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Effect of Water Amounts Applied With Drip Irrigation on Water Consumption Characteristics and Yield of Spring Wheat in Xinjiang

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Abstract: By selecting different genotypes varieties and setting up different drip irrigation amount, the data about water consumption characteristics and yield traits of spring wheat in southern Xinjiang arid area were obtained and analyzed, the results showed that: (1)Water consumption amount in drip irrigation filed of spring wheat mainly focused at the middle-late growth stage and water consumption strength reached the maximum value of 5.18-7.52 mm/d during booting and flowering period; (2)The amount of drip irrigation mainly affected grains per spike and grain weight. Excessive irrigation caused by the increase in amount and strength of water consumption and a decline in Water Use Efficiency (WUE) decreased; Deficit irrigation resulting in the field water stress, influenced wheat growth, finally led to a seriously decline in production. Appropriate irrigation could effectively regulate growth of plants, optimize phase allocation of water consumption, guarantee a high water consumption intensity during jointing-flowering stage, which was favorable to the growth of reproductive organs, so the WUE was the highest, reaching 13.75-15.21 kg (hm^2/mm).(3) Water consumption characteristics showed difference among the varieties. With the maximum values of yield of 6388.7 kg/ha and WUE of 15.21 kg (hm^2/mm) in appropriate water treatment, 181.1 kg/ha and 1.89 kg (hm^2/mm) more than Xinchun 19, respectively, Xinchun 22 was a water-saving and high efficiency variety.

Keywords: Drip irrigation, spring wheat, water consumption characteristics, yield

INTRODUCTION

Xinjiang is located in the northwest arid area of China. After years of exploitation, the utilization degree of surface water and groundwater sources for irrigation had been close to limits due to rapid development of economy and the water resources shortage had become one of the biggest factors restricting agriculture development. Xinjiang was one of the provinces facing serious water resources crisis with average occupation of only 300 m^3/ person, far below the internationally recognized warning line of 500 m^3. Currently, there were four main water-saving irrigation patterns: regulated deficit irrigation, insufficient irrigation, localized irrigation and controlled root alternate irrigation (Zheng, 2009), among which drip irrigation of local irrigation was the best modern water-saving irrigation technique with best application effects and largest promotion areas. Wheat was the major grain crops in Xinjiang with the planting area of 106×10^4 ha. In recent years, rapid development of the economic crops (such as processed tomato and cotton) and special fruit industry (red dates and walnuts, etc.) had greater impacts on water supply for crops irrigation, which caused the sown area of grain tending to decline and food security becoming a serious problem. So, how to take effective irrigation pattern to improve water productivity of wheat was the key issue to be solved. Applying in wheat and combining with the corresponding cultivation measures, drip irrigation technique was a currently hot research topic in water-saving irrigation technology (Wang *et al*., 2011; Wang *et al*., 2010) which could reduce the amount of irrigation, improve yields and production efficiency. Comparing with the conventional irrigation pattern, great changes had taken place in plant root zone, which certainly affected the growth of wheat root (Wang *et al*., 2011), thus affected aboveground growth of plants. At present, the researches mainly concentrated in the drip irrigation technology and growth physiology (Gao *et al*., 2010; Liao *et al*., 2008; Wang *et al*., 2012a; Wang *et al*., 2013), but few in water consumption characteristics and water-saving mechanism in drip wheat field (Pablo *et al*., 2007) and weak basic research limited the spread of wheat drip irrigation technology. Therefore, it was of practical significance to carry out the research of water consumption characteristics in arid area.

MATERIALS AND METHODS

Test conditions: The experiments were conducted at the net room of the experimental station in Tarim University in 2011 and 2012 growing seasons. Test site

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Table 1: Design of different drip irrigation

	Date (M-D)		Water control(mm)		
Growth stages	2011	2012	T1	T2	T3
Three-leaf stage	4-13	4-11	13.1	28.8	40.4
Tillering stage	4-25	4-26	15.8	34.5	48.3
Jointing stage	5-5	5-3	20.8	44.9	62.7
Booting stage	5-15	5-14	27.3	59.6	83.4
Flowering stage	5-21	5-18	33.8	73.2	102.6
Filling stage	6-10	6-8	33.8	73.2	102.6
Milk maturation	6-21	6-20	28.0	60.8	85.1
Total drip irrigation			172.6	375	525.1

located at the northwest edge of the Tarim Basin (40°33′N,81°16′,101.22 m elevation) had typical warm temperate inland climate, drought and abundant sunlight, with the average annual temperature 11.2°C, the average annual rainfall 45.7 mm, average annual evaporation capacity 1988.4 mm, annual average relative humidity 55%. The soil was sandy loam, with soil bulk density of 0-40 cm was 1.32 g/cm^3 and field moisture capacity was 24.8% (weight capacity). The underground water level was about 8.0 m. The content of soil organic matter was 1.03% and total nitrogen, alkali hydrolysable nitrogen, available phosphorus and available potassium were 0.685 mg/g, 49.27 mg/kg, 32 mg/kg and 214.1 mg/kg, respectively.

Materials and design: Early maturity dwarf varieties Xinchun 22 (presented by Xinjiang Academy of Agricultural Sciences) and mid-maturing tall stalk variety Xinchun 19 (presented by Shihezi University) were chosen as tested material and sowed on March 8th. Each row was planted every 15 cm and 18 rows were planted in each plot, where one drip irrigation belt was laid between 3 and 4 line every 6 rows with patterns of one tube for 6 line. The planting density was 5.7×10^6 strains per hm^2. The area of each plot was 13.5 m^2.

Three levels of drip irrigation were designed in this study according to the actual production conditions for 3 replicates (Table 1): lack of water treatment with 172.5 mm (T1), moderate water treatment with 375 mm (T2) and high water treatment with 525 mm (T3). The irrigation frequency and amount were set according to the requirement of wheat, wetting layer size and regional climate characteristics. During the whole growing period 7 times water was dripped. The amount of drip irrigation was recorded by water meter. PVC polyester plates with 80 cm depth were used to prevent penetration between plots.

225 kg/ha urea and 150 kg/ha diammonium phosphate as base fertilizers were utilized before sowing, 90 kg urea and 60 kg KH_2PO_4 per ha, 75 kg urea and 60 kg KH_2PO_4 per ha was dripped fertigation during jointing and flowering-filling period, respectively. 900-1 500 g ^{2}, 4D-Dioxide per ha was sprayed before jointing to get rid of weed.

Test items: Growth process of spring wheat was observed, plant height, tiller number and leaf number were recorded after emergency. 5 representative plantlets were chosen to measure leaf length and width for calculating leaf area with the coefficient method (length×width×0.75) (Wang, 1998).

At mature stage 3 representative points for samples were chosen and 1 m^2 of plants were cut off and threshed in each plot for calculating yield.

Soil water content (r, g/g) was test by soil drilling and oven-dry method each 5-7 days. Point was located at 22.5 cm from irrigation belt for drill soil samples, measuring the depth of 100 cm, 10 cm for each layer.

Calculation methods: Evapotranspiration (*ET*, mm) was obtained according to the water balance equation of $ET = P+I+ \Delta W$ (Zhang *et al*., 2005) in the absence of surface runoff conditions. In the formula, P is the rainfall amount (mm) during the periods; I the water irrigation (mm); ΔW the soil water storage variations between different crop growth period, namely the soil water consumption amount. Soil water storage was calculated by the formula W = 0.lrvh, among which W is the soil water storage in different depth (mm), r the soil gravimetric water content; v the average soil bulk density (g/cm^3); h soil depth (cm); 0.1 the conversion coefficient. Water Use Efficiency (*WUE*) is calculated by $WUE = Y/ET$, where Y is the crop yield, ET water consumption in field throughout the whole growing season.

Statistical analysis software SPSS 19.0 was used for testing the significance of difference of the data and Microsoft Excel 2003 was used for mapping.

RESULTS AND ANALYSIS

Difference analysis of yield and its components under different drip irrigation: The results of Table 2 indicated that different amount of drip irrigation had great influence on final grain yield of spring wheat. The yield of Xinchun 22 and Xinchun 19 reached the highest values of 6388.7 kg/ha and 6207.6 kg/ha in T2 treatment and were significantly higher than those of T1 treatment respectively ($p<0.05$), which meant that deficit irrigation seriously influenced wheat grain yield, cutting production by 1.13-1.26 times. The expected yield of two varieties in T2 treatment was slightly higher than that in T3, but had no significant difference, which meant that abundant water treatment was conducive to improving yield comparing with lack of water treatment while not comparing with suitable water. Namely, large quantity of drip irrigation was a "luxury" water supply mode against conducive to optimizing regulation of yield formation on the base of appropriate water irrigation. The Coefficient of Variation (CV) of Xinchun 22's yield among treatments was higher than Xinchun 19, indicating Xinchun 22 was more sensitively regulated by water. The expected yield of Xinchun 19 had no obvious difference between T2 and T3 treatment but had significant difference in actual output; this was because that Xinchun 19 was a

Table 2: Yield components of spring wheat under different amount of irrigation

Variety	Treatment	Kernels spike^{-1}	1000-grain weight (g)	Grain weight spike^{-1} (g)	Harvest spikes ($\times 10^6$spike ha^{-1})	Expected yield (kg ha^{-1})	Actual yield (kg ha^{-1})
Xinchun 22	T1	16.6b	35.6b	0.591b	4.871	2878.4b	2827.4b
	T2	25.9a	43.3a	1.121a	5.673	6361.7a	6388.7a
	T3	26.1a	42.6a	1.112a	5.681	6316.6a	6176.3a
	CV%	23.74	10.51	32.24	8.61	38.53	38.93
Xinchun 19	T1	18.2b	37.7b	0.687b	4.613	3168.2b	3008.9c
	T2	26.4a	45.0a	1.188a	5.315	6313.6a	6207.6a
	T3	26.7a	43.5a	1.163a	5.181	6028.2a	5709.1b
	CV%	20.29	9.15	27.90	7.40	33.65	35.60

Values followed by different letters in the same column are significantly different at $p<0.05$.

Table 3: Water consuming (mm) changes of spring wheat in each stage under different amount of irrigation

	Xinchun 22				Xinchun 19			
Growing stage	T1	T2	T3	CV (%)	T1	T2	T3	CV (%)
Sowing-emergency	38.05	37.00	36.80	1.80	31.65	29.71	33.88	6.57
Emergency-tillering	28.54	25.91	25.66	5.99	24.96	22.85	21.20	8.19
Tillering-jointing	30.72	30.58	30.61	0.24	35.84	40.83	40.51	7.15
Jointing-booting	51.44	69.31	69.07	16.20	73.84	79.41	78.31	3.82
Booting-flowing	62.18	84.29	82.25	16.02	70.64	82.69	80.56	8.24
Flowering-milky	87.86	108.84	128.27	18.66	97.60	127.22	146.77	19.99
Milky-dough	58.17	64.21	71.97	10.68	71.34	83.36	106.75	20.66
Total	356.97	420.14	444.64	11.11	405.86	466.06	507.98	11.16

tall and late mature variety and excessive irrigation led to lodging before harvest and yield loss.

Analysis of yield components showed, with increasing irrigation, harvesting spikes appeared increasing trend; grains per spike in T2 and T3 were not significantly different, but had significant difference with T1. Change rule of 1000-grain weight was as follows: T2>T3>T1, the reason why 1000-grain weight decreased in T1 treatment, mainly was that lower irrigation caused continuously drought in wheat field, leading to poor growth of wheat, low assimilate accumulation, earlier leaf senescence during filling period and less nutrients for grain filling, then grain weight decreased. Under excessive irrigation 1000-grain weight was less than that of adequate irrigation, might because abundant water supply caused overgrowth of vegetative organs and poor conversion to reproductive growth, transport of nutrient to spike organs was affected in later flowering. At the same time due to the shallower root distribution (Lv *et al*., 2010; Wang *et al.*, 2012b) and accelerated decline in root function caused by water logging (Dong and Yv, 1984) in excessive irrigation in grain filling stage, the grain nutrition supply reduced, eventually lead to grain weigh decreased, but the effect was small. Difference analysis of wheat yield components showed that, kernels and grain weight per spike were sensitive to the quantity of water, that to say, drip irrigation affected final yield mainly through grain development. Coefficient of Variation (CV) of yield factors of Xinchun 22 were all higher than Xinchun 19,showing that yield components of Xinchun 22 were more sensitive to soil moisture than those of Xinchun 19.

Difference analysis of water consumption in every stage under different amount of drip irrigation: In South Xinjiang, water consumption characteristics in spring wheat field were dually influenced by climate and growth conditions. At the early stage, because plant grew slowly and the field coverage was small, evaporation among plants dominated in field water consumption, while foliar transpiration dominated with wheat rapidly growing after entering the booting period and also soil water consumption intensity increased until flowering period reaching maximum. During different growth stage the order of water consumption was: flowering stage>booting stage>milking stage>jointing stage>tiller stage>seedling stage. It showed that in South Xinjiang water consumption component in spring wheat field gave priority to growth and development in the middle-late stage, which mainly because high temperature and drought and increased surface soil moisture by drip irrigation intensified the field evapotranspiration at that period and water shortage would affect the grain nutrient synthesis and transfer, which was one of the reasons of grain weight drop of spring wheat in arid areas under drip irrigation.

Table 3 showed that with the increasing of drip irrigation, total *ET* and water consumption before and after flowering all presented increasing tendency. Generally speaking, *ET* after flowering accounted for 40-50% of the total *ET* for spring wheat in South Xinjiang. Leaf transpiration accounting for much of total water-consuming after flowering (Chen *et al*., 2007) meant that increasing soil water could effectively raise wheat transpiration and to some extent promote the plant physiological function and yield formation. While the phenomenon that yield with excessive water supply was less than that of appropriate water supply indicated that excessive water supply increased the inefficiency of wheat "physiological water consumption", then caused "luxury transpiration" (Huo *et al*., 2003). This might be the main reason why water using efficiency of too much water drip irrigation was not high.

Table 4: Water consuming strength (mm d^{-1}) of spring wheat in each stage under different amount of irrigation

	Xinchun 22				Xinchun 19			
Growing stage	T1	T2	T3	CV (%)	T1	T2	T3	CV (%)
Sowing-emergency	1.90	1.85	1.84	1.80	1.58	1.49	1.69	6.57
Emergency-tillering	2.59	2.36	2.33	5.99	2.27	2.08	1.93	8.19
Tillering-jointing	1.81	1.80	1.80	0.24	1.89	2.15	2.13	7.15
Jointing-booting	2.57	3.47	3.45	16.20	3.52	3.78	3.73	3.82
Booting-flowing	5.18	7.02	6.85	16.02	6.42	7.52	7.32	8.24
Flowering-milky	4.18	5.18	6.11	18.66	4.65	6.06	6.99	19.99
Milky - dough	4.47	4.94	5.54	10.68	4.76	5.56	7.12	20.66
CV%	41.51	52.17	53.69	74.45	49.91	56.89	59.67	63.48
Average	3.25	3.80	3.99	10.52	3.58	4.09	4.42	10.42

It can be concluded that the lower the soil moisture, the smaller water consumption during corresponding stage by comparing field water consumption characteristics in different water treatments and this trend was more obvious after booting. For the proportion of water consumption at each stage to total water consumption, it increased before jointing stage and decreased after booting as soil water deficit. This further explained that lack of water caused spring wheat growing weakly, which mainly manifested in the following respects: ground coverage at the early stage rose slowly, population easily premature senility at late stage and the soil evaporation rate in components of water consumption was high resulting in uneconomic water-consuming and reduced yield.

Difference analysis of water consuming strength in every stage under different amount of drip irrigation: According to Table 4, it could be seen that water consumption intensity in drip irrigation of spring wheat in South Xinjiang presented a parabolic trend with the growing process. It was low before jointing and rapid increased after jointing, then reached the maximum of about 5.18-7.52 mm/d at booting-flowering period, finally dropped. After flowering the average water consumption intensity was 4.33-7.05 mm/d, which was 1.25-1.54 times of before flowering with 2.81-3.40 mm/d. It showed that water demand of post-anthesis was more urgent than before flowering, so enough water should be supplied at post-anthesis to meet the demand of wheat growth.

Under different amount of irrigation water consumption intensity was also different and increased with water increasing, such as in T3 treatment water consumption intensity at flowering stage was 1.14-1.32 times of T1. Difference among growth stages was mainly reflected after flowering, Xinchun 22 easily affected by soil water was at jointing-milk stage and Xinchun 19 at flowering-milk stage. Moreover, regardless of cultivar, water consumption intensity of T2 treatment was higher than other treatments during jointing-flowering stage. This stage was the most critical phase to the panicle initiation and seed formation and high water consumption intensity was conducive to nutrient synthesis and transportation and contributed to the formation of ear organs and yield, which may be one of the causes of the yield of T2 better than the other treatment. From the total difference affected by water, Coefficient of Variation (CV) of water consumption intensity for Xinchun 22 was 74.45%, which was higher than that of Xinchun 19 (CV = 63.48%), indicating Xinchun 22 was more sensitive to water supply.

Table 5: Water use efficiency under different amount of drip irrigation

Variety	Treatment	*WUE* (kg (mm ha)$^{-1}$)	*ET*(mm)	Irrigation amount (mm)
Xincun 22	T1	7.92b	356.97b	172.5
	T2	15.21a	420.14a	375
	T3	13.89a	444.64a	525
	CV%	31.47	11.11	49.48
Xincun 19	T1	7.41c	405.86c	172.5
	T2	13.32a	466.06b	375
	T3	11.24b	507.98a	525
	CV%	28.11	11.16	49.48

Values followed by different letters in the same column are significantly different at $p<0.05$

Comparison of water use efficiency of wheat under different amount of drip irrigation: The total water consumption of spring wheat increased with the increasing of irrigation in Table 5. Water Use Efficiency (*WUE*) had great differences among different treatments. T2 treatment reached highest, up to 13.75-15.21 kg (mm/ha), followed by T3 and T1 treatment was the lowest. There were some differences in *WUE* between excessive and suitable water treatments, which indicated that under drip irrigation, large amount of water was adverse to the panicle organ growth, yield formation and water productivity. Besides, *WUE* was different in different varieties. *WUE* of Xinchun 22 was higher than that of Xinchun 19. When dwarf varieties Xinchun 22, being a water-saving varieties and sensitive to different amount of water, was applied to production, suitable water supply should be guaranteed in order to give full play to its production potential and promote *WUE*.

CONCLUSION

- In the arid region, the formation of spring wheat yield mainly depended on the amount of water supply (Zhang *et al*., 2005). Under drip irrigation, water deficit caused harvesting spikes, grains per spike and grain weight decreased, eventually yield decreased seriously. Yield increased with water supply increasing, but when water exceeded a certain level (such as excessive irrigation), yield was no more increasing and even had drop tendency. Kernels and grain weight per spike were sensitive to drip water supply, showing that the amount of drip irrigation influenced yield mainly through the grain development.

- The order of water consumption at different growth stage was: flowering stage>booting stage>milking stage>jointing stage>tiller stage>seedling stage, which showed water consumption in drip irrigation filed of spring wheat in South Xinjiang mainly focused at the middle-late growth stage, less at early and late stage. Water consumption strength reached the maximum 5.18-7.52 mm/d during booting and flowering period, so adequate water must be supplied to meet the growth need.
- The lower water was supplied, the less water consumption was at growth stage and it declined mainly after flowering, indicating that at this period water supply affected yield formation mainly by influencing water physiological activities. So in wheat production under drip irrigation, ensuring adequate water at middle-late stage was the key to obtaining high yield. Excessive drip irrigation completed invalid water consumption by adding “luxury transpiration”, so its *WUE* was low. Water deficit caused continuous drought stress during growth period, poor vegetative growth and undesirable panicle differentiation, eventually leading to deficit of assimilation “source”. Appropriate drip irrigation water supply could effectively regulate plant growth, optimize water consumption stage with the maximum water consumption strength at jointing-flowering stage, which was favorable to the growth of reproductive organs and WUE was contributed to the highest, 13.75-15.21 kg (mm/ha).
- Besides, water consumption characteristics of deferent spring wheat varieties were different. The yield and *WUE* of Xinchun 22 were higher than those of Xinchun 19 in suitable water treatment, but in different water treatments water consumption, water consumption intensity and *WUE* had great difference, which reflected that Xinchun 22 was a water saving and high efficiency variety and more easily to improve water production efficiency under drip irrigation with appropriate water.

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