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Grain Yield and Yield Components of Spring Wheat Genotypes at Different Moisture Regimes

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إنتاجية الحبوب ومكونات الإنتاج في الأنماط الوراثية لقمح الربيع عند معدلات الري المختلفة

الملخص : غالبا ما تستخدم الإنتاجية وخصائص التطور لأنواع المحاصيل عند مستويات الري المختلفة في الحبوب لانتخاب الأنماط الوراثية التي يمكن تأقلمها على بيئات الرطوبة المتغيرة. أجريت هذه الدراسة في أبردين ــ إيداهو بالولايات المتحدة الأمريكية في عامي ١٩٩٢ و ١٩٩٣م لتقييم تأثير كميات مياه الري المختلفة على إنتاجية الحبوب ومكوناته عند الأنماط الوراثية لقمح الربيع . في كلا العامين ، زرعت إثنتى عشرة نمطا وراثيا لقمح الربيع (*Triticum sativum* L.) في ثلاث مستويات ري مختلفة هي(ري كامل وإجهاد مائي معتدل وإجهاد مائي حاد) خلال الفترة من منتصف ظهور الخلفات وحتى مرحلة تفتح الأزهار ، بواسطة نظام رش خطي، وأستخدم إنتاجية الحبوب ومكوناتها (عدد السنبلات لكل متر مربع وعدد السنيبلات لكل سنبلة وعدد البذرات في كل سنيبلة والبذرات لكل سنبلة ووزن البذرة الواحدة) لتقييم مدى تحمل النمط الوراثي للإجهاد المائي . بشكل عام سبب الإجهاد المائي نقصا في إنتاج البذور ومكونات الإنتاجية كما أظهرت التركيبات الوراثية اختلافات كبيرة في الإنتاج من عام إلى آخر. وقد أعطت التركيبات متوسطة الطول إلى الطويلة (IDO 367 و IDO 369 و ريك Rick) في عام ١٩٩٢ (عام جاف نسبيا) محصولا عاليا تحت ظروف الإجهاد المائي بينما أنتجت الأنماط الوراثية القصيرة إلى المتوسطة (WPB926 و يكورا روجو Yecora Rojo و بونديرا Pondera) في عام ١٩٩٣ (عام رطب نسبيا) محصولا عاليا تحت ظروف الإجهاد المائي. كانت عينات كريس Chris وسيرا Serra الأقل إنتاجية بين التركيبات الوراثية المختلفة تحت الجهد المائي في كلا العامين . وكانت عينات IDO 367 ويكورا روجو هي الأكثر إنتاجية عندما كان الجهد المائي معتدلا. إن اختلاف إنتاجية التركيبات الوراثية تحت ظروف الإجهاد المائي بالاختلاف في عدد السنابل في المتر المربع بالدرجة الأولى وبالتالي يمكن استخدام الاتجاه لزيادة المرونة لدى عدد السنابل في وحدة المساحة، لانتخاب الأنماط الوراثية للقمح واللازمة لتحسين مدى تحمل القمح للجفاف .

ABSTRACT: Yield and developmental characteristics of crop genotypes grown at different levels of water availability are often used to select genotypes that are adapted to variable moisture environments. Field studies were conducted at Aberdeen, Idaho, USA in 1992 and 1993 to evaluate the effects of varying moisture supply on grain yield and yield components of spring wheat genotypes. In both years, 12 spring wheat (Triticum aestivum L.) genotypes were grown under three irrigation levels (well-watered, moderate water-stress and severe water-stress) imposed during the periods from mid-tillering to anthesis with a line source sprinkler irrigation system. Grain yield and yield components (spikes m^{-2}, spikelets $spike^{-1}$, kernels $spikelet^{-1}$, kernels $spike^{-1}$ and kernel weight) were used to evaluate the genotypic response to water stress. Overall, water stress caused a reduction in grain yield and yield components. Genotypes exhibited a large year-to-year variation in their ranks for grain yield. Medium-tall growing genotypes (IDO 367, IDO 369 and Rick) generally produced high yields under water stress conditions in 1992 (relatively dry year), while short -medium genotypes (WPB 926, Yecora Rojo and Pondera) produced high yields under water stress conditions in 1993 (relatively wet year). Chris and Serra were the lowest yielding genotypes under water stress conditions in both years. Under moderate stress conditions, IDO 367 and Yecora Rojo had consistently high yields. Genotypic yield differences under water stress conditions were primarily related to the differences in the numbers of spikes m^{-2}. Therefore, a tendency for high plasticity for spikes per unit area could be used to select wheat genotypes for improved drought tolerance.

Drought resistance of a plant genotype cannot be defined physiologically (Blum *et al.*, 1981), and there seems to be no simple method to quantify drought tolerance in a physiological sense (Clarke *et al.*, 1992). Thus, grain yield and yield components remain a major selection criterion for improved adaptation to stress in many wheat breeding programs. Keim and Kronstad (1979) proposed that an ideal cultivar for stressed

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environments should have a high yield in the most severely stressed environments and a strong response to more favorable environments. Bruckner and Frohberg (1987) used mean yield in stressed environments to estimate stress performance *per se* of spring wheat genotypes. Large differences in grain yield of spring wheat genotypes grown under drought conditions have been observed by Fischer and Maurer (1978), Ehdaie *et al.* (1988) and Mogensen *et al.* (1985).

Selection of wheat varieties with high plasticity for various yield components could reduce yield variation due to drought stress. Sidwell *et al.* (1976) and Knott and Talukdar (1971) suggested that yield improvement in wheat may be accompanied by manipulating the components of yield, such as spikes per unit area, kernel number per spike, and kernel weight. Aggarwal and Sinha (1987) reported that maintaining the number of spikes per unit area provides an advantage to wheat in environments varying in soil water availability. Differential production of various yield components in wheat in response to water availability has been reported in many studies (Bansal and Sinha, 1991; Ehdaie *et al.*,1988; Fischer and Maurer, 1978; Mogensen, 1985; Begg and Turner, 1976).

The objectives of this study were (i) to measure the effect of water stress on grain yield and yield components in 12 spring wheat genotypes, and (ii) to characterize these genotypes for stress tolerance and adaptation to stress-prone environments using yield and yield component responses.

TABLE 1

Relative maturity and height of spring wheat genotypes used for evaluation of drought tolerance

Genotype	Relative Maturity	Relative Height[1]
Amidon	Mid	T
Bannock	Mid	T
Chris	Late	T
Rick	Late	I-T
IDO 367	Late	I-T
Pondera	Mid	I-T
IDO 369	Late	I-T
Klasic	Early	S
Serra	Early	I
WPB 926	Mid	I
Yecora Rojo	Early	S
Vandal	Late	I

[1] Relative height: T = Tall, I = Intermediate, S = Short.

Materials and Methods

Twelve hard red spring wheat genotypes were grown in 1992 and 1993 at the Aberdeen Research and Extension Center, Aberdeen, Idaho, U.S.A. under three irrigation levels (well-watered, moderate stress and severe stress). The 12 genotypes represent a relatively wide range of maturity and plant height characteristics (Table 1). Wheat was planted on 13 May 1992 and 10 May 1993, on a Delco silt loam (coarse-loamy, mixed, mesic Xerollic Calciothid). Both experiments were seeded at 85-90 kg.ha^{-1} with an 18 cm row spacing. Each field received a pre-planting broadcast application of 110 kg N ha^{-1} as ammonium nitrate. All other nutrients were determined to be present in adequate amounts.

A line-source sprinkler system (Hanks *et al.*, 1976) was used to apply different amounts of water to three 143 m long vertical strips on each side of the sprinkler line. Horizontal strips of each genotype were 21 rows (3.7 m) wide and 31.7 m long and was oriented at right angles to the sprinkler line and the irrigation strips. Plots were arranged in a design similar to the split-block design with six replications (three on each side of the line source). Water stress was imposed at the beginning of tillering and continued until the completion of anthesis. All plots received the same amount of irrigation for the remainder of the growing season. Irrigation was scheduled to apply sufficient water to fully meet the water requirements of the well-watered plots while maintaining available soil moisture in the root zone at least above 50%. The daily crop water use was estimated using a modified Penman equation (Doorenbos and Pruitt, 1977). The frequency of irrigation was dependent upon the amount of rainfall, daily crop water use and the rate of soil water extraction.

Catch cans were placed 60 cm above the ground in the middle of each irrigation strip to measure the amount of water applied. Precipitation and other weather data were taken from the weather station at Aberdeen Research Center. Gravimetric soil water contents for the 0 to 90 cm depth were determined at the beginning and end of the stress period. Total evapotranspiration (ET) from each irrigation level during the differential stress period was calculated from the water balance equation:

$$ET = P + I - \Delta D$$

Where P is the rainfall amount, I is the irrigation amount and ΔD is the change in soil moisture storage to the 0.9 m depth. Runoff and drainage were both considered to be negligible. The amount of water applied (I + P) to severely stressed plots was 197 mm

TABLE 2

May-August precipitation, mean maximum and minimum temperatures at Aberdeen, Idaho, USA

	1992			1993		
Month	P[1] mm	$T_{max.}$[2] °C	$T_{min.}$[3] °C	P mm	$T_{max.}$ °C	$T_{min.}$ °C
May	0.3	23.8	4.4	36.6	21.6	5
June	25.1	26.1	7.7	67.8	21.6	6.1
July	15	27.7	7.2	35.8	23.3	6.7
August	0	32.2	6.1	38.9	26.7	7.2
Mean	10.1	27.5	6.4	44.8	23.3	6.3

[1] P = Precipitation, [2] $T_{max.}$ = Mean maximum temperature, [3] $T_{min.}$ = Mean minimum temperature.

and 286 mm in 1992 and 1993, respectively. Plots with moderate stress received 319 mm and 403 mm, while well-watered plots received 363 and 439 mm, respectively.

At maturity, a 0.4 m^2 area selected randomly from each plot was used to determine the number of spikes per unit area. Fifteen spikes from each plot were randomly sampled for the measurements of spikelets per spike, kernels per spikelet and kernel weight. Spikes were threshed and a random sample of 200 kernels were weighed to determine kernel weight (mg), kernel number per spike and kernels per spikelet. The plots were harvested with a small-plot combine at maturity in mid-September of both years. An area of 3.4 m^2 in 1992 and 4.6 m^2 in 1993 was harvested from the center of each plot for measurements of grain yield.

TABLE 3

Mean square values and significance levels for the yield of twelve spring wheat genotypes grown at three irrigation levels in 1992 and 1993

		Year	
Source	df	1992 (x1000)	1993 (x1000)
Block (B)	5	4135	10433
Genotypes (G)	11	6760*	15158*
Error a (GxB)	55	213	803
Irrigation (I)	2	80449 NV	48961 NV
Error b (IxB)	10	790	2208
I x G	22	821*	786*
Error c (IxGxB)	110	114	335
Total	215		

* Significant at P=0.01

NV Tests are not valid because treatments can not be randomized.

Environmental stress intensity was calculated as 1-(mean yield of all genotypes under drought/mean yield of all genotypes under well-watered conditions). Analyses of variance were performed on the grain yield and yield component data within years using a design similar to the split-block design described by Hanks *et al.* (1980) with cultivars as horizontal strips and irrigation levels as vertical strips. Fisher's protected LSD at the 5% probability level was calculated separately for each irrigation level as well as collectively for genotype x irrigation interactions.

Results

The 1992 growing season was substantially drier than normal and certainly drier than the summer of 1993 (Table 2). Weather conditions were markedly different from May to August in 1992 and 1993 growing seasons. Total precipitation for the period was 40 mm in 1992 and 179 mm in 1993. Mean maximum temperature was 27.5°C in 1992 and 23.3°C in 1993. There was a greater potential for water and heat stress in 1992 than in 1993.

Differences among genotypes and genotype x irrigation interactions for grain yield were highly significant in 1992 and 1993 (Table 3). The moisture stress treatments reduced grain yields in both years (Table 4). The 1992 yields for all genotypes at each irrigation level were lower than the corresponding 1993 yields. All genotypes exhibited differences in mean grain yield across the three moisture levels (Table 4). In 1992, genotypes IDO 367, and IDO 369 produced the highest yields in the severe stress environment, and Chris, Vandal, WPB 926 and Serra produced the lower mean yields. In 1993, WPB 926, IDO 367, Yecora Rojo and Pondera produced the highest yields under the severe stress environment and Chris, Bannock, Klasic

TABLE 4

Yield response of twelve spring wheat genotypes grown under different irrigation levels in 1992 and 1993

	1992			1993		
	Irrigation level[1]					
Genotypes	1	2	3	1	2	3
	kg•ha^{-1}					
Amidon	4409	3521	2408	6428	5670	5132
Bannock	3875	3296	2391	5476	5318	4813
Chris	2285	2133	1848	3896	3613	3088
Rick	4689	3541	2687	7073	6518	5136
IDO 367	5204	4520	3137	7851	7409	5915
Pondera	5021	3650	2503	6880	6906	5643
IDO 369	5153	3973	3023	7112	6437	5099
Klasic	5725	4378	2467	6850	6589	4849
Serra	5048	3967	2372	8020	6943	4998
WPB 926	4254	3398	2150	6843	6608	5959
Yecora Rojo	5406	4175	2594	7098	6912	5648
Vandal	4034	3027	2189	7051	6600	5199
Mean	4592	3632	2481	6715	6294	5123
[2]$LSD_{0.05}$	397	387	531	536	751	1061

[1] Irrigation levels: 1 = well-watered, 2 = moderate stress and 3 = severe stress.
[2] $LSD_{0.05}$ for genotype x irrigation level was 385 for 1992 and 663 for 1993.

TABLE 5

Mean square values and significance levels for yield components of twelve spring wheat genotypes grown at three irrigation levels in 1992

Source	df	Spikes m^{-2}	Spikelets Spike^{-1}	Kernels Spikelet^{-1}	Kernels Spike^{-1}	Kernel wt. (mg)
Block (B)	5	11915	4.4	0.08	97.2	75.1
Genotypes (G)	11	76548*	5.7*	0.72*	237.3*	199.7*
Error a (GxB)	55	2453	0.7	0.15	13.5	11.7
Irrigation (I)	2	660294 NV	22.6 NV	0.01 NV	153.3 NV	102.6 NV
Error b (IxB)	10	5599	0.5	0.2	17.9	16.1
I X G	22	7875*	0.9 NS	0.12 NS	16.6 NS	8.7 NS
Error c (IxGxB)	110	1905	0.7	0.09	10.3	6.8
Total	215					

* Significant at P = 0.01, NS not significant at P = 0.01 or 0.05, NV Tests are not valid because treatments can not be randomized.

TABLE 6

Mean square values and significance levels for yield components of twelve spring wheat genotypes grown at three irrigation levels in 1993

Source	df	Spikes m^{-2}	Spikelets Spike^{-1}	Kernels Spikelet^{-1}	Kernels Spike^{-1}	Kernel wt. (mg)
Block (B)	5	13196	6.3	0.04	12.6	54.5
Genotypes (G)	11	53959*	9.8*	2.02*	643.2*	390.9
Error a (GxB)	55	5382	0.4	0.04	13.4	7.1
Irrigation (I)	2	57101 NV	0.4 NV	0.07 NV	9.6 NV	160.3 NV
Error b (IxB)	10	2799	0.4	0.07	27	20.8
I X G	22	3515 NS	0.2 NS	0.03 NS	8.7 NS	20.3*
Error c (IxGxB)	110	2158	0.2	0.02	7.1	4.8
Total	215					

* Significant at P = 0.01, NS not significant at P = 0.01 or 0.05, NV Tests are not valid because treatments can not be randomized.

and Serra the lowest mean yields. There were substantial year-to-year shifts in genotypic ranks for yields under severe stress conditions, particularly for WPB 926 (11th in 1992 and 1st in 1993), Vandal (10th in 1992 and 5th in 1993) and Klasic (6th in 1992 and 10th in 1993). Under moderate stress conditions, IDO 367 and Yecora Rojo had consistently high yields and were among the four highest yielding genotypes in both years. All other genotypes exhibited considerable variability in their yield ranking under moderate stress in both years of the study.

There were highly significant genotype effects for all yield components studied in 1992 and 1993 (Tables 5 and 6). However, genotype x irrigation interactions were significant only for spikes m^{-2} in 1992 and kernel weight in 1993. Mean numbers of spikes m^{-2} under well-watered and moderate stress conditions were higher in 1992 than in 1993 (Tables 7 and 8). However, mean spikes m^{-2} were higher under severe moisture stress conditions in 1993 than in 1992. The reduction in mean spikes m^{-2} under severe moisture stress conditions were 30 and 10% of the well-watered control in 1992 and 1993, respectively. Moderate stress did not have much effect on mean spikes m^{-2} in both years. Reductions in mean spikes m^{-2} under moderate stress were only 10 and 7% in 1992 and 1993, respectively.

There was a wide range of variability for spikes m^{-2} among genotypes for both years. In 1992, Rick, Chris, Amidon, Yecora Rojo and IDO 367 produced the highest number of spikes m^{-2} under severe water stress, while WPB 926 and Vandal produced the lowest spikes m^{-2}. In 1993, Yecora Rojo, Klasic, Bannock and Amidon produced the highest spokes m^{-2}, while WPB 926 and Vandal produced the lowest spikes m^{-2} under severe water stress.

Irrigation treatments had little effect on mean number of spikelets spike^{-1}, kernel spikelets^{-1}, kernel spike^{-1}, and kernel weight in each year (Table 7 and 8). Mean number of spikelets spike^{-1}, kernel spike^{-1} and kernel weight were higher in the most favorable environmental conditions of 1993.

Discussion

Comparison of yield performance of wheat genotypes in drought-stressed and more favorable environments is a reasonable starting point in the selection of drought tolerant genotypes (Clarke *et al.*, 1992). The results of this study show that the 1992 yields under all moisture regimes were lower than the 1993 yields. Hot, dry weather conditions in 1992 during the later half of the grain filling period could be a reason for these differences. Mean maximum temperatures during the grain filling period in 1992 were 4-6°C higher than those observed in 1993 (Table

TABLE 7

Yield components of twelve spring wheat genotypes as affected by different irrigation levels in 1992

	Spikes m^{-2}			Spikelets Spike^{-1}			Kernels Spikelet^{-1}			Kernels Spike^{-1}			Kernel wt. (mg)		
	Irrigation level[1]														
Genotype	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Amidon	647	585	475	14.7	13.7	13.2	2	2	1.8	33	30	25	29	30	29
Bannock	593	533	445	15.2	15.2	13.8	2	2	2	29	29	26	37	33	32
Chris	697	655	501	15.7	15.7	13.8	2	1.8	2	24	25	26	27	26	26
Rick	659	613	509	14.3	13.7	13.2	2	2.2	2.2	33	31	30	30	27	26
IDO 367	591	637	454	14.7	14.7	14	2	2	2.3	32	34	34	31	29	31
Pondera	684	551	432	15.3	15.5	14.8	2	2	2.2	33	34	33	27	27	26
IDO 369	608	523	446	15.3	15	13.8	2	2	1.8	34	32	28	34	30	32
Klasic	688	648	447	13.3	13.8	13.3	2	2	1.8	29	28	26	37	33	31
Serra	689	533	369	15.5	15.3	14.5	2	2	2	35	31	29	31	32	30
WPB 926	493	446	309	15.2	14.8	14.2	2	2.2	2.3	36	34	32	36	34	34
Yecora Rojo	582	584	455	14	15	14	2	2	2	29	27	27	38	34	35
Vandal	490	401	331	15.5	14.8	13.7	3	2.8	2.5	39	39	36	28	28	26
Mean	618	559	431	14.9	14.8	13.9	2	2.1	2.1	32	31	29	32	30	30
[2]$LSD_{0.05}$	46	53	59	1	1	0.9	NS	0.3	0.4	4	3	4	3	3	4

[1] Irrigation levels: 1 = well watered, 2 = moderate stress, 3 = severe stress, [2] $LSD_{0.05}$ for moisture x genotype interaction for spikes m^{-2} was 50
NS not significant at P = 0.05.

TABLE 8

Yield components of twelve spring wheat genotypes as affected by different irrigation levels in 1993

	Spikes m^{-2}			Spikelets $Spike^{-1}$			Kernels $Spikelet^{-1}$			Kernels $Spike^{-1}$			Kernel wt. (mg)		
	Irrigation level[1]														
Genotype	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Amidon	562	517	560	15.4	15.9	15.8	2	2.2	2	33	35	31	37	37	37
Bannock	582	593	568	15.8	15.9	16.2	2	1.8	1.8	29	29	29	44	44	43
Chris	615	617	543	17.3	16.9	17.1	2	1.8	1.7	32	30	29	34	33	34
Rick	572	563	494	14.8	15.2	15.2	3	2.4	2.4	37	36	36	43	42	40
IDO 367	536	483	453	15.6	15.7	15.7	3	2.5	2.6	40	39	41	42	42	41
Pondera	542	501	545	17.4	17.3	17.3	3	2.4	2.3	44	42	40	37	38	37
IDO 369	555	500	456	16.8	16.8	17.2	2	2.4	2.2	40	39	38	43	42	40
Klasic	617	596	569	15.6	15.6	15.6	2	1.7	1.8	27	26	27	50	50	43
Serra	547	492	448	16.7	16.5	16.4	2	2.2	2.1	37	36	35	45	44	36
WPB 926	442	414	406	16.7	16.6	17	2	2.3	2.4	39	38	40	48	49	44
Yecora Rojo	618	568	569	16.2	16.8	16.8	2	1.7	1.8	30	29	31	49	50	43
Vandal	527	445	438	17.1	17.2	17	3	2.8	2.8	46	48	47	36	37	36
Mean	560	524	504	16.3	16.4	16.4	2	2.2	2.2	36	36	35	42	42	40
[2]$LSD_{0.05}$	64	65	68	0.6	0.7	0.4	0	0.2	0.2	4	4	3	2	3	4

[1] Irrigation levels: 1 = well watered; 2 = moderate stress; 3 = severe stress. [2] $LSD_{0.05}$ for moisture x genotype interaction for kernel weight was 3.

2). Sofield *et al.* (1977) reported reductions in wheat grain yields with increased temperatures during grain filling periods. They attributed this reduction to the effect of high temperature on the duration of grain-fill. The genotype ranking for grain yield under moisture stress showed substantial year-to-year shifts between 1992 and 1993. In the severe environment of 1992, medium-tall wheat genotypes generally produced the highest yields, whereas in the favorable environment of 1993 short-medium and medium-tall genotypes had similar yields. Plants were subjected to a more severe water stress in 1992 than in 1993. Environmental stress intensity for the severe stress treatment in 1993 was about the same as that for the moderate stress level in 1992 (0.21 for I2 in 1992 and 0.24 for I3 in 1993). The results of this study are consistent with those of Laing and Fisher (1979) who found that semi-dwarf wheat lines selected under optimum moisture conditions yielded well under moderate stress.

Drought can reduce grain yield through its influence upon one or more yield components. Moisture stress during the period from tillering through anthesis in 1992 reduced number of spikes up to 30%. The number of spikes m^{-2} was determined during the period from late tillering through stem elongation, a process which should have allowed a valid estimation of the effect of stress on this component. However, in 1993, as the stress period was interrupted by frequent rains, plants did not experience sufficient stress to show significant genotype x irrigation interactions for this yield component.

Water deficit during reproductive growth affects most aspects of kernel growth. Since kernel development was determined outside the stress periods, water stress should not have affected kernel number and kernel weight. However, there is a significant genotype x irrigation interaction for mean kernel weight in 1993. Large variability in mean kernel weight to grain weight across irrigation levels in some genotypes due to lodging or the differential contribution of parenthesis assimilates, stored in stem, may be the reason for this significant interaction.

Highly significant genotype effects for all the yield components could be due to differences in the genotypic potential of these components (Bruckner and Frohberg, 1987). The timing of water stress in relation to genotypic maturity and drought susceptibility could also be accountable for the differences occurred in yield components. The results of this study are consistent with those of Bansal and Sinha (1991), Ehdaie *et al.* (1988), Fischer and Maurer (1978) and Mogensen (1985).

Genotypic response to drought for the yield of 1992 appears to be determined by the differences in spikes m^{-2}. Therefore, a tendency for high plasticity for spikes per unit area could be used to select wheat genotypes for improved drought tolerance at conditions of water stress.

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