Crop Yield Variability in Irrigated Wheat

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Abstract

Optimum design and management of irrigated wheat production is limited by the scarcity of information available on yield variability. The purpose of this study was to evaluate the spatial variability in soil-water parameters and the effects compared to grain yield response under level-basin irrigation. Three levels of seasonal irrigation water and two border lengths were used. Grain yields were found to increase significantly with the amount of water applied and soil water depletion (estimate of crop evapotranspiration), although yield variability was greater with reduced or deficit irrigations. Variations in soil water content were responsible for about 22% of the variability in grain yield, indicating that other soil and crop-related factors had a significant influence on production. Spatial dependence was exhibited over a greater distance at the wetter compared with the drier irrigation regimes.

Introduction

Over time, research aimed at a better understanding of the relationship between crop yield and water has been guided by various thoughts on what constitutes a desirable level of water use and yield. Letey (1985), in a review of irrigation uniformity as related to optimum crop production, concluded that procedures for obtaining quantitative data on infiltrated water on a field scale, which can appropriately be combined with crop-water production functions to quantify and establish optimum irrigation management, have not been adequately developed.

The objectives of this paper are (1) to describe the variability of crop production under an efficient level-basin irrigation system and (2) to determine the effects of soil water variables on yield for different irrigation levels and border lengths when wheat is grown on a field scale.

Methods and Materials

Details on experimental design, water quality, cultural practices, soils, irrigation scheduling procedures, water application amounts, and soil water content measurements are presented in the preceding report (Bucks and Hunsaker, 1986). Treatments consisted of three irrigation levels and two border lengths. The three seasonal irrigation treatments were designed Wet, Medium, and Dry and designed to replace 100, 75, and 50% of the expected evapotranspiration (ET), respectively. Border lengths were 251 and 190 m (825 and 625 ft), called long and short basins; and all borders were 14 m (46 ft) wide.

Grain yield samples were machine harvested between June 10 and June 20 from three lengthwise strips, 1.27 m (50 in) wide in each border. The row of access tubes (spaced at 15 m) for soil water content measurements within each border served as the center line of the middle strip. The two outer paths were centered 3 m (10 ft) from the row of access tubes. The sampling scheme was such that each access tube site (15 and 11 for long and short borders, respectively) was located in approximately the center of the harvested area with an average harvest area of 8 m^2 (88 ft^2), while the remaining harvest areas were a known distance from each access tube.

RESULTS AND DISCUSSION

Grain Yield and Quality

Table 1 shows the mean grain yields, water use efficiencies, and standard weights of the 12 borders grouped by irrigation treatment and border length. Of particular interest is the indication that under relatively similar seasonal water application uniformity, yield variation in terms of CV was greater for the drier irrigation treatments. This suggests that the interaction between variable water application and variations in soil and crop factors may be more important under reduced water use.

Where the crop was maintained under low soil moisture conditions, as in the Dry treatment, variations in such factors as the water holding capacity of the soil, soil texture, and crop rooting depth were probably more pronounced in influencing yield differences.

For each border, the water use efficiencies (WUE) and associated CV's are also presented in Table 1. Water use efficiency, expressed as yield per quantity of water (Doorenbos and Kassam, 1979), is shown for two water variables, gross water applied (WUE_A) and soil water depletion (WUE_S) in Table 1. Gross water applied (GWA) included water received from irrigation and rainfall, plus the amount of water use from moisture stored in the soil at the time of planting.

WUE_A was significantly affected by irrigation treatments at the 5% level. However, WUES was statistically different for only the Dry irrigation treatment. No border length effects were present in either case.

Lastly, the average standard weights of the Wet, Medium, and Dry irrigation treatments, corrected to 10% moisture, were not significantly different. Bushel weight variability was low for all cases (CV < 2.7%). Additionally, the protein content of the grain averaged about 17.5%; nitrogen was 2.8%; and yellowberry was <0.05% for each irrigation treatment, with no significant statistical differences. Indications were that the reduced irrigation water levels did not lower crop quality.

Statistical Analysis of Grain Yield

Relationships between grain yield (Y), seasonal irrigation water applied (Q), seasonal gross water applied (GWA), cumulative seasonal soil water depletion (SWD), and soil water contents for 1 day prior to irrigation, 3 days after irrigation, and seasonal average (θp, θa, θ, respectively) were obtained by calculating the linear correlation coefficients (r) between each pair of variables.

The results, summarized in Table 2, are for the 52 observations in each irrigation treatment. Indications were that soil water content variations influenced grain yield to about the same extent in all three irrigation treatments. The correlation coefficients (r) between Y and 0 were 0.50, 0.43, and 0.46 in the Wet, Medium, and Dry irrigation treatments, respectively, implying that about 25, 18.5, and 21% (R^2 values) of the variability in grain yield was explained by soil-water content differences.

Stern and Bresler (1983) found correlation coefficients of 0.62 and 0.59 between corn yield and seasonal average soil water content in two fields under sprinkler irrigation. In another study, Bresler et al. (1981) showed that the variability in soil water properties generally explained 40% or less of the variability in fresh yields of peanuts irrigated by sprinklers.

Our results suggest that a smaller proportion of the yield variability can typically be attributed to soil water parameters under surface irrigation than for other irrigation methods.

The negative correlation between Q and Y in the Wet treatment indicates that increased water application amounts generally did not increase crop yield in the Wet treatment. In the Medium treatment, the high positive correlation found between yield and seasonal irrigation water applied indicated that yield variations were affected by water applications, as well as soil water content differences at this water management level.

Y and Q were not highly correlated in the Dry treatment, suggesting that other factors were fairly dominant in determining grain yield variations at low water use. The higher correlation between Y and GWA, (r = 0.46) indicated that the antecedent soil moisture variations were probably responsible for a fairly large part of the variation in yield in the Dry treatment.

Spatial Dependency of Grain Yield

The spatial dependence analysis for Y followed the same procedures used by Bucks and Hunsaker (1986) for Q and SWD. The semivariograms were calculated for lags (distances in x and y directions) of 6.0 m (20 ft) up to 33 lag intervals or 198 m (650 ft). The minimum number of pairs used to evaluate a point on the semivariogram was taken as 200.

Figure 1 shows the plotted spatial dependence obtained for the three irrigation treatments. In the case of the Wet treatment, grain yields were correlated at least up to a range of about 170 m (560 ft). In contrast, the semivariogram plotted for the Dry treatment implied that grain yields were correlated over a much shorter distance, where a constant variance was attained at a lag distance of perhaps 60 m (200 ft). The range of spatial dependency of Y in the Medium irrigation treatment appears to be at a distance of about 105 m (350 ft), somewhere between the other two treatments.

Yield Production Functions

Crop yield is often related to water use and is summarized in a water-yield production function. One that is widely accepted is based on evapotranspiration (estimated by SWD) as a yield index. Figure 2 shows the yield (Y) related to soil water depletion (SWD) from all 156 subplot observations. The results of linear regression indicate a fairly good fit ($Y = -2414 + 13.1$ SWD, $R^2 = 0.81$), and Y yield can be assumed to be linearly related to SWD.

The observations from the three different irrigation treatments are differentiated. Of particular interest, is the rather large number of observations from the Medium treatment that fall above the regression line, reflecting the relatively high water use efficiency which occurred in that treatment, as reported earlier.

There is also a more apparent linear trend in the data of the Medium treatment data than in either the Wet or Dry treatment data which appear to be more scattered. This suggests that in the case of the Wet treatment, most of the observations are in the realm of maximum production, and the crop has reached its potential in terms of evapotranspiration (ET). On the other hand, in the Dry treatment where the crop was under fairly severe water stress throughout the season, Y was governed to a larger extent by other factors in addition to water.

REFERENCES

1. Bresler, E., S. Dasbert, D. Russod, and G. Dagan. 1981. Spatial variability of crop yield as a stochastic soil process. Soil Sci. Soc. Am. J. 45(3):600-605.

2. Bucks, D. A. and D. J. Hunsaker. 1986. Water use variability in irrigated wheat. Forage and Grain, Cooperative Extension Service, Agricultural Experiment Station Report Series P-66, The University of Arizona, Tucson, AZ 85721.

3. Doorenbos, J. and A. H. Kassam. 1979. Yield response to water. Food and Agriculture Organization, United Nations, Rome, Italy, Irrigation and Drainage Paper No. 33, 193 p.

4. Letey, J. 1985. Irrigation uniformity as related to optimum crop production - additional research is needed. Irrigation Science 6(4): 253-263.

5. Stern, J. and E. Bresler. 1983. Nonuniform sprinkler irrigation and crop yield. Irrigation Science 4(1):17-29.

Table 1. Irrigation and border length treatment means* and coefficient of variation (CV,%) for Grain Yield (Y), Water Use Efficiency (WUE), and Standard Weight (SW).

Variable	Border Length Treatment	Rep	Irrigation Treatment Means Wet(CV_W)	Medium(CV_M)	Dry(CV_D)	Border Length Means All(CV)
Grain yield, Y(kg/ha)	Long	1	5070(10.7)	3650(13.5)	1420(29.7)	3530[a](21.9)
		2	5510(7.9)	3890(26.6)	1635(42.9)	
	Short	1	5040(12.7)	4600(13.9)	1360(19.5)	3540[a](18.5)
		2	5080(17.2)	3720(14.0)	1420(33.6)	
		All	5175[a](12.1)	3970[b](17.0)	1460[c](31.4)	
Water Use Efficiency, WUE_A (kg/m^3)	Long	1	0.79(12.7)	0.67(13.0)	0.37(32.4)	0.64[a](20.4)
		2	0.87(9.1)	0.71(22.5)	0.43(32.6)	
	Short	1	0.78(11.8)	0.79(15.2)	0.40(18.0)	0.65[a](18.7)
		2	0.78(21.8)	0.74(14.9)	0.43(30.2)	
(Gross Water Applied)		All	0.81[a](13.9)	0.73[b](16.4)	0.41[c](28.3)	
Water Use Efficiency, WUE_S (kg/m^3)	Long	1	0.88(13.6)	0.81(11.2)	0.42(33.3)	0.75[a](20.4)
		2	1.00(8.8)	0.86(22.1)	0.51(33.3)	
	Short	1	0.86(7.3)	0.90(13.3)	0.42(18.8)	0.76[a](16.0)
		2	0.94(16.0)	0.94(14.9)	0.51(25.5)	
(Soil Water Depletion)		All	0.92[a](11.4)	0.88[a](15.4)	0.47[b](27.7)	
Bushel Weight, BW(kg/m^3)	Long	1	790(1.5)	810(0.9)	800(1.7)	805[a](1.6)
		2	810(2.7)	810(1.3)	810(1.3)	
	Short	1	810(1.9)	805(1.4)	810(1.1)	805[a](1.4)
		2	815(1.2)	795(1.2)	805(1.3)	
		All	805[a](1.8)	806[a](1.2)	805[a](1.4)	

* Means followed by different letters are significantly different at the 95 percent level of confidence.

Table 2. Correlation coefficients (r) of seasonal irrigation water applied (Q), seasonal gross water applied (GWA), seasonal soil water depletion (SWD), seasonal average soil water contents ($\bar{\theta}$), seasonal average soil water contents for 1 day prior to irrigation (θ_p), and 3 days after irrigation (θ_a), and grain yield (Y) for all subplots within the Wet, Medium, and Dry irrigation treatments (n=52).

Irrigation Treatment	Variable	Q	GWA	SWD	θ_p	θ_a	$\bar{\theta}$
Wet	Y	−0.29*	−0.20	0.23	0.51*	0.52*	0.50*
	Q		0.91*	0.35*	−0.50*	−0.40*	−0.46*
	GWA			0.59*	−0.42*	−0.29*	−0.38*
	SWD				−0.15	−0.09	−0.10
Medium	Y	0.44*	0.49*	0.59*	0.36*	0.49*	0.43*
	Q		0.96*	0.88*	0.17	0.06	−0.06
	GWA			0.90*	−0.06	0.16	0.05
	SWD				−0.08	0.17	0.06
Dry	Y	0.25	0.46*	0.36*	0.49*	0.43*	0.46*
	Q		0.90*	0.78*	0.19	0.53*	0.22
	GWA			0.84*	0.34*	0.61*	0.39*
	SWD				0.06	0.43*	0.11

* Significant correlation at $P < 0.05$

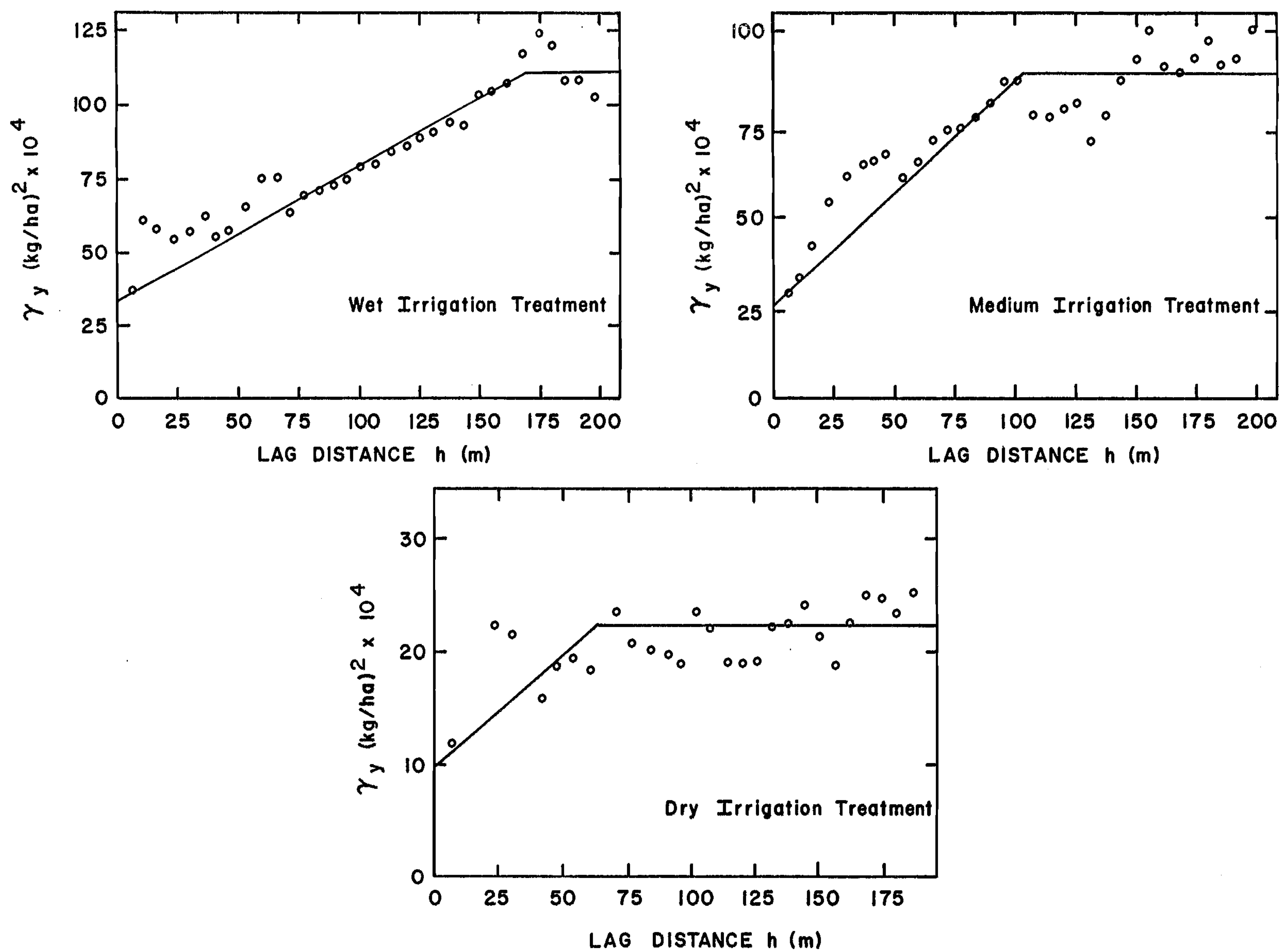

Figure 1. Spatial dependence of grain yield (Y) shown as semivariance versus lag distance for Wet, Medium, and Dry irrigation treatments.

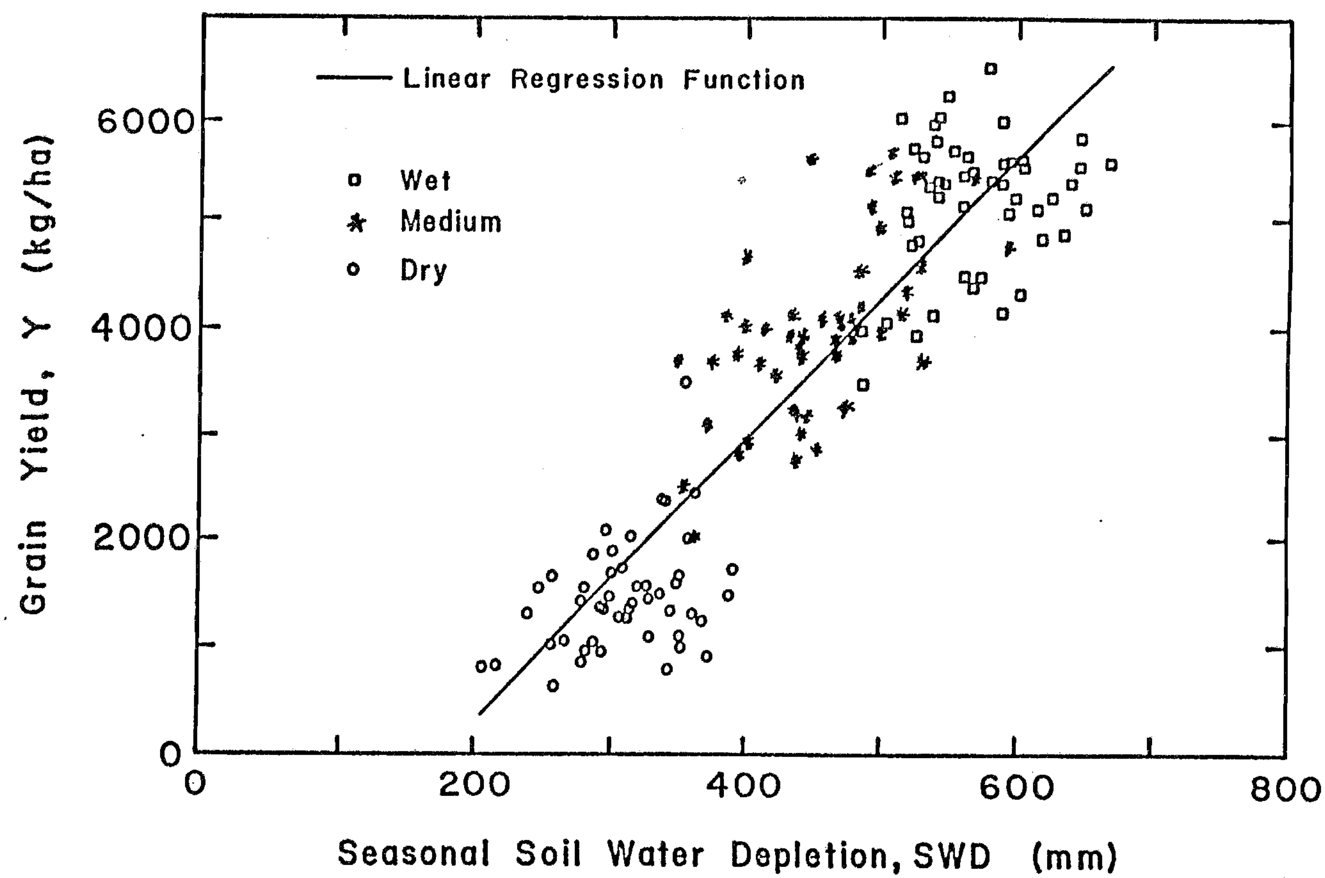

Fig. 2. Crop yield with seasonal soil water depletion and linear regression function derived from all samples (n = 156).