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FINAL REPORT

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CROP YIELD RESPONSE TO WATER STRESS IMPOSED AT DIFFERENT GROWTH STAGES

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SUMMARY

Potato has attained great importance in Pakistan during the past decade. The crop requires sufficient soil moisture and fertilization to produce high yields but the present water resources are limited compared to the cultivable land, Field experiments were conducted from 1991 to 1995 to study relationship between yield and crop water use as a function of water stress imposed at different growth stages in order to make best use of scarce water resources. The experiments were factorial combination of 7 irrigation and 2 fertilizer treatments. The irrigation treatments involved application of full and stress waterings selectively at four growth stages: Establishment, Flowering, Tuber formation and Ripening. In full watering, full water requirements of the crop were met, i.e., $ET_a = ET_m$ whereas in stress watering about half the amount of full watering was applied, i.e., $ET_a < ET_m$. Changes in moisture content of the soil prefiles after irrigation were monitored with the help of neutron moisture probe in order to compute ET_a by the water balance method.

The results obtained showed that the highest tuber yield was produced by full watering (T1) and the lowest by continuous stress watering (T2). The relative reduction in yield over T1 ranged between 4 to 54% in different treatments in different growing seasons. A plot of relative yield against relative evapotranspiration deficit revealed that ripening was the lest sensitive whereas early development followed by flowering the most sensitive growth stage to water stress. The crop water use efficiencies were generally higher in the treatments where a combination of normal and stress watering was applied compared to where all-normal waterings were applied. The water thus saved could be used to bring additional areas under cultivation. The traditional irrigation practice was not efficient; it resulted in wasteful water application with relatively lower yields, hence the results from this project will have high value for the farming community to get higher yields with scarce water resources. The studies with labelled fertilizer showed that planting and earthing-up were equally important growth stages of potato for applying fertilizer for its efficient utilization.

Similar studies were conducted with rapeseed and wheat.

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FINAL REPORT

Title of the Project

Determination of irrigation requirements of potato using nuclear and non-nuclear techniques.

Institute

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Period covered

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1. SCIENTIFIC BACKGROUND

Potato (*Solanum tuberosum* L.) is a leading food and vegetable crop in Pakistan. Three crops of potato can be grown in a year, a spring and an autumn crop in plains and a summer crop in hilly areas at high altitudes. The crop has attained great importance during the past decade. The area under the crop in Pakistan has increased from 25,000 hectares in 1980-81 to 72,000 hectares in 1990-91 and production from 0.28 to 0.75 million tonnes, respectively [1]. The yield, however, has remained stagnant at around 10 tonnes/ha. This low yield is due, in part, to improper and unscientific method of irrigation. The crop is very sensitive to irrigation. The yield [2,3,4] keeping quality [5,6] and disease resistance [6,7] are greatly influenced by timing, quantum and frequency of irrigation applied. The present water resources, however, are limited as compared to the cultivable land and are also inefficiently utilized.

It is credible that if water is applied judiciously at those growth stages that are highly sensitive to water stress and reduced or omitted at those that are least sensitive, the same water supplies could be stretched to bring additional areas of land under cultivation. Such data elucidating yield response of potato to deficit irrigation are lacking in this country. The results obtained from this project will, therefore, have high practical value for the farming community to get optimum yields with scarce water resources available.

I EXPERIMENTAL METHODS

The standard experimental design mutually agreed upon during the 1st search Coordination Meeting held in Vienna from 3-7 February, 1992 was lowed. The details of the experimental treatments are as under. Any variation these treatments is reported under the respective experiments.

I.1. Irrigation treatments:

There were 7 irrigation treatments employing full watering, continued ess watering and one stress watering at different growth stages, as detailed ow:

Full watering at four growth stages; establishment, flowering, tuber formation and ripening.

Continued stress watering at all these growth stages.

Traditional irrigation practice adopted by common farmers of the area.

Same as T1 but one stress watering applied at establishment stage.

Same as T1 but one stress watering applied at flowering stage.

Same as T1 but one stress watering applied at tuber formation stage.

Same as T1 but one stress watering applied at ripening stage.

In full watering, full requirements of the crop were met, that is, ETa tual evapotranspiration) = ETm (maximum evapotranspiration). In other words, er was not a limiting factor in this treatment. In stress watering, ETa < ETm. criterion used for determining the amount of water to be applied was pan poration from class A standard evaporation pan. The amount of water applied full watering equalled the amount of water lost through pan evaporation since last irrigation which was weighted for crop coefficient to account for the reasing crop foliage. In the stress treatment, half the amount of water for l watering was applied. The data on daily pan evaporation and other eorological parameters were obtained from the Meteorological Station of nearby icultural Research Institute, Tarnab. The amounts of water, calculated as ve, were applied to the furrows in between the potato ridges from a reservoir means of a plastic pipe attached to the water pump. The time required to igate different plots was calculated from the equation

$$t = ad/1000q$$

where t = time, min.
q = size of the stream, litres per min.
a = area to be irrigated, cm^2
d = depth of water to be applied, cm

For applying water to T3 (Traditional treatment) some local farmers were ited to the experimental site for consultation on the time and amount of water be applied. The farmers, as a general practice, apply water to potato at an erval of 10-15 days depending upon time of the year.

2. SCOPE OF THE PROJECT

Crops as well as different varieties of the same crop vary in their growth and yield response to water deficit. The response can vary greatly depending on how sensitive the crop or the variety is at a particular growth stage. The relationship between yield response and deficit irrigation, as studied for potato, will apply equally to other major crops of the area under different soil and climatic conditions as relative yield and meteorological data have been used. Hence, similar studies will be conducted with wheat, rapeseed, maize, etc which will help increase effective use of water especially in the arid and barani (rainfed) areas.

3. OBJECTIVE OF THE PROJECT

The objective was to study the relationship between crop yield and crop water use as a function of water stress. Given the yield and crop water use under stressed and nonstressed conditions, the susceptibility of potato and other crops to water stress at various growth stages will be determined. The growth stages that can withstand water stress with no significant effect on yield and that are most sensitive to water stress will be identified.

Adequate fertilization is an important aspect of irrigated agriculture. The fertilizer utilization is likely to be influenced by stress irrigation. The effect of deficit irrigation on fertilizer use efficiency and yield will be studied at optimum and suboptimum rates of fertilizer application.

4. MATERIALS AND METHODS

Field experiments were conducted with potato, rapeseed and wheat to study their yield response to deficit irrigation imposed at different growth stages. The details are as under:

Growing season	Growth period	Cultivar used	Exptl.treatments
POTATO			
1. Spring 1991	Feb.4 to June 11, 1991.	Cardinal	5 (irrigation criteria)
2. Autumn 1991	Sep.24,1991 to Jan.5, 1992.	Cardinal	10 irrigation x 2 fertilizer
3. Autumn 1992	Sep.23, to Dec.29, 1992.	Cardinal	7 irrigation x 2 fertilizer
4. Spring 1993	Feb.4 to June 10, 1993.	Cardinal	-do-
5. Autumn 1993	Sep.24,1993 to Jan. 2, 1994.	Ultimus	-do-
6. Spring 1994	Mar.8 to June 13, 1994.	Ultimus	-do-
7. Autumn 1994	Planned	Desiree	-do-

RAPESEED

1. Rabi 1992-93 Oct.21,1992 to Apr.19, 1993. Pak-Cheen 10 irrigation

2. Rabi 1993-94 Oct.10, 1993 to Apr.13,1994. RM-152-2 7 irrigation

3. Rabi 1994-95 Planned -do-

WHEAT

1. Rabi 1993-94 Nov.22,1993 to May 16, 1994. WS-10 7 irrigation

2. Rabi 1994-95 Planned -do-

All the experiments, except the last ones of the three crops, were conducted at the Experimental Farm of Nuclear Institute for Food and Agriculture (NIFA), Peshawar (34^0 04'N, 72^0 25'W). The last experiments of the three crops were conducted at Malakander Farm of NWFP Agricultural University, Peshawar.

4.1. PHYSICOCHEMICAL PROPERTIES OF THE EXPERIMENTAL SOILS

The physicochemical characteristics of the experimental soil at NIFA are presented in Table I. The soils were clayey in texture, alkaline in reaction, moderately calcareous, deficient in nitrogen and organic matter and free from salinity.

TABLE I. PHYSICO-CHEMICAL PROPERTIES OF THE EXPERIMENTAL SITE AT NIFA.

Parameter	Depth (cm)		
	0-15	15-30	30-60
pH	7.6 to 8.1	7.6 to 8.4	7.8 to 8.5
EC (dS/m)	1.8 to 2.0	1.7 to 1.8	1.0 to 1.8
$CaCO_3$(%)	14.2 to 15.6	15.0 to 15.6	14.9 to 16.1
Organic matter (%)	0.95 to 1.08	0.67 to 0.85	0.30 to 0.85
Total N (%)	0.006 to 0.007	0.005 to 0.006	0.004 to 0.005
Sand (%)	7 to 20	9 to 20	7 to 20
Silt (%)	39 to 54	43 to 54	43 to 60
Clay (%)	39 to 41	37	33 to 37
Texture	Silty clay	Silty clay to clay loam	Silty clay to clay loam
Saturation (%)	50.0 to 51.2	50.2	47.4
Field capacity (%)	25.0 to 25.6	26.2	24.0
Bulk capicity (g/cm^3)	1.7	1.7	1.8

4.2. MEASUREMENT OF SOIL HYDRAULIC PROPERTIES

The hydraulic conductivity is an important physical property of the field soils which influences water infiltration characteristics of the soil. The work on water consumption by plants, leaching of fertilizers and other chemicals, waste disposal, pollutant transfer problems, changes of water status in the plant root zone, etc all necessitate information on unsaturated hydraulic conductivity.

There are several methods for the measurement of soil hydraulic conductivity in the field. There are two main approaches that can be used to calculate hydraulic conductivity; the first one necessitates soil water tension measurements in addition to the rate of soil water content decrease within the soil profile; the second one is simpler and does not require tensiometer measurements. In the present study, the second approach was followed. The method used was that described by Libardi *et al* [8]. In this approach, $K(\theta)$ is of the form

$$K(\theta) = K_0 \exp[\beta(\theta_0 - \theta)] \quad (1)$$

where β is constant and K_0 and θ_0 are the values of K and θ at saturation, respectivley. The values of β and K_0 were calculated using the field data and the relation

$$\ln[z(d\theta/dt)] = \beta(\theta_0 - \theta) + \ln K_0$$

A semi-log plot of the absolute value of $z(d\theta/dt)$ against $(\theta_0 - \theta)$ gives $\ln K_0$ from the slope and intercept, respectivley.

For determining unsaturated hydraulic conductivity of the experimental field, the changes in moisture content of the soil profile after application of 15 cm of irrigation water were measured with the help of neutron moisture meter. For this purpose, a 5 x 5 m plot was selected. An access tube was installed in the centre of the plot. The plot was surrounded by 10 cm high levees on the four sides. The plot received a total of 15 cm of water in three 5-cm increments. After application of the last increment, the soil surface was covered with polyethylene sheet to prevent evaporation. Soil water content was measured at 20, 30 and 60 cm depths over a period of 4 days (96 hours). The data are given in Table II. The data in Table II are enough to estimate unsaturated hydraulic conductivity using equation (1). The decrease of mean soil water content with time is plotted in Fig.1. This curve could be approximated by an exponential equation, showing methematical relatiionship of variation of θ with time, whose equation is

$$\theta = 0.316t^{-0.0095}$$

The major steps involved in plotting the graph of $\ln[z(d\theta/dt)]$ vs $\theta_0-\theta$ are given in Table III. The graph itself is plotted in Fig.2. From the graph, it is seen that $K_0 = 0.061$ and $\beta = -35.294$. Hence, according to equation (1), the unsaturated hydraulic conductivity is

$$K(\theta) = 0.061 \exp[-35.294\ (0.315 - \theta)] \quad \text{cm/h}$$

The calculated values of $K(\theta)$ are presented in Table III. The values ranged from 0.0533 cm/h (at $\theta = 0.311\ cm^3/cm^3$, 6 h after ponding of water on soil surface) to 0.0399 cm/h (at $\theta = 0.303\ cm^3/cm^3$, 96 h after ponding). As is evident, the values of $K(\theta)$ are quite low.

TABLE II. CHANGES IN SOIL WATER CONTENT (θ) DOWN TO 60 cm DEPTH AFTER APPLICATION OF 3 INCREMENTS OF 5 CM EACH OF IRRIGATION WATER FOR DETERMINING UNSATURATED HYDRAULIC CONDUCTIVITY OF THE EXPERIMENTAL FIELD.

Time t(h)	Soil depth, z(cm) 20	30	60	Average θ
0	0.295	0.317	0.334	0.315
6	0.308	0.305	0.320	0.311
12	0.296	0.309	0.333	0.313
24	0.297	0.307	0.318	0.307
36	0.300	0.301	0.317	0.306
48	0.299	0.301	0.322	0.307
60	0.291	0.297	0.306	0.299
72	0.294	0.300	0.307	0.300
84	0.289	0.301	0.317	0.302
96	0.299	0.298	0.313	0.303

TABLE III. BASIC DATA FOR PLOTTING GRAPH OF LN [Z(Dθ/DT)] VERSUS $\theta_0-\theta$ FOR ESTIMATION OF K(θ)[†].

Time t(h)	$\bar{\theta}$	dθ/dt	ln[z(dθ/dt)]	$\theta_0 - \theta$	K(θ) (cm/h)
0	0.315	-	-	0	
6	0.311	-4.924×10^{-4}	- 4.215	0.004	0.053
12	0.309	-2.446×10^{-4}	- 4.915	0.006	0.049
24	0.307	-1.215×10^{-4}	- 5.614	0.008	0.046
36	0.306	-8.068×10^{-5}	- 6.024	0.009	0.044
48	0.305	-6.035×10^{-5}	- 6.314	0.010	0.043
60	0.304	-4.818×10^{-5}	- 6.539	0.011	0.042
72	0.304	-4.008×10^{-5}	- 6.724	0.011	0.041
84	0.303	-3.430×10^{-5}	- 6.879	0.012	0.040
96	0.303	-2.998×10^{-5}	- 7.014	0.012	0.040

† $z = 30$ cm
$\theta_0 = 0.315\ cm^3 .\ cm^{-3}$

4.3. SOIL MOISTURE CHARACTERISTIC CURVE

The soil moisture characteristic curve of the experimental soil at depths of 0-30, 30-60 and 60-100 cm is plotted in Fig 3. The moisture tension values were developed on a pressure membrane apparatus and the resultant water contents were determined gravimetrically (Courtesy: Soil Physics Section, Agricultural Research Institute, Tarnab, Peshawar).

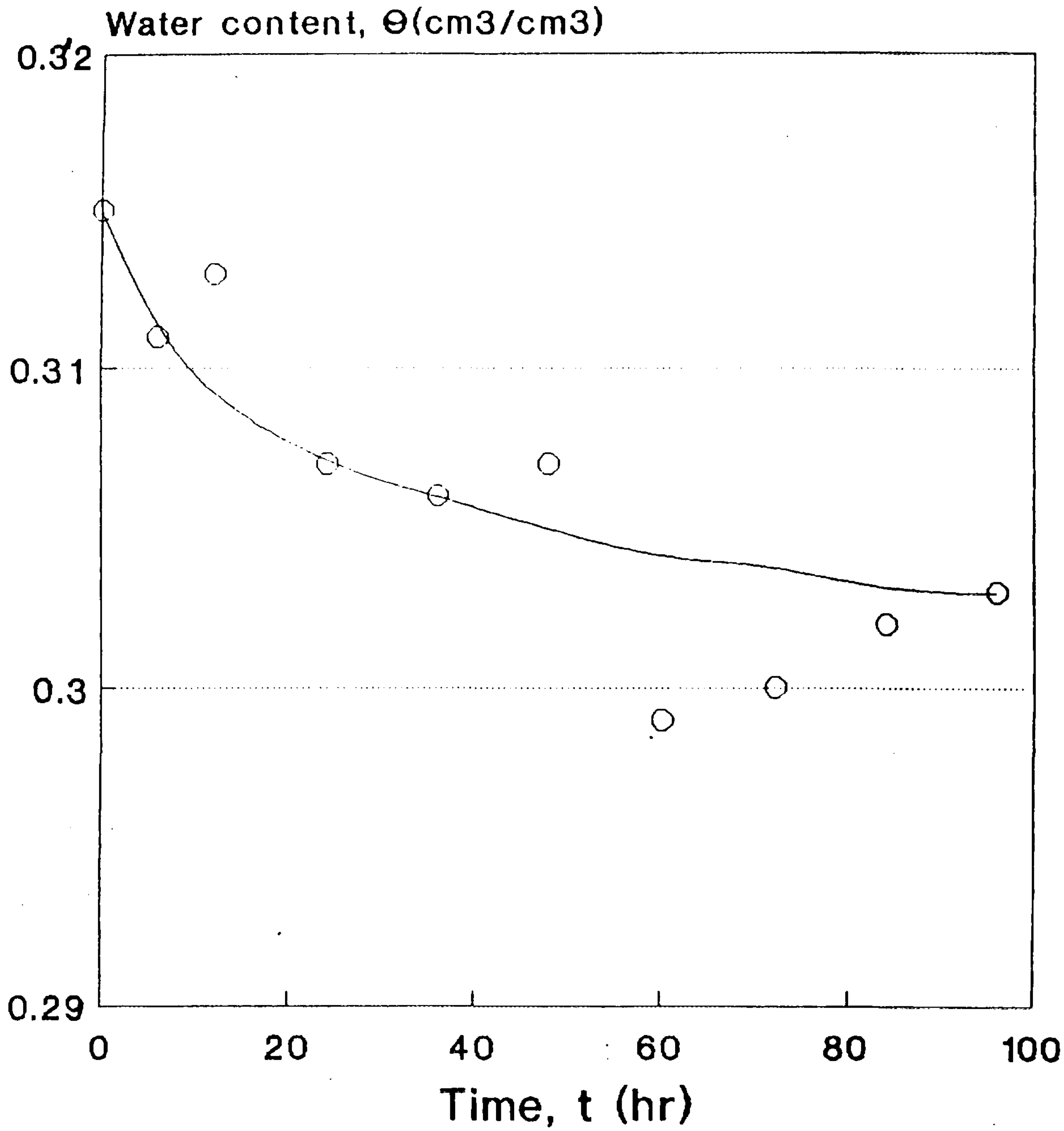

Fig 1. Decrease of mean soil water content with time within 60 cm of the soil depth.

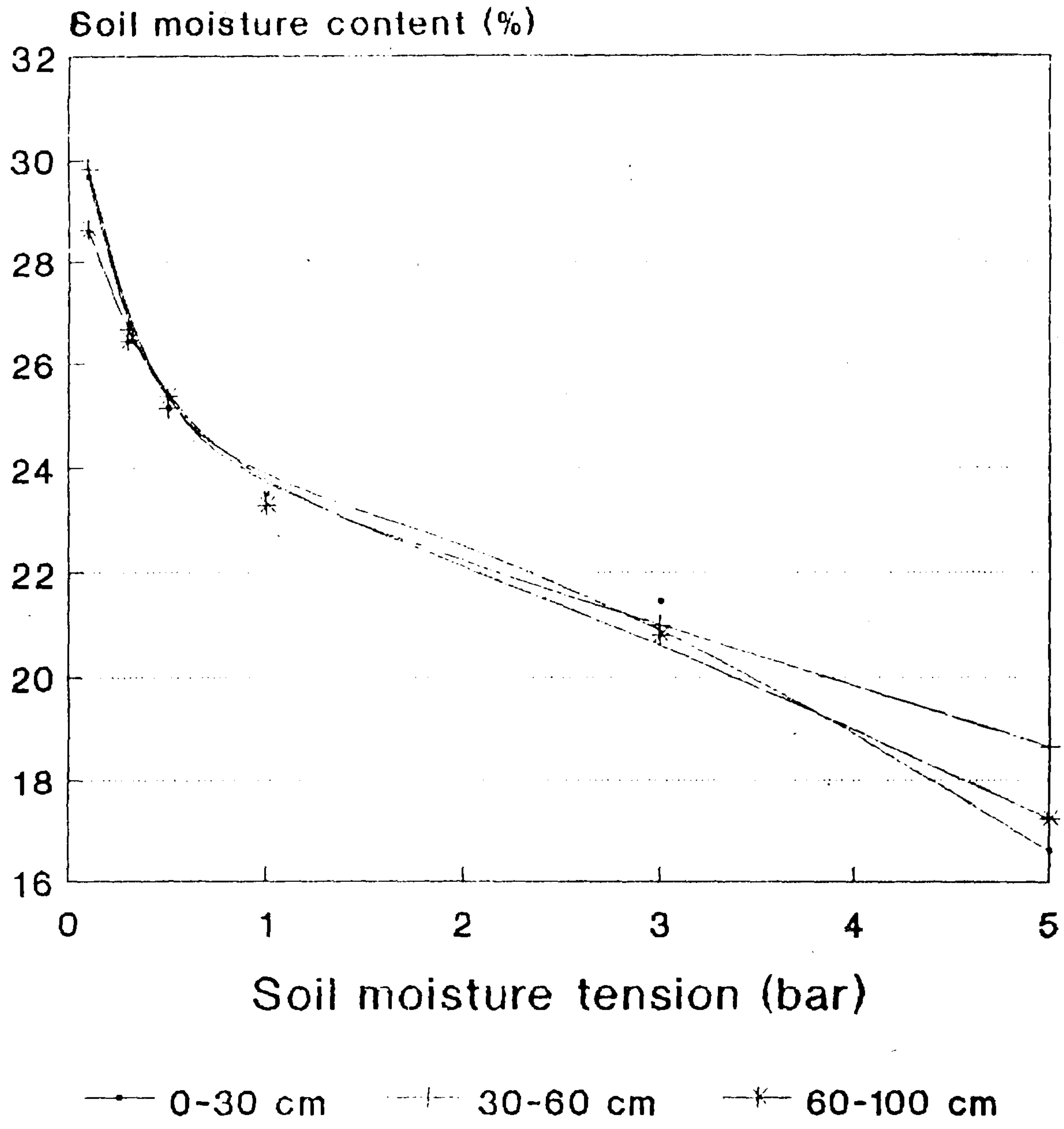

Fig.3. Soil moisture characteristic curv
of experimental soil.

4.4.2. Fertilizer treatments:

Each irrigation treatment was split into two fertilization treatments wherein normal and low fertilizer levels were applied.

F1 = 250 kg N + 150 kg P_2O_5 + 250 kg K_2O per ha

F2 = 100 kg N + 50 kg P_2O_5 + 100 kg K_2O per ha

The fertilizer sources were urea or ammonium sulphate (of N), single superphosphate (of P) and potassium sulphate (of K). Half of the N and all of the P and K were applied at planting, the remaining half of N was applied at earthing up (35 to 40 days after sowing). For autumn 1992 experiment, ^{15}N-labelled ammonium sulphate was used to study the effect of normal and stress watering on fertilizer use efficiency. The details are given under the relative experiment.

The seed potatoes were sown on ridges made 80 cm apart and 15 cm high. Just before sowing, the seed was dipped in a fungicide solution (Benlate or Dithane-M, 25g dissolved in 10 litres of water) for 5 minutes to guard against the attack of wilt and other fungal diseases. The experiment was laid out in split plot design with irrigation treatments forming the main plots of size 9.0 x 4.8 m and fertilizer treatments the subplots of size 4.0 x 4.8 m. There were four replications. In this way, there were 56 treatment plots in total (7 irrigations x 2 fertilizers x 4 reps).

4.5. INSTRUMENTATION

The experimental plots of 5 out of 7 treatments, in two replicates, of each experiment were thoroughly instrumented with access pipes for neutron moisture probe surrounded by tensiometers at three depths of 15, 30 and 60 cm. Soil moisture content and soil moisture tension were monitored before and after each irrigation, then daily during the first week, on alternate days during the second week and after every third day during third week onward until the next irrigation. These measurement provided basis for determining actual evapotranspiration of the crop using the water balance method.

5. RESULTS

5.1. POTATO

5.1.1. Spring 1991 experiment

A field experiment was conducted with potato, cv. Cardinal, to determine irrigation requirements of the crop using soil and climatic criteria as determinants of need for irrigation. The following were the experimental treatments.

T1: Climatic criteria: The basis of applying irrigation was evaporation from standard class A Pan. Irrigation was applied when cumulative pan evaporation reached 25 mm. The amount of irrigation was equal to the amount of cumulative pan evaporation.

T2: Soil criteria: The basis of applying irrigation was soil moisture content in the ridge depth. When the soil moisture stored in the root zone depleted to 65% of field capacity, irrigation was applied. The sampling for soil moisture was done manually (Neutron Moisture Meter was received after the harvest of this experiment). The irrigations restored the soil moisture to field capacity.

T3: Same as T2 but irrigation was applied when the soil moisture content depleted to 50% of field capacity.

T4: Traditional practice: The irrigations were applied according to the practice adopted by local farmers. The potato growers of the surrounding area were consulted on the timing and amount of irrigations to be applied in this treatment.

T5: No irrigation applied during the growing season. Only one post-planting irrigation was applied.

The crop was grown with the recommended doses of fertilizers, i.e. 250 kg N + 150 kg P_2O_5 + 250 kg K_2O per ha, and normal cultural practices. The field was irrigated immediately after sowing at a uniform rate. The need for further irrigations was determined based on the above criteria. There were unusual intermittent spring and summer rains during 1991 which coincided with the tuber formation and ripening stages of the crop. A total of 82.0, 61.0 and 70.6 cm of rain was received during the months of March, April and May, 1991.

The results showed (Table IV) that pan evaporation method resulted in the most frequent and highest number of irrigations (seven) spaced 5 to 11 days apart. The total amount of water applied in this treatment, however, was not the highest. The highest amount of water (29 cm) was applied in the traditional

TABLE IV. THE NUMBER AND AMOUNTS OF IRRIGATIONS APPLIED TO POTATO IN DIFFERENT EXPERIMENTAL TREATMENTS DURING SPRING 1991.

Treatments				
T1 (Pan Evap.)	T2 (0.65FC)	T3 (0.50FC)	T4 (Traditional)	T5 (No irrigation)
		Dates of irrigation		
1/4/91	1/4/91	1/4/91	1/4/91	1/4/91
11/4/91	25/4/91	30/4/91	22/4/91	
22/4/91	7/5/91		30/4/91	
30/4/91	19/5/91		14/5/91	
7/5/91				
14/5/91				
Total: 7	4	2	4	1
		Amounts of water applied, cm		
8.0	8.0	8.0	8.0	8.0
2.5	5.0	8.0	6.0	
2.5	5.5		7.0	
2.7	5.5		8.0	
2.8				
3.0				
3.0				
Total: 24.5	25.0	16.0	29.0	8.0

practice adopted by the common farmers. The results on tuber yield and density of tubers are presented in Table V. The overall yield was very good being almost double the national average of 10 tons/ha (1). The highest yield of 21.0 tons/ha was produced in T2 (i.e. irrigation applied when soil moisture content in the ridge depth depleted to 65% of field capacity) but differences between means of different treatments were not significant statistically. The same was the case with above ground biomass as well as density of tubers.

TABLE V. TUBER YIELD, ABOVE-GROUND DRY BIOMASS AND DENSITY OF POTATO TUBERS, CV. CARDINAL, AS AFFECTED BY IRRIGATION CRITERIA.

Treatment	Tuber yield (Tons/ha)	Above-ground dry biomass (Tons/ha)	Density of tubers (g/cm^3)
T1 (Pan Evap.)	19.7 a	4.5 a	1.10 a
T2 (0.65 FC)	21.8 a	4.5 a	1.09 a
T3 (0.50 FC)	19.3 a	3.9 a	1.08 a
T4 (Traditional)	18.7 a	4.1 a	1.08 a
T5 (Control)	18.9 a	3.9 a	1.06 a

The differences between different treatments appear to be vitiated due to inordinate rains during the growing season. There were, nonetheless, indications that the method based on depletion of soil moisture content to 0.65 field capacity appeared to be better than the other methods, but the labour involved in manual soil sampling for determining the appropriate moisture content for irrigation precludes its use as a routine method. It could be advisable only if moisture content is determined by a quick and non-destructive method, e.g. neutron moisture meter. Since need for irrigation is dictated by evapotranspirative demand, pan evaporation may be the easiest and straight forward method for scheduling irrigation but high frequency of irrigations involved may not be practical in places (e.g. Pakistan) where irrigation water is available to farmers according to a fixed turn per week. The best strategy would be to apply water commensurate with the plant needs, i.e. at appropriate growth stages.

5.1.2. Autumn 1991 experiment

Potato, cv. Cardinal, was sown on September 24, 1991 and harvested on January 5, 1992. The experiment was a factorial combination of 10 irrigation and 2 fertilizer treatments replicated four times. The first 7 irrigations and both fertilizer treatments were the same as given under experimental methods; three additional irrigation treatments were as follows.

T8: Same as T1 but two stress waterings applied at early development and flowering stages.

T9: Same as T1 but two stress waterings applied at flowering and tuber formation stages.

T10: Same as T1 but two stress waterings applied at tuber formation and ripening stages.

All the treatments received three uniform irrigations, one immediately after sowing and two at 10 days intervals to facilitate completion of germination. Later on, measured amounts of water were applied to various treatments according to the experimental design. The total amounts applied are given in Table VI.

The results on tuber yield and above ground dry biomass (Table VII) showed that irrigation treatments exerted a significant effect on these parameters. The T1 produced the highest tuber yield of 9.0 tons/ha but it was not statistically different from that of T5 (one stress at flowering stage) and T7 (one stress at ripening stage). The lowest yield of 4.5 tons/ha was produced by T2 which was statistically equivalent to that of T8 (two stresses during initial growth stages). The relative reduction in yield over T1 was the highest in T2 (50%) followed by T8 (47%) and the least in T7 (4%) indicating that the early development stages were more sensitive to irrigation than the later ones. The above ground dry biomass followed almost the same pattern as tuber yield. The number and density of tubers were, however, not influenced by irrigation treatments.

As regards fertilization, the normal level produced significantly higher yield than the lower level (Table VII). The later led to 10% reduction in yield over the former. The interaction among irrigation and fertilization treatments was also significant which showed that normal fertilization produced significantly higher yield, compared to lower level, in all the irrigation treatments.

TABLE VI. DEPTHS OF IRRIGATION WATER (cm) APPLIED TO POTATO, CV. CARDINAL, IN DIFFERENT TREATMENTS AT FOUR GROWTH STAGES DURING AUTUMN 1991.

Trt	Pre-treatment irrigns			Treatment irrigations				Total	
	No.1	No.2	No.3	Early Devp.	Flow- ering	Tuber form.	Ripe- ning	cm	m^3/ha
T1	7.0	3.0	3.0	3.1	3.5	3.6	NA	23.2	2320
T2	7.0	3.0	3.0	1.5	1.7	1.8	NA	18.0	1800
T3	7.0	3.0	3.0	3.1 + 3.5 + 3.5 + 3.6				28.7	2870
T4	7.0	3.0	3.0	1.5	3.5	3.6	NA	21.6	2160
T5	7.0	3.0	3.0	3.1	1.7	3.6	NA	21.4	2140
T6	7.0	3.0	3.0	3.1	3.5	1.8	NA	21.4	2140
T7	7.0	3.0	3.0	3.1	3.5	3.6	NA	32.2	3220
T8	7.0	3.0	3.0	1.5	1.7	3.6	NA	19.8	1980
T9	7.0	3.0	3.0	3.1	1.7	1.8	NA	19.5	1950
T10	7.0	3.0	3.0	3.1	3.5	1.8	NA	21.4	2140

NA = Irrigation could not be applied as the plants were killed due to frost.

TABLE VII. MEAN TUBER YIELD AND YIELD PARANMETERS OF POTATO AS INFLUENCED BY IRRIGATION AND FERTILIZATION TREATMENTS DURING AUTUMN 1991.

Trt.	Tuber yield (tons/ha)	Rel. reducn. over T1 (%)	Aboveground biomass (tons/ha)	No.of tubers per 5 kg	Density of tubers (g/cm^3)
Irrigation treatments					
T1	9.05 a	0	1.30 a	159 a	1.05 a
T2	4.48 d	50	0.58 d	182 a	1.04 a
T3	4.93 cd	46	0.63 d	168 a	1.06 a
T4	5.50 cd	39	0.70 bcd	153 a	1.06 a
T5	8.54 a	6	1.22 a	151 a	1.08 a
T6	6.34 b	30	0.81 b	154 a	1.06 a
T7	8.70 a	4	1.20 a	164 a	1.04 a
T8	4.80 d	47	0.62 d	178 a	1.05 a
T9	5.17 cd	43	0.66 cd	169 a	1.05 a
T10	6.00 bc	34	0.77 bc	171 a	1.05 a
Fertilization					
F1	6.99 a	0	0.94 a	166 a	1.06 a
F2	5.71 bd	18	0.76 b	164 a	1.05 a

The field water use efficiencies (Ef) for various treatments are given in Table VIII. The highest Ef of 3.99 kg/m^3 was produced in T5 (one stress watering at flowering stage) followed by 3.9 kg/m^3 in T1 (full watering at all stages) and 3.75 kg/m^3 in T7 (one stress watering at ripening stage). This means that applying irrigations in combination of full and stress amounts at appropriate growth stages can lead to higher water use efficiency than that for full watering at all stages. That the traditional practice adopted by common farmers of applying water at 10-12 days interval throughout the season leads to wasteful water application is evident from the lowest Ef of 1.72 kg/m^3 in T3.

Fertilizer use efficiency in respect of nitrogen and potash was 28.0 kg of tubers/kg of nutrient at the normal level and almost double at the lower level (Table VIII). Similar was the case for phosphatic fertilizer indicating that the applied fertilizers were not used efficiently for production of tubers at the higher rates.

5.1.3. Autumn 1992 Experiment

The crop was planted on September 23, 1992 and harvested on December 29, 1992. The total rainfall received during the growing season was 27.8 mm which was spread during the months of October (13.2 mm), November (12.0 mm) and December 1992 (21.6 mm). In order to study the effect of normal and stress watering on fertilizer use efficiency, ^{15}N-labelled ammonium sulphate having 5% ^{15}N atom excess was used. The labelled fertilizer was applied to two irrigation treatments only (i.e; T1 and T2) at the lower fertilization rate of 100 kg/ha and to one out of 6 rows of potatoes (4.0 x 0.8 m) in each plot. The labelled fertilizer was applied in the solution form in two splits; half at planting and half at first earthing-up, one split in each treatment receiving labelled fertilizer alternatively. The plot size was 4.0 x 4.8 m.

TABLE VIII. WATER AND FERTILIZER USE EFFICIENCIES OF POTATO AS INFLUENCED BY IRRIGATION AND FERTILIZER TREATMENTS DURING AUTUMN 1991.

Field water use efficiency (Ef)

Treatment	Tuber yield (tons/ha)	Water applied (m^3/ha)	E_f (kg/m^3)
T1	9.05	2320	3.90
T2	4.48	1800	2.49
T3	4.93	2870	1.72
T4	5.50	2160	2.55
T5	8.54	2140	3.99
T6	6.34	2140	2.96
T7	8.70	2320	3.75
T8	4.80	1980	2.42
T9	5.17	1950	2.65
T10	6.00	2140	2.80

Fertilizer use efficiency (FUE)

	Tuber yield (tons/ha)	FUE (kg of tubers/kg of nutrient) N	P	k
F1	6.99	28.0	46.6	28.0
F2	5.71	57.1	114.2	57.1

The results obtained showed that all-normal waterings produced the highest whereas all-stress waterings the lowest tuber yield; the yields from other treatments were intermediate (Table IX). The relative reduction in yield over all-normal watering varied between 11 and 47%. The least reduction occurred at ripening stage. The pattern for dry matter yield of aboveground parts was slightly different. The highest dry matter yield occurred in T7 followed by T1. The potato tubers were graded on the basis of weight(Table IX). The grade A tubers (> 100g) exhibited weights in different treatments similar to the overall tuber yield with the difference that relative reduction in weights over the all-normal treatment was of higher magnitude. The greatest reduction occurred when flowering, stage was stressed for water (T5). For grade B tubers, the highest yield was produced by T7.

TABLE IX. MEAN TUBER AND ABOVEGROUND DRY MATTER YIELDS AND WEIGHTS OF GRADE A AND B TUBERS AS INFLUENCED BY IRRIGATION AND FERTILIZER TREATMENTS DURING AUTUMN 1992.

Treatment	Tuber yield (t/ha)	Yield reduction (1-ya/ym)*	Aboveground dry matter yld (kg/ha)	Grade A (>100g) (t/ha)	Yield reduction (1-ya/ym)	Grade B (60-100g) (t/ha)
Irrigation						
T_1	6.62a	0	667abc	2.67a	0	1.41ab
T_2	3.49d	17.0	375d	0.85c	68.0	0.87c
T_3	5.16bc	22.0	776ab	1.92b	28.0	1.36ab
T_4	4.58cd	31.0	604bc	1.52bc	43.0	1.11bc
T_5	5.00bc	24.0	547cd	1.31bc	51.0	1.43ab
T_6	4.53cd	32.0	573bcd	1.44bc	46.0	1.29bc
T_7	5.88ab	11.0	838a	2.04ab	24.0	1.76a
Fertilization						
F_1	5.42a	0	670abc	1.91a	0	1.32a
F_2	4.63b	15.0	583b	1.44b	24.0	1.31a

* ym = Maximum yield, ya = Actual yield

The depths of irrigation water applied to different treatments are given in Table X. Based on these depths, field water use efficiencies Ef (i.e. kg of tubers produced per m^3 of water applied) were calculated which are presented in Table XI. The highest efficiency of 3.0 kg per m^3 of water applied was achieved in all-normal watering treatment (T1) followed by stress watering at ripening stage (T7). The lowest efficiency of 1.92 kg/m^3 occurred in the traditional irrigation treatment (T3) indicating that some of the applied water was not used productively.

TABLE X. DEPTHS OF IRRIGATION WATER (cm) APPLIED TO POTATO IN DIFFERENT IRRIGATION TREATMENTS DURING AUTUMN 1992. THE PLOT SIZE WAS 4.0 X 4.8 m^2.

Trt.	Post Planting	Light irrgn.	Estb. stage	Flowerg. stage	Tuber formn.	Ripening	Total cm	Total m^3/ha
T1	5.2	3.1	4.7	3.1	3.5	2.3	21.9	2190
T2	5.2	3.1	2.1	1.6	1.7	1.0	14.7	1470
T3	5.2	3.1	5.2 +	3.6 +	3.9 + 2.9 +	2.9	26.8	2680
T4	5.2	3.1	2.1	3.1	3.5	2.3	19.3	1930
T5	5.2	3.1	4.7	1.6	3.5	2.3	20.4	2040
T6	5.2	3.1	4.7	3.1	1.7	2.3	20.1	2010
T7	5.2	3.1	4.7	3.1	3.5	1.0	20.6	2060

TABLE XI. FIELD WATER USE EFFICIENCY (E_f) OF POTATO TUBERS AS AFFECTED BY DIFFERENT IRRIGATION TREATMENTS DURING AUTUMN 1992.

Treatment	Tuber yield (t/ha)	Depth of water applied (m^3/ha)	E_f (kg/m^3)
T1	6.62	2188	3.02
T2	3.49	1474	2.37
T3	5.16	2682	1.92
T4	4.58	1928	2.38
T5	5.00	2032	2.46
T6	4.53	2013	2.25
T7	5.88	2066	2.85

5.1.3.1. ^{15}N - Fertilizer use efficiency of microplots

The 2-split application of labelled ammonium sulphate at planting and earthing-up stages (Table XII) revealed that both stages were equally important for applying fertilizer as the fertilizer uptake at both stages was similar. The tubers stored more nitrogen than the aboveground biomass at harvest. The continued stress treatment reduced the efficiency of utilization of fertilizer. The overall nitrogen utilization was less than 10% which is quite low. The higher rate of fertilization with nonlabelled ammonium sulphate produced significantly higher yield than the lower rate.

5.1.4. Spring 1993 experiment

The crop was planted on February 4, 1993 and harvested on June 10, 1993. The ridges were furrow-irrigated immediately after planting. The germination started on 20-2-93 and 80% germination was completed by 10-3-93. In order to facilitate completion of germination, a light irrigation was applied to all the plots. The first treatment irrigation at vegetative stage was applied on 28-3-93 where 4.17 cm of water was applied to normal and 2.03 cm to stress plots. The second treatment irrigation, at flowering stage, was applied on 12-4-93 and 7.58 cm were applied to normal and 3.80 cm to stress plots. The crop was attacked by cutworm during last week of April for which Thiodan granules were applied followed by irrigation. The 3rd treatment irrigation, at tuber formation stage, was applied on 28-4-93 and 10.60 cm were applied to normal and 5.30 cm to stress plots. The 4th treatment irrigation, at ripening stage, was applied on 11-5-93 where 11.43 cm were applied to normal and 5.71 cm to stress plots. The traditional irrigation treatment received 6 irrigations on 28 March, 5 April, 25 April, 9 May and 20 May in addition to two initial uniform irrigations to all treatments. The total depth of irrigation water applied to different treatments is given in Table XIII. The total rainfall received during the growing season was 205.1 mm which was spread during the months of February (22.0 mm), March (144.0 mm), April (25.1 mm) and May 1993 (14.0 mm).

TABLE XII. THE EFFECT OF APPLYING 50 KG N/HA AS AMMONIUM SULPHATE TO POTATO AT TWO STAGES ON NITROGEN DERIVED FROM FERTILIZER (NDFF), LABELLED FERTILIZER UPTAKE AND FERTILIZER UTILIZATION IN ALL-NORMAL (T_1) AND ALL-STRESS (T_2) IRRIGATION TREATMENTS.

Fert.splits		NdFF (%)		N uptake (g/row)		Fet.N uptake (g/row)		Fert.Utilz. (%)	
S_1	S_2	T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2
				Potato Tubers					
50*	50	14.2	14.5	5.77	4.02	0.82	0.58	5.13	3.63
50	50*	18.7	18.3	4.26	3.76	0.80	0.69	5.00	4.31
				Aboveground dry matter					
50*	50	17.8	13.9	3.37	3.19	0.60	0.44	3.75	2.75
50	50*	17.7	16.8	2.73	1.78	0.48	0.30	3.00	1.88
				Total (Tubers + Aboveground parts)					
50*	50	-	-	9.14	7.21	1.42	1.02	8.88	6.38
50	50*	-	-	6.99	5.54	1.28	0.99	8.00	6.19

S1 = Planting time, S2 = Earthing-up time,

* = Labelled with ^{15}N

TABLE XIII. DEPTHS OF IRRIGATION WATER (cm) APPLIED TO VARIOUS IRRIGATION TREATMENTS OF POTATO DURING SPRING 1993. THE PLOT SIZE WAS 4.0 X 4.8 m^2.

Trt.	Post Planting	Light irrgn.	Estb. stage	Flowerg. stage	Tuber formn.	Ripening	Total cm	Total m^3/ha
T1	5.2	3.1	4.2	7.6	10.6	11.4	42.1	4210
T2	5.2	3.1	2.0	3.8	5.3	5.7	25.1	2510
T3	5.2	3.1	4.4+ 5.7+	7.8+	10.4+	10.7+ 11.5	58.8	5880
T4	5.2	3.1	2.0	7.6	10.6	11.4	39.9	3990
T5	5.2	3.1	4.2	3.6	10.6	11.4	38.1	3810
T6	5.2	3.1	4.2	7.6	5.3	11.4	36.8	3680
T7	5.2	3.1	4.2	7.6	10.6	5.7	36.4	3640

The results obtained showed that the highest tuber yield was obtained in the traditional irrigation treatment (T3)followed by all-normal treatment (T1) both being statistically in the same category (Table XIV). The relative reduction in yield over all-normal watering was 35% in all-stress (T2), 35% in vegetative stress (T4), 19% in flowering stress (T5), 30% in tuber formation stress (T6) and 14% in ripening stress. The least reduction, like the autumn 1992 crop, occurred in the ripening stress. The magnitude of yield reduction in different treatments was more or less of the same order as that in the autumn 1992 experiment. It was a common experience that unlike the autumn crop, the size of tubers in this crop was reduced. The proportion of tubers with weights < 60 g was maximum. Trebejo (4) reported more reduction in yield in hot season (52%) than cool season (20%) in Peru. The pattern of dry matter yield of aboveground parts (Table XIV) was different. The highest dry matter yield was produced in vegetative stress (T4) treatment.

TABLE XIV. MEAN TUBER YIELD AND DRY MATTER YIELD OF ABOVE-GROUND PARTS OF POTATO AS INFLUENCED BY IRRIGATION AND FERTILIZER TREATMENTS DURING SPRING 1993.

Treatment	Tuber yield (t/ha)	Yield reduction (1-ya/ym)*	Dry matter yield (t/ha)
Irrigation			
T1	7.73 ab	0.00	2.58 ab
T2	5.03 d	0.35	1.94 b
T3	8.02 a	-	2.56 ab
T4	5.05 d	0.35	2.76 a
T5	6.28 cd	0.19	2.58 ab
T6	5.44 cd	0.30	2.12 ab
T7	6.69 bc	0.14	2.46 ab
Fertilization			
F1	6.91 a	0.00	2.90 a
F2	5.73 b	0.17	1.95 b

* Ya = Actual yield, Ym = Maximum yield

Based on the depths of irrigation water applied, field water use efficiencies(Ef) in respect of different treatments were calculated(Table XV). The highest efficiency of 2.0 kg/m3 was obtained in T2 (all-stress) followed by T1 (all-normal) and T7 (ripening stress) both having Ef of 1.84. The Ef in general was quite low.

As regards fertilizer treatments, the normal rate produced significantly higher tuber and dry matter yields as compared to the lower rate (Table XIV). The fertilizer x irrigation interaction was also significant.

5.1.5. Autumn 1993 experiment

The potato, cv. Ultimus, was planted on September 24, 1993 and harvested on January 2, 1994. Just before planting, the tubers were soaked for 5 minutes in Dithane -M, at the rate of 25 g/10 L water, to guard against fungal attack during growth. The plots were furrow-irrigated immediately after sowing. The germination started on October 3, 1993. A second general irrigation was applied to all the plots on Oct 10. About 50% germination was completed on Oct 14 and 90% by Oct 18. A total of 31.0 mm of rainfall, spread during the months of October (28.0 mm) and November (3.0 mm) occurred during the growing season. The first treatment irrigation at establishment stage was applied on Oct 26, the second at flowering stage on Nov 16, the third at tuber formation stage on Nov 30 and the fourth at ripening stage on Dec 13. The depths of irrigation water applied to, and actual evapotranspiration (ETa) of, different irrigation treatments are given in Table XVI. The ETa was determined by the water balance method. The drainage term was assumed to be negligible as the water content at depths below 60 cm did not exceed field capacity.

TABLE XV. FIELD WATER USE EFFICIENCY (E_f) OF POTATO TUBERS AS INFLUENCED BY IRRIGATION TREATMENTS DURING SPRING 1993.

Treatment	Tuber yield (t/ha)	Depth of water applied (m^3/ha)	E_f (kg/m^3)
T1	7.73	4210	1.84
T2	5.03	2520	2.00
T3	8.02	5880	1.36
T4	5.05	4000	1.26
T5	6.28	3830	1.64
T6	5.44	3680	1.48
T7	6.69	3640	1.84

TABLE XVI. DEPTHS OF IRRIGATION WATER APPLIED AND ET_a AT DIFFERENT GROWTH STAGES OF POTATO, CV. ULTIMUS, FOR VARIOUS IRRIGATION TREATMENTS, DURING AUTUMN 1993.

Trt	Pre-trt irrgn No.1	Pre-trt irrgn No.2	Estb stage	Flwg stage	Tuber Form.	Ripng stage	Total cm	Total m^3/ha
	Depths of water applied (cm)							
1	8.1	5.2	6.7	5.8	4.0	2.6	32.4	3240
2	8.1	5.2	2.7	2.5	1.6	1.3	21.4	2140
3	8.1	5.2	6.6 + 5.0 +	4.0 +	3.0 +	2.2	34.1	3410
4	8.1	5.2	2.7	5.8	4.0	2.6	28.4	2840
5	8.1	5.2	6.7	2.5	4.0	2.6	29.1	2910
6	8.1	5.2	6.7	5.8	1.6	2.6	30.0	3000
7	8.1	5.2	6.7	5.8	4.0	1.3	31.1	3110
	Actual evapotranspiration (ET_a), cm							
1			9.0	4.8	4.7	3.0	21.5	2150
2			5.7	1.3	2.2	1.8	11.0	1100
3			-	-	-	-	-	-
4			5.2	3.6	3.9	2.8	15.5	1550
5			9.1	2.1	4.5	2.8	18.5	1850
6			8.7	4.7	2.5	2.4	18.4	1840
7			-	-	-	-	-	-

NOTE: The plots of treatment No.3 and 7 were not instrumented for determining ET_a.

The results obtained on tuber yield, above-ground dry matter yield and weights of Grade A (> 100g) and Grade B (60-100g) tubers are given in Table XVII. The highest yield of 7.68 tons/ha was produced by all-normal (T1) and the lowest of 5.17 t/ha by all-stress (T2) treatment. The relative reduction in yield ranged between 11.7 and 32.7%. The least reduction among the imposed treatments occurred in T7 confirming that ripening was the least sensitive stage to water stress. The aboveground dry matter yield differed from the tuber yield in that the highest yield was produced by T3 rather than T1. The weights of grade A tubers behaved similarly to the tuber yield of treatment plots while those of grade B tubers were statistically similar among themselves.

TABLE XVII. MEAN TUBER YIELD AND WEIGHTS OF ABOVE ABOVE-GROUND DRY BIOMASS, GRADE A (>100g) AND GRADE B (60-100g) TUBERS AS INFLUENCED BY IRRIGATION AND FERTILIZER TREATMENTS DURING AUTUMN 1993.

Treatment	Tuber yield (t/ha)	Yield reduction (1-ya/ym)*	Dry matter yield (t/ha)	Grade A (t/ha)	Grad B (t/ha)
Irrigation					
T1	7.68a	0	1.43abc	3.38a	2.28a
T2	5.17d	32.7	0.91c	1.58c	2.08a
T3	6.78ab	11.7	1.73a	3.28ab	2.27a
T4	5.64cd	26.6	1.08bc	1.73c	2.21a
T5	6.01bcd	21.7	1.57ab	2.31bc	2.34a
T6	6.04bcd	21.4	1.46abc	2.59abc	2.41a
T7	6.53bc	15.0	1.41abc	2.99ab	2.10a
Fertilization					
F1	6.41a	0	1.38a	2.41a	2.15a
F2	6.13a	0	1.35a	2.70a	2.33a

* Ya = Actual yield, Ym = Maximum yield

In order to study the relationship between crop yield and crop water use as a function of water stress, the relative reduction in tuber yield was plotted against the relative water use deficit (Fig 4). For calculating the relative water use deficit, data on maximum evapotranspiration (ETm) is required. The ETm was determined by

$$ETm = ET_0\ Kc$$

where ET_0 = Reference evapotranspiration, cm
Kc = crop coefficient. The values of crop coefficient for potato were taken from Table XVIII in FAO Irrigation and Drainage Paper No.33 'Yield Response to Water' [9] after consultation with staff of Water Management Department, NWFP Agricultural University, Peshawar. The values used were 0.75 for the early development stage, 1.12 for the flowering stage, 0.90 for the tuber formation stage and 0.72 for the ripening stage.

The reference evapotranspiration (ET_0) was determined by

ET_0 = E pan. Kp

where E pan = The sum of Pan Evaporation, cm, from Standard Class A evaporation pan during the inter-irrigation period.

Kp = Pan coefficient. The value used was 0.8 (for the irrigated areas). This value has been determined by the Water Management Department of NWFP Agricultural University, Peshawar.

The plot of data in Fig 4. showed that the vegetative stage was most sensitive to water deficit followed by tuber formation and flowering stages. Since the experimental plot of T7, wherein the ripening stage was stressed, was not instrumented for moisture determination by neutron moisture meter, the data on actual evapotranspiration cannot be calculated. It is, however, credible that ripening was the least sensitive stage to water stress. these findings are corroborated by the work done elsewhere. Roth [3] reported that critical period for avoiding water stress was flowering to haulm maturity especially the three weeks after flowering. In india, water stress imposed at stolon initiation stage repressed yield by 30-65% whereas the effect was less pronounced at other stages [10]. In another study, the earliest drought treatment affected the number of stolons/stem depending on the variety of potato. The later dry period did not affect number of stolons or tubers. These data corresponded with their field data which showed significant linear relationship between number of tubers/stem and total rainfall during first 40 days [11].

The field and crop water use efficiencies based on the depths of irrigation water applied and ETa, respectivley, are presented in Table XVIII. The highest efficiencies of both type were produced in all-stress (T2) treatment. The next highest Ef occurred in T1; the Ef of the remaining treatments were more or less similar. The second highest Ec was produced in T4 followed by T1.

Regarding fertilization, the two rates of application produced statistically similar tuber and aboveground biomass yields. The irrigation x fertilization interaction was also non-significant.

TABLE XVIII. FIELD WATER USE EFFICIENCY (E_f) AND CROP WATER USE EFFICIENCY (E_c) OF DIFFERENT IRRIGATION TREATMENTS DURING AUTUMN 1993.

Trt	Tuber yield (t/ha)	Depth of water applied (m^3/ha)	ET_a (m^3/ha)	E_f kg/m^3)	E_c (kg/m^3)
1	7.68	3240	2150	2.37	3.58
2	5.17	2140	1100	2.42	4.70
3	6.78	3410	-	1.99	-
4	5.64	2840	1550	1.99	3.63
5	6.01	2910	1850	2.06	3.25
6	6.04	3000	1840	2.01	3.28
7	6.53	3110	-	2.10	-

5.1.6. Spring 1994 Experiment

Potato, cv. Ultimus, was sown on March 8, 1994, about 30 days later than the normal sowing time of the spring crop, and harvested on June 13, 1994. Thus the growing period remained shorter (97 days) than that of the normal crop (125 days). The delay in sowing occurred due to incessant rains during early spring which did not allow the soil to dry to a condition suitable for making ridges and planting of potato. Also, keeping in view the results of previous experiment which showed no significant effect of two fertilizer levels on yield, the fertilizer levels in this experiment (conducted at the same site) were reduced. The lower level in the previous experiment, i.e. 100 kg N + 50 kg P_2O_5 + 100 kg K_2O per ha, now formed F1; the F2 was 50 kg N + 25 kg P_2O_5 + 50 kg K_2O per ha. The experimental plots were furrow-irrigated the next day of sowing. The condition of the crop was poor in the beginning but caught up later on.

The first treatment irrigation, at establishment/vegetative stage, was applied on 19/4/94, the second at flowering stage on 4/5/94, the third at tuber formation stage on 16/5/94 and fourth at ripening stage on 29/5/94. The depth of irrigation water applied, and actual evapotranspiration (ETa) calculated using soil moisture data determined by neutron moisture meter are presented in Table XIX. The total rainfall during the growing season was 119.79 mm which was spread during the months of March (16.68 mm), April (58.11 mm) May (37.00mm) and June (8 mm).

TABLE XIX. DEPTH OF IRRIGATION WATER APPLIED AND ACTUAL EVAPOTRANSPIRATION AT DIFFERENT GROWTH STAGES OF POTATO, CV. ULTIMUS, DURING SPRING 1994.

Trt.	Post Planting	Estb. stage	Flowerg. stage	Tuber formn. stage	Ripening stage	Total cm	Total m^3/ha
Depth of water applied, cm							
T1	12.9	9.7	8.9	9.7	8.4	49.6	4960
T2	12.9	4.0	3.2	3.2	3.6	26.9	2690
T3	12.9	9.5 + 10.0 + 10.5 + 10.0				52.9	5290
T4	12.9	4.0	8.9	9.7	8.4	43.9	4390
T5	12.9	9.7	3.2	9.7	8.4	43.9	4390
T6	12.9	9.7	8.9	3.2	8.4	43.1	4310
T7	12.9	9.7	8.9	9.7	3.6	44.8	4480
Actual Evapotranspiration, cm							
T1		11.7	10.9	8.9	10.2	41.4	4140
T2		6.0	5.1	5.2	4.8	21.1	2110
T3		-	-	-	-	-	-
T4		5.8	10.3	8.4	10.8	35.3	3530
T5		10.5	6.7	7.9	11.7	36.8	3680
T6		11.5	9.8	4.2	10.5	36.0	3600
T7		-	-	-	-	-	-

The results on tuber yield (Table XX) showed that the overall yield was extremely low. The size of tubers was also very small (less than about 60 g) in all the treatments. The yield and size of tubers were adversely affected by high temperature (> 35°C) prevailing at the time of tuber initiation. It has reported that high temperature and high water deficit aggravate yield lesses [9,12]. The tuber growth is sharply inhibited when temperature is above 30°C. The highest yield was produced in T1 and the lowest in T2. The relative reduction in yield over T1 ranged from 17% (in T4) to 54% (in T2), the reduction in the remaining treatments was statistically similar. The mean above-ground dry biomass, on the other hand, was statistically similar in all the treatments. Actually, the above-ground dry biomass yield was higher than the tuber yield indicating that the photosynthates produced in the leaves were translocated to form more vegetative growth rather than tubers.

TABLE XX. MEAN TUBER AND ABOVEGROUND DRY MATTER YIELD OF POTATO AS INFLUENCED BY IRRIGATION AND FERTILIZER TREATMENT DURING SPRING 1994.

Treatment	Tuber yield (ton/ha)	Rel. reduction over T1 (%)	Aboveground dry matter yield (ton/ha)
Irrigation treatments			
T1	1.73 a	0	2.08 a
T2	0.80 b	53.7	1.86 a
T3	1.03 ab	40.5	1.81 a
T4	0.97 ab	43.9	1.89 a
T5	1.43 ab	17.3	1.95 a
T6	1.07 ab	38.2	1.54 a
T7	1.16 ab	32.9	1.66 a
Fertilizer treatments			
F1	1.29 a	-	1.84 a
F2	1.05 a	-	1.81 a

The relative reduction in yield was plotted against relative evapotranspiration deficit calculated by the method described earlier in order to determine susceptibility of different growth stages to water stress. It was revealed (Fig 5) that vegetative development was the most sensitive stage to water stress followed by tuber formation stage. This is in conformity with the earlier findings.

In view of extremely low yields, the crop water use efficiencies for different treatments were not calculated.

5.2. RAPESEED

5.2.1. Rabi 1992-93

The filed experiment on rapeseed (*Brassica napus*) was conducted with the same objectives as for potato but with extended irrigation treatments and no fertilizer treatment. Unlike the potato experiment, the stress irrigation here meant omission of irrigation altogether. There were 10 irrigation treatments as detailed below.

T1: All-normal watering at the four growth stages (Floral bud initiation, 50% flowering, Pod formation and Ripening).

T2: All-stress watering at the above four growth stages

T3: Traditional irrigation practice followed by farmers

T4: One stress at Floral bud initiation, normal watering at other stages

T5: One stress at 50% flowering, normal watering at other stages

T6: One stress at Pod formation, normal watering at other stages

T7: One stress at Ripening stage, normal watering at other stages

T8: Two stresses at first two stages, normal watering at others

T9: Two stresses at 50% flowering and pod formation stages, normal watering at others

T10: Two stresses at last two stages, normal watering at others.

The results obtained on grain yield, biological yield, number of pods per 5 plants and number of branches per 5 plants are given in Table XXI. The yield differences among different treatments were not significant statistically. The growth period of the crop was characterized by intermittent rains especially during the flowering 4stage which interfered in setting of the seed hence differences among the treatments were masked. Regarding number of branches and number of pods, a variable pattern was observed, hence it is difficult to draw some valid conclusions.

5.2.2. Rabi 1993-94

The experiment consisted of 7 irrigation treatments which were the same as the first 7 treatments in the previous year experiment. The crop (*Brassica napus*, mutant RM-152-2 developed by Mutation Breeding group of the institute) was sown in 'wattar'(meaning moist soil) conditions in the seedbed on 21-10-1993 and harvested on 13-4-1994. No irrigation was applied immediately after sowing like potato. The crop was fertilized uniformly at the recommended rate of 90 kg N and 60 kg P_2O_5 per ha. Half of the N and all of the P were applied at the time of sowing; the remaining half of N was applied at floral bud initiation.

TABLE XXI. GRAIN YIELD, BIOLOGICAL YIELD, NUMBER OF BRANCHES AND NUMBER OF PODS PER 5 PLANTS OF RAPESEED AS INFLUENCED BY IRRIGATION SCHEDULING DURING RABI (WINTER) 1992-93.

Treatment	Grain yield (t/ha)	Biolog.yield (t/ha)	No.of branches per 5 plants	No.of pods/ 5 plants
T1	1.48 a	7.45 a	19.7 ab	367.0 cd
T2	1.41 a	6.67 a	17.7 b	353.3 d
T3	1.48 a	7.45 a	19.7 ab	367.0 cd
T4	1.77 a	7.67 a	23.7 ab	566.7 ab
T5	1.79 a	6.91 a	20.0 ab	413.0 bcd
T6	1.35 a	7.11 a	21.3 ab	430.0 bcd
T7	1.37 a	7.11 a	21.3 ab	570.0 cd
T8	1.23 a	6.35 a	17.7 b	330.3 d
T9	1.37 a	6.71 a	20.7 ab	598.3 a
T10	1.23 a	6.35 a	17.7 b	330.3 d

The first treatment irrigation at floral bud initiation stage was applied on 1-12-93, the second irrigation at 50% flowering stage on 11-1-94 and the third irrigation at pod formation on 10-2-94. The fourth irrigation which was due at ripening stage was omitted as 13.5 mm of rainfall was received during this period. A total of 195.95 mm of rainfall was received during the growing season which was spread during the months of October (3.0 mm), November (28.04 mm), December (Nil), January (16.04 mm), February (74.08 mm), March (16.68 mm) and April (58.11 mm). The depths of irrigation water applied to and actual evapetranspiration, calculated by water balance method, for different treatments are presented in Table XXII.

The results on seed and biological yields (Table XXIII) showed that irrigation treatments did not exert a significant influence on the yields. The fact that the yield from T2 was at par with T1 showed that water requirements of rapeseed were not high and were easily met by the stress watering applied in T2. The harvest index was also highest in T2 indicating greater proportion of grain relative to straw. The frequent rains during the growing season further aggravated the non-differences among various treatments.

5.3. WHEAT

5.3.1. Rabi 1993-94

The experiment comprised 7 irrigation treatments which were the same as those described under 'Experimental Methods' with the different that growth stages for irrigation application were as follows.

i) Seedling
ii) Tillering
iii) Boot
iv) Ripening

TABLE XXII. DEPTHS OF IRRIGATION WATER APPLIED AND ACTUAL EVAPOTRANSPIRATION FOR DIFFERENT TREATMENTS OF RAPESEED DURING RABI 1993-94.

Treatment	Folaral bud initiation stage	50% flowering stage	Pod formation stage	Ripening stage	Total
Depth of water applied, cm					
T1	5.17	6.25	6.00	-	17.42
T2	2.58	2.08	2.25	-	6.91
T3	4.0 +	5.5 +	6.3 +	5.0	20.80
T4	2.58	6.25	6.00	-	14.83
T5	5.17	2.08	6.00	-	13.25
T6	5.17	6.25	2.25	-	13.67
T7	5.17	6.25	6.00	-	17.42
Actual evapotranspiration, cm					
T1	9.56	5.14	7.51	-	22.21
T2	6.98	1.15	3.54	-	11.67
T3	-	-	-	-	-
T4	-	-	-	-	-
T5	*	2.08	7.50	-	9.58
T6	-	-	-	-	-
T7	-	-	-	-	-

* The plot of T5 was instrumented for neutron moisture meter and tensiometers towards the end of floral bud initiation stage (on 5-1-94)

TABLE XXIII. SEED AND BIOLOGICAL YIELD, AND HARVEST INDEX OF RAPESEED (MUTANT RM-152-2) AS AFFECTED BY IRRIGATION TREATMENT DURING RABI 1993-94.

Treatment	Seed yield (ton/ha)	Biological yield (ton/ha)	Harvest index‡ (%)
T1	1.31 a	6.60 a	19.8
T2	1.43 a	6.18 a	23.1
T3	0.99 a	5.28 a	18.8
T4	0.95 a	6.49 a	14.6
T5	1.12 a	5.76 a	19.6
T6	1.67 a	8.96 a	18.6
T7	1.20 a	7.08 a	16.9

‡ Harvest Index (%) = $\frac{\text{Seed yield}}{\text{Biological yield}} \times 100$

The crop (Advanced Mutant WS-10, developed by Mutation Breeding Group of this institute) was sown in the prepared seedbed at appropriate moisture condition on 22-11-1993. The crop was fertilized uniformly at the recommended rate of 135 kg N plus 80 kg P_2O_5 per ha. Half of the N and all of the P were applied at sowing time; the remaining half of N was applied at boot stage. The crop was harvested on 16-5-1994.

The first treatment irrigation at seedling stage was applied on 12-12-93, the second irrigation at tillering stage on 17-1-94, the third irrigation at boot stage on 17-3-94 and the fourth irrigation at ripening stage on 12-4-94. A total of 193.91 mm of rainfall was received during the growing season which was spread during the months of November (Nil), December (Nil), January (16.04 mm), February (74.08 mm), March (16.68 mm), April (58.11 mm) and May (29.00 mm). The depths of irrigation water applied to various treatments and actual evapotranspiration, calculated by the water balance method, for the three instrumented treatments are presented in Table XXIV.

TABLE XXIV. DEPTHS OF IRRIGATION WATER APPLIED AND ACTUAL EVAPOTRANSPIRATION FOR DIFFERENT TREATMENTS OF WHEAT DURING RABI 1993-94.

Treatment	Seedling stage	Tillering stage	Boot stage	Ripening stage	Total
Depth of irrigation applied, cm					
T1	7.02	6.12	7.00	6.91	27.05
T2	3.51	2.63	3.50	2.76	12.40
T3	7.50 +	8.70 +	7.50 +	6.00	29.70
T4	3.51	6.12	7.00	6.91	23.54
T5	7.02	2.63	7.00	6.91	23.56
T6	7.02	6.12	3.50	6.91	23.55
T7	7.02	6.12	7.00	2.76	22.90
Actual evapotranspiration (ETa), cm					
T1	6.22	7.75	14.19	19.93	48.09
T2	3.28	3.02	11.89	10.70	28.89
T3	-	-	-	-	-
T4	-	-	-	-	-
T5	7.02	4.22	13.26	15.46	39.96
T6	-	-	-	-	-
T7	-	-	-	-	-

The results on grain and biological yields (Table XXV) showed that yield from the experimental plots was very good being almost double the national average of 1600 kg/ha (1). The irrigation treatments, however, did not exert a significant effect on yield. The effect of treatments was compounded by the heavy rainfall received during the growing season particularly from the end of tillering stage onwards. This is reflected in higher ETa values compared to amounts of water applied during this period.

TABLE XXV. GRAIN AND BIOLOGICAL YIELD, AND HARVEST INDEX OF WHEAT (MUTANT WS-10) AS INFLUENCED BY IRRIGATION TREATMENTS DURING RABI 1993-94.

Treatment	Grain yield (ton/ha)	Biological yield (ton/ha)	Harvest index[‡] (%)
T1	4.75 a	16.45 a	28.9
T2	4.68 a	15.28 a	30.6
T3	4.68 a	15.35 a	30.5
T4	5.26 a	16.59 a	31.7
T5	5.19 a	17.32 a	30.0
T6	5.19 a	17.25 a	30.0
T7	5.04 a	17.54 a	28.7

‡ Harvest Index (%) = $\frac{\text{Grain yield}}{\text{Biological yield}} \times 100$

6. CONCLUSIONS

From the results obtained from the field experiment conducted the framework of this project, the following main conclusions can be drawn.

1. The highest tuber yield of potato was obtained from the continous normal watering and the lowest from the continued stress watering treatment, the yields from other treatments being intermediate. The relative reduction in yield over all-normal waterings ranged between 4 and 54% in different treatments in different growing seasons.

2. The plot of relative yield reduction versus relative evapotranspiration deficit revealed that ripening was the least sensitive whereas early development followed by tuber initiation the most sensitive growth stage to water stress.

3. The crop water use efficiencies were generally higher in the treatments where a combination of normal and stress waterings was applied compared to the one where all-normal waterings were applied. The water thus saved could be used to bring additional areas under cultivation.

4. The studies with labelled fertilizer showed that planting and earthing-up were equally important growth stages of potato for applying fertilizer for its efficient utilization.

5. The prevalent practice of common farmers (of applying water at 10-12 days interval without regard to actual needs of the plant at appropriate growth stage) is not efficient; it results in wasteful application of water with relatively lower yields. Hence, the results from this project have very high value for farming community to get optimum yields with scarce water resources.

6. The rapeseed does not appear to have high water requirements. The requirements could be met easily by the continued stress watering of the present experimental design.

7. Using the relationship between relative yield reduction and relative water deficit and under a given quantity of limited water supply spaced during entire growing season or at a particular growth stage, reduction in yield can be predicted for any set of conditions as relative (rather than absolute) values of yield reduction and evapotranspiration deficit have been used.

PUBLICATIONS

The following publications have emanated from the work done under this contract.

1. Iqbal, M.M., S.M. Shah,. Mohammad and H. Nawaz (1993). Critical growth stages of potato for applying irrigation water. <u>In</u> Science International, Proc. 2nd All-Pakistan Science Conference, Lahore, Dec. 26-30, 1993, pp 164-166

2. Iqbal, M.M., S. M. Shah, W. Mohammad and H. Nawaz (1994). Irrigation scheduling of potato using soil and climatic criteria. Presented at 5th National Congress of Soil Science, Peshawar, Oct 23-25 1994. Submitted to Pakistan J. Soil Sci.

3. Irrigation - a necessary evil. Popular article (under preparation).

4. Effect of 2-split application of fertilizer to potato on yield and fertilizer utilization (Planned).

5. Yield response of potato to water stress imposed at different growth stages (Planned).

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