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水分胁迫效应对冬小麦生长发育影响的试验研究

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摘要: 利用大型水分试验场遮雨棚遮挡自然降水,采用人工定量补水进行冬小麦土壤含水量占田间持水量 40%~50%、45%~50%、50%~55%、50%~60%、55%~60%、60%~70%持续时间分别为 5、10、15d 水分胁迫处理的控制试验。试验结果表明:控制期结束复水后,50%~60%、55%~70%水分胁迫处理能诱发冬小麦根、茎、叶、总生物量显著增长或明显减缓其衰老速率。土壤含水量占田间持水量 50%~60%处理,具有明显的增产、节水效应。确定土壤含水量占田间持水量 55%为冬小麦拔节期水分胁迫效应增产节水的水分临界指标。

关键词: 冬小麦; 水分胁迫效应; 田间试验

The experimental research on water stress effects on growth and development of winter wheat

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Abstract: Using large movable rainshelters to keep off precipitation, the field experiments on the effects of treatments of different soil moisture and duration on the growth, development and yield of winter wheat are conducted by controlled irrigation. The responses of the growth, development and yield of winter wheat to water stress are studied, and processes and methods to improve water use efficiency and to mitigate spring drought are also discussed. These studies provide scientific bases for economical irrigation, and guarantee the stable and high yield of winter wheat as well.

The experiment was carried out at the agrometeorological experimental station of China Meteorological Administration (located in Gucheng, Dingxing county, Hebei Province, 39°08′N, 115°48′E) from March 1997 to June 1998. The selected winter wheat variety in the experiment is Jingdong 6 (main planting variety in the area). All of the control experiments were made in plots, and the experiments from October 1997 to June 1998 were divided into two groups (from regreening to elongation and from elongation to flowering). Precipitation over the plots can be shut out by large movable rainshelters, and the plots can be irrigated with the calculated irrigation amount according to different soil moisture treatments.

The soil relative moistures for different treatments were controlled at 40%~50%, 50%~60%, 60%~70% and CK (80%) from March to June 1997, and 45%~50%, 50%~55%, 55%~60% and CK (80%) from Oct. 1997 to June 1998, respectively. The duration of water treatments was 5, 10 and 15 days, respectively, and after the duration of treatment, soil moisture resumes to the level of the control experiment. Because of the limited number of plots, every treatment was repeated in only two plots.

The area of every plot was 8 square meters (2m×4m), with concrete waterproof walls (2 meters in

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depth) to prevent the horizontal exchange of soil water, and the soil of every plot was original. The planting and managing measures of the plots were as same as those of other fields.

The measured depth of soil moisture was from 0 to 200 cm. The soil moisture from 0 to 30 cm and from 40 to 200cm were measured by the drilling method and by the neutron instrument, respectively. The soil moisture was measured by the interval of 10 cm once every five days during water control treatments, and once every ten days for other periods.

The irrigation amount of the plots can be calculated using the following equation:

$$P = \sum_{i=1}^{n} (\rho_i \times h_i \times (r - W_i/T_i) \times T_i \times 10) \tag{1}$$

$$Q = S \times P/1000 \tag{2}$$

In equation (1), P is the supplement of irrigation (unit: mm); ρ is the measured bulk density of soil in the experimental field (unit: g/cm^3); h is the measured soil thickness (unit: cm); r is six treatment grades and the upper value of CK, which are 50%, 55%, 60%, 70% and 80% (CK) respectively; W is the water content of soil by weight (unit: %); T is the measured field capacity in the experimental field (unit: %) and n is the calculated levels of water supplement, here n=10.

In equation (2), Q is the irrigation amount (unit: mm); S is the plot area (unit: m^2) and P is the calculated irrigation amount by equation (1) (unit: mm).

Observed items of every plot on winter wheat include the development stages, the number and length or height, and the fresh and dry weight of all organs (including the length and number of roots, the fresh and dry weight of roots, the height and number of stems, the fresh and dry weight of stems, and the leave area, the number of green leaves and yellow leaves, the fresh and dry weight of green and yellow leaves; and the length of spikes, the number of spikes and unfertilized spikes, the fresh and dry weight of pikes.), and the fresh and dry weight of total biomass etc. Samples were taken once every five days during water control treatments, and once every ten days for other periods, and ten sample plants were taken every time. In the end, all organs (including roots, stems, leaves, spikes and biomass) and yields were measured after harvest.

According to the experimental data, and based on the differences during the growth and development of winter wheat before and after rewatering, the responses of the growth and development of winter wheat to water stress were analyzed, and water-saving processes of slight and moderate water stress on winter wheat were studied also. The results show that, for treatments with soil relative moistures being 50%～60% and 55%～70%, the daily increment of the length and number of roots increased remarkably after five days of rewatering, compared to that of the same period of CK, and even so when there existed a negative daily increment of the length and number of roots of CK. The daily maximum length increment of roots is about 26 times than that of CK. The daily maximum increment of number of roots can reach 10.4 though there is no change in the number of roots of CK. The mean number of roots increased for the treatment with a soil relative moisture of 50%～60% compared to that of CK. All these indicate that slight and moderate water stress can accelerate the root growth and development of winter wheat.

For treatments with soil relative moistures being 50%～60% and 55%～70%, the daily stem increment increased significantly, and even when the daily increment of stems is negative in the period of CK. For treatments with a soil relative moisture of 50%～55%, the daily dry weight increment of stems was most evidently, the next is the case with a soil relative moisture of 55%～60%, which shows that slight and moderate water stress could induce the fast increase of the daily stem increment of winter wheat.

On 5 and 10～20 days after rewatering, the daily increment of leaf area could increase very remark-

ably for the treatments with soil relative moistures being 50%～60% and 55%～70% compared to that of CK. And even under the negative daily increment of leave area of CK, the daily increment of leaf area increased significantly, or the senescent rate decreased markedly. For a certain water stress duration, the longer the water stress duration , the more favorable it is to the growth of green leaves. From 5 to 10 days after rewatering, the daily dry weight increment of yellow leaves decreased evidently for the treatments with soil relative moistures being 50%～60% and 55%～70%. During the whole development stage of winter wheat, the mean dry weight of yellow leaves reduced, and the senescent rate of leaves was delayed. The experimental results show that there may be certain memory in winter wheat, and rewatering can resume its memory after slight and moderate water stress, and stimulate the leaf area increase of winter wheat. At same time, the dry weight of yellow leaves decreases, which retards the senescent rate of green leaves.

In comparison with that of CK, the daily dry biomass increment of winter wheat would increase markedly in 5 days after rewatering with soil relative moistures being 50%～60% and 55%～70%. And the phase of daily maximum total biomass increment will predate 9 to 25 days during the late development stage of winter wheat. For the treatment of water stress, the daily total biomass increment of winter wheat increased by 122% compared to that of CK.

The treatment, with a soil relative moisture of 50%～60%, can save water by 1500～1650m^3/hm^2, increase yield by 1.9%～10.7%, and improve economic benefit by 705～1395 yuan/hm^2. The studies show that water stress of winter wheat could save water and increase yield and economic benefit markedly. In the light of high yield and high benefit of winter wheat, the soil relative moisture of 55% is the critical index of water stress to economic irrigation and high yield during the heading stage of winter wheat.

Key words: winter wheat; water stress effect; field experiment

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干旱造成的水分亏缺,是农作物经常和周期性地经历的一种逆境胁迫现象。在冬小麦进化历程中,其为适应环境而生存发展已形成了有效的适应反应机制,使其能应付不同强度的水分亏缺。据研究[1]轻度缺水虽对小麦叶片扩展有影响,但并不影响叶片气孔的开启,对光合作用影响不大。在某些发育期,减少土壤水分,诱导轻度至中度水分胁迫,可避免植株旺长,改变植株体内水分和养分的分配,使同化物从营养器官向生殖器官转移,有利于经济产量的形成[2]。我国传统栽培管理技术措施中的“促”、“控”措施,“蹲苗”或中耕切断部分根系,都是利用水分亏缺后的水分胁迫效应。小麦耗水与产量的关系表明[3],在一定限度内产量随耗水量增加而提高,但超过一定限度,反而随耗水量增加而下降;根据试验结果,产量为 500kg/666.7m^2 的高产小麦耗水量与中下等产量的需水量相似。一定程度的干旱能促进小麦灌浆速度。本项研究拟通过冬小麦春季主要发育阶段不同土壤水分及持续时间组合处理对其生长发育和产量形成影响的田间试验,研究冬小麦生长发育和产量对水分胁迫效应的反应机制,探讨提高水分利用效率的内在机理,为在保证冬小麦稳产增产的情况下,进行节水灌溉提供科学依据。

1 冬小麦水分胁迫效应试验设计

1.1 水分处理设计与控制

试验设置于中国气象局农业气象试验基地(位于河北省定兴县固城镇,39°08′N、115°48′E),1996 年 10 月 1 日播种,1997 年 3 月返青后测定取样至 1998 年 6 月,供试品种为当地主栽品种京冬 6 号。控制试验均在小区内进行,其中 1997 年 10 月～1998 年 6 月控制试验分返青—拔节、拔节—开花两组进行。小区水分试验场以大型遮雨棚遮挡自然降水,根据不同水分处理的控制需要经实测计算补水量进行人工灌溉。

1997 年 3～6 月水分处理分土壤含水量占田间持水量的 40%～50%、50%～60%、60%～70%和 CK(80%),1997 年 10 月～1998 年 6 月水分处理分土壤含水量占田间持水量的 45%～50%、50%～55%、

55%～60%和 CK(80%)；每个水分处理水平控制水分的持续时间分别为 5、10、15d。持续时间一过，立即复水到对照水平。受水分试验场内小区数量的限制，不同水分处理组合的小区设 2 个重复。

小区样方面积为 2m×4m，深度为 2m 的原状土，样方间有水泥隔离层，可避免土壤水分在水平方向上发生交换，各项栽培管理措施与大田完全一致。冬小麦水分胁迫效应试验设计方案见表 1。

表 1　冬小麦水分胁迫效应试验设计方案

Table 1　Experimental design of water stress effects of winter wheat

年份 Year	土壤含水量占田间持水量 Relative moisture of soil (%)	持续时间(d) Persisting time	控制日期(日/月) Controlling date (day/month)	代码 Code	平均根数(条) Average root number	平均黄叶干重(g) Average dry weight of yellow leaf	冬小麦生育后期总生物量干重增重最大期的日增重量(g) Diurnal increase of weight at the biggest total biomass dry weight increase times at late growing periods of winter wheat
1997	40～50	5	28/5～2/6	1	97.6	0.548	0.706
		10	28/5～7/6	2	103.4	0.600	0.506
		15	23/5～7/6	3	101.8	0.549	0.804
	50～60	5	22/4～27/4	4	115.2	0.416	0.714
		10	22/4～2/5	5	108.2	0.442	0.695
		15	3/4～18/4	6	126.1	0.394	0.985
	60～70	5	13/4～18/4	7	118.9	0.334	0.697
		10	3/4～13/4	8	119.3	0.394	1.441
		15	22/4～7/5	9	117.0	0.310	0.768
	CK				110.7	0.515	0.648
1998	45～50	5	9/3～14/3	10	98.1	0.543	0.969
		10	19/3～29/3	11	83.5	0.447	0.681
		15	9/3～24/3	12	99.5	0.585	0.797
	50～55	5	4/4～9/4	13	96.7	0.643	0.928
		10	14/4～24/4	14	99.5	0.652	0.823
		15	4/4～19/4	15	101.5	0.576	0.794
	55～60	5	9/3～14/3	16	108.4	0.584	0.820
		10	19/3～29/3	17	106.8	0.598	0.721
		15	9/3～24/3	18	102.1	0.692	0.765
	CK				100.6	0.660	0.804
	45～50	5	24/4～29/4	19	106.2	0.615	1.098
		10	24/4～4/5	20	109.2	0.673	1.519
		15	24/4～9/5	21	103.6	0.592	1.199
	50～55	5	19/4～24/4	22	109.6	0.697	0.666
		10	14/4～24/4	23	114.9	0.716	1.291
		15	14/4～29/4	24	113.8	0.751	1.014
	55～60	5	19/4～24/4	25	105.3	0.855	1.016
		10	14/4～24/4	26	104.3	0.640	1.803
		15	19/4～4/5	27	105.5	0.703	0.868
	CK				110.8	0.798	0.866

1.2　测定项目和方法

1.2.1　土壤湿度测定　土壤湿度测定深度为 0～200cm，其中 0～30cm 用土钻测，40～200cm 用中子仪测；测定土层厚度间距为 10cm；测定时间是在水分控制时段内每 5d 测定 1 次，其余时段每 10d 测定 1 次。

1.2.2　补水量计算　小区的补水量按下列公式计算：

$$P = \sum_{i=1}^{n} \{\rho_i \times h_i \times (r - W_i/T_i) \times T_i \times 10\} \tag{1}$$

式中：P 为补水量，单位为 mm；可折算成立方米进行补灌。ρ 为试验基地地段实测土壤容重，单位为 g/cm^3；h 为测定土层厚度，单位为 cm；r 取 6 个土壤水分处理等级和 CK 的上限值，分别为 50%、55%、60%、70%、80%(CK)；W 为土壤重量含水率，单位为%；T 为试验基地地段实测田间持水量，单位为%；n 为土壤补水量计算层数，$n=10$。

1.2.3　冬小麦群体生长动态测定　冬小麦群体生长动态测定项目包括：根长、根数、根鲜干重，株高、总茎数、茎鲜干重，叶面积、绿叶数、绿叶鲜干重、黄叶数、黄叶鲜干重，穗数、穗长、小穗数、不孕小穗数、退化小穗数、穗鲜干重，总生物量鲜干重；测定时间：水分处理控制阶段每个供试样本每 5d 取样 1 次，其它阶段每 10d 取样 1 次，取样株数 10 株。收获后进行考种测定。

2　试验结果分析

2.1　冬小麦生长发育对水分胁迫的反应

利用水分控制期结束、复水前后冬小麦生长发育状况变化的试验观测资料，探讨冬小麦生长发育对水分胁迫效应的反应机制。

2.1.1　复水后根系生长发育状况的变化　图 1 给出了复水后 5d 冬小麦根长日增量处理与 CK 的对比，可以看出 1997 年除土壤含水量占田间持水量 50%～60%持续 10d 处理外，其它处理的同期根长日增量与 CK 相比显著增加，最大日增量是 CK 的 13 倍。1998 年返青～拔节期控水，除 45%～50%持续 10d 处理外，其它处理的同期根长日增量均比 CK 显著增加。其中 50%～55%持续 15d 处理在 CK 根长日增量减少 0.009cm 情况下，同期根长日增量达到 0.340cm；50%～55%持续 5d 处理，同期根长日增量是 CK 的 26 倍。1998 年拔节～开花期控水，除个别处理外，其它处理在 CK 根长日增量负增长的情况下，其根长日增量仍有显著的正增长。

由图 2 可以看出复水后 5d，1997 年除 50%～60%持续 15d 处理外，其它处理的冬小麦同期根数日增量与 CK 比明显增加；尤其是 60%～70%持续 10d 处理，在 CK 根数没有增加的情况下，日增量达到 10.4 条。1998 年返青～拔节期控水，除个别处理外，其它处理的同期根数日增量与 CK 相比明显增加；拔节～开花期控水，除个别处理外，其它处理在 CK 根数日增量负增长的情况下，其根数日增量仍有显著的正增长。

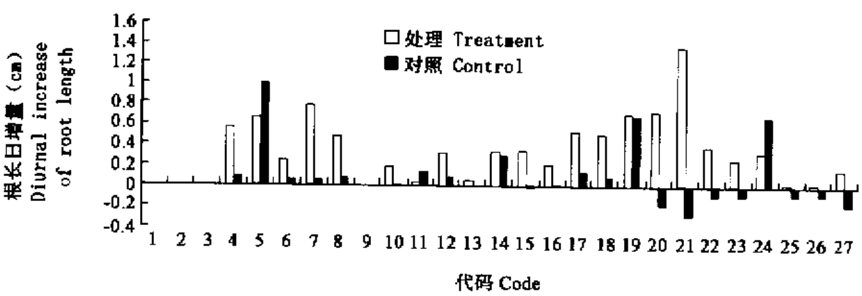

图 1　复水后 5d 冬小麦根长日增量处理与 CK 的对比

Fig. 1　Diurnal increase of root length in 5 days after irrigation in comparison with control

冬小麦全生育期平均根数处理与 CK 的对比表明(表 1)，1997 年 50%～60%、60%～70%处理能增加冬小麦的平均根数，其中以 50%～60%持续 15d 处理根数增加最多，比 CK 增加了 13.9%。1998 年返青～拔节期控水，45%～50%处理平均根数比 CK 减少，50%～55%处理对平均根数影响不大，55%～60%处理平均根数增加；拔节～开花期控水，50%～55%处理的平均根数比 CK 增加，45%～50%、55%～60%处理的平均根数比 CK 减少。

上述结果表明中轻度的水分胁迫结束后，能诱发刺激冬小麦根系显著增长。土壤含水量占田间持水量 50%～55%水分胁迫处理全生育期的平均根数增加。

2.1.2　复水后茎生长发育状况的变化　复水后 5d 冬小麦茎干重日增量处理与 CK 的对比表明(图 3)，

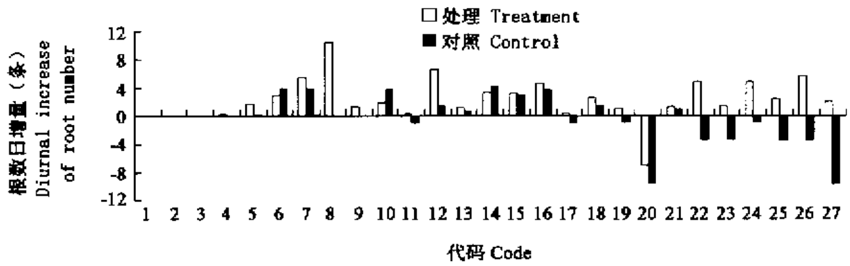

图 2 复水后 5d 冬小麦根数日增量处理与 CK 的对比

Fig. 2 Diurnal increase of root number in 5 days after irrigation in comparison with control

1997 年除土壤含水量占田间持水量 50%～60%持续 15d、60%～70%持续 5d 处理的茎干重日增量与同期 CK 基本持平外，其它处理的茎干重日增量与同期 CK 相比均有显著增加；其中 60%～70%持续 10d 处理的茎干重日增量是同期 CK 的 13.5 倍；50%～60%持续 10d、60%～70%持续 15d 处理的茎干重日增量在同期 CK 茎干重日增量负增长的情况下，仍然有明显的正增长。1998 年返青－拔节期控水，除个别处理外，其它处理在 CK 茎干重日增量正增长时，其茎干重日增量呈显著正增长，以 50%～55%处理茎干重日增量增长最为明显，最大是 CK 的 3.54 倍；在 CK 茎干重日增量负增长时，其茎干重日增量仍呈正增长。拔节－开花期控水，以 50%～55%处理茎干重日增量增长最为明显，其次是 55%～60%处理。这表明中轻度水分胁迫结束复水后 5d，能诱发冬小麦茎干重日增量的快速增长。

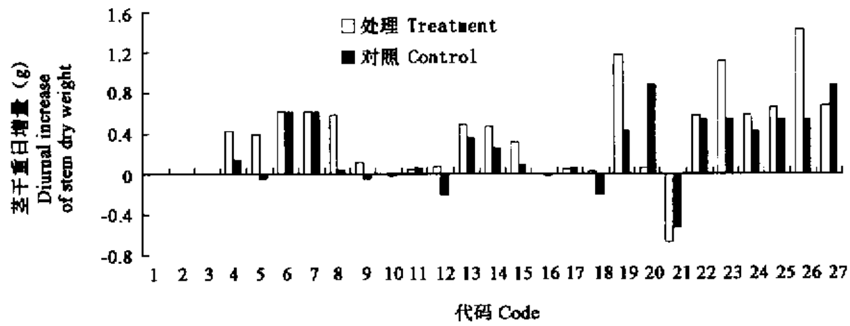

图 3 复水后 5d 冬小麦茎干重日增量处理与 CK 的对比

Fig. 3 Diurnal increase of stem dry weight in 5 days after irrigation in comparison with control

2.1.3 复水后叶生长发育状况的变化 复水后 5d 冬小麦绿叶面积日增量处理与 CK 的对比(图 4)表明，1997 年除土壤含水量占田间持水量 50%～60%持续 15d、60%～70%持续 5d 处理的绿叶面积日增量低于 CK 外，其它处理绿叶面积日增量与同期 CK 相比，均显著增加或降低绿叶的衰老速率。60%～70%持续 10d 处理的绿叶面积日增量是同期 CK 的 4.7 倍；50%～60%持续 5d、10d 处理的绿叶面积日增量在同期 CK 叶面积日增量负增长的情况下，仍然呈显著正增长；60%～70%持续 15d 处理的绿叶面积日减少量比 CK 降低了 2.71 cm，减缓了绿叶的衰老速率。1998 年返青～拔节期控水，除 50%～55%持续 15d 处理外，其它处理的绿叶面积日增量均比 CK 同期日增量显著增加，或在 CK 呈显著负增长时，仍呈明显的正增长；拔节～开花期控水，除个别处理外，其它处理的绿叶面积日增量均比 CK 同期显著增加，或衰老速率显著减缓。

由图 5 可以看出复水后 10～20d，1997 年 50%～60%持续 5d、10d 处理的冬小麦绿叶面积，在同期 CK

绿叶面积明显减少情况下,仍继续增加,日增量分别为 0.24、1.99 cm^2。其它处理绿叶面积均减少,但其减少速率与同期 CK 相比明显降低。1998 年返青～拔节期控水,45%～50%、50%～55%、55%～60%持续 15d 处理,绿叶面积日增量比同期 CK 显著增加,即在一定时间范围内,水分胁迫时间越长,复水后(10～20d)越有利于其绿叶面积的增加;拔节～开花期控水,除个别处理外,其它处理的绿叶面积日减少量均比 CK 同期显著降低,减缓了冬小麦绿叶的衰老速率。

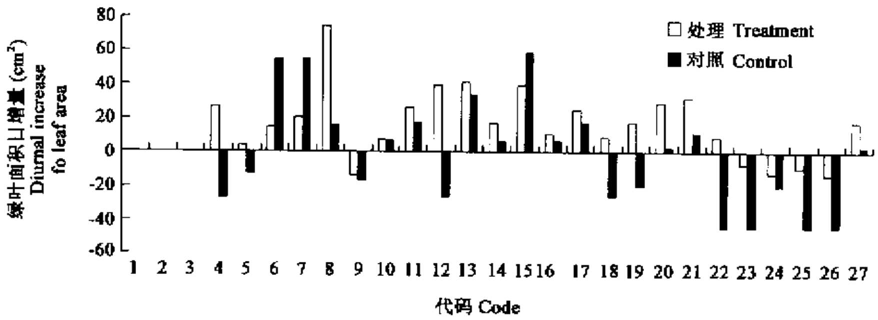

图 4　复水后 5d 冬小麦绿叶面积日增量处理与 CK 的对比

Fig. 4　Diurnal increase of leaf area in 5 days after irrigation in comparison with control

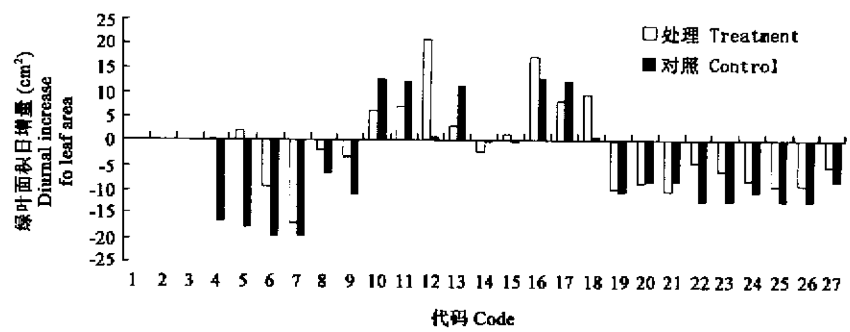

图 5　复水后 10～20d 冬小麦绿叶面积日增量处理与 CK 的对比

Fig. 5　Diurnal increase of leaf area during 10～20 days after irrigation in comparison with control

图 6 给出了复水后 5～10d 冬小麦黄叶干重日增量处理与 CK 的对比,可以看出 1997 年 50%～60%、60%～70%处理的黄叶干重日增量均降低;而同期 CK 的黄叶干重日增量,除 60%～70%持续 15d 处理外,其它处理的黄叶干重日增量均增加。1998 年返青～拔节期、拔节～开花期控水,除个别处理外,其它处理的黄叶干重日增量均比 CK 减少,或明显增加其负增长速率。

冬小麦全生育期平均黄叶干重处理与 CK 的对比表明(表 1),1997 年 40%～50%处理的冬小麦黄叶干重增加,促进植株叶片的衰老;50%～60%、60%～70%处理的冬小麦平均黄叶干重降低,减缓植株叶片的衰老。1998 年返青～拔节期控水,除 55%～60%持续 15d 处理外,其它处理的平均黄叶干重均比 CK 降低;拔节～开花期控水,除 55%～60%持续 5d 处理外,其它处理的平均黄叶干重均比 CK 降低。

这表明冬小麦存在某种记忆功能,中轻度水分胁迫结束复水后能诱发其记忆功能的恢复,刺激冬小麦叶面积的快速增长,黄叶干重降低,明显减缓绿叶的衰老速率。

2.1.4　复水后总生物量的变化　复水后 5d 冬小麦总生物量干重日增量处理与 CK 的对比(图 7)表明,1997 年除土壤含水量占田间持水量 50%～60%持续 15d、60%～70%持续 5d 处理的总生物量干重日增量比同期 CK 稍偏低外;其它处理的冬小麦总生物量干重日增量均比同期 CK 显著增加,其中 60%～70%持

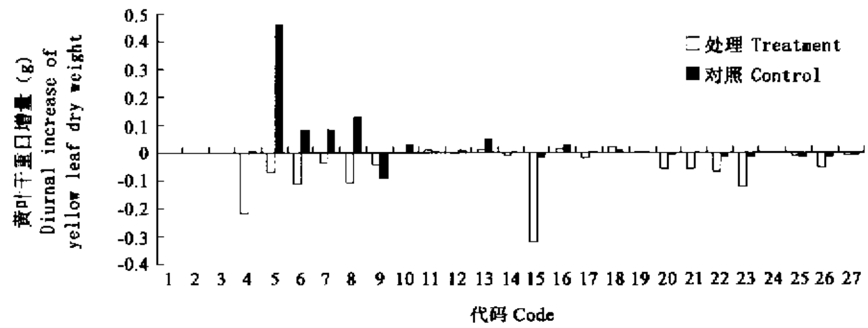

图6 复水后5～10d冬小麦黄叶干重日增量处理与CK的对比

Fig. 6 Diurnal increase of yellow leaf dry weight during 5～10 days after irrigation in comparison with control

续10d处理的总生物量干重日增量是同期CK的25.9倍。与CK相比,总生物量干重增重最大期提前了9～25d;持续天数处理与CK接近或有所增加。冬小麦生育后期总生物量干重增重最大期的日增重量处理与CK的对比(表1)表明,水分胁迫效应能提高其生育后期总生物量干重增重最大期的日增重量,最大比CK增加了122%。

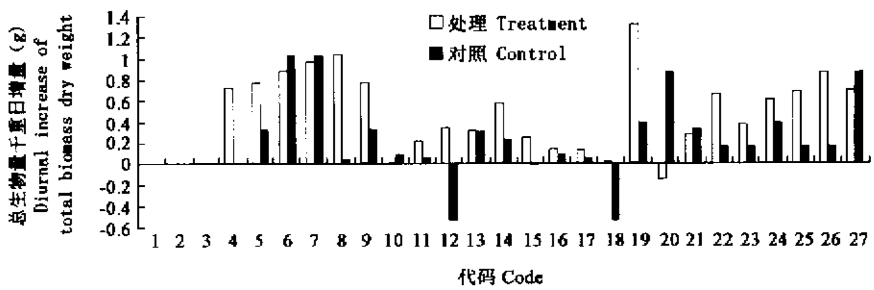

图7 复水后5d冬小麦总生物量干重日增量处理与CK的对比

Fig. 7 Diurnal increase of total biomass dry weight in 5 days after irrigation in comparison with control

1998年返青～拔节期、拔节～开花期控水,复水后5d,除45%～50%的个别处理外,其它处理的总生物量干重日增量均比同期CK显著增加。与CK相比,总生物量干重增重最大期约提前了10～20d;持续天数处理与CK接近或有明显增加;特别是拔节～开花期控水,50%～55%持续5d处理的总生物量干重增重最大期持续天数比CK延长了12d;虽然50%～55%持续5d处理的总生物量干重增重最大期日增量比CK低,但其总生物量干重增重最大期内累积的总生物量仍明显高于CK;其它处理的总生物量干重增重最大期的日增量均明显高于CK。返青～拔节期控水,50%～55%处理的总生物量干重增重最大期的日增量高于CK(表1)。

2.2 冬小麦水分胁迫效应的经济效益评估

以1997年的价格标准,小麦1.6元/kg、农业灌溉用水0.4元/m^3计算,2a试验各处理的平均经济效益见表2。可以看出,土壤含水量占田间持水量40%～50%处理,灌溉量为1959m^3/hm^2(自然降水全部被遮雨棚阻挡,下同),减产16.2%,经济效益低于CK。土壤含水量占田间持水量50%～60%处理,灌溉量为2892m^3/hm^2,增产1.9%～10.7%,经济效益显著高于CK。土壤含水量占田间持水量60%～70%处理,灌溉量为3328.5m^3/hm^2,增产9.9%,经济效益高于CK。特别是1998年土壤含水量占田间持水量50%～

55%处理，灌溉量为 3202.5m^3/hm^2，增产 10.7%，经济效益增加了 1402.5 元/hm^2；土壤含水量占田间持水量 55%～60%处理，灌溉量为 3385.5m^3/hm^2，增产 6.8%，经济效益增加了 1065.9 元/hm^2。

表 2 冬小麦水分胁迫处理增产、节水及其经济效益

Table 2 Effect evaluation of water stress on yield increase, water saving and economic benefits of winter wheat

试验年份 Year	土壤含水量占田间持水量 Relative moisture of soil (%)	灌溉量(m^3/hm^2) Irrigation amounts	产量(kg/hm^2) Yield	经济效益*(￥/hm^2) Economic benefits
1997	40～50	1959	3433	4709.55
1997	50～60	2892	4174	5521.95
1997	60～70	3328.5	4502	5871.60
1997	CK(80)	4348.5	4096	4815.15
1998	45～50	2670	3611	4710.30
1998	50～55	3202.5	4766	6343.35
1998	55～60	3385.5	4600	6006.75
1998	CK(80)	4876.5	4307	4940.85

* 经济效益计算未计种子、肥料、农药、人工、机电等投入。The expense of seeds, fertilizers, labours, machines and electric power was not calculated.

上述试验结果表明，土壤含水量占田间持水量 50%～60%处理，冬小麦生长发育性状和产量得到明显提高，具有明显的节水、增产作用，且经济效益高。因此从冬小麦生产的高产、高效出发，将冬小麦拔节期水分胁迫效应节水、增产的水分临界指标确定为土壤含水量占田间持水量的 55%。

3 结果和讨论

(1)复水后 5d，土壤含水量占田间持水量 50%～60%、55%～70%处理的冬小麦根长、根数、茎干重、绿叶面积、总生物量干重与同期 CK 相比，日增量显著增长。复水后 10～20d 期间，50%～60%、55%～70%处理与 CK 比，绿叶面积增加，叶面积衰减速率明显降低。复水后 5～10d，50%～60%处理与 CK 比，冬小麦黄叶干重增量明显降低。冬小麦生育后期总生物量干重增重最大期比 CK 提前 9～25d。

(2)土壤含水量占田间持水量 50%～60%水分胁迫处理与 CK 相比生育后期总生物量干重增重最大期的日增重量提高，平均根系数增加，平均黄叶干重降低。

(3)土壤含水量占田间持水量 50%～60%处理，节水 1500～1650 m^3/hm^2，增产 1.9%～10.7%，经济效益比 CK 高 705～1395 元/hm^2，土壤含水量占田间持水量 55%为冬小麦拔节期水分胁迫效应增产节水的水分临界指标。

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