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# YIELD RESPONSE OF WINTER WHEAT TO ROW SPACING UNDER IRRIGATED AND RAINFED CONDITIONS

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## Abstract

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In China, wheat (*Triticum aestivum* L.) is cultivated across a wide range of climatic conditions. The average rainfall was recorded at 696.6 mm per year from 1971 to 2008 at Taian in northern China. Considerable variability in the row spacing (RS) per unit area, usually referred to in agricultural practice, is expected as variation in factors affects the agronomic characters of winter wheat in different ways. Furthermore, previous studies have reported that RS limitations may affect yield in wheat. The objective of this study was to quantify the effects of RS and water availability on yield in wheat crops. The experiment reported in this article was conducted during the crop seasons of 2006/2007 and 2007/2008. Four types of RS were calculated under two different water conditions (rainfed and irrigated) and were set up as a randomized plot design. The results showed that irrigation and uniformity of monthly rainfall could increase crop yield. The population number of RS49 was the lowest in all treatments, and that of RS7 was significantly higher than all other treatments after irrigation. The LAI average of RS14 was highest under different RS treatments at 44.4% (the rainfed) and 42.1% (the irrigated) and higher than that of RS49. The order of the grain yield can be presented as RS7≈RS14>RS24.5>RS49, and grain yields for RS7 and RS14 were significantly higher than those for RS24.5 and RS49 in both years ($P < 0.05$). Consequently, we conclude that high yields of wheat can be achieved in northern China by reducing RS under uniform planting-density conditions. Winter wheat production in the northern China area can thus be cultivated with an acceptable optimum RS wherein yields increase.

*Key words: Triticum aestivum* L.; population; water condition; leaf area index; grain yield; harvest index

## Introduction

Wheat (*Triticum aestivum* L.) is extensively cultivated in China; the Shandong province has ~3.52 million cultivated hectares and a mean grain yield of ~5671 kg/ha. In areas with limited water resources, wheat productivity is highly dependent on water supply by irrigation; however, in many intensively cultivated areas, availability and quality of irrigation water are constantly on the decline as a consequence of climatic changes and increasing consumption. Irrigation water is becoming an increasingly scarce resource in many areas of Northern China and, as a consequence,

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an appropriate choice of irrigation scheduling and planting pattern is necessary to maximize yield and profit. Appropriate application of water treatments (rainfed and irrigated cultivation) and row spacing (RS) have a vital purpose in increasing yield and optimizing the wheat plant population (Zhou et al., 2007).

Growing plants in crop communities bring about competition. This competition occurs when the immediate supply of a single essential factor falls below the aggregate demands of all plants. A plant, if planted sufficiently close to another, can influence it to modify its soil or atmospheric environment and thereby decrease its rate of growth. Researchers have reported that row width influences crop-population structure and yield (Eberbach and Pala, 2005; Zhou et al., 2010). The major competitive factors identified include light, water, nutrients and weed (Brant et al., 2009). Attempts have been made to improve the physical environment of the crop population to favour root growth and increase wheat yield, and these include deep tillage, subsoiling and chiselling (Gajri et al., 1991; Oussible et al., 1992; Unger, 1993). However, these methods may not be economical.

The average rainfall was 696.6 mm per year from 1971 to 2008 in Taian, but most precipitation occurred during the hot summer months (July and August). During the growth season, winter wheat water requirement (about 400 to 500 mm) exceeds that provided by precipitation. Some approaches such as early sowing, higher planting density, straw mulching and improved fertilization have been used to increase the yield of crop (Cooper et al., 1987; Anderson, 1992; Philip and Mustafa, 2005). Although these approaches are effective, it is possible that other better methods exist.

Environmental protection is one of the priorities of the new aims of Chinese agricultural policy; therefore, a compromise between the need to maximize yield and profit and an adequate use of water required in order to reduce the impact of cultivation on the environment. An evaluation of the response of crops to water and RS, in combination, could help identify optimal allocation of available resources among crops in the farm in order to maximize profit. This study aimed to: (i) evaluate the effect of RS and its interaction with water supply for wheat cropped in a warm temperate, continental monsoon climate and (ii) analyze factors impacting on the yield wheat.

## Materials and Methods

This research work was conducted at the Experimental Farm of Shandong Agricultural University, Taian (36º09´N, 117º09´E) in northern China. This research site is representative of the main winter wheat cultivating region of the Huanghuaihai Plain in China. The long-term average rainfall was 696.6 mm, and the total rainfall was 765.5 mm in 2007 and 627.5 mm in 2008, respectively (Figure 1). During the winter wheat cycle (from October to June), the rainfall received in 2006/2007 was 42.6 mm lower than that for 2007/2008 (Table 1). The soil in this area is a silt loam with average SOM of 16.3 g/kg, N 92.98 mg/kg, P 34.77 mg/kg, K 95.45 mg/kg, and pH 6.9.

The experiments were established during the growing seasons of October to June in 2006/2007 and 2007/2008. As a part of the continuous winter wheat–summer soybean [*Glycine max* (L.) Merr.] rotation experiment, following hand-harvesting of the summer soybean plants and removal of stubble, winter wheat (cv. Shannong 919) was hand-planted

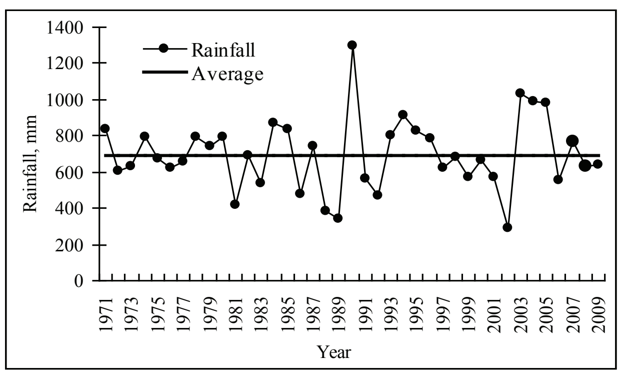


**Fig. 1. The average annual rainfall during 1971-2009**

**Table 1**
**Monthly rainfall (mm) for the winter wheat growth seasons**

| Season | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| 2006/2007 | 5.3 | 14.2 | 9.5 | 0 | 2.1 | 46.7 | 15.2 | 118.8 | 0.7 | 212.5 |
| 2007/2008 | 17.3 | 8 | 16.5 | 4 | 4.8 | 17.7 | 57.7 | 44.7 | 6.4 | 169.9 |

**Table 2**
**The timing and amount of irrigation for different treatments to winter wheat**

| Growth stages | 2007 | 2008 | Irrigated, mm | Rainfed |
|---|---|---|---|---|
| Jointing | 31.Март | 02.Април | 60 | - |
| Heading | 25.Април | 02.Май | 60 | - |
| Milk | 14.Май | 18.Май | 60 | - |

according to plant density ($4.08 \times 10^6$ plant/ha) on October 6, 2006 and October 10, 2007. The experiment comprised four planting patterns under irrigated and rainfed sectors, and row spacing × plant spacing of 7 × 7 cm (RS7, a uniform grid pattern), 14 × 3.5 cm (RS14), 24.5 × 2 cm (RS24.5) and 49 × 1 cm (RS49). Basin irrigation was used in this experiment. Irrigation water was conveyed from the outlet pump to the culture pools using plastic pipes. The total amount of irrigation water supplied was 180 mm, as measured with a water meter. The accuracy of the device was determined to be ±5%. Irrigation schedules and the amounts of irrigation water supplied are given in Table 2. Seedling thinning was adopted by hand at 5 days after wheat emergence in order to obtain the same final plant-population density ($2.04 \times 10^6$ plant/ha). Each experimental plot was 3 × 3 m in size, and was replicated thrice with a randomised block design. Concrete slabs were inserted to a depth of 2.0 m and width of 15 cm on four sides of each plot, and plastic films (0.1-mm thick) were placed along this wall of concrete, to prevent lateral flow of soil water.

Fifteen plants per plot were sampled from tillering to maturity stage every ten days to determine the number of plants in the population, dry matter weight (DM), and leaf area index (LAI). Fifteen plants per replication were randomly sampled at harvest to determine kernels per spike and 1000 kernel weight. At physiological maturity, a sample area of 2 $m^2$ (the centre two rows of each plot) was hand-harvested and the mass of plants and grain were determined on 5 June 2007 and 13 June 2008. Samples of plants and grain were oven-dried at $65^0$C until a constant weight was observed. Harvest index (HI) was calculated as grain to above-ground dry-biomass ratio.

All data were analysed with the SPSS 12.0 Statistical Software Package and least significant difference (LSD) tests were used. Values were considered significant in all statistical calculations if $P$-values were ≤0.05 (Mishra et al., 2001).

## Results and Discussion

### *Changes of individual stems at different growth stages*

There were similar characteristics for change in plant population in both growth seasons (Figure 2). Irrigation and RS had a greater impact on individual stems during growth stages. The individual numbers in the tillering stage (TS) and jointing stage (JS) were obviously higher than that in the

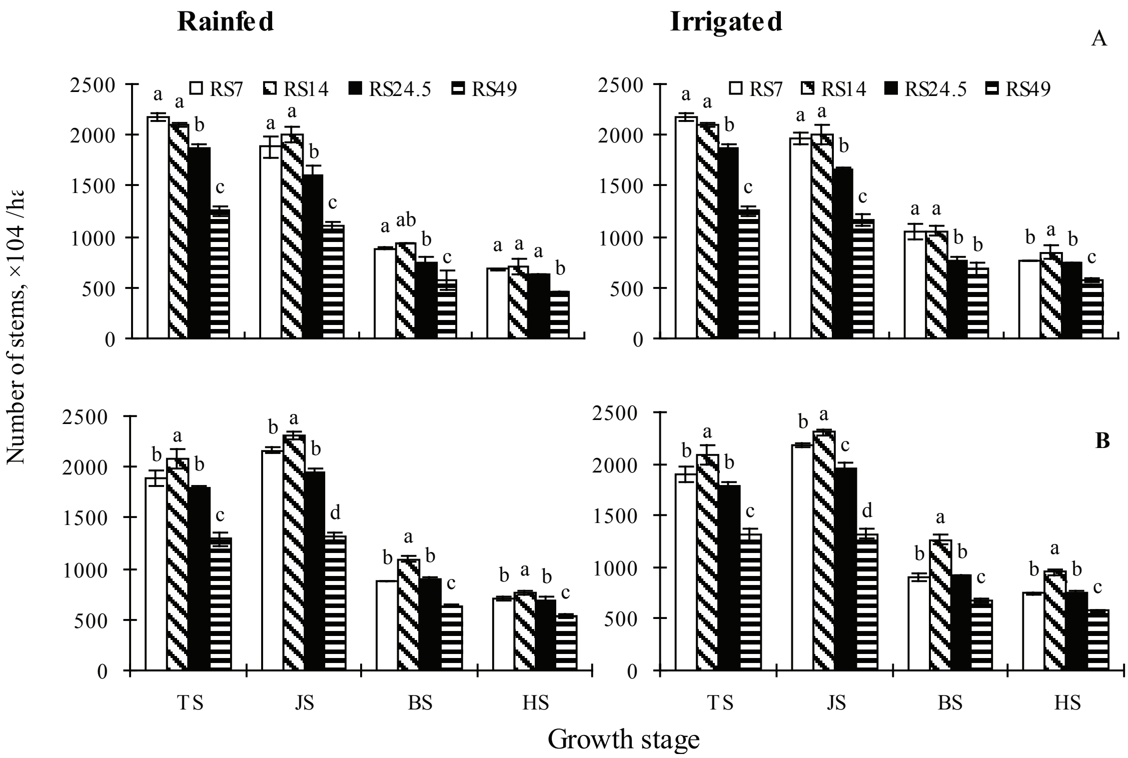


**Fig. 2. Changes of individual stems at different growth stages in (A) 2006/2007 and (B) 2007/2008. Error bars are standard deviation. Above bars small different letters point out significantly different values at P < 0.05 according to LSD Test.TS, tillering stage; JS, jointing stage; BS, booting stage; HS, heading stage**

booting stage (BS) and heading stage (HS). After irrigation, the water content in the soil increased by 10.5%–55.7% during the JS and HS (data not shown); under this water condition, crop growth was improved and numbers of plant population were higher than that of the rainfed cultivations at HS. For the different RSs, the order of the individual numbers was RS7>RS14>RS24.5>RS49. The individual numbers for RS7 were significantly higher than those of other RS treatments, and that of RS49 was significantly lower ($P < 0.05$). This could probably be attributed to increased interplant competition and greater plant mortality at the wider row spacings, where within-row plant spacings are much closer than those in the narrower row spacing. These results are similar to those obtained by Henderson et al. (2000). From TS to HS, the individual numbers of RS7, RS14, RS24.5 and RS49 rapidly decreased to 65.8%, 65.1%, 63.8% and 61.3% for the rainfed, and 63.0%, 57.0%, 59.2% and 55.3% for the irrigated cultivations, respectively.

### *Leaf area index at different growth stages*

The results indicate that, in the growing season, the LAI of different treatments had an inverted-U shaped ('∩') curve trend from JS to dough stage (DS). The inflection point of the curve appeared at the HS, both in the 2006/2007 and 2007/2008 growth seasons (Figure 3). The LAI under irrigation treatment was obviously higher than for plants subjected to rainfed treatment. During both growth seasons, LAI average of RS7, RS14, RS24.5 and RS49 was 4.40, 4.68, 3.93 and 3.24, respectively, for the rainfed plant population, and 5.94, 6.42, 5.55 and 4.52, respectively, for the irrigated plant

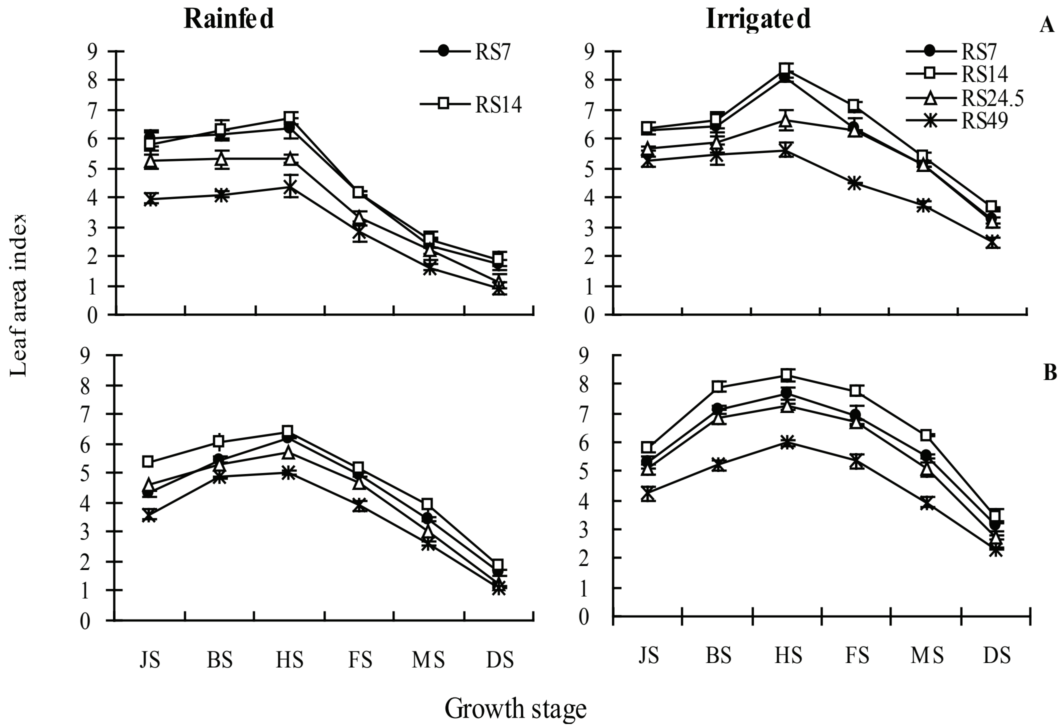


**Fig. 3. Leaf area index of winter wheat at different growth stages in (A) 2006/2007 and (B) 2007/2008. Error bars are standard deviation. JS, jointing stage; BS, booting stage; HS, heading stage; FS, flowering stage; MS, milk stage; DS, dough stage**

population.

The LAI average of RS14 was highest among different RS treatments, and 44.4% (the rainfed) and 42.1% (the irrigated) higher than that of RS49. These results differ from those reported by Philip and Mustafa (2005), as LAI did not differ between 17-cm and 30-cm row-spacing cultivation in their experiments. After the flowering stage (FS), there was an obvious decline in the LAI. The LAI averages for RS7, RS14, RS24.5 and RS49 were only was 1.69, 1.86, 1.19 and 1.01, respectively, for the rainfed crop and 3.19, 3.54, 2.97 and 2.40, respectively, for the irrigated crop at DS. An increased LAI was observed of crop grown in narrow rows, which resulted in more efficient interception of sunlight and increased rates of photosynthesis and a resultant increased yield of crop (Shibles and Weber, 1966; Zhou et al., 2010).

### *Accumulation of dry matter during growth seasons*

For both the growth seasons, a correlation analysis showed that there was a significant linear regression trend between DM and days of germination and the linear equation can be denoted as

y (DM, kg/ha) = 219.65x (days of germination) - 31015

With an $R^2 = 0.988$ ($P < 0.05$). During the JS-HS, HS-MS and MS-DS, the DM average of the irrigated crop was 10.7%, 20.5% and 25.7% higher than those of the rainfed crops, respectively. Water supply when allocated thrice (180 mm) was found to accelerate accumulation of DM, especially at the later stages of growth. For the different RSs, the order of the DM average was RS14 > RS7 > RS24.5 > RS49 for the rainfed and irrigated crops (Figure 4). The DM of RS49 was significantly

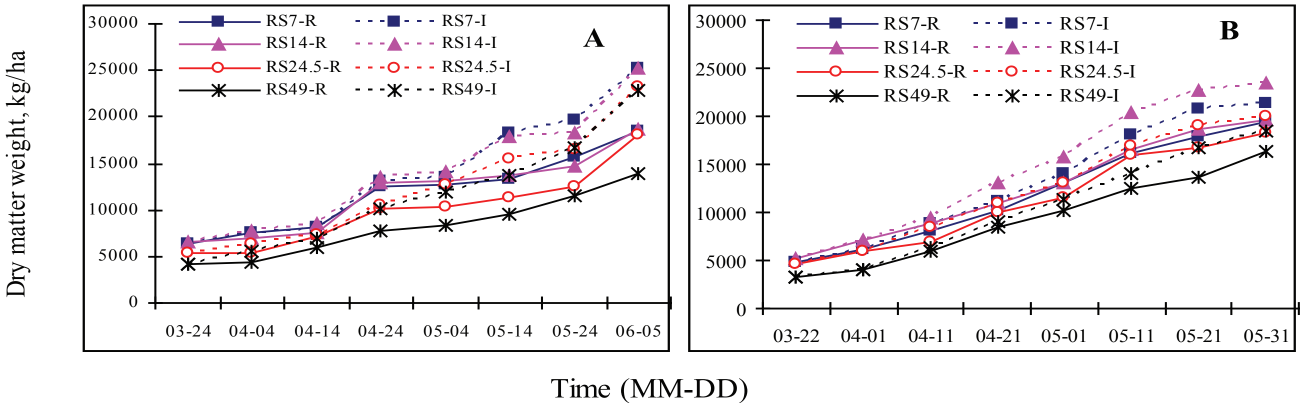


**Fig. 4. Dry matter production of winter wheat during growth seasons: (A), 2006/2007; (B) 2007/2008; R, rainfed; I, irrigated**

**Table 3**

**Mean square values of main effects and interactions for several agronomic characters of winter wheat at Taian, during 2006/2007 and 2007/2008**

| Source of variation | df | Population | Kernel per spike | 1000 kernel weight | Grain yield | Biomass yield | Harvest index |
|---|---|---|---|---|---|---|---|
| Year (Y) | 1 | 45472**** | 20.5**** | 560.5**** | 4727776**** | 1194358* | 0.0137**** |
| Water (W) | 1 | 43593**** | 70.3**** | 123.2**** | 9041145**** | 203273904**** | 0.0122**** |
| RS | 3 | 62235**** | 15.0**** | 45.7**** | 1657654**** | 18140493**** | 0.0004* |
| Y × W | 1 | 14455**** | 12.0**** | 3.4**** | 389335**** | 24643370**** | 0.0022*** |
| Y × RS | 3 | 4648**** | 0.8*** | 0.1ns | 434983**** | 266324ns | 0.0009*** |
| W × RS | 3 | 576** | 2.5**** | 2.7**** | 11985* | 956350* | 0.0003* |
| Y × W × RS | 3 | 271* | 1.2**** | 1.8**** | 8184ns | 1614629** | 0.0003* |

*, **, ***, **** indicate, respectively, significance at 0.05, 0.01, 0.001 and 0.0001 *P* level.

lower than those of other RS treatments (P < 0.05). These results indicate that oversized RS (RS49) results in waste of environmental resources and decreased accumulation of DM. However, uniformity of population (RS7) was not ideal in the all treatments.

### *Grain yield and biomass production*

Six agronomic characters were significantly affected by the main effect of year, water and row spacing (Table 3). Reports of the analysis of variance results have been derived, for each variable, and only the higher order significant sources of variation are discussed further.

The plant population at harvest differed between the two years of the experiments; there was 673 vs. 579 × $10^4$ plants/ha in 2006/2007 and 2007/2008, respectively. However, kernels per spike and 1000 kernel weight for 2007/2008 were higher than those for 2006/2007, and, consequently, grain yield and HI reflected these changes. Irrigation treatments significantly increased plant population number; kernels per spike, 1000 kernel weight, grain and biomass yield, and also decreased the HI (P < 0.05). The water stress greatly influenced the ear and grain formation of different RS groups in rainfed cultivations for both years. Some researchers have reported that the timing of drought

**Table 4**

**Effects of RS on population, kernels per spike, 1000 kernels weight, grain yield, biomass yield, and harvest index of winter wheat under rainfed and irrigated conditions**

| Water | RS, cm | Population, $10^4$ plants/ha | | Kernel per spike | | 1000 kernel weight g | | Grain yield, Mg/ha | | Biomass yield, Mg/ha | | Harvest index | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 06/07 | 07/08 | 06/07 | 07/08 | 06/07 | 07/08 | 06/07 | 07/08 | 06/07 | 07/08 | 06/07 | 07/08 |
| Rainfed | 7 | 679.6c | 619.1c | 33.5d | 36.6f | 31.3c | 37.4e | 7.0c | 7.7e | 18.4c | 19.6d | 0.38a | 0.39d |
| | 14 | 700.0c | 621.6c | 34.6c | 36.8f | 30.7c | 36.6g | 7.1c | 7.8e | 18.7c | 19.5d | 0.38a | 0.40c |
| | 24.5 | 630.6d | 614.1c | 34.5c | 36.5f | 31.2c | 37.1f | 6.8d | 7.6f | 18.1c | 18.9e | 0.38a | 0.40c |
| | 49 | 450.0f | 474.3e | 37.5b | 39.4b | 33.4b | 40.7c | 5.5e | 7.3g | 14.0d | 16.8f | 0.39a | 0.43a |
| Irrigated | 7 | 757.1b | 641.5b | 38.5a | 38.4d | 32.6b | 40.6d | 8.2a | 8.6ab | 25.1a | 22.7b | 0.33b | 0.38e |
| | 14 | 835.7a | 656.2a | 37.7b | 38.8c | 32.8b | 40.6d | 8.4a | 8.7a | 25.2a | 23.1a | 0.33b | 0.37e |
| | 24.5 | 757.1b | 632.4b | 38.5a | 37.5e | 33.4b | 41.0b | 8.0b | 8.4c | 23.2b | 22.3c | 0.34b | 0.37e |
| | 49 | 575.5e | 523.5d | 39.1a | 40.2a | 38.5a | 44.6a | 6.9cd | 8.1d | 22.8b | 19.7d | 0.30c | 0.41b |

Means within column groupings with similar letters are not significantly different from each other at the 0.05 probability level.

influences corn yield components: ear numbers are mainly reduced by water stress during the vegetative stage (Cakir, 2004); and kernel number and weight appear to have been influenced more by drought during the reproductive stage (Fapohunda and Hussain, 1990; Pandey et al., 2000). Deficiencies in irrigation at the early seed-formation stage increased the fraction of assimilate allocation to the head and, thereby, increased seed weight, while the techniques of irrigation did not bring about any remarkable increase in HI among crops (Karam et al., 2007; Banedjschafie et al., 2008).

Among the different RS-treatment crops, the population number of RS49 was significantly lower than that for other treatments under the rainfed and irrigated conditions, and that of RS7 was significantly higher than for other treatments after irrigation. The kernels per spike and 1000 kernel weight of RS49 were significantly higher than those for other crop treatments. The order of the grain yield was RS7 ≈ RS14 > RS24.5 > RS49 for the rainfed and irrigated treatment crops, and grain yields of RS7 and RS14 were significantly higher than those of RS24.5 and RS49. The order of biomass yield was similar that of grain yields (Table 4). The HI of RS49 was significantly lower than that of other treatments under the irrigation conditions in 2006/2007, but was significantly higher than those of other treatment crops in 2006/2007.

These results may have been influenced by temporal distribution of rainfall. Rainfall received was 70 mm over the average for the year 2007, and 68 mm below average for the year 2008 (Table 1). Rainfall received in the month of May was considerable and accounted for 56% of total rainfall for 2006/2007; we deduce that the climatic factors and their timing with crop development severely limited grain and biological yield potential at the research site. In the year 2007/2008, the monthly rainfall was relative uniform, which alleviated water stress, improved agronomic characters and, therefore, increased the yield of the winter wheat cultivation.

This research work illustrates substantial differences in agronomic characters among RS. Use of this knowledge in selecting RS that is suitable for wheat populations may improve total yields. Similarly, the adoption of narrower row planting has been based upon numerous, favourable reports on reduced row spacing for crop production (Roberts et al., 2001; Heatherly et al., 2002; Hussain et al., 2003). The study, extending across 2 years, has shown that the yields for irrigated wheat plantations are obviously higher than those for the rainfed wheat crop, leading to the observation that the optimal production of winter wheat in Taian is impossible without irrigation because of scarce precipitation during the growing season of wheat. Moreover, the RS affects yields of winter wheat. High yields of wheat can be achieved in northern China by reducing RS with uniform planting density. However, when the crop was sown in a grid pattern (RS7), the ineffective tillers were more than that for RS14, and yields were slightly decreased. As RS7 is difficult to practice in agricultural production, the RS14 is a highly optimal pattern for wheat cultivation.

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