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# Scheduling for Occasional Omission of Irrigation Water for Crop Production in Moisture Deficit Areas

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**Abstract**
The study aimed at improving the conventional irrigation management practices to enhance yield and water use efficiency for pre-planned irrigation scheduling of wheat and cotton crops. Five field experiments were conducted during 1990-94. A 3-year study of moisture deficit irrigation (MDI) to wheat V-85205 continued with the same irrigation schedule(s) for two years and the third year irrigation schedule(s) were modified on the basis of the preceding year's results. It indicated that the crop was most sensitive to moisture deficit at tillering stage and least sensitive at flowering stage. In the fourth experiment, three pre-selected wheat genotypes; Sarsabz, LU-26S and Pasban-90 showed different response to moisture deficit. Comparable yields to respective conventional irrigation schedule (1111) were obtained by MDI schedule (1011), (1110) and (1101) for Sarsabz, LU-26S and Pasban- 90, respectively. The fifth experiment conducted on the genetic diversity of two pre-selected cotton genotypes NIAB-86 and FH-682 subjected to moisture deficit at vegetative, generative or maturity stages yielded 7% and 9% more seed cotton at MDI (110) excess over conventional irrigation treatments (111) saving 150 mm of irrigation water. Thus, saving of 75 and 150 mm of irrigation water for wheat and cotton crops respectively was achieved by applying improved irrigation schedule without undergoing any significant yield loss.

**Key words:** Wheat, cotton, irrigation schedule, moisture deficits, evapotranspiration, soil matric potential

## Introduction

In arid and semi-arid regions of the world the evapotranspiration of field crops always exceed rainfall leading to moisture deficit. The moisture deficit during critical crop growth stages adversely affected wheat growth and production (Musick and Dusek, 1980), drastically decreased shoot fresh weight, number of tillers and root fresh weight during early vegetative growth (Mian *et al*., 1993) and resulted in the reduction of size of the wheat grain in the tillers more than the size of the grain on main stem. During heavy fruiting, mild water stress associated with long irrigation cycles triggered deterioration of the root system of cotton that was very show to reverse (Radin *et al*., 1989). High soil matric potential inhibits root growth (Schmidhalter and Oertli, 1991). Therefore, irrigations are applied to field crops to increase yield and quality of protein (Kniep and Mason, 1991). Canal closures often lead to omission of irrigation during crop growth season. Other sources of irrigation water are scarce and expensive in arid areas. Omission of irrigation is, therefore often advisable in such cases to (i) minimize irrigation inputs without much affecting the season total biomass yield, (ii) control the weed (Norris and Ayres, 1991) and (iii) increase water use efficiency. The present studies were conducted with the following objectives:

1) To improve traditionally adapted irrigation practices for efficient use of water for crop production
2) To pre-plan the irrigation scheduling for field crops by identifying specific crop growth stages sensitive to moisture deficit and
3) To study genetic diversity for moisture deficit in crops

## Materials and Methods

All experiments were conducted at 200 m above sea level located at latitude of 31° –26´ N and longitude of 73° –26´ E in field plots at NIAB, Faisalabad, Pakistan (Table 2). The experiment station is situated in a semi-arid zone with less than 350 mm of annual rainfall and around 1650 mm year$^{-1}$ class A-pan evaporation. The irrigation was conducted with canal water (E.C. = 0.3 dS/m, pH = 7.9, SAR = 2.8). The top soil with fine nodules of lime (95-120 cm) (Table 1). All experiments were conducted in a RCBD with five replications except experiment No. 3 where three replications were maintained. Experiment No. 1 to 3 were conducted in split plot design with irrigation in the main plot and fertilizer levels in sub-plots. In experiment No. 4 the split plot design involved wheat genotypes in the main plots and irrigations in the subplots. In experiment No. 5 the irrigation were placed in the main plot and cotton varieties in the subplots. All experiments were sown in mid December each year. In the first year, no pre-sowing irrigation was applied as the soil had adequate residual moisture from the previous rice crop. In the subsequent years the crop was sown after pre-sowing irrigation for land preparation. The seed rate was 90 kg $ha^{-1}$ for wheat and 16 kg $ha^{-1}$ for cotton (delinted seed). The recommended agronomic practice were employed for sowing in all cases. The cotton plants were thinned to maintain an inter-row distance of 75 cm and an inter-plant distance of 25 to 30 cm. The main plot size of all treatments was **10×7** m sq. Fertilizers were applied to all treatments in split doses as given in Table 4. Polytrin C, Novacron, Curacron and Thiodan were sprayed on the cotton crop when pest population reached economical level. The reference evapotranspiration $ET_{\circ}$ was calculated according to Penman-Monteith. Soil moisture depletion was monitored with Neutron Hydroprobe CPN-503 from the neutron access tubes installed in the soil down to 1 m for wheat and 1.65 m for cotton. Soil moisture potential was measured from tensiometers installed in the effective root zone. Actual evapotranspiration of the crop $ET_{\circ}$ was determined using water balance method considering irrigation, rainfall, soil moisture depletion and drainage (runoff being nil in the plots). Actual grain yield $Y_a$ (kg $ha^{-1}$), maximum grain yield $Y_a$ (kg $ha^{-1}$). Irrigation I (mm-period), field water use efficiency $E_r$ (kg $ha^{-1}$ $m^{-3}$) and crop water use efficiency $E_c$ (kg $ha^{-1}$ $m^{-3}$) were each determined. The yield response factor $K_3$ was calculated using:

$$\left[I - Y_a\, Y_m^{-1}\right] K_y \left(I - ET_a\, ET_m^{-1}\right)$$

Conventional flood irrigations were applied with 75-10 mm of irrigation water when available water AW was within the range of 60-90% and deficit irrigation were applied when the AW was at 30-60%. The CSM treatments were maintained at maximum soil matric potential of -50 kpa and the amount of irrigation water was calculated on the basis of effective root zone depth. The irrigation schedule and treatments are given in Table 3. The crop was harvested at maturity. Data was subjected to analysis of variance followed by Duncan's new multiple range test (Steel and Torrie, 1980).

## Results and Discussions

### Yield and irrigations

### Wheat experiment 1991-92

The experiment, with a pre-selected wheat genotype V-85205 was conducted on a rice field without a pre-sowing irrigation that received 87 mm of rainfall well distributed over crop stages II-IV. The temperature cycle and humidity was normal. maximum grain yield (Table 5) was observed at $T_1$ (1111), the conventional flood irrigation treatment. At the low fertilizer level maximum grain yield was the same for $T_7$(1101), $T_1$(1111) and $T_2$(1100) showing that at the lower fertilizer level even higher irrigation inputs could not be duly beneficial. Minimum grain yield was produced in $T_9$(0000) rainfed, as expected. Comparing two irrigation in Fig. 1, $T_2$(1100) produced maximum and $T_3$(0011) minimum grain yield. In the former case, 87-84% excess grain yield was produced applying the same quantity of irrigation water at the two fertilizer levels, respectively. This yield variation confirms those of Hassan *et al*. (1987) who reported 65% loss in grain yield owing to moisture deficit at crop stages I and II. This shows that the same irrigation water if applied at the earlier crop stage lead to consumptive use of water compared to later stages. Among three irrigation treatments the maximum grain yield was produced in $T_8$(1110) followed by $T_7$(1101) and minimum yields in $T_6$(0111) at both fertilizer levels. Shifting moisture deficit from crop stage III to IV did not affect grain yield significantly at the medium fertilizer levels. At the low fertilizer level $T_7$(1101) clearly out yielded the other moisture deficit treatments and the grain production was even better than the 4-irrigation treatment $T_1$(1111). It showed that with one irrigation at any later stages could be saved without significant loss in grain yield. Similarly grain yield in $T_4$(1001) and $T_5$(1011) was the same, again indicating that the irrigation at crop stages III did not contribute significantly to the wheat grain production. Minimum $E_f$ was observed at $T_3$(0011) and $T_6$(0111) - both missing an essential irrigation at crop stage I. $E_f$ decreased with reduced fertilizer input within an irrigation but increased when exposed to moisture deficit for a prolonged period. It may be concluded that the moisture deficit at the later stages was not a detrimental toward grain yield as at earlier stages.

### Wheat experiment 1992-93

The experiment conducted on Mung bean (Vigna radiata) fields applying a pre-sowing irrigation for land preparation. During the year 1992-93 the crop season was relatively dry and hot with an elevated temperature cycle of 4°C over average of the season and no rainfall at DAS 41 to 60. The total rainfall of the season was 41 mm of which 35 min was received in crop stage III. The generative processes started 1-15 d earlier reducing the vegetative growth duration of crop. The overall grain yield (Table 5) decreased compared to that of the previous year. This yield decrease was in accordance with the finding of Aggarwal and Kalra (1994) who reported an average grain yield loss of 428 kg-(ha C°)$^{-1}$ with temperature during vegetative growth period in this region. Maximum grain yield produced in T7(1101) at both fertilizer levels (Fig. 2) with 4-6% increase over $T_1$(1111)-the conventional flood irrigation treatment, saving at least 75 mm irrigation water. The lowest grain yield produced in the rainfed treatment. Comparable grain yield at medium fertilizer levels were observed in $T_2$(1100), $T_4$(101) and $T_5$(1011) all involving irrigation at crop stage I. The later treatments did not differ significantly from each other showing no contribution of irrigation to grain yield at crop stage III. Two stages of irrigation treatments showed grain yield increase of 29% and 84% in $T_2$(1100) over $T_3$(0011) at two fertilizer levels, respectively, applying the same quantity of irrigation water. Similar results were reported by Storrier (1965). Thus, irrigating this wheat variety at early stages was more productive than irrigating at late stages as observed last year. The treatment with and without irrigation at crop stage 1 could be separated into different groups with 3 to 55% variation in grain yield. The $E_f$ was maximum under rainfed conditions followed by $T_2$(1100), $T_4$(1001) and $T_7$(1101). The conventional flood irrigation treatment $T_1$(1111) could be ranked as lowest efficiency group at both fertilizer levels. The $E_f$ increased with reduction in fertilizer inputs within irrigations.

**Wheat experiment 1993-94**

The experiment was conducted on the field left fallow from monsoon rain up to wheat sowing in 1993-94. A pre-sowing irrigation was applied to facilitate land preparation. The crop observed a normal season with respect to temperature and rainfall (42 mm) over crop stages II to IV. The experiment was conducted with irrigation schedule modified on the basis of results obtained from the previous experiments of 1991-93. Adequate soil moisture in the soil profile at the crop stage 1 and uniformly distributed rainfall led to a good harvest. Maximum grain yield (Table 5) produced under rainfed conditions in $T_3$(0000) with 35 and 47% loss at the two fertilizer levels, respectively. Comparable grain yield (Fig. 3) produced from $T_2$(1111), $T_7$(1100) and $T_3$(1101) all were irrigated at early crop stages at both fertilizer levels. $E_f$ was maximum in $T_3$(0000) followed by $T_4$(1000). All deficit irrigation treatment observed higher $E_f$ than those for $T_1$(CSM) and $T_2$(1111) controls. The three year study on the same variety during different season showed that early crop stages of wheat were more sensitive to drought. An irrigation at crop stage III did not contribute significantly to the total variation in grain yield.

**Genetic diversity of wheat to moisture deficit**

This experiment was conducted in 1993-94 crop season to verify the result obtained during 1991-94 experiments on a wheat genotype. Three pre-selected wheat genotypes (Sarsabz, LU-26S and Pasban-90) were exposed to moisture deficit irrigations as per irrigation schedule given in Table 3. Under rainfed conditions, 33 to 44% yield loss occurred (Table 5). Different pattern of stage sensitivity (Fig. 4) was observed in the three wheat genotypes. Sarsabz in $T_4$(1011) and $T_6$(1110), LU26S in $T_6$(1110) and Pasban-90 in $T_5$(1101) with the moisture deficit irrigation treatments produced wheat grain comparable to $T_2$(1111). Thus, at least 175 mm of irrigation water was saved without affecting the ultimate grain yield. Under rainfed conditions LU26S produced up to 12% higher grain yield than those of Sarsabz and Pasban-90. The field water use efficiency $E_f$ was maximum with rainfed irrigation treatment $T_3$(0000) in all wheat varieties. Generally, the $E_f$ was lower in $T_2$(1111) than all other irrigation treatments.

**Genetic diversity of cotton to moisture deficit**

A field experiment was conducted in field after wheat crop. Pre-sowing irrigation was applied for land preparation. The crop observed a normal season with respect to meteorology. A total of 164 mm of rainfall received; 80 and 83 mm received at the generative and maturity stages, respectively which reduced the deficit period. Two pre-selected cotton genotypes, NIAB-86 and FH-682, exposed to moisture deficit irrigations responded differently to moisture deficit. Maximum seed cotton yield (Table 5) of both genotypes was observed in treatment $T_1$ (CSM) and minimum in $T_3$(000) under the rainfed conditions. However, the yield under rainfed conditions was higher than expected owing to favorable climatic conditions that prevailed during crop stages II and III. The well distributed rainfall over these stages was probably used most efficiently under $T_3$(000). Irrigation treatments $T_3$(000) and $T_6$(011) were the lowest yielding. $T_1$(CSM) and $T_5$(110) were not significantly different from each other indicating that irrigation at vegetative and generative stages was efficiently used. The seed cotton yields of NIAB-86 in treatments $T_1$(CSM), $T_2$(111), $T_5$(110) and $T_8$(010) were not significantly different from each other. The moisture deficit treatments with and without irrigation at crop stage II differed by 23% employing the same quantity of irrigation water. Similar results were reported by Radin *et al*. (1989). $T_5$ (110) and $T_8$(010) produced comparable yield by employing 300 and 150 mm of irrigation water, respectively. These results showed that irrigation at crop stage II contributed maximum to seed cotton yield of this variety. $T_5$(110) yielded 23% and 12% more than $T_6$(011) and $T_7$(100), respectively. The overall order of contribution of irrigation to the seed cotton yield of NIAB-86 was:

Crop stage II > Crop stage 1 > Crop stage III

For variety FH-682 yields from $T_5$(110) and $T_7$(100) did not differ significantly from each other, with each receiving irrigation at the vegetative stage. The treatments, with and without irrigation at vegetative stage, differed by 29% employing the same quantity of irrigation water. Similarly $T_7$(100) using 150 mm less irrigation water produced 26% more seed cotton than did $T_6$(011). In this treatment, the irrigation at crop stage III rather lowered the seed cotton yield owing to the initiation of re-vegetation process which probably limited the photo-synthates material supply to cotton bolls. Thus, the order of contribution of irrigation to seed cotton yield for FH-682 variety was:

Crop stage I > Crop stage II > Crop stage III

Water use efficiently $E_C$ and yield response factor $k_3$

**Wheat crop 1991-92**

Actual water use efficiency $E_C$ of crop was maximum (Table 5) in $T_5$(1001) followed by $T_7$(1101) and $T_8$(0111). Lowest $E_C$ was observed in $T_3$(0011) and $T_6$(0111) in which both missed an irrigation at crop stage 1. The $E_C$ values of $T_7$(1101) and $T_8$(1110) were comparable at both fertilizer levels showing that moisture deficit at irrigation stage III and IV had similar effects. $E_C$ was maximum in $T_2$(1100) and minimum in $T_3$(0011) showing that water was more efficiently used at earlier stages. The yield response factor $k_y$ was lowest in $T_2$(1100) and $T_1$(1111) while it was maximum in $T_6$(0111) indicating maximum sensitivity to moisture deficit at tillering. At the low fertilizer level $k_y$ was minimum for $T_7$(1101) comparable to lower doses. These results confirm those of Gajri *et al*. (1993) who reported that higher N fertilizer application enhanced evapotranspiration.

**Wheat crop 1992-93**

Highest water use efficiency $E_C$ was observed (Table 5) in treatment $T_9$(0000) followed by $T_2$(1100), $T_7$(1101), $T_8$(1110) and $T_5$(1011) all involving and irrigation at crop stage 1. Lower $E_C$ values were observed in $T_1$(1111), $T_3$(0011) and $T_6$(0111) owing to either over-irrigation or missing an irrigation at crop stage 1. $E_c$ increased in the irrigation treatment with higher fertilizer inputs. The overall $E_C$ decreased owing to high evaporation as is obvious from $ET_◦$ being 345 min for the year 1992-93 compared to that of 315 mm for 1991-92. $T_2$(1100) at the low fertilizer level gave a similar value as that for $T_4$(1001) at medium fertilizer level. Thus, shifting the irrigation schedule from crop stage IV to II saved fertilizer inputs by 50% without effecting the $E_C$. Maximum yield response factor $k_y$ was observed in $T_6$(0111) and $T_3$(0011) both missing an irrigation at crop stage 1. The crop showed least sensitivity to moisture deficit at crop stage III as evident in $T_7$(1101).

**Wheat 1993-94**

Maximum water use efficiency $E_C$ was observed (Table 5) in treatment $T_3$(0000) under rainfed condition. Among the moisture deficit irrigations involving irrigation treatment maximum EC was observed in $T_7$(1100) followed by $T_5$(1001), both involving irrigation at crop stage 1 and maximum in $T_6$(0101) missing an irrigation in crop stage 1. At the lower fertilizer level $T_2$(1111) and $T_8$(1101) had the lowest $E_C$ values indicating that at low fertilizer input large amounts of irrigation did not maintain $E_c$. The yield response factor $k_y$ was maximum in $T_2$(1111). At the medium fertilizer $k_y$ was minimum in $T_7$(1100) and maximum in $T_6$(0101) supporting that the moisture deficit exposed at later stage did not affect the yield as compared to crop stage 1. Three years studies on the same variety showed that the irrigation at crop stage 1 contributed most to the total variation in grain yield. On the other hand, the moisture deficit at crop sage III did not affect the yield significantly.

**Genetic diversity of wheat to moisture deficit**

Maximum water use efficiency $E_C$ was observed (Table 5) in treatment $T_3$(000) but at the cost of 38 to 44% loss of grain yield. In all cases, $E_C$ of the conventional flood irrigation treatments $T_2$(1111) was lowest. Probably, the water was more effectively utilized in the vegetative growth as compared to that during grain filling, as observed from the low values of harvest index (not reported here). For LU-26S, the order was reversed with the $E_c$ value of $T_6$(1110) being higher than that of $T_4$(1011). For Pasban-90, $E_C$ was maximum $T_5$(1101). Thus, under moisture deficit conditions the three varieties had different options for maximizing $E_C$. The yield response factor $k_y$ was lowest for $T_4$(1011) in Sarsabz, $T_6$(1110) in LU-26S and $T_5$(1101) in Pasban-90 showing least effect of moisture deficit at crop stages II. IV and III, respectively for the respective variety.

**Genetic diversity of cotton to moisture deficit**

For cotton variety NIAB-86, a maximum $E_C$ value was

Table 1: Soil profile description of experimental site

| Depth (m) | Horizon | Profile description |
|---|---|---|
| 0-0.15 | Ap | Loam massive structure |
| 0.15-0.95 | Bw | Loam week structure |
| 0.95-1.20 | Bwk | Loam with fine nodules (lime) weak structure |
| 1.20-1.80 | C1 | Very fine sandy loam, massive |
| 1.80-1.95 | C2 | Silt loam; close to sility clay loam |
| 1.95-2.10 | C3 | Very fine sandy loam |
| 2.10-2.40 | | Fine sandy loam |
| 2.40-2.55 | | Loamy fine sand |
| 2.55-3.10 | | Fine sand |
| > 3.10 | | Medium sand |

Table 2: Van Genuchten-Mualeum equation parameters (average) determined by SFIT and RETC computer programs for the experimental site at NIAB, Faisalabad, Pakistan

| Depth (cm) | α | n | λ ($cm^{-1}$) | $K_s$ (cm $hr^{-1}$) | $\theta_I$ ($cm^3$ $cm^{-3}$) | $\theta_s$ ($cm^3$ $cm^{-3}$) | $r^2$ |
|---|---|---|---|---|---|---|---|
| | | | | SFIT Program | | | |
| 25 | 0.022 | 1.853 | 1.37 | 2.623 | 0.133 | 0.344 | 0.993 |
| 50 | 0.020 | 1.429 | 0.44 | 1.426 | 0.109 | 0.354 | 0.999 |
| 75 | 0.013 | 1.462 | 0.504 | 0.903 | 0.069 | 0.360 | 0.998 |
| 100 | 0.007 | 2.030 | 2.075 | 0.768 | 0.076 | 0.367 | 0.999 |
| | | | | RETC program | | | |
| 25 | 0.018 | 1.763 | 5.774 | 6.761 | 0.135 | 0.340 | 0.855 |
| 50 | 0.008 | 1.533 | 0.0001 | 0.851 | 0.000 | 0.349 | 0.915 |
| 75 | 0.011 | 1.716 | 0.732 | 0.404 | 0.158 | 0.358 | 0.966 |
| 100 | 0.009 | 1.949 | 0.0001 | 0.815 | 0.187 | 0.367 | 0.952 |

Table 3: Irrigation schedule of treatments

| | Code | Description |
|---|---|---|
| Wheat | 1111 | Conventional 4 irrigations at tillering booting, flowering and grain filling |
| | 0000 | No irrigation up to 30% AW; rain fed |
| | CSM | Maintaining maximum soil matric potential to -50 kPa |
| | 1100 | Moisture deficit after booting |
| | 0011 | Moisture deficit up to booting |
| | 1001 | Moisture deficit at booting to flowering |
| | 1011 | Moisture deficit at booting only |
| | 0111 | Moisture deficit at tillering only |
| | 1101 | Moisture deficit at flowering only |
| | 1110 | Moisture deficit at grain filling only |
| Cotton | CSM | Maintaining maximum soil matric potential to -50 kPa |
| | 111 | Conventional irrigations at vegetative, generative and maturity stages |
| | 000 | No irrigation up to 30% AW; ran fed |
| | 101 | Moisture deficit at generative stage |
| | 110 | Moisture deficit at maturity stage |
| | 011 | Moisture deficit at vegetative stage |
| | 100 | Moisture deficit at generative to maturity stages |
| | 010 | Moisture deficit at vegetative and maturity stages |

[1]0 designates moisture deficit and 1 designates irrigated

Table 4: Fertilizer application to wheat and cotton crops

| | Fertilizer input | Medium dose NPK (kg $ha^{-1}$) | Low dose NPK (kg $ha^{-1}$) |
|---|---|---|---|
| Wheat | Basal dose | 50:100:60 | 25:50:30 |
| | With irrigation | 50:0:0 | 25:0:0 |
| Cotton | Basal dose | 23:60:60 | - |
| | 1st irrigation | 60:0:0 | - |
| | 3rd irrigation | 60:0:0 | - |

Table 5: Grain yield $Y_a$, irrigation I, evapotranspiration $Et_a$, water use efficiencies $E_I$ and $E_c$ and yield response factor $k_y$

| Treatment | Irrigation treatment | Fertilizer level | $Y_a$ (kg $ha^{-1}$) | I (mm) | $E_I$ (kg (ha $m^3)^{-1}$) | $Et_a$ (mm) | $E_c$ (kg. (ha $m^3)^{-1}$) | $K_y$ |
|---|---|---|---|---|---|---|---|---|
| | | | | Wheat 1991-92 | | | | |
| $T_1$ | 1111 | 1 | 5131 | 387 | 13.2 | 360 | 14.2 | - |
| | | 2 | 4023 | 387 | 10.4 | 349 | 11.5 | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $T_2$ | 1100 | 1 | 4942 | 237 | 20.8 | 305 | 16.2 | 0.27 |
| | | 2 | 3945 | 237 | 16.8 | 290 | 13.6 | 0.23 |
| $T_3$ | 11 | 1 | 2633 | 237 | 11.1 | 276 | 9.5 | 2.13 |
| | | 2 | 2154 | 237 | 9.1 | 257 | 8.4 | 1.81 |
| $T_4$ | 1001 | 1 | 4501 | 237 | 19 | 290 | 15.5 | 0.63 |
| | | 2 | 3692 | 237 | 15.6 | 280 | 13.2 | 0.5 |
| $T_5$ | 1011 | 1 | 4377 | 312 | 14 | 333 | 13.2 | 1.87 |
| | | 2 | 3702 | 312 | 11.8 | 315 | 11.7 | 1 |
| $T_6$ | 111 | 1 | 3533 | 312 | 11.8 | 325 | 10.9 | 3.1 |
| | | 2 | 2904 | 312 | 9.3 | 320 | 9.1 | 3.62 |
| $T_7$ | 1101 | 1 | 4738 | 312 | 15.2 | 327 | 14.5 | 0.89 |
| | | 2 | 4102 | 312 | 13.1 | 325 | 12.6 | 0 |
| $T_8$ | 1110 | 1 | 4773 | 312 | 15.3 | 331 | 14.4 | 0.87 |
| | | 2 | 3869 | 312 | 12.2 | 309 | 12.4 | 0.64 |
| $T_9$ | 0 | 1 | 2603 | 81 | 32.1 | 218 | 11.9 | 1.26 |
| | | 2 | 1884 | 81 | 23.1 | 170 | 11 | 1.06 |
| | | | | Wheat 1992-93 | | | | |
| $T_1$ | 1111 | 1 | 3911 | 341 | 11.5 | 394 | 9.9 | - |
| | | 2 | 3159 | 341 | 9.3 | 379 | 8.3 | - |
| $T_2$ | 1100 | 1 | 3397 | 191 | 17.8 | 263 | 12.9 | 0.54 |
| | | 2 | 3032 | 191 | 15.9 | 253 | 12 | 0.24 |
| $T_3$ | 11 | 1 | 2633 | 191 | 13.8 | 264 | 10 | 1.12 |
| | | 2 | 1649 | 191 | 8.6 | 235 | 7 | 1.31 |
| $T_4$ | 1001 | 1 | 3404 | 191 | 17.8 | 284 | 12 | 0.64 |
| | | 2 | 2611 | 191 | 13.7 | 258 | 10.1 | 0.62 |
| $T_5$ | 1011 | 1 | 3496 | 266 | 13.1 | 316 | 11.1 | 0.8 |
| | | 2 | 2952 | 266 | 9.7 | 303 | 9.7 | 0.5 |
| $T_6$ | 111 | 1 | 2688 | 266 | 10.1 | 314 | 8.6 | 1.75 |
| | | 2 | 2292 | 266 | 8.6 | 311 | 7.4 | 1.67 |
| $T_7$ | 1101 | 1 | 4170 | 266 | 15.7 | 330 | 12.6 | 0 |
| | | 2 | 3279 | 266 | 12.3 | 326 | 10.1 | 0 |
| $T_8$ | 1110 | 1 | 3667 | 266 | 13.9 | 324 | 11.4 | 0.61 |
| | | 2 | 3120 | 266 | 12.1 | 316 | 9.9 | 0.29 |
| $T_9$ | 0 | 1 | 2087 | 41 | 51 | 143 | 14.6 | 0.78 |
| | | 2 | 1509 | 41 | 36.8 | 137 | 11 | 0.84 |
| | | | | Wheat 1993-94 | | | | |
| $T_1$ | CSM | 1 | 6321 | 414 | 15.3 | 394 | 16 | - |
| | | 2 | 5860 | 414 | 14.2 | 371 | 5.8 | - |
| $T_2$ | 1111 | 1 | 5662 | 341 | 16.6 | 382 | 14.8 | 3.33 |
| | | 2 | 5014 | 341 | 14.7 | 360 | 13.8 | 4.67 |
| $T_3$ | 0 | 1 | 4132 | 41 | 101.1 | 189 | 21.8 | 0.67 |
| | | 2 | 3103 | 41 | 75.7 | 174 | 17.8 | 0.89 |
| $T_4$ | 1000 | 1 | 4831 | 116 | 41.6 | 242 | 19.9 | 0.6 |
| | | 2 | 4425 | 116 | 38.1 | 229 | 19.3 | 0.63 |
| $T_5$ | 1001 | 1 | 4990 | 191 | 26.1 | 248 | 20.1 | 0.57 |
| | | 2 | 4547 | 191 | 23.9 | 236 | 19.3 | 0.61 |
| $T_6$ | 101 | 1 | 4412 | 191 | 23.2 | 252 | 17.5 | 0.83 |
| | | 2 | 4143 | 191 | 21.7 | 241 | 17.52 | 0.83 |
| $T_7$ | 1100 | 1 | 5605 | 191 | 29.3 | 272 | 20.6 | 0.35 |
| | | 2 | 4561 | 191 | 23.9 | 270 | 16.9 | 0.81 |
| $T_8$ | 1101 | 1 | 5619 | 266 | 21.1 | 318 | 17.7 | 0.58 |
| | | 2 | 4778 | 266 | 18 | 313 | 15.3 | 1.06 |
| | | | | Wheat genotype Sarsabz | | | | |
| $T_1$ | CSM | | 5561 | 306 | 18.2 | 355 | 15.7 | - |
| $T_2$ | 1111 | | 5113 | 341 | 15 | 335 | 15.3 | 1.43 |
| $T_3$ | 0 | | 3130 | 41 | 76.3 | 167 | 18.7 | 0.83 |
| $T_4$ | 1011 | | 5272 | 266 | 19.8 | 310 | 17 | 0.41 |
| $T_5$ | 1101 | | 5011 | 266 | 18.8 | 307 | 16.3 | 0.73 |
| $T_6$ | 1110 | | 5107 | 266 | 19.2 | 316 | 16.2 | 0.74 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Wheat genotype LU26S | | | | |
| $T_1$ | CSM | 5540 | 308 | 18.2 | 343 | 16.1 | - |
| $T_2$ | 1111 | 5106 | 341 | 15 | 327 | 15.6 | 1.67 |
| $T_3$ | 0 | 3722 | 41 | 90.8 | 177 | 21 | 0.68 |
| $T_4$ | 1011 | 4893 | 266 | 18.4 | 289 | 16.9 | 0.74 |
| $T_5$ | 1101 | 4565 | 266 | 21.3 | 273 | 16.7 | 0.86 |
| $T_6$ | 1110 | 5174 | 266 | 19.4 | 304 | 17 | 0.58 |
| | | | Wheat genotype Pasban-90 | | | | |
| $T_1$ | CSM | 5121 | 306 | 16.7 | 329 | 15.6 | - |
| $T_2$ | 1111 | 469 | 341 | 15.2 | 308 | 15.2 | 1.32 |
| $T_3$ | 0 | 3148 | 41 | 76.8 | 172 | 18.3 | 0.81 |
| $T_4$ | 1011 | 4830 | 266 | 18.1 | 270 | 17.9 | 0.32 |
| $T_5$ | 1101 | 4987 | 266 | 18.7 | 276 | 18.1 | 0.16 |
| $T_6$ | 1110 | 4740 | 266 | 17.8 | 290 | 16.3 | 0.63 |
| | | | Cotton genotype NIAB-86 | | | | |
| $T_1$ | CSM | 3112 | 687 | 4.5 | 762 | 4.08 | - |
| $T_2$ | 111 | 2934 | 612 | 4.8 | 716 | 4.1 | 0.95 |
| $T_3$ | 0 | 2106 | 237 | 8.9 | 427 | 4.93 | 0.75 |
| $T_4$ | 101 | 2408 | 462 | 5.2 | 557 | 4.32 | 0.85 |
| $T_5$ | 110 | 3144 | 462 | 6.8 | 562 | 5.59 | 0 |
| $T_6$ | 11 | 2544 | 462 | 5.5 | 561 | 4.53 | 0.73 |
| $T_7$ | 100 | 2814 | 387 | 9 | 559 | 5.03 | 0.37 |
| $T_8$ | 10 | 3110 | 387 | 10 | 548 | 5.67 | 0.03 |
| | | | Cotton genotype FH-682 | | | | |
| $T_1$ | CSM | 3102 | 687 | 4.5 | 787 | 3.94 | - |
| $T_2$ | 111 | 2768 | 612 | 4.5 | 720 | 3.84 | 1.37 |
| $T_3$ | 0 | 2404 | 237 | 10.1 | 412 | 5.83 | 0.46 |
| $T_4$ | 101 | 2776 | 462 | 6 | 559 | 4.97 | 0.34 |
| $T_5$ | 110 | 3024 | 462 | 6.5 | 550 | 5.5 | 0.1 |
| $T_6$ | 11 | 2336 | 462 | 5 | 563 | 4.15 | 0.86 |
| $T_7$ | 100 | 2916 | 387 | 9.3 | 562 | 5.19 | 0.21 |
| $T_8$ | 10 | 2798 | 387 | 9 | 545 | 5.13 | 0.32 |

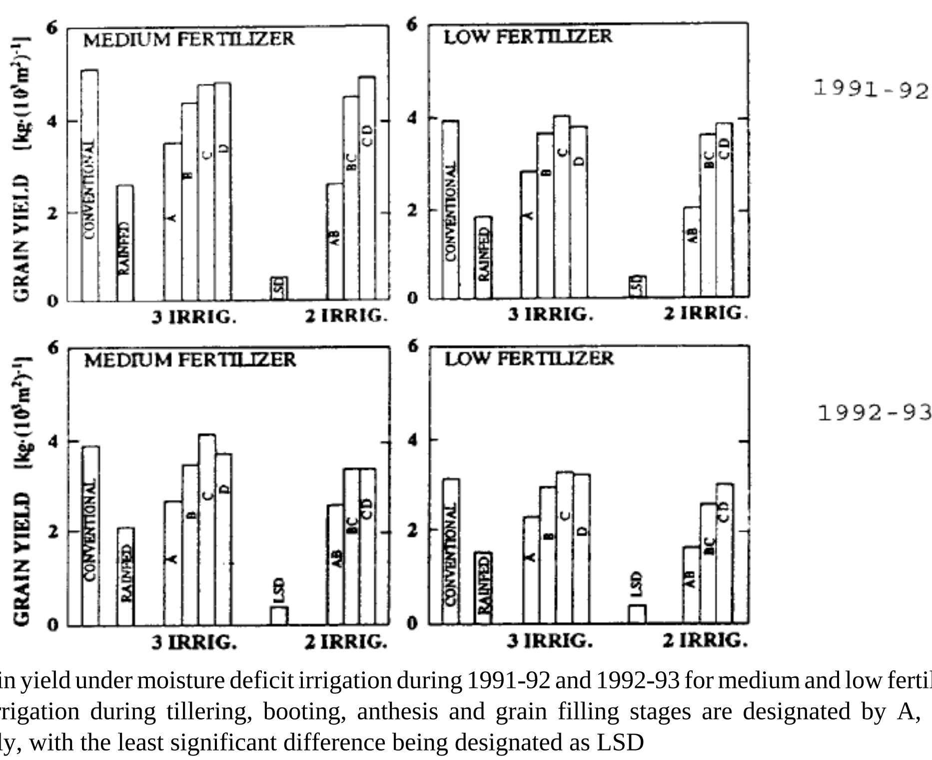


Fig. 1: Wheat grain yield under moisture deficit irrigation during 1991-92 and 1992-93 for medium and low fertilizer regimes. Missing irrigation during tillering, booting, anthesis and grain filling stages are designated by A, B, C and D, respectively, with the least significant difference being designated as LSD

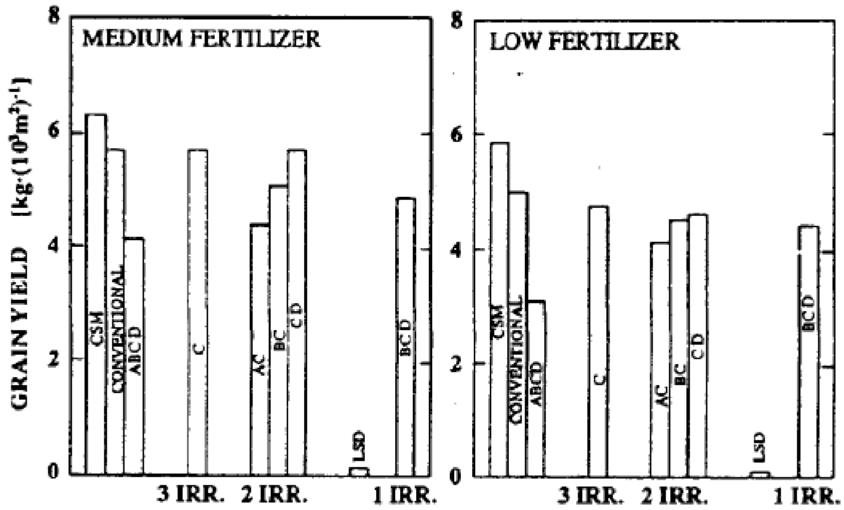


Fig. 2: Wheat grain yield under moisture deficit irrigation during 1993-94 for medium and low fertilizer regimes. Missing irrigation during tillering, booting, anthesis and grain filling stages are designated by A, B, C and D, respectively, with the least significant difference being designated as LSD

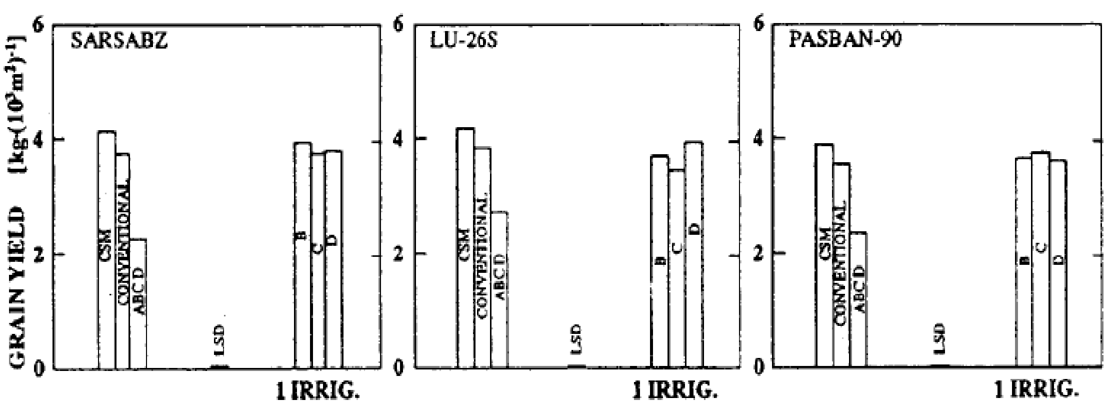


Fig. 3: Grain yield of three wheat genotypes under moisture deficit irrigation during 1993-94. Missing irrigation during tillering, booting, anthesis and grain filling stages are designated by A, B, C and D, respectively, with the least significant difference being designated as LSD

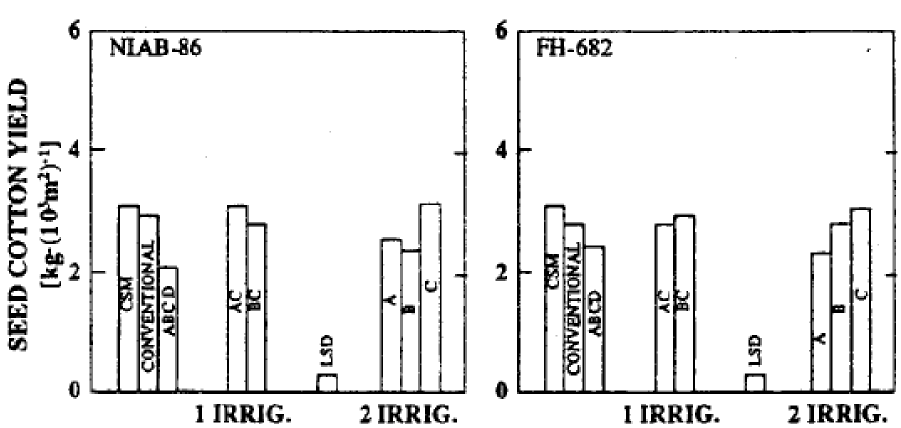


Fig. 4: Seed cotton yield of two genotypes under moisture deficit irrigation during 1994. Missing irrigation during tillering, booting, anthesis and grain filling stages are designated by A, B, C and D, respectively, with the least significant difference being designated as LSD

observed (Table 5) for treatment $T_8$(010) followed by $T_5$(110). Both treatments included an irrigation at the generative crop stage. The lowest $E_C$ was observed in $T_1$(CSM) and $T_2$(111) where the conventional flood irrigation system was used. For NIAB-86, among moisture deficit at two crop stages, treatment $T_5$(110) was most efficient as compared to the other treatments. $T_8$(010) had a higher $E_C$ than did $T_6$(011) leading to 22% more seed cotton yield and saving 19 mm water. The lowest $k_y$ value was observed at $T_1$(CSM) and $T_4$(010) followed by $T_8$(010) – all involving an essential irrigation at the crop stage II. For variety FH-682 the rainfed treatment $T_3$(000) scored the highest $E_C$ followed by $T_5$(110) and $T_8$(010). The lowest $E_C$ was observed in $T_2$(111) followed by $T_1$(CSM). Among moisture deficit irrigation $T_6$(011) was the lowest and $T_5$(110) the maximum showing that moisture deficit at vegetative stage reduced the $E_C$. After $T_1$(CSM) the lowest $k_y$ was observed in $T_5$(110) under moisture deficit at maturity stage. $k_y$ was maximum in $T_6$(011) showing that moisture deficit at vegetative stage reduced the yield in this variety. The two varieties showed different behaviour for $k_y$ in moisture deficit irrigations. The seed cotton yield of NIAB-86 and FH-682 was enhanced by irrigation at generative and vegetative stages, respectively.

## Conclusion

The moisture deficit irrigation approach helped in the pre-planned irrigation scheduling of wheat and cotton crops with multiple options to utilize water and fertilizer more efficiently. In wheat, irrigation at tillering was most sensitive to moisture deficit. At other crop stages, the varieties responded differently to moisture deficit. In cotton, FH-682 and NIAB-86 showed maximum sensitivity to moisture deficit at vegetative and generative stages, respectively. The soil moisture neutron probe proved to be a very useful tool for assessing root zone soil moisture in irrigation experiments.

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