Genotype-Environment Interactions in Two Cultivars of Spring Wheat[1]

A. D. Day
Department of Plant Sciences
University of Arizona

R. S. Swingle
Department of Animal Sciences
University of Arizona

W. G. Dewey
Department of Plant Sciences
Utah State University

Abstract

A 3-year field experiment (1976 through 1978) was conducted at Yuma, Arizona and Logan, Utah to determine the effects of environment on growth and grain yield of Siete Cerros and Cajeme 71 wheat *(Triticum aestivum L.)* geotypes grown under irrigation. The growing seasons were December to June in Arizona and April to August in Utah.

Siete Cerros produced taller plants and higher straw and grain yields than did Cajeme 71; however, Cajeme 71 required fewer days from planting to flowering and flowering to maturity, at each location each year. Cultivars grown in Arizona produced taller plants, more straw, and more grain than the same cultivars grown in Utah; however, both cultivars required more days from planting to flowering and fewer days from flowering to maturity in Arizona than they did in Utah. Some plant growth characteristics of both cultivars varied from year to year but the variations were not consistent enough to suggest genetic differences between cultivars, except for plant height.

This foregoing research suggested that a 3-year period was not long enough to indicate genotype-environment interactions; however, it may be safe to conclude that spring wheat cultivars may quickly adapt into high yielding winter annuals in irrigated, semiarid regions like Arizona. *Additional Index Words.* Genotypes, Varieties, Plant Adaptation, Plant Culture.

Introduction

Breeding techniques and improved cultural practices have resulted in the production of wheat *(Triticum aestivum L.)* cultivars with high grain yield potential. The high yielding capacity of a given cultivar may not be realized unless it is grown under optimum environmental conditions. This indicates that problems of genetic response to environmental factors are of major importance in developing cropping programs for a given location. With detailed knowledge of genotype-environment interactions as a guide, plant breeders can select wheat genotypes with desirable agronomic qualities and wide adaptation.

Literature Review

Willey and Holliday (1971) demonstrated that yield potential depends on the environment and its interaction with the developing plant. Stoskopf et al. (1974) observed that the response of spring wheat in southern Ontario, Canada appeared to be limited by environment, so that superior cultivars did not express their full yielding potential. Detailed discussion on how environment affects wheat growth and development was presented by Evans et al. (1976). Thorne et al. (1968) reported that the climate of a region determines cultivar adaptation and plant response through the normal growth states from planting to maturity.

[1]Contributions from the Arizona Agricultural Experiment Station, University of Arizona, Tucson, Arizona 85721 and the Utah Agricultural Experiment Station, Utah State University, Logan, Utah 84321. Approved for publication as Arizona Agricultural Experiment Station Research Contribution, No. 3010. Received July 25, 1980. The authors gratefully acknowledge the assistance of Mengste-Ab Solomon, Research Assistant, with portions of the research involving this contribution.

Grain yield of wheat is determined by the number of heads per unit area, number of seeds per head, and seed weight. Investigations have shown that these yield components are affected by variations in environmental factors. Power and Alessi (1978) stated that grain production from many semi-dwarf wheat cultivars was severely restricted when subjected to water-stress during grain filling. For this reason semi-dwarf spring wheat cultivars are commonly grown in sub-humid regions rather than in semiarid regions (North Dakota Crop and Livestock Reporting Service, 1974). Day and Thompson (1975) reported that barley grain yields were reduced by moisture-stress. They found that moisture-stress at flowering decreased seeds per head and moisture-stress at the dough stage decreased seed weight.

The effects of temperature and light on growth and yield of wheat has also been studied. According to Sojka et al. (1975) soil temperature and aeration affect plant response, indirectly, by influencing nutrient availability and ionic species present in the soil and, directly, by influencing metabolic rates and pathways within the plant. Boatwright et al. (1976) reported that low temperatures restricted nutrient translocation through the crown node of wheat and that the restriction reduced top growth. Fisher and Maurer (1976) observed that the growth of spring wheat was retarded by cooling and hastened by heating; however, total dry weight at maturity and grain yield were reduced by increased temperatures at any stage of growth, except during the period from seeding to floral initiation. Wheat is very sensitive to temperature changes during ear development. Warrington et al. (1977) noted that plants subjected to low temperatures at heading had longer culms, larger flag leaves, and more potentially fertile florets in each spikelet than did wheat subjected to high temperatures, and that the number of florets which produced harvestable grains and the weight of the grains at maturity were reduced by high temperatures at the grain filling stage. Spiertz (1974) reported that increases in temperature within the range of 15 to 25C increased the growth rate of wheat kernels; however, the duration of the post-floral development stage was shortened, resulting in lower grain yields.

Interactions between temperature and light influence plant growth and development. Friend (1965) noticed that the number of spikelets on a differentiating inflorescence and ear of wheat at anthesis was highest at high light intensities and low temperatures. He attributed the duration and rates of apical elongation, morphological development of the ear, and spikelet formation to the differential effects of temperatures and light intensity. Friend et al. (1963) found that under continuous illumination floral initiation of wheat was earlier with each increase in light intensity from 200 to 2000 ft-c, and with each increase in temperature between 10 and 30C after floral initiation. The growth of the apical meristem was most rapid at 30C and 2500 ft-c, resulting in early heading and anthesis. Faris and Guitard (1969) reported that highest spring barley yields were obtained when plants were grown at low temperatures and short day lengths during the vegetative stage and at low temperatures and continuous illumination during the period from flowering to maturity.

The objective of the research reported in this paper was to investigate the effects of environment on the growth and grain yield of two wheat cultivars grown under irrigation in the western United States.

Materials and Methods

An experiment to study the effects of environment on growth, forage yield, and grain yield of spring wheat was conducted at Yuma, Arizona and Logan, Utah for 3 years (1976 through 1978). Two cultivars ('Siete Cerros' and 'Cajeme 71') were grown as winter annuals in Arizona and as annuals in Utah. The experimental design was a Randomized Complete Block with four replications. Replications were nested within locations and years. The harvested plot size after discarding guard rows was $0.37m^2$. The cultivars were planted in December and harvested in June in Arizona and were planted in April and harvested in August in Utah. The wheat was planted at the rate of 112 kg/ha and grown under irrigation at each location. Nitrogen fertilizer was applied before planting at rates of 56 kg/ha in Arizona and 168 kg/ha in Utah. The grain was harvested at maturity with a hand sickle at each location.

The following data were recorded for each cultivar at each location: (1) days from planting to flowering, (2) days from flowering to maturity, (3) plant height, (4) heads per unit area, (5) seeds per head, (6) seed weight, (7) grain yield, (8) grain bushel weight, (9) seed color score, (10) straw yield, (11) grain/straw ratio, (12) lodging. All data were analyzed using the standard analysis of variance. Means were compared using the Student-Newman-Keuls' (SNK) Test as outlined by Little and Hills (1975).

Results and Discussion

The average number of days from planting to flowering was 44 days earlier for Siete Cerros and Cajeme 71 in Utah than in Arizona; however, the period between flowering and maturity for the two cultivars averaged 9 days shorter in Arizona than it did in Utah. In Arizona, as the number of days from

Table 1. Average days from planting to flowering, flowering to maturity, plant height, straw yield, grain/straw ratio, and lodging for two wheat cultivars grown in Arizona and Utah for a three-year period (1976–78).

Treatments			Planting to flowering	Flowering to maturity	Plant height	Straw yield/m²	Grain/straw ratio	Lodging
Location	Year	Genotype						
			(day)	(day)	(cm)	(g)	(ratio)	(%)
Arizona	1976	Siete Cerros	104 a+	41 a	90 a	2134 a	0.70 b	0 a
		Cajeme-71	103 b	39 b	69 b	1275 b	0.98 a	0 a
	1977	Siete Cerros	116 a	40 a	93 a	1400 a	0.66 b	0 a
		Cajeme-71	111 b	39 a	80 b	1115 b	0.83 a	0 a
	1978	Siete Cerros	100 a	52 a	101 a	1308 a	0.43 a	9 b
		Cajeme-71	97 b	46 b	83 b	1291 a	0.56 a	24 a
Utah	1976	Siete Cerros	59 a	57 a	70 a	702 a	0.95 a	4 a
		Cajeme-71	57 b	52 b	60 b	405 b	0.88 a	9 a
	1977	Siete Cerros	63 b	55 a	78 a	455 a	1.32 a	0 a
		Cajeme-71	64 a	47 b	65 b	398 a	1.30 a	0 a
	1978	Siete Cerros	64 a	52 a	79 a	382 a	1.15 a	0 a
		Cajeme-71	62 b	46 b	58 b	479 a	1.18 a	0 a
Significance of differences:								
Between locations (L)			**	**	**	**	**	*
Between years (Y)			ns	ns	**	ns	ns	ns
Between genotypes (G)			ns	ns	*	ns	ns	ns
L x Y			ns	ns	ns	ns	ns	ns
L x G			ns	ns	ns	ns	ns	ns
Y x G			ns	ns	ns	ns	ns	ns
L x Y x G			**	**	*	ns	ns	**

* ** Significant at 5% and 1% levels, respectively; ns = not significant at 5%.
+ Means followed by the same letter, within years, for the same location, are not different at the 5% level of significance, using the Student-Newman-Keuls' Test.

planting to maturity increased, the number of days from flowering to maturity decreased; however, in Utah the opposite relationship was observed in the 3 years of the study. The cultivars did not differ in number of days from planting to flowering and flowering to maturity in both Arizona and Utah. With one exception, when two cultivars were compared within years in Utah, the periods from planting to flowering and flowering to maturity were shorter for Cajeme 71 than they were for Siete Cerros in all 3 years. The same relationships were also observed in Arizona (Table 1).

Wheat cultivars grown in Arizona were 23% taller than the same cultivars grown in Utah. Both cultivars showed an increase in plant height from year to year regardless of location. Average plant heights were 72, 79, and 83 cm in 1976, 1977, and 1978, respectively. Siete Cerros produced taller plants than Cajeme 71 at both locations throughout the experimental period. This cultivar was 18 cm taller in Arizona and 12 cm taller in Utah than Cajeme 71 (Table 1).

Straw yields from wheat genotypes grown in Arizona were three times the straw yields from the same genotypes grown in Utah. There were no significant differences in straw yields due to cultivars, years, and their interactions; however, in 1976 and 1977 in Arizona and in 1976 in Utah, Siete Cerros produced more straw than did Cajeme 71 (Table 1).

The grain-to-straw ratios, in most instances, showed an inverse relationship to straw yields. Cultivars had higher grain/straw ratios in Utah than in Arizona because of the lower straw yields in Utah. Lodging was not a problem except in Arizona in 1978 and in that year Cajeme 71 lodged more severely than did Siete Cerros (Table 1).

Analysis of variance confirmed that wheat cultivars grown in Arizona produced more heads per unit area, more seeds per head, heavier seeds, higher grain yields, higher grain-volume weights, and lighter colored seeds than were obtained from the same cultivars grown in Utah (Table 2). Comparisons of mean yield components and final grain yields for cultivars in Arizona and Utah for each year showed that Cajeme 71 produced more heads per unit area in 1976 and 1977 and heavier seeds in Arizona in 1976 than did Siete Cerros. Similar results were also observed in Utah for number of heads per unit area in 1977 and 1978 and for seed weights in all 3 years. In Arizona, in 1976, Siete Cerros exceeded Cajeme 71 in number of seeds per head and grain yields. In Utah, Siete Cerros was superior to Cajeme 71 in grain yields in 1976 and in number of seeds per head and grain volume-weights throughout the 3-year period.

The two cultivars showed significantly higher vegetative growth and grain yields when grown in Arizona than they did in Utah. The only significant

Table 2. Average heads per unit area, seeds per head, seed weight, seed color score, grain yield, and grain volume-weight for two wheat cultivars grown in Arizona and Utah for a three-year period (1976–78).

Treatments								
Location	Year	Genotype	Heads in²	Seeds per head	Seed weight	Seed color score†	Grain yields in²	Grain volume-weight
			(no.)	(no.)	(g/1000)	(10-40)	(g)	(kg/hl)
Arizona	1976	Siete Cerros	750 b+	44 a	45.4 b	40	1495 a	83 a
		Cajeme-71	813 a	30 b	51.2 a	40	1256 b	84 a
	1977	Siete Cerros	457 b	38 a	52.1 a	40	906 a	78 a
		Cajeme-71	572 a	31 a	51.6 a	40	918 a	78 a
	1978	Siete Cerros	432 a	34 a	39.2 a	40	577 a	81 a
		Cajeme-71	472 a	39 a	39.5 a	40	722 a	81 a
Utah	1976	Siete Cerros	623 a	30 a	36.0 b	20	670 a	77 a
		Cajeme-71	616 a	14 b	40.0 a	20	351 b	74 b
	1977	Siete Cerros	461 b	35 a	37.0 b	20	600 a	83 a
		Cajeme-71	541 a	21 b	45.0 a	20	512 a	81 b
	1978	Siete Cerros	216 b	49 a	41.0 b	20	439 a	78 a
		Cajeme-71	426 a	29 b	47.0 a	20	565 a	77 b
Significance of differences:								
Between locations (L)			* *	* *	* *		* *	* *
Between years (Y)			*	ns	ns		ns	ns
Between genotypes (G)			ns	ns	ns		ns	ns
L x Y			ns	ns	ns		* *	*
L x G			ns	ns	ns		ns	ns
Y x G			ns	ns	ns		*	ns
L x Y x G			* *	* *	* *		ns	*

* * * Significant at 5% and 1% levels, respectively; ns = not significant at 5%.
\+ Means followed by the same letter, within years, for the same location, are not different at the 5% level of significance, using the Student-Newman-Keuls' Test.
† Visual observation: 10 = very dark and 40 = very bright.

difference between cultivars, which was not affected by environment was plant height. The rest of the parameters measured indicated that there were no conclusive genetic differences between cultivars. The environmental conditions in Utah reduced the growth and grain yield of both cultivars. Similar observations were made by Stoskopf et al. (1974) in southern Canada. In Arizona, the cultivars were subjected to over 90 days of cool temperature (13–15C) accompanied by 269–516 Langlays/day of solar radiation from planting to flowering. Temperatures and light intensities were more favorable in Arizona than they were in Utah for providing the cultivars sufficient time for maximum vegetative growth, morphological development of ears, and spikelet formation (Friend, 1965). The foregoing environmental factors in Arizona resulted in taller plants, larger heads, and more fertile spikelets (Warrington et al. 1977). In Utah, the temperatures increased from approximately 13C at planting in April to 20C at flowering in late June. The sunlight hours also were increasing during this period and they reached a maximum at flowering. High temperatures and light intensities in Utah, due to long hours of sunshine, reduced the number of days from planting to flowering, plant height, head length, and seeds/head (Guitard, 1960). The number of days between flowering and maturity were shorter in Arizona than they were in Utah, probably due to higher temperatures in Arizona during this period (Spiertz, 1974). In Arizona, both genotypes produced lighter seeds than they did when grown in Utah. The temperature range between flowering and maturity in Arizona was 15–29C. High temperatures shortened the grain filling stage and resulted in lower seed weights in Arizona than those obtained in Utah (Darwinkel et al. 1977).

Straw yields in 1976 and 1977 in Arizona and in 1976 in Utah and grain yields in 1976 in Arizona showed that Siete Cerros was superior to Cajeme 71; however, the foregoing differences in time may be due to chance alone and do not suggest that a 3-year period is long enough to conclude the presence of genotype-environment interaction between cultivars.

The increased vegetative growth and higher grain yields of the cultivars in Arizona during the winter than were observed in Utah during the spring suggested that spring wheat cultivars may readily adapt themselves into high yielding winter annuals under irrigated, semiarid conditions like those found in Arizona.

References

Boatwright, G. O., Hayden Ferguson, and J. R. Sims. 1976. Soil temperature around the crown node influences early growth, nutrient uptake, and nutrient translocation of spring wheat. *Agronomy Journal* 68:227–231.

Darwinkel, A., B. A. Ten Hag, and J. Kuizenza. 1977. Effect of sowing date and seed rate on crop development and grain production of winter wheat. *Netherland Journal of Agriculture Science* 25:83–94.

Day, A. D., and R. K. Thompson, 1975. Effects of soil-moisture regimes on the growth of barley. *Agronomy Journal* 67:430–433.

Evans, L. T., I. F. Wardlaw, and R. A. Fischer, 1976. Wheat, p. 101–149. *In.* L. T. Evans (ed.) *Crop Physiology: Some Case Histories.* Cambridge University Press, New York, N. Y.

Faris, D. G., and A. A. Guitard. 1969. Yield and primary culm yield components of two spring barley cultivars as influenced by temperature, day length, and growth stage. *Canadian Journal of Plant Science* 49: 701–713.

Fisher, R. A., and R. Maurer. 1976. Crop temperature modification and yield potential in a dwarf spring wheat. *Crop Science* 16:855–859.

Friend, D. J. C. 1965. Ear length and spikelet number of wheat grown at different temperatures and light intensities. *Canadian Journal of Botany* 43:345–353.

Friend, D. J. C., J. E. Fisher, and V. A. Helson. 1963. The effect of light intensity and temperature on floral initiation and inflorescence development of Marquis wheat. *Canadian Journal of Botany* 43:1663–1673.

Guitard, A. A. 1960. The influence of variety, temperature and stage of growth on the response of spring barley to photoperiod. *Canadian Journal of Plant Sciences* 40:65–80.

Little, T. M., and F. J. Hills. 1975. *Statistical Methods in Agricultural Research,* University of California, Davis, California.

North Dakota Crop and Livestock Reporting Service. 1974. North Dakota wheat varieties—1973. *North Dakota Agricultural Experiment Station Bulletin 31.* Fargo, North Dakota.

Power, J. F., and J. Alessi. 1978. Tiller development and yield of standard and semidwarf spring wheat varieties as affected by nitrogen fertilizer. *Journal of Agricultural Science, Cambridge* 90:97–108.

Sojka, R. E., L. H. Stolzy, and M. R. Kaufmann. 1975. Wheat growth related to rhizosphere temperature and oxygen levels. *Agronomy Journal* 67:591–596.

Spiertz, J. H. J. 1974. Grain growth and distribution of dry matter in the wheat plant as infuenced by temperature, light, energy and ear size. *Netherland Journal of Agriculture Science* 22:207–220.

Stoskopf, N. C., R. K. Nathaniel, and E. Reinbergs. 1974. Comparison of spring wheat and barley with winter wheat: yield components in Ontario. *Agronomy Journal* 66:747–750.

Thorne, Gilman, Margaret A. Ford, and D. J. Watson. 1968. Growth, development, and yield of spring wheat in artifical climates. *Annals of Botany* 32:425–446.

Warrington, I. J., R. I. Dunstone, and L. M. Green. 1977 Temperature effects at three development stages on yield of the wheat ear. *Australian Journal of Agriculture Research* 28:11–27.

Willey. R. W. and R. Holliday. 1971. Plant population and shading studies in barley. *Journal of Agricultural Science* 77:455–462.