Efficiency of Water Distribution
and
Use on the Land

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NOTE:

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FOREWORD

For increased food production, creation of irrigation potential is one aspect and its proper utilisation another. Often, there is considerable time-lag between the two and this is attributable to several causes, namely, loss of irrigation waters at various locations and overdose of irrigation waters without any consideration of the type of soil and crop. The resultant factors like water-logging and salinity further retard the progress of irrigation. The subject, therefore, requires careful consideration for proper utilisation of water for maximising food production.

The Central Board of Irrigation and Power at its Thirty-second Annual Research Session held at Ooty in June 1962 organised a Symposium on "Efficiency of Water Distribution and Use on the Land" to take stock of the prevailing practices and consider ways and means to improve upon them. Five papers were presented on the various aspects of the subject by scientists and engineers belonging to State Irrigation Research Stations, Ministry of Food and Agriculture and also Technical Institutions. The symposium was largely attended by State Irrigation Chief Engineers, Directors and Researchers from various Research Stations, Officers of Indian Council of Agricultural Research and the subject was broadly discussed.

A Sub-Committee consisting of Sarvashri D. B. Anand, A. R. Venkataraman, Baleshwar Nath, J. P. Mital, K. V. Ekambaram and J. P. Naegamvala was formed to examine the various issues arising as a result of discussion and bring out recommendations for implementation by Irrigation and Agriculture Departments.

The recommendations of the Sub-Committee, symposium papers and discussions have been compiled in the present publication for use by Irrigation and Agriculture officers and research workers. The Board is thankful to the authors of the papers and the participants who largely contributed to the success of the Symposium and Sub-Committee members in finalising the recommendations.

New Delhi;
August 1967

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

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RECOMMENDATIONS BY THE SUB-COMMITTEE*

The papers presented during the Symposium held at Ooty on 1 June 1962 cover a lot of general ground and the contributors have also disgressed from the main problem set out for the discussion. There is, however, a general pattern of thought from which certain features emerge. These features mainly refer to the losses of irrigation waters at various locations, the desirability of restricting dosages of irrigation waters and the need of research in the various aspects involved.

Arising out of the study of these papers and the discussions during the proceedings of the Seminar, the following recommendations may be considered as the consensus of general opinion : —

(*i*) Since the stored waters are expensive, the crop pattern of projects should be such as to utilise as large quantities of water from the run of the river as possible;

(*ii*) A substantial amount of water is lost in the carrier system due to transpiration, losses on account of the vegetation along the banks, berms and beds of the channels and by percolation through the same;

Therefore, attempts should be made to keep the beds, berms and the bank clean of vegetation; also, impervious lining should be adopted in the water carrier channels as far as economical and practical;

(*iii*) Heavy losses of water occur in the fields on account of percolation, evaporation and wastage. The sizes and arrangement of the plots should be fixed according to the soil types, topography, permeability and the type of crops so as to minimise losses by effecting irrigation in the shortest time possible. The irrigation should, where possible, be done by furrows rather than by flooding;

(*iv*) A substantial percentage of irrigation water can be saved by the following steps:

(*a*) Soil classification of the irrigated areas to ascertain the soil structure;

(*b*) Fixing the dosage of irrigation to the type of crop, the type of soil, the climatic conditions and the conditions of wetness before application of water;

(*c*) Agrononomical measures like mulching and levelling to obviate avoidable evaporation losses;

(*d*) Localization of crops so that management, distribution and drainage become easy; and

(*e*) Use of improved implements to help agricultural practices which may lead to economy in the use of water.

(*v*) Water-logging and salinity have almost become an integral part of our irrigation systems. They block the pores of the soil and lead to land going out of cultivation or becoming unfit on

*This Sub-Committee was formed to study the recommendations made at the Symposium on the subject held at Ooty in May-June 1962.

account of increased salinity. In order, therefore, to maintain soil conditions amenable to fruitful and economical irrigation it is necessary to take steps to obviate the occurrence of water-logging and salinity. For these, the following measures have been recommended :

(*a*) Keeping the surface drainages clear and avoid blocking thereof by canals, roads, railways and other structures;

(*b*) Where necessary, instal sub-surface drainages (open and covered) in order to reduce and keep down the sub-soil water-table to a reasonable limit;

(*c*) Where suitable and practicable, utilise tube-well pumping to keep down the sub-soil water-table; and

(*d*) Where salts have appeared, increase water allowance, to wash down the salts and reclaim the saline lands for irrigated cultivation.

(*vi*) It was the general consensus of opinion that a lot of research work and demonstration is necessary and that a large amount of planning of irrigated agriculture was essential with the aim of achieving maximum yields with the minimum quantities of water without causing damage to the land. For this purpose, the following are recommended: —

(*a*) Extensive evapo-transpiration studies for the varying factors of soils, climate and allied factors:

(*b*) Determination of water requirements and irrigation dosages for varying conditions of crops, soils, climatic and other conditions;

(*c*) Determination of cropping patterns and improvements of irrigation and agricultural practices;

(*d*) Laying Standards for suitabilities of irrigation waters for application to the lands; and

(*e*) Effective cooperation between the Irrigation, Agricultural and Rural Development Departments for the purposes of research, training demonstrations and propagating improved methods amongst the farmers.

Experimental and Empirical Studies on Water Requirements of Principal Crops of Uttar Pradesh

by

A. P. Bhattacharya* & B. P. Srivastava*

SYNOPSIS

The utility of the subject for a State like Uttar Pradesh wherein agriculture is the mainstay of 70 per cent of the population is indicated. The relevance is, however, only for the irrigated areas, which form 12·9 million acres (5·22 million ha.) out of 39·8 million acres (16·11 million ha.) of net cultivated area in Uttar Pradesh.

The function of water for irrigation in the growth of the crop is discussed and the need for the application of the correct dosage of water for maximizing the growth of the crop is explained.

The approach in the experimental studies was to single out the effect of watering, both its level and frequency, keeping all other factors such as type of seed, type of manure, quantity of seed, quantity of manure, etc., and cultural practices the same and in conformity with local practice. Randomised block system with parallel yield trials was adopted in all the experiments. The work had been undertaken for three principal crops of Uttar Pradesh, namely, wheat, rice and sugar-cane from 1942-43 to 1949-50. The experiments were taken up again at Dhanauri for the years 1956-57, 1957-58, 1960-61 for wheat and for rice for the year 1961. Great care was taken in the accurate measurement of the water applied with the aid of a V-notch. Randomisations in the design of experiments were varied from year to year.

For sugar-cane, significant indications were obtained only for one station, namely, Bulandshahr, for which it was brought out that 4 in. (10·2 cm.) depth of irrigation at an interval of three weeks produced the maximum yield.

For wheat, which was the main crop experimented upon and which is being pursued in recent years, the object was to study the effect of three depths, 2, 3 and 4 in. (5·1, 7·6 & 10·2 cm.), three intervals, 2, 3 and 4 weeks and three dates for first irrigation. Latterly, the factor of first irrigation has been replaced by the level of nitrogen, for which three levels, 0, 20 and 40 lb. per acre were introduced mainly with the idea of seeing as to how far the correct level of nitrogen could be instrumental in bringing down the watering needs of the crop. With four replications, there were one hundred and eight treatments in all. Two applications of 3 in. (7·6 cm.) depth of irrigation at an interval of 5 weeks, apart from a pre-sowing irrigation of nearly the same depth with 40 lb. (18·14 kg.) of nitrogen gave the maximum yield for Dhanauri.

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For rice, for which experiments had been conducted previously at Atarra, Tisuhi and Nagina, studies were taken up at Dhanauri in 1961 *for testing the efficacy of various combinations of level and frequency of irrigation, supplemented by the additional factor of the level of nitrogen, in producing the maximum yield. Tentative indications were that* 4·5 *in.* (11·4 *cm.*) *depth of irrigation at an interval of* 2·5 *weeks gave the highest yield with* 40 *lb.* (18·14 *kg.*) *of nitrogen per acre for Dhanauri.*

Apart from the experimental determination of water requirements of crops, a number of empirical formulae, used by the United States Bureau of Reclamation, United States Department of Agriculture and Rothamsted Experimental Station, Harpenden, U.K. for the assessment of irrigation requirements from climatological data, were applied with a view to provide a check-up for the experimental work as also to test their utility for application in areas for which no experimental data was forthcoming and for which a rough guess could be available regarding the irrigation requirements from climatological data alone. Blaney-Criddle formula used extensively in the United States Department of Agriculture was recommended for adoption.

Another approach by an indirect determination of evapotranspiration losses was introduced by the initiation of studies on transpiration losses apart from evaporation losses. Evapotranspiration losses give the water requirements directly, which are irrigation requirements plus precipitation. Plans were afoot to start work on other standard approaches, namely, those of Thornthwaite of the United States Weather Bureau (turbulence or aerodynamic method) volumetric method, Penman method of U.K. (energy balance method).

A study was carried out regarding the actual usage of water by the cultivator in the irrigated areas of Uttar Pradesh in the light of values of optimum depths of irrigation as determined experimentally. It was indicated that there was over-irrigation invariably wherever water was available for irrigation to the extent of 30 *per cent to* 40 *per cent with the result that the yield was going down from* 10 *per cent to* 20 *per cent. Economics of this was worked out on the basis of an estimation of the value of crops in irrigated areas of U.P. in* 1957-58 (*which amounted to Rs.* 248 *crores*). *It was indicated that the yearly loss accruing to the State in the agricultural sector resulting from over-irrigation was of the order of Rs.* 40 *crores, which gave an idea of the enormity of the loss due to wasteful irrigation in the State of Uttar Pradesh.*

A three-pronged drive was suggested for devising ways and means for checking the enormous loss due to over-irrigation. This consisted of (i) the initiation of experimental studies on water requirements of principal crops of Uttar Pradesh on crop-wise, soil-wise and region-wise basis, (ii) dissemination of the knowledge to the cultivator and (iii) inducing the cultivator to take to the correct usage of irrigation water.

1.0. Introduction

1.1. The subject of water requirements of crops is inextricably connected with that of irrigation, as it is only a correct determination of such requirements which can ensure the best use of limited supplies of irrigation waters and serve as an aid towards the maximization of food production of the country, which is the most important problem being faced by the Government, besides being helpful in the crop planning of all irrigation projects. The success of the latter is mostly dependent upon a rational cropping pattern, moreover, the utilization of the irrigation potential created by such projects is also dependent upon the maximum use of the available supplies which alone can step up the area under irrigation within the commanded area of the irrigation project.

1.2. The correct use of irrigation water maximizes the yield. This is the main object of the determination of the proper dosage of irrigation treatment. Besides the aspect of increased food production, the dangers of over-irrigation are averted which further results in considerable savings in irrigation waters. Many more fields which would have been deprived of irrigation waters by the practice of over-irrigation in some fields may be supplied water, thus increasing the yield further.

2.0. Method of Approach

2.1. In the present series of experiments, studies were confined to the determination of the optimum water requirements of a crop for producing the maximum yield at a particular experimental station, where other controllable factors influencing the yield such as manure and other cultural practices were kept more or less the same and conformed to local conditions. It was believed that this, along with the smoothening of vagaries of climatic variations as a result of experimentation under the same set of conditions regarding normal climatic factors, character of the soil and sub-soil over a number of years, was likely to yield fairly dependable results pertaining to the depth and frequency of irrigation.

2.2. The experiments were conducted with parallel yield trials of different irrigation treatments, consisting of combinations of the depth of watering and the frequency of waterings or the interval between these along with the date of first irrigation in some cases, based on randomized block system. In this method, the experimental area was divided into a number of sub-plots on each of which different dosages and frequencies of irrigation were applied in accordance with the designed experiments. In previous experiments, conducted from 1942-43 to 1949-50, the crops under experimentation were sugar-cane, wheat and rice. There were a number of experimental stations, as marked in Figure 1, but since 1956-57, only the two staple crops of Uttar Pradesh, namely, wheat and rice, are being experimented upon at the Government Agriculture Farm, Dhanauri. They were carried out for the years 1956-57, 1957-58, 1960-61, being discontinued for two years due to failure of Farm Tubewell.

2.3. The method of irrigation adopted for these experiments was the usual system of irrigation followed in India. The plots are made practically level and water is allowed to run at the higher end and is stopped as soon as the lowest part has received a sufficient supply.

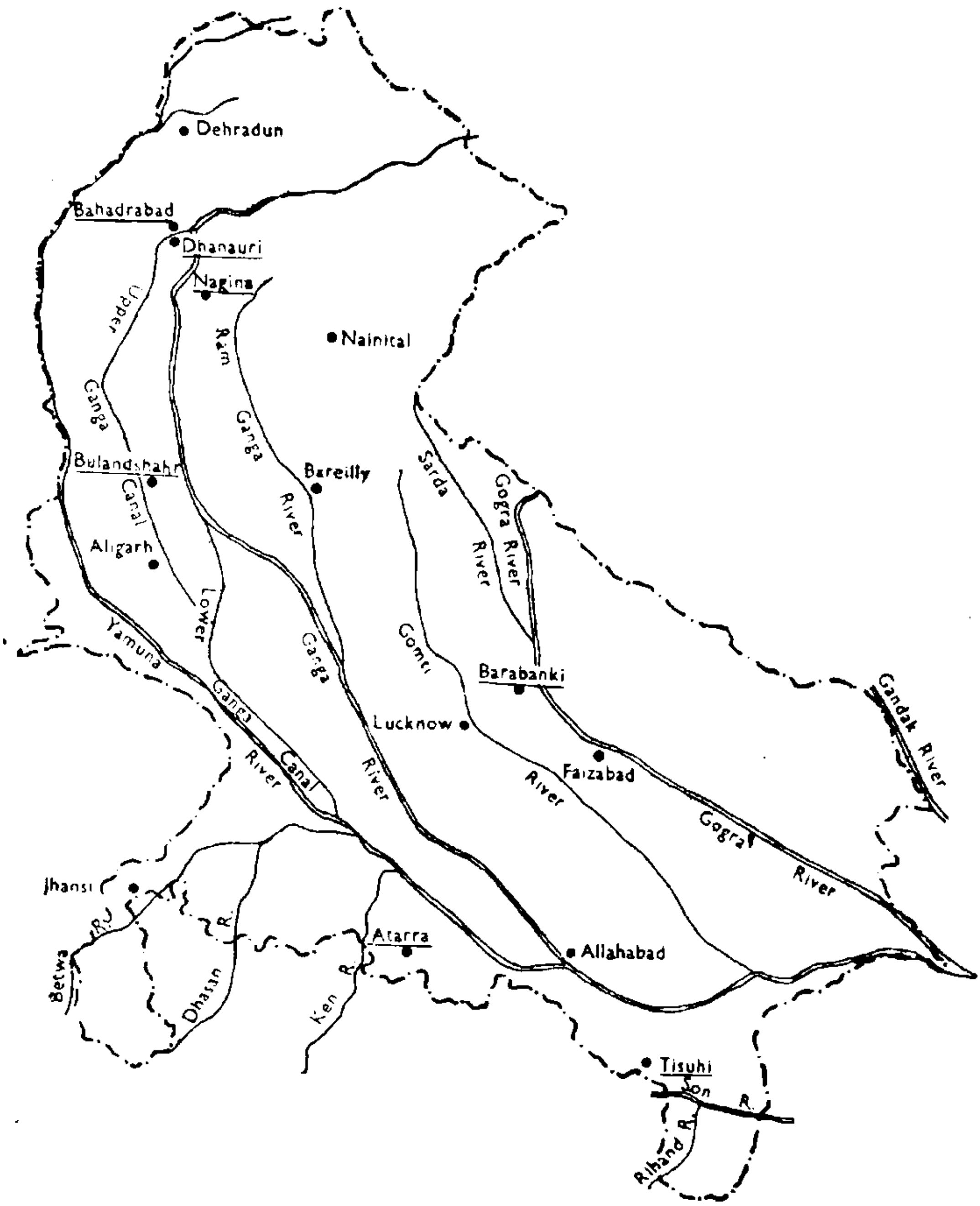

FIGURE 1 : *Index map of Uttar Pradesh showing Experimental Stations (underlined).*

2.4. Particular care was taken to achieve the maximum accuracy in irrigation depths. This was done with the aid of a calibrated V-notch.

2.5. Figure 2 gives a general idea of the design of the experimental sub-plots. The number of sub-plots depended upon the total number of treatment combinations. The number of a particular sub-plot was allotted on a strictly randomized basis. To ensure the completely non-biased nature of the experiments, the randomizations were altered from year to year for each set of experiments for a particular crop.

2.6. To irrigate the sub plots, a constant discharge was passed from the V-notch and taken down to the tail end of the sub-gul. The constant flow at the tail was suddenly closed with the help of steel gates or wooden planks, and simultaneously a cut was made into the sub-plot in which water was allowed to flow at such a rate that the gauge at the tail of the sub-gul was kept constant throughout the period of irrigation.

3.0. Experimental Station

3.1. Dhanauri, lying in the district of Saharanpur, is only seven miles from Roorkee. This district is the northernmost area within the Ganga-Yamuna *Doab*. Most of the tract therein is level, and the soil is mostly loam. *pH* value of the soil has been found to be 7·0. The principal crops are rice, maize and sugar-cane among *kharif*, and barley, gram and wheat among *rabi*. The district is a healthy one. The normal rainfall is 41·12 in. (104·44 cm.) with a higher winter rainfall than eastern or southern districts. The experimental station lay in a 4-acre (1·62 ha.) plot within the Government Agriculture Farm, Dhanauri.

4.0. Sugar-cane

4.1. Experiments on water requirements of of sugar-cane had been conducted at Bara Banki and Bulandshahr from 1942-43 to 1949-50. At Bulandshahr, it indicated that 4 in. (10·2 cm.) depth of irrigation at intervals of three weeks gave the maximum yield.

4.2. A review of the experiments at the two places showed that it was not the quantity of water alone which produced the maximum yield, for although Bara Banki is wetter with 43 in. (109·2 cm.) of normal rainfall than Bulandshahr whose normal rainfall is 26 in. (66·0 cm.), the water requirements of sugar-cane for the former station are not less as the maximum yield was obtained with 5 in. (12·7 cm.) of irrigation for Bara Banki at an interval of two weeks as compared to 4 in. (10·2 cm.) for Bulandshahr at a wider interval of three weeks.

5.0. Wheat

5.1. Experiments on wheat were carried out at Bara Banki, Atarra, Bulandshahr, Bahadrabad, Dhanauri. The details of the experiments are given below :

5.1.1. *Object*—The object of the experiments was as follows :

5.1.1.1. To find the best combination of irrigating wheat with two irrigation treatments of varying depths of 2, 3 and 4 in. (5·1, 7·6

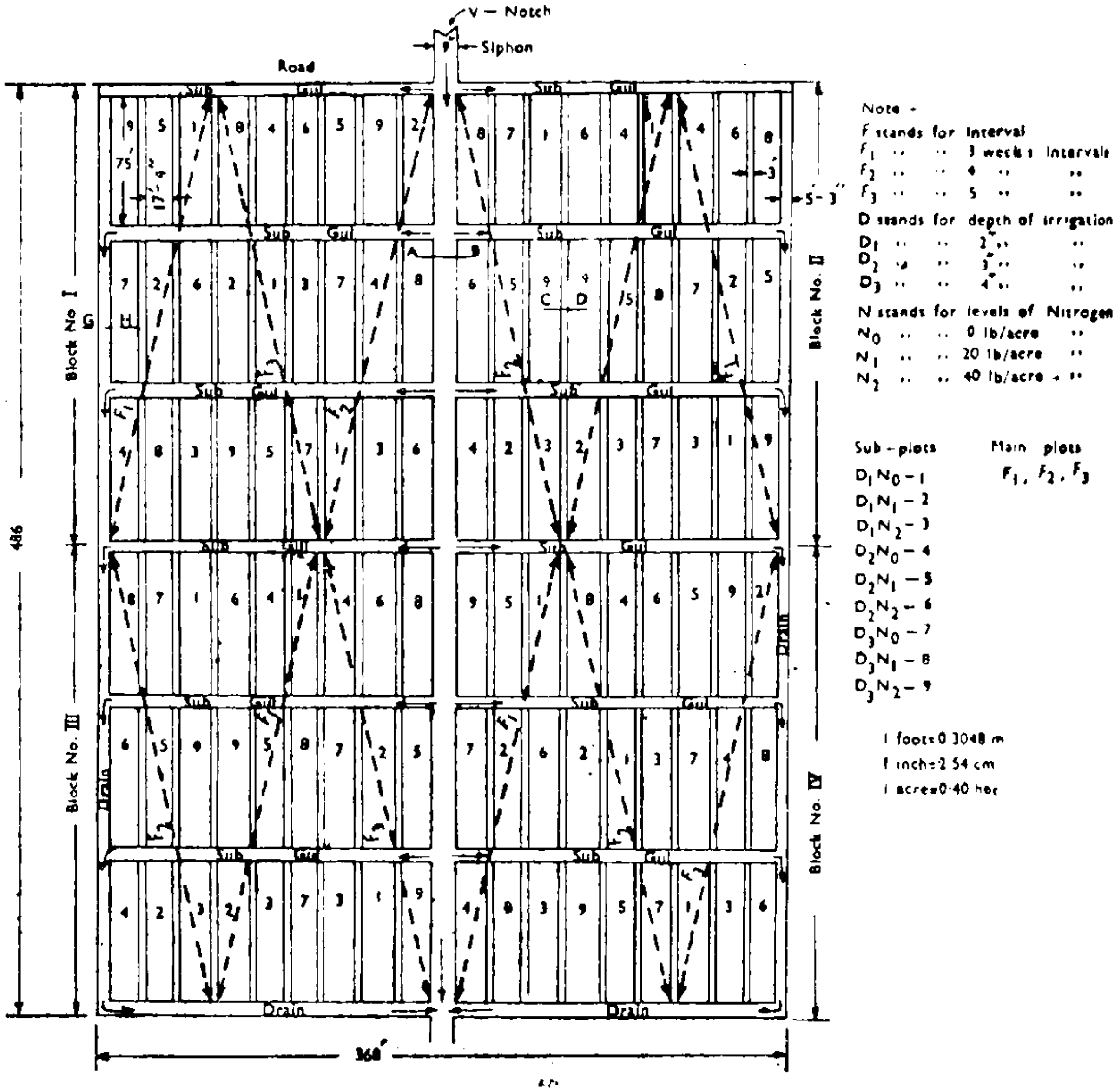

FIGURE 2 : *Layout plan for experiments on water requirements of wheat at Government Agriculture Farm, Dhanauri (1960-61).*

and (10.2 cm.) with intervals varying from 3 to 5 weeks. Some experiments had also been conducted with one watering alone.

5.1.2. *Method of Layout*—The method was the same as indicated in Figure 2. There were three blocks each consisting of thirty-six sub-plots. Details are given for experiments at Dhanauri since 1956-57.

5.2. The type of wheat used was Pb-591 for the years 1956-57 and 1957-58, and N.P. 710 in 1960-61.

5.3. For the years 1956-57 and 1957-58, the factors studied were the same. From 1960-61, the approach was altered in some respects. The factor of the date of first irrigation was dropped and was replaced by the level of nitrogen with a view to seeing whether the application of the correct dose of nitrogen could bring in some reduction in the watering needs of the crop. Three levels of nitrogen, namely, 0, 20 and 40 lb. per acre were taken up for experimentation. The design and the layout were modified accordingly. Some idea of the details of the design may be had from Figure 2.

5.4. Tables I, II and III give the yield data for the years 1956-57, 1957-58 and 1960-61. Details of statistical analysis may be seen in Appendices I, II and III.

5.4.1. It was found analytically that the effects of depths, intervals and dates as also their interactions were significant for the year 1956-57. Although there were no significant differences amongst the mean yields due to 3 and 2 in. (7·6 and 5·1 cm.) of irrigation at intervals of 4 and 5 weeks given on the first three dates, it was indicated that an early 3 in. (7·6 cm.) irrigation produced the maximum yield.

5.4.2. For the year 1957-58, the effect of dates was found to be highly significant. The combination of a depth of irrigation of 2 in. (5·1 cm.) at an interval of 4 weeks gave the maximum yield, although the effect was statistically indistinguishable from the combination of the depth of 3 in. (7·6 cm.) at 5 weeks' interval.

5.4.3. For the year 1960-61, the effects of intervals, levels of nitrogen, and the interactions of depths of irrigation and nitrogen as well as depths, intervals and nitrogen were found to be significant. It was indicated therefrom that 3 in. (7·6 cm.) depth of irrigation at 5 weeks' interval with 40 lb./acre of nitrogen produced the maximum yield followed by 4 in. (10·2 cm.) depth at 4 weeks' interval with 40 lb./acre of nitrogen which was found to be the next best. The experiments will be continued in order to arrive at conclusive results.

5.5. Water samples of the tube-well water were taken and analysed in the Chemical Laboratory of the Institute for testing the quality of irrigation water (Table IV). It was found that the water was of medium salinity having low sodium with safe limits of bicarbonates. The quality of water fell in C_2S_1 according to Wilcox classification adopted by the United States Salinity Laboratory, Riverside, California and was found to be suitable for irrigation.

TABLE I

Showing yield of wheat crop (Pb-591) at Government Agriculture Farm, Dhanauri for the year 1956-57.

Number of treatments	Main plot (sub-plot) number and depth of irrigation	Sub-plot number	Block I		Block II		Block III		Total		Average yield per sub-plot	Average yield in maunds per acre	Actual dates of irrigation	
													Ist Irrigation	IInd Irrigation
			Srs.	*Ch.*	*Srs.*	*Ch.*	*Srs.*	*Ch.*	*Srs.*	*Ch.*	*Srs.*			
1	2 inches (A)	1	6	11	7	4	6	13	20	12	6·938	16·23	23-12-56	4-2-57
2	,,	2	6	13	7	4	6	5	20	6	6·813	15·94	23-12-56	11-2-57
3	,,	3	5	3	4	12	5	6	15	5	5·125	11·98	23-12-56	18-2-57
4	,,	4	5	15	6	4	5	14	18	1	6·000	14·13	2-1-57	6-2-57
5	,,	5	7	2	7	10	7	8	22	4	7·438	17·41	2-1-57	13-2-57
6	,,	6	7	2	6	7	7	3	20	12	6·938	16·23	2-1-57	20-2-57
7	,,	7	4	9	4	14	5	8	14	15	4·938	11·69	4-2-57	4-3-57
8	,,	8	7	13	8	8	7	10	23	15	8·000	18·73	4-2-57	14-3-57
9	,,	9	6	11	7	0	5	10	19	5	6·438	15·11	4-2-57	22-3-57
10	,,	10	5	2	5	10	6	0	16	12	5·563	13·11	6-2-57	8-3-57
11	,,	11	5	12	6	4	5	10	17	10	5·875	13·79	6-2-57	22-3-57
12	,,	12	4	15	4	12	5	8	15	3	5·063	11·88	6-2-57	27-3-57
13	3 inches (B)	1	7	12	8	10	8	2	24	8	8·188	19·17	23-12-56	4-2-57
14	,,	2	8	9	7	10	7	5	23	8	7·813	18·39	23-12-56	11-2-57
15	,,	3	5	15	5	6	4	15	16	4	5·438	12·71	23-12-56	18-2-57
16	,,	4	4	15	5	7	4	12	15	2	5·063	11·83	2-1-57	6-2-57

17	,,	5	6	7	6	12	5	15	19	2	6·375	14·96	2-1-57	13-2-57
18	,,	6	6	7	6	14	6	3	19	8	6·500	15·26	2-1-57	20-2-57
19	,,	7	6	5	5	9	5	13	17	11	5·875	13·84	4-2-57	4-3-57
20	,,	8	6	11	6	15	7	13	21	7	7·125	16·77	4-2-57	14-3-57
21	,,	9	6	7	5	15	6	7	18	13	6·250	14·72	4-2-57	22-3-57
22	,,	10	5	12	5	14	6	7	18	1	6·000	14·13	6-2-57	8-3-57
23	,,	11	5	10	6	7	6	3	18	4	6·063	14·28	6-2-57	22-3-57
24	,,	12	5	5	5	10	5	14	16	13	5·625	13·15	6-2-57	27-3-57
25	4 inches (C)	1	5	7	4	13	5	12	16	0	5·313	12·52	23-12-56	4-2-57
26	,,	2	6	3	6	9	5	15	18	11	5·437	14·62	23-12-56	11-2-57
27	,,	3	5	11	5	5	5	6	16	8	5.437	13·59	23-12-56	18-2-57
28	,,	4	5	9	5	9	6	0	17	2	6·437	13·40	2-1-57	6-2-57
29	,,	5	6	7	6	13	6	1	19	5	6·437	15·11	2-1-57	13-2-57
30	,,	6	6	6	6	1	5	12	17	3	5·750	13·45	2-1-57	20-2-57
31	,,	7	5	9	6	3	5	14	17	10	5·875	13·79	4-2-57	4-3-57
32	,,	8	6	2	7	0	6	7	19	9	6·500	15·31	4-2-57	14-3-57
33	,,	9	4	13	5	9	4	11	15	1	5·000	11·78	4-2-57	22-3-57
34	,,	10	5	8	5	14	5	4	16	10	5·563	13·01	6-2-57	8-3-57
35	,,	11	5	8	5	11	5	0	16	3	5·375	12·67	6-2-57	22-3-57
36	,,	12	5	6	6	2	5	1	16	9	5·500	12·96	6-2-57	27-3-57

Notes— 1. Date of sowing— 20-25 November, 1956.

2. Date of harvesting—25-30 April, 1957.

3. Rainfall during the crop season—7·75 in.

4. Area of each sub-plot—36 ft. × 16 ft. 2 in.

1 ft. = 0·3048 m. = 30·48 cm. ; 1 in. = 2·54 cm.

TABLE II

Showing yield of wheat crop (*Pb*-591) *at Government Agriculture Farm, Dhanauri for the year* 1957-58.

Number of treatments	Main plot (sub-plot) number and depth of irrigation	Sub-plot number	Block I		Block II		Block III		Total		Average yield per sub-plot	Average yield in maunds per acre	Actual dates of irrigation	
													Ist Irrigation	IInd Irrigation
			Srs.	*Ch.*	*Srs.*	*Ch.*	*Srs.*	*Ch.*	*Srs.*	*Ch.*	*Srs.*			
1	2 inches (A)	1	6	7	9	0	9	0	24	7	8·125	18·06	6-12-57	6-1-58
2	,,	2	6	0	7	12	9	11	23	7	7·813	17·33	6-12-57	10-1-58
3	,,	3	6	11	9	10	10	8	26	13	8·938	19·82	6-12-57	17-1-58
4	,,	4	7	9	7	14	9	2	24	9	8·188	18·16	6-1-58	3-2-58
5	,,	5	5	5	8	10	9	10	23	9	7·813	17·42	6-1-58	10-2-58
6	,,	6	7	4	8	8	9	9	25	5	8·438	18·71	6-1-58	17-2-58
7	,,	7	6	7	8	8	8	13	23	12	7·875	17·56	17-1-58	14-2-58
8	,,	8	7	8	8	10	9	10	25	12	8·563	19·03	17-1-58	21-2-58
9	,,	9	5	12	9	12	8	12	24	4	8·063	17·93	17-1-58	28-2-58
10	,,	10	7	12	9	8	11	3	28	7	9·500	21·02	24-1-58	21-2-58
11	,,	11	6	1	8	8	10	4	24	13	8·250	18·34	24-1-58	28-2-58
12	,,	12	5	12	9	8	10	0	25	4	8·438	18·66	24-1-58	7-3-58
13	3 inches (B)	1	5	12	7	5	9	5	22	6	7·438	16·54	6-12-57	6-1-58
14	,,	2	6	10	6	0	10	10	23	4	7·750	17·19	6-12-57	10-1-58
15	,,	3	8	0	8	5	6	6	22	11	7·563	16·77	6-12-57	17-1-58
16	,,	4	8	2	6	5	9	13	24	4	8·063	17·93	6-1-58	3-2-58

17	,,	5	5	8	6	12	8	4	20	8	6·813	15·15	6-1-58	10-2-58
18	,,	6	7	12	7	15	10	8	26	3	8·750	19·36	6-1-58	17-2-58
19	,,	7	8	5	7	10	10	2	26	1	8·688	19·27	17-1-58	14-2-58
20	,,	8	7	0	7	8	9	0	23	8	7·813	17·37	17-1-58	21-2-58
21	,,	9	6	8	7	10	8	12	22	14	7·625	16·91	17-1-58	28-2-58
22	,,	10	8	2	7	6	8	6	23	14	7·938	17·65	24-1-58	21-2-58
23	,,	11	7	10	9	14	10	7	27	15	9·313	20·65	24-1-58	28-2-58
24	,,	12	7	10	7	9	9	5	24	8	8·188	18·11	24-1-58	7-3-58
25	4 inches (C)	1	7	12	6	7	5	6	19	8	6·500	14·46	6-12-57	6-1-58
26	,,	2	5	8	6	11	7	12	19	15	6·625	14·74	6-12-57	10-1-58
27	,,	3	8	7	8	12	7	12	24	15	8·313	18·43	6-12-57	17-1-58
28	,,	4	7	14	10	4	8	1	26	3	8·750	19·36	6-1-58	3-2-58
29	,,	5	8	11	7	13	8	9	25	1	8·375	18·53	6-1-58	10-2-58
30	,,	6	7	10	10	1	9	15	27	10	9·188	20·42	6-1-58	17-2-58
31	,,	7	7	1	10	1	7	8	24	10	8·188	18·20	17-1-58	14-2-58
32	,,	8	7	4	9	2	6	13	23	3	7·750	17·14	17-1-58	21-2-58
33	,,	9	8	12	9	2	7	0	24	14	8·313	18·39	17-1-58	28-2-58
34	,,	10	9	4	9	7	8	3	26	14	8·938	19·87	24-1-58	21-2-58
35	,,	11	7	7	9	12	7	0	24	3	8·063	17·88	24-1-58	28-2-58
36	,,	12	7	4	9	2	11	1	27	7	9·125	20·18	24-1-58	7-3-58

Notes—
1. Dates of sowing—6-9 November, 1957.
2. Dates of harvesting—15-20 April, 1958.
3. Rainfall during the crop season—5·45 in.
4. Area of each sub-plot—36 ft. × 16 ft. 2 in.

1 ft. = 0·3048 m. = 30·48 cm.; 1 in. = 2·54 cm.

TABLE III

Showing yield of wheat crop (N.P. 710) at Government Agriculture Farm Dhanauri harvested during the year 1960-61.

Serial number	Main plot of interval	Sub-plots	Treatment combination of depths and level of nitrogen	Yield of wheat grain net sub-plot-wise: Block I		Block II		Block III		Block IV		Total Yield			Average yield per sub-plot of 1/41·05 acre		Average yield in Mds. per acre
				Srs.	*Ch.*	*Srs.*	*Ch.*	*Srs.*	*Ch.*	*Srs.*	*Ch.*	*Mds.*	*Srs.*	*Ch.*	*Srs.*	*Ch.*	
1.	3 weeks' interval (F_1)	1	2″ N_0	28	13	25	13	27	13	27	5	2	29	12	27	7	28·17
2.	,,	2	2″ N_1	28	5	26	5	23	11	29	9	2	17	14	27	0	27·71
3.	,,	3	2″ N_2	24	13	28	9	23	13	26	13	2	24	0	26	0	26·69
4.	,,	4	3″ N_0	24	13	24	5	27	7	24	1	2	20	10	25	3	25·87
5.	,,	5	3″ N_1	25	13	25	5	25	1	29	7	2	25	10	26	7	27·14
6.	,,	6	3″ N_2	23	11	27	1	27	13	28	9	2	27	2	26	13	27·51
	,,	7	4″ N_0	24	5	25	13	25	9	24	2	2	19	13	24	15	25·58
	,,	8	4″ N_1	26	13	25	15	27	5	28	4	2	28	5	27	1	27·80
	,,	9	4″ N_2	28	1	25	13	23	9	27	2	2	24	9	26	2	26·81
10.	4 weeks' interval (F_2)	1	2″ N_0	24		25	5	21	11	28	7	2	19	12	24	15	25·58
11.	,,	2	2″ N_1	25	[illegible]	22	13	20	1	29	5	2	17	8	24	6	25·01
12.	,,	3	2″ N_2	26	9	24	5	22	7	27	13	2	21	2	25	4	25·91

13.	,,	4	3″ N_0	23	1	25	11	28	15	28	1	2	25	12	26	7	27·14
14.	,,	5	3″ N_1	22	13	26	1	24	5	28	7	2	21	10	25	7	26·11
15.	,,	6	3″ N_2	27	9	26	13	25	13	28	13	2	29	0	27	4	27·96
16.	,,	7	4″ N_0	22	5	20	15	21	11	29	6	2	14	5	23	9	24·18
17.	,,	8	4″ N_1	27	5	26	11	25	9	30	0	2	29	9	27	6	28·25
18.	,,	9	4″ N_2	28	1	30	1	26	9	30	0	2	34	11	28	11	29·44
19.	5 weeks' interval (F_3)	1	2″ N_0	27	11	28	13	25	1	31	9	2	33	2	28	5	29·07
20.	,,	2	2″ N_1	24	3	27	13	29	1	28	13	2	29	14	27	8	28·25
21.	,,	3	2″ N_2	25	1	29	1	26	13	23	9	2	29	8	27	6	28·09
22.	,,	4	3″ N_0	27	13	28	1	26	5	24	5	2	26	8	26	10	27·35
23.	,,	5	3″ N_1	26	1	28	1	29	5	27	5	2	30	12	27	11	28·41
21.	,,	6	3″ N_2	27	9	29	5	27	13	32	8	2	37	3	29	5	30·10
25.	,,	7	4″ N_0	28	7	23	1	27	9	29	0	2	33	1	28	4	29·00
26.	,,	8	4″ N_1	25	15	26	7	26	9	33	4	2	32	3	28	1	28·82
27.	,,	9	4″ N_2	26	1	25	1	27	7	33	12	2	32	5	28	1	28·82

Notes— (1) Dates of sowing—1-7 November, 1960.

(2) Dates of harvesting—17 April to 3 May, 1961.

(3) Rainfall during the crop season—6·2 in.

(4) Area of each sub-plot—73 ft. × 17 ft. 4 in. = 0·029 acre.

(5) Area of net sub-plot—67 ft. × 15 ft. 10 in. = 0·024 acre.
1 ft. = 0·3048 m. = 30·48 cm.; 1 in. = 2·54 cm.
1 acre = 0·4047 hectare.

(6) N_0, N_1 and N_2 stand for 0, 20 lb. and 40 lb. per acre of levels of nitrogen respectively.

TABLE IV

Results of chemical analysis of water sample from tube-well at Government Agriculture Farm, Dhanauri.

Serial number	Constituents	Sample Number 1	Sample Number 2
1.	Dissolved solids in p.p.m.	352	359
2.	Iron in meq/l	Nil	Nil
3.	Aluminium in meq/l	Nil	Nil
4.	Calcium in meq/l	5·18	5·215
5.	Magnesium in meq/l	1·695	1·76
6.	Sodium in meq/l	0·088	0.079
7.	Pottassium in meq/l	0·039	0.036
8.	Chlorides in meq/l	0·24	0.24
9.	Sulphate in meq/l	Nil	Nil
10.	Nitrates in meq/l	0·04	0.04
11.	Bicarbonates in meq/l	6·807	7.27-
12.	*pH* value	7.1	7.1
13.	Electric conductivity in mhos/cm.	$361 \cdot 3 \times 10^{-6}$	$361 \cdot 3 \times 10^{-6}$

5.6. A resume of the experiments on wheat brings out that for the one irrigation treatment, the maximum yield is obtained with 3 in. (7·6 cm.) of irrigation for eastern and western Uttar Pradesh while this depth is higher for southern Uttar Pradesh being 4 in. (10·2 cm.). Similar results were obtained for experiments with two irrigation treatments, wherein the depths are practically the same for Uttar Pradesh with an interval of four weeks. This can only be explained by the fact that the winter rainfall is practically negligible in southern Uttar Pradesh, although the annual rainfall is not less than in western Uttar Pradesh. The important effect of the distribution of rainfall is thus clearly brought out.

5.7. The average yield of wheat was the highest in 1960-61 at Dhanauri, being 29·0 maunds (2,386·3 lb. or 39·6 bushels) per acre which compared favourably with the yield recorded in some of the advanced countries such as the U.K., Germany, France and Egypt.

6.0 Rice

6.1. For this important crop, experiments on water requirements had previously been undertaken at Atarra, Tisuhi and Nagina, but no significant results could be derived therefrom, as the experiments were conducted only for short periods. Well planned experiments were accordingly laid out in 1961 on a 4-acre (1·62 ha.) plot in the Government Agriculture Farm, Dhanauri.

6.2. The object of the experiments was to study the effect on yield of varying depths and frequencies of irrigation, using 0, 3, 4, 5, 6, 7.5

and 9 in. (0, 7·6, 10·2, 12·7, 15·2, 19·1 & 22·9 cm.) of irrigation at intervals of 2, 2·5, 3 and 4 weeks. In the experiments at Dhanauri, the interval of 4 weeks was dropped. For the latter, an additional factor of level of nitrogen was introduced with the same object as mentioned for wheat in 5·3. Three levels of nitrogen were taken up for rice, namely, 0, 20 and 40 lb. per acre.

6.3. Method of layout : The principles were the same as for wheat.

6.4. Variety of paddy used: N-12 was used in the experiments.

6.5. Type of soil was the same as mentioned in 3.1.

6.6. The nursery was sown on 18-19 June, 1961. It was preceded by green manuring.

6.6.1. The germination, maturing, stand and flowering were good. Incidence of pest, such as white ants, stemborer and hessian fly were visible in a few sub-plots which were duly eradicated.

6.7. Table V gives the yield data and other experimental details. Detailed statistical analysis may be seen in Appendix IV.

7.0. Empirical Assessment of Irrigation requirements from Climatological Data

7.1. Apart from the experimental determination of water requirements of crops, which is the most direct method of tackling the problem, there are empirical formulae for the assessment of water requirements from climatological data. These provide not only a valuable check-up of the experimental data but also an important guide in areas where no such data is forthcoming and where a rough guide may be needed for the framing of irrigation projects for which a knowledge of the watering needs will be a prerequisite. Such a guide may be had readily from climatological data alone.

7.2. The first formula tested was one of the oldest devised by Lowry and Johnson of the United States Bureau of Reclamation in 1942, which is $U=0{\cdot}00015\,H + 0{\cdot}9$, where U is the consumptive use or water requirements, H is the accumulated degree days during the growing season computed from the maximum temperature above 32°F.

7.3. Tables VI(a) to VI(d) which are self-explanatory give the calculations for irrigation requirements at Dhanauri during the growing season of wheat. The latter was considered as comprising the months of November to February. Irrigation efficiency was assumed as 70 per cent. while K was assumed to be 0·70 on the basis of experimental data of the United States Department of Agriculture for grains with a growing season of 4 to 5 months. The calculations are given for three seasons, 1956-57, 1957-58 and 1960-61, during which the experiments on water requirements of wheat were conducted at Dhanauri. The mean irrigation requirement works out to 22·83 in. (58·2 cm.), which is considerably higher than the actual figure.

7.4. The next approach was that of the most common formula adopted by the United States Department of Agriculture, advocated by H. F. Blaney, which is also known as the Blaney-Criddle formula.

TABLE V

Showing yield of rice crop (N-12) at Government Agriculture Farm, Dhanauri harvested during 1961.

Serial number	Interval in weeks	Sub-plot number	Treatment combination: Levels of Nitrogen in lb./acre	Treatment combination: Depth of irrigation in inches	Yield of rice (paddy) grain net sub-plot-wise: Block I *Srs.*	Block I *ch.*	Block II *Srs.*	Block II *ch.*	Total *Mds.*	Total *srs.*	Total *ch.*	Average yield per sub-plot of 0·01952 acre *Srs.*	Average yield per sub-plot *ch.*	Average yield in maunds per acre
1.	2 weeks ..	1	0	0	17	10	11	8	0	29	2	14	9	18·65
2.	,, ..	2	,,	3	23	4	12	0	0	35	4	17	10	22·57
3.	,, ..	3	,,	4·5	19	4	9	12	0	29	0	14	9	18·57
4.	,, ..	4	,,	6	17	12	18	7	0	36	3	18	1	23·17
5.	,, ..	5	,,	7·5	20	4	11	4	0	31	8	15	12	20·17
6.	,, ..	6	,,	9	19	6	20	10	1	0	0	20	0	25·61
7.	,, ..	7	20	0	20	10	20	12	1	1	6	20	11	26·49
8.	,, ..	8	,,	3	18	0	23	0	1	1	0	20	8	26·25
9.	,, ..	9	,,	4·5	25	8	21	6	1	6	14	23	7	30·01
10.	,, ..	10	,,	6	26	10	15	0	1	1	10	20	13	26·65
11.	,, ..	11	,,	7·5	19	0	21	0	1	0	0	20	0	25·61
12.	,, ..	12	,,	9	28	8	21	4	1	9	12	24	14	31·85
13.	,, ..	13	40	0	16	12	19	4	0	36	0	18	0	23·05
14.	,, ..	14	,,	3	22	8	23	4	1	5	12	22	14	29·29
15.	,, ..	15	,,	4·5	17	6	24	8	1	1	14	20	15	26·81
16.	,, ..	16	,,	6	18	8	26	2	1	4	10	22	5	28·57
17.	,, ..	17	,,	7·5	29	0	22	12	1	11	12	25	14	33·13
18.	,, ..	18	,,	9	24	12	25	10	1	10	6	25	3	32·25
19.	2½ weeks ..	1	0	0	16	8	13	12	0	30	4	15	2	19·37
20.	,, ..	2	,,	3	16	8	16	12	0	33	4	16	10	21·29
21.	,, ..	3	,,	4·5	21	4	13	12	0	35	0	17	8	22·41
22.	,, ..	4	,,	6	20	14	16	4	0	37	2	18	9	23·77

23.	,,	..	5	,,	7·5	20	0	12	0	0	32	0	16	0	20·49
24.	,,	..	6	,,	9	21	12	13	12	0	35	8	17	12	22·73
25.	,,	..	7	20	0	24	4	13	0	0	37	4	18	10	23·85
26.	,,	..	8	,,	3	19	8	16	14	0	36	6	18	3	23·29
27.	,,	..	9	,,	4·5	23	4	31	0	1	14	4	27	2	34·73
28.	,,	..	10	,,	6	25	2	20	0	1	5	2	22	9	28·89
29.	,,	..	11	,,	7·5	26	8	17	12	1	4	4	22	2	28·33
30.	,,	..	12	,,	9	26	0	18	0	1	4	0	22	0	28·17
31.	,,	..	13	40	0	18	8	24	4	1	2	12	21	6	27·37
32.	,,	..	14	,,	3	22	6	29	6	1	11	12	25	14	33·13
33.	,,	..	15	,,	4·5	30	0	30	0	1	20	0	30	0	38·41
34.	,,	..	16	,,	6	20	0	31	2	1	11	2	25	9	32·73
35.	,,	..	17	,,	7·5	22	6	29	8	1	11	14	25	15	33·21
36.	,,	..	18	,,	9	19	2	26	2	1	5	4	22	10	28·97
37.	3 weeks	..	1	0	0	17	6	15	12	0	33	2	16	9	21·21
38.	,,	..	2	,,	3	17	0	18	0	0	35	0	17	8	22·41
39.	,,	..	3	,,	4·5	17	8	17	4	0	34	12	17	6	22·25
40.	,,	..	4	,,	6	16	14	18	8	0	35	6	17	11	22·65
41.	,,	..	5	,,	7·5	19	6	16	2	0	35	8	17	12	22·73
42.	,,	..	6	,,	9	17	8	17	8	0	35	0	17	8	22·41
43.	,,	..	7	20	0	20	8	16	4	0	36	12	18	6	23·53
44.	,,	..	8	,,	3	18	12	22	4	1	1	0	20	8	26·25
45.	,,	..	9	,,	4·5	21	12	17	12	0	39	8	19	12	25·29
46.	,,	..	10	,,	6	16	8	20	6	0	36	14	18	7	23·61
47.	,,	..	11	,,	7·5	17	14	20	0	0	37	14	18	15	24·25
48.	,,	..	12	,,	9	21	9	18	10	0	39	12	19	14	25·45
49.	,,	..	13	40	0	22	0	17	12	0	39	12	19	14	25·45
50.	,,	..	14	,,	3	25	0	23	10	1	8	10	24	5	31·13
51.	,,	..	15	,,	4·5	23	8	21	2	1	4	10	22	5	28·57
52.	,,	..	16	,,	6	20	10	20	14	1	1	8	20	12	26·57
53.	,,	..	17	,,	7·5	18	8	17	8	0	36	0	18	0	23·05
54.	,,	..	18	,,	9	20	8	23	0	1	3	8	21	12	27·85

Notes—(1) Dates of sowing—18-19 June, 1961. (2) Dates of transplanting—27 July to 13 August, 1961. (3) Dates of harvesting—15-27 November, 1961. (4) Rainfall during the crop season—48·05 in. (5) Area of each sub-plot—69 ft. × 16·5 ft. = 0·02613 acre. (6) Area of net sub-plot—63 ft. × 13·5 ft. = 0·01952 acre.

TABLE VI (a)

Computation of effective heat in day-degrees for Dhanauri, Uttar Pradesh, India during the growing season of wheat by Lowry-Johnson method.

Month	1956-57	1957-58	1960-61
November	1,383	1,366	1,482
December	1,262	1,116	1,359
January	1,073	1,144	1,195
February	1,134	1,159	1,052
TOTAL . .	4,852	4,775	5,088
Consumptive use from Lowry-Johnson equation in feet .	1·63	1·62	1·66

TABLE VI (b)

Showing monthly precipitation in inches at Dhanauri during the growing season of wheat.

Month	1956-57	1957-58	1960-61
November	0·33	0·39	0
December	0	2·66	0·48
January	4·47	0·18	2·79
February	0·03	0·30	6·30
TOTAL . .	5·33	3·53	9·57

TABLE VI (c)

Effective precipitation in inches from actual precipitation in inches for Dhanauri for the growing season of wheat.

The effective precipitation is determined by a curve passing through the following points:

Actual	Precipitation in inches Effective
1	0·95
2	1·85
3	2·67
4	3·33
5	3·82
6	4·02
7 and over	4·10

So effective precipitation in inches at Dhanauri is as follows:

Year	Actual	Effective
1956-57	5·33	3·89
1957-58	3·53	3·00
1960-61	9·57	4·10

7.4.1. By multiplying the mean monthly temperature, t, by the monthly percentage of daytime hours of the year, p, there is obtained a monthly consumptive use factor, f.

7.4.2. Expressed mathematically,

$$U = KF = \text{Sum of monthly } kf\text{'s.}$$
$$= \Sigma u$$

where

U = consumptive use of crop in inches during the growing season.

F = sum of the monthly consumptive use factors for the period (sum of the products of mean monthly temperature and monthly per cent of annual daytime hours) $(t \times p)/100$.

K = empirical coefficient (annual or irrigation season or growing season).

t = mean monthly temperature in degrees Fahrenheit,

p = monthly per cent of daytime hours of the year (from "Sunshine Tables", United States Weather Bureau Bulletin 805),

f = monthly consumptive use factor, $(t \times p)/100$.

$u = kf$ – monthly consumptive use in inches.

7.4.3. On the basis of this formula, calculations are shown in Table VII for the growing season of wheat at Dhanauri. Irrigation requirement at the head of the field was found to be 8·31 in. (20·1 cm.) from this formula. From actual experimental results, it was found that two irrigation treatments of 3 in. (7·6 cm.) each gave the maximum yield. If to this be added a pre-sowing irrigation of 2·5 in. (6·4 cm.), the total irrigation requirements work out to 8·50 in. (21·6 cm.), which agrees very closely with the theoretical figure of 8·31 in. (20·1 cm.) arrived at from Blaney-Criddle formula. It may be added that this formula is being used successfully in many tropical countries and Europe as also in the United States of America wherefrom it originated. The agreement with the experimental results from Dhanauri is thus very close.

7.4.4. Another formula which was attempted was the Penman formula whose detailed calculations are shown in Table VIII(a), which gives the evapo-transpiration losses or consumptive use for the growing season of wheat at Dhanauri.

7.4.4.1. The following three formulae are used by Penman in estimating evapo-transpirations:

(i) $H = R_A(1-r)(0{\cdot}18+0{\cdot}55n/N) - \sigma T_a^4(0{\cdot}56 - 0{\cdot}092\sqrt{e_d})(0{\cdot}10+0{\cdot}90\,n/N)$

(ii) $E_a = 0{\cdot}35(e_a - e_d)(1+0{\cdot}0098u_2)$ and

(iii) $E_t = (\Delta H + 0{\cdot}27\,E_a)/(\Delta + 0{\cdot}27)$,

where

H = daily heat budget at surface in mm. H_2O/day.

R_A = mean monthly extra trerrestrial radiation in mm. H_2O/day.

r = reflection coefficient of surface.

n = actual duration of bright sunshine.

N = Maximum possible duration of bright sunshine.

σ = Boltzman constant.

$= 2 \cdot 01 \times 10^{-9}$ mm./day.

σT_a^4 = mm.H_2O/day [*See* Table VIII (*a*)]

e_d = Saturation vapour pressure at mean dew point (*i.e.* actual vapour pressure in the air) mm. *Hg*.

E_a = Evaporation in (mm.) H_2O/day.

e_a = Saturation vapour pressure at mean air temperature in mm. *Hg*.

u_2 = mean wind speed at 2 metres above the ground (miles/day).

E_T = Evapo-transpiration in mm. H_2O/day.

u_1 = Measured wind speed in miles per day at height h in feet.

Δ = Slope of saturated vapour pressure curve of air at absolute temperature T_a in °F (mm. *Hg*. F.)

7.4.4.2. Irrigation requirements have been deduced in Table VIII (*b*), which shows a very close analogy of the calculated figure of 8·51 in. (21·6 cm.) with the experimental figure of 8·50 in. (21·6 cm.). The Penman formula is, however, lengthy and involves laborious calculations.

TABLE VI(d)

Showing irrigation requirements at Dhanauri for the growing season of wheat by Lowry-Johnson method.

Assuming an irrigation efficiency, E, of 0·70, irrigation requirement, I, is given by $I = (U - r)/E$, where U is the consumptive use and r the effective precipitation.

Year	U in inches	R in inches	U—R	I (in inches) $=(U—R)/E$
1956-57	19·56	3·89	15·67	22·39
1957-58	19·44	3·00	16·44	23·49
1960-61	19·92	4·10	15·82	22·60
			Mean ..	22·83

Hence mean irrigation requirement at Dhanauri for the growing season of wheat by the Lowry-Johnson method is 22·83 in.

1 in. = 2·54 cm. = 25·4 mm.

TABLE VII

Showing computations of irrigation requirements for the growing season of Wheat at Dhanauri on the basis of Blaney-Criddle formula.

Months	Mean temperature (t) °F			Per cent day time (P)	Monthly consumptive use factor(f)			Monthly rainfall (r) in inches			Remarks
	1956-57	1957-58	1960-61		1956-57	1957-58	1960-61	1956-57	1957-58	1960-61	
1	2	3	4	5	6	7	8	9	10	11	12
November	65·0	64·4	64·4	7·19	4·67	1·63	4·63	0·83	0·39	0	Per cent day time hours have been computed from Sunshine Tables U. S. Weather Bureau Bulletin 805, 1905 edition for a latitude of 30° (for Dhanauri).
December	59·2	57·9	59·1	7·14	4·23	4·13	4·22	0	2·66	0·48	
January	56·5	58·1	57·3	7·30	4·12	4·21	4·18	4·47	0·18	2·79	
February	57·6	59·4	56·7	7·03	4·05	4·18	3·98	0·09	0·30	6·30	
Total	..	..	..	..	17·07	17·18	17·01	5·33	3·53	9·57	
							(F)		(R)		

Year	F	K	$U=KF$	R	$U-R$	Irrigation efficiency, E	$I=(U-R)/E$
1	2	3	4	5	6	7	8
						Per cent	
1956-57	17·07	0·70	11·95	5·33	6·62	70	9·46
1957-58	17·18	0·70	12·03	3·53	8·50	70	12·14
1960-61	17·01	0·70	11·91	9·57	2·34	70	3·34
Mean . .	..	..	..	..	..	..	8·31

TABLE VIII(a)

Showing details of calculations of evapo-transpiration losses or losses on consumptive use in inches for the growing season of wheat at Dhanauri by Penman method.

	November 1956	December 1956	January 1957	February 1957	November 1957	December 1957	January 1958	February 1958	November 1960	December 1960	January 1961	February 1961
1	2	3	4	5	6	7	8	9	10	11	12	13
1. Air temperature in °F.	65·5	59·2	56·5	57·6	64·4	57·9	58·1	59·4	64·4	59·0	57·4	56·7
2. Relative Humidity percentage	67·7	64·3	76·0	51·9	57·2	72·2	64·9	46·1	49·0	51·0	71·0	56·0
3. Sunshine n/N percentage	84·0	55·0	54·0	82·0	83·0	62·0	63·0	70·0	91·0	74·0	72·0	74·0
4. Wind speed U_2 (miles per day at 2 metre height)	55·90	61·75	80·60	103·55	62·40	61·10	64·35	91·00	47·25	76·50	63.75	195·75
5. Radiation rate, R_A in mm. of H_2O/day	9·1	7·9	8·5	10·5	9·1	7·9	8·5	10·5	9·1	7·9	8·5	10·5
6. Reflection coefficient, r.	0·25	..	0·25	0·25	0·25	0·25	0·25	0·25	0·25	0·25	0·25	0·25
7. (1-r)	0·75	0·75	0·75	0·75	0·75	0·75	0·75	0·75	0·75	0·75	0·75	0·75
8. (0,18+0·55n/N)	0·64	0·48	0·48	0·63	0·64	0·52	0·53	0·56	0·68	0·59	0·58	0·59
9. R_A (1-r) (0·18+0·55 n/N)	4·37	2·84	3·06	4·96	4·37	3·08	3·38	44·1	4·64	3·49	3·70	4·65
10. Vapour pressure:												
(*a*) Saturated E_a mm. of Hg	17·0	14	13	13	16	14	14	14	16	14	13	13
(*b*) Actual $e_d = (RH \times e_a)$	11·51	9·00	9·88	6·75	9·15	10·11	9·09	6·45	7·84	7·14	9·23	7·28
(*c*) $\sqrt{e_d}$	3·39	3·00	3·14	2·60	3·02	3·18	3·01	2·54	2·80	2·67	3·04	2·70
11. $6t_{a4}$	14·57	13·82	13·60	13·71	14·46	13·75	13·76	13·90	14·45	13·80	13·69	13·61
12. (0·56—0·092 $\sqrt{e_d}$)	0·25	0·28	0·27	0·32	0·29	0·27	0·28	0·33	0·30	0·31	0·28	0·31
13. (0·10+0·90 n/N)	0·86	0·60	0·59	0·84	0·85	0·66	0·67	0·73	0·92	0·77	0·75	0·77

14. Item 11 × item 12 × item 13	3·13	2·32	2·17	3·69	3·56	2·45	2·58	3·35	3·99	3·29	2·87	3·25
15. Item 9—item 14 = H	1·24	0·52	0·89	1·27	0·81	0·63	0·80	1·06	0·65	0·20	0·83	1·40
16. 0·35 ($E_a - e_d$)	1·92	1·75	1·09	2·19	2·40	1·36	1·72	2·64	2·86	2·40	1·32	2·00
17. (1 + 0·0098 U_2)	1·55	1·60	1·79	2·06	1·61	1·60	1·63	1·90	1·46	1·75	1·62	2·92
18. Item 16 × Item 17 = E_a	2·98	2·80	1·95	4·51	3·86	2·18	2·80	5·02	4·18	4·20	2·14	5·84
19. $\triangle$	0·57	0·47	0·44	0·45	0·55	0·45	0·46	0·48	0·55	0·47	0·45	0·44
20. $\triangle H$	0·71	0·24	0·39	0·57	0·44	0·28	0·37	0·51	0·36	0·09	0·37	0·62
21. 0·27 E_a	0·80	0·76	0·53	1·22	1·04	1·59	0·76	1·36	1·13	1·13	0·57	1·58
22. $\triangle$ + 0·27	0·84	0·74	0·71	0·72	0·82	0·72	0·73	0·75	0·82	0·74	0·72	0·71
23. $ET = \dfrac{\triangle H + 0{\cdot}27\, E_a}{\triangle + 0{\cdot}27}$												
mm. of H_2O/day	1·80	1·35	1·30	2·48	1·80	1·21	1·55	2·50	1·82	1·65	1·31	3·10
inches of H_2O/day	0·071	0·053	0·051	0·097	0·071	0·048	0·061	0·098	0·072	0·065	0·052	0·122
inches of H_2O/month	2·13	1·64	1·58	2·72	2·13	1·49	1·89	2·74	2·16	2·02	1·61	3·42

TABLE VIII(b)

Showing calculations of irrigation requirements for the growing season of wheat at Dhanauri by Penman method.

Year	U in inches (November to February)
1956-57	8·07
1957-58	8·25
1960-61	9·21
Mean	8·51

TABLE IX(a)

Showing calculations of consumptive use during the growing season of wheat at Dhanauri by Thornthwaite method.

Year	Month	t in °C	Head index $i=(t/5)$ 1·514	Potential monthly evapo-transpiration
1956-57	November	18·33	7·15	9·5
	December	15·11	5·32	8
	January	13·61	4·56	7
	February	14·22	4·88	7·5
1957-58	November	18·00	6·96	9·5
	December	14·39	4·95	7·5
	January	14·50	5·02	7·5
	February	15·22	5·39	8
1960-61	November	18·00	6·96	9
	December	15·06	5·32	8
	January	14·06	4·79	7·5
	February	13·72	4·63	7·5

TABLE IX(b)

Showing corrected evapo-transpiration for the growing season of wheat at Dhanauri by Thornthwaite method.

Year	Month	Uncorrected evapo-transpiration (e_t)—cm.	Corrected evapo-transpiration (e)—cm.
1956-57	November	9·5	8·46
	December	8	7·04
	January	7	6·30
	February	7·5	6·53
1957-58	November	9·5	8·45
	December	7·5	6·60
	January	7·5	6·75
	February	8	6·96
1960-61	November	9	8·01
	December	8	7·04
	January	7·5	6·75
	February	7·5	6·53

NOTE.—Uncorrected evapo-transpiration values have been deduced from the nomogram as per Graph 10, from which corrected values have been deduced with the aid of a conversion of factor (0·89, 0·88, 0·90, 0·87 for the months of November to February respectively).

TABLE IX(c)

Showing irrigation requirements of wheat at Dhanauri by Thornthwaite method.

Year	*I* in cm.	*I* in inches
1956-57	28·33	11·15
1957-58	28·76	11·32
1960-61	28·33	11·15
Mean	..	11·21

TABLE X(a)

Showing computations of monthly evaporation during the growing season of wheat at Dhanauri by Hargreave's method.

	Month	Mean rel. humidity at noon per cent	Mean temperature °F	d	0·38— 0·0038×h	t—32	e= (4)×(5) ×(6)
1956-57 . .	November .	45·2	65·0	0·86	0·20324	33·0	5·910
	December .	43·2	59·2	0·86	0·21584	27·2	5·049
	January . .	61·3	56·5	0·88	0·14706	24·5	3·171
U=14·1477 .	February .	33·5	57·6	0·94	0·25270	25·6	6·081
1957-58 . .	November .	41·6	64·4	0·86	0·22192	32·4	6·684
	December .	58·3	57·9	0·86	0·15846	25·9	3·530
	January . .	48·2	58·1	0·88	0·19684	26·1	4·521
U=14·6573 .	February .	31·5	59·4	0·94	0·26030	27·4	6·704
1960-61 . .	November .	25·0	64·4	0·86	0·27360	32·4	7·624
	December .	31·0	59·1	0·86	0·26220	27·1	6·111
	January . .	53·1	57·3	0·88	0·17822	25·3	3·968
U=16·0979 .	February .	40·0	56·7	0·94	0·22800	24·7	5·294

$U_F = \sum_{Nov.}^{Feb.} Ke$ where $K = 0\cdot7$ $\qquad$ $U_M = \sum_{Nov.}^{Mar.} Ke$ where $K = 0\cdot7$

TABLE X(b)

Showing computations of consumptive use of wheat at Dhanauri by Hargreave's method.

Year	E in inches	K	U=KE
1956-57	20·21	0·70	14·15
1957-58	20·94	0·70	14·66
1960-61	22·99	0·70	16·09
Mean . . .	..	..	14·97

TABLE XI(a)

Showing number of drought days during the growing season of wheat at Dhanauri.

Year	November	December	January	February
1956-57	28	31	21	27
1957-58	28	26	27	25
1960-61	30	30	25	23
Mean . . .	29	29	24	25

TABLE XI(b)

Showing mean daily evapo-transpiration in inches month-wise during the growing season of wheat at Dhanauri.

Year	November	December	January	February
1956-57	0·071	0·053	0·051	0·097
1957-58	0·071	0·048	0·061	0·098
1960-61	0·072	0·065	0·062	0·122
Mean	0·071	0·054	0·058	0·106

TABLE XI(c)

Showing monthly irrigation requirements of wheat at Dhanauri by Van Bavel method.

November	December	January	February	Total
29 × 0·071 = 2·06	30 × 0·055 = 1·65	24 × 0·055 = 1·32	25 × 0·106 = 2·65	7·68

TABLE XII

Showing experimental and calculated water requirements of wheat at Dhanauri by different formulae.

No.	Formula	Calculated depth in inches	Experimental depth in inches	Remarks
1	Lowry Johnson . .	22·83	8·50	Wide divergence.
2	Blaney-Criddle . .	8·31	8·50	Agreement remarkably close.
3	Penman . . .	8·51	8·50	Agreement perfect.
4	Thornthwaite. . .	11·21	8·50	Agreement not very close.
5	Hargreave's . .	14·97	8·50	Wide divergence. Agreement poor.
6	Van Bavel . .	7·68	8·50	Agreement good.

NOTE.—Although the agreement is almost perfect by Penman method, it is the Blaney-Criddle formula which is recommended for adoption in view of its remarkable analogy and extreme simplicity, calculations by Penman formula being quite laborious. Similarly Van Bavel approach is also not quite practical in view of the calculations involved in determining evapo-transpiration by Penman formula.

1 in = 2·54 cm.

Depth of Irrigation	Yield in maunds per acre					
	2 weeks' interval	3 weeks' interval	4 weeks' interval	5 weeks' interval	6 weeks' interval	1 Inch=2·54 cm. 1 acre=0·404 hec. 1 maund=37·32 kg.
3"	944·84	810·23	931·23	794·54	891·90	
4"	970·55	1104·13	1026·99	623·58	838·97	
5"	976·59	911·57	805·69	826·30	790·54	
6"	953·35	817·22	926·69	901·92	941·85	

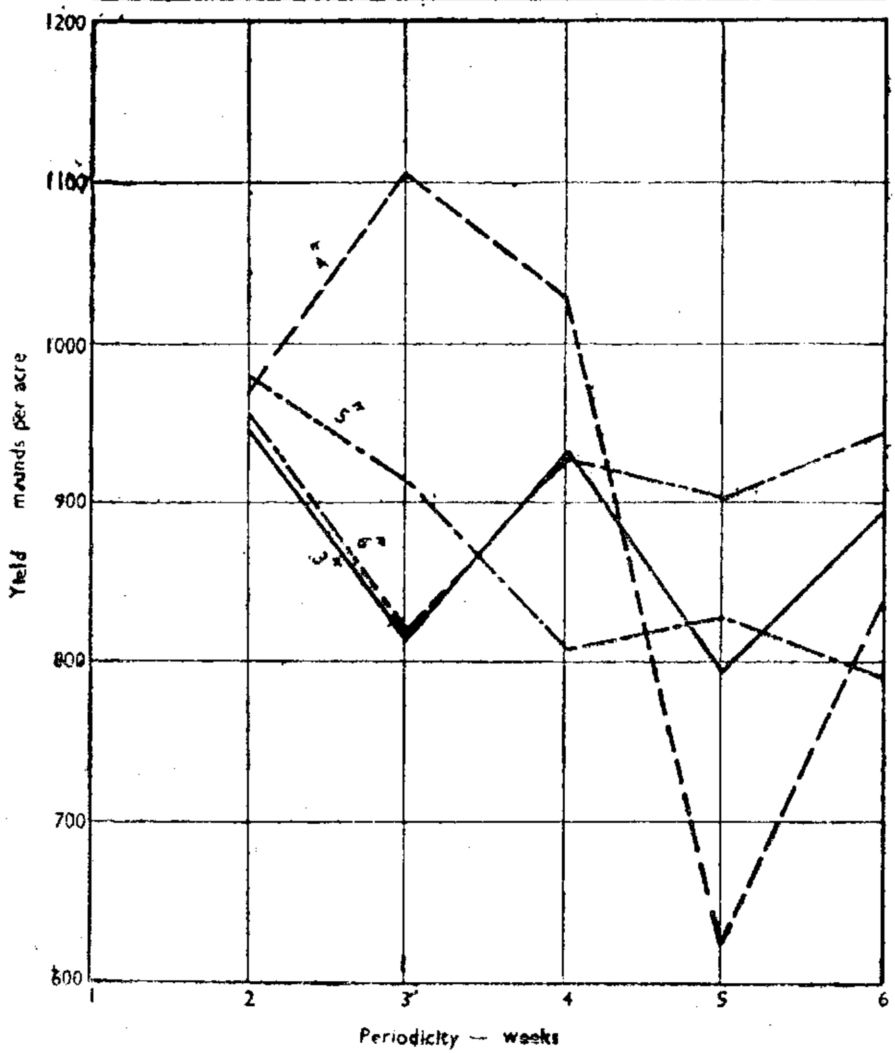

FIGURE 3: *Yield of sugar-cane (Co-4u) for 1948-49 at Bulandshahr.*

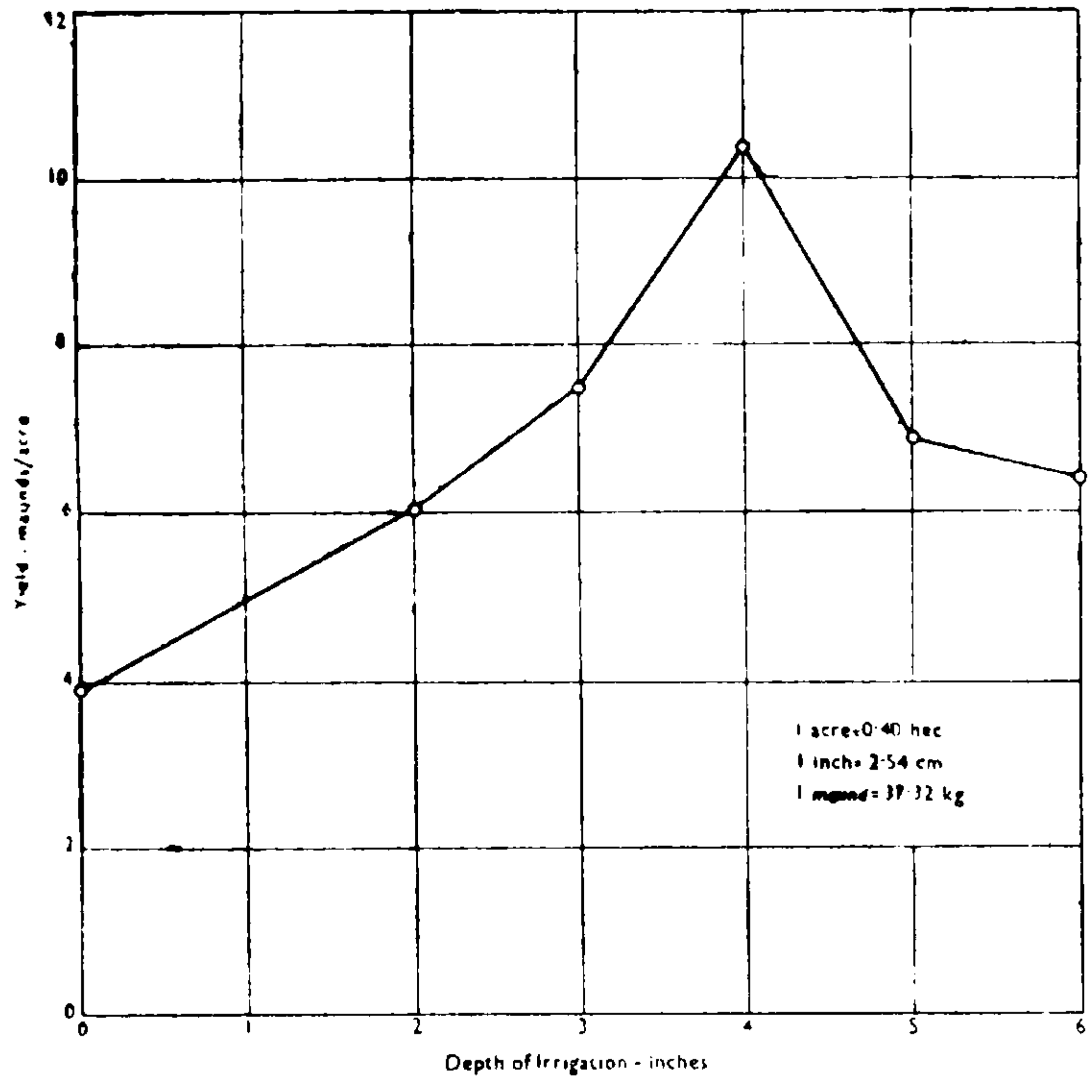

FIGURE 4: *Yield of wheat (Pb-591) at Atarra (Banda) for one irrigation treatment for 1947-48.*

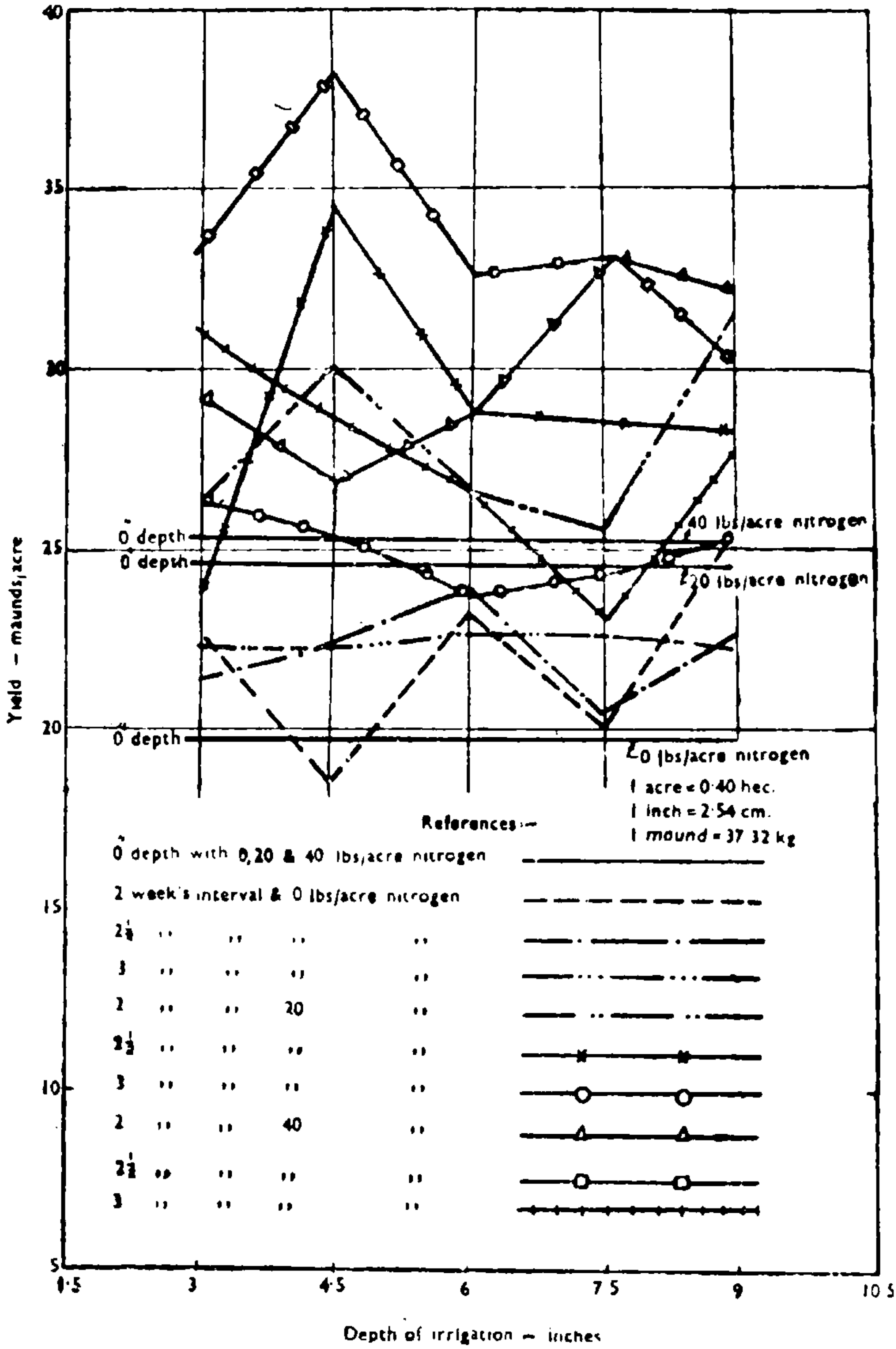

FIGURE 5: *Yield of rice for the year 1961 at Government Agriculture Farm, Dhanauri.*

Depth of watering	Yield-maunds per acre				Reference
	2 weeks' interval	2½ weeks' interval	3 weeks' interval	4 weeks' interval	
0"		4·09			
3"	21·70	18·44	17·94	22·77	
4½"	17·40	25·68	18·87	22·58	
6"	15·96	22·46	20·54	15·45	
7½"	20·67	20·48	19·55	20·23	
9"	19·43	18·87	16·45	25·47	

1 *maund* = 37·32 kg 1 inch = 2·54 cm 1 acre = 0·40 hec.

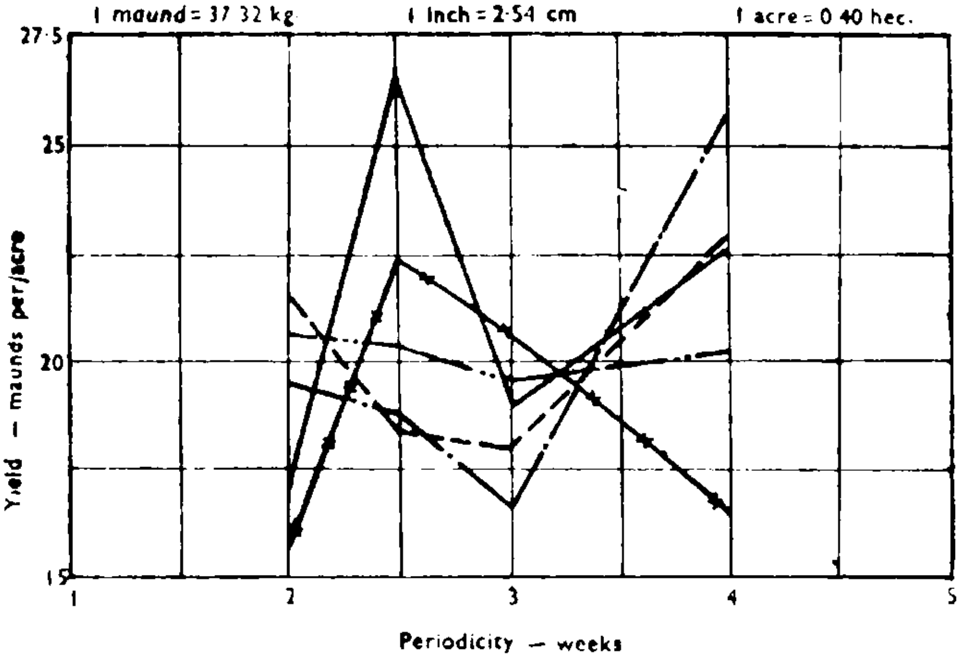

FIGURE 6: *Yield of rice T-36 at Atarra (Banda) for 1950.*

7.4.5. Thornthwaite formula was applied next. Using the standard monograph, values of heat index were derived as per Table IX(*a*). These values, when corrected as per Table IX(*b*), gave the monthly consumptive use in centimeters. The corrections were based upon a table deduced for making allowance for possible duration of sunlight expressed in units of 30 days of 12 hours each. For Dhanauri with a latitude of 30°N, the correction factors were found to be 0·89, 0·88, 0·90 and 0·87 for the months of November to February respectively. Table IX(*c*) shows the computed consumptive use during the growing season of wheat at Dhanauri. It is obvious that the values by Thornthwaite method are somewhat higher, being 11·21 in. (28·4 cm.) against 8·50 in. (21·6 *cm.*).

7.4.6. The next formula applied was that of Hargreave which is as follows:

7.4.6.1. $e=d(0{\cdot}38-0{\cdot}0038h)\ (t-32)$,

where e=monthly evaporation in inches,

d=a monthly day time coefficient dependent upon latitude,

h=mean monthly relative humidity at noon,

t=mean monthly temperature in °F.

7.4.6.2. Table X(*a*) gives computations of monthly evaporation, *i.e.*, during the growing season of wheat, at Dhanauri by Hargreave's method. In Table X(*b*) are given the values of E which is the total evaporation during the growing season. This multiplied by K which is assumed as 0.70 as per previous calculations, gives the value of consumptive use.

7.4.6.3. It is clear that the mean consumptive use arrived at by Hargreave's method is rather high as compared to the experimental figure, being 14.97 in. (38.0 cm.) against 8.50 in. (21.6 cm.) for the latter.

7.4.7. The last approach was that of Van Bavel in which the mean daily evapo-transpiration is calculated by the number of drought-days in a month for the growing season of a particular crop. Table XI(*a*) gives the number of drought-days every month during the growing season of wheat at Dhanauri. Table XI(*b*) gives mean daily evapo-transpiration for the same period worked out by Penman formula. Irrigation requirements by Van Bavel method have been shown in Table XI(*c*). It is to be seen that the calculated figure of 7·68 in. (19·6 cm.) is slightly lower than the experimental figure of 8·50 in. (21·6 cm.).

7.5. A review of the various empirical approaches for the assessment of irrigation requirements from climatological data shows that although the Penman formula gives the most accurate figure it is the Blaney-Criddle formula which may be recommended for adoption in view of its simplicity and remarkable accuracy in estimation, the Penman formula calculations being extremely laborious and time-consuming. Results are tabulated in Table XII.

8.0. Other Approaches

8.1. Along with the experimental and empirical approach, another set of experiments were initiated for the determination of transpiration losses. This is planned by a comparative study of soil moisture determinations in two adjacent plots, one cropped (with the crop under experimentation, being wheat for the first year) and another uncropped, the difference being attributable to transpiration losses.

8.2. Evaporation losses are being recorded at a nearby experimental station at the Meteorological Observatory, Bahadrabad. It is expected that losses accruing from evaporation and transpiration (or evapo-transpiration losses) are likely to prove a valuable guide for consumptive use or water requirements of crops.

9.0. Actual Usage of Water for Irrigation by the Cultivator and the Economics thereof

9.1. Actual usages of water for irrigation by the cultivator were studied for the experimental crops in a number of Irrigation Divisions of Uttar Pradesh in the light of the figures for correct watering needs as indicated experimentally. It was found that invariably the usage of water was in excess of the correct water requirements by 30 per cent to 40 per cent. This was ascertained more definitely for wheat and sugar-cane, for which some significant results were obtained previously. The economics of this is discussed below.

9.2. Figure 3 shows the yield of sugar-cane for Bulandshahr for 1948-49 for various depths and periodicities of irrigation. With the optimum depth of 4 in. (10·1 cm.) and interval of 3 weeks, the yield was over 1,100 maunds per acre. With 5 in. (12·7 cm.) depth of irrigation, the yield dropped to 920 maunds per acre, whereas with 6 in. (15·2 cm.) the yield fell to as low as 830 maunds per acre, which was the same for 3 in. (7·6 cm.) of irrigation. It is thus easy to see that while under-irrigation brings down the yield by nearly 30 per cent, the adverse effects of over-irrigation on the yield easily amount to the order of over 20 per cent.

9.3. Figure 4 shows the yield data of wheat for Atarra for the year 1947-48. With the optimum depth of 4 in. (10·1 cm.) of irrigation the yield exceeded 10 maunds per acre. With under-irrigation of 3 in. (7·6 cm.) the yield fell down to 9 maunds per acre, but with over-irrigation of 4 and 5 in. (10·2 and 12·7 cm.) the yield dropped to less than 9 maunds per acre. The harmful effects of over-irrigation for wheat can be assessed as being of the order of over 10 per cent.

9.4. Figures 5 and 6 show the yield data for rice for Dhanauri for 1961 and Atarra for 1950. Although indications are not equally prominent because of greater complications in the experiments on water requirements of rice, it is apparent for Dhanauri that with actual usages of 6 to 7·5 in. (15·2 to 19·0 cm.) the yield drops from 38 to 33 maunds per acre, a drop of over 20 per cent, whereas for Atarra, the loss in yield (from 26 maunds per acre to 23 maunds per acre) is over 10 per cent.

9.5. In the light of the above, it is indicated that the actual usage of water by the cultivator is invariably wasteful, wherein the loss in yield is easily of the order of 10 per cent to 20 per cent. For working out the economics of this wasteful practice, it may be worthwhile mentioning that the total value of all crops produced in irrigated areas of Uttar Pradesh was estimated to be Rs. 248 *crores* for the year 1957-58. If it is assumed that the degree of over-irrigation in other crops was of the same order as that for the three principal crops of Uttar Pradesh, wheat, rice and sugar-cane, the yearly loss due to over-irrigation may work out to Rs. 30 *crores*. But the excessive use of water in irrigated fields is preventing its utilization in many fields. Prevention of the waste of water for irrigation in the former will mean the irrigation of many new fields whose yield will be augmented. Generally, it has been seen that the yield in irrigated fields exceeds that of unirrigated fields by over 50 per cent. In this way, the yearly loss may well work out to the order of Rs. 40 *crores* which will give some idea of the enormity of the problem of over-irrigation.

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* 1 maund 37·3 kg.

9.6. But, there are many more harmful effects of over-irrigation. The quality of the crop suffers. A visual inspection of the yield from over irrigated fields is convincing enough to substantiate this point.

9.7. Over-irrigation may also lead to water-logging, although the primary cause of the latter is faulty drainage. Thus, the evil effects of water-logging, such as loss of soil fertility, sanitation and public health besides being a forerunner of the scourge of malaria, may be attributable to some extent to over irrigation.

9.8. A three-pronged drive is suggested in the matter. A systematic and planned study of water requirements of crops should be undertaken all over the State on a (*i*) crop-wise, (*ii*) soil-wise, (*iii*) region-wise basis. As this is a time consuming process, necessitating experimentation for a number of years to smoothen the effect of climatic variations, the adoption of empirical formulae for the assessment of irrigation requirements from climatological data (among which Blaney-Criddle formula is suggested as the most practical) is recommended as an interim measure.

9.9. The knowledge of the correct water requirements of crops has to be disseminated to the cultivator.

9.10. Apart from the dissemination of knowledge, the cultivator has got to be induced to take to the correct usage of water for irrigation.

10.0. Conclusions

10.1. Experimentation on the determination of optimum water requirements of principal crops has been discussed. For wheat and sugarcane, some indications regarding the correct level and frequency of irrigation for a few experimental stations were obtained.

10.2. A check-up of the experimental determination of water requirements was attempted by the assessment of irrigation requirements of crops from climatological data. A number of standard formulae were tested. Blaney-Criddle formula was found to be the most suitable and hence recommended for adoption wherever no experimental results were available.

10.3. Actual usages of water for irrigation by the cultivator were tested against optimum requirements of water, as determined experimentally. It was evident that wherever water was available for irrigation, the cultivator invariably resorted to over-irrigation whose economics worked out to a loss to the extent of forty *crores* of rupees to the State of Uttar Pradesh. The enormity of the colossal waste accruing to the State on account of wasteful usage of water in irrigated areas was thus brought out.

10.4. To mitigate this evil and to prevent this enormous loss to the State, a three-pronged drive is suggested. Water requirements of principal crops of the State have first to be assessed correctly by initiating experiments in this direction on a crop-wise, soil-wise and region-wise basis. The knowledge has then to be disseminated to the cultivator. He has then to be induced to adopt the correct practice for irrigation.

APPENDIX I

Statistical Analysis of Yield Data of Experiments on Wheat with Two Irrigation Treatments Conducted at Government Agriculture Farm, Dhanauri, during the year 1956-57 with 2, 3 and 4 in. (5·1, 7·6 *and* 10.2 *cm.*) *of Irrigation and with 4 Dates and at Intervals of 4, 5 and 6 Weeks.*

The final analysis of variance of yield of wheat in (chatak)^2 is given in the following table in which items significant at the 5 per cent, 1 per cent and 0.1 per cent levels of probability are marked with one, two and three asterisks.

Table of analysis of variance of yield of wheat in (chatak)^2.

Variation due to	Degrees of freedom	Sum of Squares	Mean Square
Blocks	2	340·663	170·332
Depths of irrigation	2	1,918·463	959·232***
Error (E_1)	4	146·137	36·534
Dates	3	2,370·163	790·054**
Weeks	2	4,236·463	2,118·232***
Dates × Weeks	6	4,213·937	702·323**
Depths × Dates	6	2,177·337	362·889*
Depths × Weeks	4	428·337	107·081
Depths × Dates × Weeks	12	3,831·863	319·322*
Error$_2$ (E_2)	66	8,724·600	132·191
Total	107	28,387.963	..

No significant differences are noticed amongst the mean yields due to the combinations of a depth of 3 in. (7·6 cm.) with intervals of 4 and 5 weeks and a depth of 2 in. (5·1 cm.) at an interval of 5 weeks, although the maximum yield was obtained with an early 3 in. (7·6 cm.) irrigation at 4 weeks' interval.

APPENDIX II

Statistical Analysis of Yield Data of Experiments on Wheat with Two Irrigation Treatments Conducted at Government Agriculture Farm, Dhanaura, during the year 1957-58 with 2, 3 and 4 in. (5·1, 7·6 and 10·2 cm.) of Irrigation and with 4 Dates and 3 Intervals of 4, 5 and 6 Weeks.

The final analysis of variance of yield of wheat in (chatak)^2 is given in the following table in which item significant at 1 per cent level of probability is marked with two asterisks.

Table of analysis of variance of yield of wheat in (chatak)^2

Variation due to	Degrees of freedom	Sum of Squares	Mean Square
Blocks	2	15,151·30	7,575·65
Depths	2	544·96	272·48
Error E_1	4	10,492·09	2,623·02
Dates	3	3,269·22	1,089·74**
Weeks	2	1,109·85	554·93
Dates × Weeks	6	1,705·11	284·19
Irrigation × Dates	6	2,034·22	339·04
Irrigation × Weeks	4	818·04	204·51
Irrigation × Weeks × Dates	12	3,103·45	258·62
Error$_2$ (E_2)	66	15,555.28	235·69
Total	107	53,783·52	..

The effect of dates was found to be highly significant. The combination of a depth of irrigation of 2 in. (5·1 cm.) at an interval of 4 weeks gave the maximum yield, although the effect was statistically indistinguishable from the combination of the depth of 3 in. (7·6 cm.) at 5 weeks' interval.

APPENDIX III

Note on the Statistical Analysis of Experiment on Water Requirements of Wheat (Experiment No. 2 with Two Irrigation Treatments) Conducted at Government Agriculture Farm, Dhanauri during 1960-61.

There were three different levels of irrigation 2 in., 3 in. and 4 in., (5·1, 7·6 and 10·2 cm.) with three levels of nitrogen (0, 20 and 40 lb./acre) and 3, 4 and 5 weeks' intervals. There were four replications.

The final analysis of variance of yield of wheat in (chatak)^2 is given in the following table, in which items significant at 5 per cent levels of probability are marked with one asterisk.

Analysis of variance of yield of wheat in (chatak)^2.

Variance due to	D. F.	Sum of Squares	Mean Square
Blocks	3	37,581·48	12,527·16*
Intervals	2	20,152·80	10,076·40*
Error (E_1)	6	9,256·47	1,542·74
Depths of Irrigation	2	1,005·24	501·12
Nitrogen	2	4,841·69	2,420·85*
Depths × Nitrogen	4	8,789·37	2,197·37*
Depths × Intervals	4	5,564·60	1,391·15
Intervals × Nitrogen	4	4,010·48	1,002·62
Intervals × Depths × Nitrogen	8	17,638·37	2,204·80*
Error$_2$ (E_2)	72	56,936·47	790·78
TOTAL	107	165,776·97	..

The following conclusions may be drawn from the above analysis:—

(1) *Intervals*.—The variation due to this effect is significant. Forming the critical difference at 5 per cent level of probability for the mean yields based on 36 sub-plots, we get,

$$c.d. = \sqrt{\frac{E_1 \times 2}{36}} \times t_5\%(6) = 22{\cdot}63 \textit{ chataks} \text{ per sub-plot.}$$

Summary of results for mean yields in descending order for intervals

	5 weeks	3 weeks	4 weeks	*c.d.* at 5 per cent
Mean yield in *chatak* per sub-plot	446·4	421·2	414·8	22·63

From above mean yields, we find that the mean yield due to 5 weeks' interval is significantly higher than the rest. It is more effective in producing the maximum yield.

(2) *Nitrogen.*—The variation due to this effect is just significant at 5 per cent level of probability. Forming the critical difference at 5 per cent level for the mean yields based on 36 sub-plots we get,

$$c.d. = \sqrt{\frac{E_2 \times 2}{36}} \times t_{5\%}(72) = 12{\cdot}60 \textit{ chataks} \text{ per sub-plot.}$$

Summary of results of mean yields in ascending order for levels of nitrogen

	N_0	N_1	N_2	*c.d.* at 5 per cent
Mean yield in *chatak* per sub-plot	418·97	428·14	435·33	12·60

Although there are no significant differences between the mean yields due to different levels of nitrogen from the above table, yet it is seen that nitrogen introduced with 40 lb./acre produces the maximum yield followed by that at 20 lb./acre. The yield with no levels of nitrogen is minimum.

(3) *Depths × Nitrogen*—It is just significant at 5 per cent level of probability. Forming the critical difference at 5 per cent based on 12 sub-plots, we get,

$$c.d. = \sqrt{\frac{E_2 \times 2}{12}} \times t_{5\%}(72) = 22{\cdot}84 \textit{ chataks} \text{ per sub-plot.}$$

Summary of results of mean yields for the interaction effect of depths of irrigation and levels of nitrogen.

Depths of Irrigation, Nitrogen	N_0	N_1	N_2	*c.d.* at 5 per cent
2″	430·2	420·3	419·5	22.84 *chataks* per sub-plot
3″	417·2	424·0	414·4	
4″	409·6	440·1	...	

1 in. = 2·54 cm.

Comparing the mean yields with the *c.d.* in the above table, we find that there are statistically no significant differences amongst the mean yields due to the interactions of (*i*) 3 in. (7·6 cm.) depth of irrigation with 40 lb./acre level of nitrogen (*ii*) 4 in. (10·2 cm.) depth with 40 lb./acre level of nitrogen and (*iii*) 4 in. (10·2 cm.) depth with 20 lb./acre level of nitrogen (*iv*) 3 in. (7·6 cm.) depth of irrigation with 20 lb./acre of nitrogen and (*v*) 2 in. (5·1 cm.) depth of irrigation with control nitrogen, although the maximum yield is produced with 3 in. (7·6 cm.) depth with 40 lb./acre of nitrogen.

(4) *Intervals × Depths × Nitrogen*—This is just significant at 5 per cent level of probability. Forming the critical difference at 8 per cent level based on 4 sub-plots, we get,

$$c.d. = \sqrt{\frac{790{\cdot}78 \times 2}{4}} \times t_{5\%}(72) = 39{\cdot}56 \textit{ chataks} \text{ per sub-plot.}$$

Summary of results of mean yields for the effect of interaction of intervals, depths and levels of nitrogen

Intervals, Nitrogen	2 in. depth			3 in. depth			4 in. depth			c.d. at 5 per cent
	N_0	N_1	N_2	N_0	N_1	N_2	N_0	N_1	N_2	
3 weeks	*439*	*431·5*	416	402·5	422·5	428·5	399·25	*433·25*	418·25	39·50 ch. per Sub-plot
4 weeks	399	390	404·5	423	406·5	*436*	377·5	*438·25*	*458·75*	
5 weeks	*452·5*	*439·5*	*438*	426	*443*	*468·75*	*452·25*	*448·75*	*449·25*	

1 in=2.54 cm.

Now testing the critical difference against the mean yields of the different effects of interaction, we find statistically no significant differences amongst the mean yields in italics in the above table. However, the maximum yield is found to be obtained with 3 in. (7·6 cm.) depth of irrigation and N_2 (40 lb./acre) level of nitrogen at 5 weeks' interval followed by 4 in. (10.2 cm.) depth at N_2 (40 lb./acre) level of nitrogen at 4 weeks, interval which is found to be next best.

APPENDIX IV

Note on the Statistical Analysis of Yield of Rice in Connection with the Experiment on Water Requirements of Rice (Paddy) Conducted at Government Agriculture Farm, Dhanauri during 1961.

There were six doses of irrigation [0, 3, 4·5, 6, 7·5 and 9 in. (0, 7·6, 11·4, 15·2, 19·1 and 22·9 cm.)] with three levels of nitrogen (0, 20 and 40 lb./acre) and 8, 2½ and 3 weeks' intervals. There were two replications. It was a factorial design based on randomized block system. The area of each sub-plot was 0.0261 acre (0.0.11 ha.).

The final analysis of variance of yield of rice (paddy) in $(chatak)^2$ is given below, in which item significant at 0·1 per cent level of probability is marked with three asterisks.

Analysis of variance of yield of rice (paddy) in $(chatak)^2$.

Variation due to	Degrees of freedom	Sum of Squares	Mean Square
Blocks	1	10,900·24	10,900·24
Intervals	2	18,760·80	9,330·40
Depths	5	32,736·50	6,547·30
Nitrogen	2	1,68,465·81	84,232·90***
Interval × Depth	10	36,186·20	3,618·62
Depth × Nitrogen	10	19,002·52	1,900·25
Interval × Nitrogen	4	20,295·14	5,073·79
Interval × Depth × Nitrogen	20	23,823·53	1,191·18
Error	53	3,10,252·26	3,967·02
TOTAL	107	6,40,423·00	..

The following conclusions may be drawn from the above analysis.

Nitrogen—The variations due to this effect is highly significant. Forming the critical difference at 5 per cent level of probability for the mean yield based on 36 sub-plots, we get,

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

$$= \sqrt{\frac{3967 \cdot 02 \times 2}{36}} \times 1 \cdot 998$$

$= 29 \cdot 66$ *chataks* per sub-plot.

Summary of results of mean yield in ascending order of levels of nitrogen

	No	N_1	N_2	*c.d.* at 5 per cent
Mean yield in *chatak* per sub-plot . .	272·4	334·9	367·6	29·66

Comparing the difference of mean yields due to the effect of different levels of nitrogen with the critical difference we find that the mean yield due to 48 lb./acre of nitrogen is significantly higher than the rest.

Although the remaining effects of depths of irrigation, intervals and their interactions are not significant, yet it is seen that the maximum yield (38·41 maunds per acre) is obtained with 4·5 in. (11·4 cm.) depth of irrigation and 40 lb./acre of level of nitrogen and at 2½ weeks' interval.

The Problems of Irrigated Land in Uttar Pradesh

by

P. N. Gupta*

SYNOPSIS

The successful growth of crops depends, among other things, upon the sufficiency of water content in the soil during the crop growth. Rainfall is the chief natural source of water supply to crops, but, in most places it may be scanty and ill-distributed and the deficiency of water supply to crops in such places need be supplemented by Irrigation which is the controlled application of water to lands, (to supply requirements to bring them to maturity). If proper and scientific study of the nature of soils, crop pattern, the quality and quantity of water to be supplied to the crops, the necessity and importance of surface and subsurface drainage, and the behaviour of ground water-table during different seasons is conducted and the knowledge thus gained is usefully applied, irrigation can become a permanent feature for optimum utilisation of land and water resources. However, if irrigation is practised extensively anywhere, and everywhere, without proper study of its limitations, it may lead to its ill-effects (such as the rise of water-table, water-logging and salt efflorescence, etc.) and may thus, defeat the very purpose which it is meant to serve.

The paper discusses in detail such ill-effects and the deterioration of irrigated land and its loss of productivity in the State of Uttar Pradesh, on such accounts. The paper emphasizes on the inter-relation between irrigation and drainage in order to render the soil more suitable for cultivation, and also suggests the remedial measures for preventing the soil deterioration from its main causes for salinity, alkalinity and water-logging, etc.

Introduction

The State of Uttar Pradesh is bounded by Himalayan ranges in the North and Vindhyachal mountains in the South. According to geological conditions this tract is in a syncline and is thus very rich in underground storage. It is crossed by a number of perennial rivers such as Ganga, Yamuna, Sarda, Ghagra, Gomti and Rapti, *etc.* The State is 630 miles (1013·7 km.) in length and extends in width to about 210 miles (337·9 km.). The area consists mainly of the alluvium plain of the Ganga and Yamuna Rivers.

The area is characterised by a gently rolling topography except, in the hilly regions of Garhwal, Naini Tal, Almora, Dehradun districts. The gradient gradually flattens from 4 ft. to 2 ft. per mile in the North-Western districts of Meerut to Lucknow and thereafter it reduces from

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about 1·5 ft. to even less than a foot per mile in the Eastern districts of Farrukhabad, Kanpur, Fatehpur, Allahabad, Rae Bareli, Pratapgarh, Sultanpur and Jaunpur. In the plains area of the State, summer months frequently have daily temperatures above 110°F and in winter the temperature often falls below 40° F. The higher temperatures of Summer are often accompanied by strong winds and low relative humidity, a condition which causes rapid evaporation of the soil moisture. The average annual precipitation is of the order of roughly 30 in. (70·2 cm.) in the western districts and about 50 in. (127 cm.) in the eastern ones. This amount of precipitation is sufficient for crop production if it is received at favourable times during the growing season. The distribution of precipitation is however unfavourable, its major part being received during the months of July and August. The higher yield of crops is, therefore, dependent on irrigation.

The State is traversed by network of canal systems, the more important ones being the Eastern Yamuna Canal system, Upper Ganga Canal system, Lower Ganga Canal system, Sarda Canal system, and Agra Canals, *etc.* In addition there are about 7,000 State tube-wells and a large number of private ones. The irrigated land in this paper, however, does not refer to the land irrigated by State Canals and tube-wells only but to all the land irrigated either by State Canals and tube-wells or by private canals, wells, tanks and any other means.

Inter-relation between Irrigation and Drainage

The fact that many irrigation projects have already been constructed in this State and others are yet under planning, and the fact that the demand is on the ever increase by the farmers, goes to show that irrigation in this State has become a permanent feature for the utilisation of land and water resources. But how far the irrigation water is being used to the optimum benefits is the main factor which governs the yield from a land.

Irrigation, though it is one of the main solutions to the problem of achieving self-sufficiency in food production, has its own limitations. If it is practised extensively, anywhere and everywhere, without proper study of its limitations, it may over a period of several years produce the ill effects, *viz.*, raising of the water-table, creating water-logging conditions, and depositing salt patches, and thereby rendering the land infertile which is a challenge to the Engineer, the Soil Scientist and the Agricultural Economist.

The roots of plants thrive in a three-way medium of soil, water and air, and each is essential. Water applied by irrigation may temporarily fill almost all soil pore spaces, but within a few hours the excess must drain away allowing the soil to refill with air and leaving only capillary moisture to nourish the plant. The drainability of the land in its turn, depends upon the physical and chemical properties of the soils, such as permeability, salinity, and alkalinity and upon land slopes and sub-strata position and characteristics, as well as the specific use to which the land is put.

The object of drainage is thus, to control the surplus water in order to render the soil more healthy and suitable for cultivation. The irrigation and drainage are thus closely connected, the latter being an effective measure to prevent the evil effects of the former and therefore, the subject of their inter-relation assumes great importance. Today drainage in the Bureau of Reclamation begins when first consideration is given to the agricultural phases of multiple-purpose projects.

Deterioration of Irrigated Land in U.P.

Roughly, the total area [15] of land in Uttar Pradesh excluding the hill *pattis* of Kumaon, is about 60 million acres (24·28 million ha.), out of which about 40 million acres (16·19 million ha.) is the actual cultivated area. The total irrigated area is of the order of 12 million acres (4·86 million ha.) and is thus only about 30 per cent of the actual cultivated area. The existing *usar* and *reh* lands (which constitute the soils only mildly alkaline or saline, soils with pronounced alkalinity and soils with an efflorescence of *reh* on the surface), are of the order of 3 million acres (1·21 million ha.) and yet more and more land is being rendered saline every year in some parts of the state on account of the continuous rise of the water-table. The state of Uttar Pradesh already contributes about 5 *lakh* acres (2,02,343 ha.) of water-logged land to the total water logged areas of this country which is of the order of 60 *lakh* acres (24,28,110 ha.). The last few years have, however, brought a further rise in the water-table leading partially to water-logging conditions over areas of about 10 *lakh* acres (4,04,686 ha.). and these areas may be completely water-logged in the near future if preventive measures are not immediately adopted.

The deterioration of the irrigated land in U.P. is thus, becoming or may become a serious problem after a period of only a few years. The principal causes to which the deterioration of irrigated land and its loss of productivity in U.P., can be traced, are the rise of water-table, water-logging, and the salinity and alkalinity of the soil, and these can be ascribed partly to natural and partly to man-made causes. Following in the wake of the rise of water-table has been the accumulation of sodium salts in the surface of soils. These salts lead to the formation in the first instance of saline soils and subsequently to the formation of alkaline soils. The rapid deterioration is confined to areas in which the water-table is high. Under these conditions of high water-table the tendency has been for the salts, originally distributed throughout the soil, to accumulate in the surface zone thus, rendering the soils alkaline.

Water-logging

Water-logging occurs when the top of the water-table is so near the surface as to create marsh conditions and suffocate the roots of vegetation. Due to water-logging the productivity of the land becomes affected in three ways:

(*i*) Difficulty of carrying out agricultural operations.

(*ii*) As the root zone of plants get flooded with water, there is lack of aeration in the soil, and ordinarily crops cannot grow on such land.

(*iii*) The ground water-table being very near the ground, the water from water-table rises up by capillary action and brings with it the alkali salts in solution. Water evaporates from the surface of land leaving behind an accumulation of salts in patches on the surface of land. The concentration of salts when present in the root zone of any plant, has corresponding effect on the roots with the result that the growth of the plant gets checked and the plant ultimately dies.

According to the findings of the Irrigation Research Institute, Roorkee from a study of the variation of ground water-table from about 2,000 observation surface wells in Ganga Yamuna[12] *Doab* and the Sarda Canal area of this State, for the last 40 years, it has been indicated that in the tracts of Hindon-Yamuna, Isan-Kali, Kali-Ganga and Arind-Pandu, which are irrigated both by a network of canal system and a large number of tube-wells, more or less a balanced ground water-table has been created and that there is no appreciable rise or fall in the ground water-table for these tracts. For a stabilised ground water-table, the inflow must equal the outflow for any particular ground-water basin, and the ground-water equation in its most general form for such tracts may be expressed as :

$$A+(I+R_p)+D=T+E+C+O(P\pm V.S.)$$

where

A = Percolation from surface streams.

I = Inflow into the unit from the surrounding area.

R_p = Rainfall penetration.

D = Percolation from artificial irrigation.

T = Transpiration losses.

E = Evaporation losses.

C = Effluent seepage.

O = Outflow from the unit into the surrounding area.

V = Volume of ground watered or unwatered.

S = Specific yield of the formation, and

P = Pumpage.

A tentative relationship as worked out at the Irrigation Research Institute, Roorkee between the penetration of rain-water R_p [13] and the rainfall R, for Western U.P., is given by $R_p=2\cdot0\ (R-15)2/5$. This indicates that for an average annual rainfall of about 30 in. (76·2 cm.) in the North-Western districts of U.P., the total penetration of rain-water is only of the order of 6 in. (15·2 cm.).

Whenever the factors contributing to inflow are more effective than the outflow factors, it leads to the rise of the water-table and as indicated from the study of the behaviour of ground water-table in U.P. water-logging conditions have either been created or are being created on account of the water-table having been risen to within 2 to 10 ft. (0·6 to 3 m.) of the ground surface, in the tracts of Sengar-Yamuna, Sengar-Arind, Isan-Pandu, Karon-Yamuna, Ganga-Purwa Branch, Lucknow-

Hardoi Branches, Allahabad-Pratapgarh Branches, Purwa-Maurawan Branch and at Kheri Branch. The details of these water-logged areas are shown in Figure 1. The approximate areas of these tracts leading to water-logging conditions are of the order of :

	Acres
Sengar-Yamuna	2,56,000
Sengar-Arind	6,80,000
Isan-Pandu	3,70,000
Karon-Yamuna	4,10,000
Ganga-Purwa Branch	40,200
Lucknow-Hardoi Branches	94,500
Allahabad-Pratapgarh Branches	36,800
Purwa-Maurawan Branch	31,200
At Kheri Branch	46,700

Note.—One acre 0·4047 hectare.

These areas are being rendered in this condition on account of the continuous rise of the water-table over a period of about 50 years only. A few representative data of the continuous rise of water-table of these areas, are given in Tables I, II & III. The district-wise details of the water-logged areas as shown in Figure 2 indicate that the Northern and the North-Western districts are free from any appreciable rise of the water-table. This may be attributed to lesser rainfall of these areas, lesser rainfall penetration, the drainage effect of the Yamuna River, the underground drainage along the slope, and the simultaneous effect of canal and tube-well irrigation. The Eastern and the South-Eastern districts, on the other hand, have the greatest tendency towards water-logging conditions. The increasing tendency of water-logging in these districts may be attributed to one or more of the following causes :

(1) Excessive irrigation on the land, resulting in heavy percolation, and the subsequent rise of the water-table.

(2) Excessive rainfall with high intensity precipitation resulting in heavy percolation.

(3) Inadequate surface drainage on land.

(4) Soils with hard stratum or having no good drainage properties.

(5) Flat gradients both of the country and the water-table, being in the order of 1·5 ft. (0·46 m.) to even less than a foot per mile, and thus with poor outfalls of drainage.

(6) The cumulative effect of seepage through bed and sides of adjoining canals, branches, reservoirs or tanks, *etc.;* over a period of several years.

(7) Uneconomical use of the irrigation water and its effects being aggravated by faulty water distribution, over consumption and misuse of water.

FIGURE 1: *Index map of Uttar Pradesh showing canal systems and areas partially leading to water-logging conditions.*

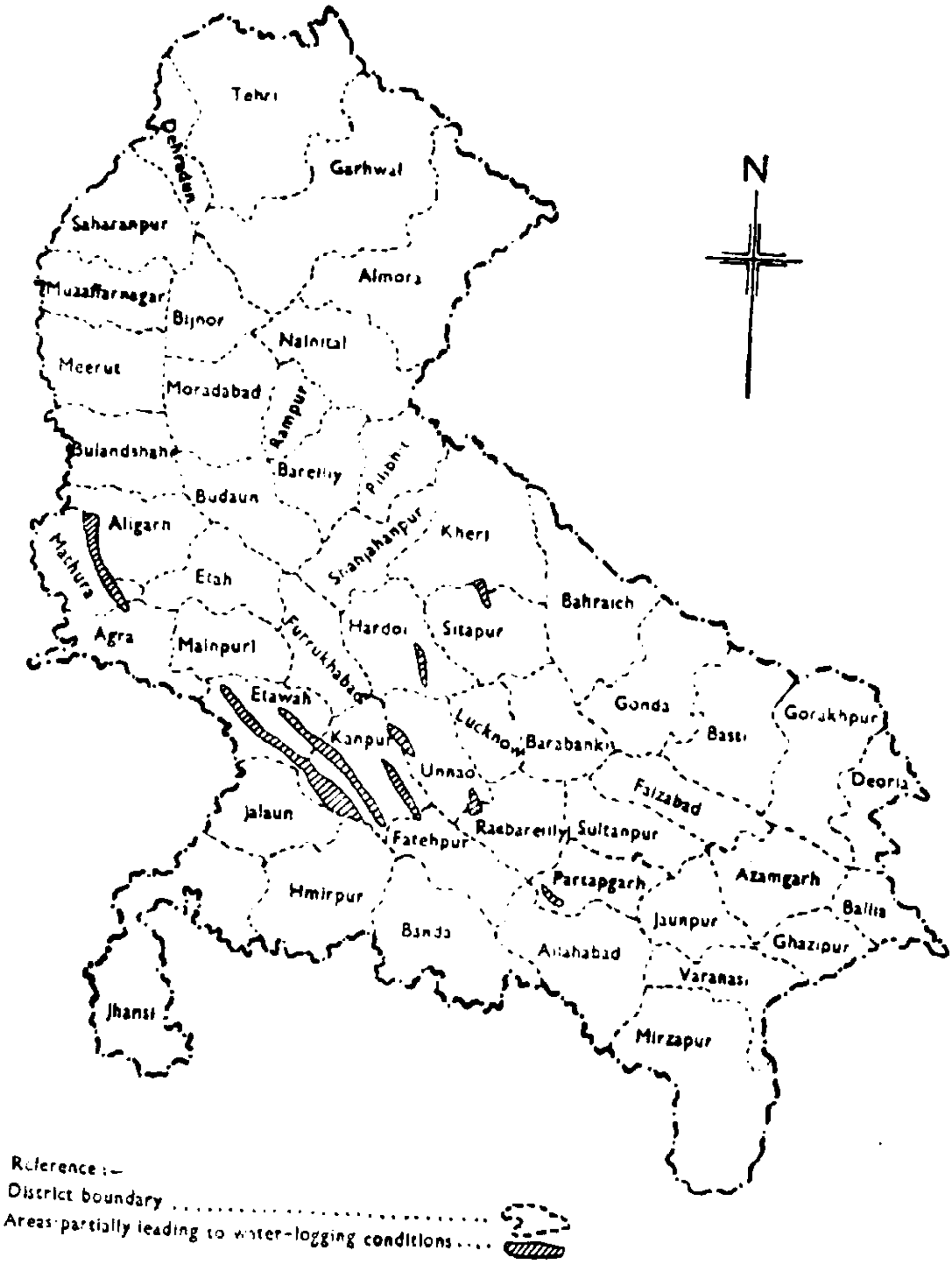

FIGURE 2 : *Approximate distribution of areas partially leading to water-logging conditions in the different districts of Uttar Pradesh.*

(8) The recharging of the ground water-table in these areas through Ganga River, during and after the flood stage.

(9) Highly rice areas, with use of overflowing depths of water, leading to heavy percolation and subsequent rise of the water-table.

Table IV gives the district-wise rice areas of the State. From a comparison of this with Figures 1 and 2 of the water-logged areas, it is indicated that most of the highly rice areas are now leading partially to water-logging conditions. As per experiments on the water requirement[11] of crops carried out by the Irrigation Research Institute, Roorkee at Bahadrabad and Dhanauri Government farms, it has been indicated that the optimum requirements of water are much less than the actual usages of water for irrigation by cultivators. The maximum yields of rice and wheat crops are obtained with 4½ in. (11·4 cm.) depth of irrigation at 2½ weeks' interval and 3 in. (7·6 cm.) depth of irrigation at 5 weeks' interval respectively, both at a dosage of nitrogen of 40 lb. per acre. In addition, the experiments have indicated that over-irrigation invariably reduces the yield as well as affects adversely the quality of the crop besides resulting in the loss of valuable water for irrigation elsewhere. All this goes to indicate the effect of over-irrigation, on the rise of water-table specially in the rice areas, and the consequent results on the crop yield.

In the early phase of irrigation development the demand for canal water fell short of supply conditions and thus the irrigation authorities had to make special efforts to induce the cultivators to adopt themselves to canal irrigation in preference to their old methods. The charges for canal water were kept low so that the cultivators could get ample water at cheap rates. All this tended to make the cultivators less conscious of the need to economise canal water. In the early stages of development, therefore, there was lack of controlled and planned irrigation and this coupled with improper sub-soil drainage caused damage to lands.

There is evidence to show that seepage from canals in some localised areas have been responsible for the rise of the water-table, formation of swamps and accumulation of *reh*. After only about 50 years of the opening of Western Yamuna Canal in 1820, Mr. Robert[10], a planter in the Aligarh District petitioned the Board of Revenue in 1870, for relief on the ground that he had suffered from deterioration of fertility of his land. Mr. Hutton[10] Chief Engineer, Irrigation Department, U.P. also expressed in 1913 that—

> "There can be no doubt that introduction of the canal has raised the spring level in this neighbourhood to some 40 or 50 ft. (12·2 or 15·2 m.). The spring level even in the month of May is now from 8 to 10 ft. (2·4 to 3 m.) below the surface and therefore well within the influence of surface vegetation."

Then again, the existence of fairly extensive lengths of *bhur* on Lower Ganga Canal, the existence of saline soils in certain areas of Mat Branch of the Upper Ganga Canal, and the water-logging conditions in certain areas near the Hardoi Branch and Mat Branch, all indicate the effect of seepage from canals on the rise of water-table and the subsequent rise of salts. The causes of this rise, for a number of areas, have been the lack of drainage channels capable of dealing with the monsoon rainfall and it is in fact indisputable that in many areas water-logging could

TABLE I

Statement showing continuous rise of water-table.

Mat Branch Division G. C. Mathura:		Mat Branch Division G. C. Mathura:	
Line No.	6	Line No.	7
Well No.	4	Well No.	4
Field No.	1342 and 1343	Field No.	6329
General Level of Ground	603·79	General Level of Ground	551·70
R. L. of Point of Measurement	605·76	R.L. of Point of Measurement	582·86

Year	R.L. of Water surface in well in May	Year	R.L. of water surface in well	Year	R. L. of water surface in well	Year	R.L. of water surface in well in May
1913	563·51	1937	589·36	1913	515·1	1937	541·65
1914	573·26	1938	583·01	1914	521·6	1938	540·48
1915	570·76	1939	520·07	1915	522·1	1939	541·4
1916	569·56	1940	Not observed	1916	522·4	1940	542·9
1917	571·56	1941	590·0	1917	521·9	1941	541·5
1918	575·76	1942	585·60	1918	525·0	1942	541·57
1919	572·83	1943	588·36	1919	524·8	1943	543·48
1920	573·86	1944	590·30	1920	528·2	1944	544·32
1921	562·96	1945	585·76	1921	527·3	1945	543·9

1922	562·36	1946	589·66	1922	529·4	1946	543·67
1923	569·59	1947	588·26	1923	529·7	1947	544·40
1924	571·56	1948	589·96	1924	529·8	1948	546·6
1925	572·61	1949	591·56	1925	528·4	1949	548·9
1926	570·76	1950	591·51	1926	533·4	1950	550·5
1927	581·56	1951	591·76	1927	537·4	1951	558·7
1928	580·56	1952	591·30	1928	535·9	1952	559·5
1929	576·51	1953	587·76	1929	534·4	1953	558·0
1930	575·76	1954	585·06	1930	533·4	1954	558·52
1931	579·96	1955	598·54	1931	533·98	1955	558·60
1932	580·34	1956	594·26	1932	532·48	1956	558·72
1933	579·51	1957	523·77	1933	532·9	1957	558·50
1934	583·76	1958	594·00	1934	534·4	1958	558·6
1935	588·34	1959	596·36	1935	538·48	1959	558·8
1936	586·01		..	1936	538·48	..	..

TABLE II

Statement showing continuous rise of water-table.

Fatehpur Division Ghatampur System:

Line No.	II
Well No.	1
Field No.	516
General Level of Ground	384·14
R.L. of Point of Measurement	388·39

Fatehpur Division Ghatampur System:

Line No.	II
Well No.	2
Field No.	688
General Level of Ground	388·76
R. L. of Point of Measurement	391·01

Year	R. L. of water surface in well	Year	R. L. of water surface in well	Year	R. L. of water surface in well	Year	R.L. of water surface in well
1914	330·39	1937	342·39	1914	337·00	1937	350·01
1915	329·39	1938	336·06	1915	335·76	1938	346·26
1916	335·97	1939	332·29	1916	349·51	1939	349·01
1917	339·39	1940	339·39	1917	350·41	1940	350·01
1918	337·79	1941	335·89	1918	352·01	1941	345·51
1919	336·29	1942	333·09	1919	345·41	1942	343·01
1920	338·89	1943	334·99	1920	352·01	1943	343·51

1921	336·39	1944	338·89	1921	346·95	1944	351·51
1922	335·89	1945	337·69	1922	345·61	1945	350·61
1923	337·14	1946	338·09	1923	349·51	1946	351·11
1924	345·31	1947	336·39	1924	356·33	1947	346·11
1925	345·40	1948	336·79	1925	359·93	1948	346·51
1926	349·06	1949	336·42	1926	367·63	1949	346·42
1927	348·56	1950	339·39	1927	360·43	1950	349·01
1928	348·56	1951	342·39	1928	359·99	1951	352·90
1929	339·73	1952	341·39	1929	350·01	1952	351·76
1930	344·76	1953	342·09	1930	353·33	1953	352·71
1931	343·76	1954	343·69	1931	353·33	1954	355·05
1932	333·77	1955	344·39	1932	342·51	1955	354·01
1933	334·64	1956	349·26	1933	339·68	1956	364·01
1934	335·39	1957	348·42	1934	339·01	1957	358·01
1935	335·39	1958	347·89	1935	343·50	1958	361·71
1936	332·64	1959	349·49	1936	338·20	1959	365·68

TABLE III

Statement showing continuous rise of water-table.

	Rae Bareli Division	Rae Bareli Division	Rae Bareli Division	Rae Bareli Division
Line No.	M2	M1	M1	M2
Well No.	6	3	6	3
Field No.	3610	326	645	318
General Level of Ground	338·89	344·34	347·0	338·69
R.L. of Point of Measurement	338·64	348·40	350·5	339·14

Year	R.L. of water surface in well	Year	R.L. of water surface in well	Year	R.L. of water surface in well	Year	R.L. of water surface in well
1940	303·97	1940	323·40	1940	313·64	1940	290·89
1941	318·64	1941	326·57	1941	325·72	1941	297·14
1942	318·00	1942	332·36	1942	316·95	1942	299·74
1943	319·19	1943	335·28	1943	319·64	1943	308·46
1944	327·10	1944	337·50	1944	324·80	1944	309·22
1945	323·64	1945	335·50	1945	328·00	1945	307·39

1946	323·30	1946 . . .	336·75	1946 . . .	322·80	1946 . .	308·14
1947	325·22	1947 . . .	336·83	1947 . . .	332·00	1947 . .	306·29
1948	332·19	1948 . . .	339·83	1948 . . .	340·80	1948 . .	318·30
1949	332·21	1949 . . .	338·10	1949 . . .	341·22	1949 . .	320·40
1950	329·82	1950 . . .	337.05	1950 . . .	339·40	1950 . .	320·00
1951	328·40	1951 . . .	337·00	1951 . . .	339·05	1951 . .	315·90
1952	327·50	1952 . . .	336·79	1952 . . .	338·00	1952 . .	314·30
1953	330·80	1953 . . .	338·60	1953 . . .	341·55	1953 . .	319·40
1954	330·30	1954 . . .	336·00	1954 . . .	339·09	1954 . .	317·50
1955	331·90	1955 . . .	342·53	1955 . . .	344·05	1955 . .	321·90
1956	332·84	1956 . . .	340·20	1956 . . .	341·05	1956 . .	321·14
1957	330·50	1957 . . .	337·80	1957 . . .	338·08	1957 . .	321·10

TABLE IV

District-wise list of rice areas of U.P. for the year 1956-57.

Name of District	Rice area in acres	Name of District	Rice area in acres	Name of District	Rice area in acres
Dehra Dun	22,728	Farrukhabad . . .	9.362	Azamgarh	1.189
Saharanpur	80,575	Etawah	57,660	Naini Tal	43.577
Muzaffarnagar	38,923	Kanpur	74,137	Lucknow	9.487
Meerut	11.623	Fatehpur	39,638	Unnao	28.960
Bulandshahr	1,458	Allahabad	4,254	Rae Bareli	23,923
Aligarh	1,990	Jhansi	850	Sitapur	5,232
Mathura	61	Jalaun	213	Hardoi	3,231
Agra	32	Hamirpur	21	Kheri	2,073
Mainpuri	25,602	Banda	1,16,377	Faizabad	43
Etah	5,202	Varanasi	63,994	Gonda	226
Bareilly	53,404	Mirzapur	1,38,397	Bahraich	..
Bijnor	7,445	Jaunpur	1	Sultanpur	835
Budaun	279	Ghazipur	11	Pratapgarh	306
Moradabad	1,987	Ballia	827	Bara Banki . . .	18,323
Shahjahanpur	25,692	Gorakhpur	2,095	Tehri	..
Pilibhit	22,199	Deoria	253	Garhwal	..
Rampur	6,734	Basti	3.539	Almora	..

1 acre = 0.4047 hectare.

TABLE V

District-wise list of Usar lands (Saline and alkaline) of U. P. for the year 1956-57.

Name of District	*Usar* land in acres	Name of District	*Usar* land in acres	Name of District	*Usar* land in acres
Dehra Dun	28,481	Farrukhabad . . .	71,793	Azamgarh	66,812
Saharanpur	15,894	Etawah	1,70,042	Naini Tal	5,479
Muzaffarnagar	37,363	Kanpur	1,77,492	Lucknow	60,588
Meerut	50,151	Fatehpur	87,204	Unnao	1,09,187
Bulandshahr	72,481	Allahabad	1.15,700	Rae Bareli	87,397
Aligarh	1,02.996	Jhansi	1,53,568	Sitapur	14,905
Mathura	15,506	Jalaun	82,029	Hardoi	68,832
Agra	87,751	Hamirpur . . .	1,16,663	Kheri	12,873
Mainpuri	1,74,784	Banda	1,50,797	Faizabad	28,803
Etah	37,191	Varanasi	40,966	Gonda	7,699
Bareilly	18,440	Mirzapur	2,12,025	Bahraich	9,713
Bijnor	29,224	Jaunpur	42,115	Sultanpur	82,585
Budaun	30,691	Ghazipur	21,996	Pratapgarh	68,868
Moradabad	31,603	Ballia	43,656	Bara Banki . . .	28,342
Shahjahanpur	20,542	Gorakhpur	7,929	Tehri	..
Pilibhit	9,231	Deoria . . .	13,341	Garhwal	..
Rampur	12,552	Basti	30,801	Almora	..

1 acre = 0.4047 hectare.

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have been avoided if provision had been made for drainage systems when the first irrigation canals were constructed.

Remedies

The remedies lie in arresting all the surplus waters from percolation by taking measures for the rapid surface removal of the rain-water, and applying only a limited quantity of water over the surfaces so that the depths of percolation water are made as little as possible. The problem needs to be dealt with as under :

(1) *Improvement of Land by Surface Drainage*—The natural drainage lines should be demarcated, acquired, obstructions removed and flow maintained from the beginning. Additional drains in sub-soil valleys or cut off drains should also be opened soon after the irrigation develops and not after the drains get clogged. In the planning of programmes for irrigation projects first priority should be given to drainage of those irrigated lands which have not yet been provided with drainage.

(2) *Lining of Watercourses, Main Canals and Distributaries if Economically Possible*—If the consequent reduction in section of canal and saving of water and land are considered, this should not be an uneconomical proposition.

(3) Minimisation if not total prevention of flooding of the effected areas from rivers and big streams.

(4) *Reducing Intensity of Irrigation, or use of just sufficient Irrigation Water*—Special attention is required to be given for the correct usages of water for irrigation by the cultivators specially in the rice areas.

(5) *Crop Planning*—The crops should be grown in rotation so that few of the lands will require less water to compensate large volumes required by other crops. By such rotation the water that drains off can be reduced and the drainage problem minimised. The lands also will yield more.

(6) *Educating the Farmers for Economical use of Water*—Many farmers are still of the view that if the fields are flooded the yield will be more. The Irrigation Engineers and the Agricultural Department Officers in conjunction with the Block Development Officers, must demonstrate the benefits of the correct usage of water depths and the farmers must be educated about this vital point alongwith the improving of irrigation practices.

(7) *Co-operative System of Irrigation*—The farmers must be induced to cultivate the system of co-operative farming. This will promote the feeling of oneness among them. The tendency among some farmers using more water to the detriment of other needy farmers will vanish. This will give rise to economic utilisation of water and the drainage problem will automatically be solved.

(8) Construction of seepage drains and intercepting drain where necessary.

(9) Transferring part of the commanded areas of the Etawah Branch, Kanpur Branch and Mat Branch Systems in the water-logged areas possibly from canal irrigation to tube-well irrigation. It would have the double advantage of reducing the water-logging conditions in these tracts as well as releasing the canal water for irrigation in areas in the lower reaches where there is acute shortage of water.

(10) Installation of an adequate number of shallow tube-wells, in order to stabilise the sub-soil water at the proper level.

On account of low land gradients which may be even less than one foot per mile associated with poor drainage outfalls in the south-eastern districts, the design of the drainage systems for these areas may be complicated and without constant maintenance both natural and constructed drainage channels may be choked with vegetative growth. The more effective method of lowering the water-table for these areas will probably be through pumping by wells and these wells will have the further advantage of increasing the supplies of usable water for lower reaches.

Alkalinity and Salinity

A total of about 3 million acres (1·21 million ha.) of land of the State is under alkalinity and salinity at present Table V[15]. The northern and south-western districts, namely Saharanpur, Bijnor, Moradabad, Budaun, Bareilly, Pilibhit, Kheri, Bahraich, Gonda, Basti, Gorakhpur, Hamirpur, Jhansi and Banda, *etc.*, are comparatively free from alkali. It seems likely that the drainage action of the rivers Yamuna, Ghagra and Rapti plays an important part. The southern and south-eastern districts, on the other hand namely, Bulandshahr, Aligarh, Mainpuri, Etawah, Kanpur, Unnao, Rae Bareli, Pratapgarh, Allahabad, Hardoi, Lucknow, Sultanpur and Azamgarh, constitute the greater parts of the State *usar* lands which cover a wide range of soils, *e.g.*, soils only mildly alkaline or saline, soils with pronounced alkalinity, and soils with an efflorescence of *reh* on the surface.

The alkali soils constitute by far the greater part of the *usar* lands of this State. These soils have a strong alkaline reaction and are in a deflocculated condition. They are characterised by the presence of sodium carbonate and bicarbonate in comparatively large quantities. The exact depth of the alkaline layer varies very much in different localities. On an average it is found to extend to 3-4 ft. (0·9-1·2 m.) depth. It is not un-common to find the salt concentration in the deeper layers of the soil, making them impervious to water. These alkali soils possess low percentage of exchangeable calcium, high *pH* value, high percentage of exchangeable sodium, and high dispersion factor. The barrenness of these soils is due to the adverse physical conditions induced by the excess of exchangeable sodium and the deficiency of calcium brought about by excess of hydroxions.

The area of predominantly saline soils in the State is very much less than that of the alkali soils and a major belt of such soils comes across only in certain areas of the Mat Branch of the Upper Ganga Canal. Saline soils contain mostly sodium salts like sodium sulphate and sodium chloride and very little of sodium carbonate or bicarbonate. Contrary to the alkaline soils, the saline soils show on 'Open' texture, and are in a state of flocculation.

The behaviour of the soil salinity in this State is often in two stages. In the first phase of salinization the salts accumulating in the soil or on its surface are neutral—mainly chlorides and sulphates of sodium. The presence of these salts on the surface is usually indicated by a white film (white alkali) and the soil has a slightly alkaline reaction with *pH* value between 7 and 8·5. Irrigation water dissolves these salts but when their concentration exceeds a certain figure they are no longer tolerated by the roots of crops. At a later stage in salinization, the salts present in or on the soil are no longer neutral but definitely alkaline, consisting of carbonate and bicarbonate of soda. The *pH* of the soil varies between 8 and 9 or may rise as high as 10. The dark humous formed by decayed vegetable matter is soluble in these alkaline solutions and gives the surface of the ground a blackish colour (black alkali). No cultivated vegetation tolerates this degree of salinity and such soils have been rendered completely sterile.

Soil salinity is traceable rather to geological causes and the existence of alkali soils is in the majority of cases traceable to climatic conditions alone, nevertheless, the irrigation practices over the last 100 years may be blamed for the redistribution of salts in the soil profile. The absence of any land drainage system in most parts of the areas now under irrigation has had the effect of raising the water-table and increasing the salinity of the soil on a progressively rising scale.

REMEDIAL MEASURES

Prevention of salinization of irrigated land can be done by reducing the evaporation from soil surface and by a decrease in the feeding of ground waters. Large portions of the heavily affected and deteriorating lands can, however, be restored to their former levels of productivity only by an intensive programme of the control of water-logging conditions and reclamation of saline and or alkali lands. However, before taking up any treatment for such lands, a complete knowledge of the quality of soil, quality of proposed irrigation water, and nature and distribution of salts, *etc.*, based on field investigations and laboratory testing, is necessary. The type of investigations should consist of—

(1) Establishing Grid System Points, at which observations and testing may be carried out.

(2) *Test Pit and Hole Logging*—These should be excavated and drilled to depths of 3 to 5 m. and logged for all significant layers. A few samples should be taken for complete and routine chemical and physical analysis and for salinity determinations.

(3) *Field Permeability Tests*—These are required at the points of observation in order to have an idea of drainability of the soil and to judge the feasibility of removing undesirable chemicals such as sodium and boron.

(4) The location of the position of ground water-table with respect to the ground surface to have an idea of the extent of measures required for the control of water-logging conditions.

(5) *Field Reclamation Tests*—These tests will indicate the best remedial measures for the deteriorated lands. Accurate measurements and tests of the quantity and quality of water used,

changes in the contents of salts, alkali and toxic elements resulting from leaching, ground water discharges, soil permeabilities (pre-, during and post-leaching) and infiltration rates are all required to be carefully recorded.

(6) *Laboratory Testing*—The disturbed soil samples collected for laboratory analysis should be chemically analysed or soluble cations and anions, exchangeable sodium and potassium, gypsum, lime and boron contents, *pH,* and *Ca* ion exchange capacities and the disturbed samples should be analysed for unit dry weight, specific gravity, specific yield, moisture content, soil structure and swelling, *etc.*

(7) Study of the irrigation methods, water depths, water requirements of crops and the crop patterns.

(8) *Classification of Waters for Irrigation Purposes*—Waters from all sources—surface, canals water-table, tube-wells and artesians should be classified for irrigation purposes as water quality is an important consideration in assessing the salinity or alkalinity of a certain area.

(9) *Interpretation of the Field and Laboratory Tests*—A correct interpretation of all these tests will give the extent of water-logging, salinity and alkalinity conditions, and will also help in predicting the reclaimability of the deteriorated land within economical means.

The new method of reclamation assessment developed in Russia with the help of radio-active isotopes, by the Institute of Soil Science of the U.S.S.R. Academy of Sciences[16], is based on determination in the water and soil subjected to test of *Na* and *Ca* ions, absorbed *Ca* in the soil, and absorption capacity by using *Ca*-45. Application of the method showed that if the lack of *Ca* in the soil exceeded 50 per cent of the exchange capacity, the soil being irrigated by water containing over 2 gm. of salts per litre, reclamation measures were required.

The remedial measures to be adopted for the reclamation of alkali soils, after having assessed the reclaimability of the deteriorated land, may consist of treating the alkaline land with any of the following universal methods :

(*a*) Use of chemicals, *viz.*, gypsum, calcium chloride, molasses *plus* lime sludge, and distillery waste, *etc.*

(*b*) Green manuring.

(*c*) Electro-dialysis.

(*d*) Powdered carbon charged with calcium.

The decisive factor will be the availability and the cost of the agent, and the economy of the particular method. For permanent reclamation, the adequate lowering of the water-table is the most essential factor.

The Quality of Irrigation Water

The subject of the quality of water that may be used for irrigation without causing soil deterioration, is of great importance specially for this State as it utilises the largest amount of the pumped ground water in this country. The extent and composition of dissolved salts in any water largely determines its quality. The water in rivers is affected by variations in their dischareg; it tends to be diluted during period of high discharge and concentrated during hot dry months.

The suitability of ground water for irrigation is contingent upon the effects of the mineral constituents of the water on both the plant and the soil. Effects of salts on plant growth may be physical by limiting the uptake of water through modification of osmotic processes, or chemical by metabolic reactions. Effects of salts on soils cause changes in soil structure, permeability and aeration thus indirectly affect the plant growth. Specific limits of permissible salt concentrations for irrigation water cannot be stated because of the wide variations in salinity tolerance among different plants, still there are numerous ways in which the quality of irrigation water is designated. According to the practice prevalent in the Irrigation Department, Punjab, all waters with 60 parts of soluble salts per 1,00,000 parts of water are considered suitable for irrigation and those with salt content above 120 parts unsuitable. For those with salt content ranging between 60 to 120 parts, Puri ([9]) formulated a relationship to account for such waters by defining the salt index.

$$\text{Salt index} = \text{total } Na - 24.5 - (Total\ Ca - Ca\ in\ CaCo_3) \times 4.85.$$

All quantities in the relationship refer to parts per 1,00,000. The salt index is negative for all good waters and positive for those unsuitable for irrigation purposes.

A classification after Wilcox ([4]) based on the measurements of electrical conductivity, sodium content, and boron concentration gives the suitability standards as :

Water Class	Per cent	Electrical Conductivity $EC \times 10^6$	Boron p.p.m.
Excellent	<20	<250	$<0\cdot67$
Good	20—40	250—750	0·67 1·33
Permissible	40—60	750—2000	1·33—2·00
Doubtful	60—80	2000—3000	2·00—2·05
Unsuitable	>80	>3000	$>2\cdot50$

According to the latest classification by the U.S. Salinity Laboratory based on electrical conductivity and Sodium Adsorption Ratio (S.A.R.) a direct indication of the salinity and alkalinity hazards can be obtained by locating the point for a particular irrigation water in the classification diagram (Figure 5) with electrical conductivity and S.A.R. as co-ordinates. The figure is binomial and C_1, C_2, C_3, C_4, C_5, and C_6, represent water classes with increasing hazards from total salt concentrations and S_1, S_2, S_3, and S_4, representing water classes for increasing hazards of exchangeable sodium accumulation in irrigated soils.

Agarwal and co-workers made a study of the quality of irrigation water in the central-western districts of U.P., *viz.*, Etah, Farrukhabad and Kanpur as typical of the Gangetic alluvium. Following the classification system of the U.S. Salinity Laboratory they concluded that whereas the canal water constitutes the best source of irrigation water supply in U.P., the quality of well water, vary with the nature of soil formation and the level of the ground water from which they are derived.

The analysis of a few water samples from Saharanpur, Muzaffarnagar, Bulandshahr, Bijnor, and Farrukhabad Tube-well Divisions were carried at the Irrigation Research Institute, Roorkee to judge their suitability for irrigation purposes. The results of the main constituents are given in Tables VI & VII. On the basis of the latest classification of U.S. Salinity Laboratory, the results indicated that all waters except that of Tube-well Division, Bulandshahr (marked by in Table VII) were suitable for irrigation purposes. The water of tube-well No. 37, Bulandshahr Division, falls in the C_4—S_1 group of the U.S. Salinity classification (Figure 3) and is thus highly saline (total salt concentration being 1,755 p.p.m.). This water can be used for irrigation only on soils of good permeability and where special leaching is provided to remove excess salt concentrations.

It is, therefore, most desirable that a co-ordinated programme of work on the quality of irrigation waters is taken up in the State to designate the limits of salinity of waters with reference to irrigation applied to normal agricultural land and for purposes of reclaiming the deteriorated land.

Conclusions

Recognising that increase in population creates a need for expanding the cultivated area of the State, it becomes of utmost importance to sustain the productivity of lands already irrigated. For preventing the further deterioration of the irrigated land in U.P. and to preserve the fertility of the soils permanently, it has now become most necessary to maintain good surface and sub-surface drainage and avoiding the concentration of harmful salts within the root zone. Agricultural practices governing the maintenance of optimum amounts of nutrients, addition of organic manures, crop rotations and cultivation operations will all fail to give adequate response if the basic factors of soil moisture control are not attended to.

And hence in the planning of programmes designed to increase food production, first priority should be given to drainage of those irrigated lands which have not yet been provided with drainage to be followed by a consideration of the relative advantages of bringing new areas under irrigation and improving drainage of those irrigated lands which are inadequately drained. Programmes of research and investigation, both fundamental and applied, should be undertaken or expanded to determine requirements of drains, including depth, spacing and types in relation to effectiveness and feasibility of drainage and the choice and rotation of crops, their water requirements, irrigation methods, and prevention of seepage from canals, branches and distributaries by economical means. Technical laboratories which, in addition to determining textures, soluble salts, and *pH* values, should be equipped to determine base exchange capacities, complete water analysis, water conductivity capacities of soils disturbed and undisturbed in both vertical and lateral directions, soil densities, capillary and non-capillary porosities and other

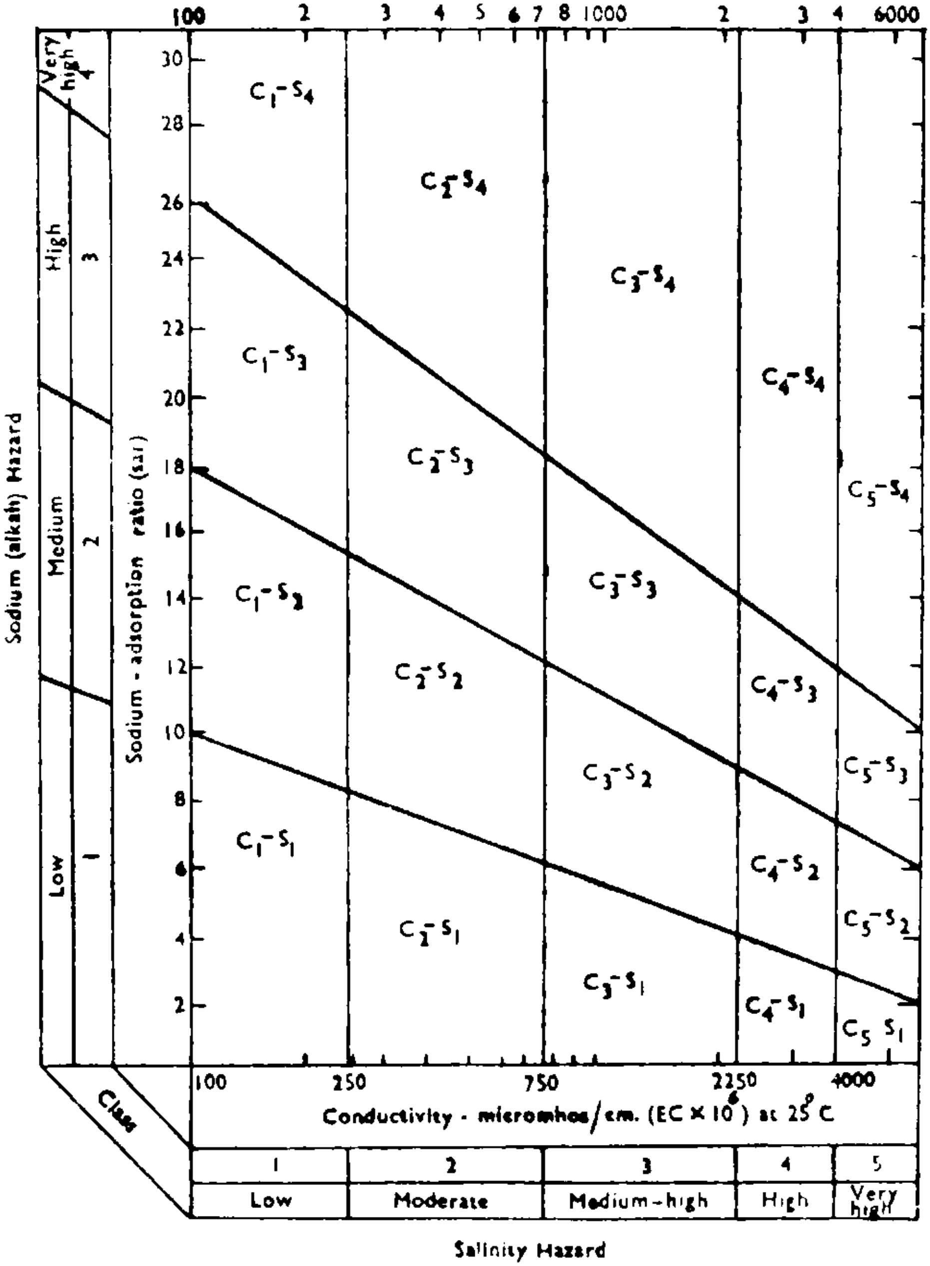

FIGURE 3: *Diagram for determining the quality rating of an irrigation water from its absorption ratio and electrical conductivity (modified for higher salt classes) by U.S. Salinity Laboratory.*

TABLE VI

Resutls of chemical analysis of water samples from tube-wells.

Sl. No.	Constituents	Saharanpur Group					
		Tube-well No. 22 p.p.m.	Tube-well No. 24 ppm.	Tube-well No. 26 p.p.m.	Tube-well No. 28 p.p.m.	Tube-well No. 29 p.p.m.	Tube-well No. 30 p.p.m.
1.	Total Dissolved Solids	410·75	372·62	222·92	393·37	238·75	294·62
2.	Suspended matter .	90·30	11·00	33·56	87·47	82·87	77·53
3.	Electrical Conductivity	390·60 mmh.cm.	448·00 mmh.cm.	355·00 mmh.cm.	459·00 mmh.cm.	325·00 mmh.cm.	381·00 mmh.cm.
4.	Sulpha teions .	82·64	125·47	96·26	167·99	109·63	32·50
5.	Chloride ions. .	6·82	3·59	3·23	2.79	2·82	3·49
6.	Bi-carbonate . .	142·92	166·74	130·93	238·31	107·12	119·10
7.	Silica . . .	24·00	16·62	10·80	21·37	18·07	17·62
8.	Aluminium . .	1·39	1·59	3·62	0·46	3·17	2·57
9.	Iron . . .	1·31	0·70	1·39	0·26	0·31	0·35
10.	Calcium . .	34·48	20·54	47·28	23·48	49·73	14·59
11.	Magnesium .	Nil	3·18	8·53	0·93	5·96	3·05
12.	pH value . .	7·35	7·20	7·30	7·40	7·40	7·35

TABLE VII

Results of chemical analysis of water samples from tube-wells.

Sl. No.	Constituents	Tube-well Division Farrukhabad	Tube-well Division Bijnor	Tube-well Division Bulandshahr	Tube-well Division Bulandshahr T.W. No. 37	Tube-well Division Muzaffarnagar T.W. No. 10
1.	Dissolved Solids in p.p.m. .	828·40	274·00	1,775·00	2,685·00	195·00
2.	Suspended matter in p.p.m. .	24·36	40·30	..	1·00	Nil
3.	Electrical Conductivity in Micro-hmos per cm. . .	978·50	373·00	2,894·00	4,171·01	304·14
4.	Sulphate ions in p.p.m. . .	95·40	173·60	695·30	1,077·82	17·28
5.	Chloride ions in p.p.m. . .	32·96	7·07	277·50	451·92	8·80
6.	Bi-carbonates in p.p.m. . .	210·51	212·07	300·42	268·40	158·67
7.	Silica in p.p.m. . . .	20·40	6·50	..	Nil	Nil
8.	Aluminium in p.p.m. . .	..	Nil	26·99	Nil	Nil
9.	Iron in p.p.m. . . .	..	Nil	..	Nil	Nil
10.	Calcium in p.p.m. . . .	98·57	81·00	71·43	45·00	57·14
11.	Magnesium in p.p.m. . .	40·97	Nil	17·43	93·08	3·40
12.	pH value	7·2	8·1	6·65	..	7·30
13.	Sodium in p.p.m. . . .	34·39	..	36·00	703·39	1·96
14.	S.A.R. (Sodium Adsorption Ratio)	0·731	..	0·99	13·676	0·068

chemical and physical properties which may be needed for specific soil conditions. Also the existing facilities and personnel should be utilised, or such services established, for an extensive programme of propaganda and education to impress upon the farmers and the population in general the need for economical use of water and the drainage of the irrigated land, specially where the danger of deterioration due to rising water-table and salinization exists.

In the end, it may be emphasized that after having known the deterioration of the irrigated lands of Texas, Oklahoma, Kansas, Nebraska, North and South Dakota in the United States of America, in Turkey, U.S.S.R. and the Punjab in India, and the increasing associated problems of the irrigated lands of Uttar Pradesh it has now become the principal responsibility of the irrigation engineers to anticipate drainage requirements and salinity problems on new projects, to ensure that the proper drainage facilities are provided and the adequate financial provisions are made for their maintenance. Without this assurance, the expenditures to bring dry lands under irrigation and to maintain them into good productivity are not justifiable and an irrigation project so developed may be burdened with ever increasing drainage problems and costs, and may thus, be a liability to the nation.

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Concepts in Irrigation Efficiency

by

Shri Mohan *

ABSTRACT

Proper use of irrigation water pre-supposes accurate methods of measurement and evaluation of performance in terms of efficiency. There are various concepts of efficiencies which have relative importance with reference to specific phases.

Generally speaking, water use in an irrigation project under development will have a lower efficiency. However, as water becomes more and more scarce and as the need becomes more pressing, the water is better utilised.

This paper deals with various concepts of efficiencies in vogue, concerning use of irrigation water.

1. Irrigation Efficiency— (Ei)

It is defined as the ratio of water consumed by the crops of an irrigation farm or project, to the water delivered from a river or other natural water source into the farm or project canal or canals. In view of the water losses likely to occur at various stages before the plants ultimately utilize it, several partial efficiencies have been defined. It is, of course, implied that for obtaining maximum overall efficiency, the various partial efficiencies should individually be maximum.

Let, Ei = Irrigation efficiency, per cent.

W_c = Irrigation water consumed by the crop of an irrigation farm or project during their growth period.

W_r = Water diverted from a river or other natural source into the farm or project canals during the same period.

Then,

$$Ei = 100 \times \frac{W_c}{W_r}$$

The irrigation efficiency percentage is influenced by the water conveyance and delivery efficiency and the water application efficiency. When these efficiencies are increased, the irrigation efficiency also is increased. These efficiencies can be increased by reducing the loss of water in conveyance, delivery run off, deep percolation and evaporation. Although difficult to increase this efficiency, however, serious consideration should be given to reduce the various losses. In most projects this efficiency ranges from 12 to 34 per cent.

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2. Water Conveyance and Delivery Efficiency—(E_c)

The water conveyance and delivery efficiency is defined as the ratio of the sum of water delivered to all the farms to the water delivered from the river or other water source during the same period.

Let, E_c = Water conveyance and delivery efficiency, per cent.
W_f = Water delivered to the farm under the canal.

Then, by definition:

$$E_c = 100 \times \frac{W_f}{W_r}$$

When the irrigation water is conveyed from its source in the river or reservoir to the farms, invariably the water is lost through leaks in irrigation gates, spillways, waterways, evaporation and seepage. This efficiency could be increased by timely and proper upkeep and maintenance of the irrigation system. It is very difficult to increase this efficiency specially in canals where the water is conveyed through permeable canal linings and for long distances.

During 1940, Israelson, recorded a loss of 38 per cent on a 1,25,000 miles (2,01,168 km.) long canal, between the points of diversion and delivery. Thus the E_c was 62 per cent.

3. Water Application Efficiency—(E_a)

Water application efficiency has been defined as the per cent of water applied that can be accounted for as increase in soil moisture in the soil as occupied by the principle rooting system of the crop.

Let E_a = Water application efficiency.
W_f = Irrigation water delivered to the farm.
W_s = Irrigation water stored in the root zone of farm soil.

Then, by definition:

$$E_a = 100 \times \frac{W_s}{W_f}$$

Common sources of loss of irrigation water during application are represented thus:

R_f = Surface run off from the farm.

D_f = Deep percolation below the root zone of farm soil.

Neglecting evaporation losses during application.

$$W_f = W_s + R_f + D_f$$

Therefore,

$$E_a = 100 \left\{ \frac{W_f - R_f + D_f}{W_f} \right\}$$

It is necessary to apply irrigation water efficiently to the land after having it stored and conveyed through costly diversions and conveyance structures. Generally water is applied indiscriminately where cheaply available. This concept of water application efficiency focuses attention

7. Summary

Performance of the application of irrigation water is measured in terms of efficiency. There are various efficiencies stressing importance of various points relating to soil, water and plant.

Irrigation efficiency has importance over a complete project. Loss of water in conveyance, delivery, runoff deep percolation and evaporation, all are taken into account.

Water conveyance and delivery efficiency considers losses between diversion and delivery of irrigation water.

Water application efficiency is considered only after the point of delivery. Increase in soil moisture in the principal root zone is accounted for.

Water storage efficiency stresses on the stored water and the needed water in the root zone of the soil.

Water distribution efficiency stresses on the uniformity of distribution of irrigation water throughout the root zone.

Consumptive use efficiency stresses on the availability of the irrigated water to the crop.

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Efficiency of Water Distribution and Use on the Land

by

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1. Surface Irrigation

There are a number of methods of applying irrigation water to the land. They vary in different countries because of difference in topography, soil conditions, available water supply, feasible amounts of land preparation, crops grown and even the customs of the cultivators. Certain methods are of general applicability and are used, to some extent, in all irrigated regions. Irrigation methods are commonly designated according to the manner in which water is applied to the soil or nature of the irrigation unit of land to which water is applied. All these methods can be classified as follows: —

(1) Surface flooding.

(2) Irrigation through furrows, thus wetting only a part of the ground surface.

(3) Sub-irrigation, in which the surface is wet a little, if any.

(4) Sprinkling, in which the soil surface is wetted as much as it is by rainfall.

In India mainly the first two methods are used.

2. Surface Flooding

2·1. WILD FLOODING OR UN-CONTROLLED FLOODING

Irrigation by surface flooding may be controlled or uncontrolled, the latter is sometimes called "Wild Flooding". This is a primitive method of flooding which was practised in the past particularly for irrigation from inundation canals, when water is in abundance and growing seasons are relatively short. The water is turned on to practically unprepared land surface and is allowed to follow natual slopes without much guidance or obstruction. This is mostly applicable on relatively smooth areas sloping gradually; and is sometimes used as a temporary measure on new lands on a project, till land is properly prepared. In this method there are only small depths of infiltration.

2·2. FLOODING FROM FIELD WATERCOURSES

When flooding is controlled it is called "Ordinary Flooding" and is generally designated according to the methods of delivering water to the area within the unit, as for example, flooding from field watercourses. It is the most common method, particularly where irrigation water is abundant and inexpensive. The field ditches or field watercourses have to be properly spaced, the spacing depending largely on topography and

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soil texture. This method can be used on steep slopes as well as on flat areas. Steep slopes require close spacing of field watercourses than flat slopes. Porous soils require closer spacing than tight soil. If the water is made to flow over too quickly, an insufficient amount will percolate into the soil. If it is kept on the surface too long, it may result in waste by percolation into the deep sub-soil. The spacing may vary from less than 50 ft. (15·2 m.) to more than 200 ft. (61 m.). The lands with soils of medium texture and with slopes neither too steep nor too flat are best suited for this method of irrigation. For this method the irrigation operation usually begins at the higher area and proceeds to the lower elevations.

2·3. FLOODING IN BORDER STRIPS

Border strips are long narrow parallel irrigation units, preferably about 30 to 60 ft. (9·1 to 18·3 m.) wide, and about 300 to 1,300 ft. (91·4 to 396·2 m.) long, laid out in the direction of the ground slope and separated by low borders or *'bundhs'* or 'levees'. Water is supplied from the main watercourse along the upper end of the field and the flowing sheet of water is allowed to flow down the strips between the borders. The surface between the two borders is level, so that the advancing sheet of water covers the entire width of land strip. Slopes down the strips should be continuous and uniform wherever feasible, somewhat according to the natural slope of the land. This method is widely used for grain crops, fodder crops, *etc.* It is important to study the physical soil properties in advance of preparing land for border irrigation. The border method is best adopted to soils which take water fairly rapidly so that the desired depth per irrigation may be absorbed from the water as it flows over the land. The following table gives suitable dimensions for border strips on different soils:—

Discharge in cusec	Sand		Loam		Clay	
	W. in ft.	*L.* in ft.	*W.* in ft.	*L.* in ft.	*W.* in ft.	*L.* in ft.
1	20—30	200—300	30	300—400	30	440—660
1—2 . . .	30—40	300—400	30—40	440—660	30—40	660
2—4 . . .	30—40	440	40	440—660	50	660—800

W=width; *L*=length; 1 ft.=0.3048 m.=30.48 cm.

2.4. FLOODING IN LEVEL CHECKS

It consists of running comparatively large streams into relatively level plots or *'chacks'* surrounded by small levees or *'bundhs'*. *The 'chacks'* may be laid out as rectangular areas, approximately parallel to the contours and normal to the sides of the field. Generally field watercourses are run down the slopes and water diverted to *'chacks'* on both sides. *Chacks* are filled to desirable depths. This method is suited to very permeable soils which must be quickly covered with water in order to prevent excessive losses, through deep percolation. It is also suited to heavy soils into which water percolates so slowly that they are not sufficiently moistened during the time. A sheet of water flows over them.

making it necessary to hold the water on surface to assure adequate penetration. This method is mostly used in India.

2·5. DISTRIBUTION OF WATER

For efficient irrigation, it is essential to distribute the water uniformly, so that there is neither ponding which may cause excessive deep percolation losses, nor inadequate wetting of the soil, and thereby the objective is to cause enough water to the root zone. It is desirable that discharge of watercourse applied to unit area of land should vary according to the rate of infiltration of water into the soil. Or, in other words, with a constant discharge the unit area should vary with the rate of infiltration.

If we analyse the time required to cover a given area with water mathematically it can be expressed by the equation:

$$t = 2\cdot303 \quad \frac{Y}{I} \log \frac{q}{q - IA}$$

where,

A = Area covered with water in time t.

I = Rate of infiltration of water into the soil of the wetted area, surface inches per hour.

q = Quantity of water turned on to the strip, acre inches per hour (cusec).

t = Time to cover the area, hours.

y = Average depth of water as it flows over the land in inches.

If the time rates (q/A) of water application are low there will be too much water losses due to excess percolation. So, in the case of highly permeable soils irrigation water must be applied in large discharges to small plots in order to prevent excessive deep percolation losses.

In northern India where there are vast areas of extremely flat land, with gradient of even 1 in 4,000 and less, the square system of settlement has been in vogue, which has many advantages. The land is surveyed into big rectangles of 25 acres (10·12 ha.) in area [1,100 ft. × 990 ft. (335 m. × 302 m.)] each rectangle being again sub-divided into 25 units of one acre (0·4 ha.) each [220 ft. × 198 ft. (67 m. × 60 m.)]. The most efficient method of distribution is the intermittent flow, the former obtaining a certain definite discharge over a definite period of time and at fixed intervals. Surface irrigation is practically the universal method adopted by flooding the entire surface of the area to be irrigated or by turning the water into a number of furrows. The former is more common. Surface flooded land is sometimes further sub-divided into small plots known as *kiaries* or *chacks*, each *chack* is fed at its highest point from the adjoining watercourse. This elaborate and efficient layout is not only peculiar to India but is found in other countries as well. *Chacks* (or *kiaries*) of half an acre (0·2 ha.) or less are generally laid out. Where agricultural machinery is used, very small *chacks* are not practicable. The divide walls between such *chacks* should be broad and low, so that agricultural machinery can be readily taken out from one *chack* to another. For efficient irrigation the proper levelling or grading of land is essential.

3. Irrigation through Furrows

The engineer should deliver water to the field in a manner such as to encourage rather force the agriculturist to utilise it to the best advantage. This can be done by delivering water in as large a stream as they can handle, generally about 1 to 2 cusec (0·03 to 0·06 cusec) and into small plots or *kiaries* or *chacks as* shown in para 2.5. He should economise water by dividing the fields into plots of an appropriate area and irrigate it separately from the watercourse. He can further economise by carefully smoothing the ground previous to irrigation. This is affected by drawing a flat beam of wood across the newly sown ground thus crushing down the clods and irregularities.

4. Losses and Waste of Irrigation Water

Losses and waste of irrigation water occur in three ways: (1) in conveyance and distribution system, while water is being delivered to the fields, (2) in field watercourses, and (3) in *chacks* or *kiaries* or in furrows, while irrigators are applying water to fields. These losses depend upon slopes of ground surfaces, soil conditions, sub-division of farms into field units, preparation of field surfaces, methods of irrigating and skill of the irrigators.

4·1. CONVEYANCE AND DELIVERY LOSSES

They include: (*i*) evaporation from canal surfaces, (*ii*) transpiration by vegetation on canal banks, (*iii*) seepage from the bed and banks of channels. Item No. (*i*) seldom amounts to appreciable quantity and item No. (*ii*) depends on the nature of the bank materials and the extent to which weeds, *etc.*, are allowed to grow. Seepage losses, however, take place through the beds and banks of canals, distributaries and field watercourses, principally in unlined channels excavated through earth. They can be avoided or minimised by lining the channels.

4·2. IRRIGATION LOSSES AND WASTE

Irrigation losses and waste include evaporation, surface run off, and percolation. When irrigation water is delivered to a field through furrows or by flooding, a small part of the water, evaporates during and immediately following delivery, a part runs off the lower end of the field as waste, and the remainder infiltrates into the soil. Some water that enters the soil may move to depths below the root zone, through percolation. The rest of the infiltration which is held in the root zone by capillary action is lost in the shape of evapo-transpiration during intervals between irrigations. It is this part that should be kept as high as possible.

The aim should be to apply only such amounts of water as can be retained in the root zone, and to reduce as much as possible the percolation losses.

4·3. IRRIGATION EFFICIENCIES

It is defined as percentages of the water delivered from a river or other natural source, that are retained in the root zone and do not percolate beyond reach of the plant roots, and where they are available for use in crop growth. In other words they represent proportions of the deliveries remaining in the upper soil layers after all losses and waste of water are deducted.

Let,

E_i = Irrigation efficiency, per cent.

W_c = Irrigation water consumed by the crops during their growth period.

W_r = Water diverted from a river into the field.

W_s = Water stored into root zone soil.

Then,

$$E_i = \frac{100 \times W_c}{W_r}$$

The irrigation efficiency percentage is influenced by the water conveyance and delivery efficiency and water application efficiency. Because of the many sources of losses of irrigation water between the time and place it is delivered from the source, and the time and place it is stored in the root zone soil, as water readily available to plants, the irrigation efficiency is very low on most of the projects—probably less than 33 per cent. Efficiencies can be improved by reducing the loss of water in conveyance, delivery, runoff, deep percolation and evaporation.

4·4. ECONOMIC IRRIGATION REQUIREMENT

On all irrigation projects, successful agriculture can be maintained largely by the application of water with high irrigation efficiencies. A farmer is interested in securing maximum return at minimum cost and at the same time without impairing the productivity of his land (due to water-logging, *etc.*). Where water supplies are more than ample, irrigation efficiencies have been relatively low and quantities delivered to the lands have been greater than irrigation requirements. Total depth of irrigation water needed is the sum total of depth required for consumptive use, surface runoff and percolation. Crops commonly require more water when grown on light sandy soils than when grown on heavy clay soils, because more water percolates to depth below the root zones. Experiments have been carried out and observations made, which showed higher efficiencies for deep rooted crops than for shallow rooted crops.

In general, low efficiencies have been due to application of too much water for irrigation, uneven distribution of water over the field surfaces, irrigating when the soil is too moist, or combination of such conditions.

5. Improving Irrigation Efficiencies

As already stated in para 4.3, efficiencies can be improved by reducing the loss of water in conveyance, delivery, runoff, deep percolation and evaporation. Losses in conveyance and delivery can be prevented or mostly eliminated by making the surface of channels less permeable by means of lining. But reduction in losses in field can be achieved by suitable agricultural practices and efficient management, for which cooperation of the agriculturist is absolutely necessary in our country.

5·1. EVAPORATION LOSSES

Evaporation losses during irrigation by flooding are greater than during irrigation through furrows. The losses can be reduced by terminating the delivery of water as soon as practicable. Evaporation losses following irrigation can be reduced by cultivating as quickly as possible.

5·2. PERCOLATION LOSSES

They depend on depth of water applied to the fields, distance the water has to travel in reaching the lower end of the field, ground slope and soil texture throughout the root zones. Percolation losses are particularly objectionable on poorly drained lands, because they raise ground water-level consequently causing-water-logging.

Percolation losses in pervious soils may be reduced by providing properly planned system of field watercourses, by applying water in relatively shallow depth and in large streams to small plots, and carefully controlling irrigation deliveries. The watercourses should be laid out, so that water can be released to the land at different locations as needed and can reach all parts of the irrigation units without flowing long distances.

5·3. DEPTHS OF WATER

The depth of watering is determined by the fact that water is cut off, when the soil farthest removed from the point, where the water is turned on to the land, is seen to be wetted, or covered with water. Sometimes, as in Punjab, they give extra depth in a ploughing watering due to the fact that the agriculturist does not cut off the water until the clods have fallen in pieces through being soaked in water.

The depth of watering is, therefore, fixed principally by the time in which the whole area of each plot into which the field is divided is covered with water. During this period the portions of the plot nearest to the point where the water enters the field is covered with water, which is then absorbed by the soil. Thus the least depth of watering is secured when the field is divided into very small plots, each of which is rapidly covered with water. Finally, the smaller the individual plots, and the greater the rate of flow of the water, the smaller is the depth which is needed over and above the minimum requirements of the crops. The rate at which the water should be delivered and also the approximate size of the plot, can be investigated mathematically as per equation in para 2.5.

5·4. ECONOMICAL USE

We may assume plouging or other heavy waterings to be 0.33 ft. (10 cm.) and succeeding moderate waterings may be taken as 0·25 ft. (7·6 cm.). In careful irrigation on scientific lines, such depths can be reduced to 0·25 and 0·2 ft. (7·6 and 6·1 cm.) respectively whereas unscientific ways may require depths as much as 0.50 and 0.40 ft. (15.2 and 12.2 cm.) respectively and the waterings usually succeed each other at much closer intervals than a skilled irrigator finds requisite. Thus a careful irrigator can improve his irrigation efficiency by about 25 per cent.

In the past, the requirements of water were viewed from the practical point rather than from the scientific angle. But now when the cost of irrigation water has gone up so high and every drop of it is required for essential uses, the engineers must think about economical use of water.

It has been established that quantity and growth of most crops are not affected unless the moisture content falls to willing point and remains there for some days. It is also the experience in India that draught for a short period has little effect on ultimate yield. It is obvious that with copious supply there is likely to be most wastage. Therefore, some economy of water may be affected, if the supply each time is made smaller and is given at more frequent intervals than larger supply with longer intervals.

Much will, however, depend on the practical irrigator himself who is the best person to co-operate in field application of the results of experiments and scientific reasearch. He must be trained to adopt latest methods. It has been generally found that an ordinary cultivator uses fully 20 per cent more water than would be required to give the same outturn if water was applied with due regard to economy specially by dividing the fields into compartments. In careless irrigation, not only they waste water but tend to ruin the land by water-logging and appearance of alkaline salt.

6. Drainage of Sub-soil

The loss due to deep percolation into the sub-soil by gravity, is not useful to the plant, and is a waste, but it cannot be avoided altogether. It may, however, be kept within limits if the land is ploughed properly and over-irrigation is avoided.

In naturally well-drained soil, gravitational moisture is not of much importance, but such conditions hardly exist and excess gravitational water creates several problems, like water-logging, loss of plant nutrients, poor aeration, *etc., etc.,* and ultimately the soils themselves lose their capacity to support plant life. There is thus necessity of adequate drainage.

6.1. Artificial drainage produces a deep and well developed granulation of the soil. This allows of the ready penetration of water and also what is of the greatest importance in the case of fine grained soils, it provides a ready means of exit for the imprisoned air which is the greatest obstacle to the easy penetration of water into a fine grained soil. It likewise, allows for the quick removal of surplus water. With the exception of very sandy soils, all irrigated soils should be drained in order to get the best out of them and to maintain their fertility.

6.2. Attention is drawn to the systematic drainage of irrigation lands in other parts of the world, notably in U.S.A. where large irrigation schemes had been carried out by them. In India too as back as 1928, the Royal Commission of Agriculture has drawn attention to the fact that "Careful drainage survey which should include estimate for drainage construction, will in future, form an integral part of all new irrigation projects". It is high time that this aspect of drainage of soil, particularly in low-lying lands, should be given due attention from the very beginning of a canal project in order to improve the irrigation efficiency.

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Investigations on the Design of Furrow Irrigation System in Lateritic Soils of West Bengal

by

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Introduction

Furrow irrigation is a partial surface flooding method. The irrigation water does not cover the entire surface of the field. Rather, it is applied in small channels or furrows between the plant rows or beds. Water soaks into the soil along the furrows and spreads laterally to supply moisture to the roots of growing plants.

In planning an efficient irrigation system the following characteristics are of importance:—

(1) Intake rate of the soil, *i.e.*, infiltration rate;

(2) Length of run;

(3) Size of stream;

(4) Slope of the land;

(5) Furrow cross-section and spacing;

(6) Nature and magnitude of erosion.

The design aspects include proper selection of furrow cross-section, its spacing and length of run with respect to available size of stream slope, and type of crop.

The following objectives have been studied in field in laterite soil of District Midnapur, West Bengal:

(1) To study the factors affecting the design of furrow irrigation.

(2) To evaluate the relative water application efficiency for different combinations of discharge rate, length of slope and initial moisture content of the soil.

(3) To study the vertical distribution of moisture before and after irrigation.

Review of Literature

The time rate of advance of stream of various sizes has been analysed by Criddle[4]. In one experiment which was performed on a typical soil of uniform furrow slope, a stream of 2 gallons per minute in one furrow advanced very slowly after first 25 minutes. In 100 minutes, this stream flowed a distance of 225 ft. (68·6 m.) and, thereafter, the entire stream percolated into the soil of the 225 ft. (68·6 m.) length. The maximum allowable furrow stream of 5 gallons per minute equivalent to 90 furrows per cusec flowed a distance of about 620 ft. (189m.) in 2 hours. Furrows larger than 225 ft. (68·6 m.) length would not be used for streams of 2 gallons per minute or less, without sustaining excessive deep percolation

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losses and low water application efficiency. Likewise the results of other similar experiments revealed that with highly permeable soils, irrigation water must be applied in large streams to small length of furrows to prevent excessive deep percolation losses.

Herman Bower[5] presented an approach to determine depth of water absorbed under different periods of inundation as governed by the change of infiltration rate with time from a limited number of field experiments. However, the correct evaluation of the factors involved is extremely difficult. Recently, the method of numerical integration proposed by Hall[6] which was originally worked for border irrigation has been applied to furrow irrigation by some workers.

Israelson[7], Criddle[4], Fuhriman and Hansen[8] conducted experiments in Utah State and found that the application efficiency ranged from 18—58 per cent.

There does not seem to be much work done in evaluating the design factors of furrow irrigation in India.

Experimental Technique

The experiments have been performed on the Agricultural Engineering Department Farm, Indian Institute of Technology, Kharagpur, West Bengal. The soil in this region is classified as lateritic. The land was levelled uniformly with a tractor leveller. The experimental site has an average slope of 0·68 per cent from West to East. A plot of 400 ft. × 50 ft. (121·9 m. × 15·2 m.) was used for the experiment.

Experiments have been conducted on three different lengths of furrow—200, 300 and 400 ft. (61, 91·4 and 121·9 m.) and at two different infiltration rates of the soil with three sizes of the furrow stream. The number of replications in each case were two. All furrows made were 1½ ft. (0.5 m.) wide and 7 in. (17.8 cm.) deep. Equalisers were constructed to convey water into the furrows. Supply was obtained from over-head tank through a constant discharge device.

The following soil characteristics were studied: —

1. Soil Profile

0—2 in. (0—5·1 cm.) —	Light brown, sandy clay full of small roots.
5—7 in. (12·7—17·8 cm.) —	Lighter brown sandy clay with less of root population.
7—12 in. (17·8—30·5 cm.) —	Sandy clay.
12—20 in. (30·5—50·8 cm.) —	Light yellow, sandy clay with spare, light brown patches.
20—28 in. (50·8—71·1 cm.) —	Red patches, interspersed with white patches, no roots, increased moisture, sticky, coarser, iron concretion.

2. Texture

Coarse sand	33·51 per cent
Fine sand . . .	23·15 per cent
Silt	20·91 per cent
Clay	22·01 per cent

According to U.S. Bureau of Soils Triangular Classification chart this soil belongs to sandy clay Loam Group.

3. Apparent specific gravity	1·56
Real specific gravity	2·65
Porosity	41·2 per cent
Void ratio	0·7
4. Water holding capacity	39·6 per cent
Moisture equivalent	14·8 per cent

Infiltration tests were performed with three 12 in. (30·5 cm.) diameter single cylinder infiltrometers distributed randomly in the field. The infiltrometers were pushed 6 in. (15·2 cm.) below the soil surface and a constant head of 4 in. (10·2 cm.) was maintained. Readings were taken at 5, 10, 15, 30 and 60 minutes interval. Soil moisture samples for determining initial moisture content were taken before each infiltration test.

Soil moisture samples were also taken at distances of 0—10 ft., 90—100 ft., 190—200 ft. and 290—300 ft. (0—3 m., 27·4—30·5 m., 57·9—61 m. and 88·4—91·4 m.) along the furrow at depths of 0—1 in., 5—6 in., 23—24 in., 35—36 in. and 47—48 in. (0—2·5 cm., 12·7—15·2 cm., 58·4—61·0 cm., 88·9—91·4 cm. and 119·4—122·0 cm.) before and after each irrigation to study the moisture distribution.

The general procedure followed was:—

(1) Few trial experiments were performed to select suitable sizes of non-erosive stream which showed that a maximum size of 12 gallons per minute could be used. The three sizes of stream selected were 6 g.p.m., 10 g.p.m. and 12 g.p.m. The discharge was diverted to the equaliser from which it flowed into furrow through aluminium pipes.

(2) The time when water just started to flow in the furrow and when it reached every 10 ft. (3 m.) section were recorded by a stop watch.

(3) In the first set of experiments [200 ft. (61 m.) length] water supply to equaliser was stopped when 20 ft. (6·1 m.) more length was left to be wetted. In the second set of experiments [300 ft. (91.4 m.) length] water supply was stopped just when it reached the lower end. In the third set of experiments [400 ft. (121·9 m.) length] water supply was continued 5 minutes more after the water reached at the lower end.

(4) The time for recession for the entire length was also recorded after the supply was stopped.

(5) From the data obtained, an analysis was made to find the time of inundation, depth of water infiltered at different points along the furrow and percolation losses.

Results and Discussion

INFILTRATION

Two infiltration tests were performed, the first one on 3 May 1960 and the second one on 4 June 1960 before each irrigation trial. There was rainfall on 2 June 1960, due to which soil moisture content and infiltration were different on these two days. The plot of the cumulative infiltration and time on double log paper is shown in Figure 1 (*a* & *b*). The empirical equations relating cumulative infiltration with time has been found to be

$$I_c = 0\cdot2\ t^{0\cdot575} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and $$I_c = 0\cdot1\ t^{0\cdot654} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where $I_c =$ cumulative infiltration in in./hr.

and t = time in minutes.

Equation (1) is for the infiltration data obtained on 3 May 1960 and Equation (2) for the data obtained on 4 June 1960. The average moisture content up to 4 ft. (1·2 m.) depth was 6·95 per cent and 10·02 per cent in the first and second tests respectively, the difference being 3·07 per cent. However, the difference in moisture content of surface soil up to 1 ft. (0·3 m.) was 3·26 per cent which has more direct influence on absorption of water in the soil.

Differentiating Equations (1) and (2) with respect to time it gives

$$I = \frac{d\ I_c}{d\ t} = 0\cdot115\ t^{-0\cdot425} \quad . \quad . \quad . \quad . \quad (3)$$

and $$I = \frac{d\ I_c}{d\ t} = 0\cdot0654\ t^{-0\cdot346} \quad . \quad . \quad . \quad . \quad (4)$$

where I = instantaneous rate of infiltration

which shows higher rate of infiltration in the first case. At the end of 5 mts. the total depth of water infiltered was 0·48 and 0·28 in. (12·2 and 7·1 cm.) and the average rate of infiltration was 5·76 in. (14·7 cm.)/hr. and 3·36 in. (8·5 cm.)/hr. in the first and second tests respectively. However, the total depth of water infiltered at the end of 120 mts. was 3·1 and 2·29 in. (7·8 and 5·8 cm.) and the average rate of infiltration was 0·9 in. (2·3 cm.)/hr. and 0·86 in. (2·2 cm.)/hr. in the first and second tests respectively. It is interesting to note that even though the average of infiltration approaches approximately a constant value after 120 mts. there remains greater difference in the value of cumulative infiltration.

ADVANCE, RECESSION AND TIME OF INUNDATION

The observed values of advance, recession, time of inundation and the depth of water infiltered have been plotted for different combinations of variables (Figure 2 reproduced as sample).

With higher discharges, the surface head increases and the time required to cover a given length of furrow decreases. As the advancing front of surface stream moves along the furrow, the total amount of water infiltering into the soil increases, resulting in the decrease of advance rate. The time required to cover 400 ft. (121·9 m.) length of furrow for stream sizes 12 g.p.m., 10 g.p.m. and 6 g.p.m. is 54·50 mts. 81·16 mts. and 92.34 mts. respectively, which shows that besides slope of the land and infiltration characteristics of soil, the rate of advance is considerably affected by the quantity of water flowing per unit time into the furrow. The time to cover a distance of 100 ft. (30·5 m.) and 400 ft. (121·9 m.) lengths of furrow under identical conditions has been found to be 8·5 mts. and 54·50 mts. (Figure 2) from which it is evident that the rate of advance decreases appreciably with increase in the advance distance. A limit may reach beyond which the rate of advance will approach zero value.

The nature of the recession curve shows that it is function of slope of the land and the infiltration characteristics of the soil. Since the slope of the land was only 0·68 per cent the slope of the recession curve is not much in most cases.

Infiltration characteristics of the soil has considerable influence on the rate of advance also. It has been found that for the same values of discharge, length of furrow and slope of the land, and $Ic=0.2\ t^{0.575}$ the rate of advance was slower as compared to other trials where all the conditions were kept same except that $Ic=0.1\ t^{0.654}$. The total time required for a 12 g.p.m. stream size to cover a distance of 400 ft. (121·9 m.) was 54·50 mts. and 39·82 mts. in the first and second case respectively.

If t_1 is the time when the advancing water along the furrow reaches a point X_i and t_2 is the time when it recedes X_i measured from $t=0$ at $X=0$, then the time of inundation $t_0=t_2-t_1$. This time signifies the net time allowed for the water to infiltrate. In an ideal irrigation system, at each point along the furrow, the time of inundation should be same. However, this is practically never possible. It has been evident from analysis that in the case of 12 g.p.m., it is more uniform than 10 g.p.m. and 9 g.p.m. size of streams. This is due to the fact that if the advance rate is slow which is so in the case of smaller size streams, the inundation time is more at the head than at the tail of the furrow.

DEPTH OF WATER INFILTERED AND PER CENT PERCOLATION LOSS

Depth of water infiltered was calculated from the equations (1) $IC=0.2\ t^{0.575}$ and (2) $IC=0.1\ t^{0.654}$ where is the depth of water infiltered. Hence, t will be equal to the time of inundation t_1. The percolation loss was determined from the area of the depth of infiltered water curve, assuming 0·5 in., 0·75 in., 1·0 in., 1·25 in. and 1·5 in. (1·3 cm., 1·9 cm., 2·5 cm., 3·1 cm. and 3·8 cm.) of water required to fill the root zone and also the area not receiving sufficient amount of water being found out.

Referring to Figure 2 the area of the depth of water infiltered$=ABFE$.

Depth required to fill the root zone$=AC$.

Then $CDFE$ is the percolation loss.

Therefore, per cent percolation loss$=CDEF/ABFE \times 100$.

If the depth of water required to fill the root zone$=AH$, then area KFI is not getting any amount of water.

Therefore, the percentage of area not getting any amount of water$=KFI/ABFE \times 100$.

The values of per cent percolation loss and percentage area not irrigated for different depths of water application are plotted. It is observed from Figure 3 that the depth of water required to fill the root zone is limited to 1·5 in. (3·8 cm.), the percolation loss is 11·05 per cent in case of 12 g.p.m. (stream size) which is less in comparison to 10 g.p.m. and 6 g.p.m. where the percentage percolation loss has been found to be 26·1 and 30·0 respectively. But the area not receiving sufficient amount of water is less in the case of 10 g.p.m. and 6 g.p.m. than of 12 g.p.m. It is due to the fact that in case of 10 g.p.m. and 6 g.p.m. the depth of water infiltered at the beginning is more than the water infiltered at the end.

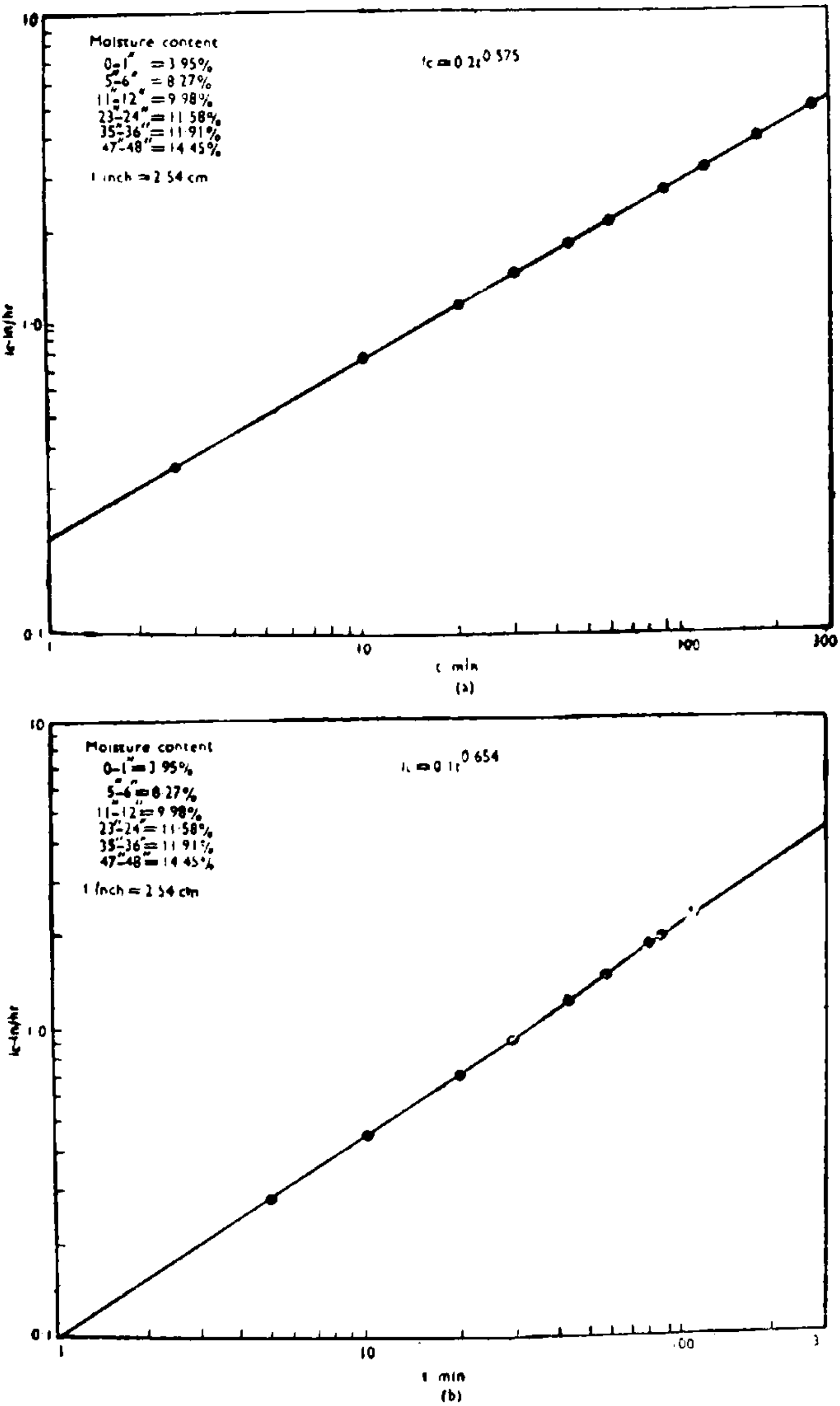

FIGURE 1 (*a* & *b*): *Cumulative infiltration.*

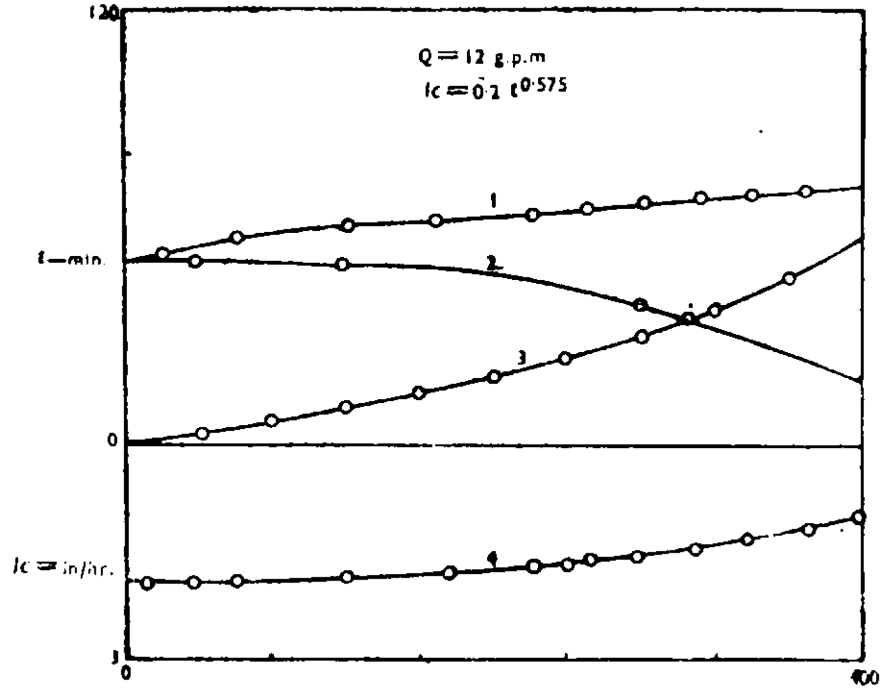

FIGURE 2: *Hydraulic characteristics.*

1. *Recession* 2. *Time of inundatian*
3. *Advance* 4. *Depth of water infiltered* (Sample Graph).

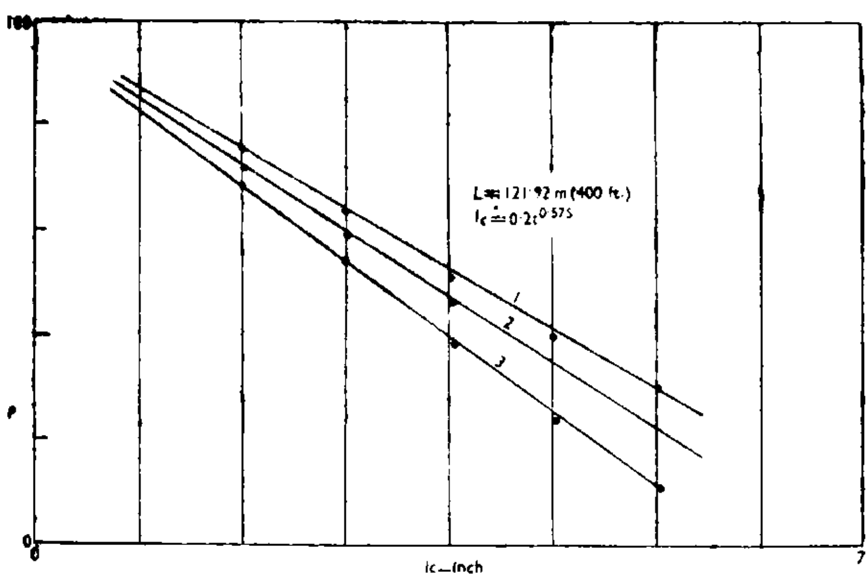

FIGURE 3: *Percentage percolation loss as function of depth of water required to fill the root zone.*

1. *6 g.p.m.* 2. *10 g.p.m.* 3. *12 g.p.m.* (Sample Graph).

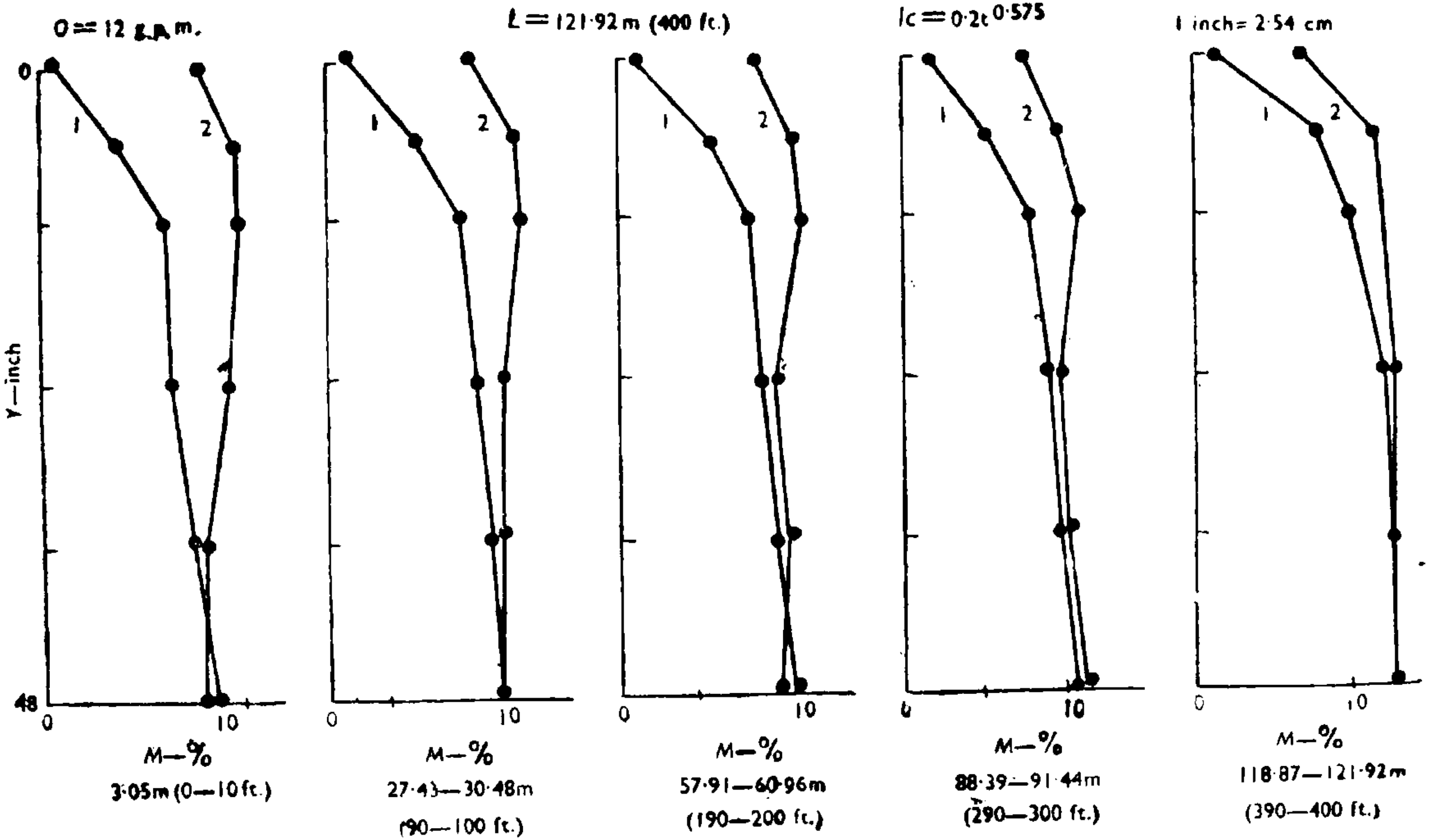

FIGURE 4: *Vertical distribution of moisture before and after irrigation.*

1. *Before irrigation.* 2. *After irrigation* (Sample Graph).

It is also seen that if the length of run is 300 ft. (91·4 m.) the depth of water to fill the root zone is limited by 1·25 in. (3·1 cm.) beyond which the area not receiving water increases. The percolation loss was found to be 11·6 per cent in case of 12 g.p.m. (stream size) which is less as compared to 10 g.p.m. and 6 g.p.m. But the non-irrigated area is more than the streams of 10 g.p.m. and 6 g.p.m.

In case of 200 ft. (61 m.) length of furrow a stream size of 12 g.p.m. caused 15·2 per cent percolation loss for the 0·75 in. (1·9 cm.) of water application which is less as compared to the stream sizes 10 g.p.m. and 6 g.p.m. respectively. But if the depth of water application is 1 in. (2·5 cm.) more than for 200 ft. (61 m.) length of run, 6 g.p.m. stream caused 13·4 per cent percolation loss and the area not receiving sufficient amount of water was 4·37 per cent.

From the analysis it is found that 17·5 per cent percolation loss occurred with a stream size of 10 g.p.m. in the 400 ft. (121·9 m.) length of run which is less in comparison to 6 g.p.m. stream. In the 300 ft. (91·4 m.) length of run, the percolation loss is 6 per cent for stream size of 12 g.p.m., if the water required to fill the root zone depth 0·75 in. (1·9 cm.) which is comparatively low as compared to streams of 10 g.p.m. and 6. g.p.m. But the depth of water to be applied when increased to 1 in. (2·5 cm.) the percolation loss is 7·55 per cent. This is due to the fact that the initial infiltration rate is low which has affected the rate of advance and recession.

MOISTURE DISTRIBUTION BEFORE AND AFTER THE IRRIGATION

The distribution of moisture is intimately related with the time of advance, time of recession, time of inundation and infiltration rate of the soil which are in turn related to the physical properties of the soil, slope of the furrow and size of the stream.

The variation of moisture content before and after irrigation was studied up to a depth of 48 in. (122 cm.) of soil at distances 0—10 ft., 90—100 ft., 190—200 ft., 390—400 ft. (0—3 m., 27·4—30·5 m., 57·9—61 m., and 118·9—121·9 m.), respectively.

Neglecting the variation in evaporation losses, it is observed that in case of experiments performed between 3 May and 16 June 1960, the depth up to which irrigation water has altered the moisture content has been 24 in. (61 cm.). However, there is larger increase in the moisture content in the first 6 in. (15·2 cm.) depth and it decreases slowly with depth.

Where ponding has been allowed, the effect of irrigation was observed up to a depth of 36 in. (91·4 cm.). In later case, the percentage increase in moisture content has been more at all depths up to 36 in. (91·4 cm.) with higher addition of moisture in the first 6 in. and 12 in. (15·2 cm. and 30·5 cm.) depth, gradually decreasing at lower depths.

The percentage increase in moisture content at different depths has also been found to vary along the furrow length (Figure 4) depending on the time of inundation of each point. It was seen that the percentage increase in moisture content just at the surface was 13·82 between distance 0—10 ft. (0—3 m.) as compared to 5·73 per cent at the surface between the distance 390—400 ft. (118·9—121·9 m.) along the furrow. The difference in addition of moisture is more than twice when L=400 ft. (121·9 m.), Q=12 g.p.m., $Ic = 0{\cdot}2 \; t^{0 \cdot 575}$ a comparison has been made keeping all the conditions same except Q which was 12 g.p.m. in one case and in the other 6 g.p.m. It was found that the percentage increase in moisture content between 0—12 in. (0—30·5 cm.) depths at different points along the furrow was more than when the discharge was less, the addition being 1½ times more in the case of the latter (6 g.p.m.).

After the rain, moisture content of the soil increased resulting in lower initial infiltration rate ponding was allowed in all the experiments performed after rains. Ponding tends to increase the moisture content at the lower ends of the furrow. A uniform moisture distribution can be obtained by ponding if it is done properly with a proper duration.

The length of run of the furrow has also an effect on moisture distribution. There has been higher moisture content at the upper and lower end of the furrow in the case of 400 ft. (121·9 m.) length and comparatively much less difference in distribution in the case of 300 ft. (91·4 m.).

Conclusions

The rate of advance increases with slope of the land, larger stream size, and lower infiltration rate. It decreases with increase in the length of run.

The rate of recession is influenced by infiltration rate of the soil and slope, there being decreasing its rate at higher infiltration rate value, and increase at higher slope.

The time of inundation decreases along the length of the furrow but it can be made uniform by controlling the size of the stream and allowing desired amount of ponding.

It is possible to obtain a suitable combination of discharge and length of run for a given soil of known infiltration rate and slope. This can be attained more successfully by trial than by the theoretical approaches of Israelson, Milne and Hall which do not agree with the field data. Higher sizes of streams and shorter length of run give better results. In the present investigations, stream sizes up to 12 g.p.m. did not cause erosion and gave best results.

In this country, laying out of the furrow and selection of the proper sizes of the stream and length of run is not considered necessary as a result of which the application efficiency is very low causing numerous drainage problem. It is stressed that furrow irrigation system should be designed properly, and suitable combination of hydraulic variables should be selected for maximum application efficiency. Further work on different soils having variable slopes is necessary to co-ordinate this work.

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DISCUSSIONS

Gulhati (N. D.) initiating the Symposium called upon the authors to briefly narrate the salient features of their papers.

Bhattacharya (A. P.) (*U.P.I.R.I.*) introducing the paper "Experimental and Empirical Studies on Water Requirements of Principal Crops of Uttar Pradesh" informed that experiments were conducted by the U.P. Irrigation Research Institute, Roorkee, on water requirements of crops, for aiding the cultivators in the efficient use of water. The paper gave the results of the experiments conducted on sugar-cane and wheat. There were no tangible results yet on experiments on rice.

Over-irrigation was very harmful, it was experimentally confirmed, and the excessive application was usually of the order of 30 to 40 per cent. Whenever water was available for irrigation, the cultivator always applied in excess of the optimum needs. Due to excessive application of water, the yield went down by nearly 20 per cent. This resulted in a net loss of income from crops which could otherwise accrue to the farmer. For example, the value of all the crops grown in U.P., during 1957-58, was Rs. 248 *crores*. Due to over-irrigation, yearly loss of about Rs. 40 *crores* was estimated to have accrued to the state. In the context of the problem of increased food production, proper management of water was necessary for meeting the food deficiency. The paper has also attempted empirical approach to the problem from climatological data, to check up experimental work and for application in other areas for which experimental data was not available. The Blaney-Criddle formula of U.S. Department of Agriculture has been found to give results very close to the experimental results.

Gupta (P.N.) (*U.P.I.R.I.*) introducing the paper "The Problems of Irrigated Land in Uttar Pradesh", pointed out that it attempted to bring out the problems of irrigated tracts such as the rise of water-table, water-logging and salt efflorescence and soil deterioration with loss of productivity, *etc.* If irrigation is practised extensively anywhere, and everywhere, without proper study of its limitations to the nature of soils, crop pattern, the quality of water, the quanity of water required for different crops, and the behaviour of ground water-table in view of the importance of surface and sub-surface drainage, it may lead to its ill-effects and may thus defeat the very purpose which it is meant to serve. In the State of Uttar Pradesh there were 12 million acres (4·86 million ha.) of irrigated land which is only about 30 per cent of the actual cultivated area. Yet a study of water-table levels during the last 40 years observed with the help of 2,000 surface wells, revealed a rise of water-table in several areas which in certain localised areas was even of the order of 50 ft. (15·2 m.). There were about 6 *lakh* acres (24·28 *lakh* ha.) of water-logged land in the country to which about 5 *lakh* acres (2·02 *lakh* ha.) were already contributed by U.P. The paper, therefore, emphasised on the inter-relation between irrigation and drainage, the economic use of water and the quality and quantity of water, and also suggested that before starting a new project, the planning of drainage facilities is necessary as now practised in the United States Bureau of Reclamation.

Jagat Kishore Jain (*Ministry of Food and Agriculture*) briefly summarised the points discussed in the papers by Sarvashri Shri Mohan and

Talwani, in the absence of the authors. The paper by Shri Mohan "Concepts in Irrigation Efficiency" tried to bring out the concepts of irrigation efficiency in various phases. The main objective of the paper was to point out whether there could be improvement in water uses, after its diversion at the source.

The paper "Efficiency of Water Distribution and Use on the Land", by Shri Talwani brought out the various aspects of the use of water after the canal outlets. The different methods of irrigation such as surface flood, furrow, sprinkler, *etc.,* were discussed along with their merits and demerits. Border strip method, with strips ranging in length from 200 to 800 ft. (61 to 244 m.) was discussed. The sizes of strips were correlated with the type of soil and discharge capacity. A table of strip spacing was furnished for three types of soils with discharges ranging from 1 to 4 cusec (0·03 to 0·11 cumec). The author also recommended that the size of the run in border strips and furrows should be kept to the minimum, so that there was no loss of water. Loss of irrigation waters which occurred in different phases of water conveyance and distribution, were also discussed. A concept of irrigation efficiency was given. Methods of improving irrigation efficiency were also pointed out.

Jaswant Singh (*I.I.T., Kharagpur*) introducing the paper "Investigations on the Design of Furrow Irrigation System in Lateritic Soils of West Bengal" carried out at Kharagpur, pointed out that in a country like India, surface irrigation was going to play a more important part than sprinkler irrigation. The main idea behind the studies on furrow irrigation was to attempt a correlation of all the variables involved in the design of furrow irrigation. The main variables involved were the infiltration rate of the soil, slope of the land, size of the stream and spacing and length of the furrow. In this direction, there were no conclusive results, so far, anywhere. Regarding the estimation of losses, and design of the dimensions, certain authors advocated a trial method under field conditions for evolving a design. The theoretical approaches usually gave results far from those obtained in practice. The author felt that it was possible to develop certain relationship between discharge, length of furrow, cross-section, infiltration rate, soil properties, and slope of the land for minimum percolation losses and maximum efficiency, by proper study. The losses due to percolation were not altogether avoidable but it was possible to reduce them to say up to 10 to 20 per cent by proper design.

Mukhtar Singh (*I.C.A.R.*) while offering comments on the paper by Shri Bhattacharya, referred to the methodology of experiments. Studies were conducted for finding water requirements of crops with different intervals of irrigation and different depths of water. It was recognised that there was an upper limit of water availability for most crops and a lower limit also. The water requirements of each crop could be studied separately, on the basis of the concept of water-regime. There was a great scope for a better system of irrigation and economic use of water. Referring to the climatological approach, he pointed out that the 70 per cent efficiency assumed by the author for the empirical assessment of irrigation requirements was purely arbitrary. The consumptive use was to be worked out by means of soil moisture studies and correlated with empirical formulae for working out the *K* (empirical coefficient). The value of coefficients so obtained could be extended to areas for which experimental results were not available. A correlation with climatological factors, without recourse to soil moisture data, was misleading.

Regarding the paper by Shri Gupta, Dr. Singh was in agreement with the stress on the need for drainage in relation to irrigation. It was to be ensured that the wastage of water was minimum. The drainage aspect had, therefore, to be taken care of.

Regarding the paper by Shri Mohan, Dr. Singh observed that some of the efficiencies included there mainly applied to sprinkler irrigation. Moreover, the field irrigation efficiency and farm irrigation efficiency could be separated out.

Referring to the paper by Shri Talwani, Dr. Singh said that evaporation losses were to some extent unavoidable. The evaporation losses following irrigation could perhaps be reduced by mulching to some extent and not by cultivation as suggested by the author. The author also recommended more doses of irrigation water at shorter intervals for economy. This was not correct. The depth of water required for irrigation was just the depth necessary to wet the soil in the root zone to field capacity. Therefore, no economy was possible if heavier irrigations were given at close intervals. He also felt that with most crops there should be no irrigation when the water-table was within 3 ft. (0·9 m.) of the soil surface, as indicated by recent experiments at the I.A.R.I.

Regarding the paper on "Furrow Irrigation", he pointed out that the Indian method of furrow irrigation was different from that followed in other countries. Optimum relationships were to be found out and ways of reducing seepage explored for Indian conditions.

Dr. Singh gave his view regarding the ways for the efficient use of irrigation water for crop production. Referring to the studies proposed for determining the water requirements of crops and reducing water wastage, he informed that studies were to be initiated under the Third Plan. Research Centres were proposed in Bhakra Nangal, Hirakud, Damodar Valley Corporation, Tungabhadra, and Chambal Project areas. Cropping patterns were to be indicated by these centres. These new centres proposed to engage specialists in different faculties, such as, agronomy, soil physics, soil chemistry, engineering, *etc*. The Planning Commission had also expressed the need to consolidate the earlier work in this line and laying down of procedure for the future. There were many centres in India doing similar work. And all the work was to be reviewed by the Indian Council of Agricultural Research.

Jagat Kishore Jain (*Ministry of Food & Agriculture*) stated that it was recognised that water management, irrigation and drainage practices in India were wasteful, and irrigation efficiency low. The situation called for improvement. The farmer had to be told to properly align his field channels and to line them by economic materials to reduce wastage of water. He was also to be told about the improved implements, and the need for levelling and preparing the field according to the characteristics of the soil available. The farmer had also to be educated about the water requirements of his crop and the depths to which irrigation was to be carried. There was some literature available on this subject. But it was worthwhile to test this under local conditions. There was also not much of research in our own country on this aspect. The research needed to be promoted and reorientated to suit our requirements.

Due to several reasons and socio-economic conditions, the irrigation rates were fixed on the crop area basis. The rates were not based on the volumetric assessment of water consumed by the farmer. The crop-area basis of fixing water rates gave no incentive to the cultivator for economy in the use of water.

RAO (Y. P.) (*I.M.D.*) commented on the meteorological aspects of the paper, submitted by Shri Bhattacharya. The paper showed the amount of evapo-transpiration about 2·7 in. (6·9 cm.) for February 1957 and 1958, while it was 3·42 in. (8·7 cm.) for the same month in 1960. This was a difference of some 25 per cent. With such a wide variation in the results, it was not possible to advise the cultivator about the precise water requirement of his crop for the particular month on the basis of climatic normals. The paper also did not take into account the difference in water requirements at various stages of crop growth. The water requirements during February, were usually double the amount of water required in the preceding two months. It was also not helpful to take the climatological factors for the whole month for deciding the water requirement. A part of the month was sometimes extremely dry, resulting in variations in evaporation by 30 per cent. More water was needed in parts of a month. As such it was difficult to specify to the farmer to use only that quantum of water which was worked out with the help of monthly figures. The author worked out with the help of monthly figures. The author had used the Penman's formula. The formula allowed only for meteorological conditions of transpiration. But transpiration was different at different stages of growth of the crop. Parts of the paper were, therefore, over-simplification of the problem.

The India Meteorological Department had conducted studies at Poona on the loss of water by evapo-transpiration from cropped fields during 1954-60. This was a I.C.A.R. Scheme which was later discontinued. Evaporation studies are being made at a number of stations in the country. The problem of transpiration required greater study. He hoped that the five stations proposed to be started by the Indian Council of Agricultural Research would be able to produce some useful results.

GUPTA (P. N.) (*U.P.I.R.I.*) referring to the paper by Shri Mohan, stated that in addition to all the efficiencies enumerated in the paper, the more important from the practical point of view was to educate the cultivator for the economic use of water or correct usage of water depth as most of the cultivators were still of the view that if the fields were flooded the yield will be more. This could be achieved by demonstrating the benefits of the correct usage of water depths to cultivators, and the same could be done by the Irrigation Engineers in conjunction with the Agricultural Officers and the Block Development Officers. Commenting on the paper by Shri Jaswant Singh on Furrow System of Irrigation, he pointed out that the design of furrows depended on two factors namely, the uncontrollable factors and the controllable factors. The infiltration rates, the soil characteristics, and the slope of the land come under the uncontrollable factors, whereas the spacing of the furrows, the length of furrows and the size of stream are the controllable factors. In heavy textured soils the contours of moisture progress widely in the lateral direction while in light textured soils the downward progress is quicker. The length of the furrows in light porous soil should thus be very short whereas in heavy textured soils long furrows could be adopted. The furrows, therefore, should be designed in a suitable way.

RADHAKRISHAN (*Madras*) referred to the problem of water distribution when there was both dry and wet crop under the same system. The

Parambikulam Aliyar Project, for instance, sought to irrigate 80 per cent dry and 20 per cent wet. It was proposed to provide one pipe point for every block of 75 acres (30·35 ha.). This area of 75 acres (30·35 ha.) was further divided into blocks of 12½ acres (5·06 ha.), comprising of 10 acres (4·05 ha.) dry and 2½ acres (1·01 ha.) wet. The dry land in each block was further split into parts of 3⅓ acres (1·35 ha). While supplying water to the 12½ acre (5·06 ha.) blocks on alternate days, the wet land got watering on every alternate day, whereas an acre (0·4 ha.) of dry land got a wetting once in 6 days. There were smaller land-holdings than 12½ acres (5·06 ha.) unit and the holder was anxious to have 1/5 of this land localised as wet. It was preferable to localise the wet portion in the topmost area of the unit so that the seepage from the wet land above was useful for wetting the dry land of the farmer, lower down. The Parambikulam Canal System was also proposed to be lined, down to the field channel of a 50 acres (20·23 ha.) limit.

Anand (D. B.) (*Maharashtra*) referred to the suggestion for formulating drainage schemes along with the preparation of irrigation projects. In Maharashtra, there was no need for preparing drainage schemes alongwith the irrigation project. It was also difficult to know how much drainage capacity was required while planning the canal. The crop pattern was also liable to change and conditions of water-logging changed it further. Drainage provision was usually necessary when there was perennial irrigation like sugar-cane and paddy. In Maharashtra, sugarcane was localised from the considerations of soil classification and drainability of soil. In dry crop areas, there was no water-logging problem. It was possible that localisation was not done in areas of Punjab and U.P. where large tracts of irrigated lands became water-logged. The problem of water-logging was greatly reduced by localising the *ayacut* on the basis of soil characteristics and drainage of the area.

The tagging of drainage scheme along with irrigation projects at the very beginning was likely to go wrong and involved extra expenditure at the very beginning of a project. In Parambikulam Project, the watercourses were planned to carry 0·3 cusec (0·008 cumec). It was better to give larger quantum of water to minimise the transmission losses. The discharge of watercourses in Maharashtra was between 3/4 to 1 cusec (0·02 to 0·03 cumec). Referring to the adoption of scientific methods of cultivation, he felt that it might take a long time at the moment. It was, therefore, desirable to stress on demonstration farms for educating the cultivator.

Sreeramasastry (A.) (*Andhra Pradesh*) referred to the recent Conference in Indian Council of Agricultural Research, where it was suggested that the crop pattern for a particular area should be of a rigid type. Once the canal was designed for a particular crop pattern a deviation in the pattern made the canal inefficient. To use waters in an efficient manner, it was also necessary to plan crops with the local conditions in view. For example, the Western *Ghat* catchments received their monsoon supplies in July and August, and a crop pattern of *Rabi* type in such area called for large storages involving huge evaporation losses. It was, therefore, advisable to pattern the crops on the run-of-the-river basis wherever possible. Regarding lining of watercourses, he was of the opinion, that lining was necessary only in areas of dry cultivation.

Chakravarty (R. B.) (*Ministry of Irrigation & Power*), said that there was neither the problem of alkalinity nor of water-logging in areas subjected to irrigation in West Bengal. Even in case of over-irrigation in

West Bengal no large scale salt formation was noticed. Survey in that State also revealed no traces of alkalinity in soils up to 20 to 30 ft. (6·1 to 9·1 m.) depth in irrigated areas.

The lower staff in Irrigation and Agricultural Departments felt that they were quite separate from each other. It was necessary to improve administrative machinery, improve agricultural practices, and undertake research. The Irrigation and Agricultural Departments were to be combined instead of Irrigation and Power. Certain findings of agricultural research workers were different from realities. Research workers, for example, felt that rice could not be grown without 36 to 56 in. (91·4 to 142·2 cm.) of water. But there were areas in West Bengal, where rice was grown with 15 in. (38·1 cm.) of water in winter. He also referred to a recent paper of the Institute of Civil Engineers, London, on the inter-relationship between water application and yield in irrigated areas. It is pointed out that the ratio of net weight of crop grown to the water utilised was a constant figure. Research could, therefore, be conducted on this basis. Experimentation with a different quantum of manure for different crops might also indicate properly the water requirements of crops.

GHOSH (S. K.) (*Bihar*) called for studies for making artificial rain for irrigation. Rainfall, which was the basis of all cultivation could be supplemented by artificial rain.

DODDIAH (D.) (*Mysore*) referred to the difficulties met with in enforcing a crop pattern after completion of a project. In the case of Krishnarajasagar, it was contemplated to grow paddy, sugar-cane and dry crops each on an area of 40 thousand acres (16·19 thousand ha.) in rotation. The dam was completed in 1931 but the development of irrigation naturally took some time. In the initial stages, the storage being more than the requirement of the smaller *ayacut*, there is a temptation to grow crops that require more water without following the restrictions imposed by approved crop pattern. Further the prevailing price structure of different crops influences the decision and desire of the *ryots* to grow such crops as pay him the maximum. With the interplay of these factors, the crop pattern tends to change in spite of restrictions.

Again in the case of Tungabhadra Project with a view to extending the benefit of irrigation to as large an area as possible certain crop pattern has been adopted. Even here, infringement of the sanctioned pattern is being noticed. It, therefore, requires a great deal of study in arriving at the crop pattern and imposing simultaneusly certain measures in the interest of over-all benefit and optimum utilisation of water rate from the beginning and follow them up.

BHATTACHARYA (A. P.) (*U.P.I.R.I.*) in his reply to the comments made by the various speakers informed that they would try to amplify their approach in the light of the suggestions for adopting the moisture-regime concept. He also concurred with the suggestion of Shri Y. P. Rao for calculating the evapo-transpiration losses on a daily basis.

GUPTA (P. N.) (*U.P.I.R.I.*) replying to the remarks on his paper stated that it was possible to anticipate the drainage while planning the project. It could be obtained by working out the values of the different factors involved in the balanced ground water equation which in other words involved a combined study of the hydrology of the area, the ground water storage, and the soil characteristics. In the end he further emphasized that the principal responsibility of the Irrigation Engineers associated with the planning of new projects was to anticipate drainage requirements and salinity problems on new projects, to ensure that the proper drainage facilities were provided and that the adequate financial provisions were made for their maintenance.

GULHATI (N. D.) in his concluding remarks said that it was necessary to ensure that planning of irrigated agriculture was on a permanent basis and necessary steps should be taken to this end. He added that the object of research and studies should be the maximum yield in crops that can be obtained from a given quantity of water and a given area. There were very large areas in this country fit for cultivation; in general there was more land than water.

Regarding the discussions at the Symposium, he felt, that the subject could not be covered properly in such a short time. It was a vast subject and required a much more detailed discussion. He suggested that the subject be broken into a number of component parts and each part discussed at one meeting.

THE PRESIDENT, SHRI U. ANANDA RAU proposed a vote of thanks to Shri Gulhati, for his able handling of the Symposium discussions.

30. Annual Report (Administrative) of the work of the Central Board of Irrigation, 1942-43. (*For the use of Board Members only*).

*31. Annual Report (Technical) of the work of the Central Board of Irrigation, 1943.

32. Annual Report (Administrative) of the work of the Central Board of Irrigation, 1943-44. (*For the use of Board Members only*).

*33. Annual Report (Technical) of the work of the Central Board of Irrigation, 1944.

34. Annual Report (Administrative) of the work of the Central Board of Irrigation, 1944-45. (*For the use of Board Members only*).

*35. Annual Report (Technical) of the work of the Central Board of Irrigation, 1945.

36. Role of Glaciers and Snow on the Hydrology of Punjab Rivers—by Shri Kanwar Sain, I.S.E.

37. Annual Report (Administrative) of the work of the Central Board of Irrigation, 1945-46. (*For the use of Board Members only*).

38. Annual Report (Technical) of the work of the Central Board of Irrigation, 1946.

39. Annual Report (Administrative) of the work of the Central Board of Irrigation, 1946-47. (*For the use of Board Members only*).

40. Annual Report (Technical) of the work of the Central Board of Irrigation, 1947.

41. Resolutions and Recommendations (Technical), 1931-1947.

42. Standards for Testing Soils.

43. Land Reclamation—Vol. I by Shri M. L. Mehta, Vol. II by Dr. R. C. Hoon and Vol. III by Dr. C. L. Dhawan.

44. Annual Report (Administrative) of the work of the Central Board of Irrigation, 1947-48. (*For the use of Board Members only*).

45. Central Board of Irrigation Library Manual.

46. Annual Report (Administrative) of the work of the Central Board of Irrigation, 1948-49 (*For the use of Board Members only*).

47. Annual Report (Technical) of the work of the Central Board of Irrigation, 1948.

*48. Data of High Dams in India.

49. Annual Report (Technical) of the work of the Central Board of Irrigation, 1949.

50. Annual Report (Technical) of the work of the Central Board of Irrigation, 1950.

51. Silting of Reservoirs—by Shri A. N. Khosla.

52. Annual Report (Technical) of the work of the Central Board of Irrigation and Power, 1951.

53. Symposium on "(*i*) Role of Models on the Evolution of Hydraulic Structures and (*ii*) Sedimentation of Reservoirs," 1952.

54. Symposium on "Determination of Costs and Benefits of River Valley Projects," 1953.

55. The Application of Electrical Analogy to the Design of Hydraulic Structures.

56. Annual Report (Technical) of the work of the Central Board of Irrigation and Power, 1952.

57. Annual Report (Technical) of the work of the Central Board of Irrigation and Power, 1953.

58. Investigation Manual for Storage Reservoirs.

59. Design of Siphons—by Prof. N. S. Govinda Rao.

*60. Manual of River Behaviour, Control and Training.

61. Symposium on "Nation-wide Survey of Irrigation and Power Projects for working out long-term programme of development" 1956.

62. Annual Report (Technical) of the work of the Central Board of Irrigation and Power, 1954.

63. Annual Report (Technical) of the work of the Central Board of Irrigation and Power, 1955.

64. Annual Report (Technical) of the work of the Central Board of Irrigation and Power, India, 1956.

65. Symposium on "Spillway Capacity of Dams", 1955-1956.

66. Annual Report (Technical) of the work of the Central Board of Irrigation and Power, 1957.

67. Catalogue of Books (Lib. & Inf. Bureau)—Vol. I.

68. Annual Report (Technical) of the work of the Central Board of Irrigation and Power, 1958.

69. Tube-well and Ground Water Resources.

70. Symposium on "Energy Dissipators".

71. Symposium on "Economic & Optimum Utilization of Irrigation Supplies—Parts I and II.

72. Symposium on "Inter-relation between Irrigation and Drainage".

73. Symposium on "Problems of Continuity of Supply and Voltage Regulation on Large Power Systems—Vol. I.

74. Symposium on "Tariffs and Financial Policies to be followed in the Electricity Supply Industry in India".

75. Annual Report (Technical) of the work of the Central Board of Irrigation and Power, 1959.

76. Development of Irrigation in India.

77. Administration and Financing of Irrigation Works in India—by Shri N. D. Gulhati.

78. Irrigation Research in India.

79. Sediment Control in Rivers and Canals.

80. Ganesh Iyer's Volute Siphons—by Prof. N. S. Govinda Rao.

81. Symposium on "Manufacture of Power Generating Equipment in India".

82. Symposium on "Canal Lining".

83. Annual Report (Technical) of the work of the Central Board of Irrigation and Power, 1962 (in Press).

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