Irrigation treatments for corn with limited water supply in the Loess Plateau, China

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[1]Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Northwest Sci-Tech University of Agriculture and Forestry, Shaanxi Province, 712100, P.R. China; and [2]Département des Sols et de Génie Agroalimentaire, FSAA, Université Laval, Québec, QC, Canada G1K 7P4

Huang, H., Zhong, L. and Gallichand, J. 2002. **Irrigation treatments for corn with limited water supply in the Loess Plateau, China**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **44**:1.29-1.34. The lack of available growing-season water in the middle reaches of the Yellow River watershed has caused the development of deficit irrigation in the Loess Plateau of China. This research was conducted to evaluate the effect of different irrigation frequencies and timings on water use and corn yield and to determine optimum water management practices with limited water supply. Irrigation treatments were zero (I0), one (I1), two (I2), three (I3), and four (I4) irrigations per growing season with each irrigation consisting of a 87.5 mm depth of water. For treatment I1, the irrigation water was applied at tasselling, whereas I2 consisted of I1 plus an irrigation during the vegetative stage. Treatment I3 consisted of I2 plus an irrigation at silking, while for I4 an additional irrigation was provided at the grain filling stage. Irrigation quantities ranged from deficit to excess irrigation. The study was conducted at the Changwu Agri-ecological Station of the Loess Plateau from 1991 to 1995 on a moderately permeable silty clay loam soil. A single irrigation increased yield by an average of 20%. On average, two, three and four irrigations increased yields by an additional 16.9, 6.7, and 4.3%, respectively. There were no significant differences in corn grain yield and water use efficiency (WUE) among treatments I2, I3, and I4, but I1 yield was significantly lower. We concluded that substantial water savings can be achieved by applying two irrigations, one at tasselling and one during the vegetative stage. This should increase yield significantly compared to the no irrigation treatment, without significantly reducing yield compared to four irrigations per growing season. **Keywords**: corn, irrigation treatments, water use efficiency, deficit irrigation.

Le développement de l'irrigation de déficit au centre du bassin versant de la Rivière Jaune, dans le Plateau des Loess en Chine, est causé par un manque d'eau durant la saison de croissance. Ce projet visait à évaluer l'effet de la fréquence et du moment d'irrigation sur l'efficacité d'utilisation de l'eau et le rendement du maïs, pour déterminer la stragégie optimale d'irrigation. Les traitements comportaient un nombre d'irrigation variant de zéro à quatre par saison: I0 - aucune irrigation; I1 - une irrigation (à l'épiaison); I2 - deux irrigations (I1 + une au stade végétatif); I3 - trois irrigations (I2 + une au stade de formation des soies); I4 - quatre irrigations (I3 + une au stade de remplissage des grains). Chaque irrigation était d'une épaisseur d'eau de 87.5 mm. Cette étude a été réalisée de 1991 à 1995 à la station agroécologique de Changwu sur un loam argilo-limoneux modérément perméable. Une seule irrigation (I1) a augmenté le rendement moyen de 20% par rapport à I0 alors que ces augmentations, par rapport au traitement avec une irrigation de moins, ont été de 16.9% (I2), 6.7% (I3) et 4.3% (I4). Aucune différence significative n'est apparue entre le rendement en grains et l'efficacité d'utilisation de l'eau entre les traitements I2, I3 et I4, mais le rendement de I1 était significativement moindre. Nous concluons que des économies substantielles d'eau peuvent être réalisées en applicant deux irrigations, une à la formation des soies et une autre au stade végétatif. Cette pratique devrait augmenter le rendement significative-ment tout en minimisant l'utilisation de l'eau. **Mots-clés:**. maïs, irrigation, efficacité d'utilisation de l'eau, irrigation de déficit.

INTRODUCTION

Corn is an important feed grain crop in the Loess Plateau of China and responds well to irrigation. It occupies more irrigated hectares in this region than any other crop. Much of this area is irrigated from the Yellow River and its tributaries; but water resources of the Yellow River are becoming insufficient because of extensive irrigation development projects and the increased water requirement of industry. Since 1987, water flow in the Yellow River has frequently stopped in its lower reaches. Its water flow from 1990 to 1995 decreased by an average of 49.4% relative to that from 1960 to 1969 (Li 1997). In recent years, irrigation using collected surface runoff has been extensively applied in corn fields in most of the regions of the Gansu and Shaanxi Provinces that cannot be irrigated with water from the rivers. The water collected by surface runoff is very costly. It is, therefore, important to determine optimum water management practices for good yield with limited water supply throughout the Loess Plateau.

In general, methods of irrigation scheduling can be classified as full and deficit irrigations, based on plant, soil, and climate conditions (Martin et al. 1990). In Nebraska, Hergert et al. (1993) reported corn yields of 5.6, 10.1, and 11.8 Mg/ha for dryland, limited irrigation, and full irrigation, respectively, and marginal returns of 31 kg ha^{-1} mm^{-1} for limited irrigation and 11 kg ha^{-1} mm^{-1} for full irrigation. Camp et al. (1988) compared three irrigation scheduling methods for corn in South Carolina using tensiometers, evaporation pans, and a water balance procedure. These scheduling methods showed no significant differences in yield or amount of irrigation water. Cassel et al. (1985) compared tensiometers and a water balance model to irrigated corn in North Carolina and found no significant differences in corn grain yield between these two methods.

Irrigation water can be conserved and yields maintained by using adequate irrigation timing to avoid stress at critical growth stages. In Minnesota, Johnson et al. (1987) showed that irrigated corn responded as well to a single irrigation at midseason as it did to more frequent irrigation based on 50% soil water

Table 1. Rainfall and potential evapotranspiration (mm) during the study period.

Rainfall	1991	1992	1993	1994	1995	30-year average
April	31	11	9	83	13	35
May	89	38	76	9	9	50
June	30	83	86	98	31	74
July	12	41	139	83	59	95
August	88	213	94	20	112	108
September	47	92	40	50	4	73
Growing season	237	376	415	233	201	391
Annual	405	558	573	479	274	584
PET¶	661	575	554	755	788	632

¶ Potential evapotranspiration for the growing season

depletion. In Texas, Musick and Dusek (1980) found water stresses during tasselling and silking to be the most harmful, followed by those at grain filling and vegetative stages. However, Eck (1984) determined that water stress for durations of 14 and 28 days, during the vegetative stage, reduced corn yields by 23 and 46%, respectively. Plant water stress during the vegetative stage lowered yield by reducing the number of emerging plants, whereas stress during grain filling resulted in lower grain weight. Based on a 3-year study, Lyle and Bordovsy (1995) concluded that substantial water saving and increased net return could be achieved with deficit irrigation by providing water to the crop at a high frequency.

The objective of our study was to identify the most efficient water management practices for water use and corn yield with limited water supply in the Loess Plateau of China.

MATERIAL and METHODS

The field plot experiments with different irrigation treatments were conducted from 1991 to 1995 at the Changwu Agri-ecological Station of the Loess Plateau (107°40′30″E, 35°12′00″N) in Changwu County. The experimental site is 1220 m AMSL, and the land surface slopes at 0.07%. The climate of Changwu County is semi-arid with average annual temperature of 9.1°C and annual precipitation of 584 mm, falling mainly from June to September. The mean frost-free period is 194 days and open pan evaporation is 1440 mm. Rainfall and evapotranspiration during the study period are presented in Table 1. For the period of the experiment, rainfall during the growing season was the highest in 1993 (415 mm, wet year) and the lowest in 1995 (201 mm, dry year). Potential evapo-transpiration (PET) in the growing season was calculated by the Penman-Monteith method (Monteith and Unsworth 1990).

Soils of the experimental site belong to the Loess series (Zhu 1989), which is a silty clay loam and very homogeneous with a permanent wilting point of 0.105 m^3/m^3, a field capacity of 0.299 m^3/m^3, and an average bulk density of 1.3 kg/m^3 for the 0 - 3000 mm layer. On average, the groundwater level is 60 m below the soil surface (Xue 1995). The sowing layer (0 - 300 mm) has an average pH and organic matter content of 8.3 and 10.4 g/kg, respectively, whereas total nitrogen, available phosphorus, and potassium are 0.6 g/kg, 3.0 mg/kg, and 129 mg/kg (Dang 1995).

The experimental design was a randomized block consisting in a 504 m^2 area divided into three blocks. Each block was further divided into five plots for a total of 15 plots. Individual plots measured 4 by 6 m. Each year, at preplanting, all plots were fertilized with 150 kg N/ha, 75 kg P/ha, and 37.5 t manure/ha.

Irrigation treatments consisted of zero (I0), one (I1), two (I2), three (I3), and four (I4) irrigations of 87.5 mm of water applied through thin-wall tubing placed on the soil surface between rows. The plots were bordered to prevent runoff. Corn was irrigated at various dates as presented in Table 2. The single irrigation (I1) was applied when tassels became visible. For treatment I2, irrigations were applied at the tasselling and vegetative stages. Treatment I3 received the two previous irrigations (I2) plus an application at silking, whereas treatment I4 consisted of treatment I3 plus an additional irrigation at grain filling. The purpose of these treatments was to simulate dryland (I0), deficit (I1, I2, and I3), and full irrigation (I4).

Table 2. Irrigation treatments and dates.

Treatment	Number of irrigations	Water depth (mm)	Date of irrigation				
			1991	1992	1993	1994	1995
I0	0	0	-	-	-	-	-
I1	1	87.5	Jul 1	Jul 28	Jul 17	Jul 29	Jul 26
I2	2	87.5	Jun 18	Jun 6	Jun 22	Jum 22	Jun 11
		87.5	Jul 1	Jul 28	Jul 17	Jul 29	Jul 26
I3	3	87.5	Jun 18	Jun 6	Jun 22	Jun 22	Jun 11
		97.5	Jul 1	Jul 10	Jul 17	Jul 16	Jul 9
		87.5	Jul 20	Jul 28	Aug 3	Jul 29	Jul 26
I4	4	87.5	Jun 18	Jun 6	Jun 22	Jun 22	Jun 11
		87.5	Jul 1	Jul 10	Jul 17	Jul 16	Jul 9
		87.5	Jul 20	Jul 28	Aug 3	Jul 29	Jul 26
		87.5	Aug 10	Aug 13	Aug 23	Aug 24	Aug 14

Corn was planted in late April and harvested in late September to early October. Experimental measurements included duration and date of growth phases, crop yield, and soil water content. Soil water content was measured by gravimetry at sowing and harvest of each growing season by sampling soil from each plot. Soil

Table 3. Corn yield (kg/ha) as affected by irrigation treatment (1991-1995).

Year	Irrigation Treatment										Average yield
	I0		I1		I2		I3		I4		
	Means	STD	Means	STD	Means	STD	Means	STD	Means	STD	
1991	7399	369	9436	338	9745	182	11168	611	11798	784	9909
1992	9435	57	10022	240	10516	251	10546	104	10580	122	10220
1993	10312	174	10340	214	10386	274	10422	290	10435	5	10383
1994	5225	187	7993	38	9321	122	9851	128	10853	74	8649
1995	3179	243	4845	306	9789	355	11089	75	11702	400	8121
Average	7110		8527		9951		10618		11073		
Increase[¶]	–[#]		19.9		16.9		6.7		4.3		

[¶] Average percent increase from preceding treatment
[#] not applicable

Table 4. Comparison for treatment difference of yield (kg/ha).

Treatment	I1 vs I0	I2 vs I0	I3 vs I0	I4 vs I0	I2 vs I1	I3 vs I1	I4 vs I1	I3 vs I2	I4 vs I2	I4 vs I3
Difference	1417*	2841*	3508*	3963*	1424*	2091*	2546*	667[ns]	1122[ns]	455[ns]

* Difference is significant at the 0.05 probability level.
[ns] Difference is not significant at the 0.05 probability level.

samples were taken in 100 mm increments from the soil surface to a depth of 1000 mm and in 200 mm increments from 1000 to 3000 mm.

Water use efficiency (WUE) is defined as grain yield (Y) divided by the actual evapotranspiration (ET) during the growing season:

$$WUE = Y / ET \quad (1)$$

Growing season ET was estimated by a water balance as the sum of growing season rainfall (R), irrigation (I), and soil water depletion (ΔW) within the 3000 mm soil depth.

$$ET = R + I + \Delta W \quad (2)$$

Deep drainage was ignored in this calculation because soil water content measurements showed that no water percolated below the 3000 mm measurement depth.

Irrigation water use efficiency (IWUE) was determined by subtracting the grain yield of dryland treatment (Y_0) from the irrigated yield (Y_I) divided by the seasonal irrigation water (I):

$$IWUE = \left(Y_I - Y_0\right) / I \quad (3)$$

where Y_0 corresponds to treatment I0, and Y_I and I correspond to treatments I1, I2, I3 or I4. Differences between treatments and significance among means were tested with an analysis of variance and the method of contrasts using Procedure GLM, whereas Procedure REG was used to perform regression between crop yield and irrigation. Both procedures are from SAS (SAS Institute 1998).

RESULTS and DISCUSSIONS

Grain yield

Grain yield data showing average response to irrigation treatments and its standard deviation (STD) for the duration of the study are presented in Table 3. Yields ranged from 3179 kg/ha for I0 in 1995 to 11,798 kg/ha for I4 in 1991. Table 4 shows the average yield comparisons expressed between pairs of treatments. The I1 treatment increased yield by an average of 1417 kg/ha (19.9%), I2 by 1424 kg/ha (16.9%), I3 by 667 kg/ha (6.7%), and I4 by 455 kg/ha (4.3%). On average, the smallest incremental response of yield to irrigation occurred for treatments I3 and I4. Table 4 shows that average yields of treatments among I0, I1, and I2 were significantly different ($P<0.05$ for I0 vs I1 and I1 vs I2), whereas they are not significantly different among treatments I2, I3, and I4 ($P \geq 0.05$ for I2 vs I3 and I3 vs I4). Therefore, two irrigations, one at tasselling and one during the vegetative stage, significantly increase yield compared to the no irrigation treatment, and will not significantly decrease yield compared to full irrigation.

Yield responses to irrigation water are presented in Fig. 1 for the wet year and the dry year. For the 5 years of the study, the coefficient of determination (r^2) ranged from 0.946 to 0.989. These two curves show that the response of yield to irrigation was not important in the wet growing season, but much more important in the dry growing season. The least response to irrigation occurred in 1993, because the amount of rainfall most closely approached PET during that growing season (415 mm). The most pronounced effect of irrigation on yield occurred in 1995 when rainfall during the growing season was the least (201 mm).

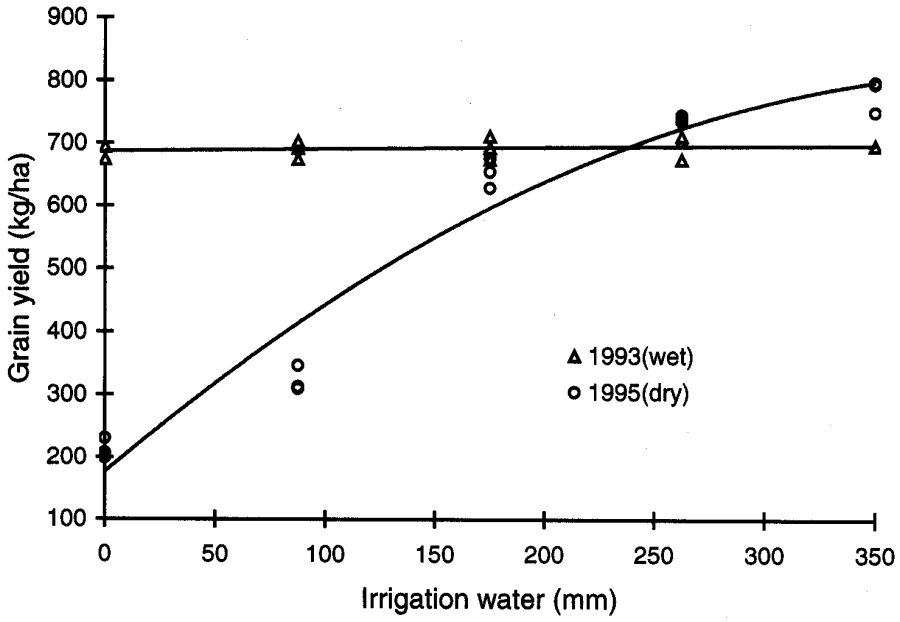

Fig. 1. Corn yield as affected by irrigation water.

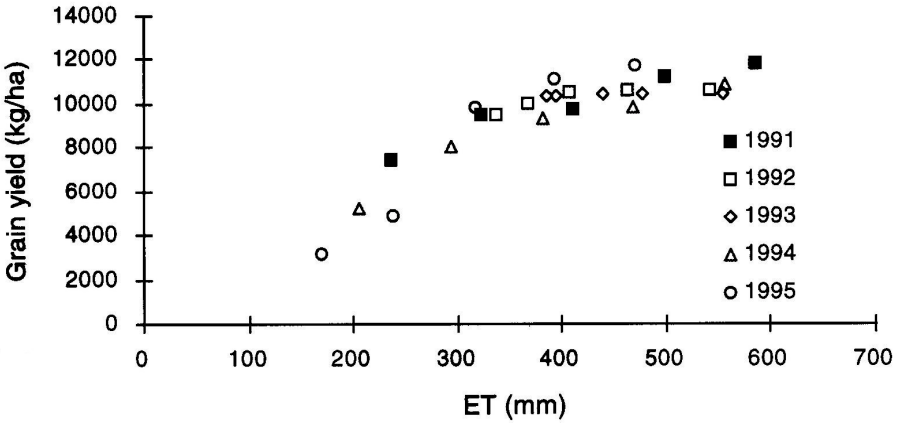

Fig. 2. ET-yield relation of corn.

ET-yield relation

The 5-year average response of grain yield to ET among all treatments is presented in Fig. 2. Generally, when ET is less than 350 mm, the relation between yield and ET is approximately linear. This zone can be characterized as the dryland zone and grain yield increases quickly with ET. The zone of ET above 350 mm can be defined as the irrigation zone and grain yield also increases with ET, but the rate of increase becomes smaller. Several researchers have found a strong linear correlation between grain yield and cumulative seasonal evapotransipration (Hanks et al. 1969; Stewart and Hagan 1973; Power et al. 1973; Yanuka et al. 1982). A review of this research is given in Stegman (1986). A curvilinear relationship between yield and ET was reported by Grimes et al. (1969) and Orgaz et al. (1992). They stated that the response of yield per unit of ET had sometimes been found to decline when ET became high. The possible factors involved in low yield under high water treatment are excessive growth during the vegetative stage and a lack of aeration under near-saturated conditions. This decreasing trend of yield with high ET was not found in the current research. Similar results were reported by Li and Shu (1991) for the Loess Plateau and by Norwood (2000) in the Great Plains of the USA.

Water use efficiency

Water use efficiencies of all irrigation treatments for the 5-year study period are presented in Table 5. WUE varied from 31.4 kg ha^{-1} mm^{-1} (I0, 1991) to

Table 5. Water use efficiency, WUE (kg ha^{-1} mm^{-1}) as affected by irrigation treatment (1991-1995).

Year	Irrigation Treatment										Average WUE
	I0		I1		I2		I3		I4		
	Means	STD	Means	STD	Means	STD	Means	STD	Means	STD	
1991	31.4	1.5	29.2	2.2	23.7	1.2	22.4	1.2	20.2	1.4	25.4
1992	28.0	0.2	27.3	0.7	25.9	0.6	22.8	0.2	19.5	0.2	24.7
1993	26.7	0.5	26.2	0.7	23.7	0.7	21.9	0.6	18.9	0.1	23.5
1994	25.4	0.9	27.3	0.2	24.5	0.3	21.0	0.3	19.5	0.1	23.5
1995	20.8	1.5	20.2	1.3	29.9	1.2	26.7	0.2	23.3	0.8	24.2
Average	26.5		26.0		25.5		23.0		20.3		
Reduction[¶]	–[#]		1.9		1.9		9.8		11.7		

[¶] Average percent reduction from preceding treatment
[#] not applicable

Table 6. Comparison for treatment difference of yield water use efficiency, WUE (kg ha^{-1} mm^{-1}).

Treatment	I1 vs I0	I2 vs I0	I3 vs I0	I4 vs I0	I2 vs I1	I3 vs I1	I4 vs I1	I3 vs I2	I4 vs I2	I4 vs I3
Difference	-0.5^{ns}	-1.0^{ns}	-3.5^{ns}	-6.2*	-0.5^{ns}	-3.0^{ns}	-5.7*	-2.5^{ns}	-5.2*	-2.7^{ns}

* Difference is significant at the 0.05 probability level.
^{ns} Difference is not significant at the 0.05 probability level.

Table 7. Irrigation water use efficiency, IWUE (kg ha^{-1} mm^{-1}) as affected by irrigation treatment (1991-1995).

Year	Irrigation Treatment								Average IWUE
	I1		I2		I3		I4		
	Means	STD	Means	STD	Means	STD	Means	STD	
1991	23.3	7.5	13.4	1.1	14.3	2.4	12.6	2.2	15.9
1992	6.7	2.7	6.2	1.4	4.2	0.4	3.3	0.4	5.1
1993	0.3	2.5	0.4	1.6	0.5	1.1	0.3	0.1	0.4
1994	31.6	0.5	23.4	0.7	17.6	0.5	16.1	0.3	17.7
1995	19.0	3.5	37.8	2.0	30.1	0.3	24.4	1.2	27.8
Average	16.2		16.2		13.3		11.3		
Reduction¶	–$^{\#}$		0.0		17.9		15.0		

¶ Average percent reduction from preceding treatment
$^{\#}$ not applicable

18.9 kg ha^{-1} mm^{-1} (I4, 1993). The I1 treatment reduced WUE by an average of 0.5 kg ha^{-1} mm^{-1} (1.9%), compared to the preceding treatment, I2 by 0.5 kg ha^{-1} mm^{-1} (1.9%), I3 by 2.5 kg ha^{-1} mm^{-1} (9.8%), and I4 by 2.7 kg ha^{-1} mm^{-1} (11.7%). Therefore, I1 and I2 treatments decreased WUE much less than treatments I3 and I4. Comparisons of average WUE values expressed between pairs of treatments are presented in Table 6. This table shows that only treatment I4 significantly reduced WUE, and the differences between all pairs of I1, I2, and I3 are not significant. Treatment I2 did not result in significant changes of WUE compared to I0 and I1.

Irrigation water use efficiencies (IWUE) for the 5-year study period are presented in Table 7. Large variations of IWUE can be observed. IWUE ranged from 37.8 kg ha^{-1} mm^{-1} for I2 in 1995 to 0.3 kg ha^{-1} mm^{-1} for I1 and I4 in 1993. The average IWUE in 1995 was 27.8 kg ha^{-1} mm^{-1} (dry year) and in 1993 only 0.4 kg ha^{-1} mm^{-1} (wet year). Therefore, IWUE is affected not only by the irrigation treatment, but also by the amount of rainfall during the growing season. The difference of average IWUE between the wet and dry years in the same treatment is larger than that between the treatments in the same year. Differences between the treatments for the average value of IWUE tended to be similar. Compared to I1, I2 did not reduce IWUE. However, I3 reduced IWUE by 17.9% compared to I2 and I4 by 15.0% compared to I3.

CONCLUSIONS

Experiments with five irrigation treatments for five years were conducted at the Changwu Agri-ecological Station of the Loess Plateau of China to determine optimum water management practices with limited water supply. The following conclusions can be drawn from this study:

1. Two irrigations, one at tasselling and one during the vegetative stage will significantly increase corn yield compared to no irrigation treatment, and will not significantly decrease yield compared to full irrigation.
2. Two irrigations per season will not significantly reduce water use efficiency (WUE) compared to no irrigation. Moreover, the two-irrigation treatment does not reduce irrigation water use efficiency (IWUE) when compared to the single irrigation treatment.
3. Faced with declining flow in the Yellow River and expensive water collected by surface runoff, two irrigations, one at tasselling and one during the vegetative stage, can be considered the optimum water management practice with limited water supply in the Loess Plateau of China.

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