Water Use Variability in Irrigated Wheat

Dale Bucks and Douglas Hunsaker

ABSTRACT

An understanding of the expected variability in irrigated crops under field size, surface irrigation conditions is needed to improve irrigation designs and water management scheduling procedures. The objective of this work is to describe water application uniformity under an efficient level-basin irrigation system and the variability of water use (soil water depletion) for three levels of irrigation and two basin lengths for a wheat crop. High water distribution uniformities with a level-basin irrigation system did not necessarily result in maximum irrigation application efficiencies where variations in soil-water factors were greater on a drier irrigation treatment than medium or wet treatment. Variations in soil water depletion were found for all irrigation treatments with the largest variation (13%) occurring for the drier treatment. Spatial dependence was exhibited for soil water depletion but not necessarily for seasonal irrigation water applications.

INTRODUCTION

Spatial variability in irrigated agriculture has been recognized for many years. Limited water supplies, expensive energy and increasing capital costs are forcing producers to manage resources more efficiently. Therefore, the effects and limitations imposed by variations in irrigation system behavior and soil parameters become more significant. Potentially, an understanding of the expected variability in irrigated crops can be used, not only to improve irrigation designs, but also to alter irrigation water management practices (e.g., scheduling and operations).

The objective of this report is to describe the uniformity of water applied under an efficient level-basin irrigation system and the variability of water use (soil water depletion) under different irrigation levels and basin lengths for a wheat crop. Soil variations will not be described in this paper, and yield variability in terms of water use and irrigation management are presented in a companion paper (Hunsaker and Bucks, 1986).

MATERIALS AND METHODS

The study was conducted on a variable Mohall sandy loam to sandy clay loam soil (fine-loamy, mixed, hyperthermic, Typic Haplargid). The field was 168 by 251 m (552 by 825 ft) located on the Maricopa Agricultural Center, University of Arizona, near Maricopa, Arizona. Durum wheat (Triticum durum cv. Aldura) was planted at a seeding rate of 129 kg/ha (115 lb/ac) on the flat in 12 level borders, 14 m (46 ft) wide on January 3, 1985. The 12 borders were separated into six differential treatments replicated twice, in a randomized block design.

Treatments consisted of three irrigation levels and two border lengths. The three seasonal irrigation treatments were designated Wet, Medium, and Dry and designed to replace 100, 75, and 50% of the expected evapotranspiration (ET), respectively. Irrigation scheduling was based on historical (Erie et al., 1982) estimates of evapotranspiration and measured soil moisture depletion, as well as adjusted for the planting date and climatic conditions. Border lengths, designated long and short, were 251 and 190 m (825 and 625 ft), respectively. A total of 180 kg/ha (160 lb/ac) of pre- and post- plant nitrogen was applied on all treatments.

The water delivery rate was measured during each irrigation by a broad-crested weir flume located in the supply ditch which was connected to an automatic water level recorder (Bos et al., 1984). The water, supplied from two farm wells, had an electrical conductivity of about 1.1 dS/m (690 mg/L). The combined delivery rate ranged between 153 and 164 L/s (5.4 and 5.8 ft^3/s).

All borders were given a pre-plant irrigation of approximately 127 mm (5.0 in) for plant establishment on December 22 and 23, 1984. In addition, 38 mm (1.5 in) of rainfall occurred on December 27 and 28, 1984. Soil water contents were measured at 200 and 300 mm (8 and 12 in) depths, and at each subsequent 200 mm interval to a depth of 2.0 m (6.6 ft) at all access tube locations.

The neutron meters were calibrated for a typical soil in the field. Soil water content measurements began after plant emergence on February 13 and were made at 52 access tube sites within a treatment, one day prior to irrigation and three days after irrigation. The total gross water applied at each access tube site included all the water received by irrigations (seasonal irrigation water applied) and rainfall (8 mm or 0.3 in) during the growing season plus the amount of water consumed prior to the first seasonal irrigation from stored soil moisture at planting.

The cumulative soil water depletion (estimated evapotranspiration) at each access tube site included the total of (1) the measured change in soil water contents for the various drying cycles at an assumed crop rooting depth of 1.0 m (3.3 ft) over the entire growing season, and (2) the estimated soil water depletion that occurred between the pre- and post-irrigation.

RESULTS AND DISCUSSION

Water Distribution and Application Variability

Border length differences had little effect on mean values for any soil water variables since irrigation timing and amount were kept fairly uniform within each irrigation treatment, as shown in Table 1. Originally, it was anticipated that irrigation uniformities should be better in borders having a shorter advance distance.

Because the soil on the study site became highly compacted due to field leveling and planting, intake rates decreased significantly following pre-irrigation. Consequently, during the irrigation season, advance times were on the order of 30 minutes for short borders and 45 minutes for long borders. Recession took up to 24 hours, hence infiltration opportunity times were about the same for the two border lengths.

The uniformity of the seasonal irrigation-applied water, Q, as measured by the CV, was 12.1% or less in all borders. Combined, the six long borders had an average CV of 6.9%, compared to an average of 5.8% for the six shorter borders. Thus, under the particular design and conditions for these borders, the variability in Q was only 1.1% higher, on the average, for the longer borders. For all soil water factors in Table 1, the variability was only slightly greater for the long borders.

An important factor affecting the infiltrated water distribution in basin systems is the land leveling precision (Dedrick, 1983). Table 2 presents the summarized results of the soil surface elevation survey made following the leveling and initial cultural practices on the field. The coefficient of variation presented for each border is the standard deviation of soil surface elevation measurements (in mm) at each neutron access site, divided by an average irrigation depth of 102 mm (4.0 in). The range is the highest and lowest deviation from zero elevation.

The data implies that the soil surface elevation was generally more irregular in borders of shorter length (a 12.7% average CV in short borders compared to a 10.3% CV in long borders). This difference can be explained by the fact that greater precision in leveling occurred in the portion of the field beyond the length of the shorter borders. Subsequently, the greater variation in surface elevation in the short borders may be one of the factors explaining why little difference in irrigation uniformity occurred between the two border lengths.

Water Applied and Soil Water Depletion Variability

Table 3 presents a summary of statistics, grouped by irrigation treatment, for the soil water variables evaluated from all 52 field samples within the irrigation treatment. In each treatment, the water applications were more uniform (lower CVs) than the three seasonal soil water content averages. This implies that variations in soil water content were influenced by soil, crop, and other factors, as well as uniformity in water distribution.

Variation in the seasonal average soil water content after irrigation (θa), due to other factors besides irrigation distribution uniformity, was approximately 3.4% ($CV_{\theta a}$ - CV_Q) for all treatments, which could be interpreted in a practical sense as the amount of variation in soil water storage capacity throughout the field.

The mean cumulative SWD in 1985 was about 566, 451, and 314 mm (22.3, 17.8, and 12.4 in) of water for the Wet, Medium, and Dry irrigation treatments, respectively. The corresponding standard deviations were 45, 53, and 41 mm (1.8, 2.1, and 1.6 in). Although the seasonal variability in water use was nearly the same for the three irrigation levels, the pattern of variability was considerably different. On the Wet and Medium treatments, the variability with time was nearly the same; but on the Dry, the greatest variation in SWD occurred later in the growing season after the last irrigation when the crop became highly water stressed.

Spatial Dependence of Water Applied and Soil Water Depletion

The spatial dependency of the observations (either Q or SWD), within the same irrigation treatment, were analyzed using semivariograms, where observations were considered as points defined in the x and y direction. The semivariograms were calculated for lags (distances between observations) of 15 m (50 ft) up to 10 lag intervals or 150 m (495 ft) for both Q and SWD.

In the case of the Wet and Dry treatments, Q exhibits a pure nugget (lack of spatial correlation) effect; and we cannot infer the existence of any spatial structure or range of dependency. On the other hand, there does appear to be some spatial structure associated with Q within the boundaries of the Medium treatment plots. In general, the semivariograms do not demonstrate an apparent trend of spatial dependency for seasonal water applied (Q) within the field (data not shown). As with Q, SWD in the Dry treatment exhibits a lack of correlation, as presented in Figure 1. However, both the Wet and Medium treatment plots indicated spatial dependency of SWD up to a range of about 45 m (150 ft) in the Wet treatment and 90 m (300 ft) in the Medium treatment.

REFERENCES

1. Bos, M. G., J. A. Replogle, and A. J. Clemmens. 1984. Flow measuring for open channel systems. John Wiley and Sons, Inc., New York, 321 p.
2. Dedrick, A. R. 1983. Irrigation uniformity with level basins. 1983 Annual Technical Conf. Proceedings, Irrigation Association, Arlington, VA, p. 217-230.
3. Erie, L. J., O. F. French, D. A. Bucks, and K. Harris. 1982. Consumptive use of water by major crops in the southwestern United States. U. S. Department of Agriculture, Conservation Research Report No. 29, Washington, DC, 42 p.
4. Hunsaker, D. J. and D. A. Bucks. 1986. Crop yield variability in irrigated wheat. Forage and Grain, Cooperative Extension Service, Agricultural Experiment Station Report Series P-66, The University of Arizona, Tucson, AZ 85721.

Table 1. Irrigation and border length treatment means* and coefficient of variations (CV) for soil water variables of seasonal irrigation water applied (Q), seasonal gross water applied (GWA), measured seasonal soil water depletion (SWD), for Wet, Medium, and Dry irrigation treatments and two border lengths.

Variable	Border Length Treatment	Rep	Irrigation Treatment Means: Wet (CV,%)	Medium (CV,%)	Dry (CV,%)	Border Length Means: All (CV,%)
Total Seasonal Irrigation Water Applied, Q (mm)	Long	1	567 (7.2)	456 (4.8)	282 (6.4)	431[a] (6.9)
		2	567 (4.6)	455 (6.1)	257 (12.1)	
	Short	1	572 (3.7)	494 (5.4)	233 (5.3)	426[a] (5.8)
		2	593 (8.4)	433 (4.3)	232 (7.6)	
		All	575[a] (6.0)	460[b] (5.2)	251[c] (7.9)	
Total Seasonal Gross Water Applied, GWA (mm)	Long	1	644 (7.1)	543 (5.3)	386 (7.6)	515[a] (7.5)
		2	633 (4.2)	549 (7.5)	375 (13.4)	
	Short	1	646 (3.5)	587 (5.4)	338 (6.1)	511[a] (6.1)
		2	661 (7.5)	505 (3.8)	330 (10.2)	
		All	646[a] (5.6)	546[b] (5.5)	358[c] (9.3)	
Measured Seasonal Soil Water Depletion, SWD (mm)	Long	1	584 (9.0)	448 (8.4)	341 (9.9)	447[a] (8.9)
		2	551 (4.6)	447 (9.7)	312 (11.5)	
	Short	1	586 (8.0)	514 (7.5)	322 (8.2)	438[a] (8.4)
		2	539 (6.7)	396 (6.1)	273 (14.0)	
		All	565[a] (7.1)	451[b] (7.9)	312[c] (10.9)	

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

Table 2. Coefficient of variations (CV) based on a 102 mm (4.0 in) irrigation and range of deviations from zero mean for soil surface elevations for Wet, Medium, and Dry irrigation treatments and two border lengths.

Border Length Treatment	Wet: Rep	CV(%)	Range, mm	Medium: Rep	CV(%)	Range, mm	Dry: Rep	CV(%)	Range, mm	Border Length Means: All CV(%)
Long	1	11.9	-20 to 20	1	8.2	-15 to 6	1	11.1	-17 to 13	10.3
	2	9.9	-15 to 15	2	11.0	-21 to 20	2	9.8	-24 to 17	
Short	1	20.1	-40 to 30	1	10.3	-17 to 23	1	13.0	-19 to 21	12.7
	2	13.8	-19 to 21	2	9.4	-11 to 19	2	9.8	-12 to 18	
	All	13.9		All	9.7		All	10.9		

Table 3. Ranges, means, standard deviations (SD), and coefficient of variations (CV) for total seasonal irrigation water applied (Q), total seasonal gross water applied (GWA), measured seasonal soil water depletion (SWD), average volumetric soil water contents 1 day prior to irrigation (θ_p), average volumetric soil water contents 3 days after irrigation (θ_a), and seasonal average volumetric soil water contents $\bar{\theta}$ for Wet, Medium, and Dry irrigation treatments (n = 52).

Irrigation Treatment	Variable	Range	Mean	SD	CV(%)
Wet					
	Total Seasonal Irrigation Water Applied, Q(mm)	503 to 701	574	36.2	6.3
	Total Seasonal Gross Water Applied, GWA(mm)	572 to 772	644	38.0	5.9
	Measured Seasonal Soil Water Depletion, SWD(mm)	484 to 667	565	45.1	8.0
	Average Volumetric Soil Water Contents 1 Day Prior to Irrigation, $\theta_p(m^3/m^3)$	0.101 to 0.219	0.178	0.027	15.2
	Average Volumetric Soil Water Contents 3 Days After Irrigation, $\theta_a(m^3/m^3)$	0.171 to 0.289	0.253	0.026	10.3
	Seasonal Average Volumetric Soil Water Contents, $\bar{\theta}$ (m^3/m^3)	0.137 to 0.254	0.217	0.027	12.4
Medium					
	Total Seasonal Irrigation Water Applied, Q(mm)	403 to 534	459	31.2	6.8
	Total Seasonal Gross Water Applied, GWA(mm)	465 to 636	546	41.1	7.5
	Measured Seasonal Soil Water Depletion, SWD(mm)	350 to 592	451	53.2	11.8
	Average Volumetric Soil Water Contents 1 Day Prior to Irrigation, $\theta_p(m^3/m^3)$	0.093 to 0.206	0.161	0.09	18.0
	Average Volumetric Soil Water Contents 3 Days After Irrigation, $\theta_a(m^3/m^3)$	0.140 to 0.279	0.238	0.030	12.6
	Seasonal Average Volumetric Soil Water Contents, $\bar{\theta}$ (m^3/m^3)	0.115 to 0.250	0.206	0.030	14.6
Dry					
	Total Seasonal Irrigation Water Applied, Q(mm)	189 to 312	254	29.6	11.7
	Total Seasonal Gross Water Applied, GWA(mm)	273 to 447	361	42.1	11.7
	Measured Seasonal Soil Water Depletion, SWD(mm)	209 to 392	313	41.3	13.2
	Average Volumetric Soil Water Contents 1 Day Prior to Irrigation, $\theta_p(m^3/m^3)$	0.091 to 0.187	0.140	0.023	17.4
	Average Volumetric Soil Water Contents 3 Days After Irrigation, $\theta_a(m^3/m^3)$	0.161 to 0.281	0.234	0.028	12.0
	Seasonal Average Volumetric Soil Water Contents, $\bar{\theta}$ (m^3/m^3)	0.120 to 0.235	0.185	0.028	15.1

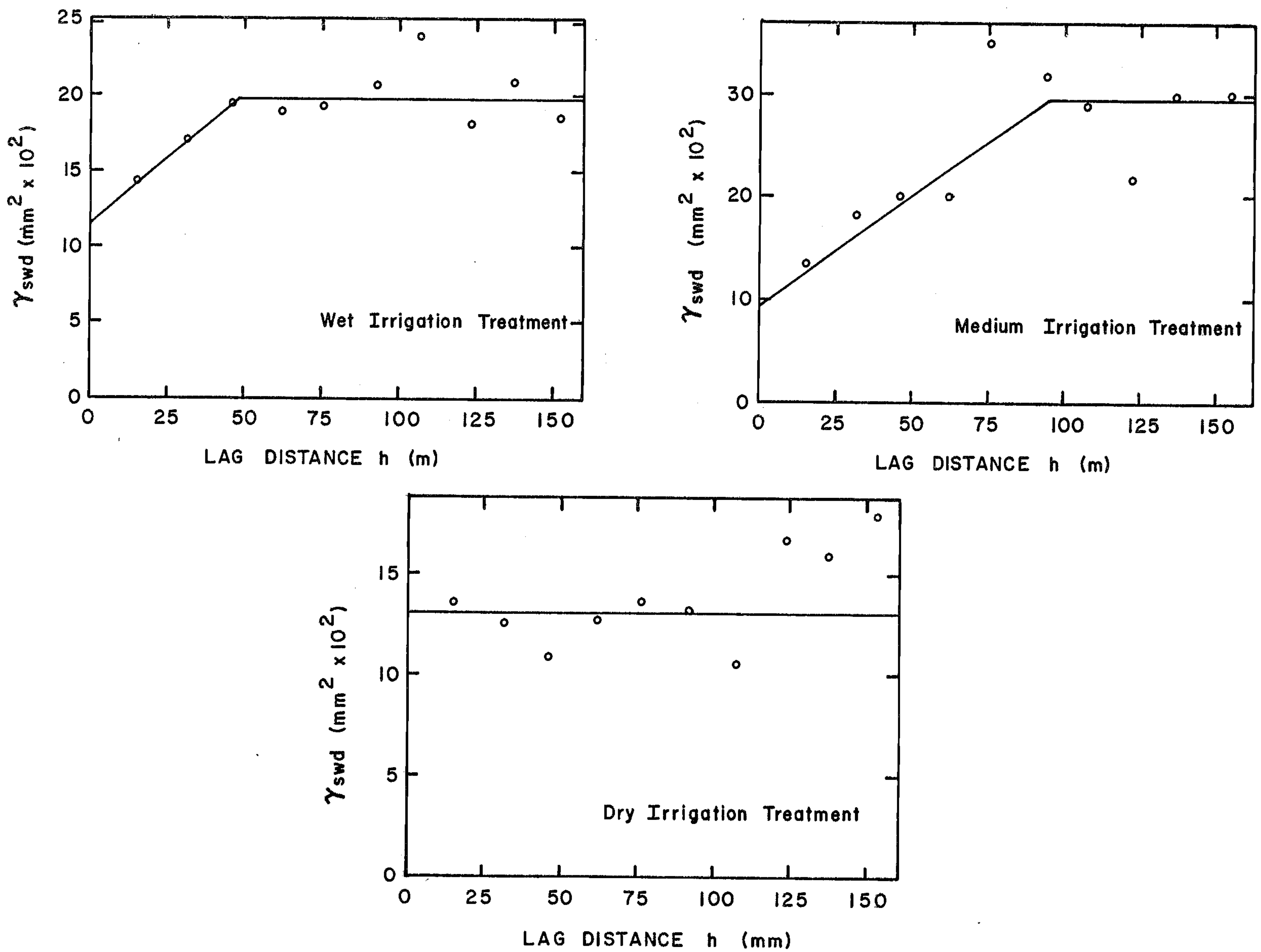

Figure 1. Spatial dependence of soil water depletions (SWD) shown as semivariance versus lag distance for Wet, Medium, and Dry irrigation treatments.