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IRRIGATION OF DWARF WHEATS IN THE YAQUI VALLEY OF MEXICO

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SUMMARY

The response of the latest wheat cultivars to irrigation regimes was studied between 1970 and 1975 in a heavy soil of the Yaqui Valley of north-west Mexico. Yield showed greatest sensitivity to water shortage in the period 65–110 days after seeding (spike emergence around 90 days), due largely to responses in grains/m². More frequent irrigation increased yields 5–10% over the average of 7 t/ha obtained with the commonly-adopted five irrigation regime. Various irrigation criteria were tested: potential evapotranspiration calculations seemed the most useful. Measurement of leaf permeability (with an air flow porometer) showed more promise than the use of plant water potential (measured with a pressure chamber).

Striking increases in wheat productivity in Mexico, India and Pakistan since the mid-sixties have largely been associated with the growing of new short-statured varieties under irrigation. Since these varieties receive higher fertilizer applications, and have higher yield potentials, than the taller wheats they have replaced, it has been necessary to re-examine irrigation practices for wheat.

In the Yaqui Valley of north-west Mexico, where the bulk of the country's wheat is now produced under irrigation, Anon. (1969) reported that irrigation at 20% (0–60 days), 40% (60–100 days), and 20% (> 100 days) available moisture in the 5–30 cm horizon, gave the highest yields with two semi-dwarf wheats which took approximately 75 days to flowering. Martinez *et al.* (1969) concluded that maximum yield of the semi-dwarf variety Inia 66 was achieved with irrigation at 20% available moisture (5–30 cm) before flowering (< 60 days) and 30% after flowering. Such experiences have led to farmer recommendations in the more practical terms of a fixed watering calendar. For an early to mid-season variety, sown in November–December on the heavier soils of the Valley, this comprises irrigations at seeding and 35, 65, 90 and 110 days later (I. de la Peña, personal communication). Rainfall is rarely sufficient to justify altering this calendar of irrigations, which may range from 100 to 150 mm each, giving a total of about 500 mm for a normal 120–130 day wheat crop.

Further irrigation studies in the Yaqui Valley were prompted by the release in the early 1970s of so-called triple dwarf bread wheats of higher yield potential (CIMMYT, 1971) and this paper reports studies with such cultivars over the period 1970–75. The stage of greatest sensitivity of yield to water stress was re-examined and, in the light of the results obtained, irrigation schedules were rearranged in an attempt to increase yield and/or the efficiency of water use.

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Various criteria, in addition to soil moisture, for determining when to irrigate were examined, including plant water potential, leaf permeability and cumulative potential evapotranspiration.

MATERIALS AND METHODS

Experiments were located at CIANO,* near Ciudad Obregon in the Yaqui Valley irrigation system. At latitude 27°N, and close to sea level, this region has a mild dry winter (Table 1). Weather during the experimental years was close to normal, with the exceptions of rain in 1972–73 (Fig. 1), no rain in the other years, and unusually cool spring temperatures in 1973 and again in 1975.

Soils of the region are gently sloping, and furrow or border check irrigation is usually practised with wheat. At the experimental site the soil was a cracking clay (40% clay, 48% sand), low in organic matter and slightly alkaline. The −15 bar soil water content was 23 and 25% gravimetric for the 5–30 cm and 30–60 cm intervals respectively (R. E. Sojka, personal communication). Water penetration was slow after initial wetting. Under a wheat crop on this site, after 2 h flooding, the available water in the top 100 cm was approximately 110 mm, with about 80 mm in the top 60 cm; with a further 22 h flooding these quantities increased by only 10 and 5 mm respectively (L. H. Stolzy and R. J. Laird, unpublished data).

Five experiments were carried out, as described below. Yecora 70 or its sister Cajeme 71, bread wheat (*Triticum aestivum* L.) cultivars of triple dwarf stature (80–90 cm), were used in each experiment as a standard.

Experiment 1 (1970–71). Four irrigation treatments (abbreviated to T1, T2, etc., throughout) included a well-watered control (T1), irrigated at seeding (3 December) and at 27, 50, 70, 91, 103 and 119 days after seeding. T2 skipped the second irrigation, T3 the third, and the fourth irrigation was advanced to 65 days for T4 and the fifth skipped. Four bread wheat cultivars were included (Ciano 67, Yecora 70, Siete Cerros 66 and Saric 70, where the year of release of each variety is indicated by the numerical suffix). The soil in Experiment 1 was somewhat coarser in texture than in the other experiments and the −15 bar moisture contents were probably 2–3% lower than values mentioned earlier.

Experiment 2 (1974–75). There were eight irrigation treatments, in which the well-watered control (T1) received irrigations at seeding (5 December 1974) and 39, 67, 90 and 110 days later; treatments T2, T4, T6 and T8, involved skipping the second, third, fourth and fifth irrigations respectively; and for treatments T3, T5, and T7, the third, fourth and fifth irrigations, respectively, were delayed by half of the interval between the irrigation involved and the following one in the control situation. Three cultivars were used (Yecora 70, Torim 73 and Cocorit 71 (a durum wheat, *Triticum turgidum* L.)).

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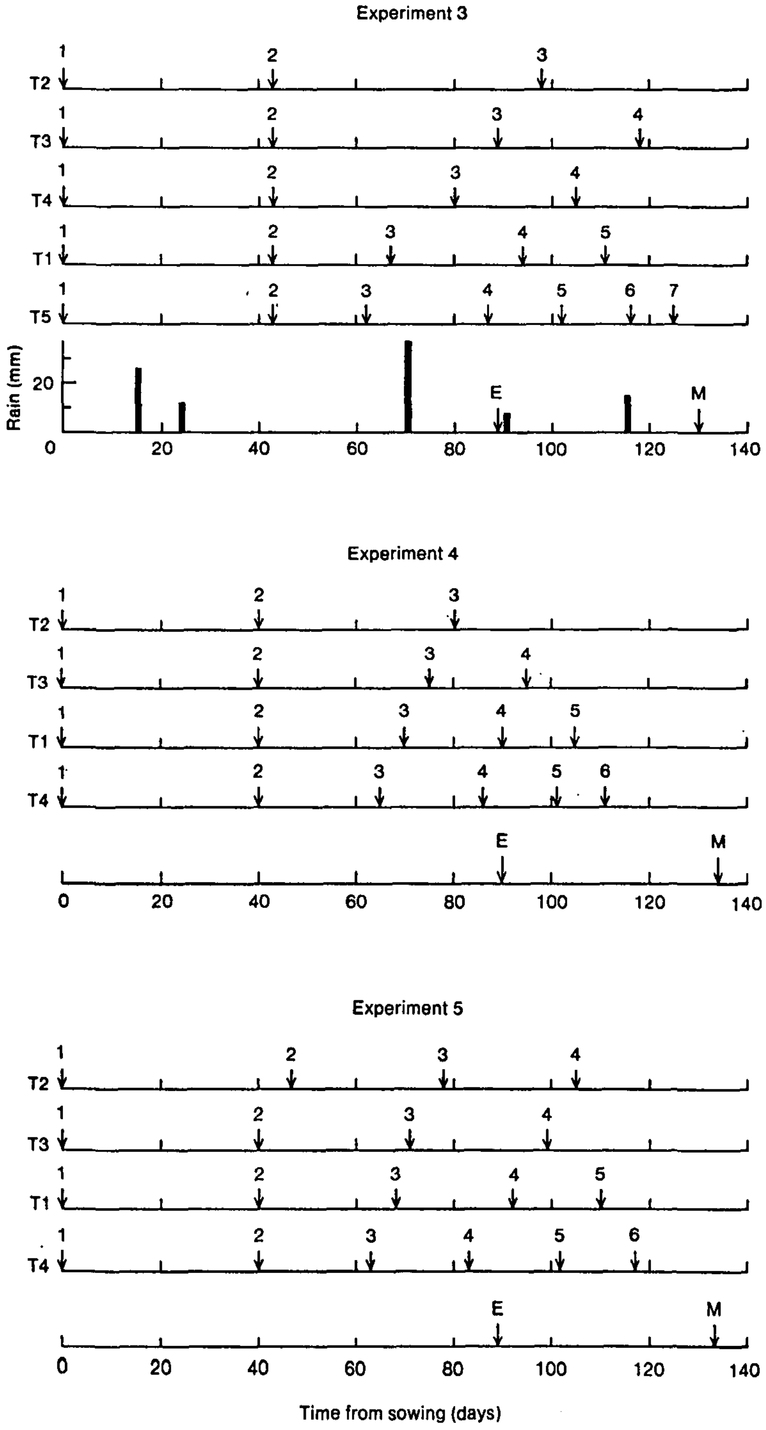

Fig. 1. Irrigation treatments in Expt 3, 4 and 5, and rainfall in Expt 3; E = 50% spike emergence, M = 50% spike maturity in T1, means of all cultivars.

Table 1. *Average climatic conditions at CIANO for the winter cropping season*

Month	Temperature		Solar radiation (ly/day)	Pan evaporation USWB Class A pan (mm/day)	Rainfall (mm)
	Mean max. (°C)	Mean min. (°C)			
Nov.	29	12	340	4·2	13
Dec.	24	8	290	3·4	18
Jan.	23	7	310	3·1	14
Feb.	25	7	400	3·7	8
Mar.	27	8	510	5·2	3
Apr.	31	10	590	7·5	1
May	34	14	620	—	0
Period	1960–75		1970–75	1970–75	1960–75

Experiment 3 (1972–73). Five treatments tested various numbers of irrigations, in each case arranged as well as possible in relation to known water stress effects on yield (Fig. 1). The experiment was sown on 12 December with a single bread wheat cultivar (Cajeme 71).

Experiment 4 (1973–74). Four treatments, developed in the same manner as in Experiment 3, were compared (Fig. 1), sowing cultivars Yecora 70, Torim 73, Cocorit 71 and a triticale (*Tritosecale* Wittmack) Cinnamon, on 24 November.

Experiment 5 (1974–75). There were four treatments (Fig. 1) and four cultivars (Yecora 70, Jupateco 73, Cocorit 71, and a triticale, Bacum), sown on 6 December.

The control treatments (T1) in each experiment approximated to the recommended irrigation frequency. Each treatment plot occupied an irrigation basin, approximately 10 × 10 m, which was fully flooded for a given time period and then drained. In Experiments 1, 2 and 3 the flooding period was 2 or 3 h. In Experiments 4 and 5 longer flooding times (16–18 h) were adopted, and water flowing into and draining from the basins was measured with V-notch weirs. In calculating the depth of water absorbed by the crop, allowance was made for absorption by the unseeded edges of the basins.

Agronomic management of the experiments approached commercial practice: dry land preparation, fertilization (100–300 kg/ha N, 26–44 kg/ha P), and seeding were followed immediately by the first irrigation. Seeding density ranged from 80 to 120 kg/ha, and row spacing was either 20 or 30 cm. There were no weed or disease problems and control yields were expectedly high.

Experiment 3 was a randomized block of six replications; other experiments used split plot designs with four replications, irrigation treatments occupying the main plots (irrigation basins) and cultivars the sub-plots. Sub-plots were 4·5 × 1·8 m, from which a central 2–4 m^2 was harvested by hand. Grain yield is expressed on a 14% moisture basis but kernel weight is on an oven dry basis; grains/m^2 was calculated. Dates at 50% spike emergence and at 50% spikes without green (maturity) were recorded.

Water stress was quantified at the end of each drying cycle by measuring gravimetric soil moisture (Expts 1, 3, 4), leaf relative water content (Expt 1), plant water potential (Ψ) with the pressure chamber technique (Expts 2, 4, 5), leaf permeability (LP) with an airflow porometer as an indicator of stomatal opening (Expt 5), and degree of mid-day wilting assessed visually (Expt 3). The measurements of Ψ and LP, which were made around mid-day or early afternoon, have been described (Fischer *et al.*, 1977). Pan evaporation (E_{pan}) was measured with a USWB class A tank located in a nearby wheat field. Use of a crop factor (potential evapotranspiration/pan evaporation), determined locally for wheat (I. de la Peña, personal communication) enabled cumulative potential evapotranspiration (ΣET_P) to be calculated during each irrigation interval. The crop factor, which rose from 0·35 just after sowing to 0·85 at flowering, and declined to 0·70 at maturity, had been determined by sampling soil moisture gravimetrically to a depth of 60 cm. Since the maximum depth of wheat roots in this soil may approach 90 cm (R. A. Fischer and R. E. Sojka, unpublished data), the crop factor may have underestimated ET_P slightly, but should be valid for comparing treatments.

RESULTS

Experiment 1

For T1, 50% spike emergence occurred at 81, 91, 96 and 99 days after seeding for the four cultivars, Ciano 67, Yecora 70, Siete Cerros 66 and Saric 70, respectively. ΣET_P, soil water at the end of drying, and especially leaf relative water content at the end of drying, all suggest an increase in stress from T2 to T4 (Table 2).

Table 2. *Water stress levels and grain yield in Experiment* 1

	Treatment			
Variable	T1	T2	T3	T4
Duration of drying cycle (days from seeding)	See text	0–50	27–70	65–103
Estimated ΣET_P during drying (mm)	42–70	92	105	116
Leaf rel. water content (%)†	88–93	86	85	58
Soil water content (% grav.)†				
5–30 cm	18–22	16·8	17·4	14·4
30–60 cm	22–25	19·6	20·7	17·9
Grain yield (t/ha or % of T1)				
Ciano 67	4·47	112	74*	63*
Yecora 70	6·27	101	87	46**
Siete Cerros 66	5·46	95	99	47**
Saric 70	5·22	93	103	43**

*, ** Significantly different from control grain yield at P = 0·05 and 0·01

† At end of drying cycle, Yecora 70

Similarly, grain yield was unaffected by T2 but reduced drastically by T4, with T3 intermediate. Yield showed a significant irrigation × cultivar interaction, Ciano 67, the earliest cultivar, being the most affected in T3 and the least in T4. The sources of yield reductions, namely fewer grains/m^2 (T3; Ciano 67, Yecora 70: T4; Siete Cerros 66, Saric 70), or reduced kernel weight (T4; Ciano 67), or a combination of both (T4; Yecora 70), also point to an ontogenetic basis for the irrigation × cultivar interaction.

Experiment 2

Mean results are presented, since there were no significant irrigation × cultivar interactions (Table 3). Time to spike emergence averaged 91 days (T1) but there were significant accelerations with T2 (82 days), and T3 and T4 (both 88 days). In the case of long drying, the minimum Ψ (just prior to rewatering) appeared to be lower in T4 and T6, and lower in T5 with short drying (Fig. 2a). Similarly, yield reductions were greatest when the third (T4) or fourth (T6) irrigations, were omitted, or when the fourth irrigation (T5) was delayed (Table 3). Using individual replicate values to take advantage of between-replicate as well as treatment variation, and pooling data of T2, T3, T4, T5 and T6, the correlation coefficient between grain yield and minimum Ψ was 0·88 ($n=20$, $P<0{\cdot}01$), yield being reduced by 1·5% of the control value for each 1 bar decrease in water potential. T7 was excluded because its minimum Ψ appeared to be anomalous (Fig. 2a), perhaps due to its advanced stage of senescence.

Table 3. *Water stress, grain yield and other crop variables in Experiment 2 (means of three cultivars)*

	Treatment							
Variables	T1	T2	T4	T6	T8	T3	T5	T7
Duration of drying (days from seeding)	—	0–67	39–90	67–100	90–100	39–78	67–100	90–121
Estimated ΣET_P of drying cycle (mm)	65–109	133	141	162	198	96	123	117
Spike maturity (days from seeding)†	136	126	136	128	126	136	133	128
Grain yield (t/ha or % of T1)	6·58	101	79**	74**	88*	99	87*	95
Number of grains (/m^2 or % of T1)†	11250	98	75	86	99	102	84	98
Kernel weight (mg or % of T1)	50·3	104	106	86**	89**	96	104	97

*, ** Significantly different from the control (T1) at $P=0{\cdot}05$ and $0{\cdot}01$

† Not analysed statistically

Stress relieved before flowering (T4) reduced the number of grains/m^2, stress after flowering (T8) reduced kernel weight, and stress before and after flowering (T5, T6) reduced both components of yield. Early stress (T2), or moderate grain-filling stress (T7), had no effect, despite marked effects on the rate of development, especially in the case of T2.

Experiment 3

The experiment was complicated by rainfall in all months, particularly when 37 mm fell at 71 days after seeding (see Fig. 1). Grain yield, number of grains/m^2 and kernel weight all increased with increased frequency of irrigation (Table 4). T3 contrasted markedly with T4 and T1: the reduction in grains/m^2 with T3 suggests that the cause was the longer interval between pre-flowering irrigations

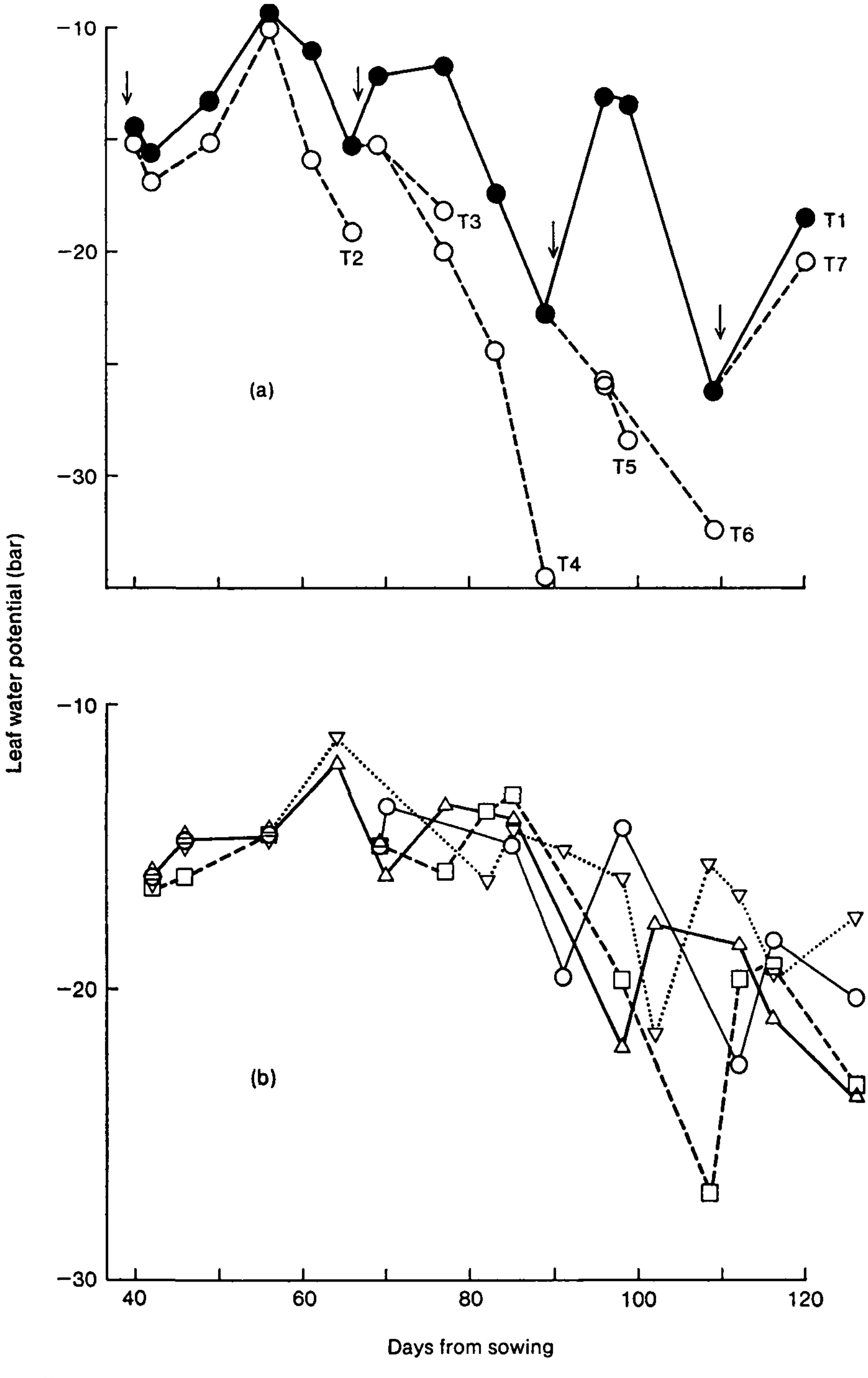

Fig. 2. Effects of irrigation treatment on mid-day leaf water potential (Ψ) as estimated by the pressure chamber technique: (a) Expt 2 (means of all cultivars), arrows show T1 irrigations; (b) Expt 5 (means of all cultivars) T1 (○), T2 (□), T3 (△), and T4 (▽).

2 and 3 (Fig. 1). Mid-day wilting scores, on a scale 1–10 of increasing severity, gave values of 1·5 just before T4 received its third irrigation at 80 days; this had increased to 6·0 when T3 received its third irrigation 9 days later. Soil moisture data just before the third irrigation of T3 were unfortunately lost; for T4 it was 21·0 and 24·5% (5–30, 30–60 cm respectively) and for T2, 18 days later, it was 19·8 and 19·7%, respectively.

Experiment 4

Maturity was hastened by 4 days in T2 relative to T1. The increase in grain yield with increase in number of irrigations was entirely the result of increases in the number of grains/m^2 (Table 5). Cultivar × irrigation interactions were small and mostly non-significant, but there was a tendency for the yield of Cocorit 71 and Cinnamon to respond more to T4. Water use efficiency (kg grain/ha mm water applied), calculated from Table 5, decreased with increasing frequency of irrigation, but the overall change was not great (17·9 kg/ha mm for T2 to 16·0 kg/ha mm for T4; 1 kg/ha mm equals 1 kg/10 m^3 of water).

Table 4. *Potential evapotranspiration between irrigations, grain yield and its components in Experiment* 3

	Treatment				
Variable	T1	T2	T3	T4	T5
Number of irrigations	5	3	4	4	7
Estimated ΣET_p between irrigations (mm)†	55, 65, 86, 63	115, 153	80, 126, 60	50, 100, 115	40, 45, 54, 70, 51, 27
Grain yield (t/ha or % of T1)	7·33	65**	69**	94	107
Number of grains (/m^2 or % of T1)	13320	72**	75**	100	107
Kernel weight (mg or % of T1)	47·5	90**	92**	95	100

*, ** Significantly different from the control (T1) at $P = 0·05$ and 0·01

† Between second and third, third and fourth, etc., irrigations, calculating until the date of maturity of T1; the value was 18 mm for all treatments between the first and second irrigations. Significant rain fell in many of these intervals; this was subtracted from the calculated ΣET_p so that the ΣET_p shown represents the evapotranspiration to be met from water stored in the soil at the beginning of the interval, as in Tables 1 and 2

Table 5. *Water applications, water stress, grain yield and components in Experiment* 4 *(means of four cultivars)*

	Treatment			
Variable	T1	T2	T3	T4
Number of irrigations	5	3	4	6
Water applied† (mm)	100, 71, 54	114	100, 71	94, 71, 54, 55
Estimated ΣET_P† (mm)	63, 63, 55, 102	92, 189	76, 66, 141	48, 61, 60, 35, 79
Soil moisture‡ (% grav. 5–30 cm)	20–22	21	20–22	21–25
Grain yield (t/ha or % of T1)	7·59	80**	91**	106
Number of grains (/m^2 or % of T1)	15630	77**	89**	104
Kernel weight (mg or % of T1)	41·9	104	102	103

*, ** Significantly different from T1 at $P = 0·05$ and 0·01

† Irrigations and intervals subsequent to the second irrigation; all treatments received 100 mm at the first and 127 mm at the second irrigation, with an estimated ΣET_P between these of 74 mm

‡ Mean values at the end of each drying cycle following the second irrigation; only range of values shown

Experiment 5

Treatments T2 and T3, with only four irrigations, yielded less than T1 (Table 6) due to reductions in grain number in T2 and kernel weight in T3. Six irrigations (T4) led to significantly higher grain yield than T2 and T3, and higher grain numbers and yield than T1. The cultivar × irrigation interaction was significant, largely because Yecora 70 and Cocorit 71 responded better to six irrigations (T4) than to five (T1). The triticale Bacum lodged heavily with the last irrigation of T4. Stress, as indicated by ΣET_P, showed a particularly even and presumably adequate pattern of watering for T4. Figure 2b shows that the differences between treatments in Ψ, especially before spike emergence, were never very great (see also Fig. 4a). On the other hand, LP measurements tend to separate treatments more clearly (Fig. 4b). Water use efficiency declined as the yield and total water applied increased, ranging from 15·2 kg/ha mm for T3 to 13·2 kg/ha mm for T4.

Table 6. *Water applications, water stress, grain yield and components in Experiment* 5 *(means of four cultivars)*

	Treatment			
Variable	T1	T2	T3	T4
Number of irrigations	5	4	4	6
Water applied‡ (mm)	77, 108, 106	88, 130	94, 120	66, 86, 124, 97
Estimated ΣET_P‡ (mm)	61, 88, 81, 89	76, 108, 114	71, 105, 140	50, 63, 76, 59, 68
Grain yield (t/ha or % of T1)	7·13	91†	90†	108
Number of grains (/m² or % of T1)	14060	93	98	109
Kernel weight (mg or % of T1)	44·4	98	92**	99

†, *, ** Significantly different from T1 at P=0·1, 0·05, 0·01

‡ Refers to irrigations and intervals subsequent to the second irrigation; all treatments received 100 mm at the first and 109 mm (113 mm for T2) at the second irrigation, with an estimated ΣET_P of 72 mm (87 mm for T2) between these irrigations

DISCUSSION

Effect of stage of development

With the exception of Experiment 1, all cultivars in all experiments showed similar developmental patterns, reaching spike emergence and maturity at about 90 and 130 days from sowing, respectively, for T1.

The results of Experiments 1 and 2 indicate that delay of the second irrigation until at least 50 days, or even later, had little effect on grain yield (agreeing with Anon., 1970, and Lagarda, 1975, the latter study involving six modern semi-dwarf varieties during 1973–74 at CIANO). The delay led to plant water stress (Table 2, Fig. 2a) and significant acceleration of development (Table 3) but the stress was not severe, presumably because evapotranspiration rates were low and roots were growing into deeper horizons of moist soil. Visual observation suggested that growth and tillering were checked; the absence of an effect on grain yield agrees with the results of experiments with early crop shading in the same environment, namely that growth checks until 60 days after sowing have little effect on grain yield (Fischer, 1975). The major importance of an irrigation at crown root initiation (around 25 days) in the Indian sub-continent (Bhardwaj *et al.*, 1975) may be due to lighter soils combined with the practice of sowing on moist pre-irrigated seed beds. In contrast to these conditions, crown roots (nodal roots) establish on the moisture from the irrigation given immediately after dry seeding in the Yaqui Valley.

Responses to water stress in the latter half of the grain filling period (after 110 days), as indicated by T7 in Experiment 2, and by the generally small changes in kernel weight in all experiments, also appeared to be relatively limited. Severe stress at that time (T8 in Experiment 2) only reduced yield and kernel weight by 11%.

Between those periods, yield sensitivity to frequency of irrigation, and associated levels of plant water stress, were greater. From consideration of the various experiments and treatments the approximate period of heightened sensitivity appeared to last from 65 to 110 days (25 days before until 20 days after spike emergence), largely associated with decreases in grain number. Figure 3 presents an attempt to quantify the effect of irrigation regime on yield and grain number by calculating an integrated measure of likely stress, namely the mean cumulative potential evapotranspiration from last watering over the period 65–110 days from sowing (65–100 days in the case of grain number). To do this, ΣET_P was summed over the period and the total divided by 45 (or 35). Any rain falling was subtracted, but ΣET_P was not allowed to become negative. The results indicate that irrigation in the period 65–110 days at a lesser frequency than T1 (five irrigations, mean ΣET_P 30–50 mm) would certainly reduce yield while irrigation at a greater frequency may increase yield slightly.

The demonstration of substantial yield sensitivity in the period 65–110 days agrees with the general observation of greater sensitivity around flowering (Robins *et al.*, 1967), but points to a period that is longer and starts earlier (25 days before flowering) than is usually considered by others. Fischer (1973) showed, in a controlled environment study, that grain yield was most sensitive to a given level of plant water stress (water potential) at about 10 days before spike emergence. The cultivar × treatment interaction in Experiment 1, and the lack of sensitivity after 110 days, probably reflect similar ontogenetic changes in crop sensitivity to given levels of plant water stress. Nevertheless, the main effect of treatment in these experiments appears to be more closely related to the minimum levels of Ψ reached, than to such changes in plant sensitivity. The correlation between yield and Ψ seen in Experiment 2, regardless of stage of development, illustrates this point. Higher plant water stress reached with drying in the 65–110 days period is only partly explained by greater values of ΣET_P, associated with the current high crop factor. In Experiment 2 T4, with approximately the same ΣET_P as T2 reached much greater plant water stress levels (Fig. 2). In the case of the earlier stress, incomplete ground cover and limited root exploration of the profile perhaps causes the slower onset of stress, which in turn may facilitate adaptive responses in crop morphology and physiology (Begg and Turner, 1976).

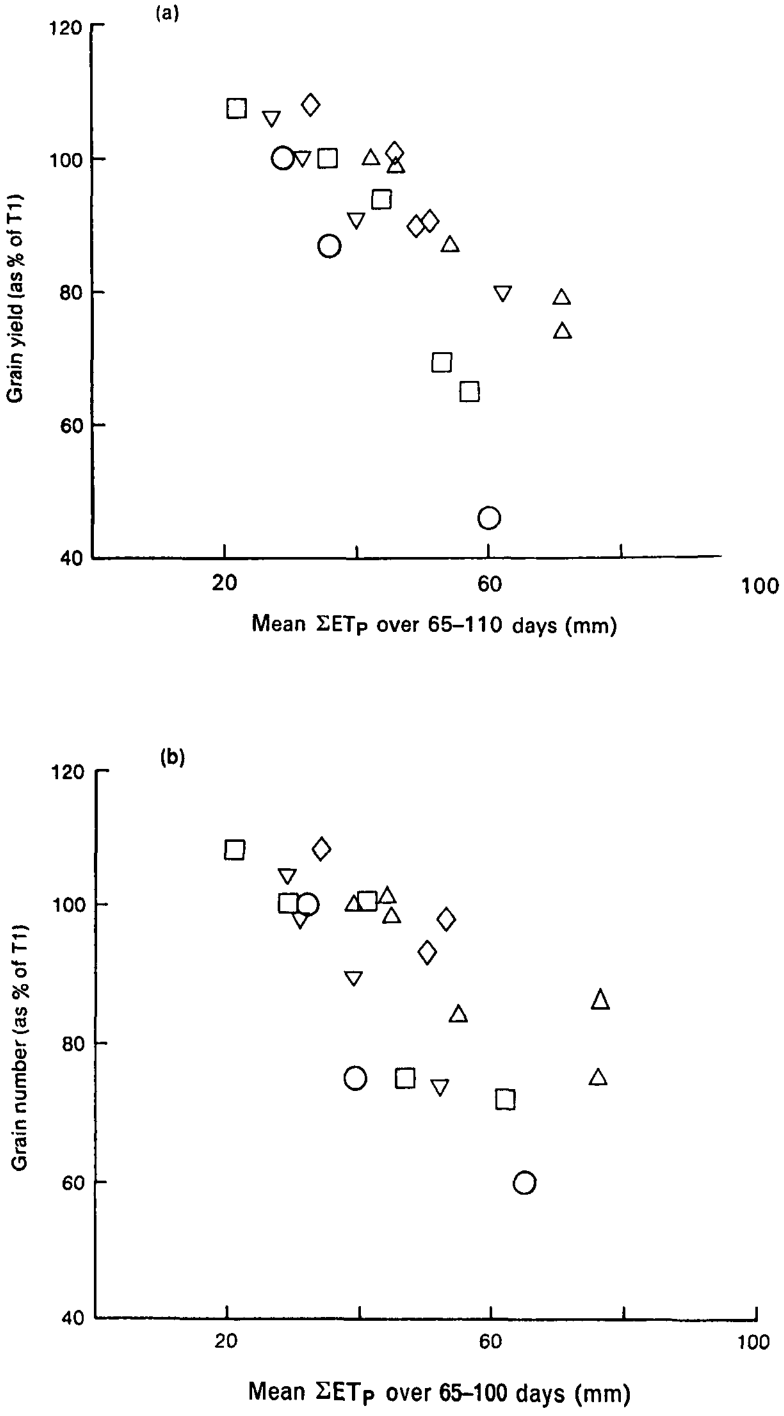

Fig. 3. (a) Grain yield (% of T1) *versus* mean cumulative potential evapotranspiration (ΣETp) over the period 65–110 days (see text); Expt 1 (○), 2 (△), 3 (□), 4 (▽) and 5 (◇); all treatments except T2 in Expt 1 and T7 and T8 in Expt 2. (b) Grain number (% of T1) *versus* mean ΣETp over the period 65–100 days; symbols as for (a) and same treatments.

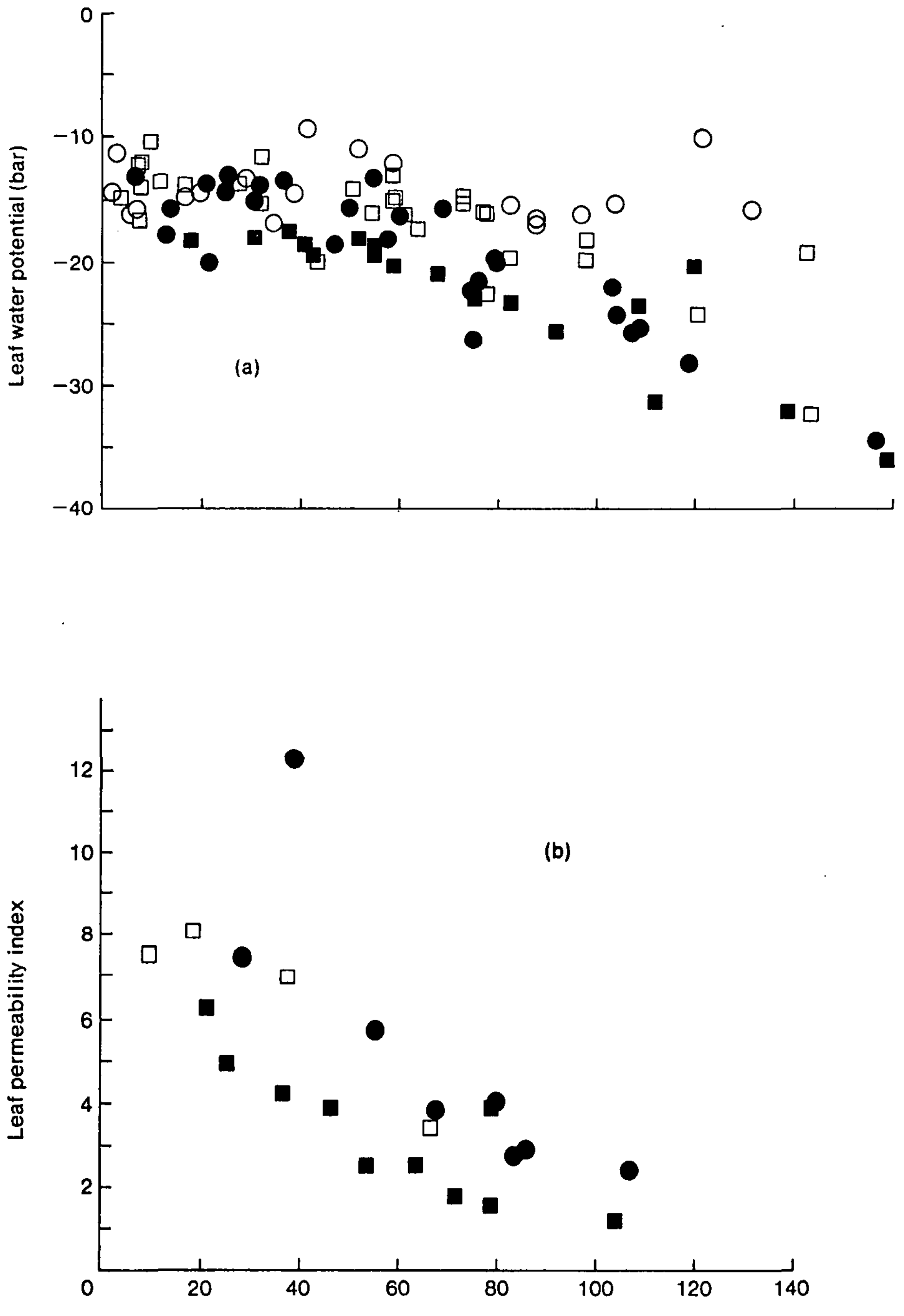

Fig. 4. (a) Mid-day leaf water potential (Ψ) as a function of cumulative potential evapotranspiration (ΣET$_P$) from the last irrigation: before 65 days (○), from 65 to 90 days (□), from 91 to 110 days (●), and after 110 days (■). Expts 2, 4 and 5; data of Expt 4 refer to measurements on stem segments adjusted to leaf water potentials by subtracting 4 bars (Fischer, Sanchez and Syme, 1977); each point is the mean of at least 24 determinations. (b) Leaf permeability (LP) index as a function of cumulative potential evapotranspiration (ΣET$_p$); Expt 5, symbols as for (a). LP index refers to $\sqrt{}$(leaf permeability in cgs units × 10^3), as in Fischer, Sanchez and Syme (1977). Each point is the mean of 32 porometer measurements; SE of mean ranged from 0·2 to 0·6.

Irrigation recommendations

The duration of flooding, and the measured absorption of water, suggest that (at least in Expts 4 and 5) the degree of soil wetting with irrigation was comparable to farmer fields. In view of the ontogenetic changes in yield-sensitivity to stress seen earlier, these experiments had longer intervals between the first and second irrigation, in order to be able to shorten the more critical intervals later. Nevertheless, maximum yield could not be achieved with only four irrigations, and in fact yields with five irrigations were perhaps 5–10% below maximum yields (Fig. 3a). The results of Lagarda (1975) from the 1973–74 season were similar, with maximum yields from seven irrigations (given at 20% available water before 60 days, and 30% afterwards), and although the corresponding 5/15% treatment, with only five irrigations, yielded 96% of maximum, other regimes with four irrigations had an average yield of only 88% of the maximum. Both studies point to the probable advantage of rearranging the currently recommended five-irrigation schedule, by lengthening the first interval. It may also be expected that a six-irrigation schedule is more clearly advantageous in unusually cool seasons, or with cultivars that are later than Yecora 70 (such as Siete Cerros 66, Saric 70 and Cajeme 71).

The gain in average efficiency of water use with decreased frequency of irrigation was small in Experiments 4 and 5 and in the Lagarda study (12 kg/ha mm with seven irrigations to 14 kg/ha mm with four) and would hardly justify a four-irrigation schedule. Overall, the marginal efficiency of the extra water used in giving six or seven irrigations compared to five irrigations ranged from 3 kg/ha mm (Lagarda, 1975) to 8 kg/ha mm (Expt 4), compared to the variable cost of irrigation below 1 kg/ha mm.

Cultivar effects

The only direct comparison with the older semi-dwarf varieties was provided by Experiment 1, where the yield interaction between variety and treatment was probably due to differences in rate of development. Lagarda found a similar association between greater yield sensitivity to early stress and earliness of the cultivar amongst his six cultivars, all released since 1970. It is suggested that differences, if any, between irrigation responses observed here with modern semi-dwarf wheats and the responses of older ones (Anon., 1969; Martinez *et al.*, 1969) can probably also be explained on the basis of small differences in maturity (the modern varieties tending to be later than the older ones used in earlier irrigation studies). The water-use efficiency at maximum yield obtained with the newer varieties (16 kg/ha mm, Expt 4; 13 kg/ha mm, Expt 5; 12 kg/ha mm, Lagarda, 1975) is considerably higher than that of the older semi-dwarfs (e.g. 9 kg/ha mm with Inia 66 in Martinez *et al.*, 1969). This gain is probably related to heavier fertilization of the newer wheats, plus their greater yield potential (Aguilar and Fischer, 1975).

Differences in rates of development and in lodging resistance led to the small cultivar × treatment interactions found here. In Experiments 4 and 5 triticales behaved no differently, but there was a tendency for Cocorit 71 to respond most to a six-irrigation regime, perhaps because of its slightly longer grain filling period, a characteristic of such durum wheats (R. A. Fischer, unpublished data). There was no evidence from the Ψ measurements of significant cultivar or cultivar × treatment effects on plant water stress.

Irrigation criteria

Particular attention needs to be paid to irrigation frequency in the approximate period 65–110 days. The approach adopted here in Experiments 3–5, when the number and arrangement of the irrigations was tested, has the advantages of not requiring time-consuming soil sampling and of being closer to commercial practice, where thinking is in terms of numbers of irrigations. Scheduling irrigations in terms of cumulative potential evapotranspiration could have possibilities.* For a given soil type this should reduce the need to adjust irrigation intervals for year-to-year weather variation or for different sowing dates.

The soil moisture data reported here show that the 5–30 cm layer dried to nearly −15 bar water potential under many treatments without drastic effects on yield, presumably because that represents only part of the root zone. Differences between treatments were always small and required a large number of samples for their detection. Sampling in the 30–60 cm layer may be better, but the time taken per sample was more than doubled.

Of the other irrigation criteria tested in this study, visual observations of wilting symptoms were not sufficiently objective to be of general use, although for experienced workers they could provide a useful rapid method. Measurement of leaf relative water content and of Ψ were time-consuming, and Ψ appeared to be rather insensitive to calculated differences in stress levels between treatments (Fig. 4a), especially before 90 days. This may be due to the greater ability of the younger crop to adapt to increasing soil moisture stress. One aspect of such adaptation could be stomatal closure during the middle of the day, and in fact LP appeared to be more sensitive to ΣET_p (Fig. 4b) than Ψ. It is interesting that, just as with yield in Figure 3a, this relation was approximately linear, LP falling as ΣET_P increased above values as low as 40 mm. Measurement of LP is simple and rapid, and the technique is recommended as a guide to plant water stress in irrigation experiments.

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* Using different quantities of cumulative evapotranspiration as the basis of irrigation treatments, Ehlig and LeMert (1976, *Soil Sci. Soc. Amer. J.* **40**, 750) working in a region adjacent to north-west Mexico (Imperial Valley of California) with the variety Yecora 70, have recently reported similar efficiencies of water use, and yield and grain number sensitivities, as obtained by us.

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