, and over 70% of groundwater is used for irrigation. According to statistic data, the amount of groundwater exploitation increases along with yield increase of wheat and corn. Crop rotation system of winter wheat and summer corn is the main reason for the over extraction of ground water. In Taihang Mount-foot Plain of NCP, the ground water decreases rapidly (Zhang et al., 2003a). Water shortage has become the key limiting factor of sustainable agriculture development in the region. Therefore, the research and application of water saving measures in order to reduce irrigation rate and water consumption for winter wheat and summer corn will be particularly important. Many researches have been conducted in water consumption of wheat and corn

(Mao et al., 1995; Wu et al., 1998; Li et al., 1999; Chen et al., 2007). Zhang et al. (2003b) concluded that in the cropping system of winter wheat and corn in Taihang Mountain areas, water requirement for whole growing season of winter wheat was 375 mm, while the average rainfall in Shijazhuang City was only 130 mm, with a shortage of 240 mm, thus large amount of irrigation was required. Water requirement for whole summer corn growing season was 365 mm, while rainfall during the same period of time was 276 mm, with a shortage of 89 mm, and therefore, controlled irrigation was required. However, there is a tendency that in NCP the rainfall will be decreasing further (Huang et al., 1999; Liu et al., 2002), and Hu (2005) proved that 100 mm precipitation reduction would cause 0.37 m groundwater dropdown. Because of the frequent droughts, water consumption and irrigation rate will be needed by wheat and corn. Under such a circumstance of decreasing rainfall and increasing water consumption and irrigation rate, the piedmont region of Taihang Mountain and Heilonggang Plain were studied, which are seriously overexploited in groundwater. In this paper, the temporal and spatial change of crop water requirement and water saving irrigation under different water conditions, as well as the advantages of optimizing irrigation system of winter wheat and summer corn in different regions were investigated and studied. The objective of this study was to provide theoretical supporting for popularization and application of optimizing irrigation measures.

Materials and methods

Data source

Data of winter wheat and summer corn were from the Center for Agricultural Resources Research, Institute of Genetic and Developmental Biology, Chinese Academy of Sciences, and China Agricultural University. Meteorological data were provided by the Meteorological Bureau of Hebei Province.

Research basis

The experiment was conducted at Luancheng Experimental Station of the Agriculture Resource Centre and Wuqiao Experimental Station of China Agricultural University. Luancheng Experimental Station is situated at the altitude of 50 m above sea level in the Taihang piedmont plain in the middle of NCP (37°53′N, 114°41′E), where wheat and summer corn cropping system is implemented with a loamy soil with a deep profile, soil organic matter of 1.7 g/kg, total N of 1.11 g/kg, and available N, P and K of 80, 21 and 120 mg/kg, respectively, for the top tillage soil layer. The Wuqiao Experimental Station at the altitude of 14–22 m above sea level, is located in the Heilonggang region of the NCP (37°41′02″N, 116°37′23″E), where winter wheat and summer corn cropping system was practiced with a saline flavo-aquic soil, 1.0 g/kg soil organic matter, 0.9 g/kg total N, and available P and K of 23 and 45 mg/kg, respectively, for the top tillage soil layer.

Based on the research results of the two experimental stations, optimizing irrigation systems have been developed for both Taihang piedmont plain and Heilonggang plain under sufficient soil moisture condition before seeding (Table 1). These irrigation systems produced a higher yield and maintained a high level of water using efficiency (*WUE*).

Trial arrangements

At the piedmont area, according to farmer's conventional practice, the treatment of conventional irrigation was set up as check and the treatment with optimizing irrigation was set up under sufficient soil moisture condition before seeding (Table 2). Winter wheat irrigation experiment was conducted from 2001 to 2003, with a plot area of 40–50 m^2 and 4 duplicates each. Summer corn irrigation experiment was conducted from 1999 to 2001, treatments of conventional irrigation and optimizing irrigation were set up under sufficient soil moisture condition before seeding, with a plot area of 40 m^2 with 4 duplicates each. Winter wheat and maize varieties were "4185" and "Zhengdan958", respectively. Fertilizers were the same for all treatments. Chemical fertilizers were applied before cultivation of winter wheat at a base rate of 145 kg/hm^2 for N, 108 kg/hm^2 for P_2O_5 and 66 kg/hm^2 for K. Nitrogen was applied again at the jointing stage at a rate of 107 kg/hm^2. In the middle of July, maize was

Table 1 Optimizing irrigation for winter wheat and summer corn at Taihang piedmont plain and Heilonggang plain

Regions	Crops	Year type/irrigation system	Total irrigation (mm)	Growing stage of irrigation
Mountain-foot	Wheat	Wet yr (rainfall:> 130 mm)	60–70	Jointing
		Normal yr (rainfall: 90–130 mm)	120–140	Jointing + booting-flowering
		Drought yr (rainfall: < 80 mm)	180–210	Jointing + booting + flowering-filling
	Corn	Wet yr (rainfall: 467 mm)		
		Normal yr (rainfall: 334 mm)	0–65	Jointing
		Drought yr (rainfall: 237 mm)	65–130	Jointing (+ silking)
Heilonggang	Wheat	No irrigation in spring	0	
		1 irrigation in spring	75	Erecting + Jointing
		2 irrigation in spring	150	Erecting-Jointing + flowering-filling

Data were from Wuqiao and Luancheng experimental stations.

Table 2   Irrigation timing and rate of different irrigation treatment in winter wheat and straw-mulching corn

Crops	Year	Treatments	Irrigation number	Growing stage of irrigation	Total irrigation (mm)
Wheat	2001–2002	Conventional	3	Winter + jointing + booting-flowering	215
	(Normal yr)	Optimizing	2	Jointing + booting-flowering	145
	2002–2003	Conventional	2	Jointing + booting-flowering	120
	(Wet yr)	Optimizing	1	Jointing	60
Corn	1999 (Drought yr)	Conventional	3–4	Jointing + silking + early grain filling (late grain filling)	210
		Optimizing	2	Jointing + silking	120
	2001	Conventional	3–4	Jointing + silking + early grain filling (seedling)	225
	(Drought yr)	Optimizing	2	Jointing + silking	130

Data were from Luancheng experimental station.

fertilized with N at a rate of 180 kg/hm². Winter wheat was harvested on the 10th of June. Wheat straw was evenly mulched on the corn field at rate of 8250 kg/hm². Corn was interplanted in the wheat field in early June at the density of 7.5 plants/m². Corn was harvested on 22nd–24th of September. A two-meter deep neutron probe was installed in each plot. IH-II neutron probe was used to measure soil moisture at different layer every week.

At Heilonggang plain, according to farmer's conventional practice, the treatment of conventional irrigation was set up as check and the treatment with optimizing irrigation was set up under sufficient soil moisture condition before seeding (Table 3). Experiment was conducted from 2007 to 2008, with a plot area of 50 m² and three duplicates each. Winter wheat variety was "Shijiazhuang 8". Chemical fertilizers were applied before cultivation at a base rate of 158 kg/hm² for N, 138 kg/hm² for P_2O_5 and 101 kg/hm² for K. Winter wheat was a typical late-seeding crop in the region, and seeded on October 19th and harvested on June 10th next year.

Methods

Potential ET (ETp)

The crop water requirement was calculated by the Penmen-Monteith method under ample water condition, sufficient fertilizer supply and without insects and diseases. Theoretically, it is not the ecological water requirement which maintains crop growth without leaf wilt.

$$ETp = ET_0 \times Kc, \qquad (1)$$

ET_0 is the reference evapotranspiration, and was estimated using FAO Penman–Monteith (Allen et al., 1998) equation, which was recommended using the FAO. Kc is the crop coefficient derived from Chen et al. (1995).

Soil water balance

Total water use or evapotranspiration (*ET*) was calculated using the soil water balance equation for the growing season as follows:

$$ET = P + I + \Delta W - R - D + CR, \qquad (2)$$

where *ET* is the total water use during a certain growing period, P = precipitation, I = irrigation, ΔW = soil water content at sowing minus the soil water contents at the harvesting for the 2 m root zone, R = runoff, D = drainage from the root zone and CR = capillary rise to the root zone. When the groundwater table is lower than 4 m below the ground surface, the capillary rising of groundwater is negligible (Liu and Wei, 1989). The runoff is also ignored because there usually is no runoff in the NCP.

Water use efficiency (WUE)

Crop water use efficiency was calculated as follows:

$$WUE = GY/ET, \qquad (3)$$

where *WUE* is the water use efficiency of *ET* calculated from Eq. (2) for the grain yield (kg/m³), and *GY* is the grain yield.

Results

The balance of water requirement and natural rainfall

The balance between crop water requirement and natural rainfall is mainly judged by water deficit amount. The deficit is the difference between crop water requirement (*ETp*) and natural rainfall of the same period. In this study, winter wheat water requirement for the whole growing season in different types of rainfall year from 1980 to 1999 at 13 counties in NCP were analyzed (Table 4). The results showed that there was no

Table 3   Irrigation timing and rate of different irrigation treatment

Year	Treatment /(irrigation times)	Irrigation number	Date of irrigation	Total irrigation (mm)
2007–2008	Conventional	2	Erecting + flowering	135
(Wet yr)	Optimizing	1	Jointing	75

Data were from Wuqiao experimental station.

significant difference among the 3 types of rainfall year between Taihang piedmont plain and Heilonggang plain. The water requirement of winter wheat for the two regions was similar. The wheat water requirement of different year type was in the following sequence: drought year> normal year> wet year.

Rainfall during winter wheat growing season in Taihang piedmont area was higher than that in Heilonggang area, indicating that the Taihang piedmont area was relatively richer in water resources than the Heilonggang area. In the three year-types, rainfall during the wheat growing season was significantly lower than water requirement of winter wheat, especially in drought year and normal year. Because of small rainfall, large amount of irrigation was required.

It was obvious that as drought year occured more frequently, the irrigation for winter wheat increased significantly, which produced an increasing pressure on ground water resources.

The water deficit in piedmont plain during wheat growing season was lower than that in Heilonggang region in all the three year-types, indicating that the deficit in Heilonggang region was larger and more irrigation was required. In addition, the water deficit in three different year-types was all positive, indicating that the water requirement of wheat significantly exceeded the rainfall of the same period, thus supplementary irrigation was needed, even in the wet year. The water deficit of Heilonggang and Taihang piedmont regions in the dry year, normal year and wet year were 403 mm, 361 mm and 276 mm, respectively. Based on the calculation in 70 mm per irrigation, 5–6 times of irrigation in drought year, 4–5 times of irrigations in normal year and 3–4 times of irrigations in wet year were required during the whole growing season when soil water supply was ignored.

Table 5 shows that the water requirement of corn in Heilonggang plain was remarkably higher than that in Taihang piedmont plain in the three different year types. The corn water requirement of the two regions was 496 mm and 480 mm, respectively. The gap between the two regions was bigger in corn than that in wheat. The corn water requirement in different year-types was in the sequence of drought year> normal year> wet year. This indicated that in the dryer region and dryer year, more irrigation was needed.

Rainfall during the corn growing season in the piedmont region was higher than that in Heilonggang region. Except for the wet year, neither of the other two year-types could meet corn water requirement. In the drought year, both of the two regions needed irrigation, while in normal years, controlled irrigation was needed. In wet year, the rainfall in both of two regions was higher than the water requirement of corn, thus no irrigation was required. Water conservation should be the main practice.

Water deficit in Heilonggang region was bigger than that in the piedmont region for both wheat and corn. During the corn growing season, water deficit in Heilonggang and piedmont regions was 199 mm in drought year, 60 mm in normal year and − 59 mm in wet year. Based on the calculation in 70 mm per irrigation, 3 times of irrigation in drought year, once irrigation in each normal year, and no irrigation were required in a wet year during the corn growing season when soil water supply was ignored.

Water consumption and water saving of winter wheat and summer corn in Taihang piedmont region

In the normal year of 2001 to 2002, water deficit was 387 mm and thus the conventional irrigation needed 5 times of

Table 4 Water deficit for winter wheat from 1980 to 1999

Regions	Counties	Water requirement (mm)			Rainfall (mm)			Deficit (mm)		
		Drought yr	Normal yr	Wet yr	Drought yr	Normal yr	Wet yr	Drought yr	Normal yr	Wet yr
Taihang piedmont plain	Sanhe	463	465	439	68	116	192	394	349	248
	Zhuozhou	466	461	459	63	114	220	403	348	239
	Dingzhou	480	460	450	66	109	184	414	351	266
	Xinji	495	470	452	66	108	173	429	362	279
	Luancheng	465	457	450	63	114	205	402	343	245
	Feixiang	576	500	501	74	121	199	502	379	302
	CiXian	446	465	464	81	118	179	209	347	285
Average		484	468	459	69	114	193	393	354	266
Heilonggang plain	Hejian	472	460	466	64	108	184	415	361	312
	Bazhou	484	474	475	69	113	163	408	352	282
	Anxin	440	452	413	70	109	171	369	343	242
	Wuqiao	469	501	457	70	111	162	399	390	295
	Nangong	520	501	486	68	122	189	452	379	297
	Daming	512	503	484	76	120	204	437	384	280
Average		483	482	464	70	114	179	413	368	285

Precipitation data are from the Hebei Provincial Meteorological Bureau.

Table 5 Water deficit for summer corn from 1980 to 1999

Regions	Counties	Water requirement (mm)			Rainfall (mm)			Deficit (mm)		
		Drought yr	Normal yr	Wet yr	Drought yr	Normal yr	Wet yr	Drought yr	Normal yr	Wet yr
Taihang piedmont plain	*Sanhe*	462	426	442	308	498	698	112	−33	−163
	Zhuozhou	498	475	426	230	425	649	268	23	−81
	Dingzhou	520	513	471	238	378	544	231	86	−27
	Xinji	472	427	410	209	376	537	263	51	−127
	Luancheng	480	474	433	275	421	687	130	39	−116
	Feixiang	563	544	505	256	403	515	195	102	−5
	Cixian	521	512	498	272	404	537	204	78	−11
Average		502	482	455	255	415	595	200	49	−76
Heilonggang Plain	Hejian	538	492	484	262	425	626	176	55	−52
	Bazhou	511	465	459	262	365	726	249	45	−97
	Anxin	482	441	426	253	362	601	166	50	−79
	Wuqiao	517	501	490	320	425	532	96	41	−23
	Nangong	550	508	533	229	369	493	292	140	11
	Daming	553	510	477	269	409	504	206	92	−5
Average		525	486	478	266	393	580	198	71	−41

Precipitation data are from the Hebei Provincial Meteorological Bureau.

irrigation to meet the water requirement of wheat with ignoring soil water supply. In our study, irrigation was supplied 3 times for the conventional treatment (Table 6). Water consumption in the conventional treatment was 3.0% lower than that of ample water supply condition, and in practice, the irrigation rate during wheat growing season basically met its requirement. The optimizing irrigation treatment required less irrigation with small water consumption, however, it produced a higher yield and higher *WUE*. The water consumption in optimizing treatment was 21.5% lower than that in conventional treatment, while the yield and *WUE* were 2.4% and 31.0% higher respectively than those in the conventional treatment. For the optimizing irrigation treatment, reducing once irrigation than the conventional treatment, saving water of 102 mm, achieving a high yield, and high water efficiency at same time.

The wet year of 2002 to 2003, the water deficit of 276 mm and 4 times of irrigation based on the traditional irrigation rate, if ignoring soil water supply. In this study, irrigation was twice applied for the conventional treatment, water consumption was 20.6% lower than that in the ample water treatment, saving 92 mm. The optimizing irrigation treatment required even less irrigation (no flowering irrigation) than conventional treatment, however it produced a higher yield and higher *WUE* mainly due to the increase in the mobilization of assimilate stored in vegetative tissues to grains by moderate water deficit during grain filling, resulting in greater grain yield and *WUE*, which was in agreement with the findings of Zhang et al. (2008). Water consumption of the optimizing irrigation was 22.8% lower than that of conventional treatment, however, the yield and *WUE* were 1.6% and 23.8% higher than those of conventional treatment, saving water by 80 mm more than the conventional treatment. The above results indicated that, from 2002 to 2003, the water

consumption of the conventional treatment was much smaller than the ample water treatment, but higher than that of optimizing treatment. The conventional treatment required more irrigation which was a waste of water resource. Optimizing irrigation had an obvious water-saving effect, only once irrigation was enough to produce high yield. Therefore, the pressure of irrigation on water resource could be mitigated in a certain degree by application of suitable water saving irrigation technologies.

There were many cloudy days in April and May in the year from 2002 to 2003, and the total water consumption and yield were lower than those in the year from 2001 to 2002, which revealed that in the rainy season, more irrigation did not bring yield-increasing effect, while limited irrigation was the most effective practice to maintain a higher yield and higher *WUE*.

Table 7 showes that the water deficit in drought years was 184 mm, which required 3 times of irrigation to meet the water requirement of corn when soil water supply was ignored, based on the calculation by conventional irrigation rate. In this study, the conventional treatment required 3–4 times of irrigation, and find that the water requirement was only reduced by 4.8% lower than that of adequate water supply condition. High irrigation amount could basically meet the water requirement but reduce the amount of water saved. Optimizing treatment consumed less water and the water consumption was 11.9% lower than that of the conventional treatment. Because the field water consumption with the maximum *WUE* is always lower than the field water consumption at the highest yield, therefore, to evaluate the irrigation system, *WUE* should be given more consideration, especially in severe water shortage regions. In our experiment, conventional treatment produced 7.2% higher yield than the optimizing treatment, but the *WUE* was 5.1% lower. Therefore, in view of sustainable agriculture, the optimizing

Table 6 Winter wheat water consumption and rainfall deficit under different irrigation regime at piedmont plain

Year	Treatments/(Irrigations)	Rainfall (mm)	Water use (mm)	Yield (kg/hm^2)	WUE (kg/m^3)	Water deficit (mm)
2001–2002 Normal yr	Adequate water supply	104	491	–	–	387
	Conventional/(3 Irr.)	104	476 a	6461 b	1.35 b	373 a
	Optimizing/(2 irr.)	104	374 b	6615 a	1.77 a	271 b
2002–2003 Wet yr	Adequate water supply	168	444	–	–	276
	Conventional/(2 irr.)	168	352 a	5180 a	1.47 b	184 a
	Optimizing/(1irr.)	168	272 b	5258 a	1.93 a	104 b

Data are from Luancheng experimental station.

irrigation had a better result. Although the yield was slightly lower, the WUE was higher, which saved 49 mm of water than the conventional treatment.

Water consumption and water saving of winter wheat and summer corn in Heilonggang plain

In wet year, the water deficit under ample water supply was 305 mm. Calculated in conventional irrigation rate, 4 times of irrigation was required if ignoring soil water supply. In this study, twice irrigation was conducted for the conventional treatment. From Table 8, it can be seen that the conventional treatment water requirement was 9.3% lower than that of ample water supply condition and 4.9% higher than that of optimizing irrigation treatment, indicating that in the field condition water supply was less than wheat water requirement, but higher than that of optimizing irrigation treatment and reduced the amount of water saved. Optimizing irrigation treatment reduced once irrigation compared to the conventional treatment, saving water by 20 mm. With the increasing of water supply, the yield was also increased, but the yield increasing effect was not obvious. The yield of the optimizing treatment was only 3.5% lower than that of conventional treatment, indicating that controlled irrigation in spring would not have negative effects on yield. The optimizing irrigation had a better WUE, reaching 2.0 kg/m^3, with 5.3% increasing than conventional treatment. The above results showed that the optimizing irrigation treatment reduced once irrigation, and increased WUE and maintain almost the same yield. It can be clearly seen that appropriate irrigation can maintain high yields and water saving.

Discussion and conclusion

Zhang et al. (2003a, 2006, 2008) and Liu et al. (2002) studied

the effects of water conditions on wheat yield and WUE in the Taihang piedmont region and suggested that 250–420 mm water supply in the wheat growing season could maintain a high yield and high WUE, which was in agreement with our experiment. Besides, according to the previous study, considering situation of severe water shortage in NCP, both yield and WUE were supposed to be important factors in the evaluation of irrigation system. Compared with farmer's traditional irrigation method, the optimizing irrigation either increased the yield or slightly reduced the yield, but had a higher WUE. With less water consumption, it required less supplementary irrigation, therefore, it was an effective technique to achieve high yield, water saving and high efficiency at same time.

In Heilonggang and piedmont plains, high irrigation rate was needed in the conventional treatment for both wheat and corn, which basically met the water requirement. Compared with optimizing irrigation, the conventional irrigation had a larger capacity of saving water. In Heilonggang plain, the optimizing irrigation could save once irrigation for wheat in the wet year compared with conventional irrigation, yielding 7710 kg/hm^2, and saving water by 20 mm, while in Taihang piedmont plain, the optimizing irrigation could reduce 1–2 times irrigation. with a yield of 6615 kg/hm^2, 5265 kg/hm^2 and 7743 kg/hm^2 for wheat and water saving by 102 mm, 80 mm and 49 mm in normal year, wet year, and drought year respectively. If the optimizing irrigation system is widely extended in Heilonggang plain and piedmont plain of Hebei Province, 201 million m^3 water in the Heilonggang plain for wheat, and 1599 billion m^3 water in the Taihang piedmont plain for wheat and corn can be saved. The water-saving effect of the optimizing irrigation system will be of great significance to the mitigation of water crisis in NCP.

With the optimizing irrigation technique, the water-saving effect in the Taihang piedmont region was significantly higher

Table 7 Summer corn water consumption and rainfall deficit under different irrigation regime

Year	Treatment/(irrigations)	Rainfall (mm)	Water use (mm)	Yield (kg/hm^2)	WUE (kg/m^3)	Water deficit (mm)
1999 drought year	Adequate water supply	273	431	–	–	158
	Conventional /(3–4 Irr.)	273	415 a	8722 a	2.11 b	142 a
	Optimizing /(2 Irrigation)	273	367 b	8131 b	2.22 a	94 b
2001 drought year	Adequate water supply	217	426	–	–	209
	Conventional /(3–4 Irr.)	217	401 a	7974 a	2.00 ab	184 a
	Optimizing /(2Irr.)	217	352 b	7356 b	2.09 a	135 b

Data from Luancheng experimental station.

Table 8 Winter wheat water consumption and rainfall deficit under different irrigation regime

Year	Treatment/(irrigations)	Rainfall (mm)	Water use (mm)	Yield (kg/hm²)	*WUE* (kg/m³)	Water deficit (mm)
2007–2008 Wet year	Adequate water supply	152	457	–	–	305
	Conventional/(2 Irr.)	152	414 a	8005 a	1.90 ab	262 a
	Optimizing/(1Irr.)	152	395 ab	7710 b	2.00 a	242 ab

Data are from Wuqiao experimental station.

than that in the Heilonggang plain, indicating that farmer's irrigation rate in the piedmont plain was too high, which may result in a large amount of water waste. Therefore, it can be concluded that the Taihang piedmont plain, as the key area for reducing irrigation rate in NCP, has a great potential of water saving.

Acknowledgements

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