

CENTRAL BOARD OF IRRIGATION AND POWER

**Symposium
On
Optimum Requirements and
Utilisation of Water for
Irrigated Crops**

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FOREWORD

Since the introduction of canal irrigation, there has always been an attempt to evolve methods for judicious and timely application of water to the various crops for its optimum utilisation for ensuing best yield. With the growing population, the present day activity in the field of irrigated agriculture has increased manifold. With widely differing soils and climatic conditions, the water requirements of crops also vary from region to region. There are, thus, three basic questions related to problems of irrigated agriculture, *viz.* (i) How to irrigate ? (ii) When to irrigate ? (iii) How much to irrigate ?

Considerable laboratory and field experimental work on water requirements of crops has been done in the country over the past two decades both by the Irrigation and Agriculture Engineers. Yet, diverse approaches and techniques have been adopted for the application of water to various crops, resulting in widely varying yields. There is need for standardising the techniques on an all-India basis. Simultaneously, dissemination of the knowledge, gained through researches, to the cultivator is of urgent necessity.

The Central Board of Irrigation and Power organised a Symposium on 'Optimum Requirements and Utilisation of Water for Irrigated Crops' at the time of its Annual Meeting held at New Delhi in November 1963, with a view to provide a forum to both Irrigation and Agriculture Engineers and Scientists to discuss the subject in detail, and to pool the progress made on the subject for the benefit of both. Twenty-eight research papers covering aspects of (i) water requirements of crops, (ii) cropping patterns, (iii) relationship between water requirements, evaporation and rainfall, (iv) soil and soil moisture studies, and (v) optimum water use, were presented. The Symposium was largely attended by State Irrigation Chief Engineers, Directors of State Irrigation Research Stations, Experts and Scientists of Agriculture Research Stations, and other engineers.

Under the first aspect, namely, 'Water requirements of crops' the studies reported pertained to rice, wheat, sugar-cane, gram, potato and cotton. The large variation in the water requirements of some of these crops in various regions of the country was brought out. The soil moisture deficit and climatological approaches were proposed for evaluating water requirements of various crops. It was suggested that economics of water utilisation should also be taken into consideration in these studies. Under the 'Cropping patterns', it was felt that the combination of rice followed by maize was worth trying. During discussion on the 'Relationship between water requirements, evaporation and rainfall', it was noted that no large scale experimental work had been carried out in India on the subject. It was felt that more climatological data were needed for planning irrigation and agriculture on a scientific basis. A resolution urging the Govt. of India to fill up the lacunae in the existing network of self recording raingauges and evaporation measuring stations was adopted. The need for conducting extensive soil and soil moisture studies was emphasised and it was suggested that pre-irrigation soil surveys should necessarily be carried out in all irrigation projects.

(ii)

This publication contains papers, general report and discussions held at the Symposium. The Central Board of Irrigation and Power is grateful to the authors of the papers, and participants who largely contributed to the success of the Symposium. Special mention is made of Dr. Mukhtar Singh, Indian Agricultural Research Institute, New Delhi who prepared the General Report and initiated the discussions. It is hoped that the publication will be of great utility to the profession.

NEW DELHI
March 1969

S. N. GUPTA
Secretary
Central Board of Irrigation and Power

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GENERAL REPORT*

The papers discussed at the symposium were classified as follows :—

- (i) Water requirements of crops.
- (ii) Water utilisation—cropping patterns.
- (iii) Water requirements and weather factors—(Evaporation and Rainfall).
- (iv) Soil and soil moisture studies.
- (v) Optimum water use.

(I) Water Requirements of Crops

Factors influencing water requirements of crops have been discussed by Doddiah (25)**. Estimates of water requirements of most of the crops based on results of experiments conducted at I.A.R.I., Delhi, have been given by Dastane and Mahendra Singh (23). Generalised estimates of irrigation requirements have been stated by Raheja (22), but from the data given it appears that the rainfall is included in the estimates. Walter (13) has indicated the water duty of important crops in Madras and concluded that mean duty of dry irrigation crops worked out to 175 and that of rice to 60. Mehta and Shekhawat (10) have given tentative water requirements exclusive of rainfall in Chambal commanded areas of different irrigability classes. Apart from the generalised estimates referred to above, some papers deal with irrigation water requirements of individual crops as summarised below.

(i) RICE

Gupta and Bhattacharya (1) have reported the results of an experiment conducted at Dhanauri (U.P.) with six irrigation depths 0, 7.6, 10.2, 12.7, 15.2, 19.05 and 22.9 cm. (0, 3, 4.5, 6, 7.5 and 9 in.) applied at three intervals (2, 2.5 and 3 weeks) in combination with nitrogen levels. They have concluded that maximum yield was obtained with four irrigations of 19.05 cm. (7.5 in.) each applied at 2.5 week intervals. Thus the total water requirements including 86.11 cm. (33.9

in.) rain was 162.31 cm. (63.9 in.). Contrary to these results, the finding of Pandey (8) emanating from the experiment on light irrigation on *Aman* paddy carried out over 5 years at Bikramganj, Bihar, clearly shows that rainfall of 76.2 cm. (30 in.) from sowing in the nursery to maturity appeared to be adequate (exclusive of the amount needed for puddling) and irrigations were without effect. In the experiment reported by Chowdhury and M. Singh (2) also, no response to supplemental irrigations after plant establishment in the case of transplanted paddy was recorded at Delhi. Although high water-table (30 cm.—60 cm.) may partly account for the absence of response to irrigation in the experiment at Delhi, yet Pandey's experiments show that irrigation was without effect under conditions of low water-table 1.83 m. to 4.88 m. (6 ft. to 16 ft.) because of well-distributed rainfall. In view of these results, it would be of interest to discuss the factors which may have led to the response to 75 cm. deep irrigations in the experiment by Gupta and Bhattacharya (1). Banerjee (24) has referred to the results of an experiment on time and frequency of irrigation on *Aus* paddy at Kalyani (West Bengal) indicating that the best and optimum results were obtained by 41.91 cm. (16½ in.) of water in doses of 10.2, 10.2, 6.35, 6.35, 2.54, 2.54, 1.27, 1.27 and 1.27 cm. (4, 4, 2½, 2½, 1, 1, ½, ½ and ½ in.) in successive irrigations. However, one would normally expect that deeper irrigations will be required in period of high water demand which generally synchronises with maximum vegetative growth. In fact, Dutta and Sen (26) have mentioned that rate of transpiration was maximum during peak tillering and pre-flowering and again during anthesis. Chaudhry and R. S. Singh (4) in their review of water requirements of rice have also cited a summarised statement of Rao that water requirement just prior to flowering was about 2-3 times the quantity required about 10-15 days before flowering or the quantity required

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**The number given in parenthesis, following authors' names, refers to the serial number of the papers for discussion.

after flowering. This review also refers to varying results obtained by different workers regarding the need for submergence in rice and the depth of submergence. Much of the evidence in favour of submergence seems to be from countries in temperate regions (Japan and Italy). Chowdhury and M. Singh (2) have suggested on the basis of the results of a preliminary experiment that if weeds are controlled and the problem of low temperature, as is met within temperate regions, does not exist, irrigation at or near field capacity may be all that is necessary. They have advocated a thorough investigation of the problem by proper techniques which may be discussed at this symposium.

The effect of manuring with farmyard manure, sulphate of ammonia, super-phosphate on transpiration ratio has been reported by Chaudhry and Mahapatra (3). In general, manuring had little effect on transpiration ratio of rice, contrary to the results generally obtained in the case of crops other than rice, (Mariakulandai, 21).

(ii) WHEAT

Two irrigations, one at flowering and the other at milk stage, were generally found to be adequate to mature wheat in U.P. (Mehrotra and his associates—5, 6 and 7). In some cases as in the central and western parts of the State the need for a third irrigation was indicated. In Gujarat, the number of irrigations needed varied with places (Gopani, 27). Optimum number of irrigations seem to be 3 at Dobhoi (Baroda), 5 at Kholwad (Surat) and at Thasra (Kaira), and as many as 9 at Jamnagar, Halwad (Surendernagar), Kukda (Surendernagar), Pilwai (Mehsana), and Junagadh. From observations on the utilisation of water in Gujarat, Talati (16) has recorded that 5-6 irrigations are commonly given to wheat under tube-well irrigation. More frequent irrigation to wheat in Gujarat as compared with northern India may be partly ascribed to high evaporation and milder winter in Gujarat. But the difference seems to be too large to be accounted for by these factors alone, particularly because the soil in many parts of Gujarat is heavy and the growing season is relatively short. The causes of varying irrigation requirements within Gujarat also need to be explained.

The depth of irrigation and delta have not been given for the experiments conducted in Gujarat. It is possible that the individual irrigations are very light and there may be scope for reducing the irrigation frequency by increasing the depth of individual irrigation. At Delhi, Dastane and Mohinder Singh (23) have given water requirements of wheat as 360 mm. inclusive of rainfall.

In the experiments conducted in U.P. (Mehrotra and Singh, 6) and in Gujarat (Gopani, 27), optimum irrigation frequency was found to be conducive to higher response to nitrogen as compared with infrequent irrigations.

(iii) SUGAR-CANE

Kulkarni and Gokhale (15) have reviewed the water requirements of sugar-cane as worked out by different methods, *viz.*, (i) pot culture for the period 1928-34, (ii) field scale experiments at Hadapsar and Padegaon, (iii) quantity of water used in relation to yield on soils of varying types in sugar-cane factory areas in Western Maharashtra, and (iv) water used under well irrigation as recorded during soil survey work. In pots, it was estimated that 0.9 m. (36 in.) water was used by transpiration, the same amount by evaporation and about half as much could be reckoned as lost in drainage, for a normal 115.2 tonnes/ha. (45 tons/acre) crop. In field experiments, the optimum was 241.3–254.0 cm. (95–100 in.). In the studies on water utilisation, 287.02 cm. (129 in.) of water, as measured at distributary head, was used. Under well irrigation, the average water used was 327.66 cm. (113 in.). If 15 per cent water, estimated as lost in transit, is added to this, the water requirements agree well with the estimates obtained by other methods. It may well be considered at this symposium as to how data of annual yield in acre-inches as given in paper were computed.

(iv) GRAM

In Gujarat, three irrigations applied on 35, 50, and 65 days after sowing increased the yield of gram after paddy particularly in combination with 13.61 kg. (30 lb.) P_2O_5 per acre (Talati, 16 and Gopani, 27). This is interesting because, in north India, gram hardly needs one irrigation after sowing.

(v) POTATO

Pushkarnath and Swaminathan (17) have concluded that : (i) 8-9 days irrigation interval was optimum for potatoes in north India, (ii) 2569.75 cu. m. (25 acre-in.) delta gave better performance than lower and higher irrigation delta, (iii) three irrigations in growth phase, four during tuberisation and two during maturity were required irrespective of the duration of varieties. The interaction between irrigations and nutrients was rather complex. Moolani and Hukkeri (18) have reported the results of an experiment conducted on the basis of water regime concept on lateritic soil at Kharagpur. They found that 44.45 cm. (17.5 in.) of irrigation water or 45.21 cm. (17.80 in.) total water were required for obtaining the best yield from the low moisture tension treatment.

(vi) COTTON

Experiments on *Deviraj* cotton at 7 centres in Gujarat show that two irrigations gave as good performance as more irrigations at Jamnagar, Pilwai, Kim and Thasra, but three irrigations at Kukda and four at Junagadh appeared to be the best (Gopani, 27). Arboreum cotton at Umerala and Herbaceum cotton at Kholwad also profited from supplemental irrigation. At some centres, *i.e.*, Bardoli and Kim, the response of Herbaceum cotton to irrigation was inappreciable. In general, irrigation requirements of the crop in Gujarat varied between 15.24 and 25.40 cm. (6 and 10 in.) (Talati, 16). The low irrigation requirements of the crop may be ascribed to high rainfall received in the monsoon season and good moisture storage capacity of the soil. If rainfall is included the water requirements would be comparable to that in Delhi, which is stated to be 980 mm. by Dastane and Mohinder Singh (23).

The inter-dependence of irrigation and fertilizers for maximising production of cotton has been brought out by the experiment conducted at Siriguppa (Mariakulandai, 21).

(II) Cropping Patterns

Mehta and Shekhawat (10) have referred to the distribution of crops under different water allowances in Chambal commanded area. It is stated that cropping patterns are based on water allowance capacity factor, water requirement of crops, *kharif/rabi* ratio, *etc.* It would be useful if a detailed

procedure as to how different factors have been taken into account is given and it is indicated how the proposed cropping patterns make for better utilisation of water than other alternatives.

Patil (9) has analysed the data on current utilisation of water in relation to yield in red soil of Bangalore District (Mysore) and worked out input-output relationship in case of different crops. He has concluded that it is highly profitable to grow cabbage, potato and garlic and among cereals it is better to grow ragi rather than paddy. The levels of irrigation adopted by farmers are indicated for different crops and it was noted that water is extravagantly used in paddy. It needs to be clarified : (i) how measurement of irrigation water was undertaken in the survey, and (ii) whether optimum use of water was consistent with optimum allocation of other resources as well.

(III) Water Requirements, Evaporation and Rainfall

Dastane and Mohinder Singh (23) have suggested the use of climatological approach to evaluate water requirements. They have given monthly values of potential evapotranspiration at Delhi calculated by Thornthwaite's formula and corresponding rainfall to indicate the periods of water surplus and water deficit. It may, however, be mentioned that these estimates should be related to consumptive use, to be more precise. Ayyar and Padmanabhamurthy (11) have reported the relationship between water losses from wheat fields and pan evaporation. Strangely enough, A.E.T./pan evaporation was higher in germination and tillering stages than in elongation (growth stage). Normally the ratio would be expected to be higher during peak period of vegetative growth.

Malik (19) has discussed the variability of rainfall in space and time in India. He has suggested that duration of wet season as given in Table IV of his paper together with water needs of crops should provide a scientific basis for determining irrigation needs of different areas. This would need to be elucidated. It would also be useful to discuss at the symposium the procedure for evaluating effective rainfall.

(IV) Soil and Soil Moisture Studies

Raychaudhury (20) has suggested that classification of soils should be such as to serve the needs of the irrigation engineer and the agronomist alike. It would be useful to list the minimum soil physical constants which should be adopted to evaluate land for irrigation and which may also help in formulating irrigation practices. Modgal (12) while giving the moisture characteristic curves of three soils has indicated the practical utility of such curves in planning irrigation experiments. These curves can eliminate use of moisture and tension measuring devices as suggested by him. It may, however, be mentioned that such devices will still be useful in conveniently following up moisture tension for scheduling irrigation in experiments.

(V) Optimum Water Use

Kumra (14) has given a detailed account of the methods of economising water use by

careful attention to the principles of reduction of water losses in conveyance, distribution and application in the field. He has also stressed the importance of coordination of irrigation requirements *vis-a-vis* rostering of channels. He has also referred to the existing programmes of research, training and demonstration in water use. Doddiah (25) has also emphasised the need for 'field control' for controlling and regulating supply of water according to crop needs. Walter (13) has reported that better results can be obtained by delivering water at intervals in large volumes than by delivering a constant flow for a definite period by the adoption of a rotational system. The scope and limitations of the suggestions may be considered at the symposium.

Based on the discussion of papers it may be considered whether (a) programmes for studies on water requirement of crops and water utilisation should be augmented and (b) if so, in what directions.

WATER REQUIREMENTS OF RICE

by

S. N. Gupta* and A. P. Bhattacharyat

SYNOPSIS

Experiments were conducted for the second year in succession during 1962 on water requirements of rice in a 1.62 hectares (4 acres) experimental field in the Government Agriculture Farm, Dhanauri with the object of finding out the best combination of depth of irrigation and interval between irrigation treatments along with the level of nitrogen for obtaining the maximum yield. 19.1 cm. (7.5 in.) of irrigation at an interval of 2.5 weeks with 18.14 kg. (40 lb.) of nitrogen gave the best yield. Water requirements were found to be 162.21 cm. (63.90 in.) irrigation requirements being 76.2 cm. (30 in.).

Net duty of water was calculated with the aid of a formula advocated by the Iowa Institute of Hydraulic Research. The resemblance of the calculated figure of 140.5 cm. (59.25 in.) with the observed figure of 162.3 cm. (63.90 in.) was closed.

Further experimental work has been planned for irrigation treatments with continued submergence or submergence with drainage at various stages of the plant growth and on soil moisture deficit approach. This will be further supplemented by climatological and evapotranspiration studies.

Introduction

The water requirements for the rice crop for the design of channels in Uttar Pradesh are worked out by (i) taking average depth of watering as 19.1 cm. (7.5 in.) at the outlet head and (ii) maximum period for one watering as 2.5 weeks. This gives the area that can be irrigated per cusec week as 8.90 hectares (22 acres). The intensity of rainfall varies in the State from 63.5 to 127 cm. (25 to 50 in.) or more. Also, the soil types vary from region to region. These consist of ML-CL (silt-clay mixture) in Tarai region, SM-Sc (sandy loam) in central region, Cl (clay) in eastern region and 'mar' soil of high plasticity in Bundelkhand region. It, therefore, appears that the above criteria for the assessment of water requirements need to be modified suitably in the present context of our objective to utilise every cusec of water usefully. This indicates the necessity of launching experimental studies for various regions of Uttar Pradesh.

The experiments on water requirements of rice were initiated in a 1.62 hectare (4 acres) field at the Government Agriculture Farm,

Dhanauri in 1961 and the work detailed hereafter pertains to 1962. This is situated nearly 14.48 km. (9 miles) from Roorkee on Roorkee-Hardwar Road. The tract is generally even and the soil is ML-Cl (silt-clay mixture) type having a pH value of 7.0. The normal rainfall is 104.1 cm. (41 in.) with winter rainfall varying from 10.2 to 17.8 cm. (4 to 7 in.).

Experimental Details

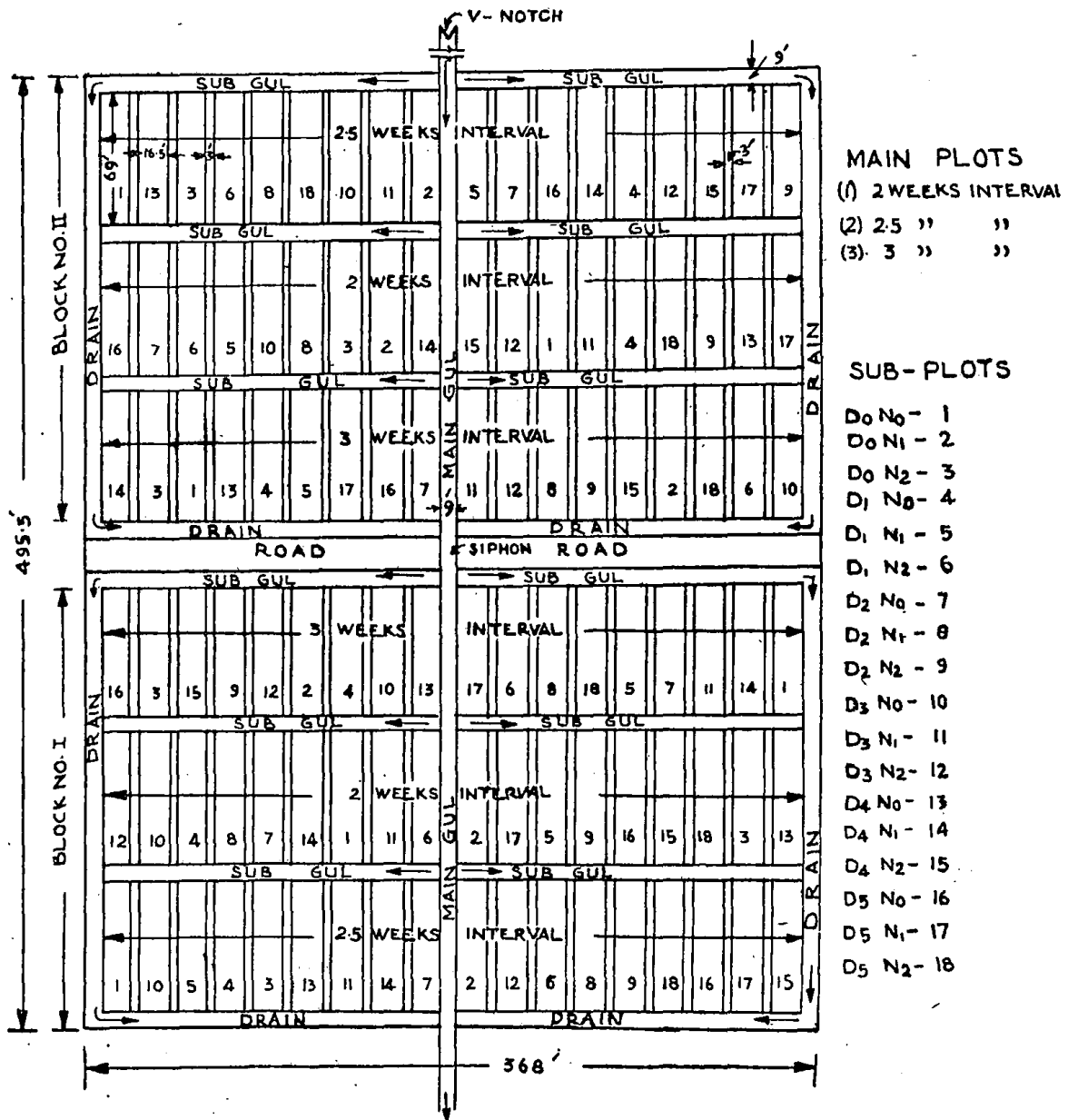
As in the previous year, the method of layout was based on randomized block system, the layout plan being as per Figure 1. The experimental field, measuring 1.62 ha. (4 acres) consisted of 108 subplots 175.3 cm. × 41.9 cm. (69 in. × 16.5 in.) corresponding to two replications in two blocks, each block comprising 54 sub-plots representing six depths, three intervals and three levels of nitrogen. The details of the treatments are given below.

The treatment combinations consisted of six depths of irrigation, viz., 0, 7.6, 11.5, 15.2, 19.1 and 22.9 cm. (0, 3, 4.5, 6, 7.5 and 9 in.) three

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intervals of 2, 2.5 and 3 weeks and three levels of nitrogen 0, 22.4 and 44.8 kg. per ha. (0, 20 and 40 lb. per acre). The yield data is tabulated in Table I and plotted in Figure 2.

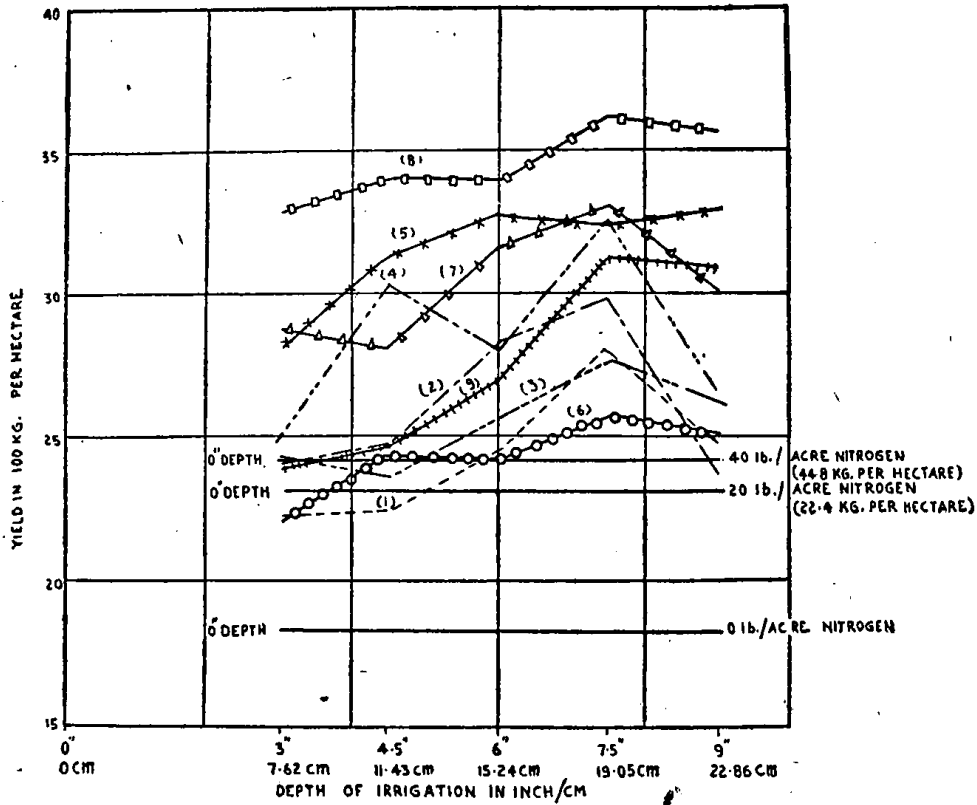


REFERENCES:-

D ₀	STANDS FOR	0"	DEPTH OF IRRIGATION
D ₁	" "	3"	" " "
D ₂	" "	4.5"	" " "
D ₃	" "	6"	" " "
D ₄	" "	7.5"	" " "
D ₅	" "	9"	" " "

N ₀	STANDS FOR	0	lb./ACRE LEVELS OF NITROGEN
N ₁	" "	20	" " "
N ₂	" "	40	" " "

FIGURE 1 : Water requirements—Rice crop—Experimental layout plan, 1962.



REFERENCES			
0	DEPTH WITH 0, 20 AND 40 lb./ACRE NITROGEN		
1.	2 WEEKS INTERVAL & 0 lb./ACRE NITROGEN	(1)	-----
	(0 KG. PER HECTARE)		
2.	2.5 "	"	NITROGEN (2)
3.	3 "	"	" (3)
4.	2 WEEKS "	20 lb./ACRE "	" (4)
		(22.4 KG. PER HECTARE) "	
5.	2.5 "	"	" (5)
6.	3 "	"	" (6)
7.	2 WEEKS "	40 lb./ACRE "	" (7)
		(44.8 KG. PER HECTARE) "	
8.	2.5 "	"	" (8)
9.	3 "	"	" (9)

FIGURE 2 : Water requirements—Rice crop—Yield with various irrigation treatments, 1962.

As regards cultural practices, the plots were ploughed with victory plough initially followed by 'desi' plough as standardised by the Department of Agriculture, Uttar Pradesh. Experience has shown that ploughings should be done as much before transplanting of rice as possible with a view to keep incidence of pests and diseases to minimum and thereby increase crop yield. In the present series of experiments ploughing was done six weeks before transplanting and number of ploughings adopted was from five to six.

Sowing of nursery was done on 22 June 1962. The type of seed was N-12 (Medium). Seed rate was at 275 kg. per ha. (3 maunds per acre). Transplanting was done

from 28 July to 4 August 1962. Harvesting operations were completed from 11 to 21 November, 1962. Details of experimental data may be seen in Table II.

The source of water for irrigation was the Farm tube-well wherefrom water was measured over a 90° V-notch and taken to the sub-plots through a main gul and branch gul. A particular sub-plot was supplied water for irrigation with the help of 10.2 cm. (4 in.) diameter, 1.2 m. (4 ft.) long outlet pipe inserted by making a cut in the levee partitioning the subplots and closed by a wooden cork after the irrigation treatment was completed corresponding to a particular depth of watering.

TABLE I

Showing yield data for rice (N-12) at the Government Agriculture Farm, Dhanauri for the year 1962

Sl. No.	Interval in weeks	Subplot number	Treatment combination			Yield of rice (Paddy) subplot-wise			Average yield per sub-plot of 0.01952 acre in kg.	Average yield in 100 kg. per hectare
			Levels of Nitrogen in lb./acre	Depth of Irrigation		Block I kg.	Block II kg.	Total kg.		
1	2	3	4	5	6	7	8	9	10	11
1.	2	1	0	0.0	0.00	13.8	12.3	26.1	13.05	16.52
2.	"	2	"	3.0	7.62	17.2	17.8	35.0	17.50	22.15
3.	"	3	"	4.5	11.43	18.2	17.2	35.4	17.70	22.48
4.	"	4	"	6.0	15.24	16.5	22.0	38.5	19.25	24.37
5.	"	5	"	7.5	19.05	24.7	19.8	44.5	22.25	28.17
6.	"	6	"	9.0	22.86	20.6	18.5	39.1	19.55	24.75
7.	"	7	20	0.0	0.00	10.6	24.3	34.9	17.45	22.09
8.	"	8	"	3.0	7.62	17.0	22.5	39.5	19.75	25.00
9.	"	9	"	4.5	11.43	23.2	24.8	48.0	24.00	30.38
10.	"	10	"	6.0	15.24	22.0	22.3	44.3	22.15	28.04
11.	"	11	"	7.5	19.05	25.0	26.5	51.5	25.75	32.60
12.	"	12	"	9.0	22.86	17.2	24.8	42.0	21.00	26.58
13.	"	13	40	0.0	0.00	14.5	20.0	34.5	17.25	21.84
14.	"	14	"	3.0	7.62	25.7	20.0	45.7	22.85	28.93
15.	"	15	"	4.5	11.43	22.3	22.2	44.5	22.25	28.17
16.	"	16	"	6.0	15.24	25.3	24.5	49.8	24.90	31.52
17.	"	17	"	7.5	19.05	22.8	29.5	52.3	26.15	33.10
18.	"	18	"	9.0	22.86	21.3	26.2	47.5	23.75	30.70
19.	2.5	1	0	0.0	0.00	16.5	17.8	34.3	17.15	21.71
20.	"	2	"	3.0	7.62	20.0	18.0	38.0	19.00	24.05
21.	"	3	"	4.5	11.43	16.0	22.9	38.9	19.45	24.62
22.	"	4	"	6.0	15.24	24.0	21.2	45.2	22.60	28.61
23.	"	5	"	7.5	19.05	21.0	26.3	47.3	23.65	29.94
24.	"	6	"	9.0	22.86	17.7	19.5	37.2	18.60	23.55
25.	"	7	20	0.0	0.00	16.0	24.0	40.0	20.00	25.32
26.	"	8	"	3.0	7.62	20.0	24.3	44.3	22.15	28.04
27.	"	9	"	4.5	11.43	18.0	31.3	49.3	24.65	31.21
28.	"	10	"	6.0	15.24	24.8	26.8	51.6	25.80	32.66
29.	"	11	"	7.5	19.05	24.0	30.0	54.0	27.00	32.45
30.	"	12	"	9.0	22.86	26.2	25.9	52.1	26.05	32.98
31.	"	13	40	0.0	0.00	20.3	22.1	42.4	21.20	26.84
32.	"	14	"	3.0	7.62	23.8	28.0	61.8	25.90	32.79
33.	"	15	"	4.5	11.43	25.0	28.7	53.7	26.85	33.99
34.	"	16	"	6.0	15.24	25.4	28.0	53.4	26.70	33.80
35.	"	17	"	7.5	19.05	24.0	33.0	57.0	28.50	36.08
36.	"	18	"	9.0	22.86	29.5	26.8	56.3	28.15	35.64
37.	3	1	0	0.0	0.0	10.0	17.0	27.0	13.50	17.09
38.	"	2	"	3.0	7.62	16.8	21.5	38.3	19.15	24.24
39.	"	3	"	4.5	11.43	12.2	25.0	37.2	18.62	23.55
40.	"	4	"	6.0	15.24	16.9	23.5	40.4	20.20	25.57
41.	"	5	"	7.5	19.05	20.7	23.0	43.7	21.85	27.66
42.	"	6	"	9.0	22.86	17.7	24.0	41.7	20.85	26.39
43.	"	7	20	0.0	0.00	13.8	20.7	34.5	17.25	21.84
44.	"	8	"	3.0	7.62	14.9	20.0	34.9	17.45	22.09
45.	"	9	"	4.5	11.43	13.2	25.3	38.5	19.25	24.37
46.	"	10	"	6.0	15.24	16.3	21.8	38.1	19.05	24.12
47.	"	11	"	7.5	19.05	16.1	24.5	40.6	20.30	25.70
48.	"	12	"	9.0	22.86	15.9	25.2	41.1	20.55	26.01
49.	"	13	40	0.0	0.00	15.3	22.0	37.3	18.65	23.61
50.	"	14	"	3.0	7.62	15.2	22.7	37.9	18.95	23.99
51.	"	15	"	4.5	11.43	15.8	23.0	38.8	19.40	24.56
52.	"	16	"	6.0	15.24	24.0	18.7	42.7	21.35	27.03
53.	"	17	"	7.5	19.05	25.5	24.0	49.5	24.75	31.33
54.	"	18	"	9.0	22.86	26.0	22.8	48.8	24.40	30.89

One acre=0.404686 hectare.

TABLE II

Showing details of rice experimental data at the Government Agriculture Farm, Dhanauri for the year, 1962

Sl. No	Name of Item	Details
1.	(a) Area of each plot	69 ft. × 16.5 ft.=0.026 acre
	(b) Net plot size	63 ft. × 13.5 ft.=0.01952 acre
2.	Variety of rice (Paddy) used	N-12 (Medium)
3.	Type of soil	ML-C1 (silt+clay mixture)
4.	Date of sowing of nursery	22 June, 1962
5.	Date of transplanting	28 July to 4 August, 1962
6.	Date of harvesting	11 to 21 November, 1962
7.	Total rainfall in inches during the growing season (July to October)	33.90
8.	Normal rainfall in inches	40
9.	Treatment combinations	0, 3, 4.5, 6, 7.5 and 9 in. depths of irrigation at 2, 2.5 and 3 weeks interval along with three levels of Nitrogen, viz., 0, 20 and 40 lb. per acre (0, 22.4 and 44.8 kg. per hectare)
10.	Maximum yield	36.08 × 100 kg. per hectare or 38.93 Maunds per acre
11.	Irrigation requirements	30 in. or 76.20 cm.
12.	Water requirements including rainfall	63.90 in. or 162.30 cm.

One ft.=0.3048 m.; One acre=0.404686 hectare.

It may be mentioned that the practice in the United States of America, wherein rice is grown in the Middle South besides one of the Western States, namely California, particularly Sacramento and San Joaquin Valleys, is slightly different in that apart from the usual applications, continued submergence to a depth of about 15.2 cm. (6 in.) is resorted to frequently during the growing season, initial flooding being generally 12.7 to 25.4 cm. (5 to 10 in.) deep followed by several shallow floodings to maintain a moisture supply at the soil surface ⁽¹⁾⁽²⁾.

Along with irrigation, good drainage is essential for the removal of alkali, prevention of water-logging of the land and putting the land and surface in firm condition at the time of harvesting. Therefore, drainage ditches were provided all along the periphery of the experimental subplots.

Discussion of Results

From an examination of the yield data as per Table I and Figure 2 and its statistical analysis as per Appendix I, it was found that the maximum yield of 36.08 in 100 kg. per hectare as recorded with four irrigation treatments of 19.1 cm. (7.5 in.) depth at an

interval of 2.5 weeks with 44.8 kg. per hectare (40 lb. per acre) of nitrogen. Second best yield of 33.99 in 100 kg. per hectare is obtained with four irrigation treatments of 11.5 cm. (4.5 in.) depth at 2.5 weeks interval and 44.8 kg. per hectare (40 lb. per acre) of nitrogen. Effects of depth, interval and level of nitrogen were found to be highly significant. Water requirements of rice, inclusive of rainfall of 86.11 cm. (33.90 in.) during the growing season (July to October), were thus 162.3 cm. (63.90 in.).

Experiments of 1961 carried out at Government Agriculture Farm, Dhanauri under similar conditions gave maximum yield of rice of 35.58 in 100 kg. per hectare, with three irrigation treatments of 11.5 cm. (4.5 in.) depth at 2.5 weeks interval and 44.8 kg. per hectare (40 lb. per acre) of nitrogen. The rainfall during growing season was 119 cm. (46.84 in.) and this gives total requirements of water as 153.3 cm. (60.34 in.). It is, therefore, difficult to derive any correlation between the two years' results in regard to the depth of irrigation for one watering although the yield significantly appears to approach the maximum value if water requirement is satisfied with increased rain and less depth of irrigation.

A comparison of the figures for water requirements of rice at Dhanuari with experimental results for other stations may be interesting. Average water requirements of the rice crops during *abi* and *tabi* (crop seasons used in Hyderabad, Deccan including the monsoons and excluding the monsoons respectively) seasons were estimated to be 108 and 114.6 cm. (42.53 and 45.10 in.) respectively for the Nizamsagar Project ⁽³⁾(⁴).

According to Fortier who conducted investigations on irrigation requirements for a number of regions in the South Western United States of America, the total water requirements of rice for clay and clay-adobe soils are 1.5 m. (5 ft.) although in certain fields the same could be as low as 1.2 m. (4 ft.) ⁽⁵⁾. The findings of the experimental studies at Biggs, California indicated this figure to be 1.2 m. (4 ft.) ⁽⁶⁾. Co-operative experiments in irrigation on rice in the Sacramento Valley conducted by the California Agricultural Experiment Station during the years 1914 to 1927 indicated water requirements of rice for clay-adobe soil to be 1.6 m. (5.13 ft.) the corresponding figures for clay and open loam soils to be 1.7 and 2.9 m. (5.39 and 9.38 ft.) respectively, while figures for Stockton clay loam near Biggs were 1.4 m. (4.53 ft.), it being observed generally that more open soils increase the water requirements through percolation losses⁽⁷⁾.

Table III gives some useful information in the form of a summary of some old rice irrigation data for various countries including U.S.A., China, Indo-China, Java, India (Madras), along with the prevailing meteorological conditions⁽⁷⁾. It is interesting to note that water requirements of rice vary within such wide limits as 62.7 to 356.9 cm. (24.67 to 140.50 in.). It is remarkable that within the same region Sacramento Valley in California, having similar climatological features, the variations of water requirements of rice lie within the wide range of 120.7 to 356.9 cm. (47.5 to 140.5 in.) undoubtedly, due to the variations in the nature of the soil. Again for the rice sections of the States of Arkansas, Texas and Louisiana, the water requirements are nearly equal averaging about 76.2 cm. (30.2 in.) owing to similarity in soils, sub-soil and climatological conditions. Moreover, higher evaporation during the growing season 124.5 cm. (49 in.) in California as compared

to 55.9 cm. (22 in.) in the three southern States seems to be the main reason for higher watering needs.

For China, water requirements for Kwangtung were lower than those in Kiangsu apparently due to lower transpiration.

Water requirements for Madras were greater due to higher evaporation and longer irrigation season. This holds true practically for whole of India.

3.4. An attempt was made to calculate the net duty of rice with the aid of a formula advocated by the Iowa Institute of Hydraulic Research ⁽⁷⁾,

$$D = 7E^{\frac{1}{2}} + sL + 4,$$

where D = total net duty of water in inches for rice,

E = total evaporation in inches from a free water surface during submergence period,

s = average daily seepage in inches in rice field during the entire irrigation season, and

L = total number of days during irrigation season.

E was taken as 15.8 cm. (6.23 in.) from the nearby Meteorological Observatory at Bahadradabad. For daily seepage which is calculated from evapotranspiration data, use was made of figures for estimated daily loss of seepage for analogous soils in California, wherein average daily seepage loss was found to be 6.9 mm. (0.273 in.) per day. The value of L was 140 days. With these figures, the value of D is found to be 150.6 cm. (59.29 in.). This figure of estimated net duty for rice has a close resemblance with the observed water requirements of 162.3 cm. (63.90 in.).

Future Programme

The approach regarding the determination of optimum combination of level and frequency of irrigation for obtaining the maximum yield has been altered radically on the basis of the latest concepts in the experiments planned for 1963. It is well known that weed growth is one of the important factors in reducing rice yield. It has been demonstrated by United States Department of Agriculture, that proper water management has been effective for the control of weeds in California. This is achieved by keeping the fields

TABLE III

Comparison of observed and computed total net duty of water for rice in various countries.

Country	Location	Period	Soil condition	Approximate date of Irrigation			Average length of Irrigation Season days			Observed total evaporation during submergence (in.)	Average seasonal temperature °F	Daily loss of seepage calculated at 70°F (in.)	Computed total net duty of water (in.)	Observed total net duty of water (in.)	Variation from observed value per cent	Remarks		
				First Irrigation	Beginning of Submergence	End of submergence	Prior to Submergence	During Submergence	Total									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
U.S.A.	Sacramento Valley California	1916—1918	Capay clay						159			0.017	48.1	47.5	+1.3	(a) All daily losses of seepage are the average values which are obtained from a curve.		
			Willows clay Adobe						154				0.017	48.1	50.6		-4.9	
			Willows clay							168				0.075	58.1		61.0	-4.3
			Stockton clay adobe															
				Tehama clay loam and clay	Ave.	Ave.	Ave.	Ave.	Ave.	157		0.075	57.3	61.6	-7.0		(b) The correction of seepage for the effect of temperature is 1.25 per cent per degree Fahrenheit.	
				Sacramento clay	21 April	11 June	30 Sept.	51	112	167	Ave. 35.13		70.0	68.6	-15.4			
				Vina clay loam						172	It is the average value from 1926 to 1936 at Davis		0.075	58.0	68.6		-15.4	
				Willows loam and clay	From 14 April to 22 May	From 19 May to 12 June	From 27 Sept. to 30 Oct.			153			0.300	97.1	97.5		-0.4	
				Willows loam and clay									0.300	91.5	97.5		-6.2	(c) In Annam there was no temperature record and, therefore, no correction is made.
				Willows loam						155			0.300	92.0	80.2		+14.8	
	Biggs, Calif.	1914—1917	Stockton clay adobe	15 April	9 June	30 Sept.	55	114	170			0.450	122.0	112.6	+8.4	(d) In Wukiang due to the new rice field the seepage was very high and in Canton due to high ground water-table the seepage was very low, therefore, the original seepage data are used in these special cases.		
	Arkansas	1928—1929	Surface soil is silt loam sub-soil is impervious clay.						174			0.450	123.9	140.8	-11.8			
									169	29.42	70.0	0.075	54.6	54.4	+10.6			
	Texas	1917—1919		20 May	1st July	30 Sept.	41	92	120	15.72	80.1	0.017	34.09(b)	34.0(e)	+0.4	(e) In these three States all conditions in the ricefield were nearly the same. There were no complete records at hand and can only be checked with 31.37 in. which was estimated by Prof. W. B. Gregory. The total water used during submergence in Arkansas was 29.85 in. and in Louisiana was 28.04 in.		
	Louisiana	1934—1935											44.40	No				
	Wuchin, Kiangsu	1928—1935	Clay	9 May	1 June	16 Aug.	23	77	100	12.79	81.1	0.154(d)	37.91(b)	38.00	-0.2			
	Canton, Kwangtung	1927—1929	Impervious clay	9 May	11 June	20 Sept.	33	102	135	20.00	81.1	0.017	31.25	24.67	+26.6			
	Ca, on, Kwang tung	1927—1929	Clay loam	20 April	5 May	28 July	15	84	99	11.05	81.4	0.041(d)	40.63	31.12	+30.6			
	Thank-Hora Annam	..	Clay loam	21 July	5 Aug.	3 Nov.	15	91	106	17.34	80.0	0.071(d)	48.50(e)	51.33	-5.6			
	Indo-China	..	Clay	11 June	1 July	30 Nov.	20	153	173	20.08	..	0.075						
	Java	..	Clay	Nov.		March	49	84	133	14.90	80.0	0.075	42.25(d)	44.01	-4.0			
	India	1937	Clay	26 June	11 July	27 Nov.	15	139	154	31.59	80.8	0.075	57.20	59.65	-4.0			

one in. = 2.54 cm. = 25.4 mm.

submerged. There is another theory that soil aeration is affected by continued submergence of rice fields and that drainage at either of the three stages of plant growth, namely, pre-til-ling, pre-flowing, pre-dough, is helpful in increasing yield. In the design of experiments planned for water requirements of rice during 1963, in accordance with a Scheme of Research on Minor Irrigation and Water Use sponsored by the Government of India, Ministry of Food and Agriculture, it is proposed to try both continued submergence and submergence with drainage at various stages of plant growth.

Apart from irrigation with continued submergence or submergence with drainage, it is also proposed to take up experimental work on soil-moisture deficit approach wherein soil-moisture depletion will be allowed by 20, 30 and 40 per cent below the field capacity and water for irrigation will be applied with a view to restore the soil-moisture to the level of the field capacity. While doing so, irrigation efficiencies of 40, 50 and 60 per cent will be tried.

This will be further supplemented by the approach based on climatological considerations and evapotranspiration measurements. The former will involve the recording of meteorological data during the crop growing season and application of the standard formulae, particularly that of Blaney-Criddle, for the assessment of water for irrigation from climatological data. A small meteorological station will be set up near the experimental fields at the Government Agriculture Farm, Dhanauri for conducting these studies. Evapotranspiration studies will be conducted in eight chambers of size 20.3 cm.×20.3 cm.×20.3 cm. (8 in.×8 in.×8 in.) in which rice will be grown, simulating field conditions of soil as far as possible and daily soil-moisture

measurements will be made from the surface to the root zone depth.

These two studies will provide additional information regarding the watering needs of rice during the growing season and also afford a check up of the results obtained by soil-moisture deficit approach.

Conclusions

The total water requirements of rice for Dhanauri did not differ materially during 1961 and 1962, being 153.3 and 162.3 cm. (60.34 and 63.90 in.) respectively, although variations in irrigation treatments were wide, being 34.3 and 76.2 cm. (13.5 and 30 in.) because of variations in rainfall during the growing season of the crop.

Optimum frequency of irrigation was found to be 2.5 weeks.

Optimum level of nitrogen was indicated as 44.8 kg. per hectare (40 lb. per acre).

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APPENDIX I

Note on the statistical analysis of yield of rice in connection with the experiment on Water Requirements of Rice conducted at the Government Agriculture Farm, Dhanauri during 1962

There were two replications, each of which consisted of three intervals of 2, 2½ and 3 weeks and six doses of irrigation [0, 7.6, 11.4, 15.2, 19 and 22.9 cm. (0, 3, 4.5, 6, 7.5 and 9 in.)] with three levels of nitrogen 0, 22.4 & 44.8 kg. per hectare (0, 20 and 40 lb. per acre). It was a factorial design based on random

ized block system. Thus, there were 108 subplots, each having an area of 0.0261 acre.

The final analysis of variance of yield of rice in (kg.)² is given in Table I.1, in which items significant at 0.1 per cent level of probability are marked with three asterisks.

TABLE I.1
Analysis of variance of yield of rice in (kg.)².

Variance due to	Degrees of freedom	Sum of squares	Mean squares
Blocks	1	363.36	363.360 ***
Intervals	2	268.46	134.230 ***
Depths	5	540.18	108.036 ***
Nitrogen	2	341.73	170.855
Intervals × Depths	10	31.39	3.139
Intervals × Nitrogen	4	75.08	18.770
Depths × Nitrogen	10	31.00	3.100
Intervals × Depths × Nitrogen	20	59.91	2.996
Error	53	597.24	11.269
Total	107	2308.35	

The following conclusion can be drawn from the above analysis :—

Intervals

The variation due to this effect is highly significant. Forming the critical difference at 5 per cent level of probability for the mean yields based on 36 subplots, we get,

$$c. d. = \sqrt{\frac{E \times 2}{36}} \times t (5\%) (53)$$

$$= \sqrt{\frac{11.259 \times 2}{36}} \times 2.012 = 1.5918 \text{ kg. per subplot.}$$

Comparing the difference in the mean yields due to the effect of intervals with the critical difference, it is seen that the yield at 2½ weeks' interval of irrigation is significantly higher than the rest (Table I.2).

Depths

This is also highly significant. Forming the critical difference at 5 per cent level of probability for the mean yields based on 18 subplots we get,

$$c. d. = \sqrt{\frac{11.269 \times 2}{18}} \times 2.012 = 2.2510 \text{ kg. per subplot}$$

A comparison of the difference in mean yields due to the effect of different doses of irrigation with that of critical difference, there is found to be no significant difference amongst the mean yields due to 19.1, 22.9, and 15.2 cm. (7.5, 9 and 6 in.) depths of watering, although the maximum yield is obtained with 19.1 cm. (7.5 in.) depth of irrigation (Table I.3).

Levels of Nitrogen

The variation due to this effect is highly significant as well. Forming the critical

TABLE I.2
Summary of results of mean yields in descending order for the effects of intervals.

	2½ weeks	2 weeks	3 weeks	c.d. at 5 per cent
Mean yield in kg. per subplot	23.52	20.92	19.75	1.5918 kg. per subplot

TABLE I.3
Summary of results of mean yields in descending order due to the effect of different depths of irrigation.

	7.5 in.	9 in.	6 in.	4.5 in.	3 in.	0 in.	c.d. at 5 per cent
Mean yield in kg. per subplot	24.47	22.54	22.44	21.35	20.30	17.28	2.25 kg. per subplot

one in. = 2.54 cm.

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difference at 5 per cent level of probability based on 36 subplots, we find,

$$c. d. = \sqrt{\frac{11.259 \times 2}{36}} \times 2.012 = 1.5918 \text{ kg. per sub-plot.}$$

Comparing the mean yields due to the effect of different levels of nitrogen with the critical difference, it is seen that the yield with the application of nitrogen at the rate of 44.8 kg. per hectare (40 lb. per acre) is significantly higher than the same obtained with applications of 0 or 9.1 kg. (0 or 20 lb.) of nitrogen per acre (Table I.4).

General Conclusion

From an analysis of the yield data, it was observed tentatively that the maximum yield was obtained with four applications of 19.1 cm. (7.5 in.) depth of irrigation at 2.5 weeks' interval with the levels of nitrogen applied at the rate of 44.8 kg. per hectare (40 lb. per acre). It was also found out thereby that the total water requirements including rainfall during the growing season of rice crop (July to October) was of the order of 63.90 in. or 162.31 cm.

TABLE I.4

Summary of results of mean yields in descending order due to the effect of different levels of nitrogen.

	N_2 (40 lb./ acre)	N_1 (20 lb./ acre)	No. (control)	Critical difference at 5 per cent
Mean yield in kg. per subplot	23.44	21.64	19.11	1.5918 kg. per sub-plot

1 lb./acre=1.12 kg./ha.

WATER MANAGEMENT IN RICE CROP

by

S. L. Chowdhury and Mukhtar Singh*

Rice is unique among the cereals in being able to establish and thrive in water. Other cereals are killed if submerged for a few days, for want of oxygen required for the respiration of roots. The distinctive behaviour of rice plant may be ascribed to its ability to transport oxygen from the leaves to the roots. This property of the rice crop to live and grow in an aquatic environment not only facilitates the utilization of low lying fields for paddy cultivation but confers on this crop some other advantages. Firstly, submerged conditions help to keep down most of the weeds by providing unfavourable environment for their growth (Jones, 1933). Secondly, such conditions benefit the crop as they prevent the fall in soil temperatures which is likely to occur in temperate regions during the winter season. These advantages appear to have contributed to the high yields obtained from transplanted paddy than from direct sown crop and seem to have led to the belief that rice flourishes best only under conditions of standing water. It is understandable that the rice needs relatively moisture conditions; and has higher water requirements than other crops but two questions naturally arise: (i) whether rice needs to be irrigated at soil moisture content above field capacity which is the accepted upper limit of available water, irrespective of the kind of crop, and (ii) whether standing water is a necessity for the optimum growth and development of rice or this crop plant has merely adapted itself to the aquatic environment in the process of evolution. Answers to these questions have a direct bearing on the irrigation practices and the water requirements of rice and are not merely of academic interest. While the evaporation and transpiration losses may not materially differ whether irrigation is scheduled to maintain the soil moisture near field capacity, or the crop is grown under submerged conditions but deep percolation is expected to be particularly high under the latter condi-

tions (Nagai, 1959). Considerable saving in water could obviously be effected by irrigating the crop at or near field capacity, instead of maintaining submergence, but the modified practice would only commend itself provided the crop yield is not adversely affected. This should be possible in areas where the problem of low temperature does not exist (as in India) and where the weeds could be controlled by cultural and chemical means. It is also possible that in the event of successful weed control, a sown crop irrigated at field capacity might yield as well as the transplanted crop.

There is some evidence to show that standing water may harm rather than benefit rice under certain conditions. (Sen, 1937) observed that standing water suppressed tiller production but the height of plants increased with the depth of water. He concluded that drainage of water was necessary in later stages of growth for improving aeration. The effect of submergence on tillering appeared to depend on the prevailing air temperature (Sato, 1951). At low temperature submergence increased tiller number but at high temperature, tiller number and grain number decreased. The adverse effects of flooding have been attributed to poor aeration, low oxygen tension and the accumulation of reduced products (Sturgis, 1936). Intermittent drying coupled with flooding has therefore been advocated by some to mitigate the deleterious effects of continued submergence. Recent experiments in Phillipines (Contambay *et al*, 1959 and Aglibut *et al*, 1962), however, do not suggest any improvement in yield by intermittent drying, although the practice would appear to be desirable as it would lower the irrigation requirements, without reducing the yield. Irrigation experiments, conducted in Andhra Pradesh and Madras have also shown that by intermittent drying and irrigating the field every third day,

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a crop yield of the same order was obtained as by maintaining continuously a 7.6 cm. (3 in.) depth of water in the field (Ghose *et al.*, 1960).

It would thus appear that two extreme views are held regarding the irrigation of rice. According to one view, the rice is an aquatic plant and needs continuous submergence but according to the other, the crop can stand intermittent drying. More work is, therefore, needed to clear up the discrepancy and formulate a sound irrigation practice for this important crop. An irrigation experiment was, therefore, conducted at the Indian Agricultural Research Institute, New Delhi, with a view : (i) to assess the effect of varying depths of submergence on the yield of rice, (ii) to ascertain whether the drainage of standing water and its replacement by fresh water was beneficial or not, and (iii) to determine the water requirements of sown rice and to study how it compared with transplanted rice by keeping the former free of weeds.

Description of the Experiments

The experiment was conducted in 1960 on a loamy soil of average productivity. The preparation of the field consisted of usual cultivation with a basal application (per acre) of 10 tons farmyard manure, 27.21 kg. (60 lb.) nitrogen (as ammonium sulphate) and 18.14 kg. (40 lb.) phosphoric acid as single superphosphate. The trial was laid out in a Youden square with 21 blocks as well as treatments, and five replicates. The variety of rice used for the trial was NP 130. The gross plot size measured 10.4 m. \times 4.3 m. (34 ft. \times 14 ft.). A net area of 7.6 m. \times 3.7 m. (25 ft. \times 12 ft.) was eventually harvested from each plot for record of yield. The treatments formed two sets, *viz.*, (a) transplanted crop and (b) drilled crop, as detailed below. Buffer strips of 1.2 m. (4 ft.) width were provided between plots.

(a) Transplanted Crop

- (1) 6 cm. submergence, replenishment after complete recession.
- (2) 6 cm. submergence, replenishment after half recession.
- (3) 6 cm. submergence, replenish after draining at half recession.
- (4) 12 cm. submergence, replenishment after complete recession.

- (5) 12 cm. submergence, replenishment after half recession.
- (6) 12 cm. submergence, replenishment after draining at half recession.
- (7) Irrigated at field capacity, land weeding.
- (8) Irrigated at field capacity, chemical weeding.
- (9) Irrigated at field capacity, no weeding.
- (10) Rain-fed crop, hand weeding.
- (11) Rain-fed crop, no weeding.

(b) Drilled Crop

- (12) Irrigated at field capacity, hand weeding.
- (13) Irrigated at field capacity, chemical weeding.
- (14) Irrigated at field capacity, no weeding.
- (15) Irrigated at 75 per cent available moisture, hand weeding.
- (16) Irrigated at 75 per cent available moisture, chemical weeding.
- (17) Irrigated at 75 per cent available moisture, no weeding.
- (18) Irrigated at 50 per cent available moisture, hand weeding.
- (19) Irrigated at 50 per cent available moisture, chemical weeding.
- (20) Irrigated at 50 per cent available moisture, no weeding.
- (21) Rain-fed crops, hand weeding.

Irrigations at 75 and 50 per cent available water were scheduled as indicated by the Bouyoucos moisture meter at any of the three positions of 15, 22.5 and 30 cm. soil depths where the gypsum blocks had been embedded. The crop was transplanted or seeded from 20 to 24 July 1960. In the case of transplanted crop the fertilizers were puddled in, whereas for the seeded crop these were applied broadcast.

The experimental field had a uniform and gentle slope. The field water channels were provided on either side of each plot to facilitate irrigation and surface drainage as required. For the transplanted crop 40 cm. water per acre of nursery was used for raising the

seedlings. 18 cm. water per acre was needed for puddling and transplanting the seedlings in the field. The plots were thoroughly levelled and bamboo sticks were fixed in the plots to guide the depth of submergence, according to treatments.

In addition to the water required for the nursery, puddling and transplanting the seedlings, the transplanted crop received the following amounts of irrigation water during its growth. These amounts include 18 cm. of irrigation water used for the establishment of seedlings, prior to differential irrigations :

Treatment	cm. water
1	78
2	69
3	120
4	90
5	66
6	114
7	48
8	48
9	48
10	18
11	18

The seeded crop received the following amounts of irrigation water under different water regimes :—

Treatment	cm. water
12	39
13	39
14	39
15	6

Treatment	cm. water
16	6
17	6
18	6
19	6
20	6
21	0

The total rainfall during the crop growth period amounted to 59.9 cm. Occasionally the rains interfered with the irrigation schedules and the amounts given above were actually applied. Also, application of water to submergence treatments had to be stopped three weeks earlier than the last irrigation given to drier regimes as the crop under submergence treatments started lodging rather badly. In fact, irrigation to drier regime treatments became necessary only during the last one and a half month of crop growth. It is also important to record here that the water-table of the field during the experimental period varied from 30 to 60 cm. This must also be taken into account to interpret the treatment effects on crop yields and to explain low irrigation requirements of the drier regimes.

Treatment effects on the Yields of Paddy

The crop was harvested during the first week of November 1960. The grain yield from each plot was recorded after sun drying for a fortnight. The yield data are summarized in Table I.

TABLE I

Treatment effects on the yield of paddy.

	Grain yield in maunds per acre				
	Full recession		Half recession	Drained at half recession	Mean
	1	2	3	4	
A. TRANSPLANTED CROP					
6 cm. submergence	(1) 39.7	(2) 44.4	(3) 40.4	41.5	
12 cm. submergence	(4) 40.7	(5) 40.7	(6) 35.9	38.8	
Mean	40.2	42.5	38.1		
Hand weeding		Chemical weeding with MCPA	No weeding		
Irrigation at field capacity	(7) 36.4	(8) 40.1	(9) 40.8	39.1	
Rainfall alone	(10) 43.2	...	(11) 39.1	41.1	
Mean	39.8	40.1	39.9	40.1	

TABLE I—(Contd.)

	1	2	3	4
	Hand weeding	Chemical weeding with MCPA	No weeding	
B. SEEDED CROP				
Irrigation at field capacity	(12) 36.8	(13) 30.8	(14) 32.7	33.4
Irrigation at 75 per cent available water	(15) 31.4	(16) 28.0	(17) 28.8	29.4
Irrigation at 50 per cent available water	(18) 29.2	(19) 27.8	(20) 23.0	26.7
Mean	32.4	28.8	28.2	
Rainfall alone	(21) 29.6	...	...	29.6
S.E. for body of the table	± 3.69			29.8
		c.d. at 5% level for the body of the table		± 7.37

Treatment number is given in parentheses.

The comparison of marginal mean yields of the transplanted crop in respect of the levels of submergence, irrigation at field capacity and the treatment 'rainfall alone' shows that yield differences were statistically not significant. Moreover, draining of standing water failed to benefit the crop. This is in conformity with the results of (Aglibut *et al* 1960). Although irrigation at field capacity combined with hand weeding gave lower yield than 6 cm. submergence with half recession, the significant decrease is anomalous because the rain-fed crop kept free of weeds gave as high yield as any other treatment under the transplanted crop. It was also observed that under conditions of submergence, weed growth was inconsequential and weeds appeared only late in the season. The suppression of weed growth by treatments did not influence the paddy grain yields. Thus, under the conditions of high water-table and the seasonal precipitation of about 60 cm., a good transplanted paddy crop was raised without any irrigation apart from that used for puddling and the establishment of seedlings, by keeping the crop free of weeds.

The seeded crop yielded significantly less than the transplanted crop. The seeded crop showed response to differential irrigation. Irrigation at field capacity combined with hand weeding gave the best yield. The yield fell off progressively as irrigation was delayed. The differences between irrigation at field capacity and that applied at 50 per cent available water was statistically significant. The reduction in yield was relatively better marked in the unweeded crop. Under the conditions of the experiment, hand weeding gave

higher yield as compared with unweeded crop. Use of MCPA did not influence the yield significantly. The fresh weight of weeds in the treatment where hand weeding was undertaken is recorded below:

Treatment No.	Fresh weed weight mds./acre
7	23.6
10	53.2
12	34.7
15	46.0
18	40.3
21	40.6

Discussion

The yields of the sown crop of rice reported here decreased when irrigation was applied at soil moisture below field capacity, in spite of the high water-table of the experimental site and heavy rains received in the crop season, inasmuch as soil moisture deficits were recorded only late in the season. The result is in conformity with the high water requirements of the crop. In the transplanted crop, 'submergence' was no better than irrigation at field capacity. In fact 'rainfall alone' after the establishment of seedlings with 18 cm. irrigation water, coupled with high ground water-table helped the crop to produce as high yield as any of the submergence treatments. It may be argued that deep percolation in the plots under submergence treatments might have resulted in lateral seepage to distances beyond the width of the buffer strip and might have improved the moisture supply and the crop

performance of adjacent plots irrigated at field capacity and those receiving rainfall only, masking thereby the difference between 'submergence' and other treatments. Nevertheless such seepage cannot bring about conditions of submergence in the plots irrigated at field capacity and those receiving rainfall only*. Therefore, the evidence indicates that submergence in the transplanted crop was unnecessary under the conditions of the experiment, *viz.*, 60 cm. rainfall, high water-table and absence of weeds and low temperature problem. Experiments in Phillipines by Catambay *et al* (1959) also did not justify the usefulness of submergence in rice.

If submergence does not increase paddy yields, the practice must be reckoned as a luxury and a potential danger. In irrigation projects, the duty fixed for rice is 50, *i.e.*, about 57 acre-in. are required to mature a crop of 120 days duration. The potential evapo-transpiration for the corresponding period will be much smaller. (At Delhi in 1960 during transplanting to harvest the evaporation based on the U.S. open pan evaporimeter readings was 27.3 in., *i.e.*, 69.5 cm.). As part of the water requirements of rice will be met by rainfall, the adoption of low water duty and submergence will lead to deep percolation and water-logging making the area unfit for other rotational crops. By eliminating submergence and only irrigating at or near field capacity there appears to be scope for minimising water-logging and economising water which could be used for increasing irrigation intensity or water duty.

Sown crop yielded much lower than transplanted crop, on the average, but it must be remembered that transplanting and sowing in the experiment reported here were done at about the same time. The initial start in the nursery conferred an advantage to the transplanted crop. If the crop was sown with irrigation in advance to transplanting date, the former might have successfully competed with the latter. Moreover, the sown crop suffered from delay in irrigation and weed infestation. Sown crop irrigated at field capacity and hand weeded gave almost as high yield as the transplanted crop. Hand

weeding improved the yield of sown crop markedly. Chemical weeding did not increase the yield because MCPA controls only broad leaved weeds but not the grasses which were the dominant weeds in rice. In recent years considerable advance has been made abroad in controlling weeds in rice with 3, 4 DPA (French and Gay, 1963). Trials with the new weedicide have also been planned in India both on the transplanted and drilled paddy. This development may have far reaching effect on water management in transplanted rice and in increasing the yield of sown rice.

The preliminary trial points to the need of a thorough study of the problem of water management in rice under controlled conditions in pots or tanks and in the field with sound experimental techniques.

Summary and Conclusions

In an experiment on the water regimes of transplanted paddy, no benefit could be secured from 6 and 12 cm. depths of submergence. Drainage of water failed to give any advantage of yield and irrigation at field capacity and the rain-fed crop yielded quite as high. In fact, clean weeded rain-fed crop gave approximately as high a yield as obtained from either submergence or with irrigation at field capacity. In the transplanted crop with wet regimes removal of weeds, did not materially affect the grain yield. But in the rain-fed transplanted crop, weeding was found to be markedly beneficial.

In the seeded crop, grain yield decreased with delay in irrigation, the highest yield being with irrigation at field capacity. The rain-fed crop also yielded as high as the one that received irrigation at 50 per cent available moisture. In the sown crop weeds reduced the yield substantially.

The trial has suggested that submergence of the transplanted crop may not be necessary in all situations, and under certain conditions as in the experiment, irrigation at field capacity (5-8 cm. water every third or fourth day) in the absence of rain, is all that is required for raising a good crop of paddy.

*Apart from that caused by rain only.

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EFFECT OF MANURING ON WATER REQUIREMENT OF RICE CROP

by

M. S. Chaudhry and I. C. Mahapatra*

It has been generally accepted that with satisfactory irrigation facilities, rice is the world's safest crop to grow. Though India has the largest irrigation system in the world and rice is, by far, the staple food of about three-fourths of her population, only about 30 per cent of the rice acreage in the country is under commendable irrigation supply. Rest of the rice acreage is a gamble in the hands of monsoons which are often erratic and ill-distributed with the result that the yields of the crop suffer considerably. With the construction of dams in the country, more and more irrigation water is becoming available. To make the best use of this costly irrigation water, it is, therefore, highly desirable that reliable basic information regarding the judicious use of water is obtained which may consist of the minimum water requirement for raising a satisfactory crop, frequency of irrigation, measurement of the loss of water through seepage, percolation and evaporation, determination of the stage of crop when water is needed most and the interaction between the optimum yield and other factors like irrigation, climatic factors, soil type, variety, manures and cultural operations, etc.

Information regarding the water requirement of rice in India is a meagre and is seldom based on the results of comprehensive field experiments. Field experiments in case of rice have not been faithfully carried out because of the lateral movement of water from one treatment to another which is very difficult to control and also the frequent heavy rainfalls during the period when rice is grown. Attempts are being made at the Central Rice Research Institute to create adequate facilities as quickly as possible for conducting irrigation experiments to work on the most needed information for finding out ways and means of raising the duty of irrigation water and similar investigation. It is also proposed to carry out a co-ordinated agro-

nomic project to determine irrigational requirements of the new *indica* × *japonica* hybrids developed in different states for assessing their suitability under different soil and climatic conditions.

The amount of information based on pot experiments on water requirement of rice crop is also not enough and whatever is available may be considered mostly of a qualitative nature rather than quantitative as the conditions for the plant under field conditions can hardly be obtained in the pots.

While investigating into the water requirement of crops, Singh *et al* (1935) found that requirement of water for rice goes hand in hand with the duration of the variety. They also observed that the water requirement of rice crop is the highest during (a) the initial seedling period covering about ten days, (b) the preflowering and flowering period covering about 25 days and (c) the grain formation period covering about 5-7 days. If there is deficiency of water during these periods, the crop growth is affected adversely. Ganguli (1950) also has found that water requirement of the crop varies according to the duration of the variety and the type of the soil—low in heavy soils and high in the lighter ones. He got the highest water requirement of rice with the application of ammonium phosphate. Rao (1951) while compiling work on water requirement of crops in India reported that in Bihar manuring of rice reduced the water requirement. Matsushima (1961) concluded that water requirement of rice varied from 401 to 766 depending upon the duration of the variety.

At the Central Rice Research Institute, water requirement experiments were conducted in pots for a period of three years. Two varieties, *viz.*, Ptb. 10 and Ch. 45 (both maturing within 110 days) were grown in

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TABLE 1

Effect of different manurial treatments on water requirement of rice varieties.

Treatments	Water requirement (transpiration ratios)									Overall Mean
	1953-54			1958-59			1959-60			
	Ptb. 10	Ch. 45	Mean	Ptb. 10	Ch. 45	Mean	Ptb. 10	Ch. 45	Mean	
1. Control	886.92	734.36	810.64	566.43	564.09	565.26	737.20	690.97	714.09	696.66
2. A/S @ 30 lb. N/Ac.	876.01	723.97	799.99	686.78	576.14	631.46	624.79	577.40	601.10	674.18
3. F.Y.M. @ 30 lb. N/Ac.	696.87	666.71	681.79	587.45	586.63	587.04	673.70	682.95	678.33	649.05
4. Superphosphate @ 30 lb. P ₂ O ₅ /Ac.	698.72	906.08	802.40	660.06	551.42	605.74	601.50	613.78	607.64	671.93
5. A/S @ 15 lb. N/Ac + F.Y.M. @ 15 lb. N/Ac.	783.51	798.23	790.87	566.88	557.26	562.07	626.35	577.89	602.12	651.69
6. A/S @ 30 lb. N/Ac. + super-phosphate @ 30 lb. P ₂ O ₅ /Ac.	1000.49	818.47	909.48	616.68	683.35	650.02	587.33	633.39	610.36	723.29
7. F.Y.M. @ 30 lb. N/Ac. + super 30 lb. P ₂ O ₅ /Ac.	1126.53	694.59	910.56	578.60	515.93	547.26	616.19	569.25	592.72	683.51
8. A/S @ 15 lb. N/Ac. + F.Y.M. @ 15 lb. N/Ac. + super-phosphate @ 30 lb. P ₂ O ₅ /Ac.	983.84	817.18	900.51	692.73	633.77	663.25	652.10	579.27	615.69	726.48
Mean	769.11	769.95	769.53	619.45	583.57	601.51	639.90	615.61	627.76	666.27
S.E. of variety means	±42.71			±37.08			±8.56			
S.E. of manure means	±85.43			±44.45			±23.83*			
C.D. (0.05)	..			..			72.28*			

One lb. = 0.453 kg.

the experiment under eight manurial treatment combinations. Well sieved upper layer of the farm soil was used to fill in the glazed pots. The pots were watered and thoroughly worked after application of required quantities of manures and fertilizers before planting. Single seedlings were planted in each pot at the centre of pot. The pots were covered with alkathene cloth which was provided with one hole through which the stem of the plant passed. The alkathene cloth was tied to the brim of the glazed pots tightly. The openings and the annular spaces in between the seedlings and holes were carefully sealed by cellotape. The loss of water thus took place only through the aerial parts of the plant. The amount of water lost from the soil during transpiration was made good on alternate days by fresh additions of water. The plants were given prophylactic spray at weekly intervals against pests and diseases. When the crop matured the dry weight of the aerial parts of the plants was taken by drying them to constant weight. The water requirement or transpiration ratios were calculated by dividing the quantity of water transpired in c.c. by the amount of dry matter in gm. The results of three years experiments on the effect of different manurial treatments on water requirement of rice varieties are presented in Table I.

It may be seen from the data presented in Table I that water requirements of two varieties Ptb. 10 and Ch. 45 were not significantly different in any of the years. It is due to the fact that the varieties were of the same duration and hence there was no difference in water requirement.

So far as the effect of different manurial treatments on water requirements are concerned, the differences were significant only during the year 1959-60. The water requirement (transpiration ratio) was the highest for the control and was followed by the treatment where only farm-yard manure was applied @ 13.61 kg. (30 lb.) nitrogen per acre. Rest of the manurial treatments decreased the water requirement of rice crop significantly. Similar results were reported by Rao (1951). The interactions between varieties and various manurial treatments were not significant in any of the years.

The combined analysis of the data, however, did not show any statistical significance. But the mean figures indicated that water requirement (transpiration ratio) of rice decreased with the application of farm-yard manure alone as well as in combination with

ammonium sulphate. The highest water requirement was, however, obtained when the crop received both ammonium sulphate and superphosphate, and also when these two fertilizers were superimposed over farm-yard manure. It is however, felt that elaborate data on this aspect need be collected to draw definite conclusions.

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IRRIGATION REQUIREMENTS OF RICE CROP—A REVIEW

by

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Commandable irrigation supply is considered to be a key to successful rice culture. Though India has got the largest irrigation system in the world and rice is, by far, the main food of about three-fourths of her population, only about 30 per cent of the rice area in the country is under controlled irrigation supply. Rest of the rice acreage is dependent upon monsoons. The uncertainty of monsoon, its mal-distribution and variation in total precipitation makes it necessary to arrange for irrigation against crop failure. With the construction of dams in the country, more and more of irrigation water is becoming available. To make the best use of this water it is, therefore, necessary to find out ways and means of increasing the duty of water. On the other hand, in some of the irrigated areas, particularly in the vicinity of the dams, irrigation water is being indiscriminately used without proper drainage facilities and anti-waterlogging measures resulting in the deterioration of the productivity status of the soil. Only the judicious use of irrigation water will, therefore, go a long way in stepping up crop production.

Unfortunately, the amount of information regarding the irrigation requirement of rice crop is not enough and is seldom based on comprehensive field experiments. A summary of the available information is presented below in a chronological order.

A. Influence of Soil Submergence on Growth and Yield of Rice

Jones (1923) observed that rice plants grown in moist plots tillered less, were stunted in height, had shorter and fewer ear-heads per plant, were not as vigorous and produced grains of inferior quality and quantity as compared to those grown in submerged plots. Chamblis *et al* (1923) obtained largest yield on land that was submerged fifteen days after the rice plants had merged. With each suc-

cessive fifteen days delay in submergence, there was a progressive reduction in yield. Cralley *et al* (1943) reported that rice plants grown on submerged soils were taller, tillered better and gave significantly higher yields than plants grown on moist land but not submerged. Vlamis *et al* (1944) reported that both upland and low land rices grew better in submerged clay and loam soils than in the same soil kept moist. Chakladar (1946) found that even upland rice gave higher yield when the soil moisture content was near saturation. Yoshino *et al* (1953) showed that if submergence is unduly delayed tillering and yields are adversely affected. Sampietro (1954) stated that in Italy, continuous submergence gave appreciably superior yield and was followed by imbibition. Senewiratne *et al* (1962) observed that plants grown under unflooded conditions made a vigorous start but showed poor tillering, depressed leaf growth, delayed flowering and ultimately low yields. Sukanya (1962) concluded that rice needs a small quantity of stagnant water to produce a satisfactory crop.

B. Irrigation Requirements of Rice Crop

Rao (1951) summarising the work reported that :

- (a) the average loss of water in seepage, transpiration and evaporation totalled to about 2.5 mm. (0.1 in.) per day;
- (b) water requirement just prior to flowering was about 2 or 3 times the quantity required about 10-15 days before flowering or the quantity required after flowering. Soon after flowering there was a decrease in water requirement;
- (c) yields were in proportion to the quantity and frequency of irrigation and

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(d) 5.1 cm. (2 in.) irrigation at 3 days interval gave as good results as standing water. Ramiah *et al* (1951) stated that a crop about 150 days duration will require about 7709.25 cu. m. (75 acre-in.) of water including rain and irrigation. Of this, about 63.5 cm. (25 in.) will be required for raising the nursery and preparation of land, (puddling and planting) 101.6 cm. (40 in.) from planting up to the time of flowering and a further 25.4 cm. (10 in.) up to the time of ripening. Adair *et al* (1955) reported that water requirement of rice in California was 3700—9869 cu. m. (3—8 acre-ft.) and in Louisiana it was 1850.2 to 3700 cu. m. (1.5 to 3 acre-ft.) Piacco (1961) stated that in Italy water requirement of rice crop is about 3906.02 cu. m. (38 acre-in.). Raney *et al* (1961) reported that water loss from tanks buried in fields was 3453.7—3700 cu. m. (2.8—3 acre ft.) during a period of 160 days from planting to harvest of the rice crop. The water requirement, therefore, should have exceeded 3700 cu. m. (3 acre-ft.) because of losses from causes other than transpiration and evaporation.

C. Stage of Plant Growth when Irrigation Need be Started

Yoshino *et al* (1953) reported that in Japan irrigation at an early stage of the plant growth gave rise to early development of tillers. Irrigation applied at six leaf stage gave the largest number of tillers. Highest yield of grain was obtained where the first irrigation was given when plants had reached the 9—12 leaf stage. Bernardes (1958) recommended that in Brazil, rice irrigation should start soon after emergence but not later than 15 days after emergence. After 20 to 30 days, the field should be drained and kept as such until the plants show signs of wilting. During this period their roots grow deep into the soil in search of water. Irrigation should be stopped again when the rice grains are in dough stage.

D. Depth and Frequency of Irrigation

Sen (1937 as reported by Rao 1951) found that plant height increased with the height

of water standing in the field but standing water suppressed tiller formation in rice, the number of tillers decreasing progressively with an increase in the depth of standing water allowed. Morison (1953) indicated that depth of water is not important for rice crop but draining the field at least once during the season considerably increased the yield. Ghose *et al* (1956) while compiling research work on irrigation done at various places in India, reported that (1) yields were in proportion to the quantity and frequency of water supplied and (2) irrigating the field every third day yielded as good results as continuous 7.6 cm. (3 in.) depth of water in the field. Bernardes (1956) stated that in Italy the yields obtained by maintaining a 25 cm. depth of water were higher than those obtained by 10, 15 and 35 cm. In this area the best results were obtained by suspending irrigation for a few days until the rice plants showed signs of wilting then irrigated again and water maintained till earing time. Ghose *et al* (1958) found that for maximum tiller production, plant height, yield of grain and straw the best conditions were submergence to an 20.3 cm. (8 in.) depth of water for about four weeks immediately after planting and then followed by draining and keeping it in a puddled condition until harvest. Pillai (1958) summarised the results of irrigation experiments on rice in India and concluded that (1) maintaining 5.1 cm. (2 in.) of standing water in the field with frequent change with fresh water resulted in the highest production of crop. The practice of giving small quantities of water at short intervals—5.1 cm. (2 in.) irrigation at 3 days interval seemed to be more beneficial than giving more quantity of water at longer intervals. (2) the yield of rice crop seems to be in proportion to the quantity and frequency of water supplied. Have (1959) concluded that in Japan the number of fertile tillers produced per plant was greater where plants were submerged to a depth of 10 cm. than where they were submerged to 25 cm. Higher water-level encouraged lodging, retarded flowering and led to uneven ripening. Chow (1961) stated that one irrigation every third day indicated a possibility of better yields than other intervals. Matsushima (1961) reported that: (1) rice crop should not suffer from want of water a fortnight before and till a week after flowering, (2) 1—6 cm. depth of standing

water is optimum for rice crop, (3) shallower the depth of water greater the number of panicles and thus the yields. Tsunoda *et al* (1962) found that deeper the water depth the higher the plant height and lower the number of tillers.

E. Suggestions for the Future Work

As the water, soil, climate and the crop are the basic factors for securing the reliable data, it naturally follows that the coordinated and comprehensive research must be carried out by a group of trained and qualified research workers consisting of an Irrigation Agronomist, an Engineer and a Soil Physicist. The agronomic experiments should be conducted in different soils and climatic conditions according to the standard designs so that the data may be comparable. The aims of these experiments should be to collect information on such items of work as:—

- (1) Minimum amount of water required for maturing varieties of different durations, geographical races and japonica and indica hybrids.
- (2) Amount of water required before planting and also at different stages of plant growth.
- (3) Frequency of irrigation.
- (4) Determination of the critical period of drought injury.
- (5) Loss due to transpiration, percolation, evaporation, lateral movement and run-off.
- (6) Consumptive use of water of different duration varieties.
- (7) Effect of different fertilizers and cultural practices on the water requirement.
- (8) Determination of the period till irrigation is necessary.
- (9) Correlating plant characters and yield of rice with meteorological data.
- (10) Effect of depth of irrigation on crop yields.
- (11) Effect of draining the fields at different stages of plant growth.
- (12) Effectiveness of the natural precipitation for normal crop growth.

- (13) Soil-water-plant relationship with particular reference to the effect of soil management, time, method and depth of tillage.
- (14) Physical and chemical changes in the soil due to continuous irrigation.
- (15) Effect of irrigation on water-table, salt content and base exchange capacity of the soil.
- (16) Counter measures for over irrigation.
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THE EFFECT OF LEVELS OF IRRIGATION AND FORMS OF NITROGEN ON WHEAT

by

O. N. Mehrotra and R. C. Garg*

Introduction

The problem of irrigation requirement for maximum production of wheat, a principal food crop of the country, is becoming more and more complicated with increasing fertilizer practices. In the arid and semi-arid plains of Indo-Gangetic alluvium, nitrogen supplies and irrigations are considered to be the main factors affecting the yield of wheat. All efforts to increase production of this crop will not be fruitful even with sufficient supplies of available nitrogen unless optimum conditions of soil moisture are met through irrigation wherever it is needed.

Indian soils, particularly the light textured soils, show a general deficiency of nitrogen. In a nitrogen deficient soil, adequacy of moisture does not mean its full utilization, but water is wasted, because nitrogen to build the tissues is not available. On the contrary, if the soil is rich in nitrogen content, the crop makes a rapid growth and water is fully utilized. Moreover, there is an optimum level of irrigation for an optimum dose of nitrogen, beyond which application of water tends to leach out nitrogen below the feeding zone and the return thus obtained as a result of either irrigation or nitrogen proves uneconomical.

The water requirements and fertilizer needs of wheat have been investigated by

many workers in India (^{1, 2, 3, 4, 5, 6, 7, 8, 10, 12}). In Uttar Pradesh these studies were largely confined to determine the response of the crop to irrigations alone or the effects of fertilizers at a few selected centres. No systematic attempts were made to study the irrigation needs of the crop in relation to fertilizer practices under the differing soil-climatic conditions of the State until 1950 when investigations were initiated by Singh (^{11, 12}) in the different regions of Uttar Pradesh, representing the chief wheat growing tracts of the State, to determine the water requirements of this crop in relation to addition of manures. The present paper deals with the results of an experiment carried out in this direction from 1950 to 1953 by the Crop Physiology Section of the State Department of Agriculture where in the effects of levels of irrigation and forms of nitrogen were studied on wheat. In the present communication the effectiveness of the treatments on grain yield of wheat is only reported.

Material and Methods

The experiments were conducted from 1950-51 to 1953-54 at seven centres (Government Agricultural Farms) situated in the different agro-climatic regions of the State. The particulars of the Stations, their soil types, topographical conditions and average annual rainfall are given in Table I.

TABLE I
Particulars of stations, Soil types, topographical conditions and rainfall.

Sl. No.	Region	Station	Years of experimentation	Soil type	Topographical conditions	Average annual rainfall (inches)
1	2	3	4	5	6	7
1.	Western	Mecrat	4	Loam	29.10° N Lat. 77.45° E Long.	35.22
2.	South Western	Etawah	4	Loam	26.47° N Lat. 79.20° E Long.	26.45

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TABLE I—Contd.

1	2	3	4	5	6	7
3.	Bundelkhand	Bharari (Jhansi)	4	Parwa	25.27° N Lat. 70.37° E Long. 824 ft. Alt.	28.80
4.	Central	Kalyanpur (Kanpur)	4	Loam	24.28° N Lat. 82.24° E Long. 500 ft. Alt.	30.54
5.	Central	Lucknow	2	Sandy loam	26.55° N Lat. 80.59° E Long. 390 ft. Alt.	24.91
6.	North Eastern	Gorakhpur	4	Sandy loam	26.45° N Lat. 83.24° E Long. 254 ft. Alt.	48.88
7.	Eastern	Varanasi	4	Loam	25.20° N Lat. 83.00° E Long. 265 ft. Alt.	42.52

One in.=2.54 cm.; one ft.=0.3048 m.

TABLE II
Particulars of treatments.

Factors	Irrigation treatments after sowing	Nitrogen treatments
	I_0 = No irrigation.	O = No manure.
	I_1 = One irrigation (at tillering stage).	S = Sulphate of ammonia
Levels	I_2 = Two irrigations (one at tillering and the other at pre-heading)	C = Castor Cake.
	I_3 = Three irrigations (one at tillering, the other at pre-heading and the third at milky stage).	

The effect of two forms of nitrogen, viz., castor cake and sulphate of ammonia at 27.2 kg. (60 lb.) N/acre, in combination with four levels of irrigations was experimented in a split plot design. The quantity of water supplied in each irrigation was approximately 308.4 cu. m. (3 acre-in.) A light preparatory irrigation (Palewa) was given before sowing the crop to secure uniform soil moisture and even germination. Particulars of irrigation and manurial treatments are given in Table II.

Results

The average response of wheat to levels of irrigation and forms of nitrogen over different years is given in Table III, while the interaction of the two factors is summarised in Table IV.

TABLE III

Sl. No.	Station	Grain yields in lb./acre						
		Irrigations				Manuring		
1	2	3	4	5	6	7	8	9
1.	Meerut	I_3 1780	I_2 1731	I_1 1543	I_0 1214	C 1651	S 1644	O 1405
2.	Etawah	I_3 1398	I_2 1285	I_1 1197	I_0 559	S 1142	C 1133	O 1054
3.	Jhansi	I_3 1344	I_2 1304	I_1 1225	I_0 1190	C 1343	S 1290	O 1165
4.	Kanpur	I_3 1554	I_2 1549	I_1 1489	I_0 1451	S 1766	C 1700	O 1066

TABLE III—Contd.

1	2	3	4	5	6	7	8	9
5.	Lucknow	I_2 835	I_3 821	I_1 768	I_0 666	S 845	0 789	C 684
6.	Gorakhpur	I_2 1013	I_3 968	I_1 911	I_0 907	S 1188	C 975	0 687
7.	Varanasi	I_2 1603	I_3 1536	I_1 1481	I_0 925	S 1466	C 1435	0 1258
Weighted Average		I_2 1376.7	I_3 1376.4	I_1 1275.3	I_0 1012.1	S 1372.0	C 1319.8	0 1081.4
% Over Control		136	135	126	100	127	122	100

1 lb./acre=1.12 kg./ha.

TABLE IV

Interaction of irrigation and manures grain yield (lb./acre).

Sl. No.	Stations	Irrigations	Manures			Mean
			0	S	C	
1.	Meerut	I_0	973	1398	1270	1114
		I_1	1385	1643	1600	1543
		I_2	1581	1684	1927	1731
		I_3	1681	1852	1806	1780
		Mean	1405	1644	1651	
2.	Etawah	I_0	522	537	617	559
		I_1	1169	1257	1165	1197
		I_2	1313	1456	1423	1398
		I_3	1211	1319	1327	1285
		Mean	1054	1142	1139	
3.	Jhansi	I_0	1115	1189	1265	1190
		I_1	1162	1247	1266	1225
		I_2	1221	1384	1307	1304
		I_3	1160	1340	1533	1344
		Mean	1165	1290	1343	
4.	Kanpur	I_0	1085	1688	1601	1451
		I_1	1040	1845	1761	1549
		I_2	995	1814	1657	1489
		I_3	1144	1737	1781	1554
		Mean	1066	1766	1700	
5.	Lucknow	I_0	545	753	702	666
		I_1	800	849	647	768
		I_2	810	982	712	835
		I_3	992	796	674	821
		Mean	789	845	684	
6.	Gorakhpur	I_0	637	1186	876	907
		I_1	697	1107	927	911
		I_2	747	1252	1041	1013
		I_3	645	1205	1054	968
		Mean	687	1188	975	
7.	Varanasi	I_0	885	966	924	925
		I_1	1316	1543	1584	1481
		I_2	1395	1599	1614	1536
		I_3	1435	1757	1619	1603
		Mean	1258	1466	1435	

1 lb./acre=1.12 kg./hectare.

In the experiments carried out at Meerut in the western zone for 4 years, highest average yield of 1993.60 kg./ha. (1780 lb./acre) was found where three irrigations were given at tillering, preheading and milk stages of the crop. This was closely followed by yields obtained through two and one irrigations. As for the manures tried, castor cake and sulphate of ammonia were equally effective in increasing the yields over the unfertilized plots. Interacting between themselves 27.2 kg. (60 lb.) *N* as castor cake under two irrigations and sulphate of ammonia with three irrigations yielded highest, *i.e.*, 2158.24 kg. and 2074.24 kg./ha. (1927 lb. and 1852 lb. per acre) respectively as against 441.3 kg. (973 lb.) in the control.

Experiments undertaken at Etawah in the south-western region showed significant responses in the irrigation practices. Highest mean yield of 1565.76 kg./ha. (1398 lb. per acre) was achieved with two irrigations, whereas under no-irrigation an yield of 253.5 kg. (559 lb.) was produced. Application 60 lb. *N* per acre whether in the form of sulphate of ammonia or castor cake, significantly increased the yields throughout the period of experimentation but their relative efficiency was not very marked. Highest yield of 1630.72 kg./ha. (1456 lb. per acre) was produced with sulphate of ammonia under two irrigations; with castor cake the yield was 645.5 kg. (1423 lb.) as against 236.7 kg. (522 lb.) in no-manured and unirrigated plots.

At Bharari (Jhansi), situated in the Bundelkhand region, different irrigation treatments generally failed to show significant responses in yield. Manuring either with sulphate of ammonia or castor cake increased the yields, but their relative efficiency was not well marked. Castor cake, however, proved consistently superior to sulphate of ammonia. Interacting between themselves highest yield of 1716.96 kg./ha. (1533 lb. per acre) was obtained with the application of castor cake under three irrigations.

In the central region, these experiments were conducted at Kalyanpur (Kanpur) and Lucknow. Different irrigation levels and forms of nitrogen application did not markedly influence average yields of wheat. However, application of 67.20 kg./ha. of *N* (60 lb. *N* per acre) with irrigation increased the yields as compared to unmanured and un-

irrigated plots. In general, sulphate of ammonia showed better response than castor cake at both the places. At Kalyanpur, with sulphate of ammonia, even one irrigation succeeded in giving the maximum yields, 2066.40 kg./ha. (1845 lb. per acre). Two irrigations with sulphate of ammonia gave the highest yield of 1099.84 kg./ha. (982 lb. per acre) at Lucknow.

For the north eastern region, the experiment was carried out at Gorakhpur. Two irrigations were found to produce maximum yields almost every year, though significant differences were obtained only during 1951-52. Highest yield of 1420.24 kg./ha. (1252 lb. per acre) was obtained with the application of sulphate of ammonia and two irrigations as compared to 713.44 kg./ha. (637 lb. per acre) in the control.

No response of irrigation practices or forms of nitrogen was obtained in these trials at Varanasi, representing the eastern region, in the first two years. However, during 1952-53, three irrigations and both the sources of nitrogen significantly increased the yield of wheat. Average response for four years has shown that higher yields were obtained through increasing irrigation levels. Sulphate of ammonia relatively proved better than castor cake and yielded under three irrigations 796.9 kg. (1757 lb.) grain per acre as against 401.8 kg. (885 lb.) in the unmanured and unirrigated plots.

Discussion

An analysis of the data presented in the preceding pages brings about certain interesting features. It was observed that wheat grown in the drier parts of the State generally required three irrigations for its successful growth and yield, whereas it was not so for wetter places like Gorakhpur. The requirement for irrigation of crops is in direct proportion to the annual rainfall. In certain areas of Uttar Pradesh, the annual rainfall is meagre and varies from 51 to 76.2 cm. (20 to 30 in.). In the plains since bulk of precipitation takes place during rainy season from June to September there is need for irrigation of wheat crop in winter months. This need is felt more keenly in the western region. In the central part of the State, the variation of rainfall is 76.2 to 101.6 cm. (30 to 40 in.), this

shows that there is need for less irrigation in this tract. In the eastern region of the State, the annual rainfall is still higher being 101.6 to 165.1 cm. (40 to 65 in.). It is, therefore, natural that the irrigational requirements of this region are comparatively still lower than the central and western parts of the State. Singh⁽¹¹⁾ also reported that the quantity of irrigation water required has got a positive correlation with the type of soils to be irrigated.

Data further revealed that of the times of waterings, irrigation given at the tillering stage of the plant was most beneficial and contributed highest to the yields produced. Subsequent irrigation, though increased yields, were not so profitable. Robertson and his associates⁽⁹⁾ found that the highest yield and most efficient use of water was obtained by irrigating wheat at the jointing stage.

Application of nitrogen to wheat either as castor cake or sulphate of ammonia gave 22-27 per cent higher yields. Similar increases in grain and straw yields of wheat by nitrogen fertilizers have been obtained by Prashar and Singh⁽⁸⁾. Between the forms of nitrogen tried, sulphate of ammonia proved better than castor cake at majority of places due possibly to its easy and rapid availability. At Bharari (Jhansi), castor cake proved to be better than sulphate of ammonia which may be due to the fact that *Parwa* soils are poor in inorganic matter but under good management practices including proper irrigations and adequate manuring with bulky organic manures prove fairly productive⁽⁸⁾.

The interaction of irrigation and added manures in these studies were found to be beneficial in increasing yields. The relative response of irrigation and manuring, however, under different soil types as pointed out by Singh⁽¹²⁾ was found to be dependant upon the physical property of soil and absence of nutrient elements.

Summary

From the foregoing evidences it is clear that increases in yield of wheat crop could be obtained with both irrigation and manuring practices. On an average, increasing num-

ber of irrigations gave 26 to 36 per cent higher yields over no-irrigation.

As between times of watering, irrigating wheat at the active tillering stage was most responsive contributing the highest grain yields, than the subsequent ones.

Application of nitrogen consistently increased production and succeeded in giving higher average grain yield. Sulphate of ammonia generally proved superior than castor cake. Highest average yields were produced with three irrigations and 67.20 kg./ha. of N (60 lb. N/acre) applied as sulphate of ammonia.

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THE RESPONSE OF WHEAT TO DOSES OF NITROGEN AND FREQUENCIES OF IRRIGATION

by

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Introduction

In recent years, nitrogenous manuring has gained considerable popularity amongst the farmers. A study of the problem in India and abroad indicates that manuring with nitrogen not only increases the yield, but also appreciably reduces the irrigation requirements of crops by increasing the efficiency of water use^(1, 2, 7, 10). Initial experiments conducted on water requirements on a variety of crops based on transpiration ratio have also pointed out the possibility of economic use of water by the application of fertilizers^(2, 3, 8, 9). This was explained as "the transpiration in the crops is curtailed". But in fact this is chiefly brought about by greater production of dry matter relative to lesser increase in the transpiration from the crops.

A detailed study about the best combination of these two practices, *i.e.*, fertilizers and irrigation is, thus felt most vital for successful production of crops.

An investigation was, therefore, planned to study the response of wheat to doses of nitrogen and frequencies of irrigation at two selected centres in the State. The present paper embodies the results for two years that the experimental enquiry has been in progress.

Experimentation

The experiment was conducted at the main Research Station, Lucknow and Regional Research Station, Varanasi during 1961-62 and 1962-63. The design adopted was split plot with nine treatments and six replications.

TABLE I

Particulars of treatments.

Factors	Irrigation frequencies	Doses of nitrogen
	I_1 = One irrigation at tillering.	N_0 = No nitrogen.
Levels	I_2 = Two irrigations (at tillering and pre-heading).	N_1 = 25 lb. nitrogen/acre.
	I_3 = Three irrigations (at tillering, pre-heading and milk stages).	N_2 = 50 lb. nitrogen/acre.
One lb. = 0.453 kg.		

TABLE II

Particulars of sowing, irrigation and rainfall.

Stations	Year of trial	Soil type	Rain-fall during the growing season (inches)	Previous crop	Date of manuring	Sowing date	Irrigation dates			Harvesting date
							1st irrigation	2nd irrigation	3rd irrigation	
Lucknow	1961-62	Sandy loam	2.28	Green manuring	4-11-61	5-11-61	5-12-61	18-1-62	2-3-62	18-4-62
	1962-63		0.54		12-11-62	13-11-62	14-12-62	21-1-63	28-3-63	17-4-63
Varanasi	1961-62	Loam	3.21	,,	4-11-61	5-11-61	2-12-61	13-1-62	27-1-62	11-4-62
	1962-63		3.69		25-10-62	26-11-62**	2-1-63	6-2-63	28-3-63	18-4-63

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**The crop was resown due to damage by white-ants.

TABLE III
Grain yields in quintal per hectare.

Treatments	Main Research Station, Lucknow			Regional Research Station, Varanasi		
	1961-62	1962-63	Pooled	1961-62	1962-63*	Pooled
LEVELS OF NITROGEN						
N_0	26.07	20.56	23.31	20.15	7.27	13.71
N_1	26.99	21.77	24.38	25.75	12.26	19.00
N_2	27.46	24.13	25.79	27.84	16.65	22.24
S.E. \pm . . . . .	..	0.58	..	0.37	0.37	..
C.D. at 5% . . . . .	..	1.70	..	1.06	1.07	..
LEVELS OF IRRIGATION						
I_1	25.38	20.64	23.01	23.00	10.17	16.56
I_2	27.41	22.28	24.84	24.87	12.00	18.43
I_3	27.72	23.53	25.63	25.87	14.00	19.93
S.E. \pm . . . . .	..	0.57	..	0.60	0.33	..
C.D. at 5% . . . . .	..	1.82	..	1.88	1.04	..

*The yields were poor this year due to damage by white-ants.

Nitrogen as sulphate of ammonia was broadcasted just before sowing. Irrigation was done by tube-well and three levels of irrigation were maintained. The depth of irrigation was kept constant and approximately 309125 litres (68,000 gallons) of water was applied per acre at each irrigation. Particulars of the treatments are given in Table I, while in Table II other connected information is portrayed.

Results and Discussion

The grain yield data is presented in Table III while growth observations including yield contributory factors recorded at the Main Station during 1962-63 have been summarised in Table IV.

(a) Nitrogen Effect

It will be seen from the data presented in Table III that with an increase in the

level of nitrogen, a marked rise in the grain yield was obtained at both the Stations. In the year 1962-63 doses of nitrogen significantly differed among themselves at Varanasi, whereas at Lucknow, differences only between 11.34 and 22.68 kg. (25 and 50 lb.) nitrogen were statistically significant. Application of 11.34 or 22.68 kg. (25 or 50 lb.) nitrogen per acre resulted in 38-62 per cent more yields at Varanasi and 17-30 per cent for the average of both the centres as compared to unfertilized treatments. Thus, considering the effect of nitrogen on grain yield, 22.68 kg. (50 lb.) N dose seemed best.

Increase in the grain yield of wheat following nitrogen application may be traced to improved vegetative growth and increased production of effective tillers Table IV. Similar results were reported by Prashar and Singh⁽⁶⁾.

TABLE IV
Growth data.

Treatments	Height (cm.)	Leaves/ plant	Tillers/ plant	Effective tillers	Ear length (cm.)	Grains/ ear	Yield quintal/hectare	
							Grain	Straw
NITROGEN								
N_0	113.97	41.9	7.5	7.4	9.29	49.6	20.56	51.42
N_1	124.71	48.6	9.2	9.2	9.42	51.7	21.77	54.81
N_2	135.67	56.3	9.7	9.7	9.71	52.2	24.13	57.05
S.E. \pm	1.88	2.59	0.36	0.36	..	..	0.58	1.14
C.D. at 5%	5.42	7.48	1.03	1.03	..	..	1.70	3.29
IRRIGATION								
I_1	113.86	43.5	7.9	7.8	9.18	48.2	20.64	50.88
I_2	125.45	48.7	8.8	8.7	9.54	51.7	22.28	54.64
I_3	135.03	54.6	9.8	9.8	9.73	53.6	23.53	57.75
S.E. \pm	2.83	..	..	..	0.13	0.78	0.57	..
C.D. at 5%	8.82	..	..	..	0.41	2.46	1.82	..

(b) Levels of Irrigation

Increasing levels of irrigation markedly increased the yield at both the centres being significant at Varanasi in both the years and at Lucknow during 1962-63 only. It appears that 5.8 cm. (2.28 in.) rain that occurred during the active growth stage in 1961-62 at Lucknow masked the effect of irrigation. On an average for both the Stations, two irrigations given at tillering and ear-emergence (pre-heading), while three irrigations applied at tillering, ear-emergence and milk-stage of the crop, accounted for 9-16 per cent more

yields respectively over crop irrigated once only during the early seedling period. These findings, therefore, emphasise the need of three irrigations for wheat at the above critical stages of growth for higher grain production. That higher number of irrigations influenced ear size and number of grains is a point for further investigation.

(c) Interaction Effects
NITROGEN \times IRRIGATIONS

The yield of grain (Quintal/hectare) for the interactions is portrayed in Table V.

TABLE V
Interaction of nitrogen and irrigation.

Treatment	Lucknow			Varanasi					
	1962-63			1961-62			1962-63		
	N_0	N_1	N_2	N_0	N_1	N_2	N_0	N_1	N_2
I_1	19.56	20.37	22.00	20.84	26.28	27.70	6.25	10.16	14.11
I_2	20.76	21.78	24.30	20.98	29.07	30.86	7.03	12.15	16.81
I_3	21.35	23.15	26.10	23.74	28.40	32.02	8.52	14.46	19.03
S.E. for N	0.58	..	..	0.36	..	..	0.37	..	..
C.D. at 5%	1.70	..	..	1.06	..	..	1.07	..	..
S.E. for I	0.57	..	..	0.59	..	..	0.33	..	..
C.D. at 5%	1.82	..	..	1.88	..	..	1.04	..	..

A critical examination of the data indicates that three irrigations alone were capable to increase the yield only by 2-3 quintal per hectare, whereas upon combination with 11.34 or 22.68 kg. (25 or 50 lb.) N, as much as 6-10 quintal per hectare respectively more grain yield was achieved as compared to unmanured wheat irrigated once only. This points out more efficient use of irrigation water by wheat crop in presence of nitrogen. Similar findings have also been reported on Bermuda grass and on Tarweed in the United States of America (^{9, 10}). These responses are even more marked when the data is subjected to work out the efficiency of the treatments in Table VI.

TABLE VI
Treatment efficiency.

.. Nitrogen .. Irrigation	Per cent of absolute yield		
	N_0	N_1	N_2
I_1	8.9	10.5	11.6
I_2	9.6	11.5	12.6
I_3	10.2	11.7	13.4

A perusal of the data presented in Table VI indicates that irrigating the crop twice or thrice without manuring has given more or less the same yield as obtained with the application of 11.34 kg. (25 lb.) nitrogen under one irrigation only. With the addition of another 11.34 kg. (25 lb.) nitrogen, *i.e.*, 56 kg./hectare (50 lb./acre), the yield obtained under one irrigation was approximately the same as obtained under two or three irrigations in the presence of only 11.34 kg. (25 lb.) nitrogen. It can, therefore, be said that the same quantity of water was more efficiently utilized with successive higher doses of nitrogen. In other way, nitrogenous manuring appeared helpful in the efficient use of water and considerably curtailed the irrigation requirement of wheat. This is in conformity with the findings of other workers on a variety of crops (^{9, 10}).

Summary

Increase in level of nitrogen increased the height, leaves, effective tillers, yield of straw

and grain of wheat. The effect of nitrogen was relatively more pronounced on vegetative growth than that on reproductive initials.

Increase in the number of irrigations from one to three augmented plant height, ear length, grain-number and ultimate yield.

Three irrigations applied at tillering, pre-heading and milk stages of growth and 56 kg./hectare (50 lb. per acre) of nitrogen appeared best combination resulting in highest grain yield of 26.10 and 25.57 quintal per hectare respectively at Lucknow and Varanasi.

Nitrogenous manuring proved helpful for an efficient use of water. Economy in the irrigation requirement of wheat appeared to be associated with the application of nitrogen.

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THE RESPONSE OF WHEAT VARIETIES TO IRRIGATION

by

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Introduction

Among the several factors influencing growth and yield of grain crops in general and wheat in particular, variety, manuring and amount of water supply are of primary importance. Rao *et al* (1957) and Modgal (1960) pointed out that an improved variety will fail to show its full potentiality to produce even with judicious manuring unless optimum conditions of the soil-moisture exist. In order to secure high yields it is of paramount importance to grow a suitable variety under optimum conditions of soil-moisture supplied through irrigation.

The present investigation was, therefore, undertaken at Lucknow (Lat. 26.55°N., Long. 80.59°E., Alt. 390') to determine the response of some improved varieties of wheat to different combinations of irrigation and select a variety suitable for this tract.

Material and Methods

Six varieties of wheat, *viz.*, C 13, K 65, NP 710, NP 775, C 281 and NP 798 were grown at the main Research Station, Lucknow from 1959-60 to 1961-62. The experiment was conducted in a split plot design with irrigations in the main plot and varieties assigned to the sub-plot. The soil was sandy loam and a basal manuring of 18.14 kg. (40 lb.) N as sulphate of ammonia and 9.07 kg. (20 lb.) P₂O₅ in the form of superphosphate, per acre was applied to the fields. The seeding was done in lines by dibbling after giving a pre-sowing irrigation (Palewa). Irrigation treatments in 8 different combinations were given as given in Table I.

Irrigation was done through a well or tube-well at the tillering, ear-emergence and milk stages of plant growth. About 66,000 gallons of water (approximately 3 acre-in.) was supplied at each irrigation. The times of sowing, harvesting and irrigation dates and source for each year are given in Table II.

TABLE I

Particulars of irrigations and varieties.

Factors	Irrigation treatments	Varieties
	I_0 = No irrigation	V_1 = C 13
	I_1 T = One irrigation at tillering	V_2 = K 65
	I_1 E = One irrigation at ear-emergence.	V_3 = NP 710
	I_1 M = One irrigation at milk stage	V_4 = NP 775
Levels	I_2 TE = Two irrigations at tillering and ear-emergence	V_5 = C 281
	I_2 TM = Two irrigations at tillering and milky stage	V_6 = NP 798
	I_2 EM = Two irrigations at earing and milk stage	
	I_3 TEM = Three irrigations at tillering, ear-emergence and milky stage	

TABLE II

Sowing, harvesting, irrigation dates and source.

	Years		
	1959-60	1960-61	1961-62
	Dates		
Sowing . . .	5-11-1959	6-11-1960	5-11-1961
Harvesting . . .	2-4-1960	21-4-1961	16-4-1962
Irrigations . . .	8-12-1959	10-12-1960	5-12-1961
	8-1-1960	12-1-1961	8-1-1962
	10-2-1960	13-2-1961	12-2-1962
Source of Irrigation . . .	Well	Tube-well	Tube-well

Results

(a) 1959-60

IRRIGATION

A perusal of the data presented in Table III showed that levels of irrigations significantly differed amongst them. One irrigation given at tillering stage was significantly superior to no-irrigation, while two irrigations applied at tillering and ear-emergence stages succeeded in giving the highest yield. Three

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TABLE III
Grain yields (Q_s/Ha) (1959-60).

Sl. No.	Irrigation	Wheat Varieties						Mean
		C 13	K 65	NP 710	NP 775	C 281	NP 798	
1.	I_0	6.1	6.4	8.3	3.2	4.9	4.5	5.6
2.	$I_1 T$	20.8	25.6	25.9	21.4	24.9	22.3	23.5
3.	E	13.3	8.4	11.6	10.5	12.8	9.5	11.0
4.	M	19.1	16.2	11.8	10.7	16.8	7.5	13.7
5.	$I_2 T+E$	32.9	41.3	25.9	32.2	32.0	25.5	31.6
6.	$T+M$	27.1	28.5	20.4	26.4	26.9	21.7	25.2
7.	$E+M$	22.0	21.1	24.6	16.0	24.9	14.7	20.5
8.	$I_3 T+E+M$	17.1	22.9	17.6	17.2	20.9	15.6	18.5
	Mean	19.8	21.3	18.3	17.2	20.5	15.2	

C.D. at 5%

Irrigation=13.1

Varieties=3.1

Irrigation \times Varieties=8.2

irrigations did not seem to be beneficial in that they gave lower yields than two.

VARIETIES

Significant differences were observed among the varieties. *K 65* and *C 281* gave significantly higher yields than *NP 775* and *NP 798*; varieties *C 13* and *NP 710* occupied mid position, while *NP 798* yielded the lowest.

IRRIGATION \times VARIETIES

All the six varieties under investigation in general responded best to two irrigations applied at the tillering and ear-emergence stages, and gave appreciably higher yields

(Table IV). Under unirrigated condition, *NP 710* gave relatively higher yields than other varieties. With one irrigation, variety *C 281* yielded highest, followed by *C 13*, *K 65* and *NP 710* the later two producing almost similar yields; *NP 775* and *NP 798* gave poorer yields. Where two irrigations were given the highest grain yield was recorded by *K 65*. This was followed by *C 281* and *C 13* with almost similar yields and *NP 775*, *NP 710* and *NP 798*. Variety *K. 65* yielded highest under three irrigations although these generally depressed grain yields.

TABLE IV
Grain yields (Q_s/Ha) (1959-60).

Irrigation frequency	Wheat Varieties						Mean
	C 13	K 65	NP 710	NP 775	C 281	NP 798	
0	6.1	6.4	8.3	3.2	4.9	4.5	5.6
1	17.7	16.7	16.4	14.2	18.2	13.1	16.1
2	27.3	30.3	23.6	24.8	27.9	20.6	25.7
3	17.1	22.9	17.6	17.2	20.9	15.6	18.5
Mean	19.8	21.3	18.3	17.2	20.5	15.2	

TABLE V

Grain yields (Q_5/Ha) (1960-61).

Sl. No.	Irrigation	Wheat Varieties						Mean
		C 13	K 65	NP 710	NP 775	C 281	NP 798	
1.	I_0	25.3	23.1	20.3	16.1	19.5	19.9	20.7
2.	I_1 T	20.0	25.3	25.0	27.2	27.0	25.8	26.6
3.	E	23.1	19.1	15.2	13.2	16.3	20.2	17.8
4.	M	20.2	22.2	21.4	18.1	20.5	14.9	19.6
5.	I_2 T+E	31.3	27.5	27.8	26.3	30.5	21.7	27.5
6.	T+M	34.7	24.3	27.8	30.2	36.3	21.7	29.1
7.	E+M	30.6	27.7	22.2	23.6	22.2	22.0	24.7
8.	I_3 T+E+M	21.0	31.3	27.5	24.1	26.5	18.7	24.9
	Mean	26.8	25.1	23.4	22.3	24.8	20.6	

C.D. at 5%

Irrigation=Not significant

Varieties=3.2

Irrigation \times Varieties=Not significant

(b) 1960-61

IRRIGATION

In the second year of trial, levels of irrigations failed to evince significant differences (Table V). One irrigation at tillering stage, however, gave higher yields than no-irrigation. Two irrigations again proved better, but this year waterings done at the tillering and milk stage of the crop yielded highest. The beneficial effect of the third irrigation was again not established for the conditions reported in the present study.

VARIETIES

C 13 gave the highest yield this year although amongst C 13, K 65 and C 281 there were no significant differences. NP 710 and NP 775 were intermediate, while NP 798 yielded poorest.

IRRIGATION \times VARIETIES

The interaction between irrigation and varieties was not significant this season

(Table VI). Under no-irrigation C 13 gave the highest grain yield followed by K 65 and NP 710; varieties NP 798 and C 281 produced almost similar yields; NP 775 yielded lowest. The later three varieties showed a similar trend as during the previous year in their grain yields produced. With respect to irrigations, one irrigation, like previous year, at the tillering stage, was most responsive than irrigations given at the ear-emergence or milky stage. Under this treatment, variety C 13 recorded highest grain yield, followed by K 65, C 281, NP 710, NP 798 and NP 775; varieties NP 798 and NP 710, however, gave similar yields.

Two irrigations responded best to give the highest yield again with C 13. This was followed by C 281, NP 775, K 65, NP 710 and NP 798. No appreciable difference in grain yield of NP 775 and K 65 varieties were noticeable. Three irrigations again produced lower yields except in K 65 and NP 710 varieties which gave higher yields under this treatment.

TABLE VI

Grain yields (Q_5/Ha) (1960-61).

Irrigation frequency	Wheat Varieties						Mean
	C 13	K 65	NP 710	NP 775	NP 281	NP 798	
0	25.3	23.1	20.3	16.1	19.5	19.9	20.7
1	24.1	22.2	20.5	19.5	21.3	20.3	21.3
2	32.2	26.5	25.9	26.7	29.6	21.8	27.1
3	21.0	31.3	27.3	24.1	26.5	18.7	24.9
Mean	26.8	25.1	23.4	22.3	24.8	20.6	

TABLE VII
Grain yields (Q_s/Ha) (1961-62).

Sl. No.	Irrigation	Wheat Varieties				Mean
		C 13	K 65	NP 710	NP 798	
1.	I_0	24.4	24.4	26.2	25.2	25.1
2.	$I_1 T$	29.5	24.1	23.7	20.5	24.5
3.	E	25.9	23.7	29.1	25.5	26.1
4.	M	30.9	33.4	32.7	23.4	30.1
5.	$I_2 T+E$	34.5	29.5	25.9	24.1	28.5
6.	$T+M$	27.7	26.6	30.9	21.4	26.6
7.	$E+M$	34.5	28.4	28.0	23.4	28.6
8.	$I_3 T+E+M$	43.2	32.4	29.5	24.4	32.4
Mean		31.3	27.8	28.3	23.5	

C.D. at 5%

Irrigation=Not significant

Varieties=2.7

Irrigation \times Varieties=7.6

(c) 1961-62

IRRIGATIONS

Data for this year are presented in Table VII. The irrigation treatments influenced grain yields appreciably although differences failed to touch the level of significance. Contrary to the findings reported for previous years, one irrigation given at the milky stage was found best this season. Two irrigations applied at the tillering + earing or ear-emergence + milk stages gave almost similar yields. As against the earlier years, three irrigations generally yielded highest.

VARIETIES

This year only four varieties were tried. Varietal differences were significant. C 13 variety significantly yielded highest followed

by NP 710 and K 65; NP 798 gave the lowest grain yield.

IRRIGATION \times VARIETIES

The interactions were significant this year (Table VIII). Under unirrigated condition, like the first year, variety NP 710 recorded the highest grain yield, next in order being NP 798, C 13 and K 65, but the last two varieties produced similar grain yields. With one irrigation C 13 and NP 710 varieties gave similar yields; K 65 and NP 798 were next best. Two irrigations favoured most variety C 13. There was no appreciable difference in grain yields of NP 710 and K 65; NP 798 gave the lowest yield. Three irrigations again registered highest yield for variety C 13; K 65, NP 710, NP 798 varieties followed in the descending order.

TABLE VIII
Grain yields (Q_s/Ha) (1961-62).

Irrigation frequency	Wheat Varieties				Mean
	C 13	K 65	NP 710	NP 798	
0	24.4	24.4	26.2	25.2	25.1
1	28.7	27.1	28.5	23.1	26.9
2	32.2	28.1	28.2	22.9	27.9
3	43.2	32.4	29.5	24.4	32.4
Mean	31.3	27.8	28.3	23.5	

TABLE IX

Average response for three years—Grain yield (Qs/Ha).

Sl. No.	Irrigation	Wheat Varieties						Weighted mean
		C 13	K 65	NP 710	NP 775	C 281	NP 798	
1.	I_0	18.6	18.0	18.3	9.7	12.2	16.5	16.1
2.	$I_1 T$	26.4	25.0	24.8	24.5	25.9	22.9	24.9
3.	E	20.8	17.1	18.6	11.9	14.6	18.4	17.3
4.	M	23.4	23.9	21.9	14.4	18.6	15.2	20.0
5.	$I_2 T+E$	32.9	32.8	26.5	29.2	31.2	23.8	29.3
6.	$T+M$	29.8	26.5	26.4	28.3	31.6	23.3	27.0
7.	$E+M$	29.0	25.7	24.9	19.8	23.6	20.0	24.1
8.	$I_3 T+E+M$	27.1	28.9	24.9	20.7	23.7	19.6	24.4
	Mean	26.0	24.7	23.3	19.8	22.7	19.9	22.9

Discussion

An examination of the pooled data for three years, presented in Table IX, showed some interesting results. All varieties of wheat exhibited a marked response to irrigation. Both number of irrigations as also its time of application were found to be important factors for determining optimum yields. Of the single irrigation, in almost all varieties tried, irrigation given at the tillering stage of the crop was most effective in increasing yields, whereas irrigation done at ear-emergence was least beneficial. The tillering stage of wheat plant, therefore, appears to be most sensitive so far as irrigation is concerned. Two irrigations proved more beneficial than one irrigation at all stages of plant growth. Application of irrigations at the tillering and ear-emergence stages yielded maximum grain yields among all irrigational treatments. Waterings done at the tillering and milky stages or earing and milky stages of the crop were not so responsive, although they still gave higher yields than no irrigation or irrigation done once only. On an average three

irrigations produced lesser yield than two and did not appear to be economic in the present study possibly due to enough moisture in soil and precipitation received during the growing period.

The performance of these varieties of wheat as judged by the grain yields produced also revealed some interesting information. It would be seen from the data illustrated in Table X that varieties C 13, K 65, NP 710 and NP 798 thrived well both under unirrigated as also irrigated conditions in producing normal yields, whereas NP 775 and C 281 gave poorer yields under no irrigation. Under one irrigation C 13 gave highest average yields followed by K 65, NP 710, C 281, NP 798 and NP 775. Where two irrigations were applied, on an average, C 13 again yielded highest; C 281 and K 65 were next best, while NP 710, NP 775 and NP 798 gave almost similar yields. With three irrigations, K 65 produced maximum yield. This was followed by C 13, NP 710, C 281 and NP 775 in the descending order. NP 798 gave the lowest yields under this practice.

TABLE X

Average response for three years—Grain yield (Qs/Ha).

Irrigation frequency	Wheat Varieties						Mean	Per cent increase
	C 13	K 65	NP 710	NP 775	C 281	NP 798		
0	18.6	18.0	18.3	9.7	12.2	16.5	16.1	100
1	23.5	22.0	21.8	16.9	19.7	18.8	20.7	128
2	30.6	28.3	25.9	25.8	28.8	25.7	26.8	161
3	27.1	38.9	25.9	20.7	23.7	19.6	24.4	151
Mean	26.0	24.7	23.3	19.8	22.7	19.9		

Summary

Some salient findings emerging out of the present study are described below :—

- (1) All the six varieties of wheat responded favourably to irrigation giving 28, 61 and 51 per cent higher yields under one, two and three irrigations respectively.
- (2) Irrigation done once only was most responsive at the tillering stage when plants showed the highest need for water.
- (3) With two irrigations, waterings done at the tillering and ear-emergence stages proved most beneficial.
- (4) Three irrigations generally failed to show superiority over two irrigations

under the prevailing conditions.

- (5) As for varietal performance, C 13, K 65 and NP 710 grew well and gave reasonably high grain yields under unirrigated conditions.
- (6) With irrigations, different varieties generally behaved more or less in a similar fashion. Two irrigations given at the tillering and ear-emergence stages seemed best particularly for C 13 and K 65.

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A STUDY OF THE EFFECT OF LIGHT IRRIGATIONS IN SPELLS OF DROUGHT ON THE GRAIN AND STRAW YIELD OF LATE 'AMAN' PADDY

by

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Systematic research work on the water needs of rice has not been attempted for this area during the past. Experiments conducted at Nagina in U. P. (1956) showed that 205.6 cu. m. (2 acre-in.) every four days interval gave the best yields. Intermittent wetting and drying of the paddy fields in Madras and Andhra States every third day yielded as much grain as a continuous standing water to a depth of 7.6 cm. (3 in.) (1956). Preliminary investigations carried out in the barrage areas of Sind (1934) indicated that the daily water use by paddy was of the order of three-fourth of an acre-in. Pandey and Haque (1963) working at Irrigation Research Station, Bikramgunj reported that submergence of paddy to a depth of 15.2 cm. (6 in.) commencing three weeks after transplanting and ending 15 days after flowering increased the yield of grain in both Aus and Late Aman Varieties of paddy.

Experimental Procedure

Cultivation of rice is done after the summer months of March to mid-June followed by heavy rains during the monsoon, late June to September. Preliminary soil moisture tests in mid-June at the Irrigation Research Station, Bikramgunj, showed that the soil moisture status at 7.6, 22.9, 45.7, 76.2, 106.7 and 137.2 cm. (3, 9, 18, 30, 42 and 54 in.) layers from the top stood at 4.77, 7.49, 9.2, 10.23, 11.84 and 13.12 per cent respectively. The mechanical analysis of the soil from the composite sample taken up to 1.5 m. (5 ft.) depth showed the presence of 61.2 per cent as coarse and fine sands, 14.9 and 21.05 per cent of silt and clay fractions, respectively. The soil is well compacted due to continuous cropping with cereal crops like paddy and wheat having specific gravity and volume weight as 2.65 and 1.64, respectively. The permeability of the soil is restricted to less than 1.3 cm. (0.5 in.) per hour. Under puddled

conditions of paddy cultivation the soil becomes almost impervious. The lowest and the highest ground water-table at the station are 4.8 and 1.8 m. (16 and 6 ft.) during May and August-September months, respectively. The plots were not affected by flood at any time.

With a view to study the effect of light irrigations in spells of drought on the grain and straw yields of paddy an experiment with late 'Aman' Paddy variety, 498-2A was laid out during the year 1958-59 and carried out for five years with the following treatments :

A. Manures

*M*₁ 25 lb. Nitrogen+20 lb. Phosphate per acre

*M*₂ 50 lb. Nitrogen+40 lb. Phosphate per acre in the forms of ammonium sulphate and single superphosphate.

B. Irrigation

*I*₁ Control (Rainfed condition).

*I*₂ Light Irrigation at the rate of 5.1 cm. (2 in.) every 7 days.

*I*₃ Light Irrigation at the rate of 6.3 cm. (2.5 in.) every 10 days.

*I*₄ Light Irrigation at the rate of 7.6 cm. (3.0 in.) every 13 days.

The experiment was laid out in a split plot design with 4 replications, the plot size being 29.8 m. × 3.6 m. (98 ft. × 12 ft.). Half of the quantity of nitrogen and full dose of phosphate were added at the time of puddling at both the levels of manuring and the rest 50 per cent of nitrogen was applied one month after transplanting. The cultural practices adopted in the nursery and the experimental plots were those recommended for Japanese method of Paddy cultivation. The source of irrigation was a branch canal from the Sone Canal system. Water was measured over 0.3 m. (1 ft.) wide iron weir at plot heads. Weekly rainfall records were maintained along with temperature, humidity and

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evaporation from the daily data obtained at the Agricultural Meteorological Observatory located at this Station. A part of these data have already been reported by Pandey and Haque (1963).

Results

Table I presents the dates of raising seedlings at the nursery stage, transplanting flowering and harvesting for 1958-59 to 1962-63.

The figures in parenthesis give the meteorological week corresponding to the dates.

The rainfall distribution week-wise at the seedling stage is given in Table II (1958-63).

Table III presents the weekly distribution of rainfall from the stage of transplanting to maturity of the crop for the years 1958-59—1962-63.

TABLE I

Dates of sowing seed, transplanting, flowering and Harvesting 1958-1963.

Particulars	1958-59	1959-60	1960-61	1961-62	1962-63
(1) Date of sowing seeds	8-7-58 (27)	4-7-59 (27)	2-7-60 (27)	28-6-61 (26)	2-7-62 (27)
(2) Date of transplanting	3-8-58 (31)	25-7-59 (30)	7-8-60 (32)	8-8-61 (32)	7-8-62 (32)
(3) Date of flowering	1-11-58 (44)	5-11-59 (44)	30-10-60 (44)	30-10-61 (44)	27-10-62 (44)
(4) Date of harvesting	3-12-58 (49)	11-12-59 (50)	7-12-60 (49)	29-12-61 (52)	22-12-62 (51)
(5) Crop period days (Transplanting to harvest)	132	139	122	143	139

TABLE II

Weekly rainfall at nursery stage (in.).

(in.)

Dates	Meteorological weeks	1958-59	1959-60	1960-61	1961-62	1962-63	Mean
2-8 July	27	0.34	0.06	5.81	3.19	0.00	1.88
9-15 July	28	3.48	3.84	6.24	7.35	0.00	4.18
16-22 July	29	5.99	5.85	1.88	0.49	6.90	4.22
23-29 July	30	3.83	..	0.23	0.26	4.21	1.76
30 July-5 August	31	..	..	0.42	5.03	3.47	1.78
TOTAL		13.64	9.75	14.58	16.32	14.58	13.82

One in.=2.54 cm.

TABLE III

Weekly distribution of rainfall (in.).

(in.)

Dates	Meteorological weeks	1958-59	1959-60	1960-61	1961-62	1962-63	Mean
23-29 July	30	..	0.66	..	..	..	1.08
30 July-5 August	31	9.60	1.45	..	..	..	3.99
6-12 August	32	1.80	1.71	3.08	7.85	1.35	3.95
13-19 August	33	0.62	4.72	3.61	0.70	4.83	3.62
20-26 August	34	2.20	1.45	5.24	1.93	1.69	3.20
27 August-2 September	35	0.25	0.38	0.97	4.02	1.56	1.79
3-9 September	36	2.17	0.34	3.57	2.68	3.25	3.00
10-16 September	37	0.91	0.72	2.43	0.34	0.74	1.28
17-23 September	38	0.48	1.79	4.35	2.33	3.64	3.15
24-30 September	39	1.10	0.16	0.63	0.51	0.32	0.68
1-7 October	40	0.80	6.60	0.35	5.05	0.67	3.37
8-14 October	41	2.91	0.00	0.00	0.29	0.00	0.64
15-21 October	42	0.78	0.00	0.02	0.00	0.00	0.16
22-28 October	43	0.00	0.06	0.00	0.00	0.00	0.01
29 October-4 November	44	0.00	0.26	0.00	0.10	0.00	0.05
5 November-31 December	45-52	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL		23.62	20.30	24.25	25.80	18.05	29.97

One in.=2.54 cm

The levels of irrigation treatment-wise and year-wise are given in Table IV. The results of the yield of grain and straw are presented in Table V and Table VI respectively.

TABLE IV
Levels and dates of irrigation.

Year	Control <i>I</i> ₁	<i>I</i> ₂		<i>I</i> ₃		<i>I</i> ₄		Remarks
		Date	Level in in.	Date	Level in in.	Date	Level in in.	
	Nil		Nil		Nil		Nil	Puddling
1958-59		Sept. 2	3.0	Sept. 2	3.0	Sept. 2	3.0	
		Sept. 20	2.0	Sept. 20	2.5	Sept. 20	3.0	
		Sept. 27	2.0	Sept. 30	2.5	Oct. 3	3.0	
		Oct. 4	2.0	Oct. 10	2.5			
	TOTAL		9.0		10.5		9.0	
1959-60		Sept. 22	2.0	Sept. 22	2.5	Sept. 22	3.0	
		Sept. 29	2.0	Oct. 2	2.5	Oct. 5	3.0	
		Oct. 6	2.0	Oct. 12	2.5	Oct. 18	3.0	
		Oct. 13	2.0	Oct. 22	2.5			
	TOTAL		8.0		10.0		9.0	
	9.0 in.		9.0		9.0		9.0	Puddling
1960-61		Sept. 22	2.0	Sept. 22	2.5	Sept. 22	3.0	
		Sept. 29	2.0	Oct. 2	2.5	Oct. 5	3.0	
		Oct. 6	2.0	Oct. 12	2.5	Oct. 18	3.0	
		Oct. 13	2.0	Oct. 22	2.5			
		Oct. 20	2.0					
	TOTAL		10.0		10.0		9.0	
1961-62	7.0 in.		7.0		7.0		7.0	Puddling
		Sept. 16	2.0	Sept. 16	2.5	Sept. 16	3.0	
		Sept. 30	1.0	Oct. 16	2.5			
		Oct. 14	2.0					
		Oct. 21	2.0					
	TOTAL		7.0		5.0		3.0	
1962-63	Nil		Nil		Nil		Nil	Puddling
		Oct. 3	2.0	Oct. 13	2.5	Oct. 16	3.0	
		Oct. 10	2.0	Oct. 23	2.5	Oct. 29	3.0	
		Oct. 17	2.0	Nov. 2	2.5			
		Oct. 24	2.0					
	TOTAL		8.0		7.5		6.0	

1 in. = 2.54 cm.

TABLE V

Grain yields, maunds per acre (Paddy 498-2A) 1958-59 to 1962-63.

Year	Treatment	Control I_1	I_2	I_3	I_4	Mean	C.D. at 50% in md./acre	Total rain from seedling to maturity in in.
1958-59	M_1	25.43	28.23	25.96	29.96	27.46	Manure (M) 3.85	37.26
	M_2	32.22	31.69	30.23	31.56	31.42	Irrigation (I) N.S.	
	Mean	28.83	27.96	28.09	30.76	29.41	Interaction (M×I) N.S.	
1959-60	M_1	29.31	29.10	30.30	28.07	29.13	(M) N.S.	30.05
	M_2	29.65	31.36	28.90	27.15	29.26	(I) N.S.	
	Mean	29.48	30.28	29.46	27.61	29.20	(M×I) N.S.	
1960-61	M_1	36.15	36.39	37.39	33.14	35.77	(M) N.S.	38.83
	M_2	32.25	37.45	27.42	30.33	31.86	(I) 4.46	
	Mean	37.73	36.92	32.40	31.73	33.91		
1961-62	M_1	38.55	37.40	38.41	41.84	39.15	(M) N.S.	42.12
	M_2	36.91	37.32	35.81	37.04	36.77	(I) N.S.	
	Mean	37.73	37.36	37.11	39.44	37.96	(M×I) N.S.	
1962-63	M_1	29.20	30.68	29.94	27.72	29.38	(M) N.S.	32.63
	M_2	30.68	27.72	30.31	31.79	30.12	(I) N.S.	
	Mean	29.94	29.20	30.12	29.75	29.73	(M×I) N.S.	
Mean of Years.	M_1	31.73	32.44	32.40	32.14	32.17	(M) NS.	36.18
	M_2	32.54	33.11	32.53	31.57	31.88	(I) N.S.	
	Mean	32.13	32.77	32.46	31.85	32.02	(M×I) N.S.	

1 in.=2.54 cm.

TABLE VI

Straw yields, maunds per acre (Paddy 498-2A) 1958-59 to 1962-63.

Year	Treatment	I_1 (Control)	I_2	I_3	I_4	Mean	C. D. at 5% in. md./acre
1958-69	M_1	45.67	52.99	40.61	47.80	46.77	Manure (M) N.S.
	M_2	57.52	59.52	65.64	68.84	62.88	Irrigation (I) N.S.
	Mean	57.60	56.26	53.13	58.32	54.83	(M×I) N.S.
1959-60	M_1	87.10	78.33	81.62	66.83	78.47	(M) 11.65
	M_2	106.27	107.37	115.04	111.75	110.11	(I) N.S.
	Mean	96.68	92.85	98.33	89.29	94.28	(M×I) N.S.
1960-61	M_1	80.07	78.88	94.21	90.93	86.28	(M) 14.48
	M_2	110.65	122.70	109.55	118.87	115.45	(I) N.S.
	Mean	95.36	100.79	101.81	104.90	100.86	(M×I) N.S.
1961-62	M_1	78.33	79.89	87.65	89.84	83.95	(M) 4.2
	M_2	91.48	86.75	89.84	86.55	88.60	(I) N.S.
	Mean	84.91	83.26	88.14	88.19	86.28	(M×I) N.S.
1962-63	M_1	79.09	80.94	79.83	79.46	79.83	(M) N.S.
	M_2	82.42	83.90	87.96	82.42	84.18	(I) N.S.
	Mean	80.76	82.42	83.90	80.94	82.00	(M×I) N.S.
Mean of Years	M_1	74.05	74.22	76.78	74.97	75.06	(M) Sig.
	M_2	89.67	92.00	93.61	93.68	92.24	(I) N.S.
	Mean	81.86	83.11	85.18	84.32	83.65	(M×I) N.S.

Discussion

Late Aman Paddy matures normally in 135 days, beginning from the date of transplanting till the date of harvest. The additional period spent in the nursery is nearly 30-35 days. The time taken from transplanting to general flowering covers about 88 days, and between the flowering to maturity accounts for 47 days.

It would appear from Table II that in four weeks' time at the nursery stage the total requirement of water is 25.4 cm. (10 in.) which is provided normally by rain. Separate experiments with Aus Paddy (CH 10) when the seeds were sown in the first week of June required [822.3 cu. m. (8 acre-in.)] and this had to be provided by irrigation. Perusal of Table III would show that beginning with the transplanting at the start of August till the 40th week (October 7), rainfall was usually regular in all the five years of experiment. The period commencing with 24 September and closing with 7 October coincides with the 'Hasta Nakshatra'. The period 31-38 weeks both inclusive embraces the tillering and growth phase of the crop and the normal precipitation amounts to 7.6 cm. (3 in.) per week. The mean weekly rainfall for the same period were found to be 6.0, 3.9, 7.3, 7.9 and 6.5 cm. (2.38, 1.57, 2.9, 3.11 and 2.56 in.) during the years 1958-59, 1959-60, 1960-61, 1961-62 and 1962-63 respectively. The period of 'Hasta Nakshatra' received 4.8, 17.1, 2.5, 14.1 and 2.5 cm. (1.90, 6.76, 0.98, 5.56, and 0.99 in.) during 1958-59, 1959-60, 1960-61, 1961-62 and 1962-63 respectively. Rainfall during the period subsequent to the 'Hasta Nakshatra' is generally not expected as is evidenced in Table III. Crop, therefore, depends largely on the moisture retained on the surface and within the soil from the rainfall obtained up to 15 October for its requirement till maturity.

It was necessary to apply on an average about 822.3 cu. m. (8 acre-in.) to the fields for puddling at the transplanting stage during three out of five years. Invariably, in the absence of this amount transplanting is not properly carried out. The total rainfall inclusive of the amount received at nursery were of the order of 94.6, 78.3, 98.6, 106.9 and 82.9 cm. (37.26, 30.83, 38.83, 42.12 and 32.63 in.) during the years 1958-59, 1959-60, 1960-61, 1961-62 and

1962-63 respectively covering a total period of nearly 165 days.

The control treatment did not receive any irrigation except the common application at the time of puddling. This amount was not found necessary during the year 1958-59 and 1962-63 only. The total amount applied to treatments I_1 and I_2 in spells of drought varied from 15.2 to 26.7 cm. (6 to 10.5 in.) in any one year and was confined to September-October period depending upon drought. Irrigations were not given beyond 24 October.

A perusal of the grain yield data, Table V showed that there was no effect of either the levels of irrigation or the levels of manure treatment except during the years 1958-59 and 1960-61. Higher level of manuring was statistically superior to the lower level during the year 1958-59, the extra yield being of the order of 164.6 kg./hectare (3.96 md. per acre). During the year 1960-61 the control and I_2 [Irrigation @ 5.1 cm. (2 in.) per week] gave the same grain yield but I_2 was found to be superior to both I_3 and I_4 . However, the control treatment did not prove superior to either I_3 or I_4 . The higher level of manuring [22.6 kg. (50 lb.) Nitrogen + 18.1 kg. (40 lb.) Phosphate] in combination with I_2 (7 days interval) recorded the maximum grain yield of 1565.5 kg./hectare (37.45 md. per acre). The results of the combined analysis however failed to bring out significant difference either due to levels of manure as well as levels of irrigation treatments. The higher level of manuring [22.6 kg. (50 lb.) Nitrogen + 18.1 kg. (40 lb.) Phosphate] induced lodging of crop which slightly reduced grain yield in three out of five years of trial.

The results in respect of straw yield, Table VI showed that the higher level of manuring gave significantly greater straw yield in three out of five years. The combined results have shown that the application of 22.6 kg. (50 lb.) Nitrogen + 18.1 kg. (40 lb.) Phosphate produced significantly more straw over the 11.3 kg. (25 lb.) Nitrogen + 9.0 kg. (20 lb.) Phosphate level of manure. The differences in respect of straw due to the two levels of manuring were found to be 16.11, 31.64, 29.17, 4.95 and 4.35 md. per acre during the years

1958-59, 1959-60, 1960-61, 1961-62 and 1962-63 respectively. The interaction between manure and irrigation levels was found to be absent. It appears that this variety of paddy is not responsive to levels of manuring higher than 11.3 kg. (25 lb.) Nitrogen + 9.0 kg. (20 lb.) Phosphate per acre.

The absence of rain between September 17 to October 14 in the years of 1943, 1947, 1949, 1950, 1951 and 1957 had caused widespread crop failures in Bihar. The rainfall in that period (17 September to 14 October) were 5.6, 3.8, 0.8, 0.3, 1.5 and 0.0 cm. (2.2, 1.5, 0.31, 0.12, 0.58 and 0.00 in.) respectively. Viewed against these rainfall figures we find that the amounts of rainfall received in the corresponding period were of the order of 13.4, 21.7, 13.5, 20.7 and 11.7 cm. (5.29, 8.55, 5.33, 8.18 and 4.63 in.) during the years 1958-59, 1959-60, 1960-61, 1961-62 and 1962-63 respectively. Therefore, it may be expected that a normal grain yield of 1337.7 kg./hectare (32 md. per acre) may be expected with 11.7 cm. (4.63 in.) rain during the period of September 17 to October 14, provided that the rain between transplanting to harvesting does not fall short of 45.8 cm. (18.05 in.) and the mean weekly rain is not less than 3.9 cm. (1.57 in.). A minimum of 3751.8 to 3906.02 cu. m. (36.5 to 38 acre-in.) of water inclusive of rainfall and irrigation required for puddling appears to be adequate which may be scheduled as follows :—

- (i) Nursery stage (10 acre-in.)
- (ii) Puddling (8 acre-in.)
- (iii) Transplanting to boot stage (14 acre-in.)
- (iv) Boot stage to maturity (6 acre-in.) with a minimum of 4.5 acre-in.)

Conclusions

(1) The level of manuring of late 'Aman' Paddy, 498-2A for optimum grain yield was

found to be 11.3 kg. (25 lb.) Nitrogen + 9.0 kg. (20 lb.) Phosphate for the medium loam soil of Bikramgunj. The higher level of manuring at 50 Nitrogen + 40 Phosphate increased the yield of straw with a tendency to lodging and reduced grain yield.

(2) The rainfall of 76.2 cm. (30 in.) from sowing in nursery to maturity appeared to be adequate exclusive of the amount of water needed for puddling provided the distribution is normal as recorded during the period of experimentation.

(3) The amount of water required at different stages of growth worked out as follows :—

- (a) Nursery stage—4 weeks, (10 acre-in.)
- (b) Puddling to boot stage—10 weeks, (22 acre-in.)
- (c) Boot stage to dough stage—5 weeks, (4.5 to 6 acre-in.)
- (d) Dough stage to maturity—4 weeks, Nil.

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OPTIMUM UTILISATION OF WATER FOR IRRIGATED CROPS IN RED SOIL AREA OF BANGALORE DISTRICT, MYSORE STATE

by

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Water is one of the scarce resources in India. This is particularly so in Mysore State, where the area under irrigation is only to the tune of 7-10 per cent as compared to the All-India average of about 20 to 25 per cent. Since the overall production is limited primarily by the most limiting factor in production, it is important to maximise returns to the scarce factor. Characteristically in Mysore State one finds large acreages of reasonably fertile land which is completely unused or produce very little because of lack of water. At the same time when one does find a tank, one usually finds that most of the water is used on crops like paddy and sugar-cane which are extravagant users of water. There is much scope for increasing total food production by shifting the water now used in crops like paddy to the much more productive uses in the production of other food crops. The Farm Management Research Centre in Mysore, therefore, focusses on the problem of reallocation of water for growing irrigated crops which have high response coefficients to water.

There are two aspects to the problem of water use, which are not mutually exclusive. It can be studied from the point of view of water requirements at different periods of growth and also from the point of view of current utilisation practices adopted by farmers. The former is mainly based on agronomic and biological considerations whereas the latter, in addition to above considerations is also influenced by economic consideration. This report dwells mainly on the current utilisation practices, the economic considerations which influence them, and the possibilities of improving the utilisation of water.

Objective

The present yields of many important crops are very low in Mysore. This may be due to the fact that the uses to which the agricul-

tural resources are put are largely results of centuries old customs and traditions. The yields can be increased appreciably by reallocating the important input factors like water. The objective of this report is, therefore, to study the present pattern of water use and based on the results, to suggest possibilities of reallocating water with a purpose of increasing food production and maximising returns to farmers.

Sample

The data were collected from about 100 selected farmers of ten selected villages in the red soils area of Bangalore District. The villages and farmers were selected by purposive sampling.

Bangalore District is in the dry zone of Mysore State and receives an annual rainfall of about 76.2 cm. (30 in.). The temperature varies from 55°F to 97°F and relative humidity varies from about 25 per cent to 72 per cent. Tanks and wells are major sources of irrigation in Bangalore District. Of the total area of 158.64 ha. (392 acres) for each selected village, 21.62 ha. (53.42 acres) were under irrigation. Out of the total irrigated area about 37 per cent was under well irrigation and 63 per cent was under tank irrigation. An overwhelming majority of tanks become full by about September, if there are good rains, and these tanks provide water for irrigation only for a short period and fill about January. Under tanks paddy is grown as a major crop and with well irrigation, irrigated *Ragi*, Potato, Cabbage, Onion, Garlic, Beans and Chillies are grown. Among irrigated crops paddy accounts for about 48 per cent of the total area irrigated.

Present Pattern of Water Use

PRESENT YIELD LEVELS

Present yield levels of different irrigated crops indicate that there are examples of a

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few farmers who have secured high yields. Farmers included in above average yields group, have realised very high yields as compared to the average of those who are grouped in the category of below average yields (Table I).

In larger percentage of cases (57 per cent) farmers have got yields lower than average indicating that there are possibilities of increasing their yields if they use the resources more efficiently.

Factors Influencing Yield

A number of factors influence the utilisation of water in each crop. A few of them are, the duration of crop (or the growth period of crop), number of irrigations, interval between irrigations and the rainfall. In addition, the levels of use of other inputs like quantity of seed, manure, fertilizer and labour also influence the amount of water needed. These factors may have different effects on the utilisation of water for crops. It is found that there is considerable difference in the total amount of water needed by different crops (Table II). It is as high as [6167.4 cu. m. (60 acre-in.)] in paddy and as low as 27.9 cm. (11 in.) in beans.

Broadcast paddy receives largest amount of rainfall and beans receive lowest amount of rainfall. However, the use of irrigation water is highest in case of transplanted paddy and lowest in case of irrigated *Ragi*. The duration of crop also varies from a low of 70 days in case of beans to a high of 177 days in case of broadcast paddy and chillies. Num-

ber of irrigations is highest in case of transplanted paddy and lowest in case of beans. Cabbage receives irrigations at smaller intervals of 4.64 days as compared to irrigated *Ragi*, which receives irrigations at intervals of 7.23 days. Farmers, however, have used farmyard manure in large quantities in all the crops except irrigated *Ragi* (Table III). In very small percentage of cases, farmers have used fertilizers and only in some of the crops like cabbage, pesticides and insecticides are used.

Fertility

Soil fertility has influenced the yields very much in almost all the crops (Table IV).

TABLE I
Distribution of yields of irrigated crops, selected villages, Red Soils Area, Bangalore District, Mysore State, 1959-60.

Crop	Yield per acre in pounds*		
	Above average	Below average	Average
Transplanted paddy	2,416(23)	1,302 (25)	1,836
Broadcast paddy	2,152(26)	1,222 (28)	1,673
Irrigated <i>Ragi</i>	2,953(15)	1,347 (24)	1,965
Potato	9,310(55)	4,597 (55)	6,960
Garlic	3,635(12)	1,788 (20)	2,481
Onion	8,090 (4)	4,350 (6)	5,846
Chillies	2,874 (3)	625 (6)	1,374
Cabbage	41,625(4)	8,266 (11)	17,162
Beans	8,086 (4)	1,112 (6)	3,902
Total No. of plots	146	191	..
Per cent to total No. of cases	43.32	56.68	100.00

*Figures in parenthesis indicate number of cases on which averages are based.

TABLE II
Selected statistics on input-output relationships of irrigated crops, selected villages, Red Soils Area, Bangalore District, Mysore State, 1959-60.

Crop	No. of cases	Duration of the crop in days	No. of irrigations	Interval between irrigations (days)	Acre-in. of water		
					Rain-fall	Irrigation	Total
1	2	3	4	5	6	7	8
Transplanted paddy	48	123	23	4.80	13.93	46.00	59.93
Broadcast paddy	54	177	9	6.96	15.77	18.00	33.77
Irrigated <i>Ragi</i>	39	84	8	7.23	8.36	8.66	17.02
Potato	110	77	14	5.15	5.71	14.98	20.69
Garlic	32	84	14	5.23	4.71	12.25	16.96
Onion	10	93	17	6.00	18.59	15.26	23.85
Chillies	9	177	20	7.11	13.69	16.14	29.83
Cabbage	15	81	19	4.64	4.80	10.21	15.01
Beans	10	70	8	7.15	2.05	9.38	11.43

TABLE III

Selected statistics in input-output relationships of different irrigated crops, selected villages, Red Soils Areas, Bangalore District, Mysore State, 1959-60.

Crop	No. of cases	Pounds of farm-yard manure per acre	Pounds of chemical fertilizers per acre in lb.	Per cent of cases using					
				F.Y.M.	Chemical fertilizers				Pesticides or insecticides
					Am_2SO_4	Super	Cake	Urea	
Transplanted paddy	48	13,621	Am_2SO_4 = 19 Cake = 160	Super=59 Urea=60	43.75	14.58	6.25	..	..
Broadcast paddy	54	19,380	Am_2SO_4 = 60 Urea = 30	Super= nil	94.44	14.81	..	..	..
Irrigated Ragi*	39	..	..	..	..	..	..	..	..
Potato	110	43,807	Am_2SO_4 = 152 Cake = 1,014 Super = 755	..	67	6.00	6.00	21.00	21.00
Garlic	32	27,625	Am_2SO_4 = 85 Cake = 527 Urea = 49	..	25	..	13.00	..	..
Onion	10	8,347	Am_2SO_4 = 88	..	10	20.00	..	..	..
Chillies	9	2,400	Cake = 64	Am_2SO_4 = 40	11	11.00	..	22.00	..
Cabbage	15	22,693	Cake = 205 Urea = 71	Am_2SO_4 = 134 Super = 143	33	..	..	..	60
Beans	10	19,427	Am_2SO_4 = 44	..	40	10.00	..	..	..

*No manure has been applied in the case of irrigated Ragi.

TABLE IV

Soil fertility and yields relationships of irrigation crops, selected villages, Red Soils Area, Bangalore District, Mysore State, 1959-60.

Crop	Fertility level		
	Relatively high	Relatively low	Average
	Yield per acre in Pounds		
Transplanted paddy	2,273 (6)	1,773 (42)	1,836
Broadcast paddy	1,756 (8)	1,660 (46)	1,673
Irrigated Ragi	2,430 (8)	1,845 (31)	1,965
Potato	8,297 (26)	6,414 (84)	6,960
Garlic	2,511 (14)	2,456 (18)	2,481
Onion	6,703 (1)	5,362 (9)	5,846
Chillies	..	1,374 (9)	1,374
Cabbage	26,549 (8)	6,432 (7)	17,162
Beans	..	3,902 (10)	3,902
Total No. of cases	71	256	327
Per cent to total No. of cases.	21.71	78.29	100.00

Only 22 per cent of plots have relatively high fertility and the remaining have relatively low fertility. In general, the high fertility plots have given higher yields as compared to the low fertility plots.

Optimum Use of Water

Optimum Levels

The physical input-output relationships between level of water application and the yield obtained indicate the direction along which a farmer has to move to maximise his returns or to attain the optimum level of water application for a given bundle of resources (Table V). For increased levels of application of water the yields of both transplanted and broadcast paddy show a tendency to decrease. Thus indicating that water is extravagantly used. Practically in case of all crops, the yields show a tendency to increase for increases in the application of water.

TABLE V

Levels of irrigation and yields relationships of irrigated crops, selected villages, Red Soils Area, Bangalore District, Mysore State, 1959-60.

Name of the crop	Acre-in. of water*			Average
	Level I	Level II	Level III	
Transplanted paddy**	1,920(22)	1,764(26)	..	1,836
Broadcast paddy**	1,698(26)	1,650(28)	..	1,673
Irrigated Ragi	1,580(18)	2,196(12)	2,427(9)	1,965
Potato	6,500(31)	6,386(35)	7,742(44)	6,960
Garlic	2,368(12)	2,483(14)	2,700 (6)	2,481
Onion	3,835(3)	6,008(4)	7,640 (3)	5,846
Cabbage	9,262 (3)	21,669(4)	16,328 (8)	17,162
Chillies	1,429 (3)	1,265 (3)	1,430 (3)	1,374
Beans	735 (2)	1,301 (4)	5,584 (4)	3,902
Total No. of cases	120	130	77	..
Per cent to total No. of cases	36.70	39.76	23.54	100.00

1 acre-in. = 102.79 cu. m.

*Levels refer to different amounts of water depending on the crop under consideration. The actual levels are given in Table VI.

**In case of paddy only two levels are taken. The quantity of water is estimated on the basis of number of irrigations.

In nearly 37 per cent of cases water is applied only up to level I, in 40 per cent of cases up to level II and in only 23 per cent of cases water is applied up to level III, indicating that overwhelming majority of farmers have not utilised water for maximising returns.

Optimum Allocation

Study of optimum allocation of water bet-

ween crops is possible if we consider the relative profitability of crops per rupee spent on irrigation. Productivity (in rupees) per rupee spent on irrigation is highest in case of cabbage followed closely by potato and garlic (Table VII). Irrigated Ragi, onion and beans provide medium returns and the returns are lowest in case of paddy.

TABLE VI

Levels of irrigation of irrigated crops, selected villages, Red Soils Area, Bangalore District, Mysore State, 1959-60.

Sl. No.	Crop	Levels of Irrigation (in acre-in.)		
		I	II	III
1.	Transplanted paddy*	Less than 20.00	20.00 to 23.99	24.00 and above.
2.	Broadcast paddy*	Less than 6.00	6.00 to 12.00	above 12.00
3.	Irrigated paddy	Less than 15.00	15.00 to 19.99	20.00 and above.
4.	Irrigated potato	Less than 14.00	14.00 to 18.99	19.00 and above.
5.	Irrigated garlic	Less than 15.00	15.00 to 29.99	30.00 and above.
6.	Irrigated onion	Less than 20.00	20.00 to 29.99	30.00 and above.
7.	Irrigated cabbage	Less than 7.50	7.50 to 14.99	15.00 and more.
8.	Irrigated beans	Less than 5.00	5.00 to 9.99	10.00 and above.
9.	Irrigated chillies	Less than 27.50	27.50 to 34.99	35.00 and above

*Levels given refer to number of irrigations.

1 acre-in. = 102.79 cu. m.

OPTIMUM UTILISATION OF WATER FOR IRRIGATED CROPS IN RED SOIL AREA OF 53
BANGALORE DISTRICT, MYSORE STATE

TABLE VII

Yield, income, cost and productivity of water applied to crops, selected villages, Red Soils Area, Bangalore District, Mysore State, 1959-60.

Crop	Yield in lb. per acre-in. of water (including rain-fall)	Cost of irrigation per acre-in. of water in Rs.	Income per acre-in. (including rain-fall)	Productivity per rupee of investment on irrigation
Transplanted Paddy } Broadcast paddy }	38	1.09	6.52	1.59
Irrigated <i>Ragi</i>	1,156	7.28	19.63	2.70
Potato	336	7.40	53.82	7.27
Garlic	146	10.90	65.83	6.03
Onion	245	8.58	22.06	2.57
Chillies	46	6.85	12.44	1.82
Cabbage	1,143	9.60	91.47	9.53
Beans	341	18.78	40.97	2.18

NOTE :—In case of paddy 2 acre-in. per irrigation has been taken and the quantity of water is calculated on the basis of number of irrigations.

Thus, the results indicate that as between the vegetable crops it is highly profitable to grow cabbage, potato and garlic and as between cereals it is most profitable to grow *Ragi* than paddy. Depending on the availability of total amount of water a farmer can decide on (i) the crops he should grow and (ii) the order in which he should select them in order to maximise his returns.

Summary

The yields of important crops are very low and they have not shown any appreciable tendency to increase over years. The average yield levels can be substantially increased by reallocating the existing resources and introducing new ones. Water is an important scarce resource in Mysore, where irrigation is available only to 7-10 per cent of the total cultivated area. The purpose of this report is to throw light on the present pattern of use of water and suggest improvement in allocation of water among crops with a view to increase total production and maximise profits to farmers.

OPTIMUM REQUIREMENT AND UTILISATION OF IRRIGATION WATER FOR IRRIGATED CROPS IN CHAMBAL COMMANDED AREA—RAJASTHAN

by

K. M. Mehta and G. S. Shekhawat*

Though at many a places, the perennial irrigation specially from canal system has resulted in making soils impermeable and compact and the problem of salinity—alkalinity has become acute, the fact, that good harvests have been maintained for centuries by irrigation supports the thesis that irrigation, if properly managed, can be permanently one of the most important and productive systems of agriculture. Irrigation agriculture permits greater control of production factors than any other system of farming and accordingly lot of potential has been created during the last ten years but the rate of water utilisation is not keeping pace with the irrigation potential created. This not only keeps the production behind the targets but deprives us of the benefits and returns of the investments in the irrigation projects.

Chambal Irrigation Project has an irrigation potential of about 244811.6 ha. (6,00,000 acres), out of which in the first two years only 30351.45—40468.6 ha. (75,000—1,00,000 acres) could be irrigated. It is imperative, therefore, to give a serious thought to the factors responsible for low utilization of irrigation waters and to suggest ways for accelerating water utilisation and achieving higher crop yields.

For successful crop production under irrigation farming, balanced coordination of many factors demands perfect timing of all operations. Among the various factors, the stage of growth, volume and frequency of irrigation have a major influence on irrigation management and production of crops. McClaughtim (1940) observed that delay in first irrigation hastens maturity and reduces growth without any effect on yield of wheat but too much delay, however starts secondary growth with consequent reduction in yield. Denmead and Shaw (1960) observed that delayed watering at the time of silking in corn has deleterious effect on yield.

In newly developed irrigation projects, balanced application of known soil and crop management techniques in accordance with the special soil characteristics are of much significance in making irrigation agriculture a success. Mehta *et al* (1958) have classified the Chambal commanded area of six lakh acres on the basis of important soil characteristics (texture, total soluble salts, permeability of sub-soil and sub-stratum, *pH*, exchangeable sodium and non-capillary porosity *etc.*) into four irrigability rating classes. Shankaranarayana and Mehta (1961) on basis of water allowance capacity factor, water requirement of crops and *Kharif/Rabi* ratio have suggested cropping pattern which is

TABLE I
Distribution of different crops under different water allowance classes for 1,000 acres.

	Kharif crops								
	Jowar, pulses and oil- seeds	Sugar- cane	Cotton	Maize	Paddy	Ground- nut	Fod- der	Green manure	Miscel- laneous fruits and vegeta- bles
Heavy irrigation (4.5 cusec)	175	100	225	125	50	50	50	175	50
Medium irrigation (3.8 cusec)	225	..	225	100	75	50	50	225	50
Light irrigation (3.0 cusec)	270	..	50	100	100	50	40	370	20

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TABLE I—Contd.

	Rabi crops					
	Wheat	Pulses, Coriander and oil seeds	Cotton	Sugar-cane	Fodder	Miscellaneous fruits and vegetables
Heavy irrigation (4.5 cusec)	300	275 (100, 50, 125)	225	100	50	50
Medium irrigation (3.8 cusec)	325	350 (100, 50, 200)	225	..	50	50
Light irrigation (3.0 cusec)	420	470 (200, 50, 220)	50	..	40	20

1 acre=0.404686 ha.

expected to play an important role in the utilization of Chambal irrigation waters with minimum wastage and soil deterioration. The distribution of crops as proposed per thousand acres for each soil group is given in Table I.

While proposing the above crop pattern the high average rainfall of 795.2 cm. in *Kharif* season spread from July to September has been taken into account. At present *Jowar* and pulses are the predominating crops occupying nearly 85 per cent of total *Kharif* area [91317.1 ha. (2,25,650 acres)]. In view of heavy rainfall, the water utilisation during *Kharif* is limited to only a few crops which require water from April to June. Among these paddy, cotton, sugar-cane, forage crops and fruits and vegetables are the chief ones and a shift to these crops from *Jowar* and pulses has started but the introduction of these on a large scale is likely to take time to utilise 40 per cent of the water meant for the *Kharif* crops and hence our problem is to utilise maximum water in *Rabi* season in a most effective manner. In view of the importance of this problem the Government has taken steps to appoint special staff in the area for educating the farmers through large scale demonstrations about the benefits of suggested crop patterns and by opening several research farms for studying soil-water and soil-crop relationship where separate distributaries have been provided for controlled and regular water supply. Since the farmers in the area are new to irrigation, large scale demonstrations on border strip methods of irrigation have been taken up in order to utilise the water in an efficient manner but still lot of scientific information will have to be obtained on several related factors before maximum and proper utilization is achieved.

There is dearth of information on water requirement of crops, irrigation losses, volume of irrigation, frequency of irrigation, bed size and time of irrigation, which is a preliminary requisite for judicious water management of crops under different soil conditions. The collection of all the above data may take some time and, therefore, inferences have been drawn for some items from data available for similar conditions in other parts of the country so that the farmers may be guided for proper utilization of water. Accordingly the tentative water requirement of various crops in Chambal commanded area as worked out for different irrigability classes is given in Table II.

TABLE II

Proposed water requirement of different crops in the Chambal commanded area in acre-in. (exclusive of rainfall).

Sl. No.	Crop	Heavy irrigation areas	Medium irrigation areas	Light irrigation areas
1	2	3	4	5
KHARIF				
1.	<i>Jowar</i> , Oilseeds and <i>Kharif</i> pulses	..	..	..
2.	Sugar-cane	63	..	..
3.	Paddy	36	36	33
4.	Maize	13	13	13
5.	Cotton	13	13	12
6.	Groundnut	8	8	8
7.	Miscellaneous (Fruit and vegetables, etc.)	36	36	33
8.	Fodder	18	18	18
9.	Green manure	4	4	4
RABI				
1.	Wheat and other food-grains	15	15	12
2.	Coriander	7	7	7
3.	Pulses	7	7	7
4.	Oilseeds	7	7	7
5.	Fodder (Legume)	39	39	39
	(Cereals)	9	9	9
	Miscellaneous	36	36	33

Accepting this to be a guide for the time being the immediate problem is to find out the optimum volume of water, frequency of irrigation, bed size and time of irrigation for different crops for arriving at the consumptive use of water. The work on these aspects of irrigation has already been initiated. Shekhawat *et al* (1961) have reported that while irrigating wheat any delay of more than 5-6 days at maturity stage significantly affects the yields whereas delay in early irrigations have no effect. Therefore, the time of sowing of wheat under different distribution systems will have to be so adjusted that there is no delay of irrigation at maturity time. This information for the farmers will be very useful in increasing their yields by timely utilising the water at maturity stage.

Linseed, gram and coriander, important *rabi* crops of the area, have been taken only under un-irrigated conditions and for utilisation of water and higher yields a few experiments are at hand to find out optimum time and number of irrigations. There are indications that one irrigation at one month crop growth or just before flowering stage is effective in increasing the yields of linseed, gram and coriander crops than the control by about 15-20 per cent.

The utilization of water in the Chambal area is confronted with the problems from

several angles and unless we have full data on the different aspects of water utilization by the crops under varying soil conditions the optimum use of water will not be possible. Some of the studies required in this connection have already been initiated while others are in progress and till then the best use is being made of the information available in the country in the similar conditions. The heavy nature of soils, presence of *kankar* layers and high rainfall have made our problems more difficult requiring a thorough study of the different aspects of soil moisture under varying irrigation management. The problem has been further aggravated by the seepage of water from distribution system and uncontrolled use of water by the farmers leading to high water-table and drainage problems in certain areas. This has already scared some of the farmers about the usefulness of irrigation water. Taking all the above aspects in consideration, the utilisation of water in Chambal commanded area is likely to be a slow process till complete information is available on different aspects of water utilization for varying soil conditions. Some of the studies have already been taken up while on other aspects for which adequate facilities are not available, work will be taken up by the Irrigation Research Station to be established shortly at Kota by the Government of India.

WATER LOSSES FROM AN IRRIGATED WHEAT FIELD AT POONA IN RELATION TO PAN EVAPORATION

by

P. S. Harihara Ayyar and B. Padmanabhamurthy*

Introduction

Among the various climatic factors of hydrological and agricultural significance, the return of moisture to the atmosphere from natural land surfaces occupies an important place. Water losses from a natural surface like a cropped field are made up of evaporation from the bare soil and transpiration from the plants, the two combined being known as evapotranspiration. A number of terms such as 'total evaporation', 'stream flow depletion', 'consumptive use', 'irrigation requirement', 'water requirement', *etc.*, are used to denote the quantity of water needed for crop production. The term 'water requirement', when used in connection with irrigation, indicates the amount of water required to be applied to the field at adequate intervals to ensure successful crop production. In raising crops with the help of irrigation, the amount of water lost as transpiration constitutes the minimum demand that has to be met. When this is required to be done through surface irrigation, the inevitable loss of water as evaporation from the bare patches of soil among the plants has also to be taken into account. The solution of the problem of water requirements of crops lies in the accurate determination of the loss of water by evapotranspiration from cropped fields.

Numerous attempts have been made to measure evapotranspiration. Of the many methods that are in use, Lysimetric (¹), soil moisture profile, aerodynamic, eddy correlation and energy balance methods deserve mention. Most of these are, however, laborious and require either constant attention by highly skilled staff or elaborate computation. It is well-known that evapotranspiration is a function of the prevailing meteorological conditions like, vapour pressure, wind, temperature, *etc.* Similarly, the evaporation from a standard pan evaporimeter is also governed

by these factors. An attempt has been made in the present paper to see whether a simple relationship could be obtained between the evaporation from a standard pan and the actual evapotranspiration from a wheat field during a *rabi* season at Poona. An attempt has also been made to see whether there is any significant relationship between the actual evapotranspiration from the wheat field and the latent evaporation measured by a Black Bellani Plate atmometer.

Data Used

The actual evapotranspiration data used in this study have been obtained by the lysimetric method (hereinafter called the gravimetric method). In this method, the plants are grown (right from the germination stage) in containers big enough to allow free growth as in the field. The container is supported on a weighing machine capable of handling large weights. The weighing machine is placed inside another tank of a slightly bigger capacity which is sunk into the middle of a field where a crop of the same variety (in this case wheat) is grown in such a way that the level of the soil in the inner tank (*i.e.*, the tank containing the plants) is the same as that in the field. To simulate field conditions, care is taken to see that the soil profile, the date of planting, seed rate, dates of irrigation, dose of manure, other cultural operations, *etc.*, with respect to the plants grown in the tanks are kept exactly the same as those observed with regard to the plants grown in the field. The soil of the experimental tank is raised to field capacity on days when the crop in the field is irrigated. Proper drainage system is also provided to ensure drainage of overflowing water when heavy showers occur. Periodical growth observations of the plants in the tanks and of those in the field are taken to check up whether the plants in the tanks are growing as freely as those in the field.

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Evaporation for the same period for which evapotranspiration was measured by lysimeter, was obtained from a U.S.A. standard pan evaporimeter installed at the Central Agricultural Meteorological Observatory. In order to prevent the loss of water through various extraneous influences like stray animals and birds the pan is covered with a wire mesh.

The Black Bellani plate atmometer (²) consists essentially of an evaporating surface which is a circular disc of black porous porcelain 7.5 cm. in diameter. This is fitted over the end of a glazed porcelain funnel. Water is conducted to the funnel by glass and rubber tubing from a reservoir. The water-level in the reservoir is kept below the level of the plate. Since the whole apparatus is air-tight, water is held in contact with the porous plate by capillary tension and the air pressure on the water in the reservoir. A mercury valve in the glass tube leading from the reservoir to the plate prevents rain or dew which might be absorbed by the plate from entering the reservoir. Evaporation is measured by noting the amount of fall of water-level in the reservoir. The instrument is exposed in the field such that the black

surface of the cup is 1.2 m. (4 ft.) above the ground surface. This height is important since evaporation is affected by the height of the cup above the ground. Water used in the instrument is either distilled or demineralised. The Black Bellani atmometer records the maximum possible rate of change of liquid water to water vapour from a black, plane horizontal surface fully exposed to the prevailing meteorological factors. This is termed 'latent evaporation' or the maximum drying ability of the air.

Results

Table I shows the ratios of the actual evapotranspiration to pan evaporation and latent evaporation during different stages of growth of the *rabi* (1962-63) wheat crop at Poona.

TABLE I

Phase of the crop	Ratio of	
	A.E.T./ Pan Evap.	A.E.T./Latent Evap.
Germination	1.14	5.22×10^{-3}
Tillering	1.17	6.01×10^{-3}
Elongation (Growth)	0.73	3.24×10^{-3}
Grain formation (Maturity)	0.55	3.09×10^{-3}

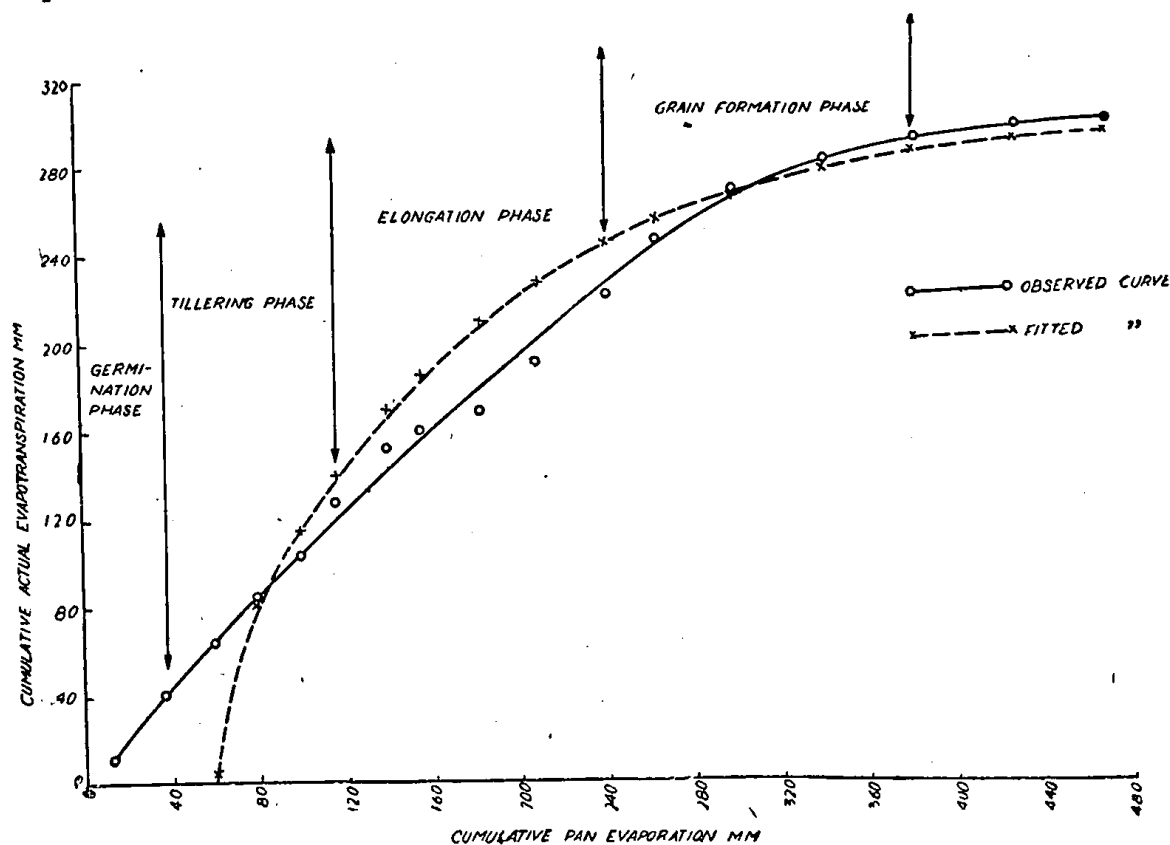


FIGURE 1.

It can be seen that the ratio of the actual evapotranspiration to pan evaporation or latent evaporation attains a maximum value during tillering phase while the minimum is registered during the maturity phase. From the table it may also be observed that the actual evapotranspiration increases correspondingly with pan evaporation during the early stages of crop growth (germination and tillering phases) while during the later stages, the ratio drops suggesting that the evapotranspiration decreases considerably in comparison with the pan evaporation.

Scatter diagrams prepared with the help of daily individual values of actual evapotranspiration and pan evaporation separately for different growth periods did not reveal any significant result. Therefore, cumulative values of evapotranspiration as obtained by lysimeter were plotted (Figure 1) against the cumulative values of pan evaporation starting from the sowing up to the harvest time. It is seen that the two sets of values lie on a smooth curve.

An attempt was made to see whether a mathematical equation could be fitted to the curve. After several trials an equation of the form

$$y = 302.3 - e^{6.06 - 0.0083x}$$

was derived. In this equation y represents the cumulative actual evapotranspiration

and x the cumulative pan evaporation. The evapotranspiration values worked out from pan evaporation making use of this equation are also plotted in the form of a curve in Figure 1. Even though this curve does not quite coincide with the lysimetric curve, it may be seen that the total evapotranspiration up to the end of the grain formation period can be obtained with this equation to a fairly good degree of accuracy. Even taking into account the individual growth phases, the agreement between observed and calculated values is quite close for the tillering and grain formation periods although computed values are somewhat higher for the elongation period.

The study pertains to one kind of soil, crop and a season. In order to extend the results, further experiments are necessary with different soils and crops and in different seasons and climatic zones.

Acknowledgements

The authors are thankful to Shri P. S. Nayar for some useful discussions in connection with the fitting of an equation to the curve.

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STUDIES ON SOIL MOISTURE CHARACTERISTICS

by

Suresh C. Modgal*

Introduction

The energy concept of soil moisture was introduced by Buckingham (1907), and further developed by Gardner (1920), Richards (1928), Scheffé (1935) and Edlefsen and Anderson (1943). Since the introduction of this concept, it has been applied in establishing soil-water relationships, more logically. Application of energy concept in characterizing soil moisture has practical significance. Soil moisture characteristic curves not only tell the amount of water present against various tensions or pF values, but they also indicate the spread of moisture availability range, which is of basic importance in working out soil-water and plant relations, and in the planning of irrigational experiments. Soil moisture characterization also gives an idea regarding the soil type in relation to its texture.

Moisture characteristic curves for three different soils have been presented and discussed in this paper. To facilitate the explanation and also to make the comparisons more sound, soil moisture has been characterized in terms of tension in atmospheres and pF .

Experimental

Three different soil types, *i.e.*, Hazoria clay, Bichpuri sandy loam and Rehovot sand were

chosen for these studies, which were conducted under controlled temperature and humidity at National and the University Institute of Agriculture, Rehovot, Israel in June 1963. The clay and sand were soils from Israel, whereas the sandy loam soil was from Agra, India.

The tensions under which the soil samples were put to determine moisture content (oven dry weight basis) were 0.1, 0.3, 1.0, 3.0, 5.0, 8.0 and 15.0 atmospheres. The various tensions chosen were such, so as to cover the entire range of soil moisture availability for different soil types. Moisture content against 0.1, 0.3 and 1.0 atmosphere tensions was estimated with the help of pressure plate apparatus, while for 3.0, 5.0, 8.0 and 15.0 atmospheres tensions were estimated through pressure membrane apparatus. Later, for each of these tensions, corresponding pF values were calculated by taking the logarithm of height in centimeters of water column equivalent to various tensions in atmospheres.

Results and Discussion

Data for total soil moisture content *versus* pF values have been presented in Table I and further explained through Figures 1 and 2.

TABLE I

Soil moisture percentage (oven dry weight basis) of three soils at mentioned tensions and pF values.

Soil Type	Tension pF						
	0.1	0.3	1.0	3.0	5.0	8.0	15.0
	2.0	2.5	3.0	3.5	3.7	3.9	4.2
(1) Hazoria clay	34.3	28.3	26.0	24.4	23.4	22.4	22.0
(2) Bichpuri sandy loam	20.1	13.6	12.0	8.8	7.9	7.3	6.8
(3) Rehovot sand	17.5	12.9	10.4	7.6	6.9	6.2	6.0

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NOTE: This paper is based on the work done by the author at University and the National Institute of Agriculture, Rehovot, Israel.

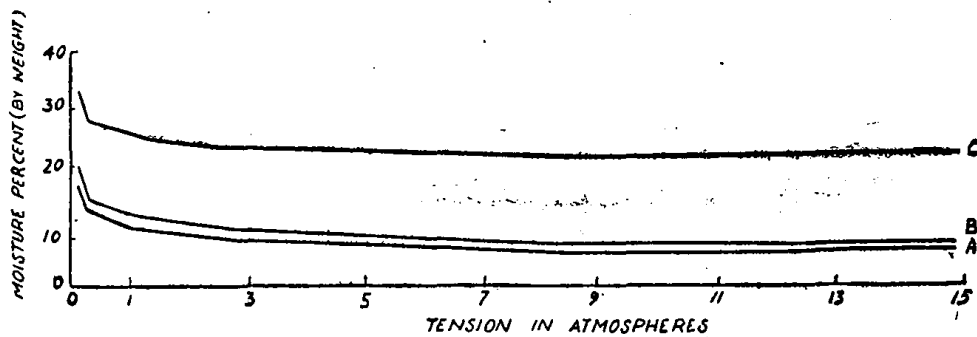


FIGURE 1: Moisture percentages of three soils at different tensions.

- A—Rehovot sand.
- B—Bichpuri sandy loam.
- C—Hazoria clay.

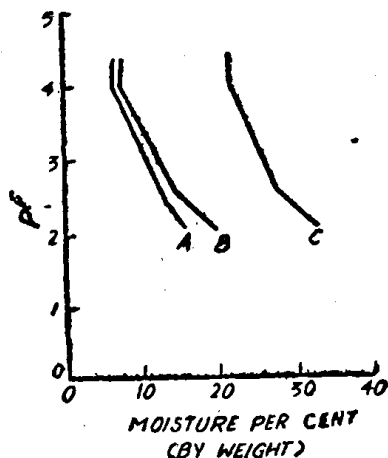


FIGURE 2: Moisture percentages of three soil at different pF .

- A—Rehovot sand.
- B—Bichpuri sandy loam.
- C—Hazoria clay.

A study of Table I reveals that irrespective of soil type, soil moisture content decreases with an increase in tension or pF . It is evident that moisture retention power of Hazoria clay, Bichpuri sandy loam and Rehovot sand is in descending order. In the light of "energy concept" it may be said that so far as the availability of water to plants is concerned 28.3 per cent of water content in Hazoria is equivalent to 13.6 per cent in Bichpuri sandy loam or 12.9 per cent in Rehovot sand, as the tension or pF values for all these varying moistures are the same *i.e.*, 0.3 atmosphere tension/2.5 pF .

Tension and pF curves as presented in Figures 1 and 2 indicate clearly that the major portion of available water in all the three soil types is removed when a tension of one atmosphere or pF value of 3.0 is

attained. However, as indicated by Hendrickson and Veihmeyer (1929), the soil moisture till it reaches 15 atmosphere tension/4.2 pF remains available to plants. This trend in soil moisture characteristics is of practical significance in irrigation agriculture and also in the soil moisture measurement technology. Thus, it is advisable, that one needs to be cautious to irrigate when soil has attained a tension of 1 atmosphere.

Practical Significance of Soil Moisture Characterization

By the help of soil moisture characteristic curves as presented in Figure 1 it is possible to read directly the total moisture present at moisture equivalent (0.3 atmosphere) and 15 atmosphere tension. The moisture equivalent has been generally considered as an acceptable laboratory determination approximating to field capacity. Richards and Weaver (1944) in their studies found that samples of soils moistened and put at pressure of one-third atmosphere had approximately the same moisture content as the same soil at moisture equivalent. Further they recommend 15 atmosphere tension as a satisfactory approximation to wilting percentage. Thus following the curve between one-third atmosphere and 15 atmosphere tension, one can judge the moisture availability range in a particular soil.

Soil moisture characteristic curves may be used directly in planning and guiding soil moisture studies and irrigational experiments eliminating the use of gypsum blocks and tensiometers. For example, if one is to irrigate Bichpuri sandy loam when 50 per cent of the available water is left in the soil, it

may be irrigated when soil is left with 10.2 per cent of total moisture. As the amount of total moisture present at one-third atmosphere is 13.6 per cent and at 15 atmosphere tension is 6.8 per cent, 50 per cent of available water in such a case will be at the time when soil is left with a total water content of 10.2 per cent.

Summary

The moisture characteristic curves were drawn at Rehovot, Israel in June 1963, for three soil types, *i.e.*, Hazoria clay, Bichpuri sandy loam and Rehovot sand. The tension/ pF values chosen were 0.1 atm./2.0 pF ; 0.3 atm./2.5 pF ; 1.0 atm./3.0 pF ; 3.0 atm./3.5 pF ; 5.0 atm./3.7 pF ; 8.0 atm./3.9 pF and 15 atm./4.2 pF .

Conclusions

Following are the conclusions which may be drawn out of the results obtained:—

- (1) Tension or pF values are inversely proportional to the soil moisture content.
- (2) Water retentivity of clay is highest while that of sand is lowest.
- (3) Water is held loosely in sand and sandy loam soils in comparison to clays.
- (4) A major portion of available water is removed by the time soil attains tension of 1 atmosphere.

- (5) Soil moisture characteristic curves may be used for guiding soil moisture regimes directly in the field of irrigational experiments.

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OPTIMUM REQUIREMENTS AND UTILISATION OF WATER FOR IRRIGATED CROPS

by

J. Walter*

The backbone of any country is its agricultural prosperity and this depends on 'water', the most important limiting factor for production of crops. The natural source of supply for all vegetation in the country is of course 'The rainfall', but wherever this is scanty and/or out of season, human enterprise has effected the requisite regulated supply of the available water by forming dams and barrages, *etc.*, across valleys and rivers and conserving the waters otherwise running waste for raising the crops.

Many such storage reservoirs have been taken up and completed in our country. In Madras State almost all the existing sources of surface waters have been tapped and we are at the tethers end. Utmost economy in the use of water with maximum production shall be the criterion, or in other words maximum utilisation of the waters available for raising the maximum crops, shall be the aim of all irrigation and agriculture engineers. To achieve this, the existing irrigation works must be well maintained and operated with the highest degree of efficiency.

Water Requirement of Crops

The water requirement of an irrigated crop is the amount of water needed for crop growth. This may be met entirely by precipitation in humid regions, by precipitation and irrigation in semi-arid regions and by irrigation only in arid regions. The irrigation requirement of a crop is denoted by 'duty' which may be defined as the area of a particular crop that can be successfully raised to maturity with a flow of 0.0283 cumec (one cusec) of water during its growth including rainfall.

The irrigation requirement of any crop depends upon: (1) the soil composition, (2) soil moisture, (3) surface topography, (4) the duration, (5) climate conditions, (6) method

of irrigation, (7) design of delivery system. Psychology, stamina, intelligence and skill of the farmer, possible maintenance of soil fertility, *etc.*, are some of the other factors, which govern the yield or the harvest.

Experiments conducted at the Paddy Breeding Station at Coimbatore for two seasons 1932 to 1934 for determining the quantity of water required for different stages of growth for Vallaisamba (white rice—one special quality) ripening in 160 days with a duty of 8716.6 cu. m. (84.8 acre-in.) of water revealed the following:—

<i>Stage of crop</i>	<i>Acre-inches (including irrigation and rainfall)</i>
(1) From preparation of plots to planting	25.63
(2) From planting to flowering	48.27
(3) From flowering to last irrigation	10.89
TOTAL	84.79

Optimum Requirements

A correct estimate of the optimum requirement of water for a crop is essential for getting the maximum yield with economical use of water. Many additional acreages could be developed if water supplies could be used more economically. Still further extensions in irrigated areas could be made if all unused stream flows could be stored, delivered to the lands as actually needed and applied with high irrigation efficiency. The supply of water more than the optimum requirement not only gives very little increase in yield of most crops but also decreases the quality of the product.

Optimum water requirements of different crops are the seasonal depths of water that result in maximum yields where the depths include soil moisture supplied by precipitation as well as water delivered by irrigation.

Soil moisture plays an important role in study of the optimum requirement of water

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for a crop. The hygroscopic water in a soil is not available for plant growth and hence disregarded in considering irrigation needs. Only when the soil moisture increases beyond 50 per cent above its content of hygroscopic water it is taken by the plant. When the water content increases further, more and more water is available for the plant growth. When the water content increases beyond the maximum capillary capacity of the soil, the excess water flows off the soil particles under the action of gravity and drops to lower level or drier soil or passes down to the water-table as gravity water. When the soil moisture decreases below a certain limit, the plant is not able to take up the available moisture it begins to show signs of distress, wilt and die (Figure 1). The soil moisture at which the wilting begins in any soil is called the wilting coefficient of that soil.

For economic utilisation of water, water must be delivered to the field in such a manner that the water content of the soil within the root zone at any time shall never fall below the wilting coefficient of the soil and shall never exceed the full load capillary capacity of the soil.

Utilisation of Water

For maximum utilisation of available waters, the minimum should be the losses. The losses may be broadly classified as (a) transmission (b) transpiration.

(a) TRANSMISSION LOSSES

To study the transmission losses in canals and field channels experiments were conducted in fields in Aradiar Parai, Kugalur Arakankottai and Thadepalli Channels. The results obtained indicated that 8 cusec/sq. ft. run of water may be safely assumed as transmission losses.

(b) TRANSPIRATION LOSSES

The transpiration losses for the important crop rice were studied in Aduthurai and Maruteru Research units. The results obtained indicate that the total loss due to transpiration by the crop, evaporation from the surface and seepage from the soil can be safely assumed as 2.5 mm. (1/10 in.) per day per acre in the deltaic areas.

In the interests of the country, attempt should be made to get the maximum production with the available water. It is the duty of the engineer to minimize the loss of water

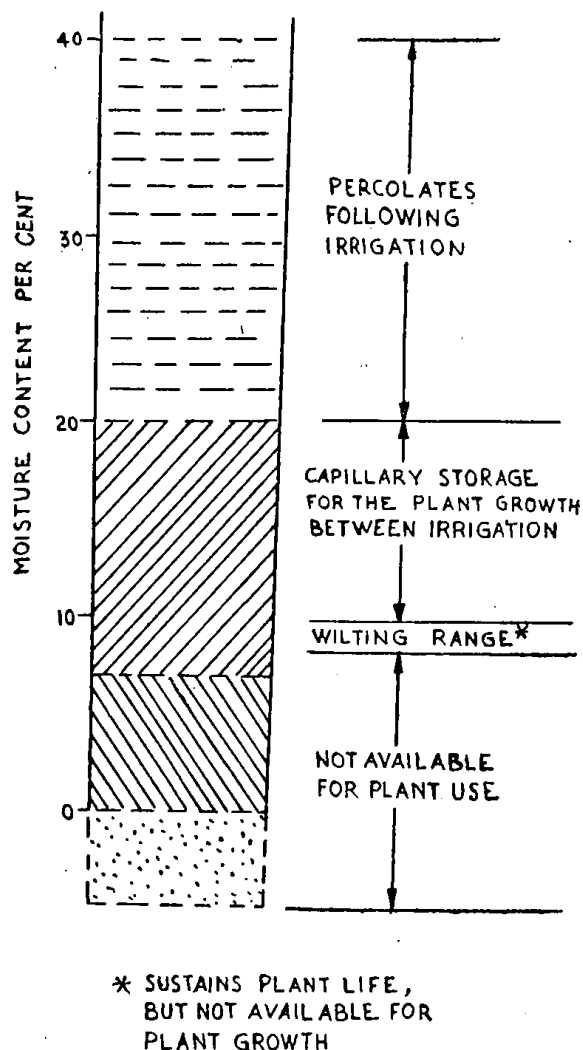


FIGURE 1 : Soil moisture forms and properties.

through the *bunds*, loss during transmission through canals, distributaries and field channels and evaporation loss. Seepage loss can be minimised by careful selection of site for the reservoir, proper selection of site for the reservoir, proper selection of materials and quality control in forming the *bund*, lining of canals, etc. Loss of water in the field can be controlled by proper methods of water delivery and proper method of cultivation. Experiments are under way for reducing the evaporation losses, as well.

When more water is supplied to the field than the optimum, the surplus water drains away and carries with it plant food in solution and impoverishes the soil. But when the water is not drained, then it descends down below the reach of crop roots by gravity, escapes to the water-table and causes an increase in the water-table. This increase in water-table curtails the root zone through which plants can be fed and hence limits production. In addition, it may cause water-logging under certain conditions and serious drainage problem.

Measures of Economy

The measures for securing the best use from the available water supply depend mainly upon the farmer himself and can be controlled by methods of water delivery. Inadequate cultivation is one of the reasons for not achieving maximum results even with adequate supply of water. It has been shown that soil kept in a thorough state of cultivation with the surface thoroughly pulverised at frequent intervals loses water much less rapidly than uncultivated ground.

Experiments have shown that a small quantity of water supplied to the plants during the earlier stages of growth gives better yield than the same quantity of water supplied at the later stage. Farmers must accommodate each other and meet the demands of the system concerning the time of application of water. Rules must be rigidly enforced forbidding wanton waste of water, such as allowing it to run at night without benefit. On account of the inconvenience of night work farmers allow to waste water in large quantities from the lower end of fields into the roads or waste ditches and other similar practices.

Rotation System

Better results can be had by delivering water at intervals in large volumes than by delivering a constant flow for a definite period. Much higher economy both in time and water can be obtained by turning on a large quantity at once so as to cover the ground several inches in depth and while the water in contact with the soil is being absorbed, the surface water is run rapidly towards the lower end of the field. The entire surface is thus soon wet and the irrigation of a certain area is soon over and the water is carried to additional fields. Larger heads of water may be used for irrigation on a pervious soil than upon impervious soils which require some time to absorb

the requisite amount of water. The system of allowing water to a farmer for one week double the amount of water which would be required for constant flow and then one week without any water delivery may be tried. This rotation system of delivery is reported to have been found to be reasonably economical and satisfactory in America.

Some field studies have already been undertaken in our country soil-wise and climate-wise to determine the optimum requirement of water considering the soil moisture for each crop during the various stages of the plant growth for the economical utilisation of water.

The Utab Agricultural College has done some experiments in the economical use of water and has concluded as follows. Deep and thorough ploughing enables the soil to absorb and retain the rain-water. The more the rain-water stored, the less will be the irrigation water required. Thorough and frequent cultivation will reduce the loss of water by evaporation from the surface of the soil. The correct method of irrigation may have to be adopted depending upon the type of crop, soil and climatic conditions.

An experiment with the following eight treatments and four replications was conducted for a period of five years commencing from 1938-39 at Coimbatore.

- (i) 5.1 cm. (2 in.) depth of water once in 3 days
- (ii) 5.1 cm. (2 in.) depth of water once in 6 days
- (iii) 5.1 cm. (2 in.) depth of water once in 9 days
- (iv) 10.2 cm. (4 in.) depth of water once in 6 days
- (v) 10.2 cm. (4 in.) depth of water once in 12 days
- (vi) 10.2 cm. (4 in.) depth of water once in 18 days
- (vii) Normal (*i.e.*, standing water of 5.1 cm. (2 in.) depth always maintained) for 4 weeks and afterwards 10.2 cm. (4 in.) of water once in 12 days
- (viii) Control normal—5.1 cm. (2 in.) depth of standing water always maintained.

The general trend of results was that the control, *viz.*, 5.1 cm. (2 in.) of water maintained always recorded as good a yield as 5.1 cm.

TABLE I

Sl. No.	Name of station	Crop	Duty of water	Remarks
1.	Maruteru	Sugar-cane	107	
		Bananas	136	
		Rice (first crop)	81	June-December
		Rice (second crop)	54	February-May
2.	Aduthurai	Kurivai rice	68	First crop
		Thaladi rice	80	Second crop
		Samba rice	76	Single crop wet lands
3.	Pattukottai	Kurivai rice	37	
		Thaladi rice	37	
		Samba rice	57	
4.	Central Farm, Coimbatore	Single-crop rice	51	Average of four years
		Ragi	130	May-September
		Sorghum	120	March-June
		Cotton	190	6 months duration
5.	Siruguppa	Sorghum	163	June-September
		Cotton	265	August-March
		Ragi	126	July-October
		Wheat	234	November-March
		Korra	103	June-September
		Groundnut	156	July-October
		Rice	60	Single crop
Sugar-cane	90			

(2 in.) in 3 days and 10.2 cm. (4 in.) in 6 days. Experiments were also conducted at different stations from 1938 onwards for some of the plantations and the results are furnished in Table I.

The mean duty of dry irrigated crops worked out to 175, whereas the approximate duty for rice is 60. It will be seen, therefore, that the duty of dry irrigated crops is roughly three times that for rice.

From the experiments conducted by the Madras Agricultural Department, it is inferred that smaller quantity of depth of water is delivered at short intervals produced better yields than larger quantities at longer intervals and that 5.1 cm. (2 in.) of standing water maintained always gave the maximum yield, for rice cultivation.

The returns of the irrigation can be increased by economic handling of water. Field studies for determining the optimum requirement of water for every crop during various stages of growth soil-wise and climate-wise will help irrigation with high efficiency. Irrigation should always be supplied before the soil moisture reaches the wilting point throughout the root zone. Loss and waste of irrigation water must be reduced to a minimum by proper method of water delivery and cultivation. It may not be out of place to mention for optimum utilisation of available water evaporation from water surfaces may be reduced wherever possible by the application of monomolecular layer on the basis of experiments done at Irrigation Research Station, Poondi and transpiration through crops is also reduced by suitable application as is reported to have been successfully practised in Japan.

METHODS FOR ECONOMISING USE OF WATER

By

O. P. Kumra*

SYNOPSIS

It is generally experienced that the usual disposal of irrigation water let out in a canal system in Northern India corresponds approximately to the following pattern :—

(1) Loss in the main canal and branches	15-20 per cent
(2) Loss in major and minor distributaries	6-8 per cent
(3) Loss in field channels	20-22 per cent
(4) Losses due to irregular distribution deep percolation and surface evaporation during application of water	25-27 per cent
(5) Utilisation by crops in the form of evapotranspiration	28-29 per cent

The above figures no doubt offer considerable scope for exercising economy in the use of water. So far attention has been given to the development of irrigation resources and not so much to the optimum utilisation of water. Attempts have been made at reducing losses in canal systems by lining the earthen channels. However the wastage that occurs in the farmers sphere of handling the irrigation supplies deserve some more serious thinking as the benefits accruing therefrom could be manifold such as additional area may be brought under irrigation from the water thus saved ; water-logging problems could be eliminated ; and the yields of crops increased by adopting improved irrigation practices. Methods for economising the use of water, as suggested in this paper are:

- (i) proper alignment, grading, construction and maintenance of field channels,
- (ii) evolving cheap designs of linings, crossings, water control equipment, and farm structures on the field channels/watercourses,
- (iii) proper irrigation methods and land preparation in the fields,
- (iv) equitable sharing of available supplies and consolidation of holdings,
- (v) charging water rates on volumetric basis,
- (vi) coordinating optimum irrigation requirements of crops vis-a-vis rosterings of channels and evolving cropping patterns in relation to available water supplies,
- (vii) elimination of weeds,
- (viii) offering incentives to progressive farmers,
- (ix) re-use of surplus salvaged water, and
- (x) finally popularising the above methods by extension and demonstration.

Introduction

Water is wealth. Irrigation, generation of hydro-power, navigation, domestic and industrial water supply are some of the important direct uses of water. Fish culture and development of recreation spots are the usual accompaniments to the projects utilising this precious source. But too much of everything, they say, is bad.

Abundant supplies of uncontrolled water lead to the havoc of floods and consequent drainage hazards. Excessive irrigation coupled with seepage, leakage and breaches in earthen channels account for the rise in water-table, water-logging, salinity and alkalinity. Interception of natural drainage by a network of rails and roads have further aggravated these problems. Again, as more and more of this source

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is being harnessed, resulting in sharply shrinking balances, controversial issues are coming to the forefront. Of late, territorial water disputes, priority claims of one aspect of water use over the other, cost allocations to the various components of multipurpose projects, are some of the ticklish problems that the engineers of today are called upon to resolve. Keeping in view the rapidly developing conditions of water utilisation in India, time now appears to be ripe to have a look back, take stock of our failures thoroughly and cry halt to the huge losses of water particularly in the extensive canal systems, the vast network of watercourses and the innumerable fields that are primarily responsible for the end-use of this commodity. This would not only eliminate the dangers of large chunks of once irrigated tracts turning waterlogged waste lands but on the other hand, water thus saved would extend controlled irrigation benefits to a much larger area.

The above, in brief, underlines the necessity for some serious thinking on the ways and means for economising use of water. Different utilities consuming bulk supplies of water have been enumerated above. Of these all, irrigation is by far the largest single consumer. Again, within irrigation itself whereas adequate attention appears to have been paid to the subject of evaporation losses in the storage tanks and seepage losses in the canal systems, but what actually happens to the water beyond Government outlets is an aspect that has largely been neglected so far. The scope of this paper is, therefore, limited to the extent of focussing attention to the need for devising methods to economise water use in the sphere, the responsibility for which primarily falls on the beneficiaries, whether individuals or *Panchayats*.

What is Water Use ?

The term '*water use*', as referred to in the context of irrigation, is generally meant to convey the efficient and economic end-use of irrigation water beyond Government controlled points of delivery, *i.e.*, the outlets. This term in brief denotes water management practices under conditions of irrigated farming with a view to ensuring optimum use of water through proper distribution and timely application in correct doses in relation to the irrigation needs of crops. If irrigation is applied at the right time and excess water drained in time from the fields, intensive cropping can be

planned for maximum production. This would then not only eliminate the harmful effects of waterlogging, but also bring more area under irrigation from the same quantity of water, thus achieving greater utilization of the existing irrigation potential. The time-lag between the two will also be reduced to the minimum.

Conveyance of Water

Construction of Field Channels

After its release in a pre-determined and measured quantity from the outlet, water is first to be conveyed in small earthen channels known as watercourses or field channels in order that the same could be distributed equitably to the various fields and farms that the outlet is intended to serve. Experience, however, shows that the beneficiaries who are themselves responsible for this job, more often fail to accomplish the same due to various reasons. Some of these are natural, like the unwillingness of the cultivators to part with land out of their already meagre holdings, and the lack of agreement on the alignment of the channel that may be acceptable to all. Others are beyond their control, such as the general shortage of finances with the farmers and the lack of technical know-how on their part.

Studies on under-utilisation of irrigation potential created on the projects highlight the absence of watercourses or field channels as one of the major reasons for this debacle. As a result of good deal of thinking on this subject during the past few years, certain conclusions have been arrived at with a view to finding a solution of this problem. It is seen that the area proposed to be commanded by an outlet is sometimes very large, even as much as 485.62 ha. (1200 acres). This necessitates a long length of watercourses to be put up and managed by a comparatively large group of beneficiaries—a factor that reduces chances of cooperation amongst them besides taking away lot of land from cultivation. On the other hand, when a number of small outlets serve compact blocks of small but economic sized areas, the idle length of water courses for merely conveying water as in the former, is reduced in this case. There is greater understanding in the smaller group of beneficiaries, less expenditure is incurred and better control is achieved.

Keeping the above in view, some suggestions have been made that the size of the area

served by an outlet should not be unduly large, that separate water courses be provided for blocks of 60.70 ha. (150 acres) each, that water-courses for *chaks* or blocks up to 40.47 ha. (100 acres) in area be constructed by project authorities at Government cost, and that for the remaining areas, the alignment of field channels should be marked out by the project authorities on village maps and these maps should be supplied to the District and Block Development authorities for getting the field channels excavated by the beneficiaries in good time. Further, since responsibility for construction and maintenance of small group works is being progressively transferred to the village *Panchayats*, suitable legislative measures are also being enacted side by side to enable them to carry out the construction of field channels and recover the cost from the beneficiaries in case of default.

It is experienced that in the absence of field channels, water is directly let into the fields for field-to-field irrigation which results in over-irrigation in the upper areas and under-irrigation in the lower fields besides all round wastage due to lack of proper control. Thus, the first and foremost step towards economising use of irrigation water is the proper alignment, grading, construction and maintenance of field channels—a task for which increasing technical guidance and credit facilities are now proposed to be made available to the cultivators.

Reduction in Conveyance Losses

As a result of observations carried out on canals in Northern India, it is estimated that, of the total quantity of water let into a canal system, about 20 to 22 per cent is lost in field channels and watercourses, mostly by way of seepage. Reduction in this loss by lining, naturally offers ample scope for exercising economy in water use. In canal systems, however, where the cultivators are charged water rates on area basis, they generally do not bother about this loss as they are not prepared to incur extra expenditure by way of lining. To make a start, therefore, lining should be encouraged as much as possible particularly in the sandy areas or where water is very valuable, for raising cash or other crops, by such local institutions as the *Panchayats/Panchayat Samitis* or the Block agencies. It is heartening to note that on tube-wells and other State-owned lift irrigation systems first mile or

more of field channels is lined at Government cost. This needs to be emulated by the cultivators. But since at present, lining is done by conventional methods, *i.e.*, masonry or concrete, involving high cost that the farmers in their present status of economy cannot afford, the need for a cheaper type of lining is keenly felt by one and all. Some research has been carried out on cheap methods of lining involving use of alkathene, bentonite, bitumen, water-proof mud plaster, sheet asphalt, compacted soil, cow dung, molasses, *etc.*, in irrigation research institutes notably in Uttar Pradesh, Punjab and Bihar. Under the Ministry of Food and Agriculture's Third Plan Scheme of Research on Minor Irrigation and Water Use, this work has been extended in other institutes also in Gujarat, Kerala, Madhya Pradesh and Maharashtra. After these experiments have been carried out, say by the middle of the Fourth Plan, it is hoped that sufficient data will be available with the research engineers to arrive at some definite conclusions on cheap lining materials and their overall economics considering their initial cost, durability, maintenance expenses, extent of damage by cattle and so on.

Reduction in seepage losses in the field channels by means of a suitable but cheap lining is, thus, the second but equally important method for economising use of irrigation water.

Proper Crossings on Field Channels

As at present, no structures are provided on field channels where small drainage lines or village roads cross the same. This results in sizeable wastage of irrigation water, which could be avoided by providing suitable cheap structures made of the locally available timber. Similarly, adequate number of wooden drops (falls) should also be provided in reaches where the country slopes steeper than the safe designed grade of the field channel to avoid excessive scour. This is necessary to ensure sustained effectiveness of the field channels for smooth conveyance of water.

The responsibility for construction of these works rests with the cultivators. Canal Acts in some States already provide for construction and maintenance of crossings by the beneficiaries, or in case of default, by the State Irrigation Department at the cost of the beneficiaries. Research schemes have also been sanctioned under Minor Irrigation and Water Use

in the States of Bihar, Kerala, Madhya Pradesh, Maharashtra, Orissa and Punjab to evolve cheap designs for drainage crossings, culverts, drops, *etc.*, so that proper technical guidance be extended to the cultivators in the construction of these works. Similar legislative and allied measures need to be taken in other States as well.

Distribution of Water

Cheap Water Control Equipment

Conveyance of water goes hand-in-hand with its distribution from the field channels to the fields and farms of the individual farmers. Farmers in India mostly try to handle irrigation water by means of small earthen *bunds* put across the field channels and by diverting the same through cuts made on the channel banks at the points where water is required to be delivered. This is responsible for wastage of water due to insufficient control, apart from the washing out of *bunds* ultimately, resulting thereby in depressions in and around the position of the *bunds* and cuts. Such wastage is capable of being avoided by the use of cheap portable water control equipment like the canvas dams, wooden regulators, syphon tubes, bamboo pipe outlets, *etc.* As stated earlier, research schemes have been sanctioned to devise the same, after which the use and merit of these appliances will be brought home to the farmers by actual demonstrations in Government farms and selected cultivators' fields. If necessary, steps may also have to be taken to make this equipment available to the cultivators at economical cost.

Equitable Sharing of Available Supplies

It is experienced that each farmer of a group receiving irrigation from a common source of supply is generally anxious to grab the maximum quantity available at the earliest possible opportunity without much regard to the needs of the other. This often results in disputes and difficulties with consequent wastage of water. To avoid this situation, it becomes necessary to fix some schedule for the distribution of available supplies amongst the various share-holders indicating in advance the turn and time of one and all. Left to themselves, it may not be always possible for the farmers to agree upon a mutually acceptable solution. In that event Canal Officers can be empowered to devise some sort of a working arrangement for this

purpose. This is already being done under the turn system in vogue in Uttar Pradesh called '*Osrabandi*' and in Punjab called '*wahr-bandi*'. These systems are governed by the rules framed under the Northern India Canal and Drainage Act of 1873. As per the procedure the turn generally begins with the first holding at the head of the watercourse and ends with the one at the tail-end. The time of each farmer's turn is proportionate to his area in the command of the outlet.

But this practice is not followed in many States with obvious consequences. Enforcement of an effective schedule for day-to-day smooth working to ensure each farmer his due share of the available water supplies could thus be an important step towards achieving proper distribution of water among the farmers. The *Panchayats*, no doubt, could play a positive role in this direction.

Water Supply on Volumetric Basis

It is well-known that the present system of charging water rates from cultivators on crop area basis does not leave much incentive with them for economic use of water. Knowing that a fixed rate irrespective of the quantity of water consumed, is to be charged from them, the farmers indulge in excessive irrigation which may even ultimately prove harmful to their crops and lands. This shows the desirability of levying irrigation charges on volumetric basis. A beginning has already been made in some States in case of State tube-wells and some lift irrigation schemes, where advantage is taken of the fact that daily or sometimes even hourly records of pump running and its discharge measurements are maintained by the operator. But extension of this volumetric rate system to the canal irrigated area is beset with a number of practical difficulties in the present stage of development. This is primarily due to small size land holdings necessitating a large number of transactions involved in measuring, recording and accounting for water released to each farmer in small doses. Non-availability of devices suitable for measuring small quantities of water consumed by individual farmers, is another handicap, whereas lack of physical control over the supplies in the field channels serving a number of cultivators and passing through their fields is still another factor against bringing this idea within the realm of possibility.

As the distribution and management of water beyond canal outlets is being progressively entrusted to the *Panchayats*, a way out of the above problem could be to charge irrigation rates on the basis of bulk supplies measured and delivered to the *Panchayats* at the outlets and leave the rest to them to work out the share of individuals on time and discharge basis. To begin with this suggestion deserves a serious trial on pilot basis. The average area irrigated and the discharge released by an outlet during the previous 10 years could be worked out and the *Panchayat* or Cooperative of the irrigators informed that a fixed rate on the basis of the previous average would be charged from them even though they may utilise the same water in irrigating more area than the previous average. The position may be reviewed after each five years or so. Meanwhile this would serve as an incentive to the farmers to conserve water so as to bring more area under irrigation therefrom.

Application of Water

We now come to the last stage of water use, *i.e.*, its application by the farmer in his fields. The importance of this phase can well be imagined from the fact that losses in fields due to irregular distribution, deep percolation and surface evaporation during application of water account for as much as 25 per cent to 27 per cent of the irrigation water diverted at the source of supply. Whereas it may not be possible to completely eliminate this huge wastage without running the risk of starving the plants, yet these losses appear susceptible to some reduction provided certain improved irrigation practices are adopted by the farmer.

Proper Irrigation Method

During the course of development of irrigated agriculture in India, many methods have come up for applying water to the crops. Vegetable crops are raised in furrows which are rows of short lengths; orchards in depressed basins surrounded by rings of earthen *bunds*; cereals in flat rectangular beds of varying sizes; fodder in strips of a little larger size than the beds, and so on. But as the above methods involved lot of labour in the preparation of fields and channels, a large number of farmers still practice wild flooding from one end of the field to the other end and in case of paddy even field-to-field

irrigation. This results in over-irrigation of low spots and under-irrigation of the higher ones, excessive loss due to deep percolation, leaching of plant nutrients, non-uniform growth of the crop, *etc.*—factors that may ultimately be responsible for poorer yields.

It is, therefore, very essential that proper irrigation methods are adopted by farmers suited to their crop, topography and soil conditions. The optimum sizes of beds, *kharries*, streams and furrows need to be told to them after results backed by thorough research are available for as many crop and soil types as possible with due regard to the consideration that an unduly large area be not occupied by the *bunds* and channels, and that the use of bullock power and labour saving devices is popularised. Contour strip and contour furrow methods of irrigation need to be encouraged in foot-hills of mountains and peninsular regions of rolling topography to avoid erosion as well as excessive and costly land levelling operations which may even remove shallow soils completely thereby exposing the barren sub-soil incapable of sustaining the roots. Sprinkler irrigation can be equally helpful in conserving water in undulating areas and lands having steep slopes or permeable (sandy) soils. But at present on account of high cost involved in installing foreign made imported equipment, its use is mostly limited to plantation crops like coffee, tea and orchards. The programme of manufacturing cheaper sprinkler irrigation equipment indigenously need to be pursued more vigorously. Concerted efforts should also be made to render this method economic by a judicious selection of other paying cropping patterns, especially in places where water is scarce or costly.

Land Preparation

Before applying irrigation water, it should be necessary to ensure that fields are properly prepared so that a uniform depth of water be applied to every nook and corner. Depending upon the irrigation method to be used, the correct laying out of fields and compartments may involve levelling the land by cutting and removing soil from high spots and spreading the same in low lying patches; grading the fields with a gentle slope in the direction of irrigation and making furrows and *bunds*. The shovel, spade, plough and other implements that the Indian farmers generally use

for this purpose involve lot of manual labour besides being uneconomic and somewhat inefficient. Of late, research and extension workers have brought out a few improved designs of bullock-drawn implements for land preparation such as the floats for shaving, smoothing and planing, scrapers for cutting and chipping, ridgers for *bund* forming and ditchers for channel making. Though the utility of these improved implements has been successfully demonstrated in a few research, training or demonstration centres, yet much remains to be done to persuade the cultivators to switch on to these simple cheap wooden frameworks capable of being made by any village carpenter. Lack of finances with individual farmers is perhaps a strong reason against popularisation of these implements. This bottleneck could be removed by the *Panchayat* or other village cooperative owning a few sets and hiring out the same to the farmers at nominal rates. Government in turn could either extend liberal credit facilities to the cultivators or *Panchayats*, etc.

Irrigation Requirements of Crops—Depth and Frequency of Water Applications

An ideal irrigation system would be the one where farmers could apply just sufficient quantity of water to wet the root zone of a crop, a little earlier than the stage at which moisture deficiency in the soil is likely to affect its growth. But this is not a simple affair. It presupposes considerable research on the irrigation requirements of different crops in various regions of the country based on sound scientific lines and modern concepts of moisture regime linked up with the rainfall, humidity, temperature, and other climatic and soil conditions met with in a region. The data so obtained from research centres would then require to be carefully sifted, analysed and correlated to arrive at results that may be made universally applicable to the average representative conditions in the region. Based on such research findings, the ultimate aim should be to prepare and publish irrigation guides for each district indicating the depth of water to be applied on each irrigation along with the optimum interval between two successive waterings. In short, a serious endeavour needs to be made to educate our farmers on how to irrigate, when to irrigate and how much to irrigate. This indeed is a stupendous task.

The Ministry of Food and Agriculture's research and training schemes on Minor Irrigation and Water Use; its five agro-irrigation research centres in the project areas of Bhakra-Nangal, Hirakud, Chambal, Tungabhadra and Gandak and about 34 model agronomic centres under the Indian Council of Agricultural Research are steps in the right direction to achieve the objective outlined above. Gaining knowledge is something but putting the same to practical use is quite different. A great handicap in extending the know-how to the farmers is the non-evolution of a simple and cheap soil moisture measuring technique. A farmer is not expected to possess costly scientific instruments used in research to measure soil moisture. In the absence of cheap locally made varieties, we have to be content in educating him with certain simple tests of touch and feel, based on the oozing out of moisture from the soil sample when squeezed in his palm by the fingers and the thumb. The soil may be extracted from the desired depth with the help of country-made soil augers or depth probe rods. The tests so carried out should be indicative of the moisture status which could enable a farmer to decide upon the right time for irrigation.

Coordination of Irrigation Requirements of Corps vis-a-vis Rostering of Channels and evolving Cropping Patterns in Relation to available Water Supplies

As stated above, the irrigation requirements vary with the cropping pattern, soil and climatic factors and the different stages of crop growth. In order, therefore, that the available irrigation water is put to most effective use for maximum crop production, it would be necessary to arrange supplies according to the optimum water needs of the crops. While this could be possible to some extent in storage systems, but in cases of diversion schemes the supplies available at any time or period entirely depend upon the discharge of the river during the period. On storages as well, the total supplies in a season are limited by the capacity available or run-off actually impounded. So far as multipurpose storages are concerned water may not always be available for irrigation if the other interests suffer. It may sometimes be even otherwise when water has got to be released purely for power, flood control or navigation though the crops may not be in need of irrigation at that time. Then there are other limitations by

way of irrigation rights already established in an area, or the desire to extend benefits to as large an area as possible within the command of a canal system, *etc.* These factors ultimately boil down to the fact that in an irrigation system the cropping pattern should be so diversified, subject of course, to soil and climatic considerations, as could not only be adjusted within the available supplies but ensure the maximum use of available water during all seasons of the year.

This calls for utmost coordination between scheduling of irrigation supplies in the canal system and the planning of the cropping pattern in the command areas so as to fit in with the order of supplies expected specially during the period of critical irrigation demand. A practical way to do so on storage schemes would be to take into account the water actually stored in the reservoir after the monsoon season and to inform the cultivators the extent of water available as well as the area likely to be irrigated therefrom during the forthcoming season. Crop sowing could thereafter be planned according to the supplies forecast. The sowing time and the variety of seeds to be used should also be so adjusted as to stagger the period of keen demand as much as possible and thus bring maximum crop area under irrigation from the available supplies.

Elimination of Weeds

Excess of weeds in the channel sides, banks, or in the fields is frequently responsible for loss of water due to transpiration at the cost of crop itself. Elimination of weeds could thus result in some economy in water-use.

Consolidation of Holdings

Consolidation of land holdings could make it easier for the farmers to implement the suggestions stated above.

Extension and Demonstration

Some methods in brief, for economising use of water have been outlined above. Before, however, we expect the farmers to adopt the same readily, lot of extension work by way of actual demonstration of the main steps and measures will be necessary. The band of engineering subordinates and agriculture graduates now being trained under the Ministry of Food and Agriculture's scheme of Training on Minor Irrigation and Water Use could be handy for achieving this objective. Likewise the Community Development and National Extension Agencies employing Village Level Workers may also contribute their mite.

Incentive

Some incentive by charging a differential/concessional water rate could be offered to those cultivators who carry out improved irrigation practices as outlined above, so that others may follow suit readily.

Re-use of Water

In spite of the best and sincere efforts of extension workers and cultivators, some wastage would be unavoidable in actual practice. In case the quantum of loss due to surface run-off in the fields be high, an attempt should be made to recover and re-use the same to the extent possible after ensuring that the same has not been rendered saline during the process of its initial use in such soils or due to the after effects of fertilizers. One way could be to have small field drains at the tail-ends of the farms or big holdings, in which surplus surface run-off could be channelised for being dropped either into the nearest field channel or passed on in a controlled manner to a needy neighbour. If not required by anyone, it may be let into the nearest drain so that at least the danger of waterlogging is kept away.

A NOTE ON OPTIMUM REQUIREMENTS AND UTILISATION OF WATER FOR IRRIGATED CROPS.

by

Dr. D. G. Kulkarni and M. Y. Gokhale*

Introduction

It is very difficult almost impossible to state correctly one figure as the water requirement of any particular crop, as it depends upon a variety of factors such as the soil, the season, date of plantation, vigour of crops, manures applied, etc. However, it is still necessary to know with fair degree of accuracy the water requirements under the known and common factors. This knowledge of the optimum water requirements of different crops helps to avoid excessive use of irrigation water leading to water-logging conditions and also enables to design an irrigation project more precisely.

The paper takes a review of the basic work done in the laboratory as also of the experimental and observational work carried out in the fields. Main items on which work has been carried out and data collected comprise the following :—

- (1) Laboratory scale experiments.
- (2) Regularly laid out field experiments at Hadapsar Effluent Experimental Area.
- (3) Field experiments at Sugar-cane Research Station, Padegaon, District—Satara.
- (4) Volumetric supply of water to sugar factories in the Western Maharashtra.
- (5) Irrigation on wells.

Water Requirement of Crops under Controlled Conditions

The importance of correct estimate of water requirement of crops in an irrigation system was realised long back in the state of Maharashtra and experiments were carried out under controlled conditions both in the laboratory and in the fields.

Laboratory Experiments

The object of these experiments was to determine the minimum water requirements of sugar-cane at all stages of growth in order to ascertain whether it was practicable to restrict the supply of irrigation water without detriment to cane growers, and if so, to see how far distribution could be improved within the practical limitations of irrigation practice.

Experiments in pots were conducted during 1928 to 1934 to study the water requirement of sugar-cane crop. Of the total water added part was utilised by the crop for the development of crop (transpiration), part was evaporated from the soil and part was lost as drainage.

In earlier stages the main difficulty was to grow the normal crop of sugar-cane under pot conditions but a technique was soon developed to grow normal cane under controlled conditions by providing pots of suitable size and the moisture content needed by the plant. The details are given in the Bombay P.W.D. Technical Paper No. 57, Volume II, published in the year 1938.

The results show that the rate of transpiration for the cane crop is about $4/5$ acre-in. per ton of sugar-cane crop provided the growth is normal and the yield exceeds 89.60 tonnes/ha. (35 tons per acre).

For a normal crop of sugar-cane of 115.20 tonnes/ha. (45 tons per acre) the figures of transpiration and evaporation in different seasons work out to 91.4 cm. (36 in.) by transpiration and an equal amount due to evaporation from the soil (the figures are exclusive of rainfall).

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Field Scale Experiments

The field scale experiments carried out at Hadapsar Experimental area with the sugar-cane crop gave the following results :—

Quantities of water added per acre in in.	Yield of Gul per acre in lb.
75	7910
100	8290
125	8017
150	7858

Optimum yields were obtained with 254 cm. (100 in.) of irrigation.

Experiments conducted at the Sugar-cane Research Station at Padegaon during the same period stated 241.3 cm. (95 in.) as the optimum requirement of water for sugar-cane crop.

Water Requirement of Sugar-cane in Sugar Factory areas in the Western Maharashtra

The problem of water requirement of sugar-cane in sugar factory areas is a complex one. There are a number of varying factors which come into play such as the type of soil, the quantity of water and manure applied, variety of sugar-cane grown, date of planting, cultural methods used, *etc.*, which determine the yield of sugar-cane and the recovery of sugar therefrom.

It is, therefore, very difficult to exactly assess the role played by the quantity of water applied to the yield of sugar-cane and recovery of sugar obtained. But as the modes and methods adopted in the various sugar factories in the Western Maharashtra have been almost standardised, it may be of interest to examine the question of yield of sugar-cane and sugar to the total quantity of water utilised and has thus been examined.

Percentage Distribution of Different Soils in the Sugar Factory Areas

The soils in the sugar factory area have been classified according to Genetic System of classification of soils. The percentage distribution of different types of soils in the sugar factory area is shown in Table I.

A brief description of the important soil types is given below :—

B-type Soils

B-type is characterised by three "Horizons", the first horizon is about 51 cm. (20 in.) in thickness greyish black in colour with a distinct brown shade, with a more or less cloddy structure, the second horizon is mottled with black and brown, brown increasing with depth; thickness 51 to 76.2 cm. (20 to 30 in.), a pure reddish brown horizon follows which shows concretions of lime and often gypsum crystals. The soil depth is never less than 1 m. (3½ ft.) but may extent up to great depths.

This type of soil is predominantly found in Godavari Sugar Mills, Changdev Sugar Factory, Maharashtra Sugar Mills, Phaltan Sugar Works Ltd. and Walchandnagar Industries Limited.

D-type Soils

D-type has a single horizon possessing a dark grey colour with brown shade, fairly loose and granular with faint structure appearing in lower depths which attains distinct lamination in the lowest layer. Intervening between the soil and *murrum* below is a lime band of dirty white colour and of varying thickness. The depth of the soil layer varies from 0.6 to 1.2 m. (2 to 4 ft.).

TABLE I

Showing the percentage distribution of different types of soils in various sugar factories.

Sl. No.	Name of Sugar Factory	Percentage distribution of soil types					
		G	A	D	F	G	B
1.	Belapur Sugar Factory Limited	62	..	3	..	16	13
2.	Maharashtra Sugar Mills Limited	34	11	10	..	11	30
3.	Godavari Sugar Mills Limited	17	15	16	..	9	43
4.	Shri Changdeo Sugar Factory Limited	30	5	10	..	12	43
5.	Walchandnagar Industries Limited	30	..	44	..	1	25
6.	Phaltan Sugar Works Limited	1	5	20	34	9	25
7.	Saswad Mali Sugar Factory Limited	37	25	38	..	..	..
8.	Ravalgaon Sugar Farm Limited	54	..	..	14	..	..

TABLE II

Showing the percentage distribution of different sugar-cane varieties in some of the sugar factories in the Western Maharashtra.

Years	Walchandnagar Industries				Phaltan Sugar Works				Kolhapur Sugar Works					
	POJ 2878	Co. 419	Co. 290	EK. 28	POJ 2878	E.K. 28	Co. 419	Co. 423	Co. 290	POJ 2878	E.K. 28	Co. 290	Co. 419	other varieties
1939-40	43.98	21.35	23.89	4.85	29.3	2.5	37.5	..	30.7	..	..	..	..	..
1940-41	34.64	47.47	14.07	1.41	15.7	..	60.6	..	23.7	26.28	3.74	38.34	28.92	2.8
1941-42	34.18	59.78	4.22	..	10.8	..	83.5	..	5.7	18.98	4.08	10.42	66.13	0.38
1942-43	35.99	61.67	0.98	..	10.7	..	87.9	..	1.4	9.40	0.18	7.91	87.09	2.42
1943-44	41.05	56.83	..	..	3.42	..	95.86	..	0.72	2.84	0.18	0.44	86.32	10.22

These soils are in predominance in the Walchandnagar Industries and Saswad Mali Sugar Factories.

F-type Soils

F-type has a shallow soil 30.5 to 38.1 cm. (12 to 15 in.) in depth, consisting of two well defined horizons; the upper horizon [17.7 cm.—20.3 cm. (7 in.—8 in.) thick] has a light brown colour, lighter texture loose and granular structure with broken pieces of *murrum*. The lower horizon is darker in colour. The lower horizon is of variable thickness and in very shallow phase may often be entirely absent. The *murrum* is hard with a faint incrustation of lime. This soil type is predominantly found on the Phaltan Sugar Factory area.

G-type Soils

G-type has a uniform dark brown colour, throughout but the upper horizon has a structure which yields small grains under pressure, while the lower horizon shows slight limination with white concretions of lime and particles of well weathered *murrum* in the lowermost parts. The *murrum* below is fairly weathered and coated with lime. The soil depth is from 0.3 to 0.9 m. (1 to 3 ft.).

This soil type predominates in the areas of Belapur Sugar Factory, Ravalgaon Sugar Factory, Saswad Mali Sugar Factory and the Maharashtra Sugar Mills Ltd.

Distribution of different Sugar-cane Varieties in the Factory Areas

Sugar-cane varieties giving high yields of cane and sugar have been introduced in different sugar factories. The percentage

distribution of the important varieties grown in some factories and on the whole in the sugar factories in the Western Maharashtra has been shown in Table II. Co. 419 is cultivated on a large-scale.

Sugar-cane under different Plantation Periods

Adsali cane is being planted on a large-scale allowing its ratoon to continue in the subsequent year. There is good deal of variation in the yields of sugar-cane due to different plantations. In support of the above fact the following figures are quoted for information :—

Plantation	Yield in tons per acre
(a) Adsali	54.0
(b) Adsali ratoon	42.5
(c) Plant cane	39.9
(d) Plant ratoon	25.0

Inch Depth of Water Utilised by the different Sugar Factories in Various Years

Requisite information for the sugar factories in the Western Maharashtra has been given in Table III for years 1940 to 1944.

Working out the average annual variation of acre-inches utilised by the factories in the Western Maharashtra, it is seen that lowest is 281.9 cm. (111 in.) in Godavari Sugar Mills and the highest is 365.7 cm. (144 in.) in the Saswad Mali Sugar Factory. Working out the overall average for all factories for the 4 years under reference the inch depth of water utilised is 327.6 cm. (129 in.).

Yield of Sugar-cane in different Sugar Factories in Various Years

The yields of sugar-cane were round about 51208.6 kg./ha. (45 tons per acre) except the Saswad Mali Sugar Factory which started recording higher yields. The results are shown in Table IV.

Yield of Sugar in Different Sugar Factories in Various Years

Tons of sugar produced per acre in different sugar factories in various years is shown in Table V.

TABLE III

Showing the inches of irrigation given per acre by various sugar factories during different years.

Sl. No.	Name of Sugar Factory	1940-1941	1941-1942	1942-1943	1943-1944	Average in. depth of irrigation taken by each sugar factory
1.	Belapur Sugar Company Ltd.	146	130	110	125	128
2.	Maharashtra Sugar Works	122	129	104	134	122
3.	Godavari Sugar Mills	106	109	115	112	111
4.	Changdev Sugar Factory	123	120	117	119	120
5.	Walchandnagar Industries (N.R.B.C.)	117	133	124	129	126
6.	Walchandnagar Industries (N.L.B.C.)	139	137	124	129	132
7.	Phaltan Sugar Works	123	139	143	163	142
8.	Saswad Mali Sugar Factory	162	157	123	136	144
9.	Brihan Maharashtra Sugar Syn. Ltd.	162	148	136	113	140
10.	Average inches of irrigation in different years	133	133	121	129	129

TABLE IV

Showing the yield of sugar-cane in tons per acre in different sugar factories in various years.

Sl. No.	Name of Sugar Factory	1940-41	1941-42	1942-43	1943-44	Average
1.	Belapur Company Ltd.	45.44	41.46	41.23	38.03	41.54
2.	Maharashtra Sugar Mills Ltd.	45.10	41.00	36.00	40.00	40.52
3.	Godavari Sugar Mills, Sakharwadi	48.96	43.31	38.82	..	43.69
4.	Shri Changdeo Sugar Mills	..	30.00	35.30	42.30	36.03
5.	Walchandnagar Sugar Industries	47.50	50.40	43.30	46.40	46.90
6.	Phaltan Sugar Works Ltd.	46.70	50.40	45.50	46.40	47.25
7.	Saswad Mali Sugar Factory	56.50	54.00	50.00	53.45	53.48
8.	Brihan Maharashtra Sugar Syn. Ltd.	47.00	47.50	47.50	40.60	45.65
9.	Kolhapur Sugar Mills	36.00	40.00	37.00	37.12	37.53
10.	Ravalgaon Sugar Farm	52.27	35.26	43.48	..	43.67

1 ton/acre=2.56 tonnes/hectare.

TABLE V

Showing the tons of sugar produced per acre by various factories during different years.

Sl. No.	Name of Sugar Factory	1940-41	1941-42	1942-43	1943-44	Average
1.	Belapur Sugar Company Ltd.	4.77	3.93	4.25	4.08	4.2
2.	Godavari Sugar Mills (G. L. B. C.)	4.80	4.18	4.16	...	4.3
3.	Changdev Sugar Factory	—	2.96	3.62	4.53	3.7
4.	Walchandnagar Sugar Industries Ltd.	4.57	4.73	4.69	5.10	4.7
5.	Phaltan Sugar Works	4.96	5.48	5.22	5.31	5.2
6.	Saswad Mali Sugar Factory	5.33	5.35	5.18	5.75	5.4
7.	Brihan Maharashtra Sugar Syn. Ltd.	4.10	4.92	5.51	4.69	5.0
8.	Ravalgaon Sugar Farm Ltd.	5.17	3.33	4.46	..	4.3
9.	Kolhapur Sugar Mills	3.92	4.98	4.93	4.76	4.6
10.	Average	4.7	4.4	4.6	4.9	4.6

The yield of sugar per acre generally varies between 4551.9 to 5689.8 kg./ha. (4 to 5 tons per acre). The general average yield being 5234.6 kg./ha. (4.6 tons per acre) of sugar.

Quantities of Water used by the Sugar Factories in relation to out-turn of Cane per acre

Quantities of water used to produce one ton of sugar-cane in different factories have been worked out for various years and are shown in Table VI. The results indicate the lowest minimum quantity to produce 1 ton of cane is 5.4 cm. (2.1 in.) in the case of Godavari Sugar Mills in 1940-41 the highest quantity is 7.7 cm. (3.5 in.) per ton in the case of Phaltan Sugar Works in the year 1943-44.

On an average a ton of sugar-cane is produced for 7.1 cm. (2.8 in.) of irrigation.

Quantity of Water required to Produce one ton of Sugar

The quantities of water in acre-inches required to produce one ton of sugar in different sugar factories during different years between 1940 to 1944 are shown in Table VII. It is a clear cut index to show the economic use of water by the various sugar factories under the canals. Here again the most economic use of water per ton of sugar is seen in the case of Godavari Sugar Mills, *viz.*, 56.1 cm.

(22.1 in.) of water to produce 1.0160 tonnes (one ton) of sugar. Maximum inch depth taken is 76.2 cm. (30 in.). Average inch depth of irrigation required to produce 1.0160 tonnes/ (one ton) of sugar works out to 70.3 cm. (27.7 in.).

The average out-turn of sugar per acre in the sugar factories in the Western Maharashtra is of the order of 5.08 tonnes (5.0 tons). The quantity of water required on the whole in a year to produce 1.0160 tonnes (1 ton) of sugar-cane should not ordinarily exceed 63.5 cm. (25 in.) as seen from the performance of the promising sugar factories in the first 4 years of volumetric supply. For the economic use of water and in the larger interest of the nation, this criteria may be well applied. In cases where this economic ratio is well maintained there appears to be some ground to ask for more water. The quota of water to be allotted to the different sugar factories may preferably be based upon the quantities of sugar produced by them during the past 5 years, than on the area basis. It may prove to be a solution on a more rational basis as a result of data obtained under varied conditions. Once this is done, there would be an impetus for the sugar factories to reduce all sources of losses of water and to increase their efficiency.

TABLE VI

Showing the inch depth of water consumed to produce one ton of sugar-cane in different years and by various sugar factories in Western Maharashtra.

Sl. No.	Name of Sugar Factory	1940-41	1941-42	1942-43	1943-44	Average
1.	Belapur Sugar Company Ltd.	3.2	3.10	2.6	3.4	3.0
2.	Maharashtra Sugar Mills	2.70	3.20	2.90	3.25	3.0
3.	Godavari Sugar Mills	2.10	2.50	2.90	..	2.5
4.	Walchandnagar Sugar Industries—(N.R.B.C.)	2.8	2.9	3.1	2.7	2.9
5.	Walchandnagar Sugar Industries—(N.L.B.C.)	2.5	2.4	2.6	2.8	2.6
6.	Saswad Mali Sugar Factory	2.8	2.9	2.4	2.5	2.6
7.	Phaltan Sugar Works	2.6	2.7	3.1	3.5	2.9
8.	Brihan Maharashtra Sugar Syn. Ltd.	3.4	3.1	2.8	2.7	3.0
9.	Average water used to produce one ton of sugar-cane Average	2.76	2.85	2.80	2.95	2.8

TABLE VII

Showing the inch depth of water required to produce one ton of sugar in different years by the various sugar factories in Bombay-Deccan.

Sl. No.	Name of Sugar Factory	1940-41	1941-42	1942-43	1943-44	Average
1.	Belapur Sugar Company Ltd.	30.6	33.07	25.8	30.6	30.0
2.	Maharashtra Sugar Mills	..	..	..	..	..
3.	Godavari Sugar Mills	22.1	26.0	27.9	..	25.3
4.	Walchandnagar Sugar Industries Ltd.—N.L.B.C.	26.7	28.9	24.6	25.2	26.3
5.	Walchandnagar Sugar Industries Ltd.—N.R.B.C.	29.6	31.8	28.5	25.2	28.7
6.	Phaltan Sugar Works	24.8	25.5	27.6	30.8	27.1
7.	Saswad Mali Sugar Factory	30.4	29.3	23.7	23.6	26.7
8.	Brihan Maharashtra Sugar Syn. Ltd.	39.5	30.2	34.7	24.0	29.6
	Average	29.2	29.2	26.1	26.6	27.7

Economic Utilization of Water under Well Irrigation

Well irrigation is a major source of irrigation in the State of Maharashtra as can be seen below, showing areas irrigated under different sources of irrigation :—

Source of Irrigation	Areas irrigated in acres
(1) Govt. Canals	5,14,100
(2) Private Canals	72,900
(3) Tanks	4,28,800
(4) Wells	12,88,400
(5) Other sources	80,200
	<u>23,84,400</u>

Thus 50 per cent of the total area under irrigation is under wells. Nearly 121405.80 ha. (3 lakh acres) are under perennial crops such as sugar-cane, plantain and other fruit crops and the rest 364217.40 ha. (9 lakh acres) are under seasonal crops.

Under the conditions of well irrigation where normally water is applied to crops according to their optimum requirements, data collected from such sources can be considered more representative.

In the Soil Survey Organisation which deals with the sub-soil surveys of the area under the command of various projects, the hydrological conditions as they exist at present are

exhibited by the intensity of wells in the area, sub-soil water-levels in the existing wells, the rates of recuperation in the wells and total areas under well irrigation in different villages under the projects.

Intensity of Wells in the areas Commanded by Different Projects in Maharashtra State

Sub-soil surveys are being carried out in the commanded areas for the irrigation projects which fall under the following categories.

- (1) Projects in the scarcity areas with rainfall of 51 to 63.5 cm (20 to 25 in.).
- (2) Projects in areas with more than 76.2 cm. (30 in.) rain.
- (3) Projects in areas with rainfall of 40.6 to 76.2 cm. (16 to 30 in.) where seasonal irrigation already exists
- (4) Projects with rainfall of 76.2 cm. (30 in.) and above and well irrigation in practice.

Category	Project	District
I	(i) Ghod Left Bank Canal	Ahmednagar
	(ii) Mula Right Bank Canal	Ahmednagar
	(iii) Karanjwan	Nasik
	(iv) Katepurna	Akola
II	(i) Nalganga	Buldhana
	(ii) Ber	Wardha
	(iii) Purna	Parbhani and Nanded
III	(i) Khadakwasla	Poona
	(ii) Vir	Sholapur
	(iii) Girna	East Khandesh
IV	(i) Warna	Sangli and Kolhapur
	(ii) Koyna	Sangli and Satara

The range of variation of wells per square mile is as shown below :—

Category	No. of wells per sq. mile.
I	1.0 to 3.3
II	3.3 to 6.0
III	6.0 to 8.0
IV	Above 10.0

Intensity of wells in the areas is generally governed by (1) rainfall in the area and water contributed to the sub-soil, (2) ground slope and the nature of sub-starta available, (3) distribution of different types of soils through which water is infiltrated.

In the case of Mula Project, the number of wells per sq. mile is particularly low because of the greater distribution of the deep soil areas where the permeable strata is not available in a reasonable depth and rate recuperation in well is the least and possibility of saline waters being wet with.

Distribution of Wells in the Commanded areas

Wells are generally located in areas adjacent to the village sites and along the sub-soil depressions and, therefore, are not uniformly distributed all over the area. As a general observation, it may be stated that rough distribution of wells according to soil types would be of the following order :—

Soil depth	Percentage distribution of wells
(1) Light soils 0 to 45.7 cm. (0 to 18 in.)	20 per cent
(2) Medium soils 45.7 cm. to 2.4 m. (18 in. to 8 ft.)	60 per cent
(3) Deep soils more than 2.4 m. (8 ft.)	20 per cent

Out of the wells in the medium soil, most of them are located along the sub-soil valleys or surface depressions or a *nala*.

Generally few wells are located in deep soils probably because (1) the rate of recuperation is low, (2) possibility of saline waters being met with.

Composition of Sub-soil Waters

Although in about 75 per cent cases the sub-soil waters are suitable for irrigation, yet there are cases to the extent of about 20 per cent wherein the salt content exceeds 200 parts per 100,000 and in a few cases even more than 400 parts per 100,000.

The quality of sub-soil waters is, therefore, closely related to the development of well irrigation.

Generally the rate of recuperation varies from 0.05 cusec to 0.4 cusec and is classified into three groups as shown below :—

Rate of recuperation in cusec	
1.	0.05 to 0.10
2.	0.10 to 0.30
3.	0.30 to 0.40

Crops Grown under Well Irrigation

Three types of croppings are generally adopted on well irrigation :

- | | |
|---------------------|--------------------------------|
| (1) Perennial Crops | (i) Sugar-cane |
| | (ii) Fruit trees |
| | (iii) Lucern |
| (2) Mixed Crops | (i) Perennials |
| | (ii) Two seasonals like cotton |
| | (iii) Seasonals |
| | (i) Kharif |
| | (ii) Rabi |
| | (iii) Hot weather |
| (3) Seasonals | |

Area irrigated on wells per million cu. ft. of water in the different croppings is as below :—

(1) Perennial	0.97 ha. (2.4 acres)
(2) Mixed	3.2 ha. (8.0 acres)
(3) Seasonals	8 ha. (20.0 acres)

Water Requirement of Sugar-cane under Well Irrigation

During the soil survey work under various projects water utilised by sugar-cane under well irrigation was worked out with the following results :—

Sl. No.	Project	Village Survey No.	Annual yield in acre-in.	Sugar-cane grown in acres
1	2	3	4	5
1.	Khadakwasla	Mundhawa 84-C	340	2.75
2.		Manjri 21	400	4.0
3.		86-B	400	3.0
4.		Fursungi 43	220	2.0
5.	Warna	Khujgaon 213	280	1.5
6.		Bhedasgaon 55	440	3.0
7.		Kande 342	480	4.0

1	2	3	4	5
8.		Satve 133	420	3.0
9.		Kodoli 486	520	6.0
10.	Koyna	Bauchi 248	340	3.0
11.		Walve 721	300	3.0
12.		Gotkbind 99-B	240	3.0
13.		Walve 56-B	300	2.25
14.		Ankalkop 174	340	4.0

1 acre-in. = 102.79 cu. m.; 1 acre = 0.404684 ha.

Average water requirement of sugar-cane per acre under well irrigation is, therefore, 287 cm. (113 in.).

For different valleys under study the requirement varies as below :—

(1) Khadakwasla Project	292.1 cm. (115 in.)
(2) Warna Project	309.8 cm. (122 in.)
(3) Koyna Project	254 cm. (100 in.)

Similar information under well irrigation was collected during the soil surveys of Mahi Project with the following results :—

Name of Crop	Water requirement in in.
Bananas	125
Lemons	62
Rabi crops	19
Hot weather crops	25

1 inch = 2.54 cm.

Summary

Optimum requirements and utilization of water for irrigated crops is very important in the preparation of irrigation projects and generally the data suited to the climatic and soil conditions of the area is not available with the result that the assumptions made require to be revised in view of the conditions actually in the fields irrigated.

The question of water requirements of crops has been under examination both in the laboratory and in the fields for the past 35 years in the State of Maharashtra. The results obtained under laboratory and field conditions have been given in the paper for the crop of

sugar-cane which requires water all the year round and in fairly good quantities.

Experimental work in connection with the laboratory and field scale experiments takes a lot of time and need a good deal of correction before the results are adopted for an irrigation system. In the areas where canal irrigation is to be newly introduced, well irrigation already exists and the water is most judiciously utilised. Data regarding water utilisation under wells, therefore, serves a good guide. Selection of wells for collection of such data has to be made with care and wells with higher recuperation and growing specific crops provide useful data for adoption.

In this paper data regarding the water requirements of sugar-cane crop has been examined as under :—

- (1) Laboratory conditions.
- (2) Field scale experiments at the effluent farm near Poona.
- (3) Field scale trials for the sugar-cane crop at the Sugar-cane Research Station at Padegaon, District Satara.
- (4) Data regarding the volumetric supplies of water made to sugar factories.
- (5) Water utilised by sugar-cane crops under wells in different projects.

It is interesting to review the results obtained under the above conditions.

- (1) Laboratory results show that out of the total water applied, 40 per cent is taken up by plant, 40 per cent is lost by evaporation and 20 per cent lost as drainage.

A normal crop of 51208 kg./hectare (45 tons per acre) if grown under pot conditions shows a transpiration of 80 on the basis of green weight of cane ready for harvest. This works out to 3700.4 cu. m. (36 acre-in.) as the requirement of transpiration. Equal quantity is lost by evaporation and half the quantity as drainage. The

water requirement of sugar-cane under laboratory conditions works out to 91.4 cm.+91.4 cm.+45.7 cm.= 228.6 cm. (36 in.+26 in.+18 in.= 90 in.).

- (2) The field scale trials carried out at the Effluent Farm show optimum yields for 10,279 cu. m. (100 acre-in.).
- (3) Field scale trials carried out at the Sugar-cane Research Station at Padegaon indicate 149.8 cm. (95 in.) as the optimum dose of water for a sugar-cane crop.
- (4) Water used by the various sugar factories is on volumetric basis and on variety of soils and climatic conditions and the requirement of water of a sugar-cane crop at the distributary headworks out to 327.6 cm. (129 in.) as detailed in the paper.
- (5) Observations made under well irrigation indicate the following water requirements for the sugar-cane crop.
 - (1) In predominantly heavy soils = 254 cm. (100 in.)
 - (2) With a fair distribution of medium and deep soils = 292.1 cm. (115 in.)
 - (3) In well drained soils = 309.8 cm. (122 in.)

The water requirements for irrigation are as calculated on field site. Allowing for the losses in transit, the requirement would be 15 per cent more at the distributary head.

From the above it would be clear that the data obtained under well irrigation agrees fairly well with other methods and is a suitable one under different projects.

Water requirement for other crops can also be similarly worked out and results adopted. Irrigation water being a highly priced commodity has to be correlated with the money returns from various crops per unit volume of water. With increased out-turns of various crops grown, it would go a long way to economise water to achieve increased production and adequate returns.

OPTIMUM REQUIREMENTS AND UTILISATION OF WATER FOR "IRRIGATED CROPS" IN THE GUJARAT STATE

by

Dr. R. P. Talati*

Introduction

In recent years, when we are expanding irrigation facilities by way of new canals, tube-wells, etc., it is of utmost importance to know how best and most effectively this water can be utilised for increased crop production. To realise this objective it is necessary to know (i) when to irrigate a particular crop and (ii) how much to irrigate.

There are three approaches to this problem on when to irrigate: (i) Soil moisture approach, (ii) Plant approach and (iii) Meteorological approach, the first one is the most convenient and practical one for the guidance of the farmers.

The soil moisture approach is based on the concept of "Available moisture" in the soil which governs plant growth. Available moisture is the difference in moisture content at field capacity (F.C.) and permanent wilting percentage (P.W.P.), i.e., equal to F.C.—P.W.P. when the moisture content in the soil falls below a particular point in the available moisture range, the plant growth suffers. So it is necessary to irrigate at this particular moisture content of the soil. The moisture content of the soil can be easily measured by various devices such as by means of changes in electrical conductivity or resistance, by means of tensiometers, etc.

Review of Literature

Peters and Johnson (1960) in their experiments in open soil surface receiving natural rainfall, plastic covered surface with no water added during growing season and plastic film covered surface with irrigation in 2.5 cm. (1 in.) applications, concluded that evaporation from soil surface alone was responsible for half or more of the total moisture lost from the soil profile under a soyabean crop when the soil surface was kept moist, most of

the season and for one fourth to one half of the total moisture lost in a dry season. They emphasised that recharge of sub-soil moisture was very important for maximum crop production. Grimes and Musick (1960) in their researches on the effects of plant spacing and irrigation management showed that irrigation water management greatly influenced yield in drought years but had very little effect in the wetter year. In all years highest yields were produced from the wetter soil moisture treatments. They were of opinion that accurate soil moisture measurements were required to define this relationship of row width to use of soil moisture and resulting yield. Vasudeva (1957) stated that at Pade-gaon Research Station, old Bombay State, 9765.05 cu. m. (95 acre-in.) of water with 102 kg. (225 lb.) of nitrogen gave as good a yield as 330.2 cm. (130 in.) of water and 102 kg. (225 lb.) of nitrogen, which showed that any increase in water and/or nitrogen would lead to a wastage of both.

Review of results obtained in U.P. and Madras also showed that different crops required different amounts of water depending on their duration, physiological requirements, rainfall and the conditions under which they were grown. For wet crops like rice, the duty will be low, for dry irrigation crops the duty will be high.

In Madras the duty for rice in alluvium ranged from 68 to 81 and for black soil 51 to 60. While for canal conditions the duty worked out to only 30 or 50.

From calculations of delta figures, it was found that well irrigation was about twice as efficient as canal irrigation as the farmer exercised utmost care in economy of water.

Mahida (1957) gave an account of losses in storage lakes with different depths of water,

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losses in canals and distributaries under Decan Canal conditions. About 50 per cent of the water losses occurred till it reached the field channels. He suggested various measures of achieving economical use of water—like levelling of lands, unitising of areas, volumetric supply. He pointed out that on extensive irrigated areas under flow command of canals, water supply drawn by agriculturist is generally much in excess of the requirements of crops. The irrigator is tempted to take a bigger inch depth of water each time, as he is afraid that he may not get the next turn on the due date and wants to ensure his crops against damage, to tide over the delay in next interval of watering.

Mukhtar Singh, Gandhi and Raheja (1960) gave a critical review of the methods used to determine water requirements of crops and suggestions for planning future irrigation experiments in India. The need for evaluating water requirements based on water regime concept was emphasised and broad suggestions were made for the conduct of further irrigation experiments in India.

In the irrigation and drainage research seminar (1962) several recommendations were made like collation of scattered information on water requirements of crops in the country; to establish a suitable organisation to conduct intensive research in field of irrigation and drainage; to set up speedily research-cum-demonstration centres, experiments to find out the best method of irrigation in different areas—flat and furrow methods of irrigation for different crops, early introduction of volumetric supply of irrigation, need to develop a wet farming cropping pattern system on the lines of dry farming system in the country.

Fourth irrigation practices seminar held in Turkey (1962) where India was represented passed a number of recommendations for adoption in the participating countries. India has still to adopt those recommendations specially under Field Irrigation Research.

Water Requirements of Crops

Water requirements of crops may be defined as the quantity of water, exclusive of precipitation that is required for the crop production vary with natural factors like the soil—and rainfall conditions both vary within a

wide-range. This is illustrated in Figure 1 showing broad soil classes and iso-hytes. The gross commands of the various river-valley and the tube-well projects are also shown on the map, showing their placings with reference to soils and the rainfall.

The study of the water requirements of crops has, therefore, to be made with reference to the regions of similar soil climatic conditions. It is the policy of this Government, therefore, to establish experimental stations in the project command areas to represent the regional sets of soil climatic conditions. So far experimental stations established are four in the Tapi command area, one in the Mahi Canal area, one in the Dantawada Project area and two in the tube-well areas. Studies being conducted at these farms are principally agronomic experiments, varietal experiments and experiments to determine the optimum water requirements of crops for producing the maximum yields. Irrigation experiments with different crops consisted of combinations of the depth of watering and the frequency or the interval between two waterings, laid out on a randomised block system. The method of irrigation adopted for these experiments was the one usually followed by the farmers, *viz.*, the plots were made level and water was allowed to run at the higher end and was stopped when the lower end had received a sufficient supply.

Experimental

Optimum Water Requirements under Tube-wells

The northern portion of Gujarat State commencing from Palanpur to Ahmedabad consists of soils comprising deep alluvium brought down by the various rivers which flow through this part of the country. The ground waters in this area are very low. The area receives rainfall averaging 51 cm. (20 in.) which is all distributed and is in need of irrigation to enable raising of good crops. The existing rivers flowing in the area do not have adequate flow after the rains are over. Over 500 tube-wells, are now under use which play an important role in providing irrigation facilities in this part of Gujarat State. Most of these tube-wells draw the supplies from sub-artesian and artesian sources of water.

A few tube-wells were selected for observations on utilisation of water for important *rabi*

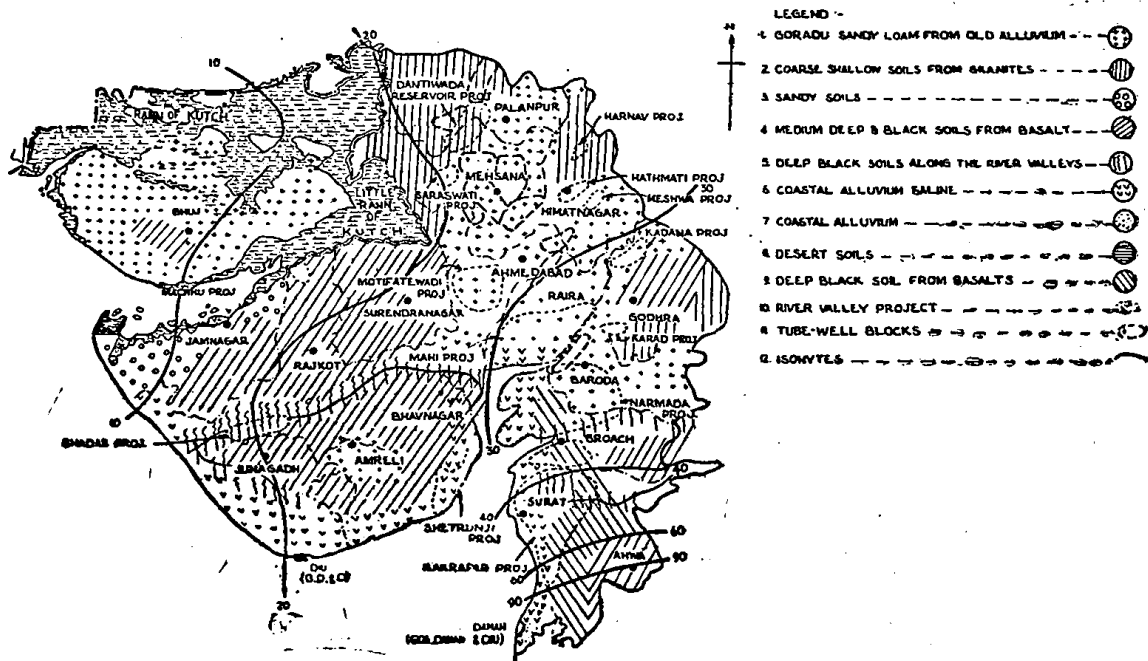


FIGURE 1 : Map of Gujarat showing soil zones and irrigation command.

and hot weather crops. The out-turns of irrigated crops obtained were recorded and compared with the yields obtained for similar crops under well irrigation. The total soluble salts in (tube-well) irrigation water ranged from 100 to 200 parts per 100,000 pH values ranged from 7.5 to 8.5. The soil profiles from observation areas were loamy resting on silty loam (sub-soils).

Conditions of tube-well irrigation gave optimum utilisation of water for crops due to following reasons :—

- (1) V notches were fixed at the distribution head for measurements.
- (2) The farmers were charged for the actual volume of irrigation water supplies, so that they took only the irrigation requirements of the crop.
- (3) The main channels were lined.
- (4) The command being small the losses in channels were negligible.
- (5) The observations recorded below were collected from fields selected just near the tube-well.

Experimental Results

Wheat and Jira (Cumin)

These are two principal crops grown in the *rabi* season under tube-well irrigation.

The irrigation data was collected from 63 observations for wheat crop—the first watering started from middle of October while the last watering continued till middle of March (Table I).

TABLE I

No. of waterings given	No. of observations	Mean irrigation in acre-in.	S. D. (Standard Deviation)	C. V.% (Coefficient of Variation)
4	8	15.27	4.81	31.49
5	23	17.36	3.81	21.94
6	22	20.43	6.22	30.44
7	10	29.38	7.47	25.42

1 acre-in. = 102.79 cu. m.

Mean irrigation in acre-inches increased with increasing number of waterings given. The relative dispersion was least when the number of waterings given was 6.5.

The equation worked out as under :—

$$y = 4.541x - 4.36$$

where y = Inch Depth.

x = No. of waterings given.

It was observed that timely sowing of wheat in middle of October required watering till middle of February which required five to six waterings. Yields ascertained from farmers showed that they varied between 1119.7 to 1492.7 kg. (30 to 40 maunds), *i.e.*, 609.6 to

812.8 kg./ha. (1200 to 1600 lb. per acre) while for late planting and late harvest which required more water the yields ranged from 362.8 to 544.3 kg. (800 to 1200 lb.). Thus the optimum water requirement for wheat crop was about 18 acre-in.

Jira (Cumin)

The irrigation data was collected from 78 observations for *Jira* crop. The first watering started from 3rd week of October and last watering in 1st week of February. The results are tabulated in Table II.

TABLE II

No. of waterings given	No. of observations	Mean irrigation in acre-inches	S.D. (Standard Deviation)	C. V.% (Coefficient of Variation)
3	7	10.29	4.575	44.46
4	48	11.45	3.974	34.71
5	15	11.45	3.789	33.09
6	8	16.97	3.395	20.00

Mean irrigation in acre-in. increased with increasing number of waterings given. The relative dispersion was least when the number of waterings given was 6.

The equation worked out as under :—

$$y = 2.38x + 1.81$$

whereas $y =$ Inch Depth

$x =$ No. of waterings given.

Regular sowing in last week of October required watering till middle of February, with 4 to 5 irrigations measuring 1175.9 cu. m. (11.45 acre-in.). The yields were 544.3 to 680.4 kg. (1200 to 1500 lb.) of *Jira* per acre. Late sowing and late harvesting required more number of waterings and irrigation depths and the yields were 362.8 to 544.3 kg. (800 to 1200 lb.). Thus 4 to 5 waterings measuring 1175.9 cu. m. (11.45 acre-in.) were the optimum requirements for a cumin crop.

Hot Weather Crops

Jowar and *Bajri* were also the crops grown by farmers during hot weather (Table III).

TABLE III

<i>Bajri</i> crop			<i>Jowar</i> crop		
No. of waterings	No. of observations	Mean irrigation in acre-in.	No. of waterings	No. of observations	Mean irrigation in acre-in.
4	4	17.89	4	6	18.96
5	4	19.01	6	6	28.73
6	4	23.72	9	6	36.88
7	4	23.88	..	..	..

1 acre-in. = 102.79 cu. m.

The first irrigation in *Bajri* commenced from 3rd week of February and ended in second week of May. The waterings for such crops ranged between 4 and 5. Late sowing in 3rd week of March and harvesting by 1st week of June required more number of waterings and high irrigation depths with lower yields of grains and *Kadbi*.

In case of *Jowar* crop, the first watering started from third week of February and last watering ended by middle of May. For late sowing the number of waterings were more with increased inch depths of irrigation. The first watering in this case was given from third week of March and continued till second week of June. This gave lower yields as compared to regular sowing.

Thus the optimum water requirements were five waterings equivalent to 1954.04 cu. m. (19.01 acre-in.) for *Bajri*—and six waterings equivalent to 2953.16 cu. m. (28.73 acre-in.) for *Jowar*.

Irrigation Experiments at Thasra (Dist. Kaira) Trial-cum-Demonstration Farm under Mahi Canal

This farm was started with an object of utilisation of maximum quantity of canal water by introduction of new crops and giving a new crop pattern in place of existing ones to the irrigators. The average rainfall for the last 3 years was 64.7 cm. (25.5 in.). July, August and 1st of September were wettest months.

The *Kharif* crops grown were paddy, hybrid, maize, virginia, tobacco, cotton and the *rabi* crops were wheat and gram.

Results of drilled paddy are given in Table IV.

TABLE IV

Paddy	No. of irrigations 1961-62	Yield of paddy in kg./acre	No. of irrigations 1962-63	Yield of paddy in kg./acre	Yield of paddy strain kg./ acre Total
(1)	(2)	(3)	(4)	(5)	(6)
Variety					
(1) Sathi 34-36	2	562	4	723 1019	1742
(2) E. K. 70	2	423	4	697 1059	1756
(3) S. K. 20	2	523	4	914 938	1852
(4) Kada 176-12	2	367	4	654 1019	1673
(5) Sathi (Local)	2	527	4	592 890	1482

During 1961-62, paddy was sown (drilled) on 27 June 1961 and harvested on 13 October 1961. Two irrigations measuring about 15.2 cm. (6 in.) were applied on 22 August 1961 and 3 October 1961. During 1962-63, paddy was drilled on 7 July 1962 and harvested on 24 October 1962. Four irrigations were applied beginning from 20 August 1962 to 3 October 1962. The results show S. K. 20 to be superior to other early varieties of paddy as it has responded to irrigation better than the rest.

Late Strains of Paddy

With a view to utilise water of the Mahi Canal during *kharif* and part of *rabi* season fine-grain high yielding variety, of paddy were tried in six randomised blocks. One seedling per hill was transplanted at a distance of 30.5 cm. x 20.3 cm. (12 in. x 8 in.). 5.08 tonnes (5 tons) of farm-yard manure with 18.1 kg. (40 lb.) of nitrogen and 9.07 kg. (20 lb.) of P₂O₅ per acre were given to the crop.

The results are given in Table V.

TABLE V

Variety	No. of irrigations 1961-62	Yield of paddy grains kg./acre	No. of irrigations 1962-63	Yield of paddy grains in kg./ acre	Average of two years
Zinya 149	6	1129	8	1509	1400
K. 42	6	1480	8	1424	1452
JirasaI 280	6	1126	8	1472	1299
S. E.	21.54				
C.D. at 5%	67.84				

Late strains of paddy have a great future in irrigation development under this canal.

Hybrid Maize

This was sown on 9 July 1962 and harvested on 13 October 1962 only one irrigation on 30 August 1962 was required. The yields are as given in Table VI.

TABLE VI

Variety	Yield kg./acre		Remarks
	40 lb. N per acre	100 lb. N per acre	
(1) Ganga	1501	2034	20 lb. phosphate and 40 lb. potash were given prior to sowing.
(2) Ranjit	1623	1969	
(3) Deccan	1622	2176	
(4) Malan White	1580	2175	
(5) Rudarpur White.	1574	2236	
(6) Indore State	1593	1983	
(7) Local variety (Farm Sameri)	1350	1558	

Hybrid maize was tried as a *rabi* crop also after harvesting paddy (Sukhvel-20) in *kharif*. Ranjit variety of maize under irrigation in the *rabi* season gave an yield of 1360 kg. of maize grain per acre. Comparison has now to be made of such a double cropping with utilisation of irrigation water.

Wheat (Table VII)

Drilled with 36.3 kg. (80 lb.) seed rate 27.2 kg. (60 lb.) of nitrogen in form of ammonium sulphate and 13 kg. (30 lb.) of P₂O₅ in form of single superphosphate.

TABLE VII

Variety	No. of irrigations	Average yield of grain of 2 years kg./acre	Wheat/Straw kg./acre
(1) Np 710	7	1093	2510
(2) Np 718	7	1171	3116
(3) Np 824	7	1409	3256
(4) Local (Chapdushi)	7	1112	2374

Results were highly significant. Np 824 gave 27 per cent higher yield than Np 718 and 33 per cent higher than local variety.

WHEAT : Np 824 (TABLE VIII)

TABLE VIII

No. of Irrigation	Irri. Depths in inches	Yield of wheat grains kg./acre
5	10	542
7	21	574
9	36	569

Results clearly showed that optimum requirements of irrigation were 2158.59 cu. m. (21 acre-in.) which produced the highest yield.

Gram After Paddy (Table IX)

Thus three irrigations at intervals of 35, 50 and 65 days after sowing with 13.6 kg. (30 lb.) of P_2O_5 /acre was the best.

Cotton (Table X)

Variety Hybrid Cotton 170-CO₂.

Spacing 0.9 m.×0.3 m. (3 ft.×1 ft.).

The mean yield was 484 kg. per acre with 15.2 kg. (6 in.) of irrigation.

Virginia Tobacco

Two improved varieties of virginia tobacco were tried under irrigated conditions as shown in Table XI.

TABLE IX

Average Yields.

Irri. interval	No. of fertilizer	15 lb. P_2O_5 /acre kg./acre	30 lb. P_2O_5 acre.	Average	Per cent increase over control
(1)	(2)	(3)	(4)	(5)	(6)
No irrigation	229	300	332	290	..
One irrigation after 20 days	330	335	386	350	20.7
One irrigation after 35 days	296	369	442	369	27.2
One irrigation after 50 days	306	355	396	352	21.3
One irrigation after 65 days	319	370	411	367	26.5
Two irrigations after 20 and 35 days	337	378	443	386	33.1
Two irrigations after 20 and 50 days	334	376	446	385	32.7
Two irrigations after 35 and 50 days	318	373	413	368	26.8
Three irrigations after 30 and 50 days	330	428	474	412	42.0
Three irrigations after 35, 50 and 65 days	371	447	520	446	53.8
Average	317	374			

TABLE X

Name of crop	Irri. inch depth	Out-turn of seed cotton kg./acre
Hybrid	6 in 1st year	476
Cotton	6 in. 2nd year	501
180-CO ₂	6 in. 3rd year	477

TABLE XI

1962-63

Variety	No. of Irrigation	Average yield of green leaves/acre in kg.	Average yield of cured leaves/acre in kg.
(1) Delcrest	3	3109	470
(2) Hicks	3	2952	488

Transplanting was done on 13 September 1962. Three irrigations were given on 16 October 1962, 14 November 1962 and last on 8 December 1962. First harvesting of leaves for curing started from 27 November 1962 and completed on 15 January 1963.

Irrigation Experiments under Kakrapara Canal System

Bardoli Trial-cum-Demonstration Farm.

Average rainfall for last three years rises 147.3 cm. (58.0 in.). July, August and some time September are the wettest months.

<i>Experiment 1</i> :	Nitrogen levels	.	2—30 lb.—60 lb. per acre
(1962-63)	wheat P_2O_5	..	2—30 lb.—60 lb. per acre
	Seedrate	.	2—60 and 80 lb. per acre.
	Irr. turns	.	3—3, 4, and 5.
	Inch depths	.	2.5 acre-in.
	Variety	.	2 Np. 710 and Np 814.

The maximum out-turns were obtained with five irrigation turns or with 1284.87 cu. m. (12.5 acre-in.) of water. A dose of 26.12 kg. (60 lb.) of nitrogen gave significantly higher results.

<i>Experiment 2</i> :	Variety	.	2087 Vejalpa.
	Cotton. Irrigation turns	.	3, 4 and 5
	Inch depths	.	2.5 acre-in.

The average results of four years showed that 770.92 cu. m. (7.5 acre-in.) of water was the best.

Kholwad Trial-cum-Demonstration Farm

<i>Experiment 1</i> :	Variety	.	N.p. 814.
	Wheat No. of irrigations	.	5, 7 and 9.
	Inch depths	.	2.5 acre-in.

The experiment was tried for 3 years. Nine irrigation turns or 2312.77 cu. m. (22.5 acre-in.) gave maximum out-turns.

<i>Experiment 2</i> :	Variety	.	Vejalpa.
	Cotton No. of Irrigations	.	3, 4 and 5.
	Inch depths	.	2.5 acre-in.

The experiment was tried for 3 years. The average results were in favour of 770.92 cu. m. (7.5 acre-in.).

Kim Trial-cum-Demonstration Farm

Average reinforce for last three years was 92.8 cm. (36.94 in.). July is the wettest month.

<i>Experiment 1</i> :	Varieties	.	Np 710 and Np 824.
	Wheat No. of Irrigations	.	3, 4 and 5.
	Inch depths	.	3 acre-in.

Five irrigation turns or 1541.8 cu. m. (15 acre-in.) gave higher out-turns. These were, however, not statistically significant.

<i>Experiment 2</i> :	Variety	.	2087 Vejalpa
	Cotton Irrigation turns	.	3, 4 and 5 at 4, 3 and 2 weeks interval.
	Inch depths	.	2.5 acre-in.

The experiment was tried for 3 years. The results showed that 1027.90 cu. m. (10 acre-in.) applied in 4 turns at intervals of 3 weeks gave maximum yields.

Vyara, Agricultural Farm

This farm mainly conducted research work on paddy and sugar-cane. The irrigation source was from Doswada Tank.

The rainfall varied from 127 to 228.6 cm. (50 to 90 in.). The season commencing from middle of June to end of September with a few showers in October. The soils were black, fairly deep and heavy (40 to 60 per cent clay). *pH* values of soils varied from 7.5 to 8.5 water requirements of plant cane [Nitrogen 45.35 to 68 kg. (100 to 150 lb.) P_2O_5 up to 45.35 kg. (100 lb.) spacing :—0.9 to 1 m. (3 to 3½ ft.)].

The results showed that with 15 days interval and 3083.7 cu. m. (30 acre-in) of water, a normal cane crop was obtained, *viz.*, 312944 kg./ha. (27.5 tons per acre). Giving irrigations at 20 days interval and increasing irrigation depths actually lowered the yields.

Amongst the different sugar-cane varieties tried, Co 807, Co 853, Co 894 and Co 419 gave promising results. January planting gave an out-turn of 41.3 tonnes (40.66 tons) of cane (Co 419 variety) per acre.

Paddy tried was 2.31, which gave an yield (3 years) average of 1259.8 kg./ha. (2480 lb. per acre).

Irrigation Experiments in Saurashtra*Junagadh-Sagdi Vidi Farm*

88.9 to 101.6 cm. (35 to 40 in.) rainfall. July, August are wettest months (Table XII).

TABLE XII

Name of crop	No. of irrigation	Yield of wheat per acre
		(Average of 3 years lb. per acre)
Np 710	5 (18 days interval)	1400
Wheat	7 (13 days interval)	1646
	9 (10 days interval)	1758
	11 (8 days interval)	1826
	13 (6 days interval)	2042
	15 (4 days interval)	1772

Results of 3 years indicated that 13 irrigations at 6 days interval under Junagadh conditions where soils were medium black gave superior results over other irrigations.

Halvad and Umralla Farms (Table XIII)

51 to 63.5 cm. (20 to 25 in.) rainfall. July is wettest month.

TABLE XIII

Yield of wheat per acre in lb.

No. of irrigation and description	Halvad Farm	Umralla Farm
	Np 710 wheat (average of 3 years)	Np 718 wheat
5 (18 days interval)	1734	1548
7 (13 days interval)	1918	1592
9 (10 days interval)	1954	1827

This experiment is now modified to include 11, 13 and 15 irrigations during 1963-64. The above results show 9 irrigations at 10 days interval to be superior to the other irrigation treatments.

TABLE XIV

No. of crops	No. of Irrigation with description	Average yield of seed cotton (lb. per acre) Average of 4 years	Remarks
Deviraj	7 (13 days interval)	588	Halvad Farm
Cotton	5 (18 days interval)	599	
	3 (30 days interval)	615	
	No irrigation	446	

Results show 3 irrigations at 30 days interval give superior results to rest of the treatments (Table XIV).

Summary

(1) Tube-well irrigation is supplied to farmers on volumetric basis.

(a) In case of wheat crop about 85 per cent of farmers took 5 to 6 irrigations measuring on an average 257 cu. m. (2.5 acre-in.) of irrigation to produce a 635 kg. (1400 lb.) wheat crop on retentive soils.

(b) In case of *Jira* (cumin) crop 90 per cent of farmers took 5 irrigations to get an optimum crop of 685.7 kg./ha. (1350 lb. per acre).

(c) In case of *Bajri* and *Jowar* as hot weather crops there was a tendency to use more water on account of spreading of sowing seasons from February to end of March.

(2) Experiments under canal conditions for the principal crops of paddy, wheat, cotton, hybrid maize for the determination of their optimum requirements are described.

(3) Experiments under medium irrigation works and lift irrigation in Saurashtra Division are also described for their optimum requirements.

Conclusions

Experiments which are yet in an initial stage, have shown indications for the determination of the optimum requirements for some of the principal crops. They need to be tried under controlled conditions so that the recommendations are passed on to the farmers and adopted by the irrigation engineers for their planning and administration of irrigation waters.

The Gujarat State irrigation potential from the major, medium and minor irrigation projects is in the neighbourhood of 1.33 million ha. (3.3 million acres). The research work on optimum irrigation requirements for principal crops and proposed pattern under wet farming has to be intensified. As this investigation is dependent on many complex conditions like soil types, climate, rainfall, agronomic practices, manure, fertilizer applications, tillage, times of sowing, plant-

ing, and so on, it can be better tackled at a couple of irrigation research stations in all its aspects.

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OPTIMUM REQUIREMENTS OF IRRIGATION FOR INDIAN POTATO VARIETIES

by

Pushkarnath and K. Swaminathan*

Potato is an irrigated *rabi* crop in the plains of India, occupying an area of about 24 lakh hectares (6 lakh acres). There is paucity of published work in India on the water requirements of this crop in marked contrast to its extensiveness and profit potential. The earliest information available on this aspect is of Singh *et al* (1935) who have worked out the relative requirements of a number of crop plants under Banaras conditions. According to them potatoes require about 2775.33 cu. m. (27 acre-in.) of irrigation water for optimum production. Dutta and Bose (1953) working under Delhi conditions have found the optimum level of irrigation for potatoes as 2158.59 cu. m. (21 acre-in.), in addition to a rainfall of 11.6 cm. (4.56 in.) during the crop season.

After the establishment of the Central Potato Research Institute in 1949, work was undertaken at the regional stations of this Institute to study this important problem. This paper embodies the results so far obtained in respect of (i) suitable intervals between irrigations, applied at a uniform rate; (ii) optimum irrigation delta required for different varieties; (iii) the water requirements under different growth phases of the plant; and

(iv) interaction between rates and manurial requirements of potato varieties. All the experiments reported herein were conducted on a sandy loam type of soil at all the locations.

Interval of Irrigation

Early work at this Institute. (Pushkarnath *et al* 1960) was restricted to the evaluation of the optimum interval between irrigations. Each dose of irrigation was applied at a standard and uniform rate in such a way that the furrows between potato rows were filled to about two-thirds of their depths [roughly 7.6 cm. (3 in.) deep] and the variable factor studied was the spacing of the intervals of irrigation. The yields of potatoes obtained under different irrigation intervals are given in Table I.

It appears from the above data that at all these centres, which are dispersed along with east-westerly direction in the Indo-gangetic plains, irrigation once every 8-9 days would be optimum, under sandy loam type of soil.

The effect of this wetting cycle on the soil moisture was followed tensiometrically at Patna only. It was observed that with irrigations spaced at 7, 10 and 14 days' intervals the minimum moisture levels in the soil

TABLE I

Yield of potatoes (kg./acre) under different irrigation intervals.

Centre	Year	Interval of irrigation			C. D. at 5% level
		6-7 days	10 days	13-14 days	
Patna	1957-58	8211	7016	6158	160
	1958-59	6047	5823	5935	NS
	1959-60	5113	4927	4628	NS
Babugarh	1958-59	9630	9256	8268	1060
	1959-60	10413	9555	7353	885
Jullundur	1958-59	5375	6457	5673	NS
	1959-60	7577	7577	6942	NS

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during these cycles were 46 per cent, 30 per cent and 25 per cent of the field capacity values respectively. It would thus appear that if tensiometers are available, irrigation should be applied as and when the soil moisture content falls below 40 per cent of the field capacity level, for optimum productivity of potatoes.

Optimum Irrigational Delta for three Indian Potato Varieties

In the second phase of work, the needs of total delta of irrigation for three Indian potato varieties were studied at the same three centres. The varieties, up-to-date, Kufri red and Kufri *Safed*, represented the three distinct maturity classes, early, medium and late respectively.

In all 10 irrigations were given to the crop at each centre. While the interval of irrigations was fixed at 8 days on the basis of the earlier findings, the rate per irrigation was varied from 3.8 to 8.9 cm. (1.5 to 3.5 in.). The irrigation water was measured by a Parshall flume, with a 15.2 cm. (6 in.) throat, fitted to the main irrigation channel. Usual precautions of saturating all the sub-channels up to the experimental plots thoroughly before letting in water into the plots, were observed to avoid seepage losses.

The yield results from the trial conducted for two years at each centre are given in Table II.

The results show that for all the three varieties 2572 cu. m. (25 acre-in.) of water is the optimum at all the three centres.

Phasic Requirements of Irrigations

The potato crop has three distinct phases in its growth. These have been set forth as follows (Pushkarnath *et al* 1962) under plain conditions in India :

	Early maturing variety (up-to-date)	Medium maturing variety (Kufri Red)	Late maturing variety (Kufri <i>Safed</i>)
(1) Germination phase .	20 days	20 days	20 days
(2) Growth phase .	50 days	60 days	60 days
(3) Tuberculosis phase .	50 days	60 days	75 days

Considering the marked variations in the maturity period of these three varieties, experiments were carried to find out if the water requirements of each one of them were different during the three phases of growth and necessitated any change in the interval of irrigation as well as the quantity of water to be supplied during different growth phases. The treatments and the yield data for one season, 1962-63 at all the three centres mentioned above are given in Table III.

TABLE II

Effect of delta of irrigation on potato yields (kg./acre).

Centre	Varieties	1960-61 Delta of irrigation acre-inches					1961-62 Delta of irrigation in acre-inches				
		15	20	25	30	35	15	20	25	30	35
Patna	Up-to-Date	6458	7260	6679	8582	7550	10122	11574	10648	11920	11271
	Kufri Red	6845	7744	6721	7163	6942	11769	10427	10427	10855	11090
	Kufri <i>Safed</i>	4481	5213	5918	4785	5684	10538	10925	9819	9321	9320
	Mean \pm 635	5928	6739	6439	6177	6725	Mean \pm 304	10939	1193	10666	10865	10560
Babugarh	Up-to-Date	13760	13600	13240	13340	13280	4476	4268	4228	4662	4200
	Kufri Red	12860	11560	10980	12460	12600	8380	7748	8260	8392	8794
	Kufri <i>Safed</i>	9420	9260	9080	1086	10680	5972	5800	5876	6060	5328
	Mean \pm 1405	12013	11473	11099	12553	12186	Mean \pm 266	6276	5939	6121	6371	6289
Jullundur	Up-to-Date	7152	7388	8230	8124	7926	5368	6744	6304	6132	6330
	Kufri Red	7496	8026	7042	8646	8478	8808	8928	9288	9524	9964
	Kufri <i>Safed</i>	8074	8508	8026	8588	8468	8440	9000	8716	9008	8900
	Mean \pm 331	7574	7974	7766	8452	8291	Mean \pm 392	7837	8037	8197	8124	8104

TABLE III

Phasic requirements of irrigation for potato varieties (yield in kg./acre).

		No. of irrigations in each phase @ 2.5 acre-in. per irrigation				
		P_1	P_2	P_3	P_4	P_5
Growth phase						
Germination and growth		3	4	5	2	5
Tuberisation		2	3	4	5	5
Maturity		2	2	2	2	2

Centre	Varieties	Yield in kg./acre					
Patna	Up-to-Date	5508	5613	5878	5693	6027	Mean±57 5744
	Kufri Red	5773	6200	6580	6349	6177	6216
	Kufri Safed	5186	5485	7042	4840	6165	6744
	Mean±203	5489	5766	6499	5628	6123	..
							Mean±
Babugarh	Up-to-Date	5536	5564	5896	5276	5264	5507
	Kufri Red	7828	8648	8088	8724	8804	8418
	Kufri Safed	6116	5728	11028	6840	6336	7209
	Mean±286	6493	6646	8336	6946	6810	..
							Mean±291
Jullundur	Up-to-Date	6146	6874	7412	6814	7264	6902
	Kufri Red	3916	3267	4846	5848	4218	4419
	Kufri Safed	2660	3410	4032	2834	2280	3013
	Mean±296	4240	4517	5430	5165	4587	..

The data show that, in general, three irrigations at the rate of 256.97 cu. m. (2.5 acre-in.) during the growth phase and four irrigations during the tuberization phase followed by two during the maturing phase are the most suitable for potatoes. This finding is in the process of confirmation by further trials.

Interaction of Irrigation Levels and Fertilizer Responses

Water is the vehicle of plant-assimilable nutrients. Irrigation, therefore, helps in greater assimilation of nutrients by plants from the soil. In earlier trials conducted at this Institute, the interactions between the frequency of irrigation and the levels of nitrogen, phosphate and potash, were studied in detail. The results made it clear that there was a significant positive correlation only in the case of nitrogen. At shorter intervals of irrigation, responses to nitrogen were significantly higher (Table IV).

TABLE IV

*Influence of interval of irrigation on response of nitrogen (kg./acre).**(Summarized data from experiments conducted at three centres for three years)*

Dose of N.	Interval of irrigation		
	6-7 days	10 days	13-14 days
None	3695	3359	2650
100 lb. N/acre	4442	3732	2837
200 lb. N/acre	4927	4927	4666

Since nitrogen is a labile element in the soil, the dissolving effects of water on nitrogenous fertilizers are foreseeable. Similarly, in the case of non-labile elements, phosphate and potash, no effect of irrigation rates or frequency should be cognizable; but in the course of experiments this was applicable to only phosphate. A separate set of experiments was carried out at Patna to study the effects of different irrigation levels along with potash

on Kufri red, a variety generally known for its non-responsiveness to potash application, and the highly responsive up-to-date. It was found that in both the varieties response to potash fell progressively with higher rate of irrigation. Potassium uptake was also affected in the same manner (Table V).

TABLE V

Response to a dose of 100th K₂O/acre under varying soil moisture regions.

Variety	Acre-inches of irrigation		
	15	25	35
	<i>Yield responses (kg./acre)</i>		
Kufri Red	+336	-187	-1493
Up-to-Date	+3285	+1792	+373
	<i>Leaf K responses (per cent)</i>		
Kufri Red	+0.64	+0.43	+0.41
Up-to-Date	+1.77	+1.29	+1.19

Similar observations have been reported by Larson (1954) with sugar beets and he attributes this trend to the low oxygen content of the wet soils.

Summary

Results of field experiments with potatoes laid out at three Regional Centres spread over Bihar, Uttar Pradesh and the Punjab relating to (i) the frequency of irrigation; (ii) optimum irrigation delta required by potato varieties; (iii) phasic irrigational requirements of potato varieties of different maturity characteristics; and (iv) interactive effects between rate of irrigation and fertili-

zer levels are reported in this paper. The conclusions arrived at are as follows:—

- (1) For potatoes on a sandy loam soil, irrigation spaced at 7 to 8 days' intervals during the entire crop season would prove highly beneficial.
- (2) The optimum total water requirements of Indian potato varieties is 2569.75 cu. m. (25 acre-in.) and this quantity should be distributed into 10 equal irrigations during the season.
- (3) Three irrigations of 256.97 cu. m. (2.5 acre-in.) each during the growth phase, four during tuberisation and two at maturity satisfy the phasic water needs of Indian potato varieties.
- (4) While responses to nitrogen are higher with a higher rate of irrigation, the converse holds true in the case of potash.

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INVESTIGATIONS ON THE IRRIGATION REQUIREMENTS OF POTATO CROP IN LATERITIC SOILS OF WEST BENGAL

by

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Introduction

The potato (*Solanum tuberosum* L) is capable of producing far more food per acre than any other food crop. The cultivation of this crop is of great importance in densely populated underdeveloped countries, since it maintains life through supply of cheap food energy. The total area under potato in India rose from 204.78 thousand ha. (506 thousand acres) in 1948-49 to 348.3 thousand ha. (885 thousand acres) in 1959-60 (Anonymous, 1961). The average yield per acre in the country is only 3.1 tonnes (83.5 maunds), although the yield of 8.3 to 10.4 tonnes/ha. (200 to 250 maunds per acre) are not uncommon with progressive potato growers. The low yield of potatoes are mainly due to inadequate knowledge about the optimum irrigation and other cultural and manurial requirements of the crop. Therefore, it is important to work out by sound experimentation, the optimum irrigation requirements of the crop for maximising its production consistent with economic returns.

The most important aspects of irrigation practices are 'when to irrigate?' and 'how much water to supply?' In the past these aspects were studied by fixing the irrigation intervals and the depths of irrigation rather arbitrarily. Advances in our knowledge of soil-water relations have led to the development of 'water regime' concept for evaluating the time of irrigation and the quantity of water to be applied on a more scientific basis. According to this concept, the crop is grown under varying water-regimes in each of which the soil is allowed to dry out to a pre-determined condition of dryness and then the entire dried mass of soil is re-wetted to field capacity. Although some work on water requirement of potato has been done in India both in pots (Singh *et al* 1935) there

is a lack of published work on the evaluation of irrigation requirement by the water-regime concept. Recently, Singh *et al* (1960) have made a critical review of the methods used to determine water requirements of crops and have emphasised the need for evaluating water requirement based on water-regime concept.

Review of Literature

The Concept of Water-Regime

The capacity of the soil moisture reservoir is limited by the field capacity (upper limit) and the permanent wilting percentage (lower limit) of the soil in the effective root zone of a crop and the moisture held by the soil in the range between these two limits is designated as the available range of moisture for plant growth (Veihmeyer and Hendrickson, 1927). Further it was pointed out by the same author that it is impossible to maintain the soil at any pre-determined moisture content lower than the field capacity which is in contrast to the earlier work based on the concept that pre-determined moisture content could be constantly maintained in the soil. This, therefore, led to the concept of water-regime which was originally used by Veihmeyer (1927) who grew fruit plants in larger containers and subjected them to different water-regimes. This was then followed by Wadleigh and Aiyers (1945) and others. Hendrickson and Veihmeyer (1942) have further shown that any attempt to wet a mass of soil to a moisture content lower than that of the field capacity by overhead watering results in the upper layers being wetted to field capacity and the lower ones remaining dry.

Relative Availability of Soil Moisture

The knowledge about the relative availability of soil moisture within the range between field capacity and permanent wilting point which is a subject of controversy, is more im-

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portant from the agronomic point of view. One view is that water is equally available over the entire available range of soil moisture (Hendrickson and Veihmeyer, 1942) and the other belief is that the soil moisture is not equally available in the available range of soil moisture and the plant growth is reduced as the moisture tension rises within the range (Adrich *et al*, 1935; Davis, 1940; Cyk-ler, 1946; Jacob *et al*, 1952).

Stanhill (1957) has reviewed eighty papers describing investigations concerning the effect of soil moisture status on crop growth. It was seen that in 66 experiments, the plant growth did respond to variations in the soil moisture regime and only 14 experiments showed no such significant response. Russel (1959) has attributed these conflicting observations, in respect of moisture available, to the variations in the nature of soil, the method of determining wilting point, crop species and the conditions of experimentations (pot culture or field trial). However, the bulk of the published data goes to show that the growth of the crops is affected before the soil moisture reaches the wilting point.

Soil Moisture and Potato Production

The effect of varying soil moisture levels on the growth and yield of potato have been studied by many workers and it has been reported that high yields and the good quantity of potatoes could be obtained with a moisture level above 50 to 70 per cent of the range between field capacity and the wilting point in the soil (Cykler, 1947; Struchtémeyer, 1961). The decrease in the growth and yield of potato with the increase in the soil moisture tensions have also been reported by Jacob *et al* (1952). Jones and Johnson (1958)

found that irrigating at 0.3 atmospheric tension gave higher yields of potatoes than irrigating at higher soil moisture tensions.

Experiments were also conducted to study the effect of irrigation on potato in relation to the stages of growth. Steineck (1958) stressed that irrigation must ensure a regular supply of water from the beginning of stolon formation to maturity of the crop. Struchte-meyer (1961) found that the shortage of soil moisture in the last half of growing season tended to reduce the yield more than the shortage during the first half of the growing season while as Jones and Johnson (1958) have observed that the plots kept moist over the entire period of growth gave the highest yields. So it shows that potato yields are reduced when the moisture is allowed to fall below 70 per cent of available water in the root zone or when the moisture tension in the top layers of soil is allowed to rise above 0.3 atmosphere.

Materials and Methods

The field experiments were carried on the lateritic sandy loam soil of the Agriculture Engineering Department Experimental Farm to find out the effect of depths of ploughing and levels of fertilizers on the yield of potato, variety Royal Kidney, at various irrigation levels. The single value physical constants of the soil under experiment are given in Table I.

The treatments included were two depths of ploughing : 12-14 cm. and 24-28 cm.; three fertilizer mixtures; 54-0-0, 36-36-18 and 54-36-18 kg. per acre of N-P-K fertilizers and three levels of irrigations :

- t_1 : 0.25—0.30 atmosphere in wet regime;
- t_2 : 0.50—0.55 atmosphere in moist regime;
- t_3 : 0.75—0.80 atmosphere in dry regime.

TABLE I

Physical constants of the successive layers of soil.

Constants	0—6 in.	6—12 in.	12—18 in.	18—24 in.
Field capacity per cent (after 72 hours of flooding)	14.74	15.60	16.04	16.80
Apparent specific gravity (gm./cc.) (undisturbed soil sample).	1.56	1.52	1.48	1.42
Particle density	2.64	..	..	..
Maximum water holding capacity (per cent).	35.91	..	..	..

1 inch=2.54 cm.

The experiment was laid out in a factorial split-plot design with three replications. Six Gallenkamp soil moisture tensiometer (Orchard model) with Bourdon vacuum gauge, were used for recording the day-to-day changes in soil moisture tensions. Irrigation water was measured in gallons by use of water meter. Before initiating the programme of differential irrigations, two common irrigations each of 5.1 cm. (2 in.) depth were applied two and four weeks after planting. The amounts of water applied at each subsequent irrigations were 3.76 cm., 5.1 cm. and 6.3 cm. (1.5 in., 2.0 in. and 2.5 in.) in wet, moist and dry regime respectively. These amounts were sufficient to fill up the deficit of moisture percentage calculated from the moisture percentages before irrigations in the 0.6 m. (2 ft.) deep root zone of the crop by the formula :

$$d = \sum_{i=1}^n \frac{M_{fci} - M_{bi}}{100} \cdot A_{si} \cdot D_i$$

where, d = depth of water applied in in.,

n = number of soil layers in the root-zone,

M_{fci} = field capacity moisture percentages in the i -th layer,

M_{bi} = moisture before irrigation in the i -th layer,

A_{si} = apparent specific gravity of the soil in i -th layer, and

D_i = depth of soil in inches of the i -th layer.

The data on the number of irrigation given along with the amount of water applied at each irrigation, following the common irrigations are given in Table II.

Thus the irrigation interval was 5-7 days in wet regime, 9-11 days in moist regime and 12-14 days in dry regime.

Soil moisture determinations were made at planting before and after each irrigation (72 hours after) and at the time of harvest. Soil samples for moisture determination, were taken from the plots where the tensiometers were installed and also from the similarity treated plots from other replications, and the determinations were made separately for the successive soil layers at 0-6 in., 6-12 in., 12-18 in. and 18-24 in. depth from ground level. Moisture was determined by gravimetric method from a known weight of soil sample taken in weighed aluminium moisture boxes and oven drying it at 105°C for 24-48 hours. The data on soil moisture was used to know the moisture status in soil at each irrigation and for determining the rate of water use, the moisture depletion pattern and the seasonal water requirement of the crop.

Observations were made on the yield of potatoes at harvest and the yield in terms of total dry matter content of tubers. The produce was graded as 'ware' (above 2 in. size) 'seed' (1-2 in. size) and 'chat' (1 in. and below).

Results and Discussions

The statistical analysis of the data in respect of the final yield of potato in aggregate and in terms of dry matter content of tubers revealed that varying levels of irrigations produced significant responses and the direction of the treatment effects and their magnitude have been given in Table III.

TABLE II

The dates and depths of irrigations at different moisture regimes.

Wet regime		Moist regime		Dry regime	
Date	Irrigation depth (acre-in.)	Date	Irrigation depth (acre-in.)	Date	Irrigation depth (acre-in.)
10-12-62	1.5	12-12-62	2.0	14-12-62	2.5
17-12-62	1.5	21-12-62	2.0	26-12-62	2.5
22-12-62	1.5	1-1-63	2.0	7-1-63	2.5
29-12-62	1.5	10-1-63	2.0	21-1-63	2.5
5-1-63	1.5	19-1-63	2.0	4-2-63	2.5
11-1-63	1.5	28-1-63	2.0		
18-1-63	1.5				
25-1-63	1.5				
1-2-63	1.5				

TABLE III

Effect of levels of irrigation on the grades of produce, 'ware' percentage and moisture percentage in tubers at harvest.

Treatment	Yield of potatoes (quintal/ha.)				'ware' per cent	Yield as dry matter in tubers (qt./ha.)	Moisture per cent in tubers on oven dry wt. basis.
	ware	seed	chat	Aggregate			
t ₁	39.08	166.87	9.14	215.09	18.17	43.40	395.6
t ₂	37.29	163.63	8.05	208.97	17.85	40.71	413.3
t ₃	32.38	140.64	7.49	180.51	17.94	34.80	418.7
S.Em.				±8.529		±1.173	
C.D. at 5%				20.894		3.42	

From the results in Table III, it is seen that frequent irrigations at low moisture tension (0.25-0.30 atmosphere) were found to increase the crop yields by 6.12 and 34.50 quintals per hectare as compared to irrigations at medium and high moisture tensions respectively. Delayed irrigations at high moisture tension (0.80 atmosphere) reduce the yield even though the moisture percentage was well above the wilting point as seen from the tensiometer reading. These results are in keeping with the finding of many workers who have studied the response of potato to varying moisture regimes (Cykler, 1947; Jacob *et al*, 1952; Jones and Johnson, 1958; and Struchtemeyer, 1961). Frequent irrigations have increased the yield of potato by increasing all grades of produce equally well. There was little difference in the yields under wet and moist regimes. The high soil moisture requirement of the potato crop may be ascribed to the shallow and restricted root-system of the crop.

Frequent irrigations also significantly increased the yield in terms of dry matter of tubers at harvest and it is interesting to note

that frequent irrigations did not result in increasing water content of the tubers (as seen from Table III) indicating thereby that the beneficial effect of frequent irrigation on the fresh weight of tubers was solely due to increased dry matter production in the tubers.

Soil Moisture Status under various Moisture-Regimes

The average moisture status before irrigation in different irrigation treatments are given in Table IV.

The data in Table IV show that the fluctuations in soil moisture were more in the top layers when compared with the changes in the deeper layers and this may be due to more moisture depletion from upper soil layers. The available moisture was more in case of wet regime as compared to other regimes even though the fluctuations in moisture percentage in deeper layers were less marked.

Rate of Water Use

The water used by the crop during each of the different intervals after irrigation and

TABLE IV

Soil moisture status under various moisture regimes.

Treatments	Average soil moisture at the time of irrigation in different soil layers				Available moisture in 0-6 in. soil layer (in per cent).
	0-6 in.	6-12 in.	12-18 in.	18-24 in.	
t ₁	13.25	15.16	16.66	17.44	85.4
t ₂	12.24	14.93	16.23	17.09	74.6
t ₃	10.85	13.96	15.45	16.49	62.0

before the next irrigation was worked out by the following formula :

$$u = \sum_{i=1}^n \frac{(M_{ai} - M_{bi})}{100} \times A_{si} \times D_i$$

Where n = Water use in in. from the root-zone

M_{ai} = Moisture percentage on oven-dry weight basis after irrigations in the i -th layer.

M_{bi} = Moisture percentage on oven-dry weight basis before next irrigation in the i -th layer.

Other symbols are as explained before.

The daily rate of water use was computed from the water during a given interval from the root zone up to 0.6 m. (2 ft.) soil depth, by dividing with the number of days in the interval.

The average rates of water use per day for the entire crop season were 2.73, 2.56 and 2.56 mm. in the case t_1 , t_2 and t_3 treatments respectively. It may however be noted that the maximum rates were 4.98, 4.19 and 3.25 mm. per day in t_1 , t_2 and t_3 water regimes respectively. The consumptive use of water could not be calculated for want of pan evaporation data since it could not be arranged in time.

Moisture Depletion Pattern

From a study of the absolute and the relative rate of moisture depletion from different

soil depths under various irrigation treatments calculated over all the intervals of irrigations after 32 days of crop growth from which it is seen that the surface 0.3 m. (12 in.) of soil accounted for 60-70 per cent of moisture depleted, of which nearly two-third was from the surface 15.2 cm. (6 in.) soil-layer. This is due to the fact that besides transpirational losses, the evaporation losses from the surface layers are considerable. Moisture depletion decreased with the soil depth. Similar results have been reported by Bowen (1936).

Seasonal Water Requirements

The seasonal water requirements were determined with following formula :

$$U = I + R + \sum_{i=1}^n \frac{M_{bi} - M_{ei}}{100} \times A_{si} \times D_i$$

Where U = Seasonal water requirement

I = Total water applied through irrigation

R = Seasonal effective rainfall.

M_{bi} = Moisture percentage before the season in i -th layer.

M_{ei} = Moisture percentage at the end of season in i -th layer.

A_{si} and D_i as explained before.

The values of seasonal water requirements are given in Table V.

TABLE V

Seasonal water requirements under various moisture regimes.

Treatment	Stored moisture used from 2 ft. soil depth (in.)	Effective Rainfall* (in.)	Water applied through irrigation	Seasonal water requirement (in.)
t_1	0.30	..	17.50 (thru. 11 irrigation)	17.80
t_2	0.26	..	16.00 (thru. 8 irrigation)	16.26
t_3	0.16	..	16.50 (thru. 7 irrigation)	16.66

*There was no rainfall during the crop season.

‡ foot=0.3048 m, † inch=2.54 cm.

The data in Table V indicate that the seasonal water requirements were the highest in the case of crop which was irrigated most frequently. There was practically no difference in the seasonal water requirements in the moist and dry moisture regimes yet there was significant difference between the yield under the moist and dry regimes. This is because the crop growth suffered when the irrigations were delayed and the moisture status in root-zone of the crop was allowed to fall down.

Summary and Conclusions

(1) Irrigations at the lowest tension increased the yield of potatoes at harvest by 6.12 and 34.50 quintals/ha. as compared to irrigations at medium and high moisture tensions respectively.

(2) Frequent irrigations have increased the yield of potato by increasing all the grades of produce equally well.

(3) There was little difference in the yields under wet and moist regimes.

(4) The yield in terms of dry matter of tubers was significantly affected by frequent irrigation and it was interesting to note that under same treatment, it did not result in increased water content of tubers but it was due to increased dry matter production in tubers.

(5) The average rate of water use per day for the entire crop season were 2.73, 2.36 and 2.56 mm. under wet, moist and dry moisture regimes respectively.

(6) Surface 0.3 m. (12 in.) of soil accounted for 60-70 per cent of the moisture depleted of which nearly two-third was from surface 0.15 m. (6 in.) soil layer.

(7) Seasonal water requirement was highest in case of crop which was irrigated frequently. There was no difference in seasonal water requirement under moist and dry mois-

ture regimes yet there was significant difference in the yield because the crop growth suffered due to delayed irrigation in later case.

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THE RAINFALL FACTOR IN IRRIGATION PLANNING IN INDIA

by

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Introduction

The objective of irrigation is to supplement the rainfall, if and when necessary, to satisfy the water needs of crops. Therefore, a study of the pattern of rainfall should be a prerequisite for any irrigation planning. The main features of rainfall of a particular area having a direct bearing on irrigational requirements are the amount, the distribution in time, lengths of periods with specified amounts of rainfall and the dependability in terms of the variation from year to year, over a long period. In the present paper, rainfall has been examined with special reference to the above aspects.

Rainfall Regions of India

The variations in the amount of rainfall in different parts of a large country like India is obviously very great. For assessing the rainfall over any area, recourse has to be made to rainfall measurements made at selected stations in the area under consideration. Fortunately, with a network of about 5,000 rainfall measuring stations over the plains of India, the position in this respect is not too unsatisfactory. For the purpose of publications of the India Meteorological Department, our country has been divided into 31 Rainfall Sub-Divisions. Although a compromise with the political divisions for reasons of administrative convenience, these sub-divisions are fairly homogeneous areas in respect of rainfall.

The monthly and annual normal rainfall for each of the Meteorological Sub-Divisions are given in Table I. The seasonal distribution of the rainfall is given in Table II. The seasons given in Table II are as in use at present by the India Meteorological Department. The seasonal distribution of rainfall is also shown in Figure 1.

On the basis of the normal rainfall (Table I), India can be conveniently divided into the following broad regions:—

- (A) Normal annual rainfall more than 2000 mm.
- (B) Normal annual rainfall 1200 to 1600 mm.
- (C) Normal annual rainfall 900 to 1100 mm.
- (D) Normal annual rainfall less than 800 mm.

On the above basis the Meteorological Sub-Divisions coming under each class will be as follows:

Region A : Bay Islands, Assam, Sub-Himalayan, West Bengal, Konkan, Coastal Mysore and Kerala.

Region B : Gangetic West Bengal, Orissa, Bihar Plateau, Bihar Plains, Madhya Pradesh (East), Interior Mysore South and Arabian Sea Islands.

Region C : Uttar Pradesh East and West, Jammu and Kashmir, Gujarat region, Madhya Pradesh (West), Madhya Maharashtra, Vidarbha, Coastal Andhra Pradesh, Madras and Telangana.

Region D : Punjab (I), Rajasthan East and West, Saurashtra and Kutch, Marathwada, Interior Mysore North and Rayalaseema.

On the basis of the seasonal distribution of the rainfall (Table II and Figure 1) the above four regions can be further sub-divided into smaller groups with more or less the same rainfall pattern. Such a grouping of the Meteorological Sub-Divisions has been attempted in Table III. Jammu and Kashmir has not been included in Table III as this sub-division stands in a class by itself with the distribution of rainfall over the year as a whole being much more even than in any

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other part of India. The information contained in Table III may be of help in the estimation, in a general way, of irrigational requirements of the different parts of India.

However, the lengths of periods with specified amounts of rainfall are also rather important as this determines the effective crop season. The length of periods with specified values of monthly rainfall for the different Meteorological Sub-Divisions are given in Table IV.

The values given in Table IV in conjunction with the knowledge of the water needs of the different crops and varieties, can provide a scientific basis for determining the irrigational needs of the different areas and for different crop seasons.

Variability of Rainfall

Two aspects of the variability of rainfall from year to year, of vital importance to agriculture, are variability in space (*i.e.*, from place to place) and variability in time (*i.e.*, daily, weekly, monthly, seasonal and annual total rainfall). These aspects were examined with reference to the Dharwar Region to illustrate one of the techniques that may be used for the study of rainfall in relation to irrigation planning. Dharwar area was selected as four important Indian crops (*viz.*, paddy, wheat, *jowar* and cotton) are commonly grown in this area and the area is also served by a good network of rain-gauge stations.

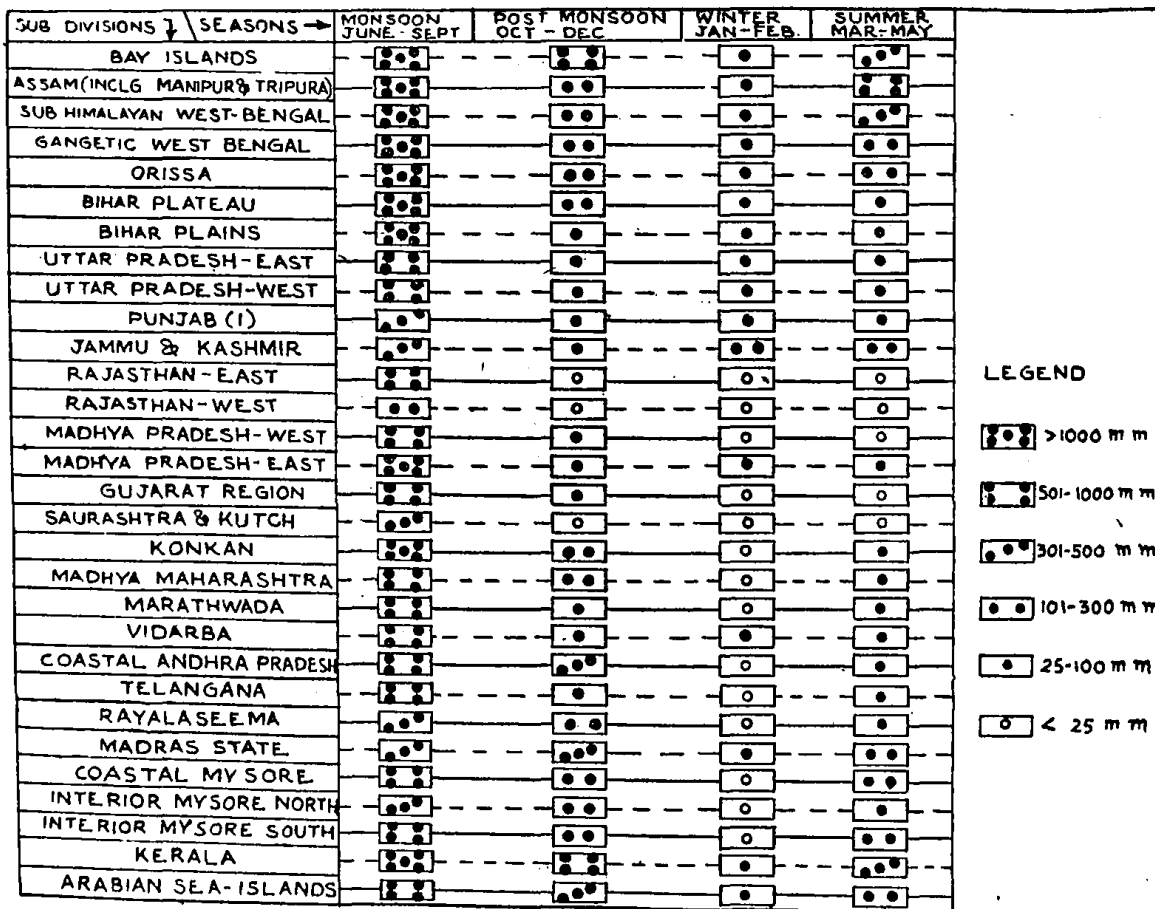


FIGURE 1.

TABLE I
Monthly and annual rainfall normals (mm.).

Meteorological Sub-Division	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Bay Islands	48.3	33.0	30.2	67.8	349.5	527.3	378.7	402.1	468.4	286.0	231.7	171.5	2994.5
Assam (Including Manipur & Tripura)	18.4	38.4	81.5	212.6	337.6	484.3	446.8	395.9	317.1	144.1	30.8	8.9	2516.4
Sub-Himalayan West Bengal	9.9	20.4	35.6	118.2	329.1	675.0	683.3	574.5	503.6	157.7	14.8	4.1	3126.2
Gangetic West Bengal	13.1	25.8	27.1	42.6	108.0	241.2	318.0	318.7	206.6	109.4	21.7	3.1	1435.3
Orissa	14.0	25.9	21.4	35.3	70.8	213.2	351.6	335.6	236.5	131.6	39.9	6.4	1482.2
Bihar Plateau	21.2	31.4	19.8	19.1	50.8	196.2	357.8	354.0	218.1	83.4	15.7	4.5	1372.0
Bihar Plains	14.4	19.6	10.6	15.7	48.0	172.4	311.4	314.0	225.1	59.4	8.8	3.5	1202.9
Uttar Pradesh East	15.8	18.9	8.7	6.8	14.9	100.5	301.6	295.8	191.2	41.6	5.9	6.0	1007.7
Uttar Pradesh West	23.9	25.3	13.7	8.6	14.7	94.1	288.7	287.9	168.1	25.6	3.9	9.7	964.2
Punjab (I) including Delhi	27.1	26.4	20.9	12.0	12.3	47.8	179.1	171.6	101.0	11.2	2.8	12.5	624.7
Jammu and Kashmir	95.7	96.0	108.3	77.6	52.0	55.2	167.1	174.5	75.5	226.1	15.2	51.4	994.6
Rajasthan East	9.0	6.0	4.7	3.2	8.5	68.3	242.8	228.5	112.0	12.2	4.3	4.6	704.1
Rajasthan West	5.4	5.9	4.0	3.1	7.7	28.6	98.5	109.9	40.4	4.3	0.8	2.5	311.1
Madhya Pradesh West	13.5	9.7	7.5	4.4	9.4	126.5	350.0	294.6	176.2	29.5	16.8	6.9	1045.0
Madhya Pradesh East	18.4	26.0	16.9	15.9	16.8	188.8	429.3	394.9	215.5	58.5	15.2	5.5	1401.7
Gujarat Region	2.4	2.0	1.4	2.5	6.7	129.9	399.8	241.5	158.4	23.0	7.6	1.3	976.5
Saurashtra and Kutch	1.7	2.4	1.3	2.9	6.4	73.6	205.9	104.2	65.9	12.9	3.9	1.5	482.6
Konkan	2.8	0.8	1.5	5.7	28.9	616.9	1076.1	630.0	373.4	103.3	29.1	3.5	2872.0
Madhya Maharashtra	5.0	1.8	3.4	11.0	24.0	148.3	281.3	178.6	161.4	68.4	31.4	6.1	920.7
Marathwada	5.8	5.9	7.2	8.3	15.9	138.2	170.5	140.1	196.0	48.4	29.1	8.2	773.6
Vidarbha	12.4	18.7	11.3	11.1	12.3	174.8	343.2	257.9	180.8	48.3	21.3	7.5	1099.6
Coastal Andhra Pradesh	10.1	13.6	12.3	24.8	51.0	103.6	152.5	148.4	165.8	188.6	116.5	21.1	1008.3
Telangana	5.1	15.0	12.4	21.9	22.0	133.4	240.5	189.7	192.9	64.4	24.6	4.0	926.5
Rayalaseema	9.2	5.8	7.1	19.7	50.1	58.2	80.8	95.8	134.0	112.3	83.1	21.7	677.8
Madras	37.0	16.4	22.9	51.0	73.2	61.5	68.6	95.8	106.4	192.8	195.9	86.6	1008.1
Coastal Mysore	2.9	1.7	5.4	30.4	108.7	843.6	1100.1	633.9	284.3	175.1	66.2	12.5	3264.8
Interior Mysore North	2.9	3.1	6.6	27.7	51.2	88.1	127.3	97.7	127.5	95.1	38.7	9.1	675.0
Interior Mysore South	4.7	5.3	10.6	49.4	103.0	177.0	311.1	208.8	144.6	150.3	66.6	13.5	1244.9
Kerala	18.8	19.6	46.1	114.9	245.1	667.5	678.4	417.2	240.0	306.2	190.7	51.6	2996.1
Arabian Sea Islands	31.9	12.1	12.5	38.3	152.4	344.9	275.1	213.3	153.9	160.1	114.5	63.4	1572.4

TABLE II

Meteorological Sub-Division	Winter (January and February)		Summer (March to May)		Monsoon (June to September)		Post-Monsoon (October to December)		
	Rainfall (mm.)	Rainfall expressed as per cent annual	Rainfall (mm.)	Rainfall expressed as per cent annual	Rainfall (mm.)	Rainfall expressed as per cent annual	Rainfall (mm.)	Rainfall expressed as per cent annual	
1	2	3	4	5	6	7	8	9	
Bay Islands		81.3	2.7	447.5	14.9	1776.5	59.3	689.2	23.0
Assam (including Manipur and Tripura)		56.8	2.3	631.7	25.1	1644.1	65.3	183.8	7.3
Sub-Himalayan West Bengal		30.3	1.0	482.9	15.4	2436.4	77.9	176.6	5.6
Gangetic West Bengal		38.9	2.7	177.7	12.4	1084.5	75.6	134.2	9.3
Orissa		59.9	2.7	127.5	8.6	1136.9	76.7	177.9	12.0
Bihar Plateau		52.6	3.8	89.7	6.5	1126.1	82.1	103.6	7.6
Bihar Plains		34.0	2.8	74.3	6.2	1022.9	85.0	71.7	6.0
Uttar Pradesh East		34.7	3.4	30.4	3.0	889.1	88.2	53.5	5.3
Uttar Pradesh West		49.2	5.1	37.0	3.8	838.8	87.0	39.2	4.1
Punjab (I) including Delhi		53.5	8.6	45.2	7.2	499.5	80.0	26.5	4.2
Jammu and Kashmir		191.7	19.3	237.9	23.9	472.3	47.5	92.7	9.3
Rajasthan East		15.0	2.1	16.4	2.3	651.6	92.5	21.1	3.0
Rajasthan West		11.3	3.6	14.8	4.8	277.4	89.2	7.6	2.4
Madhya Pradesh West		23.2	2.2	21.3	2.0	947.3	90.7	53.2	5.1
Madhya Pradesh East		44.4	3.2	49.6	3.5	1228.5	87.6	79.2	5.7
Gujarat Region		4.4	0.5	10.6	1.1	929.6	95.2	31.9	3.3
Saurashtra and Kutch		4.1	0.8	10.6	2.2	449.6	93.2	18.3	3.8
Konkan		3.6	0.0	36.1	1.3	2696.4	93.9	135.9	4.7

TABLE II—(Contd.)

1	2	3	4	5	6	7	8	9
Madhya Maharashtra	6.8	0.7	38.4	4.2	769.6	83.6	105.9	11.5
Marathwada	11.7	1.5	31.4	4.1	644.8	83.4	85.7	11.1
Vidarbha	31.1	2.8	34.7	3.2	956.7	87.0	77.1	7.0
Coastal Andhra Pradesh	23.7	2.4	88.1	8.7	570.3	56.6	326.2	32.4
Telangana	20.1	2.2	56.9	6.1	756.5	81.7	93.0	10.0
Rayalaseema	15.0	2.2	76.9	11.3	368.8	54.4	217.1	32.0
Madras	53.4	5.5	147.1	14.6	332.3	33.0	475.3	47.1
Coastal Mysore	4.6	0.0	144.5	4.4	2861.9	87.7	253.8	7.8
Interior Mysore North	6.0	0.9	85.5	12.7	440.6	65.3	142.9	21.2
Interior Mysore South	10.0	0.8	163.0	13.1	841.5	67.6	230.4	18.5
Kerala	38.4	1.3	406.1	13.6	2003.1	66.9	548.5	18.3
Arabian Sea Islands	44.0	2.8	203.2	12.9	987.2	62.8	338.0	21.5

TABLE III

Homologous rainfall regions.

Region	Sub-region	Meteorological sub-divisions in the sub-region
A	(i)	Bay Islands and Kerala
	(ii)	Konkan and Coastal Mysore
	(iii)	Assam and Sub-Himalayan West Bengal
B	(i)	Bihar Plateau, Bihar Plains and Madhya Pradesh (East)
	(ii)	Gangetic West Bengal and Orissa
	(iii)	Interior Mysore South and Arabian Sea Islands.
C	(i)	Uttar Pradesh East, Uttar Pradesh West and Vidarbha.
	(ii)	Gujarat Region, Madhya Pradesh West.
	(iii)	Madhya Maharashtra, Coastal Andhra Pradesh, Telangana, Madras.
D	(i)	Rajasthan East, Rajasthan West, Saurashtra and Kutch.
	(ii)	Marathwada, Interior Mysore North-Rayalaseema.
	(iii)	Punjab (I).

TABLE IV

Duration of wet season.

Meteorological Sub-Division	Length of period in months with normal monthly rainfall greater than			
	25 mm.	50 mm.	100 mm.	200 mm.
Bay Islands	12	9	8	7
Assam (including Manipur and Tripura)	10	8	7	6
Sub-Himalayan West Bengal	8	7	7	5
Gangetic West Bengal	9	6	6	4

	1	2	3	4
Orissa	10	6	5	4
Bihar Plateau	6	6	4	3
	1*			
Bihar Plains	6	5	4	3
Uttar Pradesh East	5	4	4	2
Uttar Pradesh West	5	4	3	2
Punjab (I)	4	3	3	0
	2*			
Jammu and Kashmir	11	10	2	0
Rajasthan East	4	2	3	2
Rajasthan West	4	2	1	0
Madhya Pradesh West	5	4	4	2
Madhya Pradesh East	5	5	4	3
	1*			
Gujarat Region	4	4	4	2
Saurashtra and Kutch	4	4	2	1
Konkan	7	5	5	4
Madhya Maharashtra	6	5	4	1
Marathwada	6	4	4	0
Vidarbha	5	4	4	2
Coastal Andhra Pradesh	7	7	6	0
Telangana	5	5	4	1
Rayalaseema	7	7	2	0
Madras State	10	9	3	0
Coastal Mysore	8	7	6	4
Interior Mysore North	8	6	3	0
Interior Mysore South	8	7	6	2
Kerala	10	9	8	6
Arabian Sea Islands	10	8	7	3

*Winter rain (not in continuity with main rainy season).

(i) Station to Station Differences in the Variability (year to year) of Rainfall

The month of July, being the most homogeneous period was selected for this purpose. The total rainfall during the month of July for the fifty years 1901 to 1950 were examined for four stations, viz., Dharwar, Hubli, Kalghatgi and Halyal situated close to one another. The average July rainfall and the

coefficients of variability for each of the five stations along with their geographical coordinates are given in Table V.

It will be seen from Table V that although there is a systematic increase in rainfall westwards (because of increase of altitude), the coefficient of variability can be considered to be more or less the same for each of the stations. Therefore, for the study of the year to year variability of rainfall for the month of July in respect of Dharwar region, for all practical purposes, it is hardly worthwhile to work out the variability on individual station-basis, but can be worked out on the basis of the total rainfall over a larger area. This aspect of the rainfall variability was next examined.

(ii) *Differences in the Year to Year Variability of Total Rainfall over Areas of Different Sizes*

For this purpose, yearly rainfall for the month of July for 50 years (1901-1950) over three areas of different sizes, around Dharwar was computed. The coefficient of variabilities (year to year) in respect of each of these three areas as well as for Dharwar Station singly were then worked out. The sizes of the areas, number of rain-gauge stations involved, average rainfall and the coefficients of variability of the rainfall in respect of Dharwar Station and each of the three areas are given in Table VI.

Table VI shows that the average rainfall increases with the size of the area. This is because the larger the area the greater is windward area of the western *ghats* (with very heavy rainfall) which gets included. Nevertheless, the coefficients of variability do not show any great difference with the increase in the area beyond 600 km. sq. It would appear, therefore, that for the study of rainfall variabilities, it may be possible to work on the basis of average rainfall over a large area. Thus, the Meteorological Sub-Divisions seem to be not too in appropriate space units for this purpose. The year to year variabilities in rainfall over the Meteorological Sub-Divisions as units were next examined.

(iii) *Year to Year Variability in the Rainfall over Meteorological Sub-Divisions*

Parthasarathy (1958) has studied the variability of rainfall in the Meteorological Sub-Divisions for the south-west monsoon season

(June to September) as a whole as well as for each of the constituent months, based on data for 70 years (1875-1944). Based on the coefficients of variability obtained by Parthasarathy, the limits (lowest and highest) of rainfall, over a long period, in the different areas of India, for each of the four monsoon months, June to September, have been worked out and are given in Table VII:

Table VII shows what amount of rainfall can be expected, with some confidence, in each of the monsoon months, *viz.*, June, July, August and September, in the different parts of India. These figures along with information about the water needs of crops, should greatly help in the determination of the magnitude of the irrigational requirements.

(iv) *Year to Year Variability of Rainfall in Relation to the Total Period for which Rainfall is taken into Account*

It is obvious that the longer the time interval under consideration, smaller will be the year to year variability of rainfall. Thus, the variability of monthly rain will be less than that for a season (a few months) which in turn will be less than the variability of the yearly rainfall. Indian Meteorologists so far have considered, mostly, monthly values only of rainfall. However, it is now realised that, for agricultural purposes, the month is too long a time interval and that distribution of the rainfall within a single month is at least as important as the total rain received during the month as a whole, *e.g.*, in respect of its effect on crops, a rainfall of 50 mm. in one week with no rain during the other weeks of the month is very different from a rainfall of the same amount (50 mm.) spread uniformly over the different weeks of the month. It, therefore, becomes necessary to ascertain what should be the period for which rainfall should be taken into consideration for purposes of agriculture. One way of doing this would be to find out the variability from year to year, with rainfall during different lengths of period. This was done in the case of Dharwar.

The period selected was 2 July to 2 September, as at Dharwar, during this part of the year, rainfall is fairly homogeneous. The different time intervals considered were 1 day, 7 days, 32 days and 63 days. The procedure adopted for working out the coefficients of variability of the daily, weekly, monthly (32

days) and bi-monthly (63 days) rainfall was as follows.

The rainfall for each calendar date from 2 July to 2 September over a period of fifty years (1901-1950) was listed and the coefficient of variability for each date was computed giving 63 values of coefficient of variability, one for each calendar date. The average of these 63 values was taken to represent to coefficient of variability of the daily rainfall. In the same way coefficient of variabilities for weekly rainfall (average of 9 values, one for each week), monthly rainfall (average of two values, one for each month) and bi-monthly

rainfall (a single value for the whole period from 2 July to 2 September) were worked out. These values are plotted in Figure 2. It will be seen from Figure 2 that the coefficient of variability shows a hyperbolic relation with the length of the period for which the rainfall is taken into account. It will be also seen that the inflection of the curves comes at about 14 days. Therefore, in the Dharwar area, during the south-west monsoon season, a fortnight should be a suitable period for considerations of rainfall variability. Any period shorter than a fortnight will be difficult to handle while a period longer than a fortnight will rather minimise the variability.

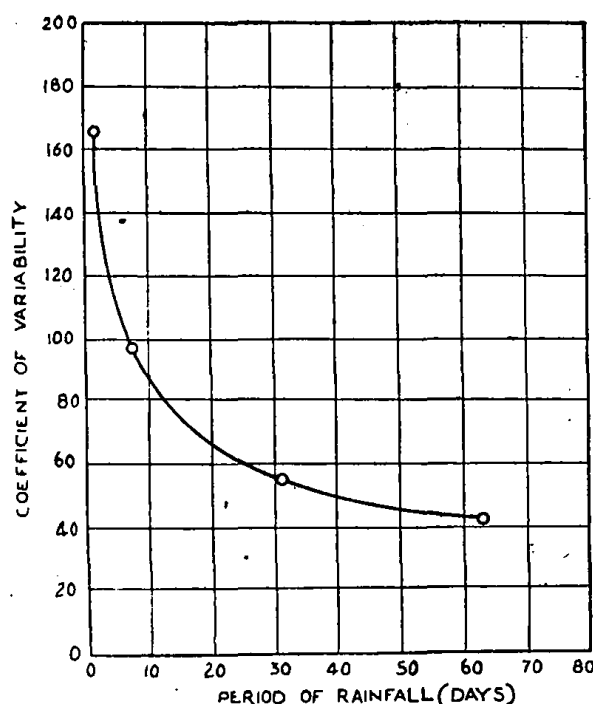


FIGURE 2.

TABLE V

July rainfall.

Station	Latitude	Longitude	Average rainfall of July (1901-1950) mm.	Coefficient of variability
Hubli	15° 20'	75° 08'	113	45
Dharwar	15° 27'	75° 00'	174	41
Kalghatgi	15° 11'	74° 58'	233	37
Halyal	15° 20'	74° 45'	397	40

TABLE VI

Variability of rainfall on area-basis.

Total area	Number of rainfall measuring stations in the area	Rainfall during July	
		Average amount (mm.)	Co-efficient of variability
Point value (Dharwar)	1	174.0	45
600 sq. km.	4	225.9	37
4000 sq. km.	7	288.1	37
12000 sq. km.	18	302.0	32

TABLE VII
Limits of rainfall.

Meteorological Sub-Division	In 80 out of 100 years rainfall is not likely to be							
	Less than June (mm.)	More than (mm.)	Less than July (mm.)	More than (mm.)	Less than August (mm.)	More than (mm.)	Less than September (mm.)	More than (mm.)
Assam	408	599	379	545	340	490	247	404
Bengal	272	444	317	455	286	438	208	333
Orissa	117	326	248	441	242	420	161	307
Chotanagpur	102	283	271	461	277	443	138	268
Bihar	104	268	237	412	231	394	139	316
Uttar Pradesh East	47	185	199	404	196	381	74	261
Uttar Pradesh West	40	174	208	386	175	380	41	258
Punjab East	13	88	95	227	81	243	7	150
Rajasthan West	3	56	36	138	24	176	0	90
Rajasthan East	29	126	141	313	107	322	23	212
Madhya Bharat West	56	192	214	416	173	376	73	259
Madhya Bharat East	33	210	222	494	212	460	43	304
Berar	90	226	165	336	99	264	75	245
Madhya Pradesh West	91	241	279	496	230	428	89	307
Madhya Pradesh East	118	326	285	579	287	478	128	300
Gujarat	51	217	176	489	82	317	34	229
Konkan	472	877	748	1330	405	861	165	482
Bombay (Deccan)	93	185	153	285	94	205	90	205
Hyderabad North	106	220	200	334	119	285	90	271
Hyderabad South	72	156	118	234	87	208	94	234
Mysore	86	153	122	240	85	186	68	187
Malabar	424	770	445	863	257	584	109	317
Tamilnāḍ	29	61	25	90	51	136	69	150
Rayalaseema	36	85	37	116	35	154	74	194
Andhra Desa	62	145	107	185	104	189	113	215

It may be added that the above findings are applicable only to the Dharwar area, for the period July and August.

Conclusions

It is now well-known that the water-soil plant relationships have to be taken into account for the planning of irrigation on a scientific basis. Before plants are made for the construction of any irrigation project and for the storage and use of water, information must be developed concerning the consumptive use of water either by direct measurements or from equations based upon weather data. Once an estimate of the consumptive use becomes available, it would be possible to decide upon the portion that is to be furnished by irrigation, after a close study of the rainfall pattern of the area concerned,

The object of this paper has been to illustrate techniques which can be gainfully applied for the study of the various aspects of rainfall. In each individual case, it will be necessary to obtain quantitative values of the kind described in this paper for obtaining reliable estimates about the different aspects of rainfall which can be expected with some degree of confidence.

Acknowledgements

The author is thankful to the officers of the Hydrology Section at Poona of the India Meteorological Department, for the help received in the preparation of this paper.

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PRE-IRRIGATION SOIL SURVEY

by

S. P. Raychaudhuri*

Soil surveys afford information about the general features of the area and properties of different types of soil not only up to plough depth but of the sub-soil to a reasonable depth. A consideration of variations of such soil characteristics as texture, soluble salt content, *pH*, *etc.*, seems essential for determining conditions for a rational utilisation of irrigation water and, if need be, for reclaiming deteriorated soil areas. It is needless to mention that without the basic information about soil of any area, as is made available from the soil survey, the work on essential development of land is hampered to a great extent. In carrying out these soil surveys, field notes with respect to such features as geology, parent rock materials, soil colour, depth of soil crust, natural flora, *etc.*, are recorded on standard form by the field survey parties. Soil sampling is done mainly by augers and at time from pits whichever is convenient. Soil samples are collected at each foot depth along the profile, except for the top foot where they are collected at each 15.2 cm. (6 in.) depth, up to a total depth of 2.4 to 3.0 m. (8 to 10 ft.) or to water-table or hard strata whichever is nearer from the surface. All changes of soil strata while sampling are noted. The soil samples are analysed for their total soluble salt content and *pH*. Representative samples are, in addition, tested for mechanical analysis and contents of exchangeable bases, calcium carbonate, manurial constituents, *etc.* The soils are categorised with respect to their salient physical and chemical characteristics for the soil survey report. A study of the agri-irrigational potentialities of soils, predominant in the area, is very essential. Apart from bringing out certain portions of the commanded area requiring special attention, *e.g.*, water-logged, deteriorated land needing reclamation, *etc.*, the soil survey helps in framing a phased development on the basis of intensity of irrigation, localisation, land ac-

quisition, *etc.*, of the command and determining such areas as could be eliminated from the command for various reasons with advantage. It may be possible to prepare command maps of cultivable commanded areas demarcating zones fit for different irrigation intensities based on engineering considerations and of soil types. These plans help in the preparation of the alignment of major and minor tributaries. Such soil survey, by indicating the condition of soil at the commencement of the irrigation project, also serves as the basis for assessment in future of any damage or amelioration of land as the result of irrigation and cropping.

The irrigation soil surveys are either pre-irrigation or post-irrigation. The purposes of the pre-irrigation soil survey are (a) allocation of areas fit for cultivation as soon as water becomes available, (b) identification of lands which can be reclaimed and determination of the amount of water required for reclamation, and (c) determination of the prospects of rise in water-table and water-logging. The objects of post-irrigation soil survey, on the other hand, are (a) to locate the areas that have already deteriorated or are in the process of deterioration, (b) to formulate methods for the reclamation of deteriorated areas, and the saving of those which are likely to deteriorate, and (c) to determine the type of drainage required for reclamation or prevention of deterioration. For such surveys, the surface and sub-soil samples are analysed for their mechanical constituents, *i.e.*, clay and slit, soluble salts and exchangeable bases. The soils are often examined to a depth of about 0.9 m. (3 ft.) or more but the morphological characteristics of the soil profile are not always taken into consideration.

The pre-irrigation soil survey can be divided into two categories (Ref: Hoon and Raychaudhuri; 1961) :

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- (i) Pre-irrigation soil survey involving large areas under command where the information regarding the suitability of soils for irrigation has to be obtained comparatively quickly with limited resources (reconnaissance soil survey). Such survey is helpful for broad crop planning. Such pre-irrigation soil survey should be done on grid basis. A general reconnaissance of the area before the soil survey is taken up, should be carried out to obtain first hand information on such aspects of soil in the area as variations both along the depth and over the area, topography, surface and sub-surface drainage and the sequence in intensity of cropping, mode of existing irrigation, if any, and quality of water so used. In fixing the size of the grid, help has to be taken from the above mentioned reconnaissance survey—but a very important factor which has to be taken into account is the time at our disposal to carry out the survey including testing of the soil samples and writing up the report.
- (ii) Comparatively smaller areas where intensive cultivation is projected it may be helpful to obtain more detailed information about the variations of soil. Such survey is helpful for detailed crop planning.
- (i) Mechanical analysis by hydrometer method or International Pipette method.
- (ii) Exchangeable calcium, magnesium (when necessary); total base exchange capacity.
- (iii) Total calcium oxide (as CaO) phosphate (as P_2O_5), sesquioxide (as P_2O_5), iron oxide (as Fe_2O_3) and aluminium oxide (as Al_2O_3 by difference).
- (iv) Available nutrients.

If as the result of the broad based soil survey, certain parts of the area are indicated to have high soluble salt content and/or pH signifying deteriorated land, such portions are generally re-surveyed at a relatively more intensive rate than before to confirm and to pinpoint areas which would have to be taken up for reclamation or which would need special attention during the post-project period.

(ii) Where detailed soil survey is necessary for limited areas the mapping scale should be at least 10.2 cm.=1.6 km. (4 in.=1 mile). The techniques of soil sampling may be as has been mentioned earlier in the case of broad based soil survey taking into account the facilities that are available.

Suggested Grouping of Soils regarding their Suitability for Irrigation

From the point of view of irrigation, a broadbased mapping may be sufficient to indicate areas which would respond suitably to irrigation and such areas which are in deteriorated state and would require extra irrigation water for their reclamation. Therefore, a general classification of the soil on the basis of the texture, total soluble salt content, pH , $CaCO_3$ content, *etc.*, might be enough. For agricultural development of the area its further classification in terms of irrigability groups may be made (Ref: Raychaudhuri and Datta Biswas, 1954).

Group I (Colour Green)

Soil quite suitable for irrigation having good available moisture holding capacity (more than $1\frac{1}{2}$ in. per foot of soil); low water-table; soluble salts (much less than 0.2 per cent) or exchangeable sodium is in negligible amounts, there is no pan formation in the horizon; salinity of sub-soil water is negligible, and internal permeability is good.

Procedure

(i) For the first category of survey which is carried out on grid basis, in view of the cost involved, usually auger samples are taken over 2.4 to 3.0 m. (8 to 10 ft.) depth or to water-table or hard strata whichever is nearer from the surface. The same practice may be continued but some representative sites may also be sampled by pit method to obtain some idea of the morphology of the soils, genesis, *etc.* The following properties of the soils foot-wise should be studied:

- (1) Texture
- (2) Soluble salt content
- (3) pH
- (4) Water holding capacity.

In the 10 per cent of the areas where profile pits will be dug the morphological features should be examined and the following physico-chemical properties of the soils should be studied in addition to the 4 properties studied above:

Group II (Colour Yellow)

This soil group is moderately suitable for irrigation farming with limited hazards which may aggravate irrigation situation if intensive water use is made; the soil is deep and the texture is loamy sand to very permeable clay; the sub-soil is permeable. The total soluble salt content and exchangeable sodium are around the maximum limits fixed for group I (0.2 per cent).

Group III (Colour Red)

These soils are suitable for limited irrigation and cropping suitability is also limited; available moisture holding capacity medium [3.8 to 1.9 cm. ($1\frac{1}{2}$ in. to $\frac{3}{4}$ in.) per acre foot of soil]; water-table below the root zone; soluble salts and exchangeable sodium in moderate amounts; internal permeability is fair; there is no pan formation within the root zone and sub-soil water may be slightly to moderately saline (0.2 to 0.5 per cent total soluble salts).

Group IV (Colour Blue)

This soil group is usually not suitable for irrigation owing to shallow depth due to rocky substrata or impervious pan formation, high *pH* and soluble salt content (0.5 per cent) low moisture supplying capacity and low internal permeability. It may, however, be brought under irrigation by engineering methods.

Group V (Dark Green)

These are broken lands, shallow or stony, impermeable sub-soil, excessive total soluble salt content and very high exchangeable sodium percentage which cannot be corrected by the usual reclamation methods (25 per cent).

The soil groupings should be divided into such sub-groupings on the basis of the following limitations: (i) risk of erosion or post-erosion damage, designated by the symbol (*e*), (ii) wetness, drainage or over flow (*w*), (iii) root zone limitations (*s*); and (iv) climatic limitations (*c*). Where soils have two kinds of limitations both can be indicated, the dominant one being shown first. The dominant one is used for summarising data by sub-classes or for sub-dividing into capability units. If two kinds of limitations are essentially equal the sub-classes have the following priority:—

e, w, s, and c

Soil Capability Units

Soil capability sub-groups are divided into capability units which respond in a similar way and require similar management although they may have soil characteristics that put them into different soil series; for example a soil capability sub-group area may have different parent materials so that the soil management practices such as application of fertilizers will be different. In such a case the capability sub-class is divided into two units.

In developing all these groups adequate consideration may be given to the availability of wide varieties of crops and their economic returns.

General Remarks

Mehta, Mathur and Shankara Narayana (1958) have rated the Chambal commanded area falling in Rajasthan into four irrigability classes based on their profile characteristics and inherent capacities for crop growth. The soil factors considered are texture, permeability, capillary porosity, soil reaction, soluble salts and exchangeable sodium. The numerical rating system is additive and the total is 100. This method suffers from the defect that adequate consideration is not given to the important role played by an individual factor which may under some cases render the soil completely unsuitable for irrigation.

In future attempt should be made to classify soils in such a way that the classification should serve the purpose of both irrigation engineers and agronomists. For such areas where soil survey has already been carried advantage should be taken of the soil maps prepared on the basis of such surveys and whatever supplemental information might be required for purposes of intensive land development may be collected.

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USE OF WATER BY CROP PLANTS IN RELATION TO SOIL FERTILITY FACTORS AND FERTILIZERS

by

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Introduction

Out of a total cultivated area of 133.5 million hectares (330 million acres), the area under irrigation in India was only 23.5 million hectares (58 million acres) in 1958. In the year 1850, this was hardly 0.9 million hectares (2.3 million acres). If all the projects in the Five-Year Plans are duly implemented under irrigation, it is estimated that by 1966, the area covered by irrigation would be 40.5 million hectares (100 million acres). Even then, the area would only be a third of the total area under cultivation and as the American Ambassador Dr. Galbrath rightly pointed out in one of his farewell addresses in July 1963, India's food problem would be solved only if we do not depend entirely on rainfall for growing crops. But, even if every available source of irrigation water is tapped, it will not be sufficient and strict economy in the use of water is needed. Hence it is of paramount importance to conserve the available water, and to know how best to use it for good crop growth and to get the maximum dry matter per unit of water put in.

The requirements of water are profoundly influenced by climate. The transpiration ratio of field crops has been found to vary due to climate and for the same crop, it varies from place to place, depending on the environmental conditions and radiation, which ultimately affect the transpiration and evaporation. The present paper does not intend to dilate on the climatic factors but to stress only on the soil fertility factors which affect the water requirements of crop plants.

Extent of Influence of Mineral Nutrients in Soil on the Water Requirements

The effects of soil fertility on the water requirements are less noticed than it is for climate and the experiments done on this aspect are also very meagre. Present data

however indicate that large decreases in crop yield, resulting from deficiencies of both nutrients and moisture may cause increase in water requirements. Stanberry, Converse, and Haise as quoted by Kelly (1954) noted that dry plot of low fertility required 88 per cent more water to produce 1.01 tonnes (one ton) of hay than the high fertility plots in wet treatments as shown in Table I.

TABLE I

The relative amount of water required to produce 1.01 tonnes (1 ton) of hay as affected by moisture and fertility level at Yuma, Arizona in 1950 and 1951.

Pounds P_2O_5 per acre	Wet	Medium	Dry
100 . . .	156	170	188
200 . . .	129	134	154
400 . . .	109	120	129
600 . . .	100	109	130

One acre=0.404686 hectares

Kiesselbach (1916) found that the dry matter production was increased in an 'infertile', "mixture of infertile and fertile" and 'fertile' soils by 194, 79 and 41 per cent respectively by the use of sheep manure and the water requirements under these treatments were reduced respectively by 29, 17 and 8 per cent. Scofield (1945) also found a similar trend in alfa-alfa, where mineral nutrients were found to produce 14 per cent increase in yield and the water requirements for fertilised and unfertilised fields were 792 and 803 respectively.

Table II gives some of the relevant data obtained in 1912 by Montgomery and Kiesselbach as quoted by Kelly (1954). It can be observed from the table that there is a marked reduction in water requirements, to produce one gram of dry matter, with increasing soil fertility.

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TABLE II

Soils	Water requirement in grams of water per gram of dry weight	
	No manure	Manured
(1) Infertile	550±16	350±8
(2) Intermediate	479±11	341±4
(3) Fertile	392±6	347±6

Similar results have been obtained in India, by Leather (1910) and also by Singh, *et al* (1935). It is clear, therefore, that soil fertility and manuring influence water requirements of crops. The more fertile the soil, the lower will be the water requirement. In other words, water will be used more efficiently if the soil fertility is higher.

Effect of Fertilizers and Manures on Water Requirement

Raheja, *et al* (1961) have reported that with increased levels of manures and fertilisers, the water requirement is reduced in crops, as the dry matter production is relatively more per unit of water used. Though there is possibility of plants absorbing small quantities of nutrients even under dry conditions, as was shown with radio-active phosphorus in legumes, by Hunter and Kelley (1946), yet this appears to be wholly inadequate for a thriving plant. Trumble (1947) states that low moisture is conducive to fixation of phosphorus and consequently to low phosphorus content of plants. Hence, it stands to reason that plants not limited by moisture supply would have a higher content of nutrients and dry matter, under comparable soil fertility, than a plant limited by low moisture supply. A number of workers have shown that for a given level of fertility, variation in soil moisture supply causes variation in the *N. P. K. Ca* and *Mg* content of plant (Greaves and Creater 1923, James 1948, Maximov 1929, Thomas *et al* 1942 and 1943). Clements and Kubota 1942 and 1943 have developed the technique of crop-logging in sugar-cane, whereby the nutrient status and sugar content of the plants are kept up by adjusting the irrigation and the fertiliser application. This would be a very efficient way of controlling water use in relation to fertilisers for proper plant growth.

Among the major nutrients, phosphates have been found to have a greater effect in reducing the water requirements of crops. Rege in 1937 has reported that the transpiration rate of rice in Bengal was found to be lowered

by the application of phosphates. Stanberry, Converse and Haise (1951) as quoted by Kelly (1954) have shown that with increase in dose of P_2O_5 there was progressive reduction in requirement of water to produce unit quantity of hay. Their results are as follows :—

Pounds of P_2O_5	In. of water per ton of hay
100	10.67
200	8.79
400	7.45
600	6.82

Raheja, *et al* (1961) found that the effect of phosphorus was more marked than nitrogen in lowering the transpiration ratio.

Fertilisers and Transpiration Ratio

Transpiration is a phenomenon by which plants absorb moisture through their roots and loose the same through their stomatal openings in the leaves. This is a continuous process, depending on the atmospheric temperature and humidity.

Transpiration ratio is defined as the pounds of water transpired by a plant for every pound of dry matter produced. Diminishing soil moisture affects the concentration of the solutes in the soil solution from which the roots of plants absorb their nutrients. The movement of nutrients dissolved in the soil moisture takes place along with the movement of soil moisture. The use of fertilisers reduces the transpiration ratio due to a more efficient use of soil moisture for every pound of dry matter produced by plants.

Effect of Nitrogenous Fertilisers on Water Utilisation

There is a noticeable difference between the levels of nitrogen in crop production for a given supply of moisture as will be evident from the data obtained by Hanks and Tanner (1952) which is presented below :

Year	Bushels of Oats per in. of water utilised	
	Low Nitrogen	High Nitrogen
1949	2.1	4.4
1950	2.7	3.7
Average	2.4	4.0

Combined Effect of Irrigation and Fertilizers on Crop Yield

It has been found that irrigation water increases the yield of both grain and straw. The

straw yield generally increases much more than grain yield. When combined with fertilisers the increase in yield is still more.

Work done at the Research Station in SIRRUGUPPA in Bellary District, in 1942-43, has shown that irrigation alone increases the cotton yield by 37 per cent. But when combined with application of fertilisers the yield had gone up by 114 per cent over control. Table III gives the yield of cotton (*kapas*) under different treatments.

TABLE III

Station reports of Madras Agricultural Department.

Treatments	Yield of cotton (<i>kapas</i>) lb./ac.	Increase over control per cent
(1) Control	232	..
(2) Fertiliser only	312	34
(3) Irrigation only	319	37
(4) Fertilizer and irrigation combined	497	114

Experiments done at Coimbatore had given indications that under different levels of irrigation and manuring, the yield of either grain or straw or both of Co. 18 sorghum, tended to be higher with higher levels of fertilisers (Dhanapalan, Daniel, and Mariakulandai 1958). This will be clear from the data given in Table IV.

TABLE IV

Levels of irrigation in in.	Levels of fertilisers applied	Yield of Co. 18 sorghum in lb.	
		Grain	Straw
20	Low (20 lb. N+10 lb. P ₂ O ₅)	3963	15871
	High (60 lb. N+30 lb. P ₂ O ₅)	4271	15888
25	Low (20 lb. N+10 lb. P ₂ O ₅)	4133	15567
	High (60 lb. N+30 lb. P ₂ O ₅)	4462	16171
30	Low (20 lb. N+10 lb. P ₂ O ₅)	4192	16454
	High (60 lb. N+30 lb. P ₂ O ₅)	4192	17450

1 in.=2.54 cm.; 1 lb.=0.4536 kg.

Thus, the possibility that growth will be limited in the available moisture range due to mineral nutrition is well established. Consequently the full utilisation of nutrients available to plants is conditioned by the soil moisture content. And if an estimate of the optimum soil moisture for good growth could be fixed either by direct estimation of moisture in soils by tensiometers or by plant tissue tests

as developed in crop-logging technique by Clements the utilisation of water for irrigated crops could be managed effectively to the maximum advantage.

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EFFICIENT MANAGEMENT OF IRRIGATION FOR CROP PRODUCTION

by

P. C. Raheja*

Introduction

Economic return in terms of crop production per cusec of water is the chief aim of efficient water management in the field. This involves the adoption of most economic cropping patterns, suitable methods and intervals of irrigation, optimum application of manures and fertilisers, cultural operations to conserve soil moisture and provide aeration including weed control. The knowledge on these aspects for practical purposes has been gained by 'fundamental analysis of the processes involved in terms both of precisely defined and measurable soil and plant properties and of equally precisely specified conditions, and 'for practical purposes, the effect of particular treatments applied to soils and crops (Childs and Collis-George, 1950)'. In India the fundamental studies on water requirement of crops were taken up very early at the turn of twentieth century. These were largely followed by applied investigations. By and large the analyses of processes involved in these experiments were not undertaken. In the past decade this gap in knowledge of efficient water management has been filled by use of equipment which has enabled study of these processes directly in the field.

Soil Moisture and Plant Growth

The downward movement of water depends upon the soil permeability and is caused by the hydraulic potential gradient composed of gravitational and pressure components. The pressure component or suction is measured by tensiometers and electrometric potential. Every soil shows a moisture characteristic of its own. The form of the curve is different for a wet soil where suction steadily increases than for a dry soil which has initially little water and the suction is steadily relaxed. This is brought about by hysteresis (Childs, 1940). The curve of soil moisture characteristic is a smooth one so that water is available to the

plant not in sharply defined groups, bound with forces of quite different groups was at one time visualised such as capillary water, wilting percentage, wilting coefficient, permanent wilting coefficient and hygroscopic coefficient. Some of these are points of inflexion specifying a feature of the moisture characteristic (Baver, 1938). Therefore, from soil moisture suction observations at every soil depth the moisture content can be determined. The tensiometers give correct indications of soil moisture up to 1 atmosphere suction. Beyond that range gypsum blocks, fibre-glass or nylon blocks are the ones employed to determine the soil moisture.

In India so far the gypsum, nylon and fibre-glass blocks were imported and this limited the study of moisture characteristics of the soils and the moisture content observations in relation to suction tension. The methods of preparation of gypsum block at an approximate cost of Re. 0.75 have been standardised at the Institute (Abichandani and Bhatt, 1962) and work on standardisation of fibre-glass and nylon blocks for study of suction tensions in the dry range is in progress to reduce the cost of these units. The standardisation of these units will go a long way in taking up irrigation studies in India.

For correction of soil moisture characteristic curves for the temperature factor the process of manufacture the thermistors has been standardised and using locally available materials. This very appreciably brings down the cost of such equipment (Abichandani, *et al*, 1963). To step up the production of this equipment at various research stations the training programme has been initiated at the Central Arid Zone Research Institute, Jodhpur for research workers interested in these studies.

The movement of soil moisture is not restricted to a single direction. When surfaces of the soil are at different potentials water flows

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from one to other to attain a level of equipotential. Several soils have structural features which encourage flow in one direction at the expense of others. These are called anisotropic soils. Besides, an unsaturated soil necessarily offers greater resistance to flow than a saturated one. But, when a soil is at a uniform moisture content and suction it is at a uniform gravitational potential gradient. In the silty and sandy loam soils, the moving water wets an every increasing depth of soil, to a constant percentage of saturation, separated by a well marked water front from the yet unwetted soil. Such a zone has no further storage capacity. The permeability through the wetted zone is five times the permeability of the sandy loam soil at 70 per cent saturation. The permeability in other soils is dependent upon geometrical configuration of its solid, liquid and air components. Relatively the permeability of clay soils is relatively negligible to a sandy soil. Therefore, heavy soils even when moist have steep moisture gradients for a long time, which means very slow movement of water applied at the surface (Childs and Collis-George, 1950).

When irrigation is applied, the rate at which the diffusion of water occurs depends upon the type of soil. In heavy soils, unless they are in a cracked state, most of the applied irrigation will infiltrate at a slow rate and water may stand over for considerable time. In sandy and sandy loams it will rapidly diffuse and infiltrate quickly into the soil to create a wetting front. Excess of water, then is required to wet the root zone, is likely to move and replenish the ground water in due course. In all cases, therefore, it indicates that shallow irrigations which are just enough to wet the root zone of the crop are adequate for the optimum growth of the crop. The studies on systems of irrigation have shown that sprinkler system has proved most economical from water use aspect than flow irrigation as it just wets the root zone of the soil and excessive irrigation causing drainage losses is avoided.

The evaporation from the surface of the soil soon after irrigation takes place at the same rate as evaporation from the free water surface. As the surface soil dries up the rate of evaporation falls off in proportion. The remaining soil moisture is utilised by vegetation for transpiration and metabolism. The depth to which this water will be taken

up depends upon the root range, the weather factors and the water requirements of the crop. This depth of water exploitation largely depends on the crop and additionally limited by the impending soil horizon, as in stratified soils or by a general impermeability as in alkali soils, which restrict adequate penetration of water.

The uptake of soil moisture by the plants is steadily restricted as the soil suction increases. The incipient wilting at first sets in when rate of transpiration exceeds the rate of absorption. As the moisture in the soil is depleted to 1 atmosphere suction temporary wilting (wilting point) occurs and thereafter at 15 atmosphere suction tension in most crop plants permanent wilting is manifested (Richard and Weaver, 1943). At 1 atmosphere moisture tension the photosynthetic activity of plants is affected and the relative growth rate tends to slow down. This is the point at which irrigation must be applied to revive the growth of plants. The upper limit of the available soil moisture is the field capacity. It is just equivalent to the physical constant of moisture equivalent for soils of medium to fine texture. This, however, does not apply to coarse textured soils (Richards and Wadleigh, 1952).

Veihmeyer and Hendrickson (1927, 1938) and Aldrich, Work and Lewis (1935) have noted that below field capacity the moisture in the soil does not move from root-free zone to the soil adjacent to the roots at a steady and adequate rate to meet the requirements of the plant for transpiration although unsaturated permeability is not negligible in the moisture range above the wilting percentage. Edlefsen (1941) observed that of the total change in free energy of water between the soil and the aerial environment of leaves of plants a very small fraction occurs between the soil and plant root. Most of this occurs over the intercellular space of the leaf parenchyma, the stomata and an air layer over the leaf surface (Gradmann, 1928; Van den Wernot, 1948). Richards introduced the term "total moisture stress" instead of total free energy difference and stated that the range from saturated soil to wilting percentage is of the order of 20 atmospheres whereas overall stress difference of the order of 1,000 atmospheres may be operating when transpiration is most active. Actually the diffusion pressure deficit in the parenchyma cells seldom exceeds 50 atmospheres although on the leaf surface the over-

all stress difference is many times more than that. From this Richards concluded that the range of moisture stress occurring in the soils is almost of the same magnitude as the diffusion pressure deficit range noted in the plants. Indirectly this is supported by the observations of Migstad, *et al* (1943), Hayward and Spurr (1944) and Gauch and Wadleigh (1945).

The soils widely differ in the release of irrigation water to the plant. Hunter and Kelley (1946) reported that 2/3 of the available water was released by Delano sandy loam soil and only 1/4 by the Sorrente silty clay soil at tension below 1 atmosphere and this affected the quality of growth of guayule in relation to moisture treatments.

Besides the textural differences in soils, other soil factors that influence the availability of water to the plant are the mechanical impedance of soil to root penetration; soil stratification and depth. Thick sowings of crops may restrict the volume of root zone per plant. The shallow water-table restricts the development of root system particularly of perennial fruit trees.

Of the plant factors the most important is the extent of root penetration and root proliferation or the special density of root distribution. This is particularly so as the rate of unsaturated flow of moisture is very restricted in soils. Shallow rooted crops like onions, garlic require frequent irrigations than sugar-cane, grape vines, grasses and small grain which have deep and proliferating root system. The sugar-cane plant although has extensive root system cannot stand total soil moisture stress of any high order because of the character of its top growth. The crop irrigated at 0.3 atmosphere moisture stress gives high cane production (Clements, 1948). From the aspect of ton-per-acre commercial cane sugar less frequent irrigations give high returns (Raheja, 1951). The yield of cotton is less influenced by frequency of irrigation. With high frequency the crazy top or legginess is developed. As against this infrequent irrigations to maintain adequate moisture stress results in optimum growth of the crop with heavy carry over of bolls (Adams, Veihmeyer and Brown, 1942). The root system of water-melon is very efficient to exploit the moisture in deeper layer and is less sensitive to moisture stress in the shallow soil layers (Doneen *et al*, 1939) with moderate stress of soil moisture peach trees produce the maximum quantity of fruit

of which the quality was superior (Hendrickson and Veihmeyer, 1929).

Soil Fertility

The irrigation water has a biological value. This value is limited by a number of factors of which soil fertility is the most potent one. In a study of sugar-cane yields in Peru Willcox (1951 a & b) observed that the yield of cane crop could be stepped up provided the nitrogen status could be increased. The survey of the fertility status of the soil gave the following results :—

Plant nutrients	Baule units	Crop producing value % of maximum yield
Nitrogen	0.5	29.33
P ₂ O ₅	4.0	98.75
K ₂ O	8.0	99.60

The fertility index of the soil is as follows :

$$F.I. 0.2933 \times 0.9375 \times 0.9960 = 27.38 \text{ per cent.}$$

The fertility index value indicated that nitrogen was the limiting factor in maximum cane production. The irrigation supplies are available for 70.25 per cent of the area which in terms of Baule unit is 2.8. This has crop producing power of 86 per cent. Including the rating of water, the soils are capable of producing the cane at the following rate :—

Cane yield producing ability = $0.2735 \times 0.86 = 0.2354$ or 23.54 per cent. The maximum cane which POJ 2878 variety can produce is 301.5 tons. Thus the present status of moisture and fertility can produce $0.2354 \times 301.5 = 71.08$ tonnes (69.96 tons) of cane per hectare. This compares very favourably the present yield of 70 tons/ha. of cane. In an experiment conducted in Peru on nitrogen doses the responses obtained are as given in Table I.

TABLE I

Sl. No.	Nitrogen applied Baule unit	Yield from experiment (Million tons/ha.)	Calculated yield (Million tons/ha.)	Difference between actual and calculated
1.	0.0	62	61.3	0.7
2.	0.25	84	83.8	0.2
3.	0.50	103	102.5	0.5
4.	0.75	119	119.5	0.5
5.	1.00	132	131.9	0.1
6.	1.25	142	143.1	1.1
7.	1.50	149	152.5	3.5

The differences between calculated and actual yields were small up to 1.00 Baule unit of nitrogen. Thereafter the calculated yields were higher than the actual yields and it appears another factor tended to limit the

cane yields. The economics of nitrogen application was worked out and it was observed that it was economical to apply nitrogen up to 1.25 Baule units, which is equal to 71 per cent of the maximum possible yield with irrigation supplies available in Sana Valley of Peru.

Most of the soils in India have very low nitrogen status; about 60 per cent of the soils have low phosphate status and nearly 20 per cent of the soils have low potash status. In all acid soils there is need for lining to neutralize the acidity. Majority of the soils have medium phosphate status and quite a high percentage of soils have moderate potash status. That largely accounts for very low yields of crops.

In a recent study under irrigated conditions at Indian Agricultural Research Institute the response to nitrogen found was as follows :—

	Wheat yield mds./acre.
No manure plot	= 16.90
20 lb. N/acre	= 21.55
Difference	4.65 mds.
Percentage increase with 20 lb. N (0.09 Baule) on control	= 27.5 per cent

This shows that nitrogen in the alluvial soil is in extreme short supply and even small additions push up the yields of crops.

Raheja *et al* (1961) have recently published experimental evidence to show that the relative efficiency of water requirements of the crops is appreciably increased by application of fertilizers and manures. It was estimated that in full use of irrigation potential is to be obtained with increased irrigation facilities by 1970 the fertiliser consumption should be stepped up to 2.0 million metric tons of nitrogen 1.5 million metric tons of phosphoric acid and 1.016 million tonnes of potash. The fertilizer consumption is not keeping pace with the expansion in irrigation facilities and, therefore, water is not being efficiently utilised for crop production. "There is an optimum level of irrigation requirement for an optimum dose of nitrogen, beyond which the application of more water tends to leach out nitrogen from the soil into the sub-soil. This is particularly so in the case of sugar-cane".

In U.S.A. the corn production has gone up firstly by taking to hybrid corn; secondly

by stepping up the application of nitrogen and finally by irrigation. In an experiment with 0.9 m. (3 ft.) of irrigation water with 120 and 240 lb. N/acre the yields were 75 and 90 bushels but by applying 1.5 m. (5 ft.) of water at these two nitrogen levels the yields could be stepped up to 115 and 130 bushels respectively (Parks, 1951). Thus use of nitrogen and water gives increased yields simultaneously. By use of high doses of nitrogen limited supplies of water are more efficiently utilised than with low doses of nitrogen.

Methods of Irrigation

Mukhtar Singh, Gandhi and Dastane (1961) have presented a critical review of the methods of irrigation in India. The authors have reviewed the advantages and disadvantages of free flooding, border strip, check basin, furrow irrigation, and ring or basin methods of irrigation. They have recommended that improvement in levelling of fields by use of scraper and floats can very much reduce the misuse of water. The long furrow method should be used for row crops on an increasing scale. In some of the row crops this has not yet been adopted and can be adopted with convenience to save water. In cotton and corn which at present are grown on the flat, the long furrow irrigation method can be adopted to avoid alternate flooding and droughting. A saving of 15-20 per cent in water consumption by the crops is affected. These crops can also be simultaneously dressed with higher doses of fertilizers. In small grains corrugated furrow system enables use of high doses of nitrogen with consequent economy of water. In U.S.A. water control equipment is widely in use. This requires introduction on as wide a scale as possible.

There is urgent need to demonstrate the value of levelling of fields to avoid dry patches and submerged spots. The use of levelling equipment is new to the farmers and unless this is brought to their notice and taken up by them the present misuse of water would remain in vogue. Considerable economy in water use can be affected by demonstrating the adoption of long furrow method in row crops. In areas where water cost is high the sprinkler system of irrigation holds great promise. This affects saving of 40 per cent in water use but needs extensive demonstration in arid areas of the country where water tends to be saline in a short time. Comparison of irrigation efficiency in flat and corrugation (small furrow)

irrigation methods indicated that the irrigation efficiency remained always high with the furrow method of irrigation. In first, second, third and fourth irrigations applied to wheat crop the relative efficiencies were 46.88 and 56.60 per cent; 57.62 and 73.34 per cent; 65.90 and 69.07 per cent and 37.78 and 52.82 per cent for flat and furrow methods of irrigation respectively (Thakur, 1960).

Cultural Practices

With provision of irrigation the reorientation of cultural practices becomes essential. The seed rate and spacing are inter-related. The mode of seeding requires a change. In irrigated areas the system of broadcast sowing is still in vogue. The drilling of seed ensures placement of seed at proper depth, gaps and patches are eliminated and seed is brought in contact with moist layer of soil. Some of the seeds like cotton and cowpeas are very sensitive to soil moisture variations. The monocots are less sensitive as they have very high imbibition pull for water and can overcome the total soil moisture stress. Wheat, barley and oats can draw water at the hygroscopic coefficient level of soil moisture.

The experiments on grain sorghum conducted in Kansas State have established a linear relationship between yield and row width which is expressed as under :—

$$Y=117.11-0.72 x$$

Where Y =yield in bushels per acre and x =width of row in inches. It was observed that within the range 56,000 to 224,000 plant per acre the yield was not materially influenced. The average water used with 17.8 cm. (7 in.) wide rows was somewhat higher than with 71.1 cm. (28 in.) wide rows. From rows more than 35.5 cm. (14 in.) apart the moisture from the middle of rows was less extracted than less than 35.5 cm. (14 in.) wide rows. Thus every crop extracts water from an optimum area and that determines the optimum plant population (Grim and Musick, 1960). Similarly interaction between seed rate of maize and irrigation levels has been found to be significant (Wiersma and Smith, 1961). The optimum spacing for cotton under irrigation was found to be 61 cm. (24 in.) between rows and 22.8 cm. (9 in.) planting spacing (Relwani, 1962a). In paddy 25.4 cm. × 25.4 cm. (10 in. × 10 in.) spacing has given the highest return under irrigation (Relwani, 1962b).

Inter-culture is practised for weed control and forming surface mulch. This is largely practicable in row crops. About 10 to 30 per cent increase in yield of crops results from inter-culture bullock hoeing under irrigation is far more economical than hand weeding.

Weed control can also be brought about by application of weedicides in standing crops. The demonstrations in cultivators fields have established, that an increase of 0.13 tonnes (3.7 md.) of wheat yield with Rs. 44.0 per acre of profit is realised by spraying with 2, 4-*D* at the rate of 1 lb. in 80 gallons of water after 40 days of sowing of the crop (Verma and Bhardwaj, 1957). Similar results have been achieved by spraying the weedicide in sugar-cane crop. The extra yield obtained was 12.6 tonnes (344 md.) of cane as against 9.82 tonnes (264 md.) by inter-culture of the crop. This required two sprayings, pre-emergence at the rate of 0.9 kg. (2 lb.) and post-emergence at the rate of 0.9 kg. (2 lb.) (a.c.) of 2, 4-*D*. This brought in very large profit and resulted in very high efficiency of water use (Verma *et al*, 1961).

In sugar-cane another practice that conserves moisture and suppresses weed growth is mulching with cane trash. This increases the yield by 2.17 to 3.55 tonnes (52 to 85 md./acre) (Bose, 1954). Similar experiments conducted at Shahjibanpur, Jamunabad, Khurpa, Panwari and Phoolbagh indicated that mulching increased the cane yield by 1.26 tonnes (34 md.) extra to that obtained by inter-cultivation. The trash covered plots gave on the average a profit of Rs. 425.70 compared with Rs. 350.13 in normal cultivated plots (Mathur, 1960). The saving in irrigation water was quite considerable.

Cropping Patterns

The cropping pattern in any irrigated area depends chiefly on three factors: (a) energy level or climate; (b) intensity of irrigation; (c) water requirements of crops. The climatic factors, particularly the temperature regime determine the suitability of crops to be grown in any region.

The irrigation requirements of the crops as determined from pot culture and field experiments are given in Table I.

The requirements of water for the irrigated crops are not uniformly the same in the growing season. In the grand growth period the

requirements are almost $1/2$ – $2/3$ of the irrigation needs of the crop. Crops need restricted irrigations early in the season like cotton and others need prolongation of irrigation interval during the maturation stage as in sugar-cane peaches and guayale. The cropping pattern has to be so adjusted that the maximum period of irrigation requirements relative to the area cropped does not cause dislocation of irrigation. The areas under crops and the rotations have to be so fixed that for every cusec of water maximum production can be achieved. In fact maximum area should be sown to short duration, high value crops such as oil seeds of the Brassica and Linseed type which have less than 1028 cu. m. (10 acre-in.) irrigation requirement. The adjustment in area is also affected in relation to the rainfall pattern of the area. The high irrigation requirement crops are fitted into the cropping pattern during the wet period (Raheja, 1961).

Resume

In recent years investigations on irrigation management for crop production have been conducted on almost all aspects both from the fundamental and applied aspects. Considerable saving in irrigation can be affected by adoption of practices which reduce soil losses in drainage and evaporation by regulating the irrigation interval, depth of irrigation and adopting suitable methods of irrigation for various crops. The value of water in terms of crop returns is very much reduced if the soil fertility is low and is not made up by application of fertilisers and manures. With the expansion of irrigation there should be simultaneous expansion in use of fertilizers for crop production. The optimum levels of fertilizer requirements for most of the irrigated crops have been determined for different regions. Besides, the fertility levels have been estimated for various soil types in different tracts by rapid soil tests. Therefore, scientific recommendations for fertiliser applications can be given out to the farmers.

TABLE I
Irrigation requirements of crops.

Sl. No.	Crop	Duration of crop season	Irrigation requirements in acre-inches	Remarks
1.	Sugar-cane	11 months in North India. 18-24 months in South India.	50 115-135	Early maturing varieties have low irrigation requirements than mid-season on late varieties.
2.	Paddy	Short duration 85 to 115 days. Long duration 225 to 250 days.	45 55	8 in. required for puddling, 24–40 in. transpired by crop.
3.	Berseem	180 days	45	6 in. water required to establish.
4.	Lucerne	365 days	70	45 acre-in. from March to June and rest from October to February.
5.	Cotton	205 days	40	First irrigation delayed from 40 days. 2-3 irrigations during boll formation stage.
6.	Maize	135 days	30	Transpiration requirements 25 acre-in.
7.	Jowar—Grain	120 days	24	
	Fodder	95 days	20	
8.	Bajra	110 days	20	Usually an un-irrigated crop.
9.	Ragi	115 days	24	Winter season crop irrigated.
10.	Wheat, Barley and Oats	150 days	11–13	
11.	Potato	100-135 days	25	In hills grown without irrigation. In plains early varieties require 20 in.
12.	Tobacco	110-130 days	25	
13.	Jute	100 days	24	Usually grown without irrigation.
14.	Groundnut	140 days	25	Usually unirrigated crop.

One in. = 2.54 cm.

The adoption of improved cultural practices can substantially reduce losses of water and conduce to efficient use of this scarce factor of crop production. The seeding and spacing trials have been conducted and these results can be applied with benefit. Weed control can be effectively practised by use of weedicides suitable for application in standing crops. The technique of mulching can reduce water loss and step up production.

There is strong need to apply the improved water conservation and efficient water use practices particularly in the wetter sections of the country where farmers have had no experience of protective irrigation. In drier sections of the country where cost of water is high a great improvement in methods of application and introduction of high value crops appears most desirable from practical aspect.

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OPTIMUM REQUIREMENTS AND UTILIZATION OF IRRIGATION WATER

by

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The problem of water use by crops has received a renewed attention in the last two decades on account of contribution from meteorologists and agro-physicists and a thorough understanding of these concepts is essential for sound planning of utilization of national water resources. The classical works of Penman (1948) and Thornthwaite (1948) have shown that consumptive use of water by crops depends primarily on meteorological factors, while soil and plant considerations play a secondary role in governing daily water use. Under a given set of climatic and non-limiting water supply conditions, rate of evapotranspiration from a field covered with a vegetation does not exceed a certain maximum termed as 'potential evapotranspiration' which is controlled by climatological elements and for maximum growth, evapotranspiration should proceed at the rate near the potential level.

Similarly, the fact that the availability of soil moisture decreases and growth rate and yields are affected with increase in soil moisture stress within the available soil moisture range from field capacity to wilting point, has led irrigationists to find out the optimum moisture regimes for maximum yields of crops. Thus, the optimum soil moisture regime, by definition, is a range with field capacity as the higher limit and another moisture level as the lower limit, the moisture fluctuations within which do not affect economic crop yields.

These two facts depicted in Figure 1 further imply that as soil moisture is depleted from field capacity to the lower limit of the optimum soil moisture range, the evapotranspiration rate falls but not necessarily the yield. Below the lower limit of the optimum soil moisture range, however, the growth rate falls very rapidly becoming zero at wilting point. The evapotranspiration rate also declines but not as fast as the growth rate but it continues till the plant survives.

In view of these basic facts, the first step in planning efficient use of water by crops, would be to find out potential evapotranspiration in a tract and then work out how much of this need is being met by rainfall. The rainfall exceeding the soil moisture deficit is a waste. The negative differences between rainfall and potential evapotranspiration will indicate net deficiencies to be met through irrigation.

Figure 2 showing precipitation and annual march of potential evapotranspiration by Thornthwaite's formula for Delhi reveals maximum irrigation water will be needed in the months of April, May and June and the minimum in July, August, September, December and January. The net irrigation needs will be about 750 mm. as shown in Table I. To this will have to be added figures of application losses. Taking a liberal estimate of 20 per cent, annual irrigation requirements

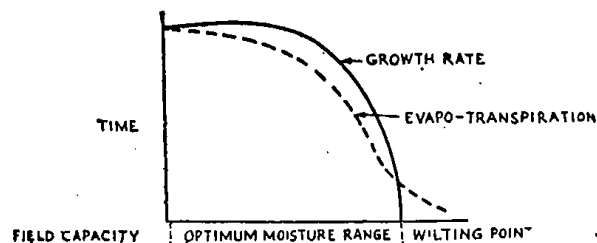


FIGURE 1: Inter-relationship of soil moisture supply, evapotranspiration rate and growth rate.

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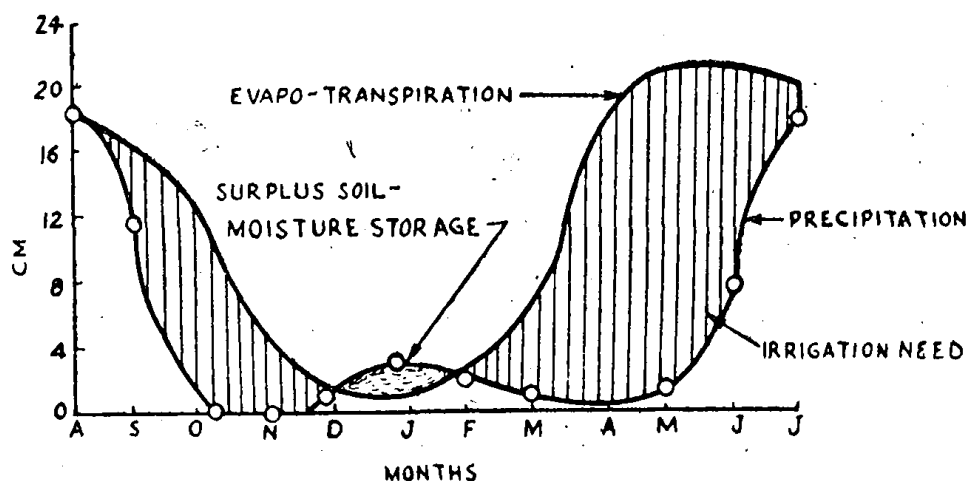


FIGURE 2: Monthly march of potential evapotranspiration and rainfall at Delhi.

TABLE I

Annual precipitation and potential evaporation and water deficiencies at Delhi (Average figures).

Month	Precipitation (cm.)	Potential evapo-transpiration by Thornthwaite formula (cm.)	Soil water balance (cm.)
August	18.4	18.2	0.2
September	12.3	16.0	-3.5
October	1.0	12.0	-14.5
November	0.2	4.5	-18.8
December	1.1	1.9	-19.6
January	2.5	1.4	-18.5
February	2.1	2.5	-18.9
March	1.3	7.0	-24.6
April	0.8	15.6	-39.4
May	1.3	20.6	-58.7
June	7.7	20.8	-71.8
July	17.9	19.8	-73.7
TOTAL	66.6	140.3	-73.7 or say -74

at Delhi should not be more than 900 mm. or (36 in.) for a perennial green crop. This is a broad schedule and a more precise one can be worked out by taking weekly figures than monthly figures.

It will be evident from Figure 2, that water deficiencies to be met are smaller from July to September and December to March on account of high precipitation and low temperatures. A given quantity of water supply can, therefore, be spread over larger areas to meet plant water needs during this period than in April, May and June. It will be preferable to give priority to *kharif* crops and early maturing *rabi* crops for higher production per cusec of water. With smaller supplies of water, potential growth rates can be achieved by allowing potential evapotranspiration. In the months of May and June,

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the moisture deficits being high, greater quantities of water will have to be applied to allow potential growth rates.

In use of the climatological formulae, it is assumed that field is completely covered with vegetation and that it is in active stage of growth. For a fortnight after sowing and again at the end of maturity of crops, the climatological formulae will not apply. The consumptive use, therefore, can be taken only as 50 per cent of the potential evapotranspiration for that period. This figure is proposed arbitrarily.

It is observed that in many irrigation projects, engineers calculate, even today, quantities of water needed by crops without any regard to the meteorological factors. Some of them assume that water needs are same throughout the growing period. In many project planning reports, the figures of evaporation from pan evaporimeter are not given. No water needs can be estimated without either field experiments or detailed climatological data.

It may be mentioned here that the climatological approach has also its limitations as this branch of science is still in the developing stage. No formula as yet is 100 per cent perfect. However, for all practical purposes, these data can profitably be used for basing estimates of water requirements of crops.

After fixing the total delta, the next problem is the frequency or the interval of irrigation. The crops have to be irrigated before they receive a setback in growth. The

optimum soil moisture regimes found out after conducting field experiments by several workers at I.A.R.I., using tools of tensiometres and resistance units are compiled and shown in Table II. Effect of reduced number of irrigation on the yield is also shown.

Another problem in water management is utilization of surplus water. Irrigating the soil when the moisture content is within the optimum moisture range is of no use. Additional irrigations at this stage will be mere

waste or even could be harmful. Experiments carried out at I.A.R.I. showed that irrigations applied to maize or *jowar*+cowpeas mixture for fodder grown in monsoon under Delhi condition gave no benefits as shown in Table III. In areas with no large storage facilities but assured rains, the surplus water, therefore, will have to be disposed off by supplying before monsoon to enable the cultivator to sow the crops early. Elsewhere, the water will have to be diverted to areas not

TABLE II
Optimum soil moisture regimes and effect of reduced irrigations on crop yields.

Crop	Optimum regime		No. of irrigations and delta inclusive of rainfall in mm.	Average yield in Q./ha.
	Higher limit of tension in Atmos.	Tension		
	Depth (soil) cm.			
Wheat	22.5	0.5	I_1-3 Irrig.	260
			I_2-2 „	230
Berseem	22.30	0.35	I_1-17 „	890
			I_2-14 „	770
			I_3-10 „	710
Potato	15-22	0.25	I_1-10 „	520
			I_2-9 „	460
			I_3-7 „	410
Cotton	30	0.5	I_1-5 „	1060
			I_2-4 „	980
			I_3-3 „	880
Sugar-cane	15-22	0.30	I_1-14 „	1630
			I_2-12 „	1500
			I_3-10 „	1400
Onion	8-12	0.65	I_1-16 „	460
			I_2-11 „	350
Radish	15-22	0.20	I_1-8 „	229
			I_2-4 „	200
Turnip	15-22	0.20	I_1-9 „	253
			I_2-4 „	214
Beet root	15-22	0.50	I_1-6 „	261
			I_2-4 „	211

I_1 —treatment of irrigation is the optimum in all cases.

TABLE III
Effect of irrigations on the yield of maize and jowar+cowpeas (F) mixture.

No. of irrigations	Total delta inclusive of rain (cm.)	Yield in quintals/hectare	
		Maize	Jowar+Cowpeas (F)
0	70.0	18.7	290
1	75.0	18.8	295
2	80.0	18.9	297

under regular command for filling soil moisture reservoir for the benefit of the *rabi* crops.

Summary

It is suggested that to estimate water requirements of crops and for optimum utilization of water, potential evapotranspiration during the crop growth should be found out in each area and these figures should be taken as basis for estimating consumptive use of water by crops. These figures should further be corrected for effect rainfall and application losses to work out irrigation requirements.

Extra irrigations within the optimum moisture range are not beneficial. In assured monsoon areas, the surplus water can be disposed off before monsoon to enable the cultivators to advance sowing schedule. In other areas, it may be diverted to areas not under regular command for the benefit of dry *rabi* crops.

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CONSUMPTIVE USE OF WATER ON RICE—AUS PADDY*

by

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PART I—TOTAL CONSUMPTIVE USE

In the soil moisture studies one comes across the term "the consumptive use" or "evapotranspiration". This term which is very fundamental in field irrigation, is really the sum total of the volume of water in transpiration and evaporation expressed as acre-inch or acre-foot. The process by which vapour escapes from the living plants principally the leaves and enters the atmosphere is known as transpiration. During the growing period of a crop there is continuous movement of water from the soil into the roots, up to stem and out of the leaves of the plant. Water thus moving acts as a carrier of essential plant food substance from the soil to the various parts of the plants. The velocity of this water is known to vary from 0.3 to 1.8 m. (1 to 6 ft.) per hour but under very extreme condition of heat and humidity, this velocity may even be increased. Transpiration is vitally essential to plant life. Only a very small amount of the water absorbed by the root system is retained at the plant. The transpiration efficiency, *i.e.*, the percentage of water drawn out by the plant as against the percentage of soil moisture at the root zone, is not a constant figure and varies under varying circumstances. At different stages of growth of the plant the root systems have a different draw on the root zone moisture content, and if this draw can be met, the plant will thrive, and if this cannot be met, the plant will decay. The question as to if there exists a fixed percentage of water below which it is unsafe to keep the moisture percentage at the root zone, or which in other words, is called the 'wilting coefficient' is one of the controversial studies. Whether there is a fixed percentage or whether there exists a limit between two percentages or which we may call the 'wilting zone' is a

matter of study which has been discussed later on in the experimental results.

For a study of the water zone, one has to know the moisture equivalent. The moisture equivalent is usually expressed as percentage of the dry weight of the soil as specified small portion of the soil will retain against a centrifugal force of 1000 times the force of gravity exerted on it for a period of 40 minutes. As stated earlier this moisture equivalent closely approximates the maximum capillary capacity. Before the experiments have been started the moisture equivalent of the soil on which the experiments have been conducted has been ascertained in order to establish a relationship between the moisture equivalent and the wilting zone.

In the Kalyani Experiment, different doses of water in different plots have been applied and periodical root zone moisture percentage recorded whereby it has been possible to find a relationship between plant growth and moisture percentage as will be seen later on. This has shown that for optimum production from the crop there is a particular moisture percentage zone, which need to be maintained and which is between the wilting point and the field capacity—a growth depicting the above will be seen later on along with the experimental results. In irrigation practices it is necessary to consider not only the amount of water transpired by the crop but that unavoidably removed during the growth period by evaporation, normal surface run-off and deep percolation. This total must be expressed in terms of the depth of water that must be applied at the surface either by rainfall or by artificial irrigation or by both together with the water taken from that stored in the soil. The experimental charts accompanying the field research works will depict a clear picture

*This paper is a copy of a portion of author's main research paper on "Crop Irrigation and Water Utilisation" (Published by the Agricultural Department, Govt. of West Bengal). This portion is an extract in the subject of dose and frequency of Irrigation and Consumptive use of water on summer rice produced in high land areas of West Bengal.

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of how this total water known as "consumptive use or the evapotranspiration" has been determined on a careful analysis of all the factors enumerated above. So that the reader may not have much difficulty to understand the experimental charts. A short note on the measurement of the consumptive use is given below.

The consumptive use is that portion of the water applied to the farm which is consumed in the complete evapotranspiration process, the whole being expressed in terms of acre-foot for the growth of the plant and is really the figure which has been wanted as a result of the experiments. This "consumptive use" as by definition shall be the sum total of the quantity of water applied to the field by irrigation plus the quantity of water supplied by rainfall minus the quantity of water removed as surface run-off and plus or minus the quantity of water absorbed from the root zone soil moisture neglecting of course the deep percolation losses.

Using symbols we may say :

$$U = W_i + W_r - W_o + W_m$$

Where

U = Total consumptive use.

W_i = Irrigation water applied.

W_r = Rainfall.

W_o = Surface run-off.

W_m = Difference in soil moisture content at the root zone.

Irrigation water applied and run-off losses can be measured by water measuring devices say watermeter or V-Notch for example both the types being used in Kalyani Experiment. Rainfall is measured by standard rain-gauges. The value of W_m , *i.e.*, the difference in soil moisture content can be calculated by actually determining the moisture percentage at the root zone before and after irrigation and converting this percentage figure into columetric measurement. The following simple rational formula can be used for this purpose :—

Moisture content in the soil to the root zone depth expressed in inches

$$= \text{Root zone depth in inches} \times \text{apparent specific gravity} \times \text{moisture percentage.}$$

Apparent specific gravity and the moisture percentage having been recorded, moisture content is calculated once before the crop is sown and once just after harvest. The difference represents W_m . Specific gravity is

determined by the process started herein before and the moisture percentage is determined by the process detailed below.

There are various methods which have been adopted by different research workers for measuring the moisture percentage. In the experiment at Kalyani the gypsum block method has been used. In this method gypsum blocks have been embedded at 15.2 cm., 0.3 m., 0.6 m., 0.9 m. (6 in., 1 ft., 2 ft., 3 ft.) below ground level and the two electrodes connecting the blocks have been brought up to the surface level through a galvanised iron pipe in which apertures have been made at the different levels for admission of the electrodes and which have been embedded in the ground at each of the experimental plots.

An electro-potentiometer and later on a battery operated soil moisture recorder was utilised to find the readings which when calibrated has given the percentage of moisture in the soil at the root zone which was determined by extracting the plant after harvesting. The difference of the soil moisture percentage prior to irrigation and after harvesting has been recorded, and this has been converted into moisture content in acre-inches by the application of the formula stated in the preceding paragraphs. It will be seen in details of the experimental data that in some cases the value of m has been negative, which is due to over irrigation in localised blocks.

Time and Frequency of Irrigation

Two major considerations influence the time of irrigation :

- (a) Water need of the crop,
- (b) Storage of soil moisture at the root zone.

In regard to the water need of the crop, the general governing rule and which is an extremely important one to be observed is that the stages of plant growth shall determine the time and amount of water application, namely, plenty of water for the germination period and then more and more water applied up to the flowering time and then decreasing amount during the maturing period and none at all during ripening. This crop need is again influenced by the atmospheric conditions such as the temperature, humidity, wind velocity, *etc.*, as evapo-

transpiration depends on the above climatic factors also. It will, therefore, be seen that the subject of assessment of crop needs is a subject matter of study by itself and is a very difficult one to determine accurately in practice except through intensive field research. In the Kalyani Experiments different dozes of water at different times have been applied to find out the optimum growth of the plant responding to maximum out-turn in the grain and straw. As a result of extended research works covering for a number of years, it has been possible to draw a mean curve depicting the relationship between the optimum water requirement at various stages of plant growth correlated with the moisture content at the root zone during the growing period of the plant. In regard to the frequency of irrigation, it will appear that this has got to be a function both of the soil and of the crop. The fundamental principles as enumerated earlier, having been accepted that the rate of evapotranspiration should at no stage be less than the absorption through the root zone—the frequency of irrigation should be so determined along with the doze of water applied so that the moisture content in the soil can perform the duties stated above. In practice, however, it is very difficult to attain. One has to go by the appearance of the crop for example, some crops with light green colour indicate the presence of plenty of moisture and dark green show the need of water, but this or similar type of physical appearance may prove sometimes as deceptive, and to depend on them may not be desirable. Scientifically, it should be better if in course of a research work in a particular type of soil one can determine the requisite moisture content zone, which should be between the wilting point and the field capacity zone below which this moisture content should not be allowed to fall. Such an index is, however, difficult to obtain unless through a series of research work results. Widely accepted studies made by Briggs and Shantz on this subject has fixed this optimum moisture zone at about 54 per cent of the moisture equivalent. But such a figure under the condition of United States has very little value in the conditions of West Bengal or even of India. As a matter of fact, other research workers even in other parts of United States have found this percentage to be a variable one. In the Kalyani Experiment we are trying to arrive at a moisture

zone percentage in relation to the wilting point, but for these preliminary studies on this subject, in our field operations, we have through fit, to irrigate where the soil moisture content has gone below 50 per cent of the moisture equivalent.

Efficiency in Irrigation

The ultimate desired goal is production of maximum yield with minimum amount of water to be artificially applied for plant growth. Mathematically considered, the irrigation efficiency can be indicated by the formula :

$$E = \frac{W_i}{W_r} = \frac{\text{Irrigation water transpired by the crop from a plot}}{\text{Irrigation water supplied to the plot}}$$

In good irrigation practice, the approximate quantity of soil moisture stored in the root zone can be taken as 50 per cent of the water supplied to the plot, and on an average, we can assume the water transpired from the root zone as representing 65 per cent of the moisture content in the root zone. Or in other words, the irrigation efficiency stands at 34 per cent. In case of bad irrigation practice, this figure of 34 per cent can go down as below as 15 per cent.

In regard to the water application efficiency there are no doubt non-controllable factors such as the physical property of the soil, permeability, rooting depth of the crop to be raised, but then there are a number of controllable factors also which if properly attended to, the irrigation efficiency can be kept at a high figure. These controllable factors, which are really correct preparation of land for irrigation so that the surface runoff is practically reduced to zero, and then the doze and the frequency of irrigation to be applied in such a way that the soil moisture percentage is kept within the optimum moisture zone, or in other words, frequent low irrigation dozes with higher units in the earlier stages and with diminishing units at the later stages and then again, personal attention to water distribution either by the border system or by the furrow system depending on the crop to be raised are some of the important controllable factors, which if properly attended to, the efficiency of irrigation will improve. In the Kalyani Experiment attempt has been made to keep a strict

watch on the controllable factors to keep the irrigation efficiency at a higher figure.

The result of the different water requirement experiments will be found in the succeeding paragraphs.

PART II—RICE IRRIGATION—AUS PADDY (APRIL-JUNE)

Preamble

With more and more irrigation water being made available to the cultivators through river valley projects and other major, minor and small irrigation schemes, the question of correct crop planning to make the best utilisation of the available water naturally comes uppermost in the minds of the Agronomists. As is well-known, that in the absence of irrigation water, the cultivators can hardly grow more than one crop. With the availability of control on water, the natural tendency shall be to grow more than one crop—generally two and if not three. The science in agriculture will naturally try to aspire for the objective of growing three crops with the availability of water supply, and if this can be achieved in practice, with economy then we shall have not only the best utilisation of water, but at the same time, there shall be abundance of crop per acreage of field with application of water and manure; or in other words, the intensive cultivation will actually be achieved in practice.

So far as West Bengal is concerned, there are huge tracts of land which we call high land and which are not suitable for growing Aman rice under puddled and submerged conditions. These are areas which could be best suited to grow three crops, e.g.,

Crops	Sowing	Harvesting
Early "Aus" (Irrigated)	April	June
Cereal like <i>Mung</i> , Pulses (Rain-fed)	August	September
Wheat, Potato, etc. (Irrigated)	November	March

The above crop planning is possible if the sowing month schedule as in above can be adhered to. In the present context of things, it is impossible to sow "Aus" in the month of April in view of the fact that without the early monsoon shower or the normal north-western shower, it is impossible to plough up fields in the high lands which remain as

stony and hard dry as rocks, and not to speak of bullock driven implement, even the tractor implements cannot penetrate into the soil. The time of sowing, therefore, entirely depends on the whims of nature. It is when sufficient rainfall is available and soil is moist that the cultivator goes into the fields and puts his plough in and then only, the Aus paddy can be grown. As a result, the sowing schedule is shifted to middle of May at the earliest with north-western showers and not earlier and this being the time crop requiring about three months to harvest, the Aus can be harvested by end of August and not before that. In case of lands, which are subject to flooding, it often happens that the flood water enters by mid August, and washes away the golden grains of the Aus paddy when they are ready for harvest. Under the existing order of things, therefore, there is no question of three crops growing and as a matter of fact, with late north-western showers, the farmer will probably be left with only one positive chance of crop in high land in November-February period and this will yield him very scanty harvest in the absence of irrigation. The cultivators would naturally, therefore, find it a positive gain and advantage if they could sow the Aus much earlier so that they could be sure of the crop and could even possibly put in a second crop in between this crop and finally the *rabi* crop as the third one.

From what has been stated above, it will be apparent that if there is full control of water in the hands of the cultivators, nothing prevents him from sowing the Aus paddy early in April. In the Government Farms of West Bengal where there are tube-wells provided for irrigation and any other private lands also where irrigation facilities exist it is becoming a common practice to sow in early Aus crop enabling him to harvest two more crops from his field.

In this process of growing the Aus paddy one must know the requirement of water for this crop. If this is unknown, it will be difficult to establish the agricultural economics of irrigation in an overall planning for the whole year's cropping, and then again, this will be extremely necessary for those Engineers, who will be called upon to design the reservoirs, which will have to supply irrigation water to the Aus crop. This April-June is a time whose early part represents

the driest sector of the year, and then the water transmission loss due to seepage will be enormous—may be even to the extent of 75 per cent as the entire high land is desert dry. The question of assessment of water requirement for growing the early Aus crop, is therefore, of paramount importance to understand the significance of economics of irrigation to justify the three crop planning in consonance thereof. With this end in view, the water requirement study of Aus paddy has been taken up.

Layout of the Experiment

This experiment has been started in the Government Agricultural Farm at Kalyani where a piece of land measuring about 0.4 ha. (one acre) has been taken and has been segmented into 25 plots, each measuring 0.017 hectares (0.043 acres) and each imperviously lined on four sides by underground masonry walls carried 1.2 m. (4 ft.) below ground level, and 15.2 cm. (6 in.) above. After the land has been levelled and the plot segments made with impervious walls, the plots have been levelled and irrigation water brought in. This water has been brought through a system of 5.1 cm. (2 in.) diameter G. I. pipes, connected to a reservoir of a deep tube-well. The leading pipe line can feed each of the plots through tap openings, and it has been so arranged that watermeter or portable V-notch can be fitted on the mouthpieces so that the quantity of water applied in any plot can be measured with precision. The 25 plots provide for 8 treatments with three replications and with one control. Prior to the preparation of land, as stated earlier, quite a good amount of irrigation water had to be given to the field to saturate the soil so that ploughing becomes possible. This pre-sowing water for making the field ready has also been taken into consideration as an indispensable quantity of water required for growing this crop. After the fields have been made sufficient moist tillage operation was started.

Soil Texture

Representative soils from the experimental plots were taken to the chemical laboratory and physical properties of the soils have been examined. The analysis of the soil reveals the following physical properties:—

Sand	. . . . .	66.6 per cent
Silt	. . . . .	22.1 per cent
Clay	. . . . .	11.3 per cent

It will thus be seen that from the study of the soil texture classification as stated earlier this soil of Kalyani Farm under experiment can be termed as 'sandy loam soil'. The apparent specific gravity has come out to be 0.66.

Moisture Equivalent and Wilting Coefficient

The moisture equivalent of the Kalyani soil under experiment has been determined by a standard centrifuge in the chemical laboratory. The moisture equivalent for this soil has been found to be 12.7 per cent. The wilting coefficient for this soil has also been determined in the chemical laboratory, and the result has come out to be 6.5 per cent.

Source and Conveyance of Water in the Experimental Plots

In this plot under experiment the irrigation water has been fed from the main tube-well of the farm. This tube-well sunk to a depth of 121.9 m. (400 ft.) with 22.8 cm. (9 in.) strainer 29.2 m. (96 ft.) in length and driven by a 15 H.P./A.C. motor with three stage turbine pump is yielding a discharge of 1,85,000 litres (40,700 gallons) of water per hour. This water is collected in the reservoir, and therefrom through underground main pipe line system, is carried to spouts which feed the lined irrigation channels. In this particular plot chosen for experiment, a pipe line has been directly connected from one of the spouts, and water carried under pressure through a 7.6 cm. (3 in.) main and 5.1 cm. (2 in.) distribution system. This distribution system consists of a network of pipe lines feeding every plot through a Globe Wheel valve wherein the measuring apparatus watermeter or a V-notch is fitted prior to its transmission through a hose pipe. The plots are very carefully levelled and with the opening of any valve irrigation water is spread into any plot through hose pipes and through the readings either in the meter or in the V-notch, the correct quantity of water can be measured which is coming over to any plot for irrigation. This volumetric measurement is converted to depth of water applied in inches and in this fashion, correct irrigation water applied for each application measured as depth in inches has been recorded for each plot. The fieldman incharge knows the irrigation schedule and adjusts his time of water application through V-notch and metres for

any water application, 3.8 or 5.1 cm. ($1\frac{1}{2}$ in. or 2 in.), etc.

Measurement of Rainfall and Evaporation

Systematically throughout the period of crop growth, rainfall record has been kept by a standard rain-gauge. The rain-water is collected at 8 A.M. in the morning and records kept in the register. The record of the rainfall has been tabulated graphically. The evaporation pan has been used in the measurement of evaporation. This consists of a standard pan 1.3 m. (4 ft. 6 in.) in diameter and 0.3 m. (1 ft.) in height made of 6.3 mm. ($\frac{1}{4}$ in.) thick M.S. Plate. This pan has been placed on a masonry platform 15.2 cm. (6 in.) above the ground level as per standard recommended. A marking gauge with a pointer reads the water-level 22.8 cm. (9 in.) from the bottom. The pan is kept full up to the mark and at the end of each 12 hours in day and night evaporation is measured by pouring known volume of water in the pan to raise the level to its original mark. The evaporation readings have been given in a graphical pattern. Humidity has also been recorded by dry and weight bulb thermometres and the readings have been graphically plotted.

Measurement of Soil Moisture

In the process of measurement of soil moisture, we have adopted the latest potentiometer and gypsum block method. With this method gypsum blocks had been embedded at different levels below ground level 15.2 cm., 0.3 m., 0.6 m., 0.9 m. (6 in., 1 ft., 2 ft., 3 ft.) underneath the surface. The two electrodes connected to each gypsum block placed at different levels were brought up to the surface of the earth. In order that these electrodes do not get jammed or are not damaged by any cultivation process, these have been led through a 1.9 cm. ($\frac{3}{4}$ in.) diameter tube, which has been inserted about 1.2 m. (4 ft.) below ground level and apertures have been made 15.2 cm., 0.3 m., 0.6 m., 0.9 m. (6 in., 1 ft., 2 ft., 3 ft.) below ground level and through these apertures the electrodes from different levels having been differently coloured for identification had been brought up to the surface level. Potentiometer connected to mains had been put into operation, and this portable potentiometer is taken to the field just close to the embedded pipe and the

electrodes across any block at any level connected to same and the resistance readings in ohms are taken against the electrodes of the different blocks. Now as this potentiometer has been calibrated in the chemical laboratory against the percentage of moisture content of the soil, it becomes easy to immediately read the moisture content percentage at different levels below the soil on a study of the reading of the potentiometer. In this way moisture percentage before sowing of crop and after harvest of crop has been determined.

Experimental Details and Consumptive Use

Herein in this experiment we have applied different doses of water in two systems of dose variation, *i.e.*, one set of 4 experimental plots got four different doses and the other four sets got the same total irrigation dose but with difference in dose application in intensity.

The moisture content of the plots were measured prior to application of water and then after the harvesting of the crops. The net difference shows the absorption by the plant from the soil.

During the course of experiment, rainfall and evaporation was regularly measured by rain-gauge and standard evaporimeter.

Water absorption at each plot was, therefore, the total of the irrigation water applied through each irrigation and to this was added the rainfall during the period as also the net difference in soil moisture all expressed in inches of water assuming surface run-off to be nil as the plots were carefully levelled and as against this, the crop out-turn in grain and straw calculated. See Part I for total consumptive use.

$$U = W_i + W_r - W_o + W_m$$

To elaborate the field man's diary will perhaps be interesting reading. In our irrigation planning. if we have, for example, desired to put 5.1 cm. (2 in.) of water in any plot, we have, on calculation, determined that an inch of water on 0.017 ha. (0.043 acre) which represents the area of any plot will mean a total of 454.6 litres (100 gallons). In an application for 5.1 cm. (2 in.) of water the field man knows that he will have to give 5,092 litres (2000 gallons) of water through the mouthpiece into any plot. In this mouth-

piece if fitted a watermeter, and therefore, the field man takes the initial meter reading and stops the regulating valve as soon as the water reading meter has recorded a flow of 5,092 litres (2000 gallons) of water into the plot. To ensure equal distribution a small rubber hose pipe with a nozzle is fitted for distribution of water into any plot. The size of the plot being 13.9 m. \times 12.3 m. (45 ft. 6 in. \times 40 ft. 6 in.) it is quite easy to control equal distribution through the nozzle. The field man thus ensures that a particular plot has got 5.1 cm. (2 in.) of water. In this way in his field work book he records the different doses that he has applied to the different plots, as per irrigation plan made earlier and as per his own readings through the current metre or V-notch.

In regard to the rainfall reading, there is not much of difficulty as the field man keeps his entry of the rain-gauge reading, and as such, the daily rainfall record throughout the crop period is known to him. In regard to the soil moisture reading, there again, it has been much simplified, as the portable potentiometer is just brought close to the electrode carrying tube and potentiometer reading taken by connecting to electrodes for each different level. These records are then sent to the headquarters once prior to irrigation and once after the harvest is over. At the headquarters where the calibration has been determined earlier, it becomes quite easy to record the moisture percentage at each level below the surface. After the crop has been harvested a few standing crops are taken out at random extracting from below the root level, and on visual inspection, the root zone level is determined, and the soil moisture difference at this root zone level can be found out from the records maintained.

For border correction, a border strip of 0.7 m. (2 ft. 6 in.) all round is left out of consideration while weighing the grain and straw. The plot from which the crop is thus actually harvested after leaving the border comes to 0.013 hectares (0.033 acre).

Time and Frequency of Irrigation

In regard to the time and frequency of irrigation, we have adopted the fundamental principle to apply plenty of water in the germination period and more up to the flowering

time, and then a decreasing amount during the maturing period and none at all during ripening.

In the 25 experimental plots leaving out one as controlled plot, three replications have been adopted with 8 variations in doses of water to see the reaction on the yield of grain and straw. The variations in doses in the different plots are tabulated below :

Plot No.	Irrigation dose	Total water in inches
1, 5, 9	8 irrigations 1 in. each	8
2, 6, 10	8 irrigations $1\frac{1}{2}$ in. each	12
3, 7, 11	8 irrigations 2 in. each	16
4, 8, 12	8 irrigations 3 in. each	24
13	No irrigation (controlled plot)	
14, 18, 22	2 in. + 2 in. + 1 in. + 1 in. + $\frac{1}{2}$ in. + $\frac{1}{2}$ in. + $\frac{1}{2}$ in. + $\frac{1}{2}$ in.	8
15, 19, 23	4 in. + 2 in. + $1\frac{1}{2}$ in. + $1\frac{1}{2}$ in. + 1 in. + 1 in. + $\frac{1}{2}$ in. + $\frac{1}{2}$ in.	12
16, 20, 24	4 in. + 4 in. + $2\frac{1}{2}$ in. + $2\frac{1}{2}$ in. + 1 in. + 1 in. + $\frac{1}{2}$ in. + $\frac{1}{2}$ in.	16
17, 21, 25	4 in. + 4 in. + 4 in. + 3 in. + 3 in. + 2 in. + 2 in. + 2 in.	24

1 in. = 2.54 cm.

In regard to the actual date of irrigation controlling the frequency we have to go by the field condition, the nature of the colour and crop growth and we have also taken care to see that the field moisture content does not approach the wilting zone condition.

Experimental Results

(1) The maximum yield averaging 3.68 tonnes per hectare (40 md. per acre) has been available, which is 50 per cent above the yield from the controlled plot—which is only 2.39 tonnes/ha. (26 md. per acre) or in other words, the difference in yield between the irrigated and non-irrigated plot is 50 per cent more other conditions remaining equal.

(2) In the particular experiment the maximum result on an average has been obtained by 9 irrigations of 7.6 cm. (3 in.) each, *i.e.*, 68.6 cm. (27 in.) in all as also by an application of 53.3 cm. ($16\frac{1}{2}$ in.) of water with higher doses in the earlier stage 10.2 cm. + 10.2 cm. + 6.3 cm. + 6.3 cm. + 2.5 cm. + 2.5 cm. + 1.3 cm. + 1.3 cm. +

1.3 cm. = 41.9 cm. (4 in. + 4 in. + 2½ in. + 2½ in. + 1 in. + 1 in. + ½ in. + ½ in. + ½ in. = 16½ in.)

(3) The earlier application of heavier dose contributes to better yield per acre. For example, a total application of 21.6 cm. (8½ in.) in the form of 5.1 cm. (2 in.) distribution in earlier stages and 1.3 cm. (½ in.) distribution at later stages has been more effective than a total distribution of 22.8 cm. (9 in.) with 2.5 cm. (1 in.) application throughout. As a matter of fact, the 21.6 cm. (8½ in.) application with increased dose in the earlier stages has given as much result as

34.3 cm. (13½ in.) with 9 equal doses of 3.8 cm. (1½ in.) each.

(4) The optimum and best result seems to have been achieved by an application of 41.9 cm. (16½ in.) of water in the doses of 10.2 cm. + 10.2 cm. + 6.3 cm. + 6.3 cm. + 2.5 cm. + 2.5 cm. + 1.3 cm. + 1.3 cm. + 1.3 cm. = 41.9 cm. (4 in. + 4 in. + 2½ in. + 2½ in. + 1 in. + 1 in. + ½ in. + ½ in. + ½ in. = 16½ in.). This has given about 3.68 tonnes per ha. (40 md. per acre) virtually equivalent to what has been obtained by an application of 68.6 cm. (27 in.) of water in 9 applications of 7.6 cm. (3 in.) each.

STUDIES ON WATER REQUIREMENTS OF CROPS

by

D. Doddiah*

Introduction

With the creation of more and more irrigational supplies, their strict regulation and timely distribution for maximum economy require greater and careful consideration. As the bulk of the stored water is utilised for growing crops, judicious use of water cannot be effected unless we know the needs of different crops. Over-irrigation is as bad as under-irrigation. In the absence of reliable data, the tendency is to use more water than is necessary. With such use, there is not only wastage of water, but there are other ill effects such as water-logging, salt efflorescence, etc. Optimum utilisation of available supplies and also the supplies to be built up in future, therefore, depends to a large extent on a knowledge of the requirement of water by various crops and application of this knowledge with necessary executive, educative and legislative measures. This paper deals with a review of the various factors that affect the water requirements of crops, present status of the knowledge and future planning for a better and more rational utilisation of irrigational supplies.

Factors Affecting Requirement of Water by Crops

The factors that influence the quantity of water required by crops directly or indirectly may be grouped under the following heads :—

- (a) *Factors pertaining to Climatology*
 - (i) Rainfall, its incidence and its distribution during the crop period,
 - (ii) Temperature,
 - (iii) Wind movement,
 - (iv) Soil evaporation, and
 - (v) Relative humidity.
- (b) *Factors pertaining to Soil and Topography*
 - (i) Type of soil, its texture in relation to moisture storage capacity,

- (ii) Soil fertility,
- (iii) Sub-soil water-table and,
- (iv) Slope of the ground.
- (c) *Factors pertaining to Cultivation*
 - (i) The system of irrigation adopted,
 - (ii) Drainage conditions,
 - (iii) Types and quantities of manure supplied,
 - (iv) Extent of mechanisation in the operations,
 - (v) Size of irrigation beds,
 - (vi) Time of sowing,
 - (vii) Preparation of land surface,
 - (viii) The variety of seeds, and
 - (ix) Double cropping and inter-cropping.
- (d) *Factors pertaining to the Water Supplied*
 - (i) Incidence and depth of irrigation,
 - (ii) Quality of water, both chemical and physical, and
 - (iii) Methods of delivery of water to the field.
- (e) *Factors pertaining to Socio-economic Conditions*
 - (i) Superstitious practices,
 - (ii) Educative propaganda and publicity,
 - (iii) Insurance against crop failure,
 - (iv) Incentives,
 - (v) Legislation.

The number and variety of factors indicate that a comprehensive and continuous study spread, perhaps, over a period of years and in various parts of the country is required. Brief review of the work that has so far been carried out to find out the effect of the various factors either individually or collectively on the quantity of water required by crops is given below.

(a) *Factors pertaining to Climatology*

Rainfall during the crop period lowers irrigation requirements provided the amount at a time is more than 1.3 cm. (0.5 in.). If less, it may add little to soil moisture for plant

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transpiration and will be lost by evaporation. Winter and spring precipitation may enable moisture to be stored in the soil for utilisation in the early part of the growing season.

The rate of consumption of water by any crop in a particular locality is probably affected more by temperature than by any other factor. While abnormally low temperatures may retard the plant growth, unusual high temperatures may produce dormancy. Transpiration is influenced both by temperature and also by the area of leaf surface and physiologic needs of the plant as related to the state of maturity. Higher water use is associated with high temperature, low humidity and long sunny days.

Evaporation from plant and soil increases more rapidly with the movement of the wind. Hot dry winds and other unusual wind conditions during the growing period affect the amount of water use.

(b) Factors pertaining to Soil and Topography

Clay and fine textured soils hold more water than coarse soils. The loss of water sustained by the plant in the process of transpiration necessitates a corresponding replenishment absorbed from the soils. Consequently, for proper development and health of plants the soil should be capable of delivering the required quantity of water to the plants. But as the moisture content decreases, the soil particles develop a force or back-pull by the virtue of which they tend to retain their water. A stage is then reached when the plant roots cannot take water fast enough to satisfy their transpiration requirements. Frequency of irrigation should be such that such a condition is not allowed to develop.

Fertility is defined as the quality of soil to aid plant growth by supplying nutrients in desirable proportion and amount. It can be varied by the application of different manures

both inorganic and organic. Different types of manure and dosages have to be supplied depending upon the type of crop. Manure undoubtedly increases the growth height, tiller number and total dry matter per plant.

Experiments have shown that there is correlation between low water requirements and high yield and between high water expenditure and high degree of fertility. In general, the fertility of soil by the addition of manures reduces the quantity of water required for unit dry matter production but enhances the total quantity of water transpired by the crop.

(c) Factors pertaining to Cultivation

The system of irrigation may be either continuous or intermittent. Studies indicate that intermittent supply is more fruitful than continuous supply. It gives scope for aeration of the area and the root zone. Studies in the Mysore Engineering Research Station, have shown that if, instead of supplying continuously water for paddy crop, it is supplied only for 5 days in a week, the yield is not only diminished but on the other hand it increases slightly.

Experiments have been conducted to investigate whether different varieties of the same crop show appreciable difference as regards their water requirements. It has been found that some varieties are more efficient in this respect. Further, results indicate varieties of the same crop differ widely in their water requirements [Tables I(a) and I(b)]. Table II gives the relevant efficiency of water requirements of different crops taking sugarcane as one.

This wide range in water requirements among varieties of the same crop reveals the possibility that strains which are still more efficient in the use of water than those now grown can yet be evolved emphasising continued experimentation.

TABLE I(a)
Water Requirements of Different Varieties of Wheat at Banaras.

Variety of crop plant	Period of growth	Average dry matter per plant in grams	Average grain yield per plant in grams	Average transpiration per plant in kilos	Transpiration ratio based on	
					Dry matter in grams	Yield in grams
Wheat Pusa 12	Dec. 6 March 4	21.670	6.360	8.264	381±6	1299±9
Wheat Kanpur 13	"	19.620	7.840	7.893	402±7	1007±11
Wheat Pusa 4	"	17.810	5.690	7.479	420±5	1314±14
Wheat Pusa 52	"	17.840	5.640	7.676	430±3	1361±16
Average		19.235	6.382	7.828	408	1245

TABLE I(b)
Relative Efficiency of Water Requirements of Different Varieties of Wheat.

Variety of crop plant	Relative efficiency
Pusa 12	1.00
Kanpur 13	1.06
Pusa 4	1.10
Pusa 52	1.13

TABLE II
Relative Efficiency of Water Requirements of Different Crops.

Crop plant	Relative efficiency of water requirements	Crop plant	Relative efficiency of water requirements
Sugar-cane	1.000	Barley	2.788
Wheat	1.894	Pea	2.841
Cotton	1.941	Oats	3.135
Potato	2.059	Tobacco	4.128
Rice	2.410	Linseed	4.371
Mustard	2.427		

TABLE III(a)
Variation of Temperature, Rainfall and Humidity in January, 1958-1962.

Year	Temperature		Rainfall		Humidity		
	M.D. of the max.	M.D. of the min.	M.D. of the total in 24 hrs. during the month	M.D. of the total rainfall	M.D. of the max.	M.D. of the min.	M.D. of the average
1958	-0.24	0.34	-0.16	-0.29	2	-12.4	-2.42
1959	0.36	0.34	-0.16	-0.29	-3	-8.6	3.18
1960	-0.24	0.34	-0.16	-0.29	-3	-4.4	-4.62
1961	0.36	-1.36	0.42	0.71	2	2.6	-0.42
1962	-0.24	0.34	0.06	0.14	2	5.6	+4.28
Mean	30.24	14.66	0.16	0.29	93	62.4	78.12

TABLE III(b)
Variation in April, 1958-62.

1958	-0.8	0.6	0.10	0.35	-0.6	-3.4	-1.9
1959	0.4	0.7	0.68	-2.29	-4.6	-1.9	-2.2
1960	0.8	-1.0	-0.72	-0.28	-0.6	5.6	1.3
1961	0.9	-0.5	0.59	-0.66	-0.6	-1.4	0.6
1962	0.4	0.1	0.87	2.17	7.4	2.2	2.3
Mean	35.22	19.88	1.326	3.052	86.6	64.4	77.12

TABLE III(c)
Variation in July, 1958-62.

1958	0.8	0.9	-0.22	-0.29	-2.6	-1.4	-0.7
1959	-2.0	-0.8	-0.35	-0.11	-2.6	0.6	1.4
1960	1.3	0.3	0.53	0.11	2.4	-2.4	-1.4
1961	-3.1	-0.3	0.43	1.65	2.4	5.6	3.3
1962	3.3	0.3	-0.37	-0.24	0.4	-2.4	-2.7
Mean	30.3	19.7	0.952	2.356	94.0	65.6	79.48

TABLE III(d)
Variation in October, 1958-62.

1958	-1.1	-0.1	-0.15	0.13	-0.6	2.4	-1.2
1959	-0.5	0.4	-0.19	-3.44	3.4	3.4	3.0
1960	1.1	0.8	0.61	0.18	8.4	-7.6	-3.4
1961	0	-0.1	-0.19	0.89	8.4	1.4	-0.6
1962	0.6	1.0	-0.07	-2.23	10.4	0.4	2.8
Mean	30.52	19.0	1.502	5.618	86.6	72.6	82.76

M.D. : Mean Deviation.

(d) Factors pertaining to the Water Supplied

Studies by Uttar Pradesh Research Station on the periodicity and depth of irrigation show significant effect on the water requirements and yield. For instance, 10.2 cm. (4 in.) depth of irrigation at an interval of 3 days for sugar-cane gave the maximum yield.

Silt and salts present in water will also affect the water requirements and yield. Improved and economical use of water will be better appreciated if water is measured and supplied on payment. The quantity above as prescribed minimum may be charged.

(e) Factors pertaining to Socio-economic Conditions

Socio-economic factors have also a bearing on the use of irrigation supplies. Practices which are sometimes governed by superstition and prejudices come in the way of improved methods conducive to economy in the use of water being adopted. Weaning the ryots away from such practices may be possible by patient and continued education and intelligent propaganda. It may sometimes be necessary to introduce an element of compulsion where persuasion fails when it is in the interest of the community as a whole.

An analysis of the review indicates that the factors that affect the requirement of water by crops are many and varied. The factors coming under the first group cannot be controlled. It may however be noted that the totality of the effect of climatological factors in a given area and during corresponding months year after year does not vary appreciably as indicated in Table III (a-d). The factors in the second group may change over a given area in a period of year or two because of the agricultural practices. The factors coming in the other three groups can be controlled to a large extent.

Studies have reached a stage when it is possible to say generally the nature and the extent of the effect of various factors on the water requirements of crops. Some are responsible for increasing the water requirement while others help to decrease that quantity. It may not be necessary and even practicable to evaluate the effect of each factor on the water requirement individually but the effects of two or more and specially of those which can be controlled require to be subjected to

continuous investigation both basic and applied.

Basic Research

Basic research is necessary where the effect of a single factor requires to be evaluated keeping others constant. Rigid control and elaborate instrumentation may be necessary. The following aspects among others, require continuous study :

- (a) Variation in the consumption of water during different stages in the growth, *viz.*, seedling, vegetative, reproductive, *etc.*, of various crops.
- (b) Evolving different varieties—early maturing, blast resistant, salt resistant, deep water resistant, insect resistant, *etc.*, hybridization.
- (c) Maximum yield *versus* optimum yield.
- (d) Combination of fertilisers to give maximum yield with minimum consumption of water.
- (e) Optimum spacing, fertiliser placement, *etc.*
- (f) Weed control.

Applied Studies

Field study connotes experimentation making use of large areas. It may be 4.0 hectares, 40-6 hectares (10 acres, 1000 acres) or more. The entire area receiving supply from a pipe outlet or commanded by a small distributary may be utilised.

The amount of water supplied for irrigation should be sufficient to meet the demand of the crop plants for transpiration and losses due to evaporation, seepage and percolation. For proper and healthy growth of the plant, certain moisture in the soil should be maintained. To maintain this quantity, at all times, one should know two important soil moisture properties, *viz.*, field capacity and permanent wilting point. Field studies should, therefore, be directed to find out reliable methods for obtaining these values so that incidence and depth of irrigation could be adjusted to maintain the optimum moisture content in the soil.

Field Control for Irrigation Requirements

Engineers are familiar with the 'Field Control' in connection with the construction of big engineering works. Irrigation as practised in India with such vast land, water and human resources may be considered as the biggest venture. It is, therefore, time to think of establishing 'Field Control' for controlling and regulating the supplies of water according to the needs of the crop and as estimated by a knowledge of the soil moisture constants. For a given crop on a given area and with the aid of data available from basic and semi-field studies and instrumentation already developed, this should be possible.

In some of the studies made on water requirement of crops, by the Agricultural Department in Mysore, irrigation by judgement has given the highest yield. This indicates that like an experienced embankment inspector, an agronomist may be able to tell when irrigation has to be resorted to and to what extent. Such field control may be applied to selected reaches to begin with. These reaches should be adjacent to those irrigated without any control. The owners of lands selected for field control may have to be assured of as much yield as his neighbour without field control would get. Both the engineers and the agronomist are required to pool their resources to established and operate such 'Field Control' units.

Conclusions

For optimum utilisation of available supplies of water and those that are being created by the investment of *crores* of rupees, year after year, a thorough knowledge of water requirement of crops is indispensable.

While basic research might continue, the application of irrigation practices conducive to the realisation of the optimum use of water requires to be put into practice in the irrigated areas. Coordinated efforts of both the engineer and the agronomist are required

in the practical application of the knowledge already available on the subject. Establishing and operating 'Field Control' units with necessary staff and instrumentation for this purpose seem to be urgent.

Irrigation practices which are proved to be beneficial should be insisted upon for adoption by offering incentives and awards, if necessary. Where persuasion fails benevolent compulsion seem to be urgent.

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PHYSIOLOGICAL STUDIES ON WATER RELATION OF RICE

by

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Knowledge of water relation at various phases of growth and development of rice is necessary for making proper utilization of irrigation and fertilizer. But, unfortunately the fundamental facts regarding the desirable soil-water relationship during the growth of the crop has not been properly evaluated. Rice is considered to have differential water requirements at different phases of growth and development and such differences vary according to varieties and prevailing climatic conditions. Water requirements also show variations due to application of fertilizers. A thorough investigation is, therefore, highly essential to study the response of the rice plants under different conditions. Determination of its optimum water requirement, and the critical stages of watering and interrelations of watering with the important major nutrient factors are of much practical importance.

With the view to elucidating differences in water utilization due to growth phases, varieties and climatic factors, and to determine physiological processes, *i.e.*, transpiration rate, osmotic pressure of leaf tissues and anatomical peculiarities of the plants as may be related to differential water relations and the differential capacities of the different varieties to tolerate drought with a minimum of adverse effect, the present investigation has been taken up in the Department of Agriculture, Calcutta University since 1960. Experiments were carried out in each of the three rice growing season (November-April), and (3) Summer, (June-December), (2) Spring, *i.e.*, *Boro* seasons, *viz.*, (1) Winter, *i.e.*, *Aman* season *i.e.*, *Aus* season, (April-July). This investigation may in due course develop into an important line of research on the physiological genetics of rice with reference to its water relations.

The effects of water supply in each season have been studied in pot culture under vary-

ing conditions of water, maintained in suitably constructed cemented tanks (Sen, 1937) at different stages of growth.

Three basic soil water conditions are as follows:—

- (1) Dry: Pots in dry tanks, watered regularly to maintain a certain condition of soil moisture in order to prevent wilting of the plants.
- (2) Saturated: Pots in tank having water up to soil surface.
- (3) Submerged: Pots in tank having water 7.6 cm. (3 in.) (submerged-I) and 15.2 cm. (6 in.) (submerged-II) above soil surface.

The varying levels of watering treatments are chosen on the basis of results of certain previous experiments carried in India (Singh *et al* 1935, Sen 1937, Ghosh 1949 and 1954). The six different watering treatments based on the above mentioned soil-water conditions are as follows:—

- (a) Dry throughout.
- (b) Dry during germination and pre-tillering, saturated from tillering to flowering, dry again during post-flowering.
- (c) Dry during germination, saturated during pre-tillering, submerged-I during tillering and pre-flowering, saturated again during flowering and dry finally during post-flowering.
- (d) Saturated throughout.
- (e) Saturated during germination and pre-tillering, submerged-I during tillering and pre-flowering, saturated again during flowering and dry finally during post-flowering.
- (f) Saturated during germination, submerged-I during pre-tillering, submerged-II during tillering and pre-

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flowering, submerged during flowering and saturated finally during post-flowering.

The optimum effect of watering treatment "C" in respect of growth and yield has been confirmed irrespective of seasons and varieties. Interesting effects of watering treatments on varietal differences in growth and yield have also been observed. These informations suggest appreciable economy in water-duty in rice crop. Among the three seasonal groups *Boro* has given maximum tillering and yield, *Aus* minimum and *Aman*, the main season crop, occupying intermediate position.

Studies on the osmotic pressure of leaf-tissues have revealed varietal differences as well as differences due to watering treatments. Osmotic pressure decreases with increase in the level of water. Variations in the micro-climate have also shown effect on osmotic pressure of the leaf-tissue. Among the three seasonal groups of rice *Aus* shows maximum osmotic pressure, *Boro* intermediate and *Aman* minimum.

Transpiration rate has shown differences due to watering treatments as well as due to varieties. Rate of transpiration is inversely proportional to the osmotic pressure of leaf-cells. It is also influenced by the micro-climate. Rate of transpiration is maximum

during the phase of growth between peak-tillering and pre-flowering. It falls during the boot-stage but shows a rise again during anthesis, thereafter it falls steadily. Thus transpiration curve shows two humps indicating the critical stages of water requirements. Leaf-water content shows a direct relationship with the rate of transpiration. Among the three seasonal rice groups *Aus* shows maximum transpiration rate, *Boro* intermediate and *Aman* minimum.

The anatomical studies reveal that the different levels of watering have pronounced effects on the cellular structure of plants. Some of the varieties from the three seasonal groups of rice show their greater ecological adaptability to a wide range of soil-water variations.

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OPTIMUM REQUIREMENTS AND UTILIZATION OF WATER FOR IRRIGATED CROPS IN GUJARAT STATE

by

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Water is the limiting factor in crop production in Gujarat State and, therefore, the State has provided Rs. 6,674 lakhs for multipurpose, major, medium and minor irrigation projects out of a total provision of Rs. 23,500 lakhs in the Third Plan.

Raheja (1961) worked out water requirements of cotton, groundnut, rice, wheat, *bajra* (*Pennisetum typhoides*) and *jowar*—(*Sorghum vulgare*) crops of India as 76.2, 63.5, 139.7, 61 and 50.8 cm. (30, 25, 55, 24 and 20 in.) respectively. In U.S.A. cotton in California needs 61 to 76.2 cm. (24 to 30 in.) while in Arizona, annual water use of this cotton is considered as 101.6 cm. (36.4 in.). Matlock mentioned 63.5 cm. (25 in.) as water requirements of groundnut. In Turkey, Beyce and Boyaci (1962) mentioned 480 to 692 mm. as consumptive use of cotton crop and 462 to 563 mm. for groundnut crop. In Iran, 89.9 cm. (35.4 in.) water is applied to cotton (Iravani, 1962).

Out of 98.7 lakh hectares (224 lakh acres) under cultivation in Gujarat State, nearly 50 per cent is situated in tracts which receive less than 76.2 cm. (30 in.) annual rainfall, mostly from last week of June to first half of September and that also is unevenly distributed. Famine and scarcity are experienced often in parts of the State which upsets the stabilised and planned production of agricultural crops. Before plan periods, the State had only 2023.43 hectare (5000 acre) under canal, 12.93 lakh hectare (7 lakh acre) under well and 39659.2 hectare (98,000 acre) under tank irrigation making a total 349648 hectare (8,64,000 acre) under irrigation. This has been increased to 6.68 lakh hectare (16.5 lakh acre) during 1960-61 which includes 5.54 lakh hectare (13.7 lakh acre) under well irrigation. It is calculated that when full benefits from all

irrigation projects included in First and Second Plans and Ukai and Narmada Projects are obtained, the total area brought under irrigation including minor irrigation projects will work out to only 20 per cent 19.42 lakh hectare (48 lakh acre) of gross cropped area. During the Third Plan period, additional 7.00 lakh hectare (17.3 lakh acre) irrigation potential will be created as under :—

Major projects	271849 ha. (6,72,000 acre)
Medium projects	163898 ha. (4,05,000 acre)
Tub-wells, tanks, etc.	97529 ha. (2,41,000 acre)
Surface wells, engine pumps, etc.	165921 ha. (4,10,000 acre)

The multipurpose projects of Ukai, Kadana, Narmada and spillover of Mahi and Kakrapar Projects will create additional potential of 6.68 lakh hectare (16.5 lakh acre) during the Fourth Plan.

Objectives

In any irrigation project, we are mainly concerned with improving the degree to which we understand our basic problems and with disseminating the results of research. As per recommendations of Fourth NESA Irrigation Practices Seminar held at Ankara in 1962 the field irrigation research should consist of :—

- (1) Irrigation practices consisting of timing of irrigation, irrigation methods and farm irrigation systems.
- (2) Agricultural practices consisting of cropping patterns and crop rotations.

The Trial-cum-Demonstration Farms started in 1958-59 and afterwards in the areas of command of the major, medium and tube-

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well irrigation projects, undertook research as under :—

- (1) To find out suitable irrigation practices consisting of irrigation requirements, *i.e.*, number of irrigations and their intervals.
- (2) To find out the suitable varieties of crops that give good response to irrigation.
- (3) To find out agronomic and cultural practices for highly responsive varieties.
- (4) To introduce new irrigated crops as supplements or substitutes of crops grown in the tracts.

The details of these Trial-cum-Demonstration Farms are given in Table I and Figure I.

The results of these two-three years cannot be considered conclusive. However, some

experiments have indicated definite trends as discussed hereafter.

Experimental

Cotton

The cotton crop occupying 18.21 *lakh* ha. (45 *lakh* acre) in the State, belongs to the species of herbaceum, hirsutum and arboreum. The first two start reproductive stage after ceasation of S.W. monsoon by September and mature by February-March. The supplementary post-monsoon irrigations are considered beneficial for maximising production. The experimemnts laid out on this crop are discussed below :

EXPERIMENTS OF NUMBER OF IRRIGATIONS

- (a) The experiment of herbaceum 2087 cotton laid out at Bardoli, Kholwad and Kim having six replications randomised is given in Table II.

TABLE I

Agroclimatic Conditions of Irrigation Research Stations in Gujarat State.

Sl. No.	Stations	District	Soil group	Soil type	Annual rainfall in in.
1.	Chikhli	Surat	Black (deep)	Clayey	67
2.	Bardoli	"	"	"	58
3.	Kim	"	"	"	48
4.	Kholwad	"	"	"	55
5.	Dabhoi	Baroda	Mixture of black and Alluvium	Clay loam	47
6.	Thasra	Kaira	Alluvial	Loamy	36
7.	Dehgam	Ahmedabad	"	Sandy loam	55
8.	Pilwai	Mehsana	"	"	32
9.	Chanasma	"	"	"	27
10.	Deesa	Banaskantha	"	"	28
11.	Halwad	Surendranagar	"	Sandy	23
12.	Kukda	"	Medium black	Loamy	24
13.	Jamnagar	Jamnagar	Alluvial	Sandy	20
14.	Umrals	Bhavnagar	Mixture of black and coastal alluvium	Clay loam	29
15.	Talaja	"	Medium black	"	30
16.	Junagadh	Junagadh	Black (Medium calcareous)	"	40

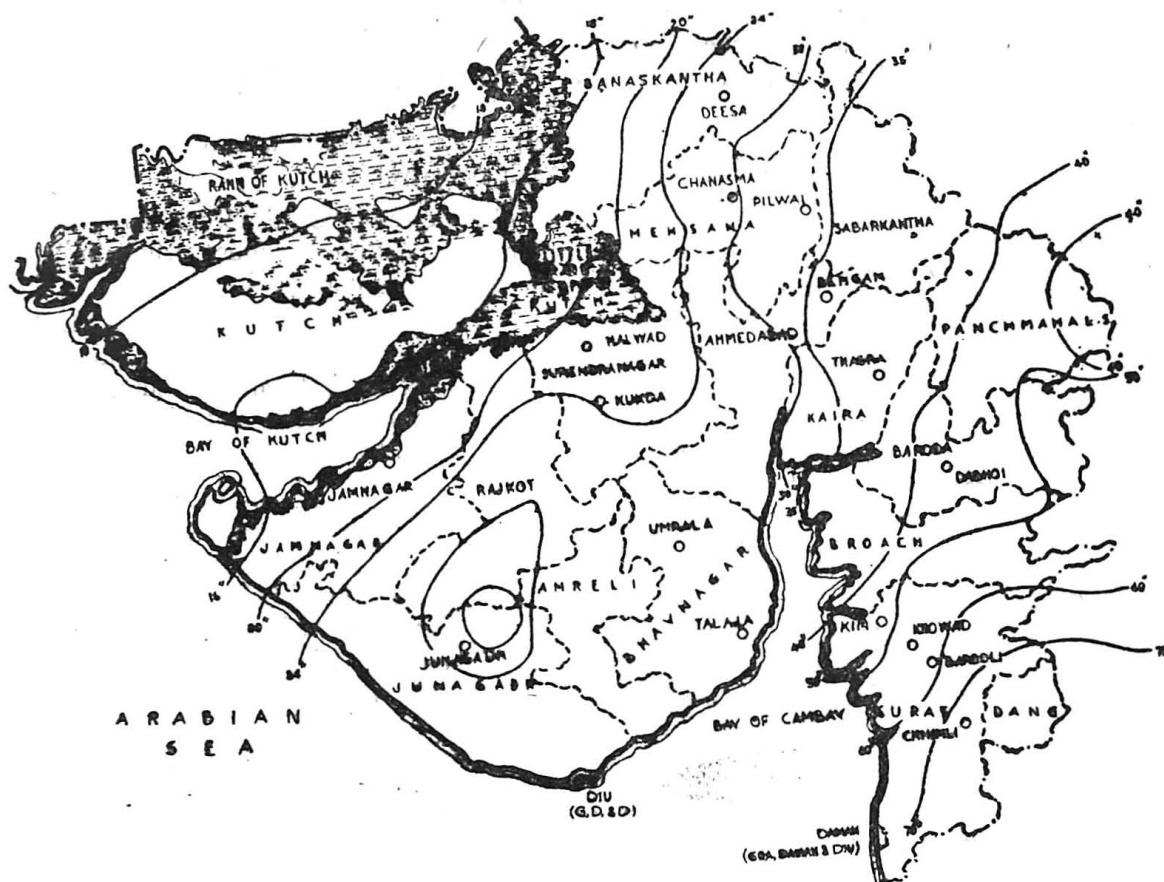


FIGURE 1 : Irrigation Research in Gujarat State.

TABLE II

Yield of Seed-Cotton in kg./acre.

Treatment	Bardoli 1959-60 to 61-63	Kholwad 1960-61 to 62-63	Kim 1960-61 to 62-63
No irrigation	355	353	327
5 irrigations at 2 weeks interval	361	512	334
4 irrigations at 3 weeks interval	363	482	343
3 irrigations at 4 weeks interval	375	461	343

Difference exhibited by the treatments reach significant level of 5 per cent at Bardoli during 1961-62 and at Kholwad during 1960-61 and 1962-63 years. The irrigation increased the yield significantly but among numbers of irrigations there was no significant difference.

(b) The experiment was laid out on Hirsutum Deviraj cotton at Halwad with six replications randomised which yielded results as under on average of 1958-59 to 1962-63.

Treatment	Yield of seed-cotton kg./acre
No irrigation	222
3 irrigations	287
5 irrigations	289
7 irrigations	294

The difference between no-irrigation and irrigation was significant during 1958-59 and 1962-63 because irrigation increased the yield. Yields due to 3, 4 and 5 irrigations were nearly same.

(c) The experiments on irrigation-cum-spacing trial with Deviraj cotton were laid out at Umralla, Jamnagar, Kukda, Pilwai, Thasra, Kim and Junagadh during 1962-63 in split plot design with four replications. The one year results on these farms are given in Table III.

Two irrigations at Jamnagar, Pilwai, Kim and Thasra, three at Kukda and four at Junagadh proved desirable. Spacing 1.8 m.×0.3 m. (6 ft.×1 ft.) proved optimum at Jamnagar and Kukda and 0.9 m.×0.3 m. (3 ft.×1 ft.) spacing at other places.

(d) Manurial-cum-irrigation experiment laid out at Umralla on arboreum cotton Sanjay (C.J. 73) in split plot design with six replica-

tions during 1962-63 yielded results as given in Table IV.

One and two irrigations increased the yield by 21 and 42 per cent respectively. The response to fertilizers is also positive specially with two irrigations.

(e) The results of the other cultural and manurial experiments under irrigation can be summarised as under :—

- (i) Potash and phosphoric acid had no effect in increasing the yield of Herbaceum 2087 and Hirsutum Deviraj cottons at Kim and of 2087 cotton at Kholwad.
- (ii) Nitrogen up to 100.8 kg/ha. (90 lb. per acre) increased the yield of 2087 and of Deviraj cotton at Kholwad and Kim. The hybrid cotton yielded better when 27.22 kg. (60 lb.) N was applied at Thasra and 13.6 kg. (30 lb.) N at Pilwai (Table V).

TABLE III

Yield of Seed-Cotton in kg. per acre.

Number of irrigations	Kukda	Jamnagar	Junagadh	Pilwai	Kim	Thasra
2	255	191	659	872	576	435
3	301	178	671	833	584	438
4	263	169	730	866	595	442

TABLE IV

Yield of Seed-Cotton in kg. per acre.

Fertilizer in lb. per acre	No irrigation	1 irrigation	2 irrigations	Mean
NO PO	187	206	264	219
N20 P10	163	216	300	226
N40 P20	179	217	319	238
Mean	176	213	261	

TABLE V

Yield of Seed-Cotton in kg. per acre.

	2087 cotton 1960-61 to 1962-63		Deviraj 1959-60 to 1962-63	Hybrid cotton 1961-62 to 1962-63	
	Kholwad	Kim	Kim	Thasra	Pilwai
N 0	321	276	296	..	..
N 30	378	310	385	292	505
N 60	450	344	497	332	493
N 90	507	392	596	331	508

In treatments of time of application of N from sowing to flowering in one dose or split doses, the performance was nearly same in all treatments.

- (iii) In spacing requirements, 0.9 m. (3 ft.) at Kim, and 1.2 m. (4 ft.) at Kholwad for 2087 cotton and 1.8 m. × 0.6 m. (6 ft. × 2 ft.) at Thasra and Pilwai for hybrid cotton proved to be optimum spacings.
- (iv) Sowing of 2087 cotton at normal time at Kim and early sowing in 1st week of June at Kholwad yielded better than late sowing.
- (v) Green manuring between cotton rows showed significant increase in yield in 1960-61 out of four years from 1959-60 to 1962-63 under trial at Halwad.
- (vi) Application of 10 cart loads of farm-yard manure per acre increased the yield of 2087 cotton at Kholwad and Kim and of Deviraj cotton at Kholwad.
- (vii) Cotton as an entire crop proved economical at Halwad and Kholwad as compared to mixed cropping.

Wheat

Wheat occupies nearly 4.05 lakh hectares (10 lakh acres) in the State. Nearly half of this area is under irrigated wheat taken as a second crop after *Kharif bajra*; groundnut or early paddy.

The complex experiment of varietal-cum-seedrate-cum-irrigation-cum-manurial trial was laid out in confounded and split plot designs at Jamnagar, Thasra, Kholwad, Kim, Bardoli, Dabhoi in 1960-61 and at Halwad, Junagadh, Kukda and Pilwai in 1962-63. Results of this experiment are presented in Table VI.

- (a) Treatments of number of irrigations were I_1 , I_2 and I_3 .
5, 7 and 9 at Jamnagar, Thasra, Bardoli, Halwad, Kukda.
7, 9 and 11 at Pilwai.
9, 11 and 13 at Junagadh.
3, 4 and 5 at Kholwad, Kim and Dabhoi.

The level of nitrogen and phosphoric acid tried were 0, 33.6 and 67.2 kg./ha. (0, 30 and 60 lb. per acre). The results are given in Table VI.

TABLE VI

Yield of Wheat in kg. per acre due to Irrigations in Presence and Absence of Nitrogen.

	Kholwad				Dabhoi			
	N0	N30	N 60	Mean	N0	N30	N60	Mean
	(1961-62 to 1962-63)				(1960-61 to 1962-63)			
I_3	309	430	489	409	612	784	817	738
I_4	360	520	579	486	698	779	756	744
I_5	374	568	693	545	688	733	684	762
Mean	348	506	587		660	765	812	
	Thasra (1960-61 to 1962-63)				Jamnagar (1960-61 to 1962-63)			
I_5	533	845	994	791	225	372	405	334
I_7	547	868	1055	823	227	399	475	367
I_9	546	891	1077	838	241	424	492	386
Mean	542	868	1042		231	398	458	
	Halwad (1962-63)				Kukda (1962-63)			
I_5	337	544	605	495	294	317	347	319
I_7	335	547	660	514	328	406	443	392
I_9	333	590	722	548	360	488	531	460
Mean	335	560	662		327	404	440	
	Pilwai (1962-63)				Junagadh (1962-63)			
I_7	545	667	756	656	I_9 1100	1189	1194	1161
I_9	541	772	848	720	I_{11} 1105	1254	1247	1262
I_{11}	578	783	871	744	I_{13} 1180	1218	1256	1211
Mean	555	741	825		1128	1220	1226	

Kholwad: There was linear increase in yield from 3 to 5 irrigations but the magnitude of increase was enhanced in presence of 33.6 and 67.2 kg./ha. (30 and 60 lb. per acre) of N.

Dabhoi: Practically little difference was experienced between irrigation treatments from 3 to 5 irrigations. Without nitrogen 4 irrigations proved optimum.

Thasra: Seven irrigations proved to be the optimum requirement in presence of 33.6 and 67.2 kg./ha. (30 and 60 lb. per acre) of N. because without nitrogen 5 to 9 irrigations gave nearly same yield.

Jamnagar: Seven irrigations without nitrogen did not increase the yield over 5 irrigations. In presence of nitrogen there is linear increase in yield up to nine irrigations.

Halwad: Without nitrogen 5 to 9 irrigations gave same yield. Every additional irrigation increased yield in presence of nitrogen. In the experiment conducted from year 1959-60 to 1961-62 irrigations 5, 7 and 9 did not show any significant difference in yield.

Kukda: There was increase in yield in linear order from 5 to 9 irrigations. The magnitude of this increase was enhanced by application of nitrogen.

Pilwai: Nine irrigations can be considered as optimum requirement of the crop. Without nitrogen 7 and 9 irrigations did not differ.

Junagadh: Eleven irrigations proved to be optimum requirement of the crop when nitrogen was applied. Without nitrogen number of irrigation requirement rose to 13.

Kim: Three to five irrigations yielded nearly same result in presence and absence of nitrogen.

Dabhoi: Three, four and five irrigations yielded respectively 700, 748 and 762 kg. grain per acre on average performance from 1960-61 to 1962-63 (Table VII).

Taking into consideration the increase in yield 33.6 kg./ha. (30 lb per acre) of P₂O₅ would be economical at Kim and Thasra, while 67.2 kg./ha. (60 lb. per acre) P₂O₅ alone increased the yield at Thasra only. Nitrogen up to 67.2 kg./ha. (60 lb. per acre) proved economical at Kholwad, Jamnagar, Thasra and Halwad while up to 33.6 kg./ha. (30 lb. per acre) at all places. In the previous experi-

TABLE VII

Yield of Grain in kg. per acre due to Nitrogen and Phosphoric Acid alone and in Combination (average of seasons under trial).

	P 0	P 30	P 60	Mean	P 0	P 30	P 60	Mean
	Kholwad (1960-61 to 1962-63)				Kim (1960-61 to 1962-63)			
N 0	320	358	362	347	264	317	356	306
N 30	462	512	546	507	335	385	443	388
N 60	520	601	637	586	352	433	497	429
Mean	434	490	515		317	378	425	
	Thasra (1960-61 to 1962-63)				Jamnagar (1960-61 to 1962-63)			
N 0	469	541	615	542	213	243	237	231
N 30	798	881	922	867	315	426	454	398
N 60	983	1045	1102	1043	366	495	516	459
Mean	750	826	880		298	388	402	
	Halwad (1962-63)				Kukda (1962-63)			
N 0	322	331	352	335	310	298	374	327
N 30	507	553	620	660	362	414	432	403
N 60	592	684	711	662	372	451	499	441
Mean	474	523	561		348	388	435	
	Junagadh (1962-63)							
N 0	1085	1124	1171	1127				
N 30	1166	1269	1226	1220				
N, 60	1131	1241	1308	1227				
Mean	1127	1211	1235					

ment conducted from 1958-59 to 1961-62, nitrogen and P_2O_5 singly increased the yield significantly when doses tried were 0, 20 and 40 in case of each.

In combination of 33.6 and 67.2 kg./ha. (30 and 60 lb. per acre) of N , 33.6 kg./ha. (30 lb. per acre) of P_2O_5 would be economical at all places, while 67.2 kg./ha. (60 lb. per acre) P_2O_5 may prove economical at Thasra and Kukda.

At remaining places of Dabhoi, Bardoli and Pilwai only nitrogen increased the yield economically up to 67.2 kg./ha. (60 lb. per acre) of N as given in Table VIII.

The results of other cultural and manurial experiments (1959-60 to 1961-62) can be summarised as under :—

- (1) Application of 10 Cl. F.Y.M. per acre increased the yield significantly in two years out of three years at Junagadh and in all three years at Halwad.
- (2) Application of 9.07 kg. (20 lb.) N increased the yield at Umralla significantly while P_2O_5 application significantly increased the yield up to 44.8 kg./ha. (40 lb. per acre). The interaction of N and P_2O_5 proved non-significant.
- (3) Seed rates 44.8, 67.2 and 89.6 kg./ha. (40, 60 and 80 lb. per acre) did not exhibit significant differences at Halwad, Umralla and Junagadh.
- (4) Sowing of wheat during first fortnight of November proved significantly better, especially over sowing

in middle of October at Jamnagar (1958-59 to 1961-62).

- (5) In placement of N fertilizer, application of fertilizer 5.1 cm. (2 in.) on either sides increased the yield significantly at Junagadh and Thasra over broadcasting, drilling or placement 5.1 cm. (2 in.) on one side, while at Jamnagar the different methods of placement of N fertilizer treatment did not differ (1961-62 to 1962-63).
- (6) If the irrigation is given 10 to 20 days after sowing, soaking of land before sowing proved desirable at Junagadh (1961-62 to 1962-63).

Paddy

Paddy occupies 5.66 lakh ha. (14 lakh acre) of land in the State. Out of this area 0.81 lakh ha. (2 lakh acre) are grown under irrigated paddy and rest under rainfed paddy. The transplanted paddy at Chikhli is given about 3 irrigations while at Bardoli about 9 irrigations are given to the crop.

The results of various agronomic and cultural experiments on paddy are summarised below :—

- (1) Varietal-cum-fertilizer experiment on paddy (transplanted) at Bardoli (1959-60 to 1962-63) and Chikhli 1960-61 to 1962-63).

Response of N was highly significant at both the places. At Bardoli 44.8 kg. N and 22.4 kg. P_2O_5 per hectare (40 lb. N and 20 lb. P_2O_5 per acre) did not increase the yield significantly over 44.8 kg. (40 lb.) N alone. Later yielded 379 kg. of

TABLE VIII

Yield in kg. per acre due to Nitrogen (average of the seasons under trial).

	Dabhoi	Bardoli	Pilwai
N 0	660	568	556
N 30	765	709	740
N 60	812	814	825

more yield over no manure. At Chikhli the increase in yields due to 44.8 kg. *N* and 44.8 kg. *N*+22.4 *P*₂*O*₅ per hectare (40 lb. *N* and 40 lb. *N*+20 lb. *P*₂*O*₅ per acre) were respectively 390 and 447 kg./acre over no fertilizer and were significant. All varieties tried showed nearly same performance.

- (2) Effect of graded doses of *N*, *P* and *K* with different spacings in transplanted paddy at Bardoli and Chikhli (1959-60 to 1962-63).

All the factor interactions behaved non-significant at both places.

Application of 44.8 and 89.6 kg. *N* per ha. (40 and 80 lb. *N* per acre) increased the yield to the extent of 407 and 457 kg. per acre respectively over no nitrogen at Bardoli and 447 and 544 kg./acre respectively over no nitrogen at Chikhli, which were significant.

The differences in yields due to three doses of *P*₂*O*₅ as well as *K*₂*O* were non-significant. Spacings 15.2 cm., 22.9 cm. and 30.5 cm. (6 in., 9 in. and 12 in.) between rows exhibited no difference.

- (3) Cultural-cum-fertilizer experiment on transplanted paddy at Chikhli (1960-61 to 1962-63).

All the interactions proved non-significant.

Planting 15 days before normal date and narrower spacing of 15.2 cm. × 15.2 cm. (6 in. × 6 in.) proved desirable. The difference in yield between different number of seedlings per hill was non-significant.

Difference in yields due to application of *N* levels was highly significant over control. The yield due to application of 44.8 kg./ha. (40 lb. per acre) *N* increased the yield by 461 kg. per acre.

Other crops

(1) Three post-monsoon irrigations to Malvan *Jowar* at Pilwai did not show beneficial effect during 1961-62 and 1962-63.

(2) Three irrigations at Halwad and Jamnagar increased the yield of gram by 258 and 138 kg. per acre respectively during 1960-61 to 1962-63.

Further research on irrigation requirements in terms of acre-inch study of economics of sugar-cane, virginia tobacco, hybrid maize, vegetable and irrigated oil seeds and spices crops are under study as new introduction according to tract.

Conclusions

(1) At least three irrigations for herbaceous and hirsutum cottons and two irrigations for arboreum proved necessary to increase the yield. Nitrogen increased the yield up to 160.8 kg./ha. (90 lb. per acre) in case of herbaceous and hirsutum cottons and up to 67.2 kg./ha. (60 lb. per acre) of *N* in case of hybrid cotton. Application of 10 cart loads of farmyard manure proved essential and effective for irrigated cotton. Green manuring was also effective at Halwad.

(2) For wheat crop at Kholwad there was increase in yield up to 5 irrigations which was more economical when 67.2 kg./ha. (60 lb. per acre) of *N* was applied. At Thasra, Jamnagar, Halwad and Kukda the yield increased economically up to 9 irrigations provided 33.6 to 67.2 kg./ha. (30 to 60 lb. per acre) of *N* was applied. Pilwai required 9 irrigations with 67.2 kg./ha. (60 lb. per acre) of *N* while Junagadh needed 33.6 kg./ha. (30 lb. per acre) of *N* with 11 irrigations for good harvest. 67.2 kg./ha. (60 lb. per acre) nitrogen combined with 33.6 kg./ha. (30 lb. per acre) of *P*₂*O*₅ are needed for good yield at Kholwad, Kim, Thasra, Jamnagar, Halwad and Kukda. For Junagadh 33.6 kg./ha. (30 lb./acre) *N* and 33.6 kg./ha. (30 lb./acre) *P*₂*O*₅ proved to be a good combination. At Dabhoi, Bardoli and Pilwai, 67.2 kg./ha. (60 lb. per acre) nitrogen gave good harvest. Sowing wheat in middle of November proved best at Jamnagar.

(3) There was increase in yield of paddy up to 89.6 kg./ha. (80 lb. per acre) *N* but 44.8 kg./ha. (40 lb. per acre) *N* was found to be an economic dose for Bardoli.

(4) There was effective increase in yield by three irrigations in gram at Halwad and Jamnagar.

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PRE-IRRIGATION SOIL SURVEY AS AN AID TO ASSESS OPTIMUM REQUIREMENTS OF WATER FOR IRRIGATED CROPS FOR THE NEW IRRIGATION PROJECTS

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and

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SYNOPSIS

Adoption of a duty on a new irrigation project requires very careful consideration and all factors like soil, climate, sub-soil water-table and drainage efficiency have to be born in mind. A generalised formula has been put forth for adopting deltas for different crops for working out the duty on the basis of data collected from the pre-irrigation soil surveys.

Introductory

In the wake of canal irrigation during the last half a century, large tracts of fertile land have either become water-logged and/or developed highly saline-alkaline soil conditions. In order to safeguard against such undesirable developments it has been accepted that pre-irrigation soil survey should be carried out in all new project command areas. Such a soil survey should not only serve as a guide for assessing the agri-irrigational potentialities of the land surveyed but also help to assess the water requirement of crops. An effort has been made in this paper to bring out the work done by the Central Water and Power Commission in the field of pre-irrigation soil survey and how the information thus collected could be of help in assessing the water requirements of the area keeping in view the aspects of water-logging and development of saline-alkaline soil conditions. A review of work done abroad on consumptive use of irrigation water and the work done on water requirements of crops in India have also been given. In the light of the experience gained during the last fifteen years on pre-irrigation soil surveys and making use of the data available on water requirement of crops a broad formula on Delta to be adopted for calculating water duties have been suggested. The main object of the suggestion is to focus attention on the desirability

of laying down some broad principles for adopting deltas in different irrigation projects which should be based on the results of pre-irrigation soil surveys.

Pre-irrigation Soil Surveys Completed

Table I gives the list of projects for which pre-irrigation soil survey was carried out in C.W. & P.C. and reports written for the guidance of the project authorities.

TABLE I

State	Project	Gross area covered by soil survey	
		Lakh acres	Lakh hectares
(1)	(2)	(3)	(4)
Assam	Kopilli	3.25	1.30
Bihar-Nepal	Kosi	32.00	12.90
	Gangdak	14.00	5.60
Bombay (now Maharashtra & Gujarat)	Broach	20.60	8.30
	Kakrapar	9.00	3.60
	Sabarmati	3.00	1.20
	Bah	12.28	0.52
	Bargi	9.00	3.60
	Barna	2.52	1.00
	Halali	1.36	0.55
	Hasdeo	6.45	2.60
	Jonk	3.25	1.30
	Kasyari	0.55	0.22
	Ken	1.36	0.55
	Korar	1.87	0.75
	Nagda Nallan	0.42	0.17
Parbati	1.18	0.48	
Pareri	0.10	0.04	
Punasa	1.56	0.63	
Raigon	0.18	0.07	
Sagar	1.18	0.48	
Tawa	9.32	3.70	

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PRE-IRRIGATION SOIL SURVEY AS AN AID TO ASSESS OPTIMUM REQUIREMENTS OF 151
WATER FOR IRRIGATED CROPS FOR THE NEW IRRIGATION PROJECTS

TABLE I—Concl'd.

(1)	(2)	(3)	(4)
	Unchera Upper	0.12	0.04
	Mahanadi	3.40	1.37
	Wainganga	2.05	0.82
Orissa	Hirakud	8.00	3.20
	Mahanadi Delta	11.41	4.60
Rajasthan	Rajasthan Canal	94.20	38.10
W. Bengal	W. Bengal Project	32.00	12.90
	Total	274.61	110.59

Some more projects are under investigation. Statement at Appendix A gives a brief summary of the pre-irrigation soil survey reports for some of the major irrigation projects investigated during the first three Five-Year Plans.

Work done on Water Requirement of Crops

Theoretically the water requirement of a plant is the one which it takes up through its roots and subsequently loses through transpiration but from the practical angle, out of the water supplied to the crops, some of it will be absorbed through its roots and the remaining portion will be lost through percolation into the lower soil strata as well as lost through evaporation from the soil surface. Again an Irrigation Engineer has to allow for the transit losses in the form of evaporation from water surface in the canal and distribution system and the percolation losses through the bed and sides of the canal.

The work of water requirement of crops in a big country like India with such varying soil and climatic conditions is very stupendous. Sub-soil water-table and drainage efficiency of the region have important role to play in the water requirement of crops. Pre-irrigation surveys have been conducted in such a way that maximum information on these essential points is available for the area surveyed.

Consumptive Use of Water

Irrigation Engineers in the West have worked on the practical aspect of consumptive use of water. The term consumptive use

is defined as the quantity of water in acre-feet per cropped acre per year absorbed by the crop and transpired and used directly in the building of plant tissues together with that evaporated from the crop producing land.

Lowry⁽³⁾ has shown that consumptive use bears a straight line relation with temperature. Again Blaney-Criddle⁽²⁾ has put forth another method of calculating consumptive use of water.

Lowry-Johnson Method

According to this method the water requirement bears straight line relationship with 'effective heat'. Growing season is the period during which the day temperature remains above 32°F and effective heat is worked out as under from the data for Pinedal Wyoming area during 1951. Growing season June 12 to September 11.

Period	Total of daily day degrees
June 12—30	848 F
July 1—31 (48×31)	1488
August 1—31 (46.9×31)	1454
September 1—11	504
Total	4294

'Effective heat' of 4,294.

The water requirement works out from Figure 1 is 0.45 m. (1.5 ft.).

Blaney-Criddle Method

According to this method the consumptive use depends upon average temperature available during Sunlight hours and growing span of the crop. It is assumed that the normal precipitation during growing season is consumptively used by the crop.

$$U = KF$$

where U = Consumptive use

K = Coefficient

F = Consumptive use factor

K is worked out for different crops for particular areas.

Tomilson⁽⁸⁾ worked on these two methods and found that Lowry-Johnson method gave higher values than the actual whereas the Blaney-Criddle tallied with his values.

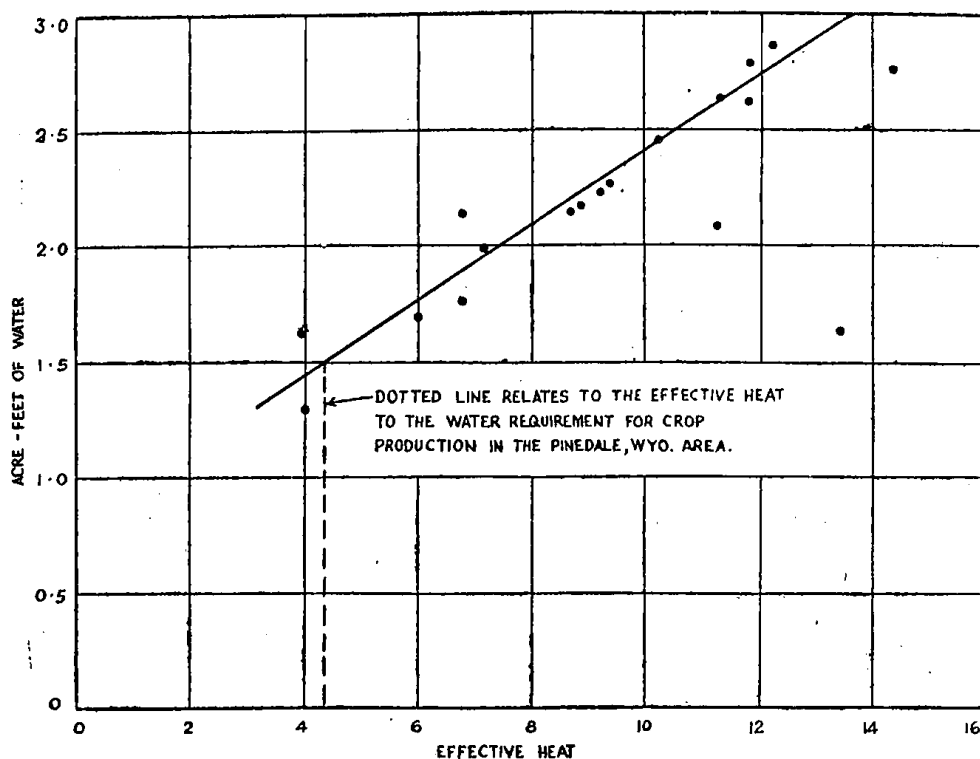


FIGURE 1 : Relationship between the effective heat and water use.
(Data from Lowry-Johnson method).

Work done in India

Although extensive work has been done in different parts of the country, considerable work still remains to be done in order to cover the wide variation of the soil and climatic factors.

Dr. Leather⁽⁴⁾ was the pioneer in India to initiate work on water requirement of crops. Most of the work has been done through pot culture experiments and as such the water requirements thus determined may not be applicable in determining the water duty of the crop but they serve as useful guide. Lately actual field trials are being conducted to simulate more closely the actual field requirements. Major experiment on field scale was first started at the Rasalawal (Lyallpur) Agricultural Farm (Pakistan).

Water Requirements of Various Crops

Rice

The general notion that rice requires standing water throughout is not correct. Singh⁽⁶⁾

and his co-workers have calculated the water requirements for evapo-transpiration as 69.7 cm. (27.4 in.) and in Bombay as 63.5 cm. (25 in.). Sen⁽⁵⁾ has proved that dewatering conditions are essential for better rice yield. Bal⁽¹⁾ also showed that non-submerged crop had better growth. Subramaniam⁽⁷⁾, however, found that swamp soils provide better conditions for silicon assimilation. Recent researches in Japan have, however, indicated that aeration of the root-zone through sub-soil pipes has resulted in higher yield of rice crop.

Wheat

Sweet lands (non-saline-alkaline) soils require about 33 cm. (13 in.) and saline-alkaline require 45.7 cm. (18 in.). It has been shown in Punjab that increased irrigation causes mottling on poor sandy soils only and not on rich soils.

Cotton

Seedling, pre-flowering and flowering stages are most critical stages from the irrigation point of view. 27 to 39 in. (68.6 cm. to 99.1 cm.) of delta including rain is the requirement of cotton varying with varieties.

Sugar-cane

Singh and Co.⁽⁶⁾ workers have shown by pot experiments that minimum requirement of water for sugar-cane is 114.3 cm. (45 in.). The water requirements with a manurial dose of 68 kg. (150 lb.) is about 228.6 cm. (90 in.) in Madras whereas if the irrigation is 304.8 cm. (20 in.) it adversely affects yield. The water requirement of the crop are maximum during the growth and flowering periods and minimum during maturing period.

Similar work has been done on other crops like tobacco, potato, barley, maize, jowar, linseed, pea, mustard, etc., but in these cases the requirements have been worked out in pot culture experiments. Only for the last few years, experiments on field scale have been taken up.

Pre-irrigation Soil Survey as an Aid for devising the Most Optimum Water Duty

The brief description of the work done in the field of water requirement of crops is illustrative of the fact that for adopting delta values for different crops in different climatic zones of the country, an Irrigation Engineer has to take into account all the factors like soils, climate, salinity-alkalinity, sub-soil water-table, drainage efficiency of the area, etc. In order that some uniform standards are available for assuming deltas for different projects, following formula is suggested for consideration. However, necessary correction for the rainfall is to be made :—

$$\Delta = \textcircled{\Delta} + C_{\text{Tex}} + C_{\text{Salt}} + C_{\text{Temp.}} + C_{\text{Water-Table}}$$

Δ = Delta to be adopted

$\textcircled{\Delta}$ = Standard delta from the table

C_{Tex} = Correction for texture

C_{Salt} = Correction for salinity and alkalinity

$C_{\text{Temp.}}$ = Correction for maximum and minimum temperatures

$C_{\text{Water-table}}$ = Correction for sub-soil water-table.

Table giving the standard crop deltas

1. Wheat	10
2. Sugarcane	60
3. Rice	60
4. Cotton	30
5. Jowar	10
6. Maize	12
7. Bajra	8
8. Vegetables	25
9. Gardens	30
10. Mustard	10

Correction table for different factors.

Texture	Salinity-alkalinity
(1) Light-sand } sandy } sandy loam }	-2 pH below 8.5-salts above .2% +2
(2) Clayey Silt/ } Sandy clay Clay } Temperature.	+2 pH above 8.5-salts above .2% +5
Maximum day temperature above 110°F	+2 pH above 8.5-salts below .2% +2
Minimum night temperature below 36°F	+2
Sub-soil water-table within 5 ft. (1.5 m.) of G. L.	-5
Between 5-10 G. L.	-3
„ 10-20	-2

Delta worked on the basis of above assumptions for Rajasthan Canal Project with the aid of soil survey data (Table II) works out as under for two types of lands, i.e., sandy and saline-alkaline.

Sandy soils

for Wheat=10+2+0+2+0=14 in. and 15 in. have been adopted for the project.
For Sugar-cane=60+2+0+2+0=64 in. and 63 in. have been actually adopted.

For Cotton=30+2+0+2+0=34 in. and 36 in. have been actually adopted.

Delta for rice : It will only be grown on saline-alkaline soils.

60+0+2+0=64 in. and 66 in. have been actually adopted.

TABLE II

Pre-irrigation soil survey summary chart for the major irrigation projects investigated by Central Water and Power Commission.

Sl. No.	State	Project	River	Area surveyed		Salient soil features texture—Soil crust topography, etc.	Salinity-alkalinity problems	Calcium carbonate content	Manurial status	Crop pattern (post irrigation)	Sub-soil water			Drainage conditions	Recommendations
				lakh acres	Lakh acres						Quality	Table premonsoon(ft.)	Table post-monsoon (ft.)		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1.	Assam	Kopilli	Kopilli	3.25	1.3	Lateritic loamy with fairly deep soil crust and flat topography	Acidic soils.	Nil	Poor	Rice, Jute, Maize, Su-1 garcane, Rabi pulses.	Good	10—20	5—8	Generally good but poor in some areas.	(1) Provision of an efficient surface and sub-surface drainage. (2) Green manuring (3) Line in more acidic patches
2.	Bihar	Kosi	Kosi	32	12.9	Sandy loam to loam with shallow to moderately deep soil crust. Area is flat.	Area being light textured is highly leached and as such no salinity problem.	Nil	Poor	Rice, Jute, Wheat.	Good	10—12	5—7	Good	Green manuring.
3.	Bombay (Now Maharashtra & Gujarat)	Broach	Narmada	20.60	8.3	Black cotton soil with deep soil crust. Topography undulating.	About 10% area has high salinity.	Present	Poor	Cotton, Jowar, Rice, Wheat, Sugarcane.	Brickish in many wells.	20—30	15—20	Fair	Provision of good drainage very essential.
4.	Do.	Kakrapar	Do.	9.0	3.6	Clayey soils becoming lighter with depth. Deep soil crust and flat topography.	Main area free from salinity but highly saline patches along sea shore only.	Present in moderate to high percentage.	Fairly Good	Cotton, Jowar, Wheat.	Good	10—20	5—10	Fair	Provision of good drainage in coastal area essential.
5.	Do.	Sabarnati	Sabarmati	3.0	1.2	Upper areas undulating lower areas flat with light textured but deep crusted soils.	About 10% area has high salinity.	High throughout.	Poor	Cotton, Wheat, Jowar, Bajra.	Brickish	..	..	Good in upper but not so in lower.	Provision of good drainage and green manuring.
6.	Madhya Pradesh	Bargi	Narmada	9.0	3.6	Black cotton soil becoming lighter with depth. Deep crusted but undulating.	Saline patches are there.	Do.	Poor	Cotton, Wheat, Sugar-cane.	Do.	15—20	5—8	Good	Saline patches need reclamation.
7.	Madhya Pradesh	Barwah	Narmada	3	1.2	The soil is mostly loamy to clay loam with variable soil crust and undulating terrain.	No Salinity problem.	Low to high	Poor	Wheat, Sugarcane, Cotton, Jowar.	Good to Fair.	7—20	5—8	Good	Efficient drainage and use of green manures and fertilizers recommended.
8.	Madhya Pradesh	Hasdo	Hasdo	6.45	2.6	Clayey soil with deep soil crust. Area is flat but a slope of 4 to 5 ft. per mile.	No salinity problem.	Present throughout but below 2%.	Poor for N&P.	Wheat, Rice, Sugarcane.	Good	10—20	5—10	Good	Green manuring and fertilisation recommended.

9-	Madhya Pradesh	Jonk	Jonk	3.25	1.3	Mostly clayey—soil crust shallow to deep. Slightly undulating topography.	No. such problem.	Present in low to high contents.	Good	Wheat, Cotton, Sugarcane.	Good	>10	Near ground level.	Good	Good drainage conditions maintained.
10	Madhya Pradesh	Parbati	Parbati	5.00	2.00	Light loamy soil with varying soil crust. Partly gravelly and rocky. Area is fairly flat.	Generally there is no salinity problem.	Low to high	Fairly Good	Wheat, Rice, Cotton, Sugarcane, <i>Jowar</i> .	Good	>20	—	Good	As the project is still under investigation, final report not yet prepared.
11	Madhya Pradesh	Narmada	Punasa	1.56	0.63	Heavy black soil—undulating terrain with fairly deep soil crust.	Some saline patches are there and need proper handling.	High throughout.	Poor with respect to N&P.	Wheat, Cotton, Sugarcane.	Good	20	5—8	Good	Saline patches be tackled properly. Efficient drainage be provided.
12	Madhya Pradesh	Tawa	Tawa	9.32	3.7	Heavy soil with deep soil crust.	Generally there is no salinity problem.	Low to high	Good	Wheat, Rice, Cotton, Sugarcane, <i>Jowar</i> .	Good	>10	Ground level	Fair	Efficient drainage to be ensured.
13	Madhya Pradesh	Upper Mahanadi	Mahanadi	3.40	1.37	Clayey with undulating topography. Generally deep soil crust but some rocky areas are also there.	Only very small areas have higher salinity.	Do.	Fair	Cotton, <i>Jowar</i> , Wheat.	Good	30	20	Good	Ditto.
14	Madhya Pradesh	Upper Wain-Ganga	Wain-Ganga	2.05	0.82	Black cotton soil with fairly deep to deep soil crust.	No problem of salinity.	Generally low.	..	Wheat, Cotton, Sugarcane, <i>Jowar</i> .	Good	5—10	30	Good	Detailed soil Survey in the post irrigation period.
15	Madhya Pradesh	Hirakud	Mahanadi	1.0	0.4	Rocky and gravelly with shallow soil crust.	No salinity problem.	Low to high	Medium to High N.P. High K.	Do.	Good	20	5	Good	Area being rocky efficient drainage be ensured.
16	Orissa	Hirakud	Mahanadi	8.0	3.2	Loamy soils—Topography undulating shallow to fairly deep soil crust.	Do.	Very low	Peer	Rice, Groundnut pulses, wheat.	Good	15	6	Good	Drainage of lower areas be ensured Green manuring and fertilization.
17	Orissa	Mahanadi Delta.	Mahanadi	11.41	4.6	Clayey with flat topography. Deep soil crust.	Salinity Problem along seashore only.	Very low.	Peer	Rice, Sugarcane, <i>Mung</i>	Good	10	5	Fair	Being a deltaic area provision of efficient drainage called for.
18	Rajasthan	Rajasthan Canal.	Sutlej	94.20	38.1	Sand to sandy Sanddune areas with hard alkaline patches in between the sand dunes.	Highly alkaline patches are present.	Kankar in alkaline patches & Gypsum in light sandy areas.	Very poor	Wheat, mustard, <i>Jowar</i> , Bajra, Cotton, Rice for alkaline patches.	Highly saline	100	100	..	The area will need green manuring and fertilization. Dune reclamation will have to be done.

NOTE.—There are a large number of comparatively smaller projects, soil survey reports which are available but they have not been included in this Statement.

No rain compensation is required in the case of Rajasthan whereas suitable reduction for rain depending upon its distribution is to be always made.

The proposed formula is just a basis to devise some standard method for fixing deltas for different crops on various irrigation projects taking the help of soil survey data and climatic factors. This is the usual procedure followed at present but the approach is more personal rather than being based on some standard basis.

Concluding Remarks

Pre-irrigation soil survey for 30 major irrigation projects investigated during the First, Second and Third Five-Year Plans covering an area of over 110.88 *lakh* ha. (274 *lakh* acres) have been carried out by the C.W. & P. Commission. A review of work done on water requirements of crops in the West and India has shown that water requirements of crops have direct relation to temperature and soil condition. A new formula accounting for

all the factors like temperature, soil, alkalinity-salinity, water-table *etc.*, have been suggested for adopting deltas for different crops in new irrigation projects on the basis of pre-irrigation soil survey data.

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DISCUSSIONS

The Symposium began with the Chairman's opening remarks in which the importance of the subject of Water Requirements of Crops was pointed out. He said that discussions of papers would be taken up subject-wise and crop-wise, as below :

I. *Water Requirements of Specific Crops* i.e., (i) Rice, (ii) Wheat, (iii) Sugarcane, (iv) Gram, (v) Potato, (vi) Cotton.

II. *Cropping Patterns.*

III. *Relationship between Water Requirements, Evaporation and Rainfall.*

IV. *Soil and Soil Moisture Studies.*

V. *Optimum Water use.*

I. Water Requirements of Specific Crops

(i) RICE

The General Reporter (DR. MUKHTAR SINGH) then gave a resume of the papers both for those selected for discussion and those circulated for information. Gupta and Bhattacharya(1) had reported the results of an experiment conducted at Dhanauri, (U.P.I.R.I.) with six irrigation depths [0, 7.6, 11.4, 15.2, 19 and 22.8 cm. (0, 3, 4, 5, 6, 7.5 and 9 in.)] applied at three intervals (2, 2.5 and 3 weeks) in combination with three nitrogen levels. Experiments were conducted in 1962. They concluded that maximum yield was obtained with four irrigation treatments of 19 cm. (7.5 in.) each applied at 2.5 week intervals. Thus the total water requirements including 86.1 cm. (33.9 in.) of rainfall was 162.3 cm. (63.9 in.). The authors had attempted to calculate evapotranspiration by a formula advocated by the Iowa Institute of Hydraulic Research and had concluded that the calculated value of depth agreed fairly well with the experimental results. Contrary to these results, the finding of Pandey (8), emanating from experiments on light irrigations on *Aman* paddy carried out over 5 years at Bikramganj, Bihar, clearly showed that rainfall of 76.2 cm. (30 in.) from sowing in the nursery to maturity was adequate (exclusive of the amount needed for puddling) and irrigations were without effect. In the experiment reported by Chowdhury and M. Singh (2) also, no response to

supplemental irrigations after plant establishment in the case of transplanted paddy was recorded at Delhi. Although high water-table (30 cm.-60 cm.) would partly account for the absence of response to irrigation in the experiments at Delhi, yet Pandey's experiments showed that irrigation was without effect under conditions of low water-table 1.8 to 4.8 m. (6 ft. to 16 ft.) because of well distributed rainfall. In view of these results, it would be of interest to discuss the factors which might have led to the response to 19 cm. (7.5 in.) deep irrigations in the experiments by Gupta and Bhattacharya (1). Banerjee (24) had referred to the results of an experiment on time and frequency of irrigation on *Aus* paddy at Kalyani (West Bengal) indicating that the best and optimum results were obtained by 41.91 cm. (16½ in.) of water in doses of 10.2, 10.2, 6.35, 6.35, 2.54, 2.54, 1.27, 1.27 and 1.27 cm. (4, 4, 2½, 2½, 1, 1, ½, ½, and ½ in.) in successive irrigations. However, one would normally expect that deeper irrigations would be required in periods of high water demand which generally synchronised with maximum vegetative growth. In fact, Dutta and Sen (26) had mentioned that rate of transpiration was maximum during anthesis. The treatments corresponded to certain moisture levels at different stages of plant growth. Chaudhry and R. S. Singh (4) in their review of water requirements of rice had also cited a summarised statement of Rao that water requirement just prior to flowering was about 2-3 times the quantity required about 10-15 days before flowering or the quantity required after flowering. This review also referred to varying results obtained by different workers regarding the need for submergence in rice and the depth of submergence. Much of the evidence in favour of submergence seemed to be from countries in temperate regions (Japan, Philippines and Italy). It was mentioned that water requirements varied between wide limits in California *viz.*, [0.9-2.4 m. (3-8 ft.)]. This was a very big range and needed an explanation. Chowdhury and M. Singh (2) had suggested on the basis of the results of a preliminary experiment that if weeds were control-

led and the problem of low temperature, as met with in temperate regions did not exist, irrigation at or near field capacity would suffice. They had advocated a thorough investigation of the problem by proper techniques which would be discussed at this Symposium.

The effect of manuring with farmyard manure, sulphate of ammonia, super-phosphate on transpiration ratio was reported by Chaudhry and Mahapatra (3). The experiments were conducted for three years. In general, manuring had little effect on transpiration ratio of rice, contrary to the results generally obtained in the case of crops other than rice, (Mariakulandai, 21). Ganguli in earlier experiments got similar results. It was interesting to enquire whether dry weight increased or not as a result of manuring.

DISCUSSION

GUPTA (S. N.) informed that the U.P. Irrigation Research Institute was associated with experiments on water requirements of three principal crops of U.P., *viz.*, rice, wheat and sugar-cane, for nearly two decades since 1942-43. The experimental work from 1942-43 onwards was taken up primarily with a view to study two major aspects on which the entire experimental layout was based, namely, (i) depth and (ii) interval of irrigation which would give maximum and optimum yields of these crops with a view to help the irrigation engineers to determine optimum requirements of water for the various types of crops, so that it would be possible for them to revise duties in respect of needs of projects and avoid wastage of water. For rice, a gist of the results given in the paper was stated.

The actual experimental technique had been reorientated with a view to get over shortcomings in the old approach namely :

- (i) Lack of soil classification,
- (ii) Variation of irrigation treatments due to incidence of rainfall.
- (iii) Lack of soil-moisture measurements.

Three new approaches were now being tried at the Government Agriculture Farm, Dhanauri, *viz.*, (i) soil moisture depletion below field capacity at specified levels, (ii) continued submergence and (iii) submergence with drainage.

Two points called for serious attention :

- (1) Whether in the present context of their experimental work, it was possible to adopt revised figures of duty for principal crops both for better utilisation of water on existing irrigation systems and economical framing of the projects.
- (2) What effort was required to educate the cultivator to adopt these practices, as he was still adopting the age old method which involved considerable wastage of water because of over-irrigation.

In a paper presented by Shri A. P. Bhattacharya for the Fifth Congress on Irrigation and Drainage, attention was drawn to the state of over-irrigation to the extent of 30 per cent in the case of principal crops of U.P. This practice of wastage of water for irrigation was a serious matter and it was obligatory to devise means to check it.

GULHATI (N. D.) wanted to know the absolute measure of the yield and the reason for low yields.

MUKHTAR SINGH stated that levels of manures were already under study and it was not possible to include more treatments in the experiments. Generally, the yields were quite high.

BHATTACHARYA (A. P.) stated that the number of waterings was changed from 3 to 4 during 1961-62 owing to change in rainfall. Regarding levels of nitrogen, it had not been mentioned in the paper that the scheduled doses of nitrogen did not include 18.14 kg. (40 lb.) of basal dressing consisting of green manure and composit manure.

WALTER (J.) stated that results in his paper were based on printed reports.

Roy (S. E.) commenting on Gupta and Bhattacharya's paper (1), enquired as to why depth of rainfall was not included while planning irrigation treatments and calculating consumptive use.

TALATI (R. P.) commenting on the same paper (1) said that as the rainfall had such an important role in total water requirements, the pattern of rainfall type of irrigation and quality of irrigation water should also have

been studied. Referring to drainage ditches mentioned in the paper, he felt that flumes should have been provided therein. He was of the opinion that the formula used in the paper should have been based on experiments conducted in India. Coming to Chaudhry's paper (4), he felt that results were vibrated due to high water-table which supplemented water requirements and so the value of the experiment was lost. The effect of weeds and tillage was not studied in Chaudhry's paper.

MUKHERJEE (B. K.) commenting on Gupta and Bhattacharya's paper (1), remarked that the concept of duty pointed out therein was a little different from the terminology used by the officers of the Department of Agriculture. This was not clarified in the paper. The duration of the crop, whether it was an early or late variety, as also information regarding water-table had not been supplied. He felt that water requirements should be specified more clearly during various stages of plant growth, because cultivators failed to get adequate water at the transplanting stage. At Nagina, water requirements of rice were found to be 101.6 cm. (40 in.) for early paddy and 127.00 cm. (50 in.) for late paddy, so it was not understood as to why water requirements for Dhanauri were so high.

SOOD (M. L.) said that rice should not be considered in such general terms as had been done in the papers under review. The experiments should take note of the availability of supplies, existing rainfall conditions, variety of seed, manure, etc.

BALESHWAR NATH wanted to know as to what physical phenomenon warranted continued submergence of the paddy fields when water was actually needed by the root zones of the plants to procure nourishment. He said that instead of continued submergence irrigations could be provided intermittently and quoted that in one of the research papers received from U.S.S.R., it was pointed that 5 days submergence and two days break in the rice crop yielded better results.

He also queried if the occurrence of storms at the time of maturity of rice crops was of any significance. A proposal of changeover from *Aman* to *Aus*, i.e., from late to early paddy in Bengal was subjected to that observation.

KHURSALE (N. V.) commenting on Gupta and Bhattacharya's paper (1), said that he did not follow as to why the interval had been taken as 17 days. In the south, there were millions of acres under paddy which were irrigated by the submergence method during the whole of the growth period. It was felt that submergence was better than intermittent irrigation. In Maharashtra, water was supplied to paddy at intervals of not less than 7 or 8 days. I.C.A.R. gave a method of calculating optimum interval, taking into consideration concepts of field capacity and wilting point. Calculating by this method, optimum interval worked out to be 9 days instead of 17 days. If the interval was taken to be 17 days, it was necessary to increase the depth correspondingly say to 31.8 cm. (12.5 in.) instead of 19.5 cm. (7.5 in.) to make up for the evapotranspiration losses unless there be any rainfall contribution during each irrigation.

SATWANT SINGH said that there was a great impact of the cropping rotation on rural economy and they should introduce pasture and legume which would reduce the intake of artificial manuring. Doses of 0, 9.7, 18.14 kg. (0, 20, 40 lb.) of nitrogen appeared to be too small. Regarding submergence, it was the general experience that it might be necessary to have submergence in the first month and intermittent irrigations subsequently. If they grew *Basmati* rice in U.P., chances of *Rabi* were likely to be better. Cost of cultivation should be reduced, and for this some legume should be introduced. In Australia, where the yields were much higher, this was being practised successfully. The economics of farming had to aim at producing two crops. Efforts were necessary for effecting gain in protein content by better agronomic practices which would lead to an improvement in the quality of the yield. A large percentage in India had rice as their staple food, so the problem of balanced diet for the rice-eating population was an important one which could be solved thus. One method of improving the quality of yield was the application of artificial manure for which they should not aim at marginal and sub-marginal doses but on maximum and optimum doses.

PANDEY (H. N.) related some of the activities on the subject in Bihar. He said that there were three irrigation research stations functioning there, including the one at

Bikramganj where apart from studying the schedule of water from the soil characteristics, the problem was also being tackled not only from agronomical principles but also from the point of view of irrigation engineering, and soil physics. Two more irrigation research stations have been sanctioned which are in the process of being established. Economic aspects, which influenced the water requirements of crops and yield therefrom, were also under study at Bikramganj during the last five years. Regarding the point as to whether *Aus* paddy would be affected by storms, he said that this would be the case if the maturity of the crop coincides with the Hasta Nakshtra which fell between 24 September to 7 October. Till a year back irrigation applied with the soil moisture concept up to a depth of 0.9 m. (3 ft.) root zone gave a yield of below 0.37 tonnes (10 maunds) but when the required depth of irrigation of 35.6 cm. (14 in.) was applied 8-10 days before puddling in 2 to 3 applications 12.7 cm.+12.7 cm.+10.2 cm. (5 in.+5 in.+4 in.), the yield went up to 1.12 tonnes (30 maunds). Experiments were in progress with late *Aman* paddy for different soils. The problem of seepage and deep percolation losses in controlled experiments was being solved by fixing 0.9 m. (3 ft.) partition walls, 0.6 m. (2 ft.) below ground level and 0.3 m. (1 ft.) above ground level. He next related some problems in the Kosi command area where water-table was between 1.8 to 2.4 m. (6 to 8 ft.). At the Irrigation Research Station, Madhepura, Kosi belt, 18 piezometers were installed 4 years ago, where readings were being taken fortnightly. It was noticed that in some cases the water-table almost rose up to the ground surface at the end of August. Crops failed even with such a high water-table and no effect of organic matter was noticeable on the survival of crops. Legume was being studied as a rotational crop in a 7-year rotation. He felt that the term 'Duty' should be used in accordance with the common terminology.

CHATURVEDI (R. S.) said that from a perusal of the experimental work of water requirements of rice, it was clear that they were either purely agronomic or water requirements *vis-a-vis*, canal rostering as in U.P. experiments in which the irrigation engineers were directly interested. He felt that the approach of S. Banerji, howsoever useful it

might be for the agronomists, was impossible in canal irrigated areas and was of no interest to the irrigation engineers. He felt there should be a common approach. For instance, when the optimum interval was one week, it was of interest to investigate how much damage was done to the crop when the interval was kept as two weeks. Rice was essentially an aquatic crop which was happy in water. There was no point in trying the field capacity approach, for any amount of rainfall had never damaged rice and he felt that too much water could never be given to rice. According to him, harm was due to an increase in temperature and not due to water. Regarding *Basmati* rice, he knew that according to the cultivator even 32 irrigations were not good enough. What was necessary for its plant growth was that there should be no rise in temperature of water. He again stressed the fertility of soil-moisture depletion approach for growing rice, as this crop thrived in heavy or clay soils, which had 40 per cent water in pore space and any reduction to the level of say 25 per cent was disastrous. He was surprised at the experiments conducted at I.A.R.I. New Delhi, where in root zone depth was below the water-table. He felt that any variation in depths of irrigation from 20 to 50 cm. as was tried in these experiments was meaningless as the crop was grown on water derived from the water-table in which irrigation treatments had absolutely no effect. He advocated research on the proper variety of rice, the temperature and the pattern of daily rainfall. Coming to fertilizers, he was in agreement with the findings of H. N. Pandey of Bihar which had shown that the effect of fertilizer was almost negligible. Bihar experiments had clearly shown that rainfall was the main factor for plant growth for rice. Affinity of water was so clear. Nothing could be said about the proper level of fertilizers as doses below 28 kg./ha. (25 lb. per acre) for nitrogen had not been tried.

SIDHU (T. S.) said that he had known the Kosi area which was surveyed by him in 1949-50. Water-table was so high in Purnea and Saharsa Districts, while soils were so light. He felt that while new Irrigation Research Stations were being set up in Bihar, it should be borne in mind that these should be representative of the various soil types occurring in Bihar along with conditions of

water-table. Too much percolation loss or high water-table vitiated experiments on water requirements of crops, he said.

BHATTACHARYA (A. P.) commenting on H. N. Pandey's paper (8), felt that instead of trying combined levels of nitrogen and phosphorous they should have been tried separately for nitrogen and phosphorous. Regarding the figure of 96.5 cm. (38 in.) for water requirements of rice as found by H. N. Pandey at Bikramganj, he felt that this was not in conformity with the views held by Dr. Mukhtar Singh in his General Report wherein he had mentioned that water requirements of rice could be met with by keeping the soil moisture at the field capacity level. If the growing season was taken as 120 days, water requirements were found to be 152.4 cm. (60 in.) assuming that an irrigation at the rate of 1.3 cm. ($\frac{1}{2}$ in.) per day would maintain the crop at the field capacity level. Commenting on Dr. P. K. Sen's paper, he wanted to enquire as to how far pot culture studies could be useful as he was not sure whether plants grown in pots could simulate field conditions. Moreover, evapotranspiration measurements were likely to be unrealistic and evaporation was likely to be particularly high.

CHOPRA (M. R.) (CHAIRMAN) said that he felt that the variables in these experiments should be as few as possible. It was desirable to start the work in a realistic manner in certain blocks where the conditions were analogous to those obtaining in the field. According to him, experimentation with too many variables might yield results after a long time. He recommended that there should be some experiments in which the effective water lost should be studied under conditions of rainfall existing in the draft.

GUPTA (S. N.) replying to the comments on his paper, said that he had already mentioned that soil moisture deficit approach was going to be tried now which would take cognizance of both rainfall and depth of irrigation. He felt that this might be a more scientific approach for applying water than the old system of applying of irrigation at fixed intervals. The term 'Duty' used in his paper was in accordance with the terminology adopted by Iowa Institute of Hydraulic Research, and it was for bringing out a comparison with the approach adopted at Iowa that the term had been used. Water-table at Dhanauri,

where the experiments were conducted, was 2.7 m. (9 ft.) below ground level. In the experiments that were under progress on rice, depth of irrigation would be governed by the extent of soil moisture in accordance with the standard formula. He pointed out that in his paper both maximum and optimum yields had been given, which were 3,600 and 3,300 kg. per hectare respectively.

BANERJI (S.) commenting on H. N. Pandey's paper, said that a point had been made out therein that the rainfall was regular for a period of 5 years and no harm to the crop was likely to accrue if rain did not fall during Hasta Nakshtra, *i.e.*, between 21 September and 10 October. He felt that the problem of patterns of rainfall was not as simple as indicated in the paper.

MUKERJEE (B. K.) said that he agreed with the Chairman that too many variables should not be tried for working out the ideal approach. But it was to be remembered that rice grew under so many variables and it was not possible to leave the major factors. Coming to figures for water requirements, he pointed out that they varied so tremendously within a State. For example, it was mentioned in J. Walter's paper that water requirements of rice at Coimbatore were 215.9 cm. (85 in.) including rainfall. For the same station, it was found by Narsingh Rao that for the *Samba* variety, the figure for water requirements excluding rainfall was 129.5 cm. (51 in.). But rainfall had to be taken cognizance of, the pattern of rainfall being more important. For Madhya Pradesh, he had studied water requirements for Chattisgarh and light *Kalhar* soils. His finding was that much more water was needed in the case of loamy soil. Late varieties consumed less water in heavy soils. What he wanted to stress was that it was meaningless to lay down water requirements for a region or a State, for soil was a very important factor governing water requirements.

FRAMJI (K. K.) said that information regarding water requirements of crops in period of short supplies, particularly for the Indo-Gangetic plains, would be of the greatest value. It is during these periods of shortages of supplies that water requirements could be curtailed and the spread-over of available supplies could be used to the greatest overall benefit.

PANDEY (H. N.) said that experiments were being conducted on *Aus* paddy at Bikramganj in the Sone command area which was a dry belt and at other irrigation stations in Bihar. It was found that the sowing of *Aus* paddy in June gave almost the same results as for late *Aman*. He was trying the sowing of *Aus* in the first week of May, as a result of which water requirements went up to 114.3 cm. (45 in.). For *Boro* paddy which was grown under standing water in Bihar, no experiments were possible on variations in irrigation treatments. Regarding Hasta Nakshtra, which is a critical period for the late *Aman*, and corresponded to pre-flowering stage, it was observed that failure of rains in this period invariably led to a failure of the crop. It had been noticed that during the last 25 years there were 8 or 9 drought years; during this period causing widespread failures of late *Aman* paddy in Bihar. Regarding the question of irrigating rice at field moisture levels below field capacity, he drew the attention to the recommendations given in the book by Nagai according to which field capacity should never be allowed to fall below 95 per cent. The optimum temperature for rice was 32°C and soil was silty there.

MUKHTAR SINGH replying to the comments of his paper (2), said that it was a controversial issue as to whether irrigation should be applied on rice grown with water-table above the root zone. For transplanted paddy, control of weeds was a necessity and this was possible by submergence which could be withstood by the crop. Physiologically, it was under investigation whether rice really needed water under such conditions and the point was under study.

SRINIVAS (L.) mentioned about the findings of two California scientists on the problem of flooding of rice fields. Physiological study showed that under conditions of submergence depth of two or 7.6 cm. (3 in.) above the soil was made free from air and the nitrification of plants was reduced thereby. It was indicated that intake of magnesium was higher in nitrate nitrogen than in ammonical nitrogen. Submergence accordingly destroyed a hormone of the plant, namely, indol acetic acid which was reduced by excess of magnesium under conditions of submergence. This could only be made up by artificial spraying of the hormone.

(II) WHEAT

DR. MUKHTAR SINGH (General Reporter) gave a resume of papers on Water Requirements of Wheat. Two irrigations, one at flowering and the other at milk stage, were generally found to be adequate to mature wheat in U.P. (Mehrotra and his associates—5, 6 and 7). In some cases as in the central and western parts of U.P. the need for three irrigations was indicated. Information regarding depth of water-table would be useful for these papers. The role of nitrogen in bringing down water needs was brought out. In Gujarat, the number of irrigations needed varied with places (Gopani, 27). Optimum number of irrigations were found to be 3 at Dabhoi (Baroda), 5 at Kholwad (Surat) and Thasra (Kaira), and as many as 9 at Jamnagar, Halwad (Surendernagar), Kukda (Surendernagar), Pilwai (Mehsana) and Junagarh. On sandy soils, more irrigation was needed. From observations on the utilisation of water in Gujarat, Talati (16) recorded that 5-6 irrigations were commonly given to wheat under tube-well irrigation. More frequent irrigation to wheat in Gujarat as compared with northern India could be partly ascribed to high evaporation and milder winter in Gujarat. But the difference seemed to be too large to be accounted for by these factors alone, particularly because the soil in many parts of Gujarat was heavy and the growing season was relatively short. The causes of varying irrigation requirements within Gujarat also needed explanation. The depths of irrigation and delta were not given for the experiments conducted in Gujarat. It was possible that the individual irrigations were very light and there could be scope for reducing the irrigation frequency by increasing the depth of individual irrigation. At Delhi, Dastane and Mohinder Singh (23) had given water requirements of wheat as 360 mm. inclusive of rainfall.

In the experiments conducted in U.P. (Mehrotra and R. G. Singh, 6) and in Gujarat (Gopani, 27) optimum irrigation frequency was found to be conducive to higher response to nitrogen as compared with infrequent irrigations.

DISCUSSION

DHANAK (G. G.) felt that too much emphasis had been laid in these papers on results

from the laboratory and demonstration farms wherein conditions would naturally be different from those in the fields. In Gujarat there is volumetric supply of irrigation under tube-wells for which there is enough systematic data. There was no significant difference in the out-turn of wheat between 5 and 7 waterings. The total water requirements were met by 2466.96 cu. m. (24 acre-in.) supply with an optimum dose of manure.

TALATI (R. P.) said that while there was no significant difference between 4 and 7 irrigations, 5 irrigations seemed to be optimum for Gujarat for which the delta was found to be 45.7 cm. (18 in.). Winter rainfall was practically nil in Gujarat.

BALESHWAR NATH said that attempts were being made to raise transplanted wheat in some of the Eastern States, namely Bengal, Bihar and Orissa. He wanted to know from experts if transplanted wheat had been tried successfully in foreign countries. Recently, he checked some of the results on transplanted wheat in Burdwan, where he found the work to be in a preliminary stage. Coming to high watering needs of wheat in Gujarat, he felt that this was attributable to the low retentive capacity of soils in Gujarat as compared to those in the Punjab. He wondered if abundance of available supplies made the cultivator use more water. In some of the reports (Report of the Indian Irrigation Commission, 1901), he had come across a recommendation according to which 8 to 10 waterings were felt to be optimum for well irrigation at the rate of 3.8 cm. (1½ in.) per irrigation. He felt that 8 irrigations 3.8 cm. (1½ in.) each, should suffice for wheat in Gujarat.

MUKERJEE (B. K.) said that observations had been made on water requirements of wheat for a number of regions in Gujarat. For instance, at Ambreli with 10 irrigations of 7.6 cm. (3 in.), i.e., with 3083.70 cu. m. (30 acre-in.), the increase in yield was as high as 60 per cent, whereas at Jamnagar with the same treatment the corresponding increase in yield was only 27 per cent. This was an interesting information on the basis of which it could be said that a general figure for water requirements of wheat for Gujarat did not make any sense. What he wanted to bring out was that while specifying water requirements all factors should be taken into account. Thus he had come across figures for

a region for which water requirements worked out to 19.1 cm. (7.5 in.) by well irrigation, while the same figure came to 33.5 cm. (13.2 in.) with canal irrigation. So the source of irrigation had also to be taken into account while considering water requirements. Similar remarks applied for the methods of irrigation.

MUKHTAR SINGH said that the figure of 76.2 cm. (30 in.) of irrigation of wheat for Gujarat appeared to be rather intriguing for he wondered as to how evapotranspiration losses would be accounted for.

CHOPRA (M. R.) (CHAIRMAN) said that it was because of this that he felt that soil moisture must be considered in these studies.

MUKHTAR SINGH said that it was true that water requirements could be high for sandy soils but the large difference between 25.4 and 76.2 cm. (10 and 30 in.), as reported for Gujarat, could not be accounted for by mere variations in the type of soils.

BHATTACHARYA (A. P.) supplied some information regarding experiments on water requirements of wheat conducted at the U.P. Irrigation Research Institute. According to these, two irrigation treatments of 7.6 cm. (3 in.) were found to be the best for Eastern and Western U.P., but for Southern U.P., the optimum depth was 10.2 cm. (4 in.), the number of treatments being the same. For soil moisture deficit approach, he said that experiments had been conducted at the U.P. Irrigation Research Institute in 1962-63 by applying irrigation in various combinations at different stages of plant growth. He said that application of irrigation in this manner needed expert opinion from plant physiologists for determining the stage of plant growth at a particular time on account of which he felt that the application of irrigation in accordance with soil moisture deficit would probably be better than this. He sought clarification on this point. Coming to R. P. Talati's paper, he said that while the average water requirements in Gujarat were of the order of 45.7 cm. (18 in.) that for Bardoli were only 30.5 cm. (12 in.).

ROY (S. E.) felt that in all the papers presented at the Symposium too many variables were being attempted on account of which the experimental technique suffered. Simplification was possible on the lines indicated in his paper based on the modern concepts, taking

into consideration the relevant factors. The aim of the experimental technique should be to bring out the correct index. From the references included in his paper, it was possible to reduce the number of variables to six. In all these experiments, rainfall pattern was important, the more so the average pattern and also the minimum expected losses in five years. This afforded useful information in rostering, for which a pre-requisite was knowledge regarding evaporation rates, data on which was lacking. An indirect index was possible by adopting the climatological approach for consumptive use. Information regarding rainfall pattern and soil was essential as also that on expected deep percolation losses and run-off. From the monograph given in his paper, it was possible to arrive at simplified means. Their importance arose from the point of view of availability of supplies. When it was not possible to apply irrigation at the scheduled date, a better solution was to put in higher depths at longer intervals or smaller depths at lower intervals according as the supplies were available. It was imperative however, that evaporation data should be disseminated freely, for which the assistance of the India Meteorological Department was essential.

MALIK (A. K.) said that the India Meteorological Department had only 34 evaporation stations of its own in the country. The department did not have adequate facilities to supply freely, evaporation data of even these 34 stations. If the Irrigation Engineers help to convince the Government of India that more evaporation recording stations should be set up in India, and after these stations have been set up, the India Meteorological Department will be in a better position to meet the requirements of Irrigation Engineers, for evaporation data.

MUDGAL (S. C.) said that one method of obtaining useful evaporation data was to set up Class 'A' pans in each farm and research station, which would supply enough evaporation data.

CHATURVEDI (R. S.) said that Dr. Mehrotra's result confirmed earlier experiments conducted in U.P. wherein entire rostering was based on one irrigation in *kor* period which occurred in November or December. Dr. Mehrotra's experiments confirmed the findings arrived at in earlier experiments in U.P., namely, one

watering alone was good enough for wheat. 80 per cent of the crop could be saved with one timely irrigation alone. For Western U.P., another irrigation was needed, which would give 95 per cent yield. For Gujarat, it had to be remembered that the little peninsula of Saurashtra had wide variations in rainfall from 25.4 to 152.4 cm. (10 to 60 in.) unlike those in U.P. wherein the climate was mostly humid and sub-humid.

MUKHTAR SINGH drew attention to the paper by Mehta and Shekhawat (10) in which it had been found that any delay in irrigation of more than 5 to 6 days at maturity stage affected the yield significantly while a delay in early irrigation had no such effect. This was in contravention to the observations of R. S. Chaturvedi that rainfall and soil patterns were the governing factors.

CHATURVEDI (R. S.) said that for U.P., rainfall and soil patterns were such as to be conducive to give optimum yield for wheat with one irrigation alone, which was not the case for Rajasthan.

GUPTA (S. N.) said that R. S. Chaturvedi's comments were confirmed in U.P.

SATWANT SINGH commenting on results of experiments for the last 8 years at Nasirpur said that 50 per cent higher wheat yields were obtained with the addition of phosphates to green manure. Cultural practices invariably lead to higher yields. Thus legume in cropping pattern gave 50 per cent higher yields. It was found that phosphates hastened maturity, potash also being helpful. It was found that early sown wheat gave better results. Variables were taken care of by the statistician. A study of the rainfall pattern showed that winter rainfall was not as erratic for the Indo-Gangetic plains as was the case for summer rainfall. It was essential to have one irrigation in March. This was found to improve food values as well besides improving the quality of straw. Greater accent was necessary on long-range agronomic practices. Coming to cropping patterns, the best combination was of two food crops, one fibre crop, one legume. Seed rate had also been studied. It was found that half of the fertilizer fixed with seed and another half applied with first watering gave best results.

SIDHU (T. S.) commenting on Talati's paper (16), said that he had also worked out a formula in his paper. Regarding the results of Gujarat, he was afraid that they might err on the higher side.

KHURSALE (N. V.) said that the growth period of wheat in Maharashtra was 4½ months and the total irrigation requirements were 40.6 cm. (16 in.) to which may be added 5.1 cm. (2 in.) of rainfall. Commenting on Talati's paper (16), he felt that with an increase in the number of waterings there should be an increase in depth which was not the case in Talati's findings and called for elucidation.

DINESH MOHAN said that the experiments on the subject should have a bias towards farmers needs. He recommended a simple device such as an ordinary Dalda tin filled up to a certain depth whose water-level observations could give an idea of the evaporation where from evaporation losses could be known. Thus if the farmer was provided with only one Dalda tin and a plastic scale he could get an idea of the evaporation and evapotranspiration therefrom which could be usefully applied for knowing the water needs of his crops.

PANDEY (H. N.) said that in Bihar water requirements of wheat could be met with just two irrigations totalling 15.2 cm. (6 in.) in depth. One irrigation was to be applied in December, *i.e.*, one month after sowing, a second at the preflowering stage when the plant was 55 or 60 days old. Experiments conducted on irrigation treatments in combination with application of inorganic and organic fertilizers indicated that irrigation alone had a significant effect upon yield. While one irrigation increased the yield by 60 per cent, two irrigations brought about a 100 per cent increase. Yield was of the order of 2.3 to 2.7 tonne/ha. (25 to 30 maunds per acre). Studies were also carried out on the relation between evaporation and water requirements for the *Rabi* crop. It was found that the amount of irrigation required was 33 per cent of evaporation whose normal value was found to vary from 48.3 to 53.3 cm. (19 to 21 in.). This was in conformity with other *Rabi* crops like winter maize. For hot weather crops, water requirements were 50 per cent of total evaporation. Commenting on high water requirements in Gujarat, he felt that

the soil might be sandy there with a low retentive capacity. He did not agree with the recommendations regarding the depth of irrigation as 3.8 cm. (1½ in.) which was not practicable as water would not reach the farther end of the plot. Irrigation at 30 per cent available soil moisture was quite good for wheat. Coming to the question of transplanting, he said that while the cost per acre for this was Rs. 200 against Rs. 100 for drilled wheat, the yields were actually much lower being only 0.6 tonnes (16 maunds) against 2.3 tonnes (25 maunds) for drilled wheat. As transplanted wheat was not found to be profitable, this was abandoned in Bihar.

SOOD (M. L.) said that like rice studies on wheat should be related to monsoon rainfall, availability of supplies, frequency of waterings, winter rainfall, soil conditions and whether 'paleo' (pre-sowing irrigation) was needed or not.

MAHIDA (U. N.) felt that economics should be the criterion for all these studies, whether it was a question of water depth or watering intervals. He drew attention to an article in the *International Journal of Hydrology*, Publication No. 28, wherein it was stated that the water used was proportional to leaf area. While this was true for pot culture studies, this was not borne out from field results because of the cooling effect of neighbouring plants. The concept advocated by Penman on the subject was worth consideration and it was for the agronomists to check this up.

MUKHTAR SINGH then commended on the Penman approach. He said that there were two fundamental assumptions involved therein, *viz.*, (i) the crop was completely covered with soil, (ii) moisture was unlimited. The crop then transpired water like a free-water surface. These two conditions were not applicable for the field, because irrigation was applied when the soil moisture was below field capacity and conditions were not similar. The interval depended upon the depth of root zone system. The point was elucidated with examples of potato, cotton, paddy. Penman's concept was quite correct. Accordingly, irrigation was not to be applied above field capacity. Application of water in this manner only made the projects unnecessarily expensive because water which was not needed by the crop went down only to raise the water-table.

MAHIDA (U. N.) said that he himself completely agreed with what Dr. Mukhtar Singh said but would like to emphasize that it is necessary that the criticism levelled against irrigation engineers, as a result of Penman's findings, be answered on appropriate occasions at the proper assemblies.

MUKHTAR SINGH said that fortunately variation was not so high in the case of wheat. Results for U.P., Punjab and other places were more or less in agreement. In new areas, however, some adjustments were needed. Ultimately it was necessary to adopt the soil-moisture approach. Regarding the question of stages of plant growth, pointed out by A. P. Bhattacharya, he stated that after all only three or four irrigations were to be applied and so no harm would accrue if the stages of plant growth were accepted for the application of water for irrigation. But for areas like Gujarat where 8 to 9 irrigations were needed, soil-moisture regime had to be adopted for deciding the time of irrigation. About Pandey's point in which he gave out water requirements as 30 per cent of evapotranspiration, he felt it was probably to irrigation requirement [stated as 15.2 cm. (6 in.) by Pandey] to which he referred in his paper. Then again the actual contribution of irrigation could even be less. It was possible that only 10.2 cm. or 12.7 cm. (4 in. or 5 in.) of irrigation might be needed and the rest might be over-irrigation.

PANDEY (H. N.) replied that wheat was grown in the first week of November. From actual measurements, it was found that there was adequate moisture to the extent of 75 to 80 per cent of available soil moisture at root zone before the sowing of wheat, which amounted to 267.25 cu. m. (2.6 acre-in.) of irrigation. Owing to low temperature, evaporation was low, being to the extent of 5.1 to 6.4 cm. (2 to 2.5 in.). 256.97 cu. m. (2.5 acre-in.) were applied at the end of one month, followed by another irrigation after a month. This was adequate for the plant for one month, *i.e.*, up to the middle of January. No irrigation was necessary after the end of January when the crop was at the milk stage.

ROY (S. E.) commenting on the problem of stage of plant growth, said that Handricks and Hanson had reported, as per reference 7 of his paper, that if they took dimensional ratio of consumptive use, with evaporation

rate using 100 units of stage of growth, solving percentage-wise, a remarkably uniform curve was obtained between the two quantities. This had an important bearing with the Penman's approach. It was possible from this curve to determine soil moisture deficit at any time for any crop, using consumptive use evaporation rate ratio. The curve was substantiated from experimental results. In this curve, the coefficient attained a value of 50 per cent at late flowering stage, being unity at the beginning and going up to 100 at the end. Knowing the extent of deficit at any stage, it was possible to know the depth of application. With this approach adjustments in rostering could be made with the aid of this curve on the basis of availability of supplies.

TALATI (R. P.) commenting on papers 5, 6 and 7 felt that measurements of irrigation water should be accurate in all irrigation experiments, which was not taken cognisance of in the studies. It was essential to have such devices as standing wave flume for such studies. This defect had been noticed by him in the experiments at Gujarat as well owing to which standing wave flumes were set up therein. Regarding a point raised about the low watering needs of wheat at Bardoli he said that it was due to the fact that rainfall there, was 147.3 cm. (58 in.) against 58.4 cm. (23 in.) at Thasra. The soil at the experimental stations in Gujarat varied from sandy loam to silty clay.

MUKHTAR SINGH intervening, said that there was no relationship between the number of irrigations and type of soil.

TALATI (R. P.) added that the experiments were taken up in Gujarat only recently and the drawbacks were being taken care of.

OTHER CROPS

FRAMJI (K. K.) (CHAIRMAN) called upon the General Reporter to introduce the subject.

MUKHTAR SINGH gave his general remarks on papers on sugar-cane, potato, cotton and other crops.

SUGAR-CANE

Kulkarni and Gokhale (15) had reviewed the water requirements of sugar-cane as worked out by different methods, *viz.*, (a) pot culture for the period 1929-34, (b) field scale

experiments at Hadapsar and Padegaon, (c) quantity of water used in relation to yield on soils of varying types in sugar-cane factory areas in Western Maharashtra and (d) water used under well irrigation as recorded during soil survey work. In pots, it was estimated that 91.4 cm. (36 in.) of water were used by transpiration, the same amount being consumed by evaporation and about half as much could be reckoned as lost in drainage for a normal 112.9 tonne/ha. (45 tons/acre) crop. In field experiments, the optimum was 241.3 to 254 cm. (95 to 100 in.). In the studies on water utilisation, 304.8 cm. (120 in.) of water, as measured at distributary head, was used. Under well irrigation, the average water used was 287.02 cm. (113 in.). If 15 per cent water, estimated as lost in transit, was added to this, the water requirements agree fairly well with the estimates obtained by other methods. It might be discussed at this Symposium as to how the data of annual yield in acre-inches as given on page 12 of the paper was computed.

POTATO

Pushkarnath and Swaminathan (17) had concluded that : (a) 8-9 days irrigation interval was optimum for potatoes in North India, (b) 2569.75 cu. m. (25 acre-in.) delta gave better performance than lower and higher irrigation delta, (c) three irrigations in growth phase, four during tuberisation and two during maturity were required irrespective of the duration of varieties. The interaction between irrigations and nutrients was rather complex. Moolani and Hukkeri (18) had reported the results of an experiment, conducted on the basis of water regime concept, on laterite soil at Kharagpur. They found that 44.5 cm. (17.5 in.) of irrigation water or 45.2 cm. (17.80 in.) total water were required for obtaining the best yield.

COTTON

Experiments on Deviraj cotton at 7 centres in Gujarat showed that two irrigations gave as good performance as higher irrigations at Jamnagar, Pilwai, Kim and Thasra, but three irrigations at Kukda and four at Junagadh appeared to be the best (Gopani, 27). Arboreum cotton at Umerala and Horbaceum cotton at Kholwad were also benefited by supplemental irrigation. At some centres, *viz.*, Bardoli and Kim, the response of Horbaceum cotton to irrigation was inappreciable. In

general, irrigation requirements of the crop in Gujarat varied between 15.2 to 25.4 cm. (6 to 10 in.) (Talati, 16). The low irrigation requirements of the crop could be ascribed to high rainfall received in the monsoon season and good moisture storage capacity of the soil. If rainfall was included, the water requirements would be comparable to that in Delhi, which was stated to be 980 mm. by Dastane and Mohinder Singh (23).

Doddiah (25) had found that early varieties of cotton had lower transpiration ratios or were more efficient users of water.

Raheja (22) had dealt with theoretical aspects of irrigation and stressed the importance of knowing optimum levels of all factors.

Mariakulandai (21) had brought out the inter-dependence of irrigation and fertilizers for maximizing production of cotton by the experiment conducted at Siriguppa.

Papers had been received on linseed from Anand and tobacco from Rajahmundry.

DISCUSSION

SWAMINATHAN gave some details of experiments on potatoes. Interval between irrigation treatments was found to have a more significant effect, while the effect of depth of irrigation was not so pronounced due to lateral seepage and low plot size. Energy concept was being introduced in the studies. 20 to 25 days were found to be the period of maturity. Interaction was detected between irrigation and level of nitrogen at 45.4 kg. (100 lbs.) of nitrogen per acre with 90.7 kg. (200 lbs.) of nitrogen and more frequent irrigations. With higher doses of nitrogen, toxic effect was noticed. There was reduction in response to potassium with two water uses.

II. Cropping Patterns

FRAMJI (K. K.) (CHAIRMAN) said that the papers on cropping patterns and water requirements *vis-a-vis* weather factors were being taken up first. He then asked the General Reporter to make the report for these two subjects.

MUKHTAR SINGH introducing the subject of cropping patterns, first touched upon the points covered in the papers namely, by Patil

(9) and Mehta and Shekhawat (10). Patil (9) had analysed the data on current utilisation of water in relation to yield in red soils of Bangalore District (Mysore) and worked out input-output relationships in case of different irrigated crops. From the point of view of allocation of water between crops, the use of irrigation water was highest for paddy as compared to garlic, onion, potato, beans. It was concluded that returns were the lowest for paddy. He had concluded that it was highly profitable to grow cabbage, potato and garlic and among cereals it was better to grow ragi rather than paddy. The levels of irrigation adopted by farmers were indicated for different crops and it was found that water was extravagantly used in paddy. It needed to be clarified as to how measurement of irrigation water was undertaken in the survey and whether optimum use of water was consistent with optimum allocation of other resources as well.

Mehta and Shekhawat (10) had referred to the distribution of crops under different water allowances in Chambal commanded area. The paper referred to the low utilisation of irrigation potential. It was stated that information was lacking regarding water requirements of crops. Special problems of the area were mentioned in the paper. It was stated that cropping patterns were based on water allowance, capacity factor, water requirements of crops, *Kharif/Rabi* ratio, etc. It would have been useful if a detailed procedure as to how different factors were to be taken into account was given and if it was indicated how the proposed cropping patterns would lead to a better utilisation of water.

Malik (19) had discussed the variability of rainfall with place and time in India. From irrigation point of view, he had drawn attention to the values of rainfall under different meteorological conditions. Limits of rainfall in 80 out of 100 years were shown. A point was brought out regarding the feasibility of this. Rainfall was to be considered on the basis of effective rainfall. He had suggested that duration of wet season as given in Table IV of his paper together with watering needs of crops would provide a scientific basis for determining irrigation needs of different areas. This needed clarification. A discussion of the procedure for evaluating effective rainfall, would have been useful.

Dastane and Mohinder Singh (23) had suggested the use of climatological approach to evaluate water requirements. They had given monthly values of potential evapotranspiration at Delhi calculated by Thornthwaite's formula and corresponding rainfall to indicate the periods of water surplus and water deficit. It was necessary that these estimates should be related to consumptive use to be more precise. It was worth consideration whether Thornthwaite or Penman formula should be adopted. Ayyar and Padmanabhamurthy (11) had reported the relationship between water losses from wheat fields and pan evaporation. Strangely enough, A.E.T./pan evaporation was higher in germination and tillering stages than in elongation (growth) stage. Normally the ratio was expected to be higher during peak period of vegetative growth.

DISCUSSION

BHATTACHARYA (A. P.) commenting on Patil's paper, said that it would have been better if an overall picture regarding the augmentation in actual crop production as a result of the switch-over in cropping pattern suggested in the paper had been given. Commenting on Mehta and Shekhawat's paper, he said that it had been stated that the irrigation potential in the Chambal commanded area was 0.24 million ha. (0.6 million acre) while the irrigation utilisation in the first two years was reported to be 0.04 million ha. (0.1 million acre). It had not been stated in the paper as to what part of the big gap between irrigation utilisation and irrigation potential was likely to be covered as a result of the change in the cropping pattern suggested in the paper.

MUKERJEE (B. K.) commenting on Patil's paper (9), said that values of acre-inches of water used for each crop had been given but it was not mentioned as to whether the use of so much water would lead to maximum yield or optimum yield. In other words, it was necessary to know the response of water application to yield.

MUKHTAR SINGH said that in Table V of the paper figures for irrigation and yield had been given.

MUKERJEE (B. K.) said that this was not sufficient as, unless it was known whether the

yield was optimum or maximum, results were not much of use.

MUKHTAR SINGH replied that it had been clearly mentioned that for paddy higher levels of irrigation had no effect on yield, rather the increased use of water for irrigation led to a decrease in the yield. It was not the case for other crops, on the basis of which it was concluded that water was being used extravagantly in the case of paddy.

MUKHERJEE (B. K.) again commented that on page 5 of the paper, optimum allocation of water had been worked out against profitability along with input-output ratios. But it was important to know the percentage increase in yield per acre-inch of irrigation.

MUKHTAR SINGH said that results were based upon a survey in which it had been ascertained as to whether high or low levels of irrigation were being used and what were the corresponding yields, presuming other conditions to be the same. He commented that the returns had been given from a rupee spent on irrigation. No information had been given regarding the other input factors such as fertilizers, *etc.*

BALESHWAR NATH enquired as to whether the measurement of water, done in Patil's paper, was made on volumetric basis or it was supplied from canals or from wells.

MUKHTAR SINGH said that he was not sure whether the quantity of water was measured accurately.

BALESHWAR NATH said that the cost element of water should have been taken into consideration.

MUKERJEE (B. K.) said that presumably the survey related to Visvesvaraya Canals which had difficult soils and wherein variations in soils were high. It was doubtful whether the wide variations in soil conditions had been taken into consideration in the survey which had mentioned the broad classification as laterite soil.

MUKHTAR SINGH said that it had been presumed in the paper that other conditions (like soils, *etc.*) were the same.

DODDIAH (D.) remarked that the region considered in Patil's paper was not in the com-

mand of Visvesvaraya Canals but round about Bangalore.

MUKHTAR SINGH said that it had been specified in the paper that the survey referred to tank and well irrigation.

CHATURVEDI (R. S.) commenting on Mehta and Shekhawat's paper (10), said that there were several difficulties, because information was lacking about cropping pattern, soil and agronomic conditions as accepted by the authors. He felt that investigations regarding Chambal Canals should have been started 10 years ago, but even now they should not wait. Instead of having one Research Centre at Kota, it was necessary to undertake field studies all over Rajasthan.

MUKHTAR SINGH informed the gathering that the Research Centre had been sanctioned by the Government of India more than one year ago, funds had been placed at the disposal of the States, but it was for the States to take steps for starting the Centre and decide whether a particular station was representative or not. He felt that time should not be wasted by the States and they should take more interest in such schemes. The Government of India undertook the responsibility of starting the Research Centre, but it was for the States to set up four Regional Centres under each Centre, although the Government of India was prepared to render cent per cent assistance.

TALATI (R. P.) said that there should have been no difficulty in locating soil types. The matter should not be delayed. It was for the Centre to issue the directive to establish a Research Centre but the State Governments should feel the responsibility to take up this work.

MUKHTAR SINGH intervening said that so far only trial-*cum*-demonstration centres had been set up by the States.

TALATI (R. P.) said that the urgency of the matter should be realised for soil conditions might get worse by waiting.

MUKHTAR SINGH said that it had been reported that problems had already come up in the form of rise in water-table and drainage, *etc.*

TALATI (R. P.) said that there were so many soil specialists in the country. If there was

any difficulty regarding soil specialists, somebody could be sent from Gujarat and it might be possible to collect information regarding soil types without any delay.

BALESHWAR NATH informed the gathering that detailed studies had been carried out for the Chambal some years back by the Plan Projects Committee (Planning Commission). Detailed recommendations were made regarding agricultural production for the field.

MUKHTAR SINGH said that pilot schemes had been worked out for the Chambal at Kota and also Ganganagar but no progress had been made so far.

RANBIR SINGH said that some steps have been taken to select the site for the Irrigation Research Centre in the Chambal commanded area. Similar action had been taken for the Ganganagar area. But he was not aware of the latest progress.

Regarding arrangements for carrying out investigations on irrigation practices, water requirements of crops, *etc.*, some work was being taken up at Borkhera Farm.

GUPTA (S. N.) enquired how far experimentation was possible for trials for double cropping and also as to what area should be required for starting trials on double cropping. He would like to know if it was possible to start this work in conjunction with studies on water requirements of crops. He was interested in this problem both from the point of view of economics and water utilisation. He also felt that certain areas should be selected in the field for taking up work regarding this.

MUKHTAR SINGH said that cropping pattern studies were not feasible by experimentation, because the second crop could never be the experimental one as the effects of growing the first crop would persist in the experimental fields. It was, however, possible to calculate combinations of cropping patterns after finding water requirements of crops.

SOOD (M. L.) said that he had a problem regarding cropping pattern in M.P. wherein the area irrigated from Govt. works was about 0.405 million ha. (1 million acre) out of which 0.324 million ha. (0.8 million acre) lay in Mahakoshal where irrigation was confined to late paddy. The irrigation season for

this was from the middle of July to the end of October. After this, the entire irrigation system lay idle. He was eager to find a solution to this problem. If the cultivator took to early paddy, yields dropped considerably, almost from (30 maunds to 15 maunds per acre). With late paddy, wheat yields were extremely low. Adoption of winter rice involved the consumption of a lot of water which could not be justified in relation to low irrigation rates. He was, therefore, keen that some guidance should be given to the cultivator of M.P. about this.

MUKHTAR SINGH pointed out that similar problems existed in Bihar.

PANDEY (H. N.) then gave an account of cropping patterns in Bihar where not only two crops but even three had been grown, including two paddys and one wheat. Regarding *Aus* paddy, although yields were not lower, a lot of damage was caused by Gundhi bug. The cultivators were not used to chemical control of the same, so *Aus* paddy was not popular. He had successfully tried combinations of *Aus* and winter maize. Even maize planted in December or January with local varieties gave quite good yields. He had tried paddy, wheat, maize as well as two paddys and gram or hot weather maize. His suggestion for Madhya Pradesh was, therefore, that paddy should be followed by winter maize which should succeed if the minimum temperature normally did not fall below 40°F.

MUKHTAR SINGH suggested onion as an alternative for combination with paddy but this was not suitable for a large area.

BALESHWAR NATH enquired about the area where the trials of H. N. Pandey had been undertaken.

MUKHTAR SINGH informed that this was for Shahabad District.

PANDEY (H. N.) said that winter maize which had been adopted as a *Rabi* crop in preference to wheat or gram gave yields as high as 1.87 to 2.23 tonnes (55 to 60 maunds). Moreover the crop possessed an adaptability to stand under conditions provided irrigation facilities were available.

BALESHWAR NATH enquired as to whether maize could succeed in West Bengal.

MUKHTAR SINGH said that maize was an ideal crop to be followed after paddy. He had already recommended maize for West Bengal, Orissa, Madhya Pradesh and Rajasthan in his tour report. He was not in favour of late wheat, as the sowing of 0.037 tonnes (one maund) of seed could yield only 0.074 to 0.11 tonne (2 to 3 maunds) of wheat.

MAHIDA (U. N.) enquired as to how late maize could be taken up.

MUKHTAR SINGH said that it could be grown even in January.

GULHATI (N. D.) enquired about water requirements of maize.

MUKHTAR SINGH said that this was of the order of 2055.80 cu. m. (20 acre-in.) for winter maize.

TALATI (R.P.) gave some information regarding results for Gujarat wherein a combination of paddy-hybrid maize had been tried. The yield of the latter was 1360 kg. per acre. According to him, maize had a great future.

PANDEY (H. N.) said that trials had been conducted on maize ever since 1959. He gave the reference of an article by him on the subject in *Indian Farming*, October, 1961.

SOOD (M. L.) enquired as to whether he could take it that it was the opinion of the House that rice could be followed by maize.

MUKHTAR SINGH suggested investigations through pilot projects. He had been surprised to find that maize was tried even in Scotland.

TALATI (R. P.) felt that one practical difficulty regarding this would be the supply of manures. When maize was to be sown after rice, tillage had to be done and applications of large quantities of manures were necessitated. The problem of dearth of manure could be solved only by application of organic manures. Another problem for this would be the question of the adoption of different varieties of paddy.

MUKHTAR SINGH said that it should not be difficult to get manure when the country was having big plans for the manufacture of fertilizers and he would be surprised if the utilisation of manures would itself pose a problem.

ANAND (D. B.) enquired as to whether market could be found for so much maize.

MAHIDA (U. N.) remarked that it could be consumed in starch factories which would be set up with increased production of maize.

GULHATI (N. D.) said that maize could be utilised as a cattle feed.

FRAMJI (K. K.) (CHAIRMAN) said that the combination of rice followed by maize was certainly worth trying and felt that large scale trials should be conducted for this.

BALESHWAR NATH enquired about the soil requirements of maize.

MUKHTAR SINGH replied that generally heavy soils under well-drained conditions were best for maize. For *Rabi*, there was no problem of excess water. Maize did need irrigation.

SOOD (M. L.) said that the projects in Madhya Pradesh were designed for one crop only, but the Government was being persuaded to adopt two crops, although it was not known still as to what second crop should be taken up.

TALATI (R. P.) said that maize was grown in Panch Mahal District in Gujarat in large areas which had light soils. But there was a *Kharif crop*.

III. Relationship between Water Requirements, Evaporation and Rainfall

FRAMJI (K. K.) (CHAIRMAN) invited comments on three papers on the subject of water requirements in relation to evaporation and rainfall.

DISCUSSION

MALIK (A. K.) regarding effective rainfall, he said the subject was not brought up in his paper, although mentioned in the general reporter's summary about his paper. He said that amongst the important factors affecting effective rainfall were intensity of rainfall and soil permeability. No large scale experiments had been conducted in India on effective rainfall. There were many equations for calculating effective rainfall, e.g., Thornthwaite, Ryder, etc. Due to the lack of an adequate network of stations with self-recording rain-gauges, there were difficulties in the

calculations of effective rainfall, as in the absence of self-recording rain-gauges, intensity of rainfall could not be obtained.

FRAMJI (K. K.) (CHAIRMAN) said that the Symposium would no doubt be interested in the proper evaluation of effective rainfall and dependable rainfall. He invited comments on these aspects of great importance of irrigation engineers, who would like to have some guidance on this important subject.

ROY (S. E.) said that comments had been given on similar lines in his paper. More data was needed on climatology to put Irrigation Engineering on a scientific basis. For this, three curves were needed urgently, namely: (1) normal rainfall distribution curves by weeks, (2) minimum rainfall distribution, by weeks expected in 5, 10, 15 years so that some idea could be had regarding expected droughts, (3) variability of rainfall from year to year for every week during normal crop season. It was very necessary to have intensity of rainfall records wherefrom it might be possible to derive some universal prediction formula for effective rainfall. He felt that graphs should be prepared for homologous regions in the country. He expressed difficulty in the collection of data, particularly regarding intensity of rainfall, from the India Meteorological Department which should make such information more easily accessible.

BHATTACHARYA (A. P.) mentioned about some studies on cycle of rainfall carried out in a number of districts in U.P., for which probabilities of extreme rainfall had been worked out.

GULHATI (N. D.) suggested that a resolution should be drafted regarding important lacuna in rainfall data and necessary steps for meeting the deficiencies.

FRAMJI (K. K.) (CHAIRMAN) welcomed this as a good suggestion.

ANAND (D. B.) said that regarding coverage of rainfall the India Meteorological Department had issued recommendations pertaining to floods on the question of rain-gauges within the catchment. He knew that there was already a move on the part of the India Meteorological Department to make further recommendations on the subject.

GULHATI (N. D.) felt that for each basin, data should be studied and processed by the project authorities; this should not be the responsibility of the India Meteorological Department. Only the collection of data should be on a centralized basis.

FRAMJI (K. K.) (CHAIRMAN) said that the need for the resolution was not so much on the issue of adequate coverage, but for the where-withal to make up the data on the intensity of rainfall and on evaporation. The study proposed by Shri Gulhati for each basin should be aimed at determining the lacunae due to the insufficiency of self-recording rain-gauges for obtaining data on intensity of rainfall and for evaporation measurement stations.

BANERJI (S.) said that recommendations had been made by the India Meteorological Department for the setting up of 1,200 rain-gauging stations, both ordinary and self-recording. But the setting up of the stations was the responsibility of States. He mentioned that no information had been supplied by the States, except Madhya Pradesh, regarding the implementation of the recommendations of the India Meteorological Department. Regarding self-recording stations, whose installation should have been completed by the end of the Second Five-Year Plan, not much had been done to carry out the implementation. For evaporation, for which 75 recording stations had been recommended by the India Meteorological Department, the position was the same. He said that the supply of information by the India Meteorological Department was not always possible owing to lack of funds. He was very happy at N. D. Gulhati's resolution which would strengthen the hands of the India Meteorological Department by having a specific recommendation from the irrigation engineers.

BALESHWAR NATH remarked that in Northern India, dew was nature's gift. He wanted to know about its part in soil conservation and effects, if any, on water requirements.

MUKHTAR SINGH said that qualitatively dew had some effect which might be statistically significant, but it was quite small and not being considered so far.

GULHATI (N. D.) enquired if any measurements were being undertaken for dew.

BANERJI (S.) said that the supply of information by the India Meteorological Department was not always possible owing to lack of staff.

MALIK (A. K.) opined that dew is not deposited on soil, but on plants from where it is evaporated off. During the day, moisture was breathed out by soil, while during the night, moisture was breathed in by the soil which has reached the hygroscopic moisture conditions. Dew may have an indirect effect on evapotranspiration by tending to increase local humidity, particularly on days with little wind.

ROY (S. E.) said that recent research had shown that dew could cut down the evaporation rate and had what is known as 'oasis' effect. So, from the microclimatic point of view, evapotranspiration was affected by dew.

BHATTACHARYA (A. P.) commenting on N.G. Dastane's paper, said that Thornthwaite formula had been recommended for the climatological approach. Studies had been carried out at the U.P. Irrigation Research Institute, Roorkee on climatological approach using a number of standard formulae including those of Thornthwaite, Penman, Blaney, Lowry-Johnson, Hargreaves and Van Bavel. Penman and Blaney-Cridde formulae both gave best results, out of which the latter is preferable in view of the simplicity. Commenting on Ayyar and Padmanabhamurthy's paper (11) he said that Black Belani Atmometer had been recommended for the determination of potential evapotranspiration. Potential evapotranspiration was connected with evaporation by a formula containing a constant which could be determined for any place. As pan evaporimeters were in wide usage for the determination of evaporation he did not understand the idea of introducing a new device for working out potential evapotranspiration.

ROY (S. E.) commented that gravimetric method, adopted in Ayyar and Padmanabhamurthy's paper (11) was very difficult. So he suggested the use of Piche's evaporimeter. In view of its inexpensive nature, it could be bought rapidly and put in Stevenson's Screen. Four to six Piche's evaporimeters would be good enough. It would be free from the trouble with evaporimeters which were disturbed by trees and animals, which also was the case with the atmometer recommended in the paper.

BANNERJI (S.) commenting on Dr. Roy's remarks, said that Piche's evaporimeter was now being given up. In view of the fact that their recording was dependent upon a number of personal factors. Even a slight pressure on the clip vitiated results. Open pan evaporimeter was undoubtedly the best approximation to field conditions, but the disturbing factor of birds and animals and the electrical gadget for measuring the water-level going out of order was there. Gravimetric approach was rather costly and not manageable. So he felt that the atmometer should be given a trial.

MUDGAL (S. C.) said that the difficulty regarding the disturbing factor of Class 'A' land pan by birds might be met with by putting a wire net above the pan.

ROY (S. E.) said that he felt that Piche's evaporimeter should not be considered to be a substitute for pan evaporimeter. According to Israelson, six Piche's evaporimeters gave as good readings, if not better, as those by open pan evaporimeter. Even the cost of six Piche's evaporimeters worked out to only 1/6th of that of a pan evaporimeter.

FRAMJI (K. K.) (CHAIRMAN) called upon the General Reporter to give a resume of the discussions held on the papers on cropping pattern and water requirements, evaporation and rainfall.

MUKHTAR SINGH while giving a resume, said that much useful discussion had been carried out on the two subjects. An important point which had emerged was the adoption of maize as a second crop. He felt that this might take the shape of a recommendation. Regarding the two papers 9 & 10 by Patil, Mehta and Shekhawat, he felt that the basis of adoption of the cropping patterns recommended in the papers had to be understood more fully and some points needed clarification, which could not be done in the absence of the authors. Coming to climatology, he felt the subject to be of importance. Even in England where there was practically no irrigation, the climatological approach was tried scientifically. He recommended this as an interim study for all irrigation projects where estimates for water requirements could be given by the water-budget method. An important suggestion had come out from N. D. Gulhati regarding the filling up of lacuna pertaining to the recording of rainfall and evaporation. He could not understand as to how

evapotranspiration worked out to be higher during germination and tillering than during elongation in Ayyar and Padmanabhamurthy studies.

PADMANABHAMURTHY (B.) intervening, said that no explanation had been sought regarding this point.

MUKHTAR SINGH continuing, said that it was time that this point was looked into and explanation sought thereof. Regarding Piche evaporimeter, he felt that this could not give a true picture of evaporation, as, being kept inside Stevenson's screen, this brought out only the drawing power of the air.

IV. Soil and Soil Moisture Studies

FRAMJI (K. K.) (CHAIRMAN) called upon the General Reporter to present his report regarding the papers on the subject.

MUKHTAR SINGH reading out his General Report said that Dr. Rai Choudhary (20) had suggested the criteria of *pH*, soil texture, water holding capacity, exchangeable salts and suggested the determination of criteria of the Snell's classification for pre-irrigation soil surveys. He had further recommended mechanical analysis of soils and the determination of available nutrients of water to assess the suitability of soil for irrigation. He had suggested five groups of soils and recommended that classification of soils should be suitable for agronomists and engineers.

Sidhu and Cuddou had also presented a paper on the same subject, *i.e.*, pre-irrigation soil surveys. Mudgal (12) while giving moisture characteristic curves of the three soils, had indicated the practical utility of such curves in planning irrigation experiments. Work had been undertaken for Hazuria clay, Rehovot sand and Bichpuri sandy loam. Moisture tension and moisture percentages were worked out within available range of soil moisture from the field capacity to the permanent wilting point. The curves were hyperbolic in shape. According to Mudgal, these curves would eliminate the use of moisture and tension measuring devices. Such devices would still be useful in conveniently following moisture tension for scheduling irrigation in experiments.

FRAMJI (K. K.) (CHAIRMAN) then called upon authors to offer comments on their papers.

DISCUSSION

SIDHU (T. S.) said that soil surveys had been undertaken for 30 irrigation projects, covering 11.08 million hectares (27.4 million acres). Reports were summarized into a brief chart giving salient features. The studies were aimed at deciding the feasibility of irrigation for soils within the commanded area of project. It was possible that ameliorative measures might be called forth for some soils. Regarding arid and semi-arid regions, studies had been taken up on sub-soil water-table, salinity and alkalinity, which were very important in such regions. For humid and sub-humid regions, like Kosi and West Bengal, the problem of rise in water-table was not as important as for arid and semi-arid regions. How soil surveys could lead to better cropping pattern was indicated in his paper (28). A simplified formula was given with the aid of which delta for different crops under different conditions was worked out. Correction factors would be needed for soil texture, salinity, alkalinity, temperature and sub-soil water-table. Deltas had been worked out for the Rajasthan Canal on this basis. The results tallied fairly well.

MUDGAL (S. C.) said that it was not meant that gypsum and tensiometers should be done away with altogether. The recommendations in his paper pertained only to such areas in which there were no facilities for gypsum blocks and tensiometers. For such areas, curves of the pattern indicated in his paper (12) could be drawn in some laboratory, such as I.A.R.I., easily and the work could be carried on thereafter with the aid of those curves. He gave figures for values of atmospheric pressure corresponding to field capacity given by a number of research workers. He wished to seek the opinion of experts present in the Symposium on the subject.

MUKHERJEE (B. K.) commenting on Ray Choudhury's paper (20), said that while a list of 4 factors had been given for evaluation for soils, the same had been elaborated wherein two more investigations were recommended. It was important to have pre-irrigation soil surveys, but it was essential to know the true criteria for determining the suitability of an area for irrigation. It was worth knowing whether there was an impervious pan in soil profile 1.2 to 1.5 m. (4 to 5 ft.) below the ground. Although the depth to water-table had no bearing on changes in water-table, information regarding the latter was pertinent. According

to him it was important to have information regarding the soil profile up to a depth of 1.8 m. (6 ft.). Commenting on Mudgal's paper (12), he said that he was unable to appreciate practical implications of arranging the values of moisture retentive power for the three soils considered in the paper in a descending order, for different groups of soils could not be connected in the same way as had been done by the author.

MUKHTAR SINGH explained the significance of soil-moisture energy concept and elaborated as to how on the basis of this irrigation was to be applied within the range between field capacity and wilting point.

MUKERJEE (B. K.) felt the energy concept to be quite useful and recommended that this should be propagated more extensively among soil workers, as this would be of great importance in crop planning.

HOON (R. C.) commenting on Dr. Ray Choudhury's paper (20), explained the way in which samples were collected. He discussed the methods used in carrying out soil surveys. In his opinion, sampling should be done up to a depth of 2.4 to 3.0 m. (8 to 10 ft.) or the sub-soil water-table whichever was less and extended to any hard pan which might be met with. For agronomists, a depth of 45.7 cm. (18 in.) was allright for soil sampling, but for irrigation engineers, this was quite insufficient. It was important to have complete information regarding sub-soil water-levels. While the practice was to collect the information from adjoining wells, it was better in some cases, particularly where there were no nearby to sink wells and have water-table readings once a month or fortnight throughout the year. The information regarding fluctuations in water-table had to be correlated with respect to the texture of the soil which might be determined by mechanical analysis. He felt that data regarding plant nutrients should be collected only when cropping pattern was to be decided. He suggested that the data collected by T. S. Sidhu pertaining to soil surveys for over 10.9 million hectares (27 million acres) should be compiled in a volume or memoir and made available to soil workers.

MAHIDA (U. N.) enquired as to the whether soil classification maps had been prepared and made available. Commenting on Dr. Ray Choudhury's paper (20), he felt that it was

important to have information regarding first permeable stratum which was not mentioned in the paper, on which depended the design of sub-soil drainage channels. He recommended soil sampling up to a depth of 2.4 to 3.0 m. (8 to 10 ft.) as this data was needed for designing land drainage system. Fertility studies were felt to be too elaborate by him.

MEYDO remarked that soil surveys should be a must in all irrigation projects. Commenting on T. S. Sidhu's paper (28) he said that no mention had been made about frequency of soil sampling. It was to be remembered that soil characteristics varied rapidly. While pre-irrigation surveys were meant for specified purpose, *e.g.*, drainage, which was to be followed frequently, it was important that frequency of soil sampling should be decided before hand. Commenting on Dr. Ray Choudhury's paper, he said that the tests mentioned were inadequate in some points. While agricultural and fertility surveys should extend up to 45.7 cm. (18 in.) soil sampling should go on up to 2.4 to 3.0 m. (8 to 10 ft.) for drainage surveys, beyond which water should not rise. Information regarding first impervious strata, drainage capabilities of soils, salt contents of drainage water was important. Soil surveys were to form a continuous process. An agency had to be set up for keeping a watch on soil conditions, water-table, salinity and making an evaluation from time to time.

SIDHU (T. S.) mentioned that fluctuations of water-table were observed in selected wells monthly for three or four years as a part of pre-irrigation survey.

MEYDO said that this was not necessary. Water-table was to be observed more extensively where it was high.

SIDHU (T. S.) said that this was done with a view to study the quick changes in the water-table during monsoons with a view to determine the durability of soils. Although the grid squares were generally 404.69 to 809.78 hectares (1,000 to 2,000 acres) this was reduced even to 40.47 ha. (100 acres), if necessary, in the event of any doubt.

BHATTACHARYA (A. P.) said that some information had been collected by him from National Vegetable Research Station, Wellesbourne, Warwick, U. K. according to which field capacity corresponded to 0.03 atmosphere in some cases, so it was not safe to lay down

a range of 0.3 to 1 atmosphere for field capacity for universal usage as had been done in Mudgal's paper (12).

ROY (S. E.) referred to Robinson and Bayer's work wherein means had been suggested on the basis of pore size distribution. Where the curve flexed the corresponding value could be taken as that for pF . For determining the tension corresponding to field capacity, standard tables were being used in America on the basis of pore size distribution. He mentioned some omissions in Dr. Ray Choudhury's paper (20) regarding the tests to be adopted for pre-irrigation soil surveys. He was referring to slope group.

MEYDO said that this had already been done in Gujarat.

ROY (S. E.) continuing, said that infiltration rate constant, omitted in Dr. Ray Choudhury's tests, should also be taken into consideration. Structure should be determined from the tension tables, wilting point from available moisture contents. Soil analysis was not necessary at every depth. The depth could be divided into three zones, out of which 'B' horizon might be more important than the 'A' horizon. Leaching requirements which might be needed after the determination of the salt contents were also to be considered. Water-table fluctuations had to be studied regularly for obtaining information regarding sub-soil water-table. It was not necessary to study sub soil and water-table conditions up to 2.4 or 3.0 m. (8 or 10 ft.). As a matter of fact, water-table below 1.1 m. (3.5 ft.) actually lowered the yield. In Holland, the depth of water-table was controlled even when the depth was up to 1.2 m. (4 ft.) below the ground. So soil surveys were needed only up to 2.1 m. (7 ft.) below the ground, for standard drainage ditches never went below 2.1 m. (7 ft.).

CHATURVEDI (R. S.) said that it was important to study the availability of water *vis-a-vis* salinity, besides the variation of pF value with variability of soil contents according to the energy concept. Osmotic pressure was an important factor in these studies, on account of which it was necessary to study the quality of water which would affect osmotic pressure in the plant. In view of the complexity of the subject, it was important that some leading agronomist should come forth to standardize this work. It was possible that high water require-

ments in Gujarat might be explained by studying the soil contents. He had found that wheat could be grown in some alkaline soils with a number of waterings.

MUDGAL (S. C.) said that total soil moisture stress was the sum of soil moisture tension plus osmotic pressure in soil solution. This was most important for saline soils. Regarding the figure of 0.03 atmosphere for field capacity, he did not understand how this could be so low for at this stage even saturation point would be crossed.

OSTERKAMP (Holland) confirmed the remarks of Dr. S. E. Roy. There were places in Holland where the water-table was maintained 0.6 to 1.2 m. (2 to 4 ft.) below the ground. He felt that infiltration irrigation or irrigation with root zone depth within the water-table, which had been mentioned in one of the papers (2) would lead to salinity danger and accumulation of salts in top soil. This was being managed in Holland by sub-soil drainage. Infiltration ratio, 'K' factor was determined in Holland under field conditions with saturation soil moisture by the auger hole method. Accumulation of salts could be done away with by leaching.

HOON (R. C.) said that Dr. Roy's point regarding stratification of soils in 'A' and 'B' horizons was feasible only in forest soils which contained organic matter and not in agricultural soils. In such soils it was important that soil surveys were carried out up to 2.44 m. (8 ft.) or water-table whichever was nearer unless some hand pan was met with which might not be probed. It had to be remembered that if salinity was not pushed below 2.44 m. (8 ft.) it would come up by itself. To ensure that salinity did not exist up to that depth, soil surveys had got to be carried out up to a depth of 2.13 m. (7 ft.). A better practice was to dig a pit and study the soil characteristics therein in detail.

BALESHWAR NATH felt that it was necessary to lay down certain specific criteria for guidance of irrigators with regard to dosage of irrigation based on requirements of soil as revealed by detailed soil surveys. He stated that vast areas in the Punjab which have become water-logged in recent years must have been subjected to wrong and unscientific irrigation applications. The errors committed in the application of water to water-logged areas

in the Punjab will prove extremely useful if they are brought out. It was a pity that such large extent of areas were lost in spite of highly developed technical knowledge available in the State of Punjab.

SOOD (M. L.) said that he knew that no soil surveys had been done in the Punjab. Due to partition, reclamation activities could not be taken in hand there.

FRAMJI (K. K.) (CHAIRMAN) informed the House that there were regular five yearly soil surveys in Sukkur Barrage area in Sind. Water-table observations were also taken regularly both in the pre-monsoon and post-monsoon periods. These data are used for determining the suitable crops for the areas as well as the effects of rice irrigation.

JAIN (J. P.) said that only spring level readings were observed in U.P. and not in Sind.

BALESHWAR NATH informed that rice irrigation was on the increase in the Punjab and so water-table was going up.

TALATI (R. P.) informed about the soil maps, containing hydro-isobars which were made in old Bombay State 40 years back, which were useful for the irrigator. Maps of different sizes were utilised for the sanction of blocks as also drainage capability. Pre-irrigation soil surveys had to contain information particularly for water-table, during *kharif* and *rabi*, electrical conductivity, texture or permeability.

FRAMJI (K. K.) (CHAIRMAN) called upon the General Reporter to give a resume of the discussions.

MUKHTAR SINGH commenting upon the discussions, said that the important tests regarding pre-irrigation soil surveys, which had come out as a result of the discussions, should be (i) soluble salt contents, electrical conductivity, exchangeable sodium percentage, water holding capacity, depth of soil, information regarding hard pan, permeability. Regarding water-table, the minimum frequency of observation should be twice a year, pre-monsoon and post-monsoon, and if possible, once in between. Regarding available nutrients, he felt that this could be adjusted by proper soil management, but a study of the soil physical constants was important. The suitability of pre-irrigation soil surveys had been fully agreed upon. While pre-irrigation surveys

might be simpler, post-irrigation surveys had to contain more detailed information. Moisture tension studies were also necessary, a knowledge regarding moisture capacity between field capacity and wilting point being important. Quality of irrigation waters had also to be studied. Regarding soil moisture characteristic curves, the variations had already been explained. He said that saturation point existed only at zero atmospheric pressure and it was possible for the soil moisture to attain the value of 0.03 atmospheric pressure. The value for clay soils was of the order of 0.05. Usually the value of 0.1 to 0.15 was taken for field capacity. Previous data had to be collected in this connection.

FRAMJI (K. K.) (CHAIRMAN) said that it was fully agreed upon that no irrigation projects should be taken up from now onwards without pre-irrigation soil surveys.

V. Optimum Water Use

FRAMJI (K. K.) (CHAIRMAN) then called upon the General Reporter to introduce the subject. Dr. Mukhtar Singh then read out the General Report.

Kumra (14) had given a detailed account of the methods of economising water use by careful attention to the principles of reduction of water losses in conveyance, distribution and application in the field. He had also stressed the importance of coordination of irrigation requirements *vis-a-vis* rostering of channels. He had also referred to the existing programmes of research, training and demonstration in water use. Doddiah (2) had also emphasized the need for field control for controlling and regulating supply of water according to crop needs. Walter (13) had reported that better results could be obtained by delivering water at intervals in large volumes than by delivering a constant flow for a definite period by the adoption of a rotational system.

The scope and limitations of the suggestions could be considered at the Symposium. As there were no discussions, the Chairman, closed the subject by thanking the General Reporter.

Future Programme

MUKHTAR SINGH commenting upon future programme of work on the subject, felt that work should be organised on a more scientific basis, the question of cropping pattern being taken into consideration. In this connection,

the suggestion from Bihar regarding the adoption of a second crop could be tried. The question of collection of meteorological data was already going to be taken up by the Sub-Committee framed on the subject. He recommended that greater use should be made of the climatological approach for the determination of water requirements.

DISCUSSION

FRAMJI (K. K.) (CHAIRMAN) said that as there was a lot of variation in the methods followed by research workers at various stations it was important that steps should be taken for a standardization under the guidance of Dr. Mukhtar Singh.

MUKHTAR SINGH replied that a Committee had already been formed on the subject by the Indian Council of Agricultural Research. A note had been prepared by him and circulated to eminent irrigation engineers and agricultural scientists. Defects in the previous approach had been pointed out therein and a programme had been chalked out for future experimentation. Comments had been invited and he had still to redraft the note incorporating the suggestions received on the subject. Dr. B. K. Mukerjee who was present in the Symposium had been asked by I.C.A.R. to compile a review of the past work done on the subject. Deliberations of the Symposium would be helpful to Dr. B. K. Mukerjee in his work, while taking stock of the past work and indicating future programme of experimentation, it was pointed out that it was for the States to implement the recommendations without which no progress was possible.

ANAND (D. B.) said that while a lot of progress was being made on research work on the subject, there being 37 stations under I.C.A.R. besides 5 in project areas, as also State Research Stations, some coordination was needed on the subject so that substantial progress could be made regarding field application of such factors as were of interest to the irrigator, e.g., level of irrigation, interval between irrigation treatment, etc. So far no ready solutions were available on the subject. While it was a good thing to know about optimum levels and frequencies of irrigation, which could possibly be applied only by private irrigators having tube-wells, it was impossible for the irrigation engineers to apply water at the time and up to the quantity recommended. It was, therefore, important that one should

know what percentage of the optimum yield would be obtained if alterations were made in optimum levels in accordance with practical considerations.

MUKHTAR SINGH said that it was certainly possible to work out suitable levels from optimum to lower figures. But still it was important that work on experimentation should be continued to gain more knowledge.

ANAND (D. B.) said that he agreed that experiments should be continued. What he felt was that practical solutions should be available. He was facing some problems such as those by M. L. Sood in Madhya Pradesh. He referred to the Vidarbha area and Gujarat where the problem of growing a winter crop was baffling the irrigation engineers.

MUKHTAR SINGH recommended water balance studies in this connection. It was important to know water requirements for any region on the basis of which it was possible to lay down criteria for the utilisation of available irrigation waters.

ANAND (D. B.) said that rough and ready results were needed immediately regarding water requirements for various regions in the State with respect to local soil and climatic conditions. It was desirable to have a table for every region. Recommendations should include multi-cropping patterns as also the quantity of water required for each crop keeping practical considerations in view.

MUKHTAR SINGH said that this could be done by the climatological approach.

FRAMJI (K. K.) (CHAIRMAN) said that what was being stressed was that up-to-date information which was available on the basis of irrigation research could be circulated.

SOOD (M. L.) wanted that a comprehensive note should be drawn up regarding the methods involved and equipment required for pre-irrigation soil surveys.

MUKHTAR SINGH said that this could be done.

SIDHU (T. S.) intervening, said that a circular had been issued by the Central Water and Power Commission to all State Chief Engineers eliciting information on the subject, but the response had been poor. The manual on pre-irrigation surveys was in preparation under a directive from the Planning Commission.

APPENDIX I

Resolution

Noting that the existing networks of recording rain-gauges and evaporation measuring stations in India are very inadequate for the purpose of proper planning of Irrigation and Agriculture on a Scientific basis;

Considering that the above basic data are

essential to meet such demands particularly in view of the large increase in the irrigation potential of our country;

Recommends that urgent steps should be taken by the Government of India to fill up the lacunae in the existing networks of self recording rain-gauges and evaporation measuring station.

LIST OF PUBLICATIONS ISSUED BY THE CENTRAL BOARD OF IRRIGATION AND POWER

(PUBLICATIONS MARKED WITH AN ASTERISK ARE OUT OF STOCK)

- *1. Digest of Technical Notes (1931).
- *2. Digest of Technical Notes (1932).
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