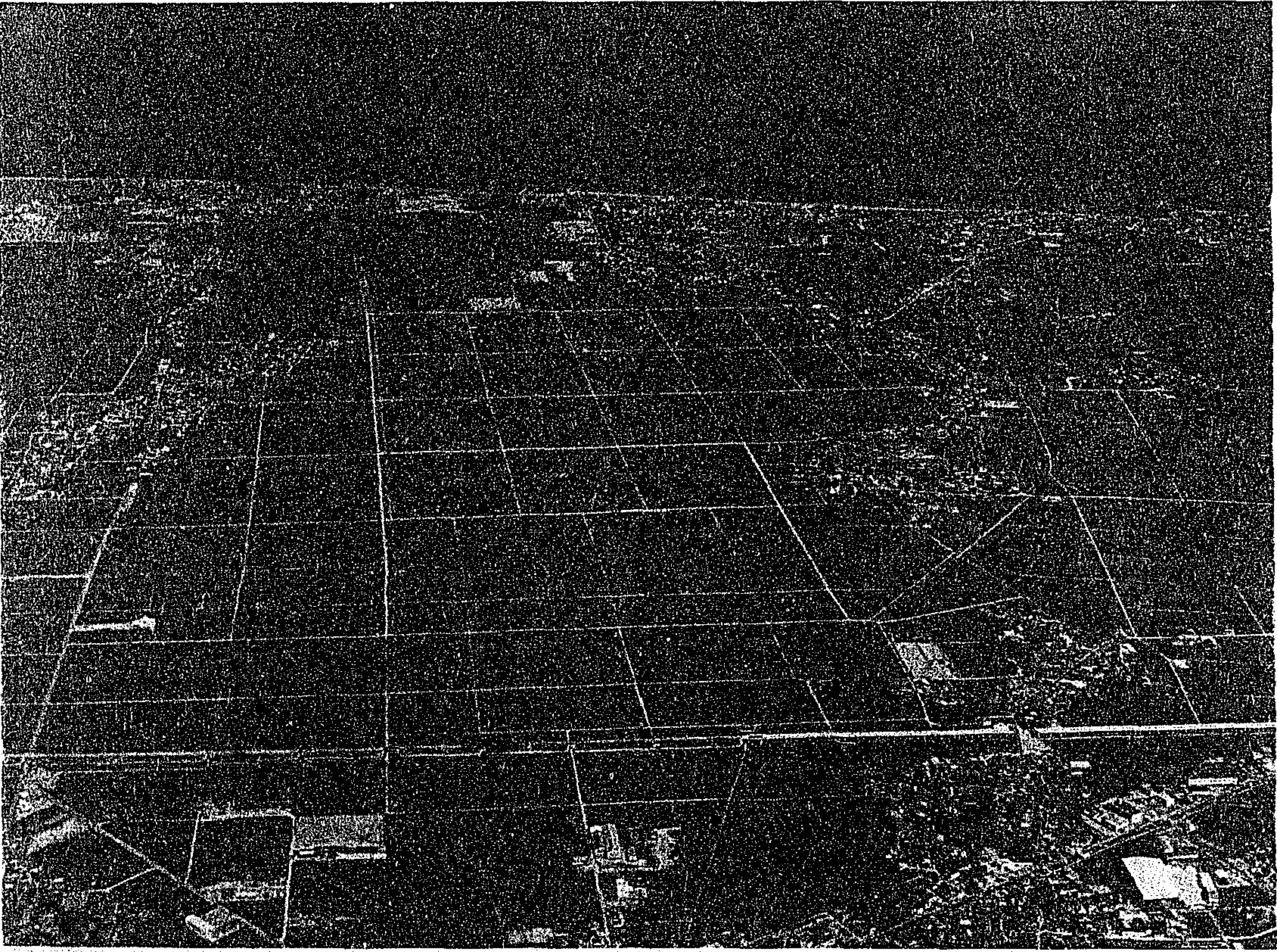
RICE IRRIGATION IN JAPAN



Overseas Technical Cooperation Agency (OTCA)

RICE IRRIGATION IN JAPAN

based on the work of

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Overseas Technical Cooperation Agency (OTCA)
Tokyo, 1973

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PREFACE

Among the main irrigated crops in the world such as wheat, rice, cotton and sugar cane, rice is somewhat peculiar in character because of the irrigation method used and the water management employed, especially terminal facilities. As is well known, rice is mostly cultivated in the monsoon area of Asia where, at present, there is an urgent need to increase the production of foodstuffs.

It was in 1968 that our paper "Rice Irrigation in Japan" was first published by the Food and Agriculture Organization of the United Nations (FAO) and since then much valuable work has been done in this line. The data and information contained in that publication required updating and supplementary information in respect to future work needed to be incorporated.

This second edition was reviewed and prepared in order to make the paper more graphic and impressive. We sincerely hope that this revised paper will help to promote better understanding of Japanese practices for paddy field irrigation.

Tokyo, December 1973, Hitoshi Fukuda
Rome, December 1973, Hikaru Tsutsui

CONTENTS

INTRODUCTION

Rice is the staple food of approximately half of the human race. For over 140 million people in the Far East, rice provides the main dietary source of energy. Ninety percent of the world's rice production 1/ 2/ is concentrated in the Far East, but there has been a remarkable expansion in the Western Hemisphere and it is rapidly increasing in importance in Africa.

Most of the major consuming countries are subject to rapid population growth while the productivity of rice still remains low. Although bright prospects have recently appeared on the horizon with the advent of high yielding varieties of rice, the so-called Green Revolution cannot take place in most of these countries until certain basic conditions are established. It has been realized that, among other things, a basic requirement for the successful cultivation of high yielding varieties is an assured and controlled water supply, that is to say, irrigation. The world's average paddy yield per hectare is slightly more than 2 000 kg, but the average in many of the major rice countries is lower. Experience has shown that in these countries a more stable and regular water supply is a prerequisite to any substantial increase in productivity or output, as average rice yields as well as the adoption rate of high yielding varieties correspond in the main with the irrigation ratio.

Japan ranks eighth 1/ 3/ in the world in total area of paddy field (2 923 000 ha) and fifth in total rice production 1/ 3/ (16 479 000 tons), but is the first in yield per unit area 1/ (5.64 tons/ha) among the major rice countries (cultivating more than 500 000 ha or producing more than 1 000 000 tons).

Some of the possible factors contributing to this high yield are Japan's climate and advanced cultural techniques, including complete adoption of high yielding varieties and correspondingly heavy fertilizer application. It must be noted, however, that an assured water supply and controlled water management at the farm level are the key to the introduction of advanced farming techniques and a heavier use of farm inputs. Nearly 100 percent of paddy fields in the country are equipped with irrigation and other water control facilities so that farmers can adopt improved farming techniques and use farm inputs without fear of drought or flood damage to crops.

This publication has been prepared in an attempt to introduce irrigation techniques widely practised in Japan to those engaged elsewhere in irrigation development and practices for rice. It does not include the detailed theoretical basis of techniques used and recent research not yet commonly known. It is hoped that rice cultivation through appropriate water control will be promoted by providing the people concerned with an opportunity to compare the features of rice irrigation in Japan with those of their own countries.

In preparing this publication, the authors have carefully reviewed the original FAO document "Rice Irrigation in Japan", published in 1968, and considerable modifications and improvements have been made, taking into account the comments given by readers. Furthermore, new chapters dealing with crop rotation and case studies have been added, and new tables, figures and photographs included.

1/ FAO Production Year Book 1970.

2/ Including China - estimated production 100 000 000 tons.

3/ Excluding China.

The authors wish to express their sincere gratitude to those who have given their assistance in the preparation of this paper by contributing material and giving advice and comments, especially Professor K. Tanabe of Kyushu University, Japan, Professor T. Cho of Tottori University, Japan, the late Professor Y. Fujioka of Kyoto University, Japan, Dr. N. Yamada, Director of the Tropical Agricultural Research Centre, Japan, Dr. S. Nakagawa of the National Institute of Agricultural Engineering, Japan and Dr. H. Matsuo of the FAO Regional Office for Asia and the Far East, Bangkok. Thanks for their assistance are also due to Mr. L. Booher of the University of California and Mr. M. Hagood of Washington State University, who worked as FAO Consultants when the original version was prepared.

1. GENERAL FEATURES OF RICE CULTIVATION AND IRRIGATION

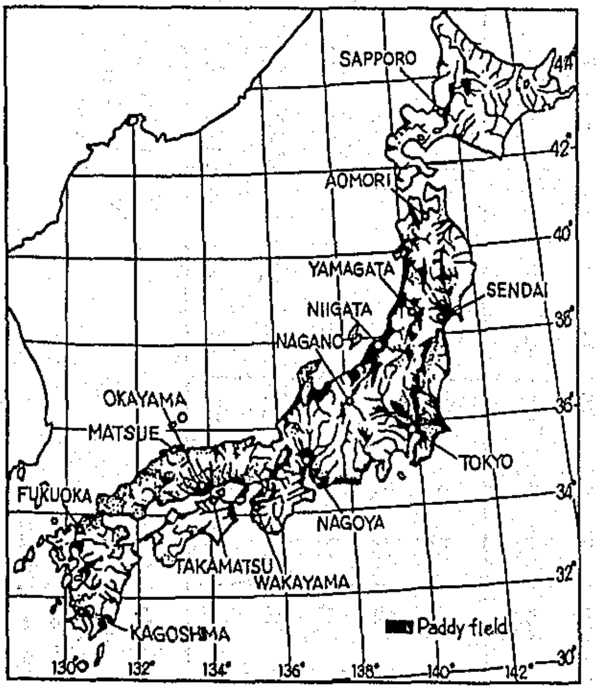
1.1 General setting and environmental conditions for rice cultivation

Japan consists of four large and many small islands, extending in a southeast direction for over 2 000 km. The total land area is about 370 000 km^2.

The North Sea Prefecture, officially known as Hokkaido, reaches 45°50' north and has a sub-frigid climate. The southern tip of the country, Kyushu, touches 30°27' north and has a subtropical climate. Due to a warm ocean current from the south, the country is warmer than places of the same latitude on the Asian Continent.

Japan is predominantly a mountainous country and the arable land comprises only 17.4 percent of the total area. This arable land includes some slopes greater than 15 degrees. The cultivated land is geologically divided into diluvial and alluvial soils; the former are situated mostly on slopes or hills which are utilized for the cultivation of upland crops, whilst the latter, mostly in the river bottoms are cultivated for rice. The total paddy field area is about 3 272 000 ha, distributed as shown in Fig. 1.

Fig. 1. Distribution of paddy fields



Although Japan's climatic and geographical conditions are complex, rice is cultivated throughout the country. In years of low air temperature the northern districts are threatened with cold damage, whilst southern districts often suffer from typhoons. Table 1.1 shows climatic conditions, including average air temperature, sunshine hours and rainfall during the rice growing period at representative locations.

Physical conditions of paddy fields are not uniform. Of the total paddy area, 3 million ha approximately, well drained fields occupy about 60 percent and poorly drained fields less than 20 percent. Paddy fields also differ with the locality. For example, peat, gley and volcanic ash soils are found mostly in the northern part, whilst grey soil and yellowish brown soil is distributed from the middle to the southern part of the country. Almost all the soils, except one in the sea polder, are acidic with some problems of alkalinity control.

Table 1.1 Average climatic conditions during the rice growing season

Items	Places 1/	April			May			June			July			August			September			October		
		2/E	M	L	E	M	L	E	M	L	E	M	L	E	M	L	E	M	L	E	M	L
Average air temperature (°C)	1	3.0	5.4	7.4	9.3	10.6	11.8	13.6	15.0	16.6	18.4	20.9	22.2	21.5	21.5	20.6	18.9	16.3	14.2	12.1	10.1	7.7
	2	10.5	12.7	11.8	15.6	14.9	17.8	18.1	19.7	20.9	23.0	24.6	25.6	26.0	25.8	25.4	24.3	22.2	19.8	17.9	16.2	14.4
	3	11.1	13.1	14.6	16.3	17.3	18.6	20.3	21.5	22.7	24.4	25.9	26.7	26.8	26.8	26.2	25.1	22.9	20.2	18.4	16.6	15.6
	4	10.9	12.9	14.5	16.1	17.3	18.8	20.3	21.7	22.9	24.5	26.2	27.1	27.2	27.1	26.5	25.3	22.5	20.5	18.5	16.5	14.8
	5	13.8	15.4	16.8	17.9	18.9	19.7	21.0	22.4	23.8	25.2	26.5	27.0	27.1	26.9	26.4	25.9	24.4	22.4	20.8	19.1	17.2
Total sunshine hours	1	63	67	66	69	64	70	67	66	65	59	61	68	69	64	66	52	53	58	56	51	53
	2	58	65	65	64	58	70	61	52	48	52	64	75	71	73	72	55	44	46	40	46	57
	3	65	69	66	66	70	82	62	59	53	60	70	85	77	82	83	65	53	52	51	58	65
	4	70	72	69	73	76	87	75	68	58	65	81	97	87	85	90	70	63	58	58	64	70
	5	58	58	55	59	63	63	56	43	40	54	71	89	78	76	82	70	64	59	58	65	68
Total rainfall (mm)	1	19	15	19	19	20	23	20	20	22	31	27	35	26	32	47	44	47	43	45	35	34
	2	49	41	43	46	50	50	50	58	64	55	37	49	46	42	57	56	82	85	88	64	52
	3	50	44	54	57	47	52	51	85	80	77	57	48	53	43	52	74	74	82	71	45	39
	4	29	30	40	37	31	33	42	51	67	68	35	36	26	28	40	44	55	49	41	32	24
	5	64	71	66	73	74	69	82	148	180	145	83	73	55	77	72	73	76	68	55	54	35

1/ 1. Sapporo - Hokkaido
2. Tokyo - Kanto
3. Nagoya - Tokai
4. Okayama - Sanyo
5. Kagoshima - Kyushu

2/ E = Early
M = Middle
L = Late

1.2 *Rice cropping seasons*

The rice growing season is usually from April to November, but it differs according to the region and the type of cultivation. For example, the season in Kyushu normally starts about one month earlier than in Hokkaido.

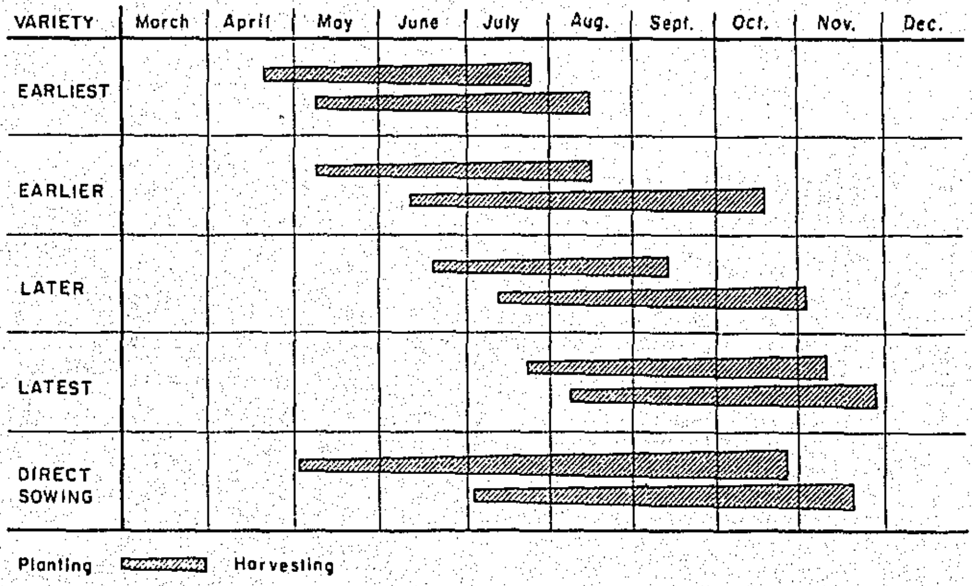
Recently there has been a tendency to plant rice earlier than the traditional practice. This early planting is intended to prevent cold damage during the ripening stage in the cool region and lessen damage from typhoons which frequently attack the warm region in August and September. In addition, it helps to reduce peak demands for labour and irrigation water if combined correctly with traditional growing methods. For most of the country this season is from March to September.

Attempts have also been made to grow rice later than the standard period with a view to introducing a third non-rice crop. This later period runs from July to November and the following crop rotations have been tried:

Wheat - Fodder - Rice
Wheat - Vegetables - Rice

Examples of seasonal variations are shown in Fig. 1.2.

Fig. 1.2 *Rice growing periods in Kanagawa Prefecture* 1/



1/ Land Development in Japan, Japanese National Committee of ICID 1963.

1.3 Factors contributing to high rice yield

For more than 2 000 years Japan has been called "the rice-growing land", and although rice is the most important crop in the country it is only since the 1860's that improved cultural practices have been used. Even in the 1890's paddy production averaged as little as 1.8 tons/ha, whereas today it averages 5.6 tons/ha.

The following factors have contributed significantly to this improvement in production.

1.3.1 Irrigation, drainage and flood control

The completion of flood control projects during the 1920's freed much of the land from flood damage, ensuring stabilized and intensive farming. Extensive work has been done on irrigation and drainage projects, coupled with flood control, which enables water to be supplied and drained at the right time, thus ensuring rational water management and giving the opportunity for intensive fertilizer application.

Rice nursery

From 1950 to 1959, irrigation and drainage works were carried out on 950 000 ha or about 19 percent of the total cultivated land. At present almost 100 percent of Japan's paddy fields are irrigated, although some of them still require considerable technical improvement. It should be noted that proper water management provided by irrigation and drainage projects is the key to the other factors contributing to high rice yield.

1.3.2 Variety improvement

Significant achievements have been accomplished in developing a large number of new high yielding varieties, far superior to traditional ones. Such new varieties are characterized by easier adaptability to heavy fertilizer application and higher resistance to blast and lodging. The success in breeding early maturing varieties resistant to blast and cold damage has contributed particularly to the yield increase in the cool northern regions.

Up to 1969 a total of 220 new varieties have been produced by the National Rice Breeding Institute. At present these new varieties are grown practically all over the country.

1.3.3 Early season culture

Early planting, mentioned under 1.2, is now widely practised. In 1949, in cold regions the use of nurseries was launched; they were covered with oiled paper - later this was replaced by vynil sheeting. This practice ensured the production of healthy seedlings and made transplanting possible 10-20 days earlier than by using the traditional way. With the development of new cold-resistant varieties, it contributed to significant yield increases of 15 to 25 percent. In 1962, this early planting culture covered about 1 000 000 ha, or about one-third of the total paddy area.

In warm regions the method of early season culture was initiated in 1950. It was applied to more than 400 000 ha and has proved its effectiveness in avoiding typhoon and drought damage and has resulted in a 20-30 percent yield increase in many instances.

1.3.4 Heavy fertilizer applications

Japan is noticed for its heavy applications of fertilizer in rice production. This is shown in Table 1.2.

Almost all rice varieties are highly responsive to applied fertilizer; however, some indica varieties grown in the tropics usually lodge under a high rate of N fertilizer application. In the past farmers selected varieties and farming practices suited to heavy doses of organic fertilizer, including manures and soyabean cake, but at present more than 400 kg of chemical N.P.K. is being applied per ha of paddy field.

Irrigation development has assured farmers of a water supply and enabled them to use abundant fertilizer without the fear of drought.

Table 1.2 Fertilizer consumption per hectare

Country	Nitrogen (N)	Phosphate (P_2O5)	Potash (K_2O)	Total N.P.K
Japan	160.09	123.04	123.15	406.28
Ceylon	31.39	3.79	25.25	60.35
India	6.15	1.45	0.92	8.52
Indonesia	13.00	3.86	0.71	17.57
Pakistan	11.28	1.76	0.88	13.92
Philippines	8.29	7.49	4.41	20.19
Korea	138.56	56.78	36.23	231.37
Ivory Coast	0.51	0.23	0.82	1.56
Madagascar	2.27	1.02	1.05	4.34
Nigeria	0.23	0.30	0.09	0.62
Italy	36.69	32.41	12.97	82.07
Spain	29.68	19.97	11.02	60.67
U.S.A.	38.35	23.49	20.75	82.59
Brazil	5.53	7.95	6.73	20.21
Colombia	10.76	10.97	9.51	31.24

Source: Annual Fertilizer Review 1970, FAO.

The continued use of plentiful chemical fertilizer, such as ammonium and superphosphate, for prolonged periods has, however, resulted in bottleneck growth or "Akiochi", and has jeopardized healthy crop growth in warm regions. Efforts were made, therefore, to determine the cause of this phenomenon by soil scientists and plant physiologists. It was found that using dressing soil containing iron, calcium, silicate, manganese, magnesium and the use of non-sulphate fertilizers or split application of nitrogen fertilizers, is the most effective method of improving "Akiochi" soil. The application of furnace slag, containing silicate, at the rate of 1-2 tons per ha resulted in a 10 percent average increase in production.

1.3.5 Disease and insect control

The introduction of DDT (dichlor diphenyltrichlorethane) and BHC (benzene hexachloride) as insecticides and the subsequent use of organic phosphorous compounds was very effective in controlling rice stem-borer and the introduction of organic mercurial compounds to control blast has been widely extended. The establishment of a disease and insect outbreak forecasting service, together with the development of power sprayers and dusters, and the performance of a cooperative control programme, have contributed to the control of disease and insects, using new chemicals, since 1955. The use of helicopters is now a popular practice.

1.3.6 Mechanization and weed control

Power and tractor-driven ploughs have replaced animals ensuring higher labour productivity. The total number of tractors was about 1.5 million in 1970 1/. The introduction of herbicides 2-4-D (2-4-dichlorophenoxyacetic acid) and MCP (2 methyl-4-chlorophenoxyacetic acid) has contributed to the control of broad-leaved weeds and the barnyard grass which emerge at the early stage of rice culture have been controlled by PCP (pentachlorophenol) resulting in great labour saving. At present, however, new chemicals, such as NIP (2.4-dichlorophenyl and nitro-phenylether) and DCPA (3-4-dichloro-proprionanilide) are being popularly used in place of PCP, which was found harmful to fish culture.

1.4 Land preparation for rice cultivation

1.4.1 Land levelling, grading and shaping

In order to facilitate water control and maintain a uniform depth, the field surface should be almost level with only a slight slope. This work is usually done by the farmer with his own equipment.

The shape and size of the plot will be determined by topographic conditions and by farm size. Where circumstances permit, a rectangular shape from 0.1 to 0.3 ha should be used. Plots in excess of 3 ha are preferable if large-scale machinery is to be used and in the Hachiro Lake Reclamation Area, for example, 60 ha plots have been constructed.

1.4.2 Puddling (harrowing with water)

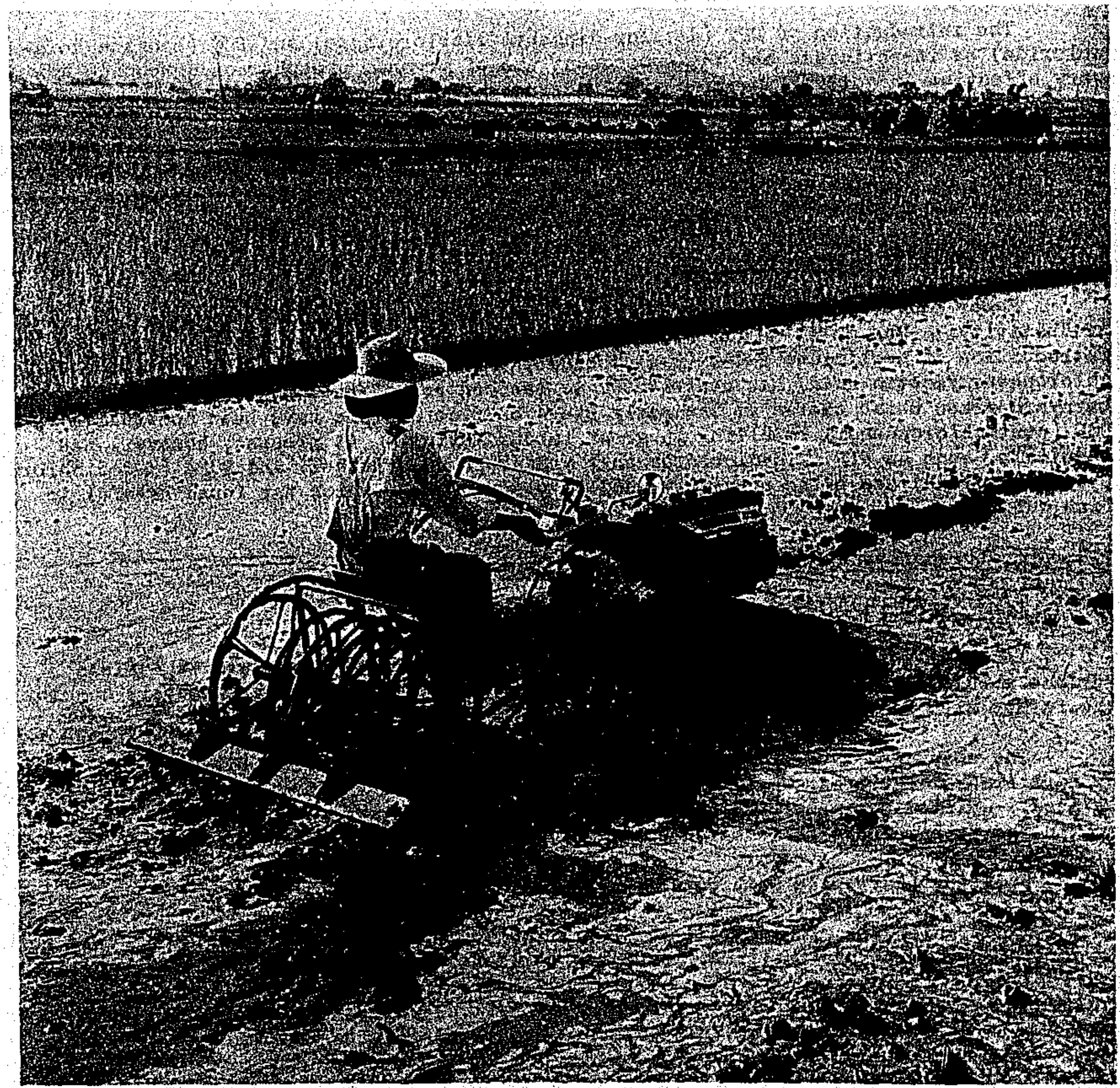
Paddy soils are ploughed and puddled prior to transplanting or sowing. This work is carried out for land levelling, loosening soils for transplanting, fertilizer mixing and weeding. It must be carefully carried out, especially where fields are subject to a high percolation rate, in order to form an impervious mud layer on the field surface to restrict percolation. Lack of this practice sometimes results in large water requirements due to excessive percolation.

1.4.3 Maintenance of border ridges

Where fields are not provided with permanent levees, ridges are reconstructed or coated with mud to prevent horizontal seepage loss and runoff. This work is carried out simultaneously with puddling. Concrete or plastic borders are now widely used to save labour and to reduce water losses.

1/ FAO Production Yearbook, 1970.

Puddling



1.5 Transplantation

The seed is sown in rice nurseries where the seedlings are grown very carefully for about 40 days before they are transplanted to the paddy field. This is common practice in most of the country and has the following advantages:

(i) Rice plants can be grown with less weeds, compared to the direct sowing method, provided that the seedlings are transplanted at the correct time to well puddled paddy fields.

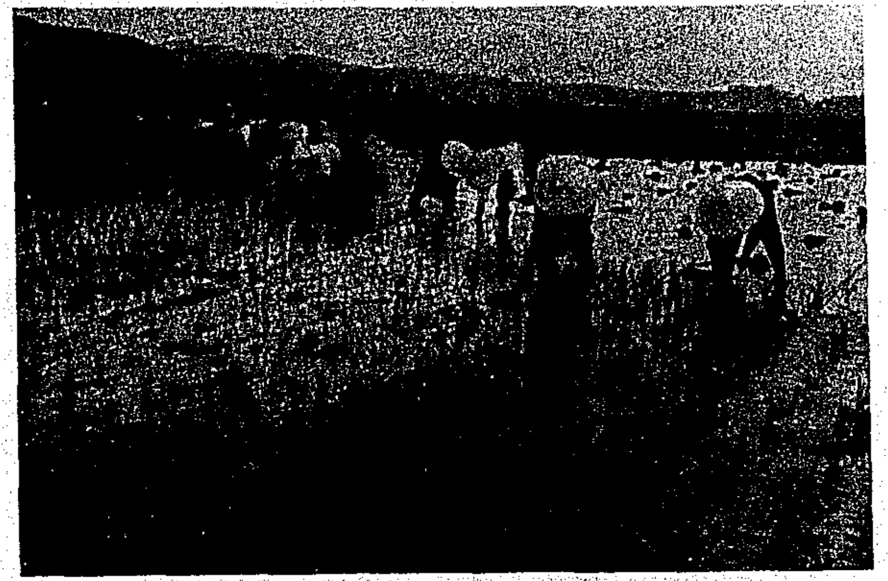
(ii) More uniform and healthy seedlings are produced since better care is provided by the farmers in the nurseries.

(iii) Bird damage can be decreased as seeds are grown under submergence.

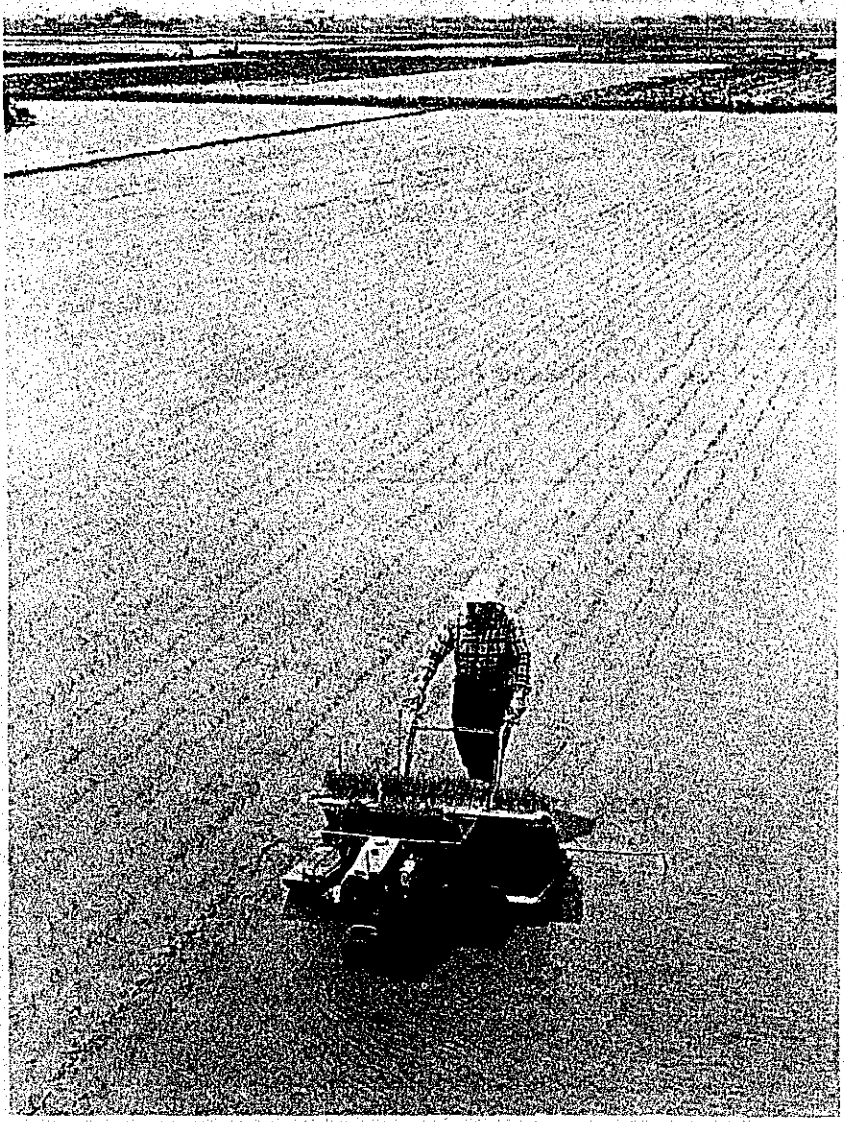
(iv) The duration for the cultivation of the second crop can be prolonged, since most paddy fields are kept free until transplanting.

(v) It safeguards against damage in the initial growing stage, since re-sowing is easily carried out in nurseries and importation of healthy seedlings from non-damaged areas is possible.

<u>Rice transplantation</u>



Rice transplantation



This method requires more labour than the direct sowing one, but in Japan rice planting machines are now widely used. In most of the other rice-growing countries this practice is successfully carried out where abundant or inexpensive labour is available and where there is intensive agriculture on relatively small areas.

1.6 Water resources and their development for irrigation

As annual precipitation averages 1 600 mm and the area of the country is 370 000 km^2, it is estimated that the total water available is about 590 x 10^9 m^3, whilst the total water consumed is about 75 x 10^9 m^3. This means that only 12.5 percent of precipitation is utilized. Water used for irrigation purposes forms the major part of 70 percent of total water consumption. This relation is shown in Table 1.3.

Table 1.3 Proportion of water used for different purposes (1965)

	m^3
Irrigation	46 x 10^9
Industry	21 x 10^9
City Water Supply	8 x 10^9
Total	75 x 10^9 m^3
Total annual precipitation	590 x 10^9 m^3

Source: Irrigation and Drainage in Japan 1972. Japanese Society of Irrigation Engineering.

Table 1.4 shows the areas irrigated by different water sources. There are many instances where certain fields are irrigated by more than two water sources.

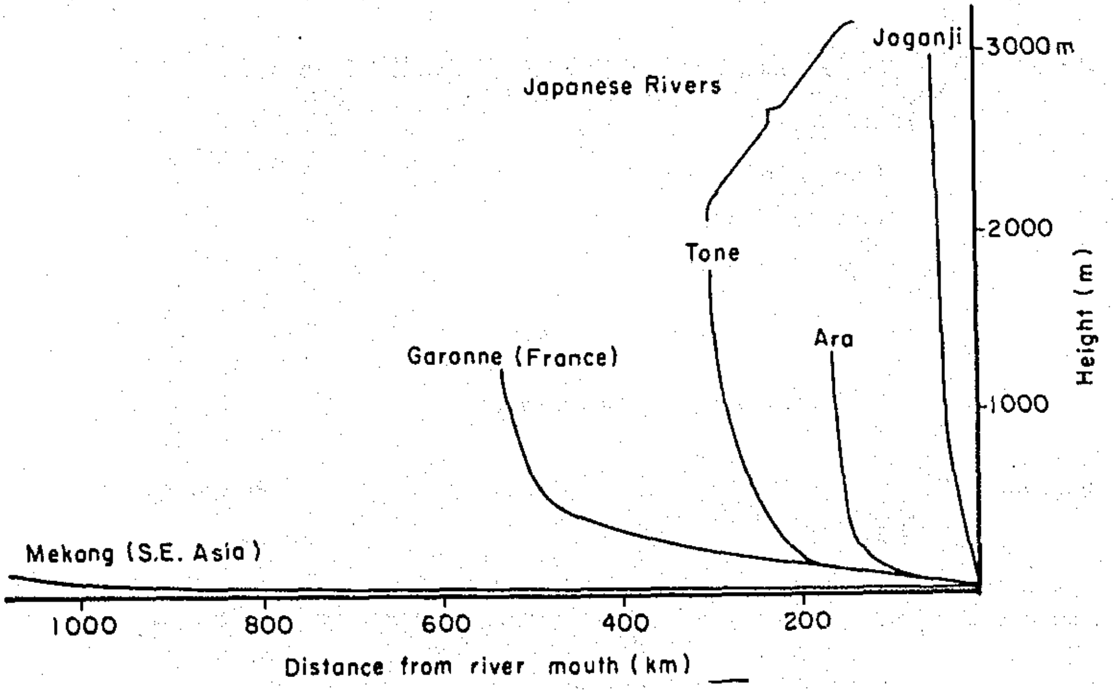
Table 1.4 Water source and irrigated area (1958)

Water sources	Irrigated area (10^3 ha)	%
River, lake	2 489	74
Reservoir	563	17
Groundwater	134	4
Others	164	5
Total	3 350	100

Source: Irrigation in Japan 1963. Japanese National Committee of ICID.

The country is favoured with abundant precipitation but its distribution is inadequate for maximum rice production. Rainfall during the rice growing period averages 600 mm, and may vary from 400 mm to 1 000 mm, while net water requirements for successful production of the standard variety of rice average about 1 200 mm. So normally rainfall can supply only 50 percent of the total net water requirements even when it is fully utilized, which is seldom the case. Due to the very steep slopes of the rivers, rainwater is rapidly runoff to the sea. The construction of reservoirs for water storage is therefore necessary and more than 300 000 dams have been constructed with a total storage capacity of 22 x 10^8 m^3. The gradient of rivers in Japan is shown in Fig. 1.4.

Fig. 1.4 Gradient of rivers



Source: Irrigation and Drainage in Japan, 1972. Japanese Society of Irrigation, Drainage and Reclamation Engineering.

1.7 Quality of irrigation water

1.7.1 Chemical composition of river water

The quality of irrigation water, especially the content of inorganic substances, influences crop growth. The quality of water differs greatly with the geological nature of the water sources and river basins and, therefore, the composition of the water varies from region to region.

The chemical composition of river water in various countries as measured by the analysis of 225 samples is shown in Table 1.5.

As can be seen from this table, river waters in Japan are characterized by: (i) abundant silica content as volcanic ash soils widely prevalent in the country contain abundant silicate; (ii) less Ca and CO_3 content as limestone is not widely distributed; and (iii) high nitrogen content compared with rivers in rice growing countries in Asia and the Far East as drainage water from paddy fields treated with abundant nitrogen fertilizer flows into rivers.

Table 1.5 Chemical compositions of river water (mg/l) (7)

Region	Ca	Mg	Na	K	CO_3	SO_4	Cl	NO_3	SiO_2	Fe	Total
Japan	8.8	1.9	6.7	1.2	15.2	10.6	5.8	1.15	19.0	0.17	70
Taiwan	43.6	12.4	13.9	1.8	71.1	63.1	6.4	0.09	10.0	0.01	222
Philippines	30.9	6.6	10.4	1.8	63.3	13.6	4.9	0.00	30.4	0.00	162
Cambodia	10.1	2.3	3.8	1.4	23.2	2.6	1.7	0.04	15.1	0.02	60
Thailand	19.8	3.7	10.7	2.5	40.7	3.3	12.7	0.35	16.0	0.04	110
Ceylon	7.0	2.1	3.7	1.4	18.3	0.8	2.9	0.07	13.1	0.01	49
W. Pakistan	36.0	5.5	6.5	3.1	60.9	18.9	3.4	0.20	7.8	0.00	142
Europe	31.1	5.6	5.4	1.7	47.0	24.0	6.9	3.7	7.5	0.80	133
N. America	21.0	5.0	9.0	1.4	33.0	20.0	8.0	1.0	9.0	0.16	107
Average for the entire world	15.0	4.1	6.3	2.3	28.3	11.2	7.8	1.0	13.1	0.67	90

1.7.2 Effects of chemical substances contained in the water

The quality of irrigation water affects the inorganic composition of rice plants. There is a close relationship between the silica content of rice straw and of water, as can be seen in Table 1.6.

It is estimated that if the silica content of irrigation water is 19.0 mg/l and 12 000 m^3 of water per ha is applied, 228 kg of silica will be supplied to one ha of paddy field.

A similar estimation can be made with other substances. For example, potassium (the content of which is usually related to that of silica) is found at the rate of 4.04 mg/l in the Shirakawa River in Kyushu and silicate at 23.5 mg/l. Therefore, one hectare of paddy field irrigated with this water can receive more than 60 kg of potassium, which is about the same amount of fertilizer being applied in other parts of the country.

In general, however, the nitrogen and phosphate content of most river waters is not appreciable (although these chemicals are present in a much higher degree in Japan than those in rivers in other rice growing countries in Asia and the Far East) except where city and industrial sewage flows into the rivers.

Table 1.6 Silica content of water and rice straw (7)

River system	Silica in river water mg/l	Silica in rice straw %
Average of 6 rivers in Oita Pref.	45.4	16.6
Average of 6 rivers in Fukuoka Pref.	24.8	13.4
Average of 3 rivers in Nagasaki Pref.	24.4	12.9
Tone-Arakawa River in Saitama Pref.	22.6	14.2
Average of 11 rivers in Shiga Pref.	12.4	10.6
Ibi River in Gifu Pref.	11.9	10.9

1.7.3 Suspended silt and clay

In addition to the inorganic nutrients mentioned previously, river water carries soil particles. The fact that the degraded "Akiochi" soil or permeable soils are usually distributed in the areas irrigated by rivers which originate in granite or liparite zones (i.e. the water carries little sediment) shows the importance of suspended clay in irrigation water. Muddy water supplied during or after flooding contains weathered products of basalt, andesite shale and the bottom mud of rivers and lakes. Soil importation or dressing is widely practised in fields consisting of permeable and degraded ("Akiochi") soils. Details of soil dressing techniques are discussed in the following chapter.

1.7.4 Salt content

Although rice is a salt-tolerant crop, its normal growth is hampered when the salt content reaches 0.1 - 0.2 percent and it dies with a salt content of 0.4 - 0.5 percent, especially during its early growth stage.

Various attempts have been made to keep salt content below 0.1 and 0.2 percent in the early and late growing stages respectively, by adding fresh water or constructing salt water intrusion barriers at tidal river mouths.

If water is subject to mineral or industrial pollution and fresh water cannot be brought from other sources, various practices to minimize the damage caused by such pollution can be carried out. A crop is greatly damaged when the acidity of the irrigation water increases and the pH becomes lower than 4.0. In such cases, neutralization should be carried out and among other methods, neutralization by limestone is widely practised.

2. WATER REQUIREMENTS AND THEIR DETERMINATION

2.1 General remarks

2.1.1 Definition

There are three factors to be considered in determining water requirements for submergence irrigation, which is the most popular irrigation method, namely evapotranspiration (ET), percolation and surface runoff. The latter can be disregarded as almost all paddy fields are surrounded by border ridges which restrict surface runoff. Percolation is the process by which water is absorbed into the soil or seeps through it to the underground water level or to the adjacent open water surface. In the transpiration process, percolation encourages water reaching the root system. In this publication, however, the term "percolation" signifies the amount of water penetrating into the soil, regardless of its direction, without being utilized for transpiration.

In formulating irrigation development projects, the amount of water needed for the project should first be determined. These water requirements include the field water requirement, the irrigation requirement and the amount of water needed at the head of the irrigation system, i.e. diversion requirement. The water requirement can be determined from climatic data, using an empirical formula, or from field experimental investigation. It is, however, hardly possible to give definite figures for amounts of water needed for crop growth from planting to harvesting as these differ greatly according to soil characteristics, crop growing period and the irrigation method. It is possible though to determine the relative amount of water required for rice crop growth by direct or indirect measurements if these are properly executed. When planning irrigation projects it should be noted that the water requirement for rice <u>crop growth</u> is not always the same as that for rice <u>cultivation</u>. In most cases the latter is much greater than the former. In this chapter field water requirements are discussed first, followed by the irrigation requirements and diversion requirements.

2.1.2 The indicating unit of water requirement

The usual practice is to indicate the water requirement by water depth (in most cases in terms of mm/day) as this unit is also used for rainfall and evapotranspiration. In some cases the water requirement is shown by the rate of water discharge (in most cases litres/second/ha), and the water volume needed to irrigate a unit area for a certain period (in most cases m^3 for a total irrigation period). The following equation and table illustrate the relationship between these units:

$$H = \frac{D \times B \times 86400 \times 100}{M} = 0.8\, D \times B \text{ cm} \qquad \text{........(1)}$$

where H = Water depth for B days

D = Water requirement (litres/sec/ha)

B = Irrigation period (days)

M = 1 ha = 10^8 cm^2

Table 2.1 Units of water requirement

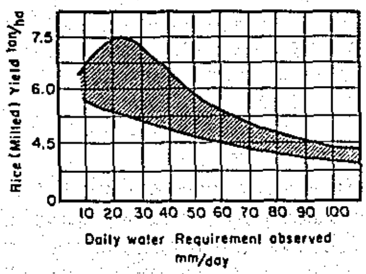
Litres/sec/ha	cm/day	M^3/day/ha
1.0	0.864	86.4
1.16	1.0	100.0

2.1.3 Average field water requirements in the country

Field water requirements in most parts of the country range from 10 to 20 mm daily which is equivalent to 1.16 - 2.31 l/sec/ha. This means that 1 m^3/sec of water can irrigate a field of 450 - 900 ha. Many experiments show that the average water requirement is 17 mm/day, which is greater than that in most tropical rice growing countries (where evaporation is considered to be much greater than in Japan). It should be noted, however, that more than half of Japan's paddy fields are located on rather high land with relatively pervious soils and that under heavy fertilizer application a certain degree of percolation may be required. The relation between soil fertility and percolation is discussed at some length in chapters 3 and 4.

Figure 2.1 illustrates the results of a recent investigation into the relation between rice yield and water requirements:

Fig. 2.1 Daily field water requirement and rice yield (9)



In view of the fact that evapotranspiration can be considered as almost constant throughout the country and that percolation often exceeds evapotranspiration, percolation is considered to be the governing factor in determining water requirements.

2.2 Evapotranspiration (ET)

2.2.1 ET vs. dry matter

The amount of water consumed in the production of one gramme of dry matter (excluding roots) is about 400 gm in a normal year and may reach 450-500 gm in a dry year. Such a relation is shown in Table 2.2.

Table 2.2 Water needed for producing one gramme of dry matter (3)

	Early variety	Medium variety	Late variety	Average
Nishigawara Agr. Exp. Sta.	392 gr	347 gr	395 gr	378 gr
Kyoto Univ.	398 gr	326 gr	417 gr	380 gr

Assuming that rice yield is 6.0 tons/ha, the total weight of air-dry matter is 14.0 tons/ha and the crop growing period is 110 days, the water needed for crop growth in a dry year is 14 x 450 = 6 300 tons/ha, which is equivalent to 630 mm in water depth or about 6 mm/day. This value is very close to the ET actually observed, which is shown in Table 2.3.

Table 2.3 Evapotranspiration actually observed (12.2)

Type of rice	ET from one stool (cm^3)	ET in mm
Early	33 000	640
Middle	29 900	540
Late	43 500	645

Remarks: A stool consists of three to five plants at the time of transplanting. This number increases to 14 or 15 plants at the ripening stage. The number of stools in an area of one ha averages as follows:

Early rice = 19 500 stools/ha
Middle rice = 18 000 stools/ha
Late rice = 15 000 stools/ha

2.2.2 Relationship between evaporation and transpiration

Transpiration varies greatly with the climate and crop growth stage and tends to increase as leaves grow. Under usual cultivation it is small immediately after transplanting, becomes larger towards tillering and reaches its peak at about the heading and flowering stages, then decreases gradually during the ripening stage. Evaporation varies with the climatological environment and the density of the leaves. The maximum is usually at the time of transplanting, but decreases with the growth of stalks and leaves which create shade in the fields. This relationship is illustrated in Fig. 2.2.

2.2.3 ET under different climatic conditions

ET varies greatly with climatic conditions. The following table shows this relationship:

Table 2.4 ET (mm) under different weather conditions (9)1/

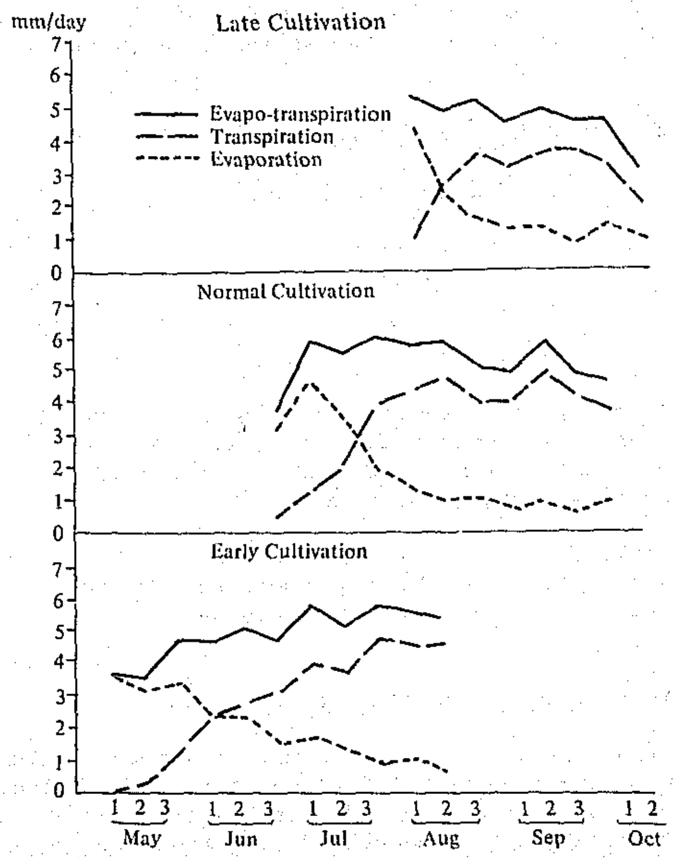
	Average2/	Sunny	Cloudy3/	Rainy
24 stools/m^2	5.1	7.5	4.8	2.9
16 stools/m^2	5.1	6.9	4.6	3.7

Remarks: 1/ Conducted by Saga Pref. Agr. Station.

2/ Average of 59 days consisting of 31 fine days, 15 cloudy days, 13 rainy days.

3/ Includes daily rainfall less than 5 mm.

Fig. 2.2 <u>Evaporation and transpiration</u> (9)



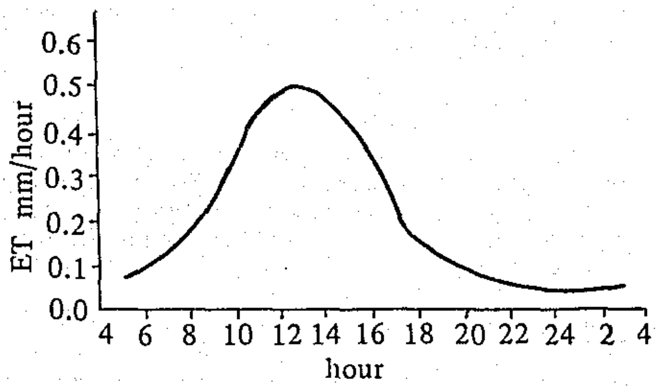
* Conducted in Shikoku Agri station

** 1, 2, 3, means 1st 10 days, 2nd 10 days and third 10 days respectively

2.2.4 Hourly change in ET

The hourly change in ET is shown in Fig. 2.3. As can be seen from it, about 80 percent of total ET occurs in the daytime from 8 a.m. to 6 p.m.

Fig. 2.3 Hourly change in ET (9) 1/2/



Remarks:

1/ Conducted at Hiratsuka Agr. Eng. Exp. Station, August 1958

2/ ET is 4.63 mm/day

2.2.5 Geographical variation in ET

The result of a countrywide investigation using lysimeters (a typical device is shown in Fig. 2.7) set in the middle of paddy fields is shown in Table 2.5.

Table 2.5 Actually measured ET in various localities (9) (ref. to Table 1.1)

mm/day

	June			July			August			September			October			Average
	E	M	L	E	M	L	E	M	L	E	M	L	E	M	L	
Hokkaido	3.4	4.9	4.1	4.3	5.0	5.2	5.9	4.4	4.3							4.6
Kanto			3.4	3.7	4.3	6.4	6.2	6.4	5.6	4.5	4.5	4.5				5.0
Tokai			3.8	4.4	3.5	-	5.3	7.1	5.5							4.9
Sanyo				4.1	5.0	7.0	6.7	6.6	6.3	4.9	4.4	4.7				5.5
Kyushu				3.7	5.9	6.1	6.0	6.5	6.3	5.1	5.4	5.1	5.0	4.8		5.4
Country-wide average	3.6	4.3	3.9	4.2	4.8	6.0	5.9	5.9	5.4	5.3	4.7	4.8	4.9	4.8		4.9

From Table 2.5, the following results are obtained:

- Average daily ET ranges from 3.4 - 7.1 mm.
- Peak ET occurs between late July and mid-August, and it appears that ET is influenced more by climatic conditions than by crop growing stage.
- Geographical variation in ET is very little. It is only 1-2 mm daily at the maximum.

- The standard daily ET in the country is 3.5 to 5.0 mm in June, 4.0 to 6.0 mm in early mid-July, 5.5 to 7.5 mm in late July to mid-August, 6.5 to 4.5 mm in late August to early September, and 5.5 to 4.0 mm after mid-September.
- Total ET during the whole irrigation period for 100 days is 440 to 550 mm, and about 500 mm on average.

2.2.6 Changes in ET due to different cultivation methods

Among the various cultivation methods, ET is affected by early or late season cultivation, direct sowing and water saving cultivation.

2.2.6.1 Early or late cultivation

As shown in Fig. 2.2 and the following Table 2.6, maximum ET is always observed from mid-July to early August, regardless of cultivation patterns. This confirms that ET is mainly influenced by climatic conditions. The total ET during the whole irrigation period (averaging 105, 100 and 80 days for early, normal and late cultivations respectively) is usually smaller in late than in early cultivation.

Table 2.6 ET under different cultivation methods (mm/day)1/ (9)

Cultivation	May			June			July			August			September			October		
	E	M	L	E	M	L	E	M	L	E	M	L	E	M	L	E	M	L
Early	3.6	3.5	4.8	4.8	5.2	4.7	5.8	5.1	5.8	5.6	5.3							
Normal						3.7	6.0	5.6	6.0	5.8	5.9	5.2	5.0	5.9	4.9	4.7		
Late									5.3	5.3	4.9	5.3	4.5	4.9	4.6	4.5	3.1	

1/ 1956-1959 at Shikoku Agr. Exp. Station.

2.2.6.2 Direct sowing vs. transplantation

There is no appreciable difference between ET under direct sowing and that under transplantation. As, however, the irrigation period for direct sowing on dry fields is 10 days shorter, and for direct sowing on wet fields 20 days longer, than for the transplanting method, total ET is smallest under direct sowing on dry fields and greatest under direct sowing on wet fields.

2.2.6.3 Water saving cultivation

Under intermittent submergence, ET tends to become smaller as evaporation from the soil surface during the non-submergence period (which is sometimes not saturated) is less than that from the standing water surface. Water requirements under different irrigation practices are discussed separately in Chapter 3 but the following table illustrates the point.

Table 2.7 Evapotranspiration under different water management (9)

	Deep water	Normal	Shallow water	Water saving
Total ET (mm)	387	394	378	345
ET/Ep	1.13	1.15	1.10	1.01

Remarks: Measured at Hiratsuka Agr. Exp. Station from 26 June to 19 September (85 days) - 1963.

2.2.7 Evapotranspiration (ET) and pan evaporation (Ep)

A recent countrywide investigation shows that ET/Ep varies from 0.9 to 1.7 (averaging 1.3) and tends to increase towards the late growing stage, showing the maximum value in September. The result of such an investigation is seen in Table 2.8.

Table 2.8 Evapotranspiration/pan evaporation (9)

	June	July	August	September	October
Hokkaido	1.1 - 1.3	1.3 - 1.4	1.4 - 1.6		
Kanto	1.3	1.3 - 1.5	1.4 - 1.5	1.7	
Tokai	0.8	1.0 - 1.2	1.2 - 1.6		
Sanyo		1.2 - 1.4	1.4 - 1.6	1.5 - 1.7	
Kyushu		1.0 - 1.1	1.2 - 1.4	1.4 - 1.6	1.5 - 1.4
Average	0.9 - 1.2	1.0 - 1.4	1.1 - 1.6	1.3 - 1.7	1.5 - 1.4

2.2.8 Measurement of evaporation

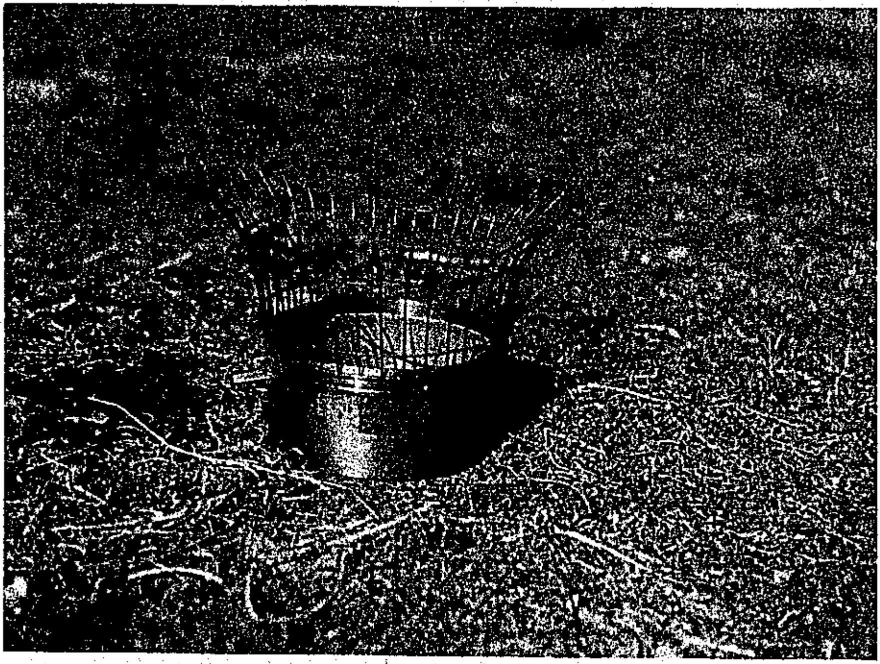
Climatic conditions are assumed to be similar within an area of 1 000 ha, and evapotranspiration is measured in every 1 000 to 2 000 ha.

2.2.8.1 Pan evaporation

A standard pan 1/ (20 cm diameter, 10 cm depth, tin-plated inside, standardized by the Japan Weather Bureau), which is illustrated in the following with 20 mm deep water, is set horizontally on a lawn without hazards, and measurements of water loss are taken at 24 hour intervals.

1/ In estimating evaporation from a large water surface such as a reservoir, a coefficient of 0.5 is used, but 0.7 is used in the United States Weather Bureau Pan (40 ft diameter, 10 in deep).

Standard evaporation pan

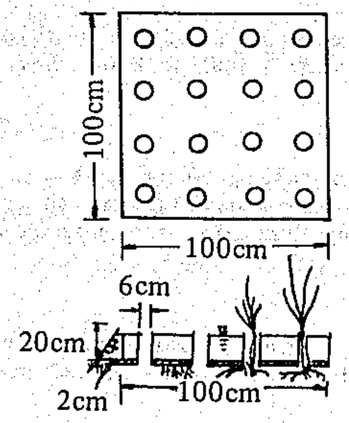


Evaporation value is commonly used to estimate crop water requirements. However, the value varies greatly with water surface conditions and the outcome of a survey may not be accurate. Nevertheless, using a pan is a practical method of measuring evaporation.

2.2.8.2 Field evaporation

The evaporation rate in a paddy field is usually measured using waterproof boxes as shown in Fig. 2.5. The water table is measured by a scale or hook gauge.

Fig. 2.5 Field evaporation measurement



In measuring evaporation, attention should be paid to the following points:

- The height of the waterproof box should not exceed 20 cm so as to eliminate any wall effect on micro-climate.
- The soil should be spread over the bottom at a depth of 2-3 cm.

2.2.8.3 Empirical approach (11)

Evaporation may be calculated from certain weather data when no actual evaporation data are available by using the following equation:

$$Ep = 0.8 + 1.18\,\frac{T.t.\sin\theta}{100} \qquad \ldots\ldots\ldots(2)$$

where Ep = mean daily pan evaporation in the given month (mm/day)

T = mean monthly air temperature in the given month ($^{\circ}F$)

t = mean daily sunshine hours in the given month

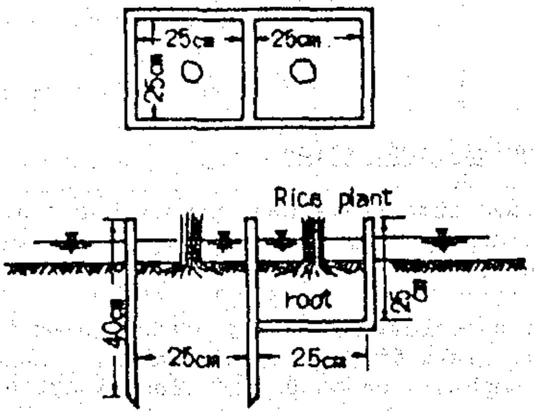
θ = mean monthly solar altitude

2.2.9 Measurement of evapotranspiration (lysimeters)

2.2.9.1 Traditional method

A set of wooden receptacles, as shown in Fig. 2.6, is traditionally employed and this method can also be used to measure percolation. Particular attention is paid to growing rice plants evenly in and outside the receptacle.

Fig. 2.6 Wooden receptacles for ET measurement

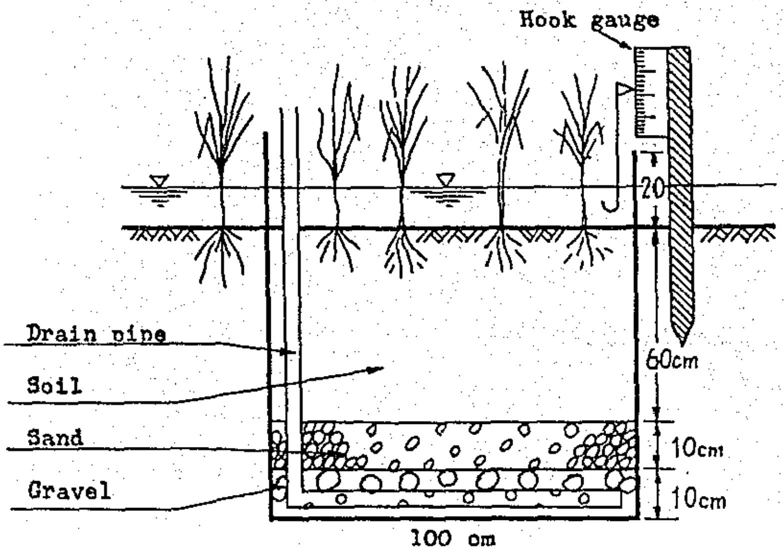


2.2.9.2 Modern method

A watertight box, as sketched in Fig. 2.7, is used, with care being given to the following points:

- The size of the box should not be smaller than 1 m^2.
- In order to provide the soil in the box with the same rate of percolation as in the actual field, water should occasionally be sucked up from the lower part and measured.
- The box should be set more than 1 m away from the border ridges.

Fig. 2.7 Evapotranspiration measuring box-lysimeter



2.3 Percolation

2.3.1 Vertical and horizontal percolation

Percolation is divided into two types, namely horizontal and vertical. Their percolation rates are governed by many factors, such as texture of soil, depth of top soil, groundwater level, etc.

Horizontal or levee percolation usually predominates in terraced paddy fields where the elevation of each field differs considerably. Some studies on horizontal percolation, with special emphasis on potential flow lines, show that horizontal percolation is 3 to 10 times greater than vertical. However, much of the water "lost" in horizontal percolation is available for reuse because it is either collected in the drainage ditches or flows into an adjacent field. It is estimated that actual losses from horizontal percolation average two to five times those of vertical. In principle, percolation should be determined by actual measurement.

2.3.2 Variation due to different soils

The average vertical percolation rate in various soils after careful puddling work in very fertile paddy fields consisting of more than 50 cm of top soil is shown in Table 2.9.

Table 2.9 Vertical percolation in mm/day (1)

Soil	Percolation
Sandy loam	3-6 mm
Loam	2-3 mm
Clay loam	1-2 mm

2.3.3 Governing factors

In general, percolation rates are governed by soil characteristics and hydraulic conditions. The former mostly refer to permeability which varies with soil texture and cracks and holes created by plant roots or small worms. The latter concerns the dynamic hydraulic gradient which is governed by the ground water table or water level of nearby canals. The relationship between these two factors is shown in Table 2.10.

Table 2.10 Classification of paddy fields in accordance with percolation elements (9)

Permeability Hydraulic head	$K>10^{-3}$	$K=10^{4\sim5}$	$K<10^{-6}$
Large-nearby surface water table is below 1.0 m	A	D	C
Medium-nearby surface water table between 0.3 - 1.0 m	B	E	H
Small-nearby surface water table 0 - 0.3 m	C	F	I

From the field survey conducted, B, D and E can be roughly classified as being suitable conditions, while F, H and I belong to the inferior category from the point of view of natural drainage.

2.3.4 Preliminary investigation for measurement

In most fields percolation accounts for the major part of the water requirement and the rate varies considerably with natural conditions. It is therefore a prerequisite that the various factors affecting percolation, such as soil, groundwater and topography should be investigated.

The following maps are usually prepared or made available for this purpose:

Topography: topographical survey maps, 1:50 000 or 1:25 000; 1:3 000 if needed.

Groundwater: water table map indicating the depth of groundwater.

Soil and stratification: soil profile map, showing the thickness of the top soil and the texture of the subsoil.

2.3.5 Measuring points and selection of test fields

2.3.5.1 Number of measuring points

As mentioned percolation rates vary according to soil and groundwater conditions. Grouping of lands and measuring points are, therefore, determined based upon soil and groundwater investigations, and in most cases, the rates shown in Table 2.11 apply.

Table 2.11 Number of measuring points

Irrigation block (ha)	Number of measuring points
0 - 20	3
20 - 40	4
40 - 60	5
60 - 80	6
80 - 100	7
100 - 150	8
150 - 200	9
200 - 250	10
250 - 300	11
300 - 350	12
400 - 500	13

2.3.5.2 Selection of test fields

Although the location of test fields varies with the percolation measuring method to be adopted, fields possessing the following conditions are usually selected:

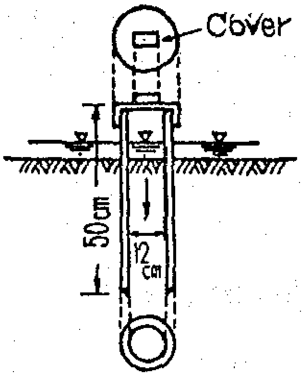
- Complete border ridges
- Characteristics typical of the locality
- Availability of water directly from irrigation ditches in a short time
- Existence of considerable hydraulic head (15-20 cm) between ditch and field surface.

2.3.6 Measurements (vertical percolation)

2.3.6.1 Cylinder method

As can be seen in Fig. 2.8, a pipe (iron or plastic) 10 to 15 cm in diameter and 50 cm long is driven into the ground and the depth of water in the pipe is measured. The pipe is covered with a cap to prevent evaporation.

Fig. 2.8 Cylinder



2.3.6.2 Quick method

Daily percolation rates (cm) can be obtained quickly using the instrument shown in Fig. 2.9 and the following equation:

$$P(\text{cm/day}) = \left(\frac{a}{A}\right) \times \left(\frac{2.3L}{t_2 - t_1}\right) \times \log\left(\frac{h_1 + L}{h_2 + L}\right) \times 86\,400 \qquad \text{........(3)}$$

where a = sectional area of glass pipe in cm^2

A = sectional area of metal cylinder in cm^2

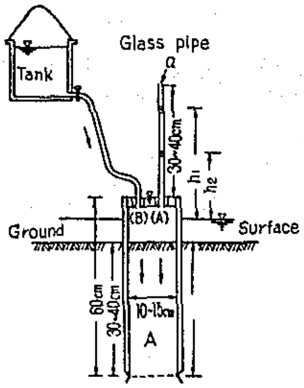
L = length of metal cylinder under soil surface (cm)

h_n = hydro-static head (cm) in the glass pipe at time t_n

Operation:

- Drive the metal cylinder into the ground to a depth of 30 - 40 cm.
- Fill the metal cylinder with water until it overflows.
- Close with a lid having a glass pipe and a rubber tube connected to a water tank.
- Let tank water flow into the metal cylinder through the entrance (B) until the water level in the glass pipe reaches its upper part (a).
- Stop water supply to the metal cylinder and measure the decrease in water level (cm) in the glass tube within a given time (seconds).

Fig. 2.9 Quick method

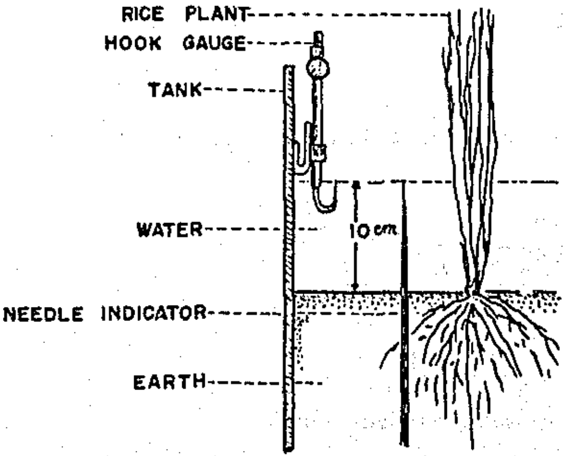


2.4 Direct field measurement of water requirements (evaporation plus percolation

2.4.1 Measurement of decreased water depth

The daily decrease in water depth should be measured, in principle, throughout the entire irrigation period. In some cases, however, water measurements are only made once or twice in every ten days. The water level is measured with a hook gauge or scale (see Fig. 2.10) once a day, usually at 9 a.m.

Fig. 2.10 Decreased water depth measurement



This measurement indicates the total water requirement, i.e. the sum of evapotranspiration and percolation (both horizontal and vertical). As the former is considered constant to some extent, and can be determined by various methods, the percolation rate can be obtained easily. This method is widely practised to determine the field water requirement.

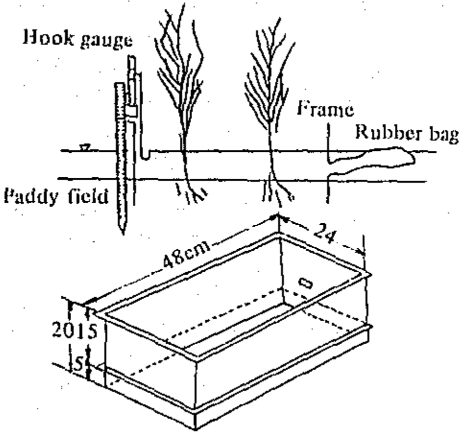
2.4.2 N-type lysimeter

2.4.2.1 Advantages of the device

In the past water requirements were usually determined by measuring the water level with a cylinder, pipe or box, which was placed in the soil. However, the disadvantages of this method, given below, often caused inaccurate results:

- Soil structure and plough pan are often disturbed when placing pipes in soils and the soil permeability could be affected.
- Subsurface flow may occur due to the difference in the watertable in and outside the pipe.
- If water is poured into the pipe after the soil has been dried for a considerable period, the percolation rate may be affected by air contained in the soil in the pipe.
- It is not easy to remove the pipe.

Fig. 2.11 N-type lysimeter



The N-type device shown in Fig. 2.11 was invented to overcome the problems mentioned above and gives accurate on-the-spot measurements of water requirements (percolation plus evapotranspiration).

2.4.2.2 Operation

This device is lightly inserted into the soil at a depth of about 5 cm. A rubber bag is attached to the wall to maintain equal water levels in and outside the device. The size of the device (box) is determined by the capacity of the rubber bag to control the water level; it has been demonstrated that two bags can regulate the water level within 2 cm for a 24 x 28 cm box. The sequence of operation is as follows:

- Insert the box into the soil and attach rubber bags.
- Raise the rubber bags so that the water in them can be poured into the box.
- Measure the water level in the box.
- After a certain period of time, usually 24 hours, raise the rubber bags again so that the water contained in them is poured into the box.
- Measure water level in the box.

2.4.2.3 Features of the device

- Water requirements (in depth) measured with this device exclude horizontal percolation (seepage through border ridges) which can be obtained by measuring the water requirements outside the device.
- Water requirements can be measured in the field when flowing irrigation takes place.
- The positional change of the percolation rate within a plot can be measured by moving the device to the required spot.

2.4.3 Discharge measurement

The total quantity of water irrigated is measured with Parshall flumes, weirs and orifices. This method is usually done in districts where flowing irrigation is practised and is used to determine the puddling water requirement. The flume for this purpose is designed to ensure the delivery of a constant quantity of water to the field through the orifice (constant hydraulic head is maintained) and the total quantity of water delivered to the field can be determined by knowing the duration of the irrigation time.

2.5 Hydrological balance (outflow-inflow) method

This method is applied to the field or to a group of fields on which surface inflow and outflow can be measured.

2.5.1 Plot water requirement

In a chosen plot the following relationship exists:

$$Is + Ig + R = ET + Pv + Ph + Os + S \qquad \text{.........(4)}$$

where Is = surface inflow-irrigation

Ig = subsurface inflow

R = rainfall

ET = evapotranspiration

Pv = vertical percolation (below top soil)

Ph = horizontal percolation (through the top soil and border ridges)

Os = surface outflow

S = storage in or on the soil

Is and Os can be measured with weirs or flumes. R is usually obtained from a nearby weather station. When measurements are made during the dry spell and the plot is already being irrigated with standing water, R can be ignored and S can be obtained by measuring the change in the watertable. The sum of ET, Pv and Ph is then obtained. Ph can be estimated by comparing the water loss of an untreated field with that of a field in which a metal, concrete or plastic barrier has been placed in the centre of the levee extending down to the impervious layer. In the absence of an impervious layer, a characteristic observed in heavy homogeneous soils, a barrier depth of 60 cm may be adequate. Pv can also be measured by using the method described under 2.4.2.3.

2.5.2 Project or area water requirements

The water requirements for a given area or irrigation system can be determined if the surface inflow and outflow in the area are measured. The terms in the following equation are either quantitatively defined, estimated or solved.

$$Is + Ig + R = ET + S + Os + Og \qquad \text{.........(5)}$$

where Is = surface inflow irrigation

Ig = subsurface inflow

R = rainfall

ET = evapotranspiration

S = storage in or on the soil

Os = surface outflow

Og = subsurface outflow

The water actually consumed ($\overline{W}$) in the area is therefore:

$$\overline{W} = ET + S - R + (Og - Ig) = Is - Os + R - S \quad \text{.........(6)}$$

The terms R, Is and Os are readily measurable as rain, river or canal, and drain flow respectively. S is measured from the depth of the static water table and soil porosity or from the depth of water on the soil surface.

Surface inflow and outflow are measured, in principle, on a daily basis. In the irrigation period during a dry spell, however, measurements are taken 3-5 times (3-5 days for each time). In most cases, water is measured with flumes or weirs that have water level recorders.

In the case of intensive measurement for a short period, R and S can be ignored and the following relation is obtained:

$$Is - O_s = Og - Ig + ET \quad \text{.........(5)}$$

The total water consumed in the area is the sum of evapotranspiration and groundwater increased or decreased. As part of the percolated water can be reutilized for irrigation purposes (while the rest flows out from the area), the following equation is established:

$$(O_g - Ig) = P_e - Pr \quad \text{.........(7)}$$

$$W = P_e - Pr + ET = D - Pr$$

where P_e = percolated water lost outside the area

P_r = percolated water being reused for irrigation purposes within the area

D = water requirement in depth in the fields

The water requirement for a large area, W, is usually smaller than the water requirement indicated by the decrease in water depth (the larger Pr, the smaller P_e - Pr, and W approaches D). In the lower stretches of the alluvial plains, where rice is usually cultivated, there is little groundwater movement and W is almost equal to ET which, in most cases, ranges from 5 to 10 mm/day.

In the upper part of an alluvial fan area or in terraced land, the greater part of percolation flows out from the area, and total water requirement, W, becomes greater than ET approaching D (this tendency is more noticeable if the area is smaller). In such a case consumed water ranges from 10 to 30 mm/day.

There are instances where O_g is smaller than I_g, usually where groundwater springs are present and cases where W is smaller than ET thus forming waterlogged or poorly drained land.

2.5.3 Relationship between the sum of plot water requirements and area water requirements

The relationship between the water requirement for a small area and that for a large area is very complicated and varies with topography, geography and hydrological features. However, the following tendencies are found:

(i) The rate of reusable groundwater varies with the size of the area being irrigated - the smaller the area, the lower the rate. The amount of water required for all the individual plots is equal to that required for an area smaller than 100 ha.

(ii) In areas (such as an alluvial fan) where most of the percolated water runs out from the area as subsurface flow, reusable groundwater should not be taken into account unless the area is larger than 1 000 ha.

(iii) In areas where no groundwater movement exists, the system of reutilizing drained or percolated water should be investigated in the first instance. It is therefore necessary to divide the area into smaller blocks in which a detailed hydrological study can be carried out and the hydrological relation of each block investigated.

2.6 Combined method

Although field measurement usually gives the most reliable result, this requires much time, labour and cost.

Since evapotranspiration can be calculated without serious difficulty or error from weather data (see previous section) the water requirement can sometimes be determined by actual measurement of percolation only.

2.7 Gross water requirements

2.7.1 Irrigation requirement and effective rainfall

The irrigation requirement is determined by deducting the effective rainfall from the net water requirement (discussed in the previous section).

2.7.1.1 Basic year for planning

An irrigation project is planned and designed on the basis of a drought year. In order to determine the amount of water to be supplied to a field and to design the irrigation systems, a basic year must be chosen. Precipitation data for the past 40-50 years should be carefully examined and a drought year which occurs once during a 15-20 year span is usually selected. If enough data are not available, rainfall in the basic year is estimated by a super-probability calculation or other statistical methods.

2.7.1.2 Irrigation requirement for a basic year

When the amount and distribution of rainfall in the basic year differ greatly from those in the year when actual measurement takes place, the irrigation requirement in the basic year is calculated in the following way:

$$Ir = \sum \left[(ET \times r) + P - Re\right] \qquad \ldots\ldots\ldots\ldots(8)$$

where Ir = irrigation requirement

ET = evapotranspiration actually observed

P = percolation

Re = effective rainfall in the basic year

$r = \dfrac{\text{pan evaporation in the standard planning year}}{\text{pan evaporation in the actually investigated year}}$

The investigation is carried out on a 10-day basis. Assuming that the total irrigation period is 110 days, the equation (8) becomes:

$$Ir = \sum_{n=1}^{n=11} \left[(ET \times r_n) + P_n - R_{en}\right] \qquad \ldots\ldots\ldots\ldots(9)$$

2.7.1.3 Effective (available) rainfall

Effective rainfall is the amount of rain falling and being utilized during the crop growing period to meet the water requirements. As crops are not able to utilize fully the total amount of rainfall available in the growing period, effective rainfall cannot be expressed in terms of total precipitation. In most cases 70-90 percent of the total rainfall during the irrigation season is assumed to be effective. Effective rainfall is calculated from the basic year as follows:

- Daily rainfall of more than 50-80 mm, depending upon the conditions, is considered as non-effective since this may overflow the border ridge of the paddy fields and cannot be stored in the fields.
- Daily rainfall of less than 5 mm is considered as non-effective. 1/

2.7.1.4 Maximum seasonal irrigation requirement

As water requirement varies with weather conditions and crop growth stages, daily net water requirement is not constant throughout the irrigation season. In order to determine the capacity of canal systems, the maximum irrigation requirement must be decided. This requirement occurs when evapotranspiration is highest, with no effective rainfall and this may be calculated as follows when the mean daily evapotranspiration is known:

$$RI_{max} = 1.7\ ET_{mean} + P_{mean} - R_{mean} \qquad \ldots\ldots\ldots(10)$$

where RI max = maximum seasonal irrigation requirement

ET mean = mean daily evapotranspiration

P mean = mean daily percolation

R mean = mean effective rainfall

1/ The authors, however, consider this effective.

2.7.1.5 Total irrigation requirements

It may be concluded that total irrigation requirements in Japan range from 550 mm to 1 500 mm, based upon the following:

Unit water requirement	10-20 mm/day
Puddling water requirement	150-200 mm
Irrigation period	90-100 days
Effective rainfall	500 mm

2.7.2 Puddling requirements

2.7.2.1 Puddling (Shirokaki) work

Transplanting is most popularly used in Japan's rice culture. Paddy fields are ploughed, harrowed and supplied with water in order to soften the soil for transplanting. Puddling by harrowing saturates paddy soil and makes it muddy, which, to some extent, prevents excessive percolation. Puddling work, customarily followed by transplanting, is carried out in the rainy season which usually prevails throughout June.

2.7.2.2 Puddling requirement

The quantity of puddling water can be determined by the soil depth to be saturated and the soil porosity. Puddling water varies from 100 to 300 mm in depth (1 000 - 2 000 m^3 per ha). Assuming that the thickness of top soil (which is to be saturated) is 30 cm, its porosity is 50 percent and submergence depth after puddling is 5 cm, the amount of water required for puddling is: (30 cm x 0.5) + 5 = 20 cm.

2.7.2.3 Maximum water requirement during the puddling period

Puddling usually requires a considerable amount of water varying from 100 m to 300 m. The maximum water requirement is during this period if there is no rainfall or the whole area is puddled within a very limited period of time. In practice, however, puddling is carried out over a considerable period ranging from 3 to 10 days depending upon the availability of water and labour. Generally, the peak demand for water occurs on the last day of the puddling period, if the daily puddling area and daily irrigation requirements are constant. The water requirement for the puddling period can be calculated as follows:

$$Wp = \left[As + Ad\ (n-1)/2 \right] \times 10\ (m^3) \qquad \ldots\ldots\ldots\ldots(11)$$

where Wp = water requirement during the puddling period

n = number of puddling days

s = puddling water depth (mm)

d = unit water requirement (mm) (evapotranspiration + percolation)

A = area to be puddled (ha)

Daily water requirement for the xth day is:

$$Wpx = \frac{A}{n} \left[s + (x - 1)d\right] \times 10 \text{ m}^3 \qquad \text{..........(12)}$$

Example:

n = 7 days; s = 200 mm; d = 15 mm/days; A = 2 100 ha

Total water requirement during the puddling period:

$$Wp = \left[2\ 100 \times 200 + 2\ 100 \times 15\ (7-1)/2\right] \times 10 = 5\ 145\ 000 \text{ m}^3$$

Daily water requirement on the 7th day which is considered to be the maximum:

$$Wp7 = \frac{2\ 100}{7} \left[200 + (7 - 1) \times 15\right] \times 10 = 870\ 000 \text{ m}^3\text{/day}$$

The maximum daily water requirement tends to increase as the duration of puddling work is being reduced by the introduction of agricultural machinery.

2.7.3 Diversion requirement

2.7.3.1 Conveyance losses

The diversion requirement is the sum of the irrigation requirement and the water losses in an irrigation system. Such losses include evaporation from the water surface, percolation from canals and operational losses. Among these components evaporation is negligibly small (5 percent of total loss) and further restriction is not practicable. Loss by percolation, which forms a major portion of conveyance losses, is greatly reduced by lining canals. Since most of the irrigation canals in the country are lined with concrete or stone, conveyance loss is relatively small, varying from 5 to 20 percent.

Canal lining techniques applied in Japan do not differ from those in other countries, so the subject is not discussed in this publication.

2.7.3.2 Determination of canal capacity under intermittent irrigation

As discussed later in Chapter 3, there are two major irrigation methods, namely the continuous method and the intermittent one. The former is the more popular where plentiful water supply is available, whilst the latter is applied in areas subject to water shortage or where the cost of water is relatively high. The continuous method usually requires less canal capacity than the intermittent one, which demands concentrated flow to the field within a limited time.

There are two basic patterns in intermittent irrigation. The first is when the whole area is irrigated intermittently and the second is when the whole area is divided into several blocks which receive water rotationally within a limited time. In the latter case, the canal capacity is decided by the following equation:

$$Q = \frac{M \times N \times A \times Dmax\ (1 + \alpha)}{T} \quad (m^3/sec) \qquad ....(13)$$

Q = canal capacity m^3/sec
where T = time needed for delivering water (seconds)
M = number of plots commanded by one canal
N = irrigation interval (days)
A = area of one plot (m^2)
α = water conveyance loss varying from 0.05 to 0.2
Dmax = maximum daily water requirement (m/day)

2.8 Some factors affecting water requirements

2.8.1 Soil

As already discussed, water requirements differ from place to place according to environmental conditions. Such difference is mainly due to soil and groundwater characteristics and drainage conditions which are the factors governing percolation. The following table, the results of which were obtained by experiment, shows this point:

Table 2.12 Soils and average net water requirement mm/day

Sand	27
Sandy loam	23
Loam	17
Clay loam	14
Clay	10

2.8.2 Water source and cost

Water requirements also vary with the irrigation method and operation of irrigation systems. These problems are discussed under a separate chapter. It should be noted, however, that the amount of irrigation water actually used differs greatly according to the source of the water and the cost; the higher the water cost and the smaller the available supply of water, the lower will be the amount of water consumed. This fact is illustrated in the following table:

Table 2.13 Average water used and type of water sources (3)

Water source	Number of surveys	Water required $m^3/sec/ha$	mm/day
Reservoir	103	0.00140	12.1
River	86	0.00295	25.5
Groundwater	12	0.00300	25.8
Pumped water	101	0.00129	11.6
Combined sources	6	0.00197	17.0
Total/average	308	0.00225	19.4

2.8.3 Water requirement for newly reclaimed fields

In newly reclaimed paddy fields, especially those in mountainous areas, the groundwater table is generally low while soil permeability is relatively high, thus causing a high rate of percolation. Percolation, however, decreases gradually year by year as the field matures with the development of an impervious soil layer (plough pan). Results of investigations in this regard are seen in Table 2.14.

Table 2.14 Change in percolation rates

Year after reclamation	Normal paddy field percolation rate 1.40-1.66 l/sec/ha	Pervious paddy field percolation rate 2.22-2.77 l/sec/ha
½	5.0 times	-
1	2.0 times	3.5 - 4.0 times
2	1.7 times	2.0 - 2.5 times
3	1.2 times	1.5 - 1.7 times
4	1.0 times	1.3 - 1.5 times
5	1.0 times	1.2 times
6	1.0 times	1.0 times

It can be said that percolation rates will be reduced to 1/3 - 1/5 within a few years of the paddy fields having been reclaimed. Particular attention should be paid to this phenomenon when estimating water requirements and determining the capacity of water delivering systems. Irrigation requirements in newly reclaimed paddy fields should not be over-estimated and land under irrigation should be extended systematically in order to utilize fully the limited water resources, avoiding the construction of irrigation systems with an excessive capacity when the fields reach maturity.

The same conception is applicable to paddy fields reclaimed from tidal land, as abundant water will be required during the first few years to leach excessive salt. 1/

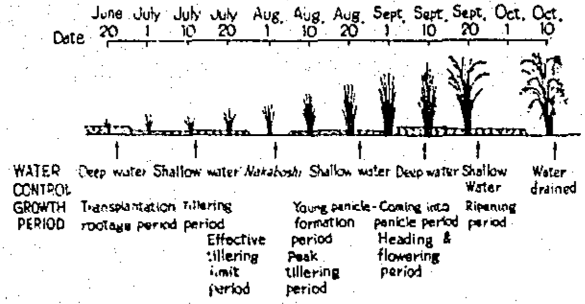
1/ The usual practice is to submerge fields to a depth of 4-6 cm every three out of four days and then drain.

3. WATER MANAGEMENT AND REQUIREMENTS UNDER DIFFERENT IRRIGATION METHODS

3.1 Life history of the rice plant

In general, the life span of a rice plant is 120 to 180 days, which can be divided into two periods - vegetative and generative growth. The most salient feature of the former is the increase in the number of tillers, whilst the latter is characterized by the formation and growth of the panicle. The life history of a rice plant in relation to water management under the usual cultivation practice in warm regions is shown in Fig. 3.1.

Fig. 3.1 Water management and crop growth stages (2)



3.1.1 Vegetative growth period

This period is divided into two stages, namely the nursery and tillering. The latter is divided into rooting, valid tillering and invalid tillering. The rooting stage usually lasts for several days after transplanting and when the plant has rooted, many tillers develop rapidly. At the next stage the number of tillers reaches the maximum, but those developed after this valid tillering stage cannot bear panicles; thus, this last stage is called the invalid tillering stage.

3.1.2 Reproductive growth stage

During this period the young panicle develops, heads and ripens. The development stage can be divided into two: formation and booting. When the young panicle develops at the lower part of the valid tillers, there is a swelling in that portion; this is called the booting stage, which is followed by heading (ear shooting) and flowering. Ripening is the last period, consisting of milky, dough, yellow ripe and full ripe stages.

3.2 Water needs and management under different growing stages

3.2.1 Transplanting and rooting period

In order to secure healthy growth of transplanted seedlings and to avoid wind damage, water is kept at a considerable depth (i.e. 10 cm) for a period of about a week after transplanting.

3.2.2 Tillering period

In order to keep the soil temperature warm, water is kept as shallow as possible (3-5 cm). In view of the fact that the respiration function of the root is at its maximum during this period, the introduction of air into the soil following drainage gives favourable conditions for root growth. During the invalid tillering period the rice plant can resist a water shortage and mid-season drainage (Nakaboshi) is usually practised.

3.2.3 Nakaboshi (mid-season drainage)

Fields are drained for a period of about 3 to 7 days, 30 to 40 days before heading. The object of this practice is:

(i) To supply soils with oxygen to ensure healthy root growth.

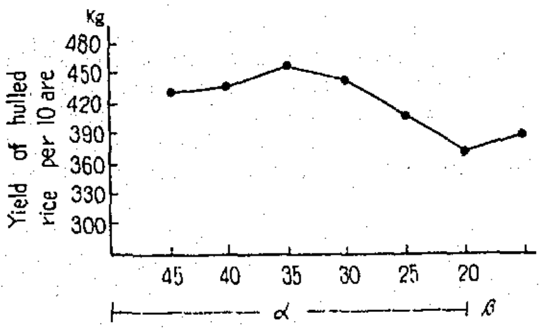
(ii) To remove hydrogen sulphide and other harmful substances which are produced by microbial action under reductive conditions of submergence.

(iii) To cut off the excess supply of ammonia-N and to renew it after irrigating to induce favourable ear formation conditions.

(iv) To harden soils for the coming farm operations, including harvesting, and to prevent lodging.

It should be noted, however, that this practice is only successfully carried out when soils are impervious, containing a considerable amount of organic matter, and rice is grown under heavy fertilizer application.

Fig. 3.2 Timing of Nakaboshi and Rice Yield



Nakaboshi must be completed 30 days prior to heading. The relation between the timing of Nakaboshi and the rice yield is shown in Fig. 3.2.

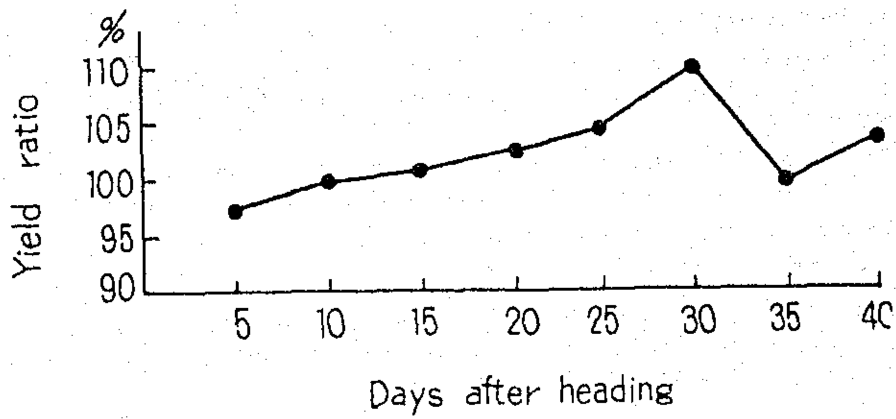
3.2.4 Panicle formation and heading periods

Drought during these periods causes severe damage and an adequate water supply is needed for healthy crop growth. Oxygen consumption by the root system increases and reaches the maximum during this period. In order to make the root absorb water and nutrients effectively, water temperature must be kept as cool as possible, say not higher than 35°C. Flowing irrigation is sometimes practised to control water temperature.

3.2.5 Ripening period

Towards the end of this period the fields are gradually drained. Untimely drainage, however, adversely affects the crop yield. For late rice varieties in warm regions it is the usual practice to drain the fields completely about 40 to 45 days after the heading period. This relation is shown in Fig. 3.3.

Fig. 3.3 Timing of drainage and yield



3.3 Flowing vs. stagnant irrigation

It is well known that irrigation efficiency under flowing practices is lower than that under stagnant methods; particularly tail water from a field cannot be efficiently utilized either by an adjacent field or by one situated downstream. There is also a danger of soil nutrients being carried away by flowing water. Therefore, generally, continuous flowing irrigation throughout the irrigation period is not practised in the country.

Nevertheless, there are instances where flowing irrigation is applied, for the following main reasons:

(i) Where paddy soils are subject to the creation of harmful substances and no proper percolation exists or drainage is impracticable, renewal of the water can give some relief.

(ii) Soil temperature can be controlled to some extent by flowing water.

(iii) Labour for water management can be saved, particularly where land parcels are relatively small and there is no access to watering points.

(iv) In newly reclaimed fields, flowing irrigation has been practised in order to reduce the expenditure on land levelling which is absolutely necessary in the case of stagnant irrigation to maintain a certain water depth.

Flowing or stagnant irrigation is practised in accordance with crop growing stages, soil and water temperature and other farming techniques, such as fertilizer application (flowing water is completely stopped when fertilizer or chemicals are applied).

3.4 Continuous versus intermittent irrigation

3.4.1 Continuous submergence

Continuous submergence with occasional interruption is the most widely practised. Water is drained at least during the late tillering period (Nakaboshi) unless soils are too pervious or poorly fertilized. It should be noted that this practice completely differs from the uncontrolled continuous submergence prevailing in some rice growing areas which do not have adequate watering systems and artificial control of irrigation water is neither feasible nor practicable. Although most paddy fields are provided with an adequate water supply and means are available for regulating the water, continuous submergence is practised for the following reasons (water depth varies with the crop growing stage and related farming practices):

(i) Continuous flooding is a traditional method and satisfactory plant growth and rice yield are attained.

(ii) Submerged fields give a better response to timely application of fertilizer.

(iii) Continued flooding saves labour for water management.

(iv) Flooding may prevent physical damage to the crop, especially in the early growing stage.

(v) Submergence helps to eliminate some weeds.

3.4.2 Intermittent irrigation

3.4.2.1 Definition

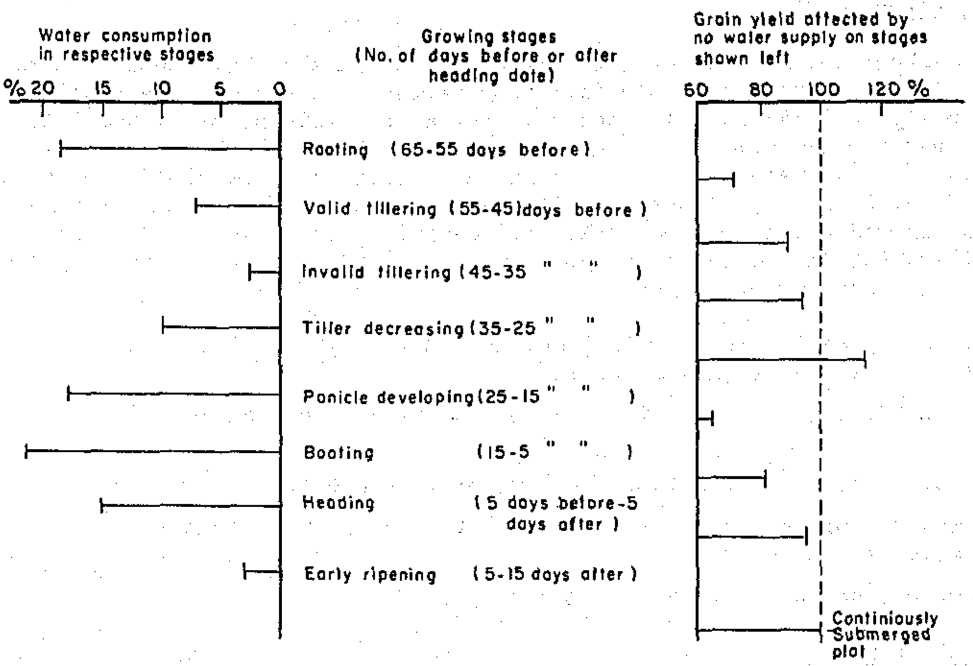
In some localities where no irrigation system exists and rainfall is not adequate or timely during the crop growing period, fields are often provided with water intermittently through natural causes (floods, etc.,) regardless of the farmer's intentions. In this publication intermittent irrigation, however, means the water supply to paddy fields which is controlled intermittently by water users. Intermittent irrigation is most popular in the areas that are often subject to water shortage or where there is no abundant supply of water for continuous irrigation. In carrying out successful intermittent irrigation, an important factor is the crop growing stage in relation to the relative tolerance of the plants to water shortage or to those periods when sufficient water supply is an absolute necessity. As already mentioned, an abundant water supply is absolutely essential for satisfactory crop growth during the periods of rooting, panicle formation and heading.

3.4.2.2 Effect of water shortage on rice yield

Many studies have been carried out on this subject. An example is illustrated in Fig. 3.4.

The experiment was conducted with water kept at a depth of 5 cm and percolation was disregarded as water consumed. Water shortage during the rooting, panicle formation and heading period resulted in a significant decrease in yield, whereas at the later tillering stage it favourably affected the rice yield. This is the stage when mid-season drainage (Nakaboshi) is practised.

Fig. 3.4 Rice yield affected by non-irrigation in various growth stages (13)



3.4.2.3 Water requirements

Water requirements for intermittent irrigation are much lower than those for continuous submergence. The main factors responsible for this saving are the restriction of percolation losses and an increase in effective rainfall during the non-submergence period. Table 3.1 shows the results of investigations.

Table 3.1 Water requirements under continuous and intermittent irrigation (3.2)

Irrigation method	Number of areas	Net water requirement m^3/sec/ha	Daily water depth decreased mm
Continuous	131	0.00278	24
Intermittent	172	0.00197	17

The following Table 3.2 shows that the most successful result was achieved with a water saving culture in which the field was only submerged after the young panicle formation stage. Water requirements under this practice were 20-30 percent lower than those under continuous irrigation.

Table 3.2 Water requirements - grain yield under different irrigation methods (13) 1,2/

	Water requirements %	Grain yield %
Continuous irrigation	100	100
Intermittent irrigation 3/	80	46
Heading stage submergence 4/	60	75
Water saving irrigation	75	110

Professor Fujioka recommended (3.3) the following water saving irrigation method, based upon an extensive study of the transpiration intensity of paddy crops and soil moisture.

After the usual puddling and transplanting, fields were supplied with water in order to keep soil moisture in the root zone at not less than 75 percent of full saturation throughout the crop growing period, and submergence was practised for only 30 days before and after heading time. It was observed that, compared with continuous submergence, this method could save a quarter of the quantity of water used by evapotranspiration; in fields subject to vertical percolation, a saving of half the quantity of water could be expected. This saving should, of course, be much greater where both vertical and horizontal percolation exist.

3.4.2.4 Particular farm management under water saving cultivation

In practising the water saving cultivation method, rice variety and fertilizer application techniques become very important. Varieties of the panicle weight type and intermediate type with resistance to rice blast disease are preferable.

Nitrogen applied as a basal dressing is changed into NO_3-N and is easily leached away by rainfall during the non-submerged period. A small amount of nitrogen is therefore applied from time to time and a more abundant quantity just before submergence.

3.4.2.5 Characteristics of intermittent irrigation

Intermittent irrigation restricts surface runoff and lessens percolation losses (both horizontal and vertical), which are greatest when fields are submerged and soils are saturated.

In addition, the amount of effective rainfall is increased by adopting the method. This amount can be greater if the soil moisture is more fully depleted and the non-irrigation period is longer. In this connection, the waterholding capacity of the soil plays a key role in determining the water application pattern.

1/ Irrigation period ranges from 188 days to 72 days, but on average 110 days.
2/ Conducted at Yamaguchi Pref. Agr. Exp. Station.
3/ 3 days submergence and subsequent 10 days without water supply.
4/ Submerged only for 20 days prior to heading.

In actual field conditions however, it is difficult and troublesome to maintain soil moisture above a certain limit (i.e. 75 percent of saturation), especially where soils are sandy and pervious, necessitating a frequent supply of water.

3.5 Irrigation for direct sowing culture

Direct sowing is practised either in submerged fields or in moist soils. In submerged conditions a field is usually kept under relatively deep submersion (i.e. more than 10 cm in depth) for about one month after seeding, in order to avoid damage by birds and to control weed growth. Subsequent practices are the same as those for transplanting culture.

After direct seeding on moist soil, fields are kept in an upland state and are submerged when seedlings develop about 5 leaves (in about 30 to 40 days). Sudden submergence of upland fields often creates toxic effects on rice plant growth because when soils are suddenly changed into the reductive state, plants which have rooted in oxidised soils during the drier period cannot adapt themselves to the reduction process. It is, therefore, better to convert from the upland to the submerged state when soils are wet after rainfall, or to increase irrigation gradually until the completely submerged state is reached.

It should be noted, however, that direct sowing on dry land often requires more water than the usual cultivation method, especially where soils are pervious and water holding capacities are low, as the puddling work (which makes paddy soils impervious) is not carried out.

Although the total water requirement throughout the irrigation period is decreased, the seasonal peak water requirement is increased because of the higher percolation rate at the beginning of submergence periods. As the capacity of irrigation systems is determined by the latter water requirement, special attention must be paid when introducing this technique without amending the capacity of irrigation systems.

3.6 Control of water and soil temperature

3.6.1 Optimum temperature

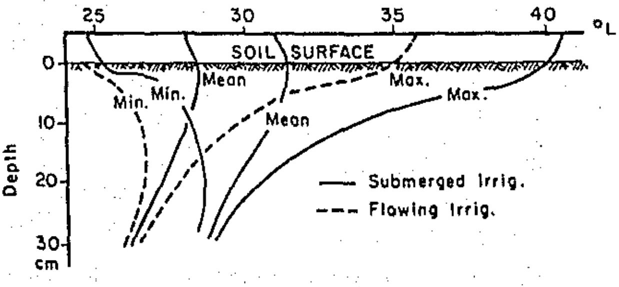
According to the physiological studies on the inter-relationships between water, soil temperature and rice plant growth, the optimum temperature for plant growth is 30-32°C. This has been further confirmed by investigation on the photoplasmic streaming in the root-hair of rice crops in relation to temperature. Velocity of photoplasmic streaming is at a maximum at 33°C and becomes zero at 40-45°C. Optimum temperature obviously varies with rice varieties. The critical temperature for varieties grown in tropical districts is higher than those in cool zones.

Temperature effect on crop growth also varies according to the latter's stage. High temperatures adversely affect crop growth at the tillering and heading stages, especially from young panicle formation to head shooting.

3.6.2 Flowing irrigation

In order to prevent high temperature damage, flowing irrigation is practised in warm districts where stagnant water temperature sometimes reaches 40°C in mid-summer. Accordingly the difference in temperature between the water irrigated and the water standing in the field becomes a dominant factor. As the plant density increases, incoming solar energy is interrupted by the plant leaves and field water temperature becomes comparatively lower, so flowing irrigation becomes less significant and sometimes acts adversely. The experiments conducted at the Niigata Agricultural Experimental Station showed that flowing irrigation carried out prior to the plant heading period resulted in a 7 percent increase in the rice yield (compared to that obtained in normal submergence irrigation) whilst an 8 percent decrease in yield was found under continuous flowing irrigation throughout the whole irrigation period. Fig. 3.5 shows the effect of flowing irrigation on soil and water temperature.

Fig. 3.5 Effect on water/soil temperature by different irrigation methods (14) 1/



* Kyushu Agri. Exp. Sta. August 1949

3.6.3 Cold water improvement

It was found that a water temperature lower than 24-25°C results in a serious decrease in rice yield as heading is delayed and ripening is obstructed. A cold water damage ratio is used to estimate the extent of such damage.

The ratio Δy is shown by:

$$\Delta y = \frac{\Delta Y}{Ymax \times A} \qquad \text{..........(14)}$$

where ΔY = decreased yield

Ymax = maximum yield per unit area

A = area under command of one inlet of irrigation water

When more than one plot is irrigated successively by one inlet the above equation can be developed to:

$$\Delta y = \frac{Ya + Yb + \dots\ Yn}{Ymax \times (a + b + \dots n)} \qquad \text{...........(15)}$$

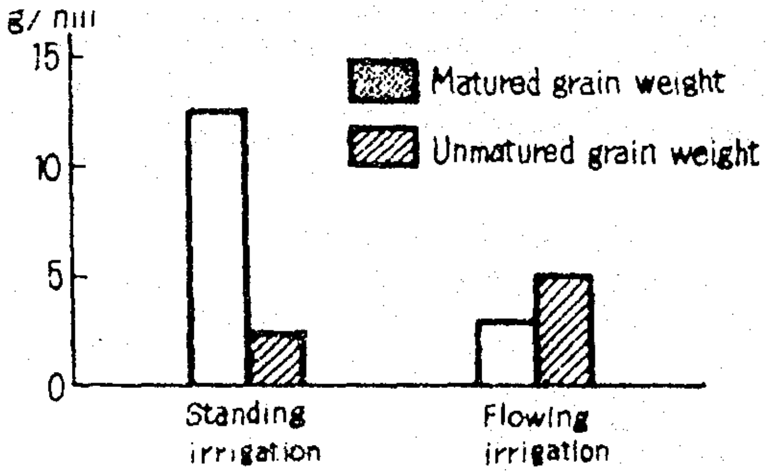
where Ya....Yn = yield actually measured

a ... n = area of each plot

1/ Kyushu Agri. Exp. Sta. August 1949.

In cold areas the irrigation method affects the rice yield remarkably. As is seen in Fig. 3.6 much higher rice yields are obtained from standing water.

Fig. 3.6 Irrigation method and rice yield (cold region) (8) 1/



In cold regions water is usually kept deeper than in warm ones, especially during the stage of young panicle formation and thereafter.

3.6.4 Water temperature at various sources

3.6.4.1 Rivers

Temperature depends on water discharge and depth, air temperature, wind velocity and incoming solar energy.

Table 3.3 shows the result of water temperature measurements in 81 rivers at the points where the rivers flow into plains from mountain areas.

Table 3.3 Number of rivers of various temperature

Monthly mean temperature	June	July	August
- 10°C	1	0	0
10 - 15°C	13	2	1
15 - 20°C	58	25	4
20 - 25°C	7	41	47
25°C -	0	4	23

3.6.4.2 Lakes and reservoirs

Temperature rapidly decreases at a certain depth which varies from 3 to 10 m, though in most cases it ranges between 4 and 7 m. The average temperature of the surface layer is 10 - 20°C in May, 15 - 25°C in June, and 20 - 30°C in July and August.

3.6.5 Practical methods to raise water temperatures

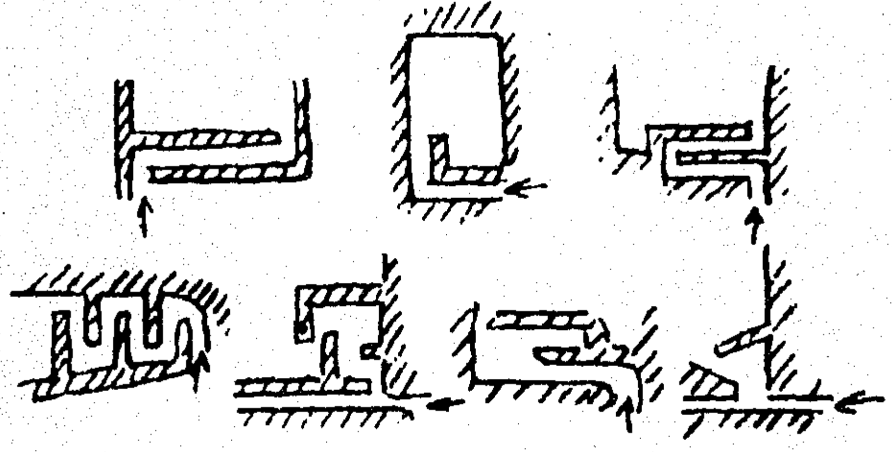
Various practices are used to raise the water temperature in cool districts. One of the most popular and effective is the restriction of excess percolation from the field, because it lowers the soil and water temperature. This practice is discussed in detail in Chapter 5.

1/ Kyushu Agr. Exp. Station.

3.6.5.1 Circulating waterway

In order to reduce cool water damage near a turnout, a circulating waterway is sometimes used in which the water temperature can be raised to some extent. The length of this waterway varies from 2 to 40 m and the width is about 60 cm. There are various patterns, some of which are shown in Fig. 3.7.

Fig. 3.7 Shapes of circulating waterways



3.6.5.2 Water warming canal

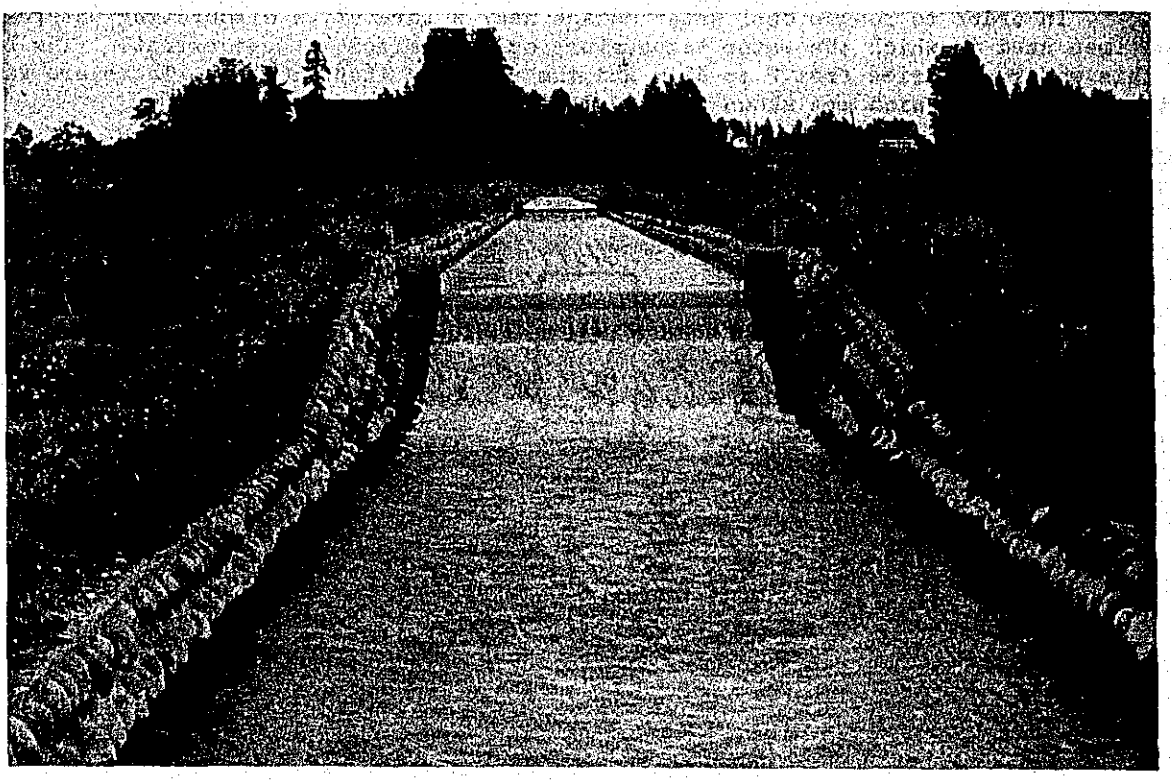
In cold districts canals are designed to raise water temperature and the following major factors must be taken into account:

- Canal route: preferably it should be kept out of woods, away from springs or other intruding cold water sources and strong wind.
- Materials: concrete lining coated with black paint such as asphalt is preferable.
- Shape and velocity: water depth should be shallower than 50 cm; the bottom width of the canal should be more than 5 m; the velocity should be less than 0.5 m/sec.

3.6.5.3 Water warming ponds

This facility is popularly used in cold parts of the country. Table 3.4 shows the effects of such reservoirs.

Water warming canal



Water warming pond

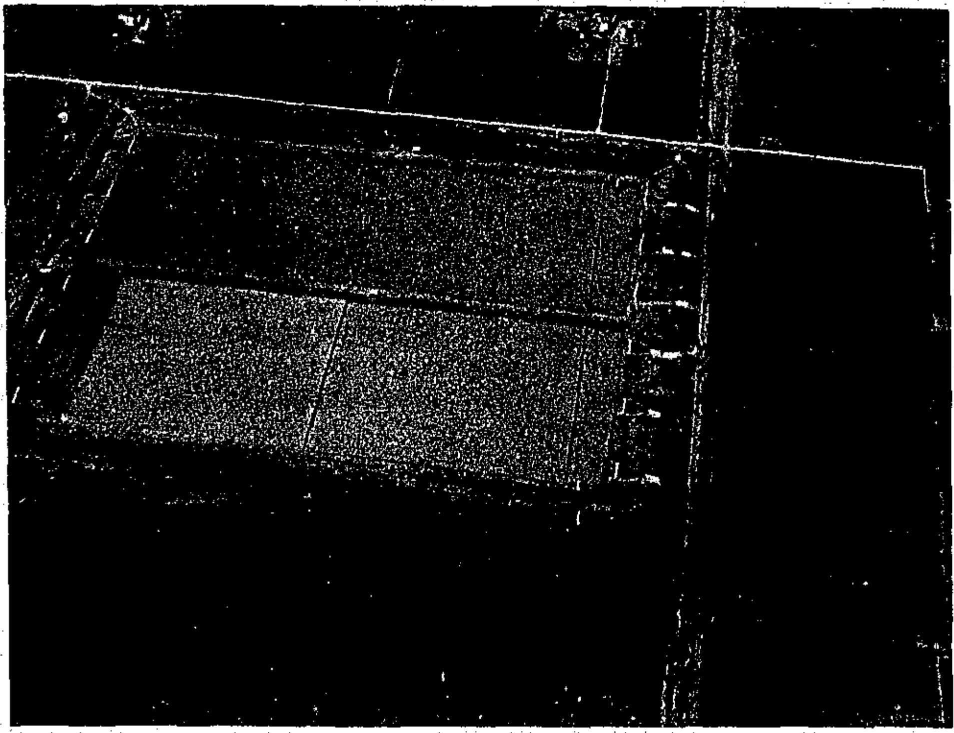


Table 3.4 Water warming ponds

Name and place of reservoirs		Water surface area m^2 water depth m	Flowing water (in and out) m^3/sec	Rise in temperature °C
Yachizawa	AKITA	4 445 1.52 (max)	0.113 0.312	4 (June-Aug.)
Tozan	TOYAMA	3 151 1.32 (mean)	0.061	1.2 - 5.3
Maruyama	TOTTORI	13 000 2.80 (max)	0.112 0.196	3 - 7
Hosono	NAGANO	2.10 (mean)	0.070	1.6 - 4.0
Kosaka	NAGANO	410 000 14.0 (max)	0.420	3.5 - 6.0

In designing reservoirs the following factors should be taken into account:

- Water will have to be stored for between 12 to 36 hours.
- In relatively warm districts, but only if the water is cold, it will have to be stored more than 24 hours and the water depth should be 2.0 - 4.0 m.
- Outlet works must be designed to take water from the surface layer.
- Water should be taken out in the afternoon.

3.6.5.4 Warming plot in paddy field

As shown in Fig. 3.8, a warming plot with as large an area as possible is established around the turnout.

Fig. 3.8 Warming plot in paddy field

In Fig. (a) water is spread on the field through notches constructed in a small bund or plate. In Fig. (b) small bunds are constructed on opposite sides of a big warming plot; water flows in and out over these low bunds and is warmed in the plot.

In some localities water is delivered into a plot through many holes drilled on a long board, which is set in the plot parallel to a levee. Recently plastic has been used as a material for such a board (50 m long per 0.1 ha).

3.6.5.5 Water application practices

Intermittent irrigation can solve cold water problems to some extent. It is the usual practice in cold districts to run water into fields in the early morning (when there is no difference between air, irrigation water and field water temperatures) and to keep the water standing during the day. This is done during the initial growing stage and the paddy field itself acts as a water warming reservoir.

Evaporation control, discussed in detail in Chapter 5, is also an effective method of keeping the water temperature high.

4. DRAINAGE

There are two reasons for draining paddy fields; the first is to remove excess water and the second to control soil fertility. In this chapter water control practices for the removal of excess surface water are called surface drainage, whilst those related to the control of soil fertility are called subsurface drainage (percolation).

4.1 Role of subsurface drainage in waterlogged fields

As quoted in Chapter 1, waterlogged (poorly drained) paddy fields occupy about 40 percent of the total paddy area. Until recently improvement in drainage did not keep pace with irrigation practices since quite high rice yields were obtained from waterlogged conditions. In these fields, the groundwater level remained high throughout the year, sometimes reaching ground surface, with no downward movement of water. Under such circumstances, organic substances in the soil are decomposed by microorganisms when the soil temperature rises. With the progress of decomposition, most of the free oxygen dissolved in the water and some parts of oxygen combined with iron, manganese etc., were also consumed, thus hastening soil reduction. Consequently, soil Eh value decreases and various toxic substances such as organic acids (i.e. acetic, butyric), CO_2, CH_4 and H_2S are produced. These substances hamper the healthy growth of the root and inhibit nutrient absorption and normal aerobic respiration.

It will be seen, therefore, that subsurface drainage can play a key role in supplying oxygen to the plant through the water and leaching away toxic substances.

With regard to the oxygen supply problem, recent studies have proved that dissolved oxygen supplied through percolation practices is mostly consumed in the upper soil layer (0-2 cm) and only a small amount is transmitted to the deeper layer. It was also found that the amount of CO_2 is proportionally decreased by percolation, whereas H_2S is markedly oxidised by percolation practices when it is present in a large quantity.

4.2 Soil fertility and fertilizer application

4.2.1 Soil fertility and percolation

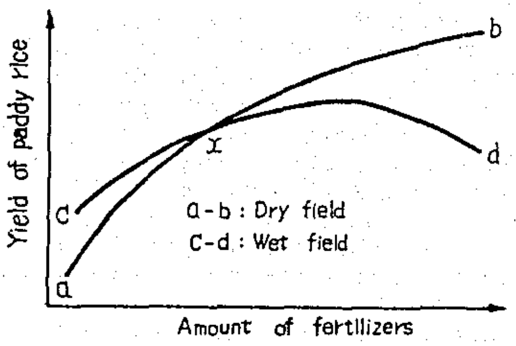
With an increase in the percolation rate, NH_4-N and K, which are kept in soils although they are cations, tend to be leached away. On the other hand, the mineralization of organic nitrogen in waterlogged soils is promoted. Consequently, soil fertility appears to be raised initially but is reduced after a few years. Percolation should, therefore, be maintained at a rate that will not progressively leach away mineralized nitrogen. However, if the rate of percolation exceeds a certain limit so that the leaching away of mineralized nitrogen is hastened, fertilizer will have to be applied a few times; this is called split fertilizer application.

It can be said, therefore, that the practice of subsurface drainage has the advantage of removing toxic products and giving a favourable environment to roots, but, at the same time, it has the disadvantage of leaching away plant nutrients.

4.2.2 Fertilizer application

The relationship between the amounts of nitrogenous and organic fertilizer applied and the yield of rice in "dry fields" (with good drainage conditions) and "wet fields" or waterlogged fields (with poor drainage conditions causing root decay) is shown in Fig. 4.1.

Fig. 4.1 Rice yield and fertilizer applied 1/



As can be seen from Fig. 4.1, the curve a-b shows that the rice yield in the dry field increases to correspond with the amount of fertilizer applied, whilst the curve c-d indicates that fertilizer application beyond certain limits does not give favourable effects on rice yield in wet fields. The left side of the cross point "x" of the two curves shows that soil fertility is the governing factor in rice production and that rice yield in the wet field is higher than in the dry one under slight application of fertilizer. The right side of point "x" indicates that a higher rice yield is secured by heavy application of fertilizer in the dry field and that the drainage condition is the dominant factor responsible for high rice yield under heavy fertilizer application.

The position of the cross point "x" is governed by the quantitative influence of the soil fertility and oxygen in the soil on crop yield. In other words, the left side of point "x" indicates that the soil fertility is the governing factor, whilst the right side implies that the availability of oxygen plays a key role in crop production. As a result of the study, it is recommended that the line a-b be aimed at if high yield under heavy fertilizer application is to be attempted.

This hypothesis was proved in the experiment conducted by Shiroshita, the results of which are shown in Fig. 4.2.

In Fig. 4.2 the tendency for an increase in yield shown in Fig. 4.1 is confirmed, although much organic fertilizer (manure) was applied for the studies shown in Fig. 4.2. Table 4.1 shows the amount of fertilizer applied - corresponding to the horizontal axis of Fig. 4.2.

[1/] Shiroshita, T. Agr. Exp. Sta. Report, Japan, Vol. 1, No. 1, 1962.

Fig. 4.2 Experimental results of rice yields and fertilizer applied

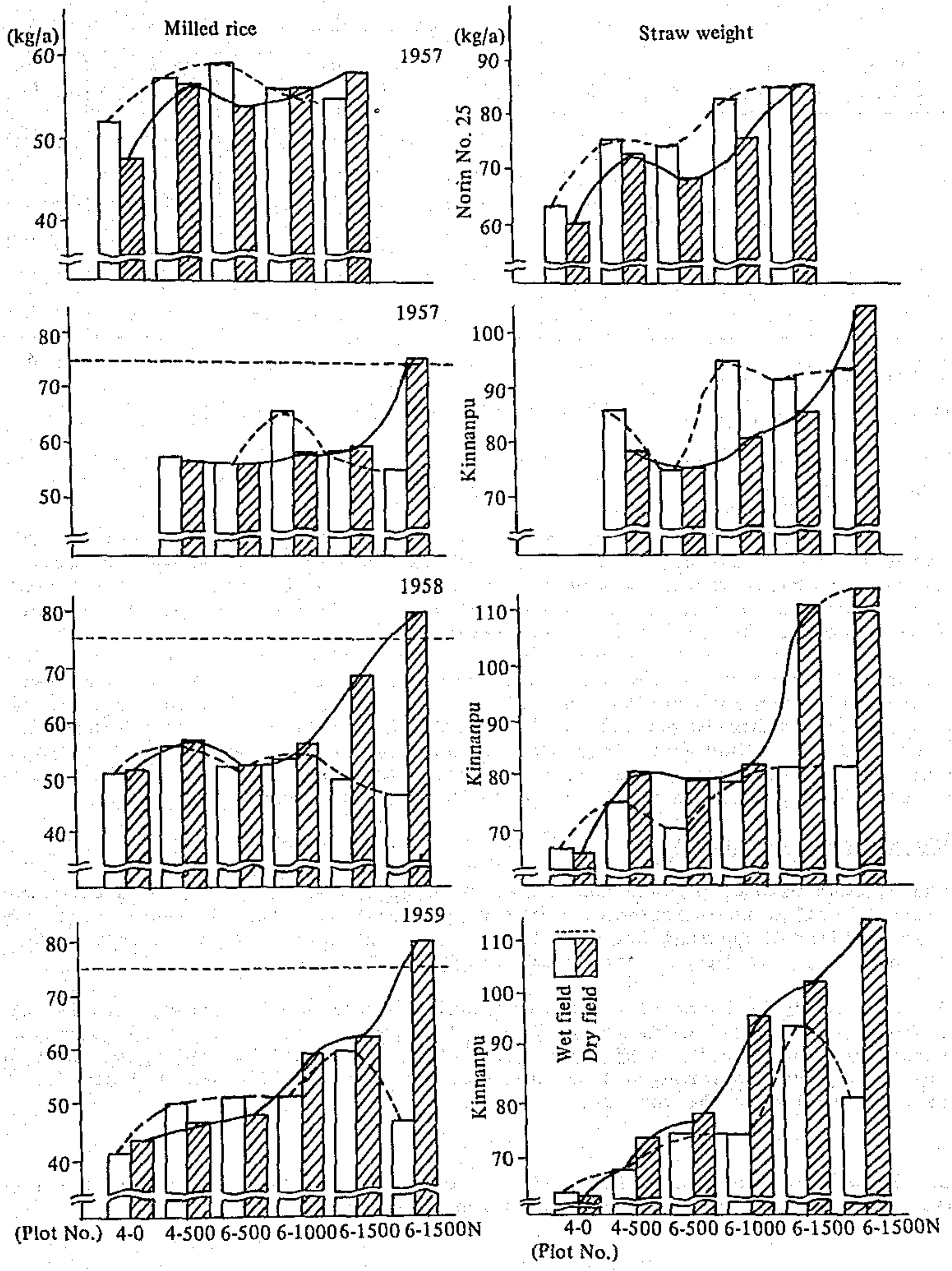


Table 4.1 Amount of fertilizer applied

		Base				Additions		
						N		K_2O
Pattern	Ploughing depth cm	Manure */	N	P_2O_5	K_2O	tillering stage	panicle formation	p.f. **/
1	12	0	0.750	1.125	0.938	0.188	0.188	0.188
2	12	187.5	0.750	1.125	0.938	0.188	0.188	0.188
3	18	187.5	0.750	1.125	0.938	0.188	0.188	0.188
4	18	375.0	0.750	1.125	0.938	0.188	0.188	0.188
5	18	562.5	0.750	1.125	0.938	0.188	0.188	0.188
6	18	562.5	1.125	1.125	0.938	0.188	0.188	0.188

*/ Composition of manure (%)

Water	N	P_2O_5	K_2O	C	C/N	SiO_2	CaO	MgO	MnO	Fe_2O_3
73.5	0.52	0.56	0.60	5.19	10.0	9.16	0.31	0.33	0.03	0.13

**/ Panicle formation

It can be said that vegetative growth is vigorous but generative growth is slow in wet fields; in dry fields, with a small application of manure, vegetative growth is inferior but generative growth is superior compared with wet fields. In other words, quicker decomposition of manure and more effective absorption of decomposed nutrients are the advantages of dry fields over wet fields.

Drainage (percolation) practices are especially required in fields under heavy fertilizer application in order to control fertilizer effects in relation to climatic conditions, crop growing stages and soil conditions (particularly the degree of soil reduction). On the other hand, they are less important where crop growth is mainly dependent upon the nutrients available in the soils and irrigation water and little fertilizer is applied. This is mostly the case in South East Asia. 1/

4.3 Optimum percolation rate

The optimum rate of percolation varies widely with the amount of toxic substances to be leached, soil characteristics, crop growing stages and related farming practices, especially fertilizer application. It is not practicable, therefore, to define the standard (optimum) percolation rate, which is applicable in every case.

A recent study in Japan (4), indicated that the optimum percolation rate in well-drained fields was about 5 mm daily, whilst that in swampy fields containing abundant toxic substances was from 15 to 25 mm daily. Attention should be paid to the fact that these are average values throughout the whole rice growing period, and that abundant fertilizer is applied in the country.

1/ Most of the rice varieties cultivated in this region are "tall, leafy and lodging-susceptible types" and their fertilizer responses are very low.

In most of the high yielding paddy fields (more than 7.5 tons/ha) the average percolation rate is 10 to 15 mm. This fact is shown in Fig. 2.1. 1/ It was also found that where percolation rates were less than 5 mm/day or more than 40 mm/day, heavy application of fertilizer did not result in high rice yield.

The above facts might not be applicable to an area where rice is grown with light fertilizer application or is cultivated rotationally with other upland crops.

4.4 Relevant factors in designing drainage systems

4.4.1 Surface drainage

4.4.1.1 Allowable submergence

The provision for perfect drainage is, in most cases, not economically feasible, so it is the usual practice to allow for a certain submergence depth when designing drainage systems. The allowable submergence depth and time differ greatly with the crop growing stage. For example, the greatest flood damage is most likely to occur at the panicle formation stage and submergence for more than two days seriously affects crop growth. Table 4.2 shows the relationship between a decrease in yield and flooding conditions.

As the heaviest rainfall usually occurs between July and September, by which time the rice plant has reached a height of 0.4 - 0.8 m, allowable submergence would be 0.3 m deep and should only last for 1-2 days.

4.4.1.2 Design rainfall

Design rainfall is determined not only from the technical viewpoint, but also for economic feasibility. Usually, heavy rainfall which occurs at a frequency of 1/10 - 1/30 years is taken into account; large-scale flood control projects usually take a frequency of 1/50 - 1/100. Rainfall is taken into account daily, or sometimes hourly, where the area is subject to temporary submergence for short periods, but continuous rainfall is considered as prolonged flooding.

4.4.1.3 Runoff and runoff coefficient

In considering drainage schemes there are two types of runoff coefficient, namely (1) the ratio of rainfall to corresponding runoff; and (2) the ratio of maximum rainfall to maximum flood. The former is generally used for relatively large low-lying areas, whilst the latter is used to estimate peak flood caused by rainfall concentrated in a short period of time. An example of the former is shown in Table 4.3.

1/ The figure shows the water requirement (sum of evapotranspiration and percolation) in which evapotranspiration is considered to be constant averaging 7 mm/day.

Table 4.2 Flooding and the rate of yield decrease

Crop growth stage	Type of submergence	Flooding period (days)			
		1-2	3-4	5-7	7+
		%	%	%	%
20 days after transplanting young panicle formation	Completely under clean water	10	20	30	35
Young panicle formation	Partly 1/ under clean water	10	30	65	90-100
	Partly 1/ under muddy water	20	50	85	90-100
	Completely under clean water	25	45	80	80-100
	Completely under muddy water	70	80	85	90-100
		(50% in case of half days submergence)			
Heading	Completely under muddy water	30	80	90	90-100
	Completely under clean water	15	25	30	70
Ripening	Completely under muddy water	5	20	30	30
	Completely under clean water	0	15	20	20

1/ "Partly" means leaves (9-15 cm long) remain above water surface.

Table 4.3 Runoff coefficient in rivers in Japan

Topography of rivers	Runoff coefficient (%)
Steep mountains	75 - 90
Forest	50 - 75
Flat upland	45 - 60
Paddy field under irrigation	70 - 80
Small rivers in plain	45 - 70
Large rivers in plain	50 - 75

Table 4.4 shows an example of runoff coefficient and length of time for drainage in paddy fields.

Table 4.4 Runoff coefficient of paddy fields used for the formula $Q = 10fR_nA/\ 3\,600T$ (m^3/sec)

Area (paddy field)	n	T	f
About 50 ha (terraced land)	4	4	0.4 - 0.7
Smaller than 100 ha	24	24	0.5 - 0.8
Smaller than 500 ha	24	24	0.4 - 0.7
Smaller than 1 000 ha	24	48	0.6 - 0.8

where A = catchment area (ha)
f = runoff coefficient
R_n = maximum rainfall during "n" hours
T = length of time for drainage (hour)

4.4.1.4 Estimation of runoff in low-lying areas

In estimating runoff in low-lying paddy field areas the following tables are used:

Table 4.5 Total rainfall and runoff

Total rainfall (mm)	0-10	10-30	30-50	50-100	100-200	200-300	300+
Runoff coefficient %	0	10	30	50	80	90	95

Table 4.6 Single rainfall and its runoff pattern (%)

	1st day	2nd day	3rd day	4th day	Total
Under 30 mm	100	-	-	-	100
30 - 50 mm	70	30	-	-	100
50 - 100 mm	60	30	10	-	100
100 mm and over	50	30	15	5	100

Table 4.7 shows an example of a calculation using the above tables, assuming that rainfall during 5 days amounted to 300 mm.

Table 4.7 Daily runoff caused by continuous rainfall (example)

(1) Day	(2) Rainfall (mm)	(3) Accumulated rainfall (mm)	(4) Runoff coefficient	(5) Runoff caused by single (daily) rainfall (mm)	(6) Daily runoff (mm)					
					1st	2nd	3rd	4th	5th	6th
1st	40	40	30	12.0	8.4	3.6	-	-	-	-
2nd	150	190	80	120.0	-	60.0	36.0	18.0	6.0	-
3rd	15	205	90	13.5	-	-	13.5	-	-	-
4th	70	275	90	63.0	-	-	-	37.8	18.9	6.3
5th	25	300	95	23.8	-	-	-	-	23.8	-
Total	300			232.3	8.4	63.6	49.5	55.8	48.7	6.3

(4) Obtained from Table 4.5

(5) = (2) x (4)

(6) = (5) x rainfall pattern (%) shown in Table 4.6

4.4.2 Subsurface drainage (percolation)

Soil permeability and hydraulic gradient are among several factors governing water movement in soil.

4.4.2.1 Soil permeability

Recent investigations showed that soil permeability itself varies with the season and is usually high during the non-irrigation period and low when soils are irrigated. Table 4.8 shows the result of recent investigations:

Table 4.8 Maximum and minimum K (in Darcy's law) and date of investigation (14)

Soil profile	Minimum K and observed date	Maximum K and observed date
Top soil	6.6×10^{-5} cm/sec, 12 July	4.2×10^{-2} cm/sec, 20 March
Plough pan	1.2×10^{-5} cm/sec, 12 July	1.0×10^{-3} cm/sec, 15 November
Subsoil	2.4×10^{-6} cm/sec, 12 July	2.0×10^{-1} cm/sec, 3 March

This fact should not be overlooked in studying the relationship between soil permeability and percolation rate, as in most cases soil permeability is observed during the non-irrigation period.

4.4.2.2 Hydraulic gradient and soil permeability

Darcy's law is also applicable to percolation in paddy fields. The following table shows the relationship between soil permeability and percolation rate when the hydraulic head is assumed at 1.0.

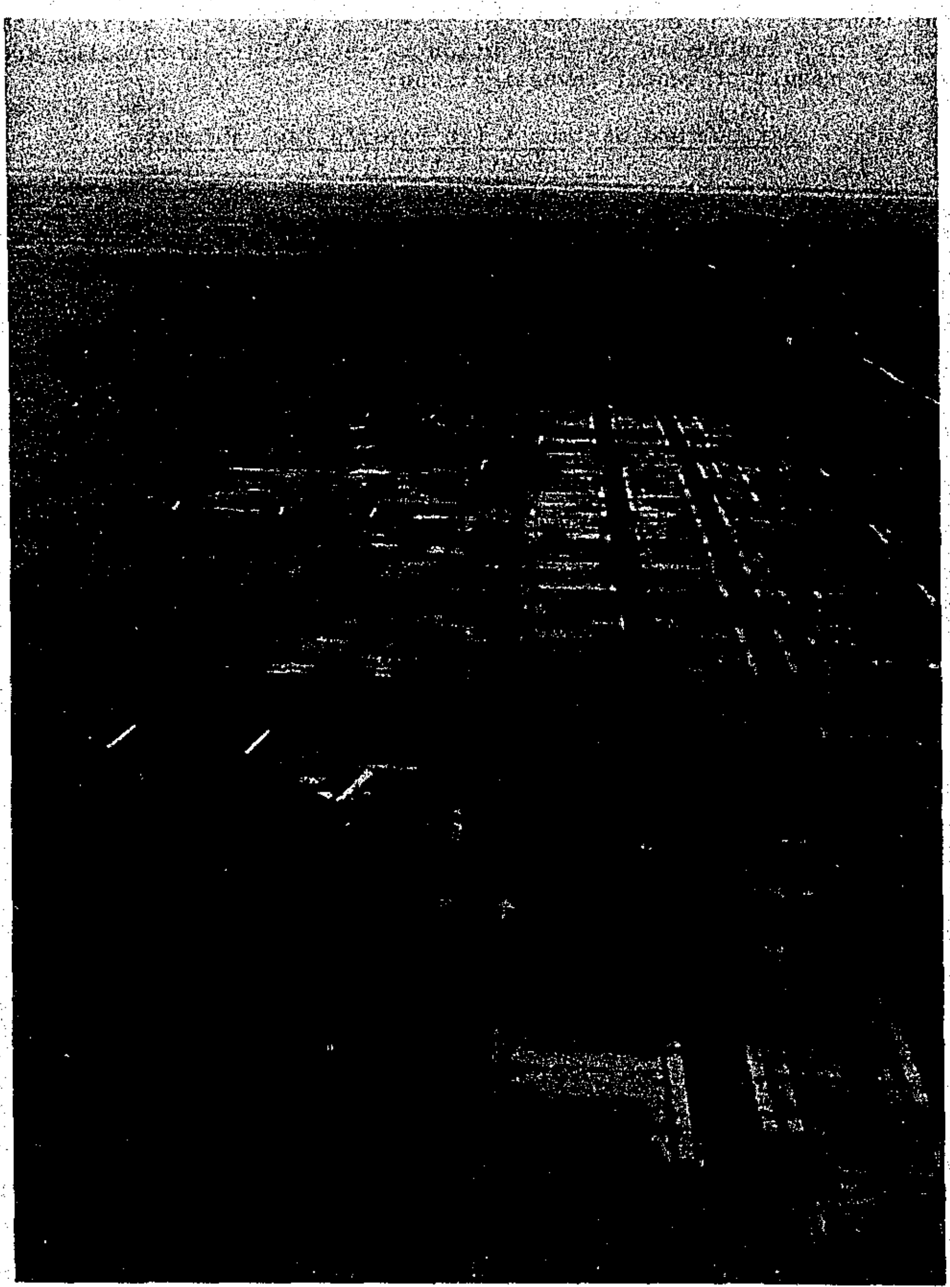
Table 4.9 Permeability and percolation rates

Permeability	Percolation rate
$n \times 10^{-6}$ cm/sec	0.86 - 8.6 mm/day
$n \times 10^{-5}$ cm/sec	8.6 - 86 mm/day
$n \times 10^{-4}$ cm/sec	86 - 860 mm/day
$n \times 10^{-3}$ cm/sec	860 - 8 600 mm/day
$n \times 10^{-2}$ cm/sec	8 640 - 86 400 mm/day

In general, hydraulic gradient is much smaller than 1.0 and its order ranges from 10^{-1} to 10^{-2}. This means that a change in hydraulic gradient influences percolation rates only where soil permeability is larger than 10^{-5} cm/sec, and that the percolation rate would be affected greatly if the soil permeability was more than 10^{-4} cm/sec (i.e. if change in hydraulic gradient is 0.1, the corresponding change in percolation rates would reach 10 mm).

It can be said that soil permeability should be in the range of 10^{-4} to 10^{-5} cm/sec for efficient control of percolation.

Installation of a drainage pipe



5. PREVENTION OF WATER LOSSES IN THE FIELD

Four factors are involved in the loss of water in paddy fields: transpiration, evaporation, percolation and surface runoff. Surface runoff can be controlled by field dykes, the construction of which is not usually determined by technical knowledge but by economic feasibility. Transpiration is physiologically required for crop growth and its control is practically impossible. In this chapter, therefore, the control of evaporation and percolation is the main point of discussion.

5.1 Evaporation control

Although evaporation is mainly a climatic phenomenon, it is variable during the crop growing season. As discussed previously, evaporation from the field surface is at its maximum in the early stage of plant growth and falls to a minimum during the period of panicle formation.

5.1.1 Mono-molecular film method

Evaporation is greatly reduced when the water surface is covered with a thin film of certain organic compounds such as higher alcohol (i.e. Mono-oxyethylene Docosanol Ether). It has been proved by experiments that the application of 3-4 grammes of this compound for every 10 ha prevents about 60-80 percent of evaporation. In addition, it restricts the growth of some kinds of duckweed and increases water temperature considerably, thus eliminating damage from cold conditions. This implies that these chemicals should be used carefully in hot areas. This method is, however, ineffective when the wind velocity exceeds 2-3 m/sec.

5.1.2 Shallow water depth

It is known that the rate of evaporation decreases when the water depth is shallow. The result of experiments on the relations between water depth (1.0, 3.0, 6.0, 9.0 cm), soil moisture (30, 50, 75, 100% of saturation) and evaporation is as follows. Evaporation from paddy fields with a water depth of 9.0 cm is at a maximum and it decreases in proportion to water depth and soil moisture. For example, evaporation from paddy fields with 9.0 cm water depth was one and a half times more than that of a saturated field.

In Japan, it is generally preferred that the water depth be kept as shallow as possible, provided that rice growth is not jeopardised by such a practice.

5.2 Percolation control

5.2.1 Horizontal and vertical percolation and their rates

Percolation is divided into two types, namely horizontal and vertical. Horizontal (lateral) or levee percolation is usually dominant in terraced paddy fields where the elevation of each field differs considerably. Recent studies on horizontal percolation, with special emphasis on potential flow lines, show that the rate is three to ten times that of vertical percolation. However, much of the water "lost" in horizontal percolation is available for re-use because it is either collected in the drainage ditches or flows into adjacent fields. On an average, it is estimated that actual losses from horizontal percolation are two to five times those of vertical percolation. The following table shows the rate of horizontal percolation.

Table 5.1 Horizontal percolation from paddy fields through the surface soil and levees in various parts of Japan (14)

Soil conditions	Horizontal percolation litres/day/lineal metre	Corresponding loss as depth of water in relevant paddy cm/day
Loam, 75 cm deep stepped paddies	5	0.00075
Sloping old paddy	15	0.022
Sandy loam, 135 cm deep stepped paddy	18	0.027
Sandy soil newly developed paddy	62	0.093
Sandy loam	302	0.45
Alluvial topsoil, volcanic ash subsoil	380	0.57

A paddy field, subject to excess percolation, can be classified into one of three groups, namely (a) presence of high vertical percolation, (b) presence of high horizontal percolation, and (c) existence of both types.

Group (a) usually exists where no plough pan is formed and the lower soil layer consists of pervious materials such as sand, gravel or volcanic ash. Percolation rates often reach 10 cm/day.

Paddy fields belonging to group (b) usually consist of fine soil or sandy loam with a developed plough pan. Such fields are often situated alongside a river in terraced land. Percolation rates sometimes reach 4 to 5 cm/day.

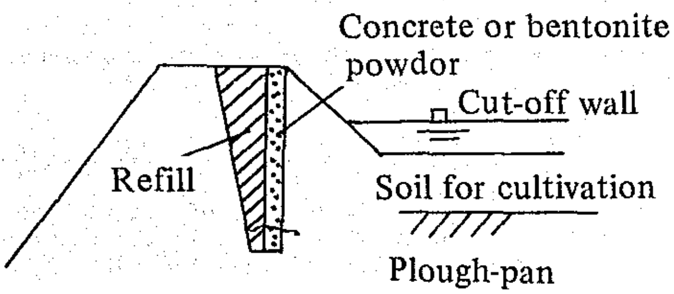
The most leaky paddy fields belong, more or less, to group (c) which is subject to both vertical and horizontal percolation.

5.2.2 Puddling work

It has long been a traditional practice to stir paddy soil with water prior to seeding or transplanting to make a rather thick mud. This mixture, acting as a waterproof layer, is spread on the field surface and along the border ridges which circumvallate the field. This work is sometimes carried out in the following way.

After removing the top soil, the subsoil is ploughed to a depth of 6 to 10 cm and puddled with water; the top soil is then put back before cracks develop in the subsoil surface.

Fig. 5.1 Impervious levee



5.2.3 Impervious levee

The building of an impervious levee to restrict horizontal percolation (an example of which is shown in Fig. 5.1) is widely practised with success. Clay, concrete and bentonite are most commonly used as impervious materials. In some localities wooden and plastic plates are also used and in others prefabricated concrete blocks.

5.2.4 Soil compaction

This method has been practised widely for centuries. At first, the top fertile soil is removed, then the subsoil layer is compacted by man, animal or mechanical power. After compaction the top soil is returned.

Apart from various methods of creating impervious strata in paddy soils by compaction by man or animals, the use of a special disk roller is common. In practising soil compaction special attention should be paid to the depth of consolidated layers. Impervious layers formed by traditional compaction methods are usually at a depth of 10-12 cm and are easily destroyed by cultivation or other operations. Special machinery consisting of a 380 kg disk and a 3 ton roller pulled by a 4 ton tractor is utilized with satisfactory results. The lower layer is compacted by the former and the layer at 30 cm depth is treated by the latter. The moisture content of the soil is important and compaction is usually carried out before the water is removed or drained completely when the paddy still has a certain degree of moisture.

Many experiments show that the rate of percolation decreases remarkably (from ½ to 1/10) by practising soil compaction. Attention should be paid, however, to the effective period of this practice, which varies from a few to about ten years; after this period compaction will have to be carried out again.

In cold districts it has been observed that soil and water temperatures increase as the percolation rates decrease. For example, an experiment at Nasunchara where soil was very pervious as it originated from volcanic ash, showed that the temperature rose by 2.7°C in water and 2.0°C in soil, and water requirements decreased to half the amount observed before the soil treatment, thus resulting in higher rice yields (10 to 30 percent).

5.2.5 Soil dressing

5.2.5.1 Usual practice

Soil quality is improved by importing soil of a different nature, i.e. clay soil to sandy soil and soil with minerals to humus soil. This method is usually practised in sandy paddy fields where satisfactory results are difficult to obtain by soil compaction. For example, after removing the top soil, clay soil - sometimes with humus (about 200-300 m^3/ha) - is brought to the field, mixed with the original soil and compacted to a thickness of about 3-6 cm, after which the previously removed top soil is returned.

The volume of soil to be imported depends on the characteristics of the original soil to be improved and the soil to be carried in, and on the depth of the original soil to be improved.

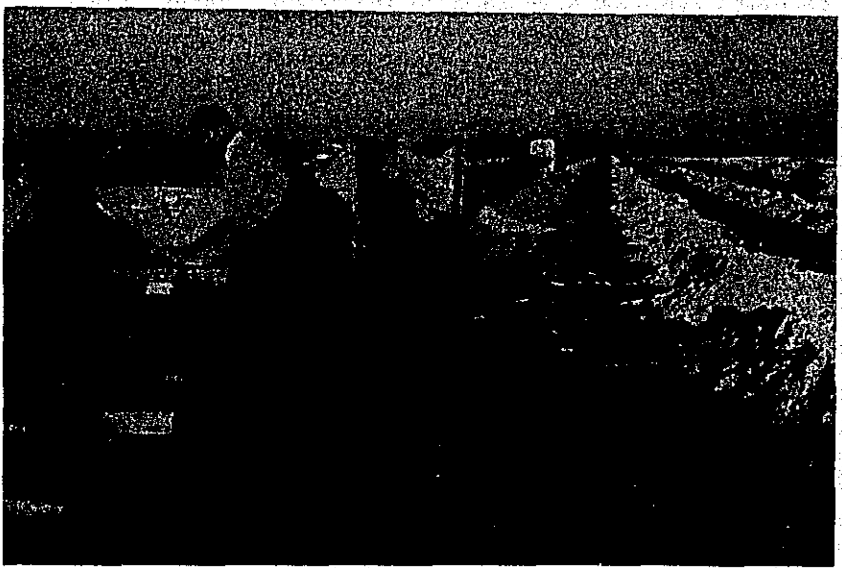
The depth of soil to be carried in can be calculated by the following formula:

$$h = \frac{HW_1 (P_3 - P_1)}{W_2 (P_2 - P_3)} \quad \ldots\ldots\ldots\ldots\ldots\ldots(16)$$

where h is the depth (cm) of soil to be carried in, H is the depth (cm) of original soil to be improved, W_1 is the apparent specific gravity of original soil, W_2 is the apparent specific gravity of imported soil, P_1 is the clay content (wt.%) of imported soil, P_3 is the clay content (wt.%) of improved soil.

In this formula P_1, P_2 and W_1, W_2 are determined by soil analysis, P_3 and H are expected to be 25-37.5 percent and 10-15 cm respectively. When h is found to be more than 10 cm, dressing work should be carried out over the period of 2 to 3 years, because a big and sudden change of soil characteristics might cause an unfavourable effect on crop growth.

Soil dressing



An economical method of soil transportation should be determined, taking into consideration soil nature, volume and transportation distance. The most popular way is to utilize transportation equipment, including that driven by man or animal power.

5.2.5.2 Soil importation by warp

Soil importation by warp (alluvial sediments deposited by water) merits careful attention. Clayey soil from a pit is conveyed to paddy fields in the form of muddy water through existing or newly constructed irrigation systems. Although the amount of clay is determined by the lack of it in the field to be treated, 150-230 m^3/ha is commonly applied. In this treatment two points require attention: a) the slope of the canal must be such that correct flow velocity can be maintained in order to avoid mud siltation in the canal systems, and b) the soil content in muddy water should be about 5 percent in weight which is considered to be the optimum.

5.2.5.3 Effects of soil importation

Table 5.2 shows the effects of soil importation on certain paddy fields, covered by very pervious top soil (15 cm deep sandy loam). Impervious loamy soils were transported by truck to the paddy fields and spread at a depth varying from 10 to 30 mm.

Soil importation by warp

It should be noted that soil importation not only improves the physical characteristics of soil but also its chemical features. So-called AKIOCHI soils are greatly improved by importing fertile soils.

Table 5.2 Effects of soil dressing on percolation, water and soil temperature

Depth of imported soil	Daily increase of water depth		Water temperature C		Soil temperature C	
	mm/day	ratio	10 a.m.	4 p.m.	10 a.m.	4 p.m.
Standard 1/	82.5	100%	23.3	26.4	21.6	24.6
30 mm	32.7	39.6	24.4	27.2	22.1	25.3
20 mm	47.4	57.5	24.3	27.0	22.1	25.1
10 mm	66.0	80.0	23.6	26.7	22.3	24.9

Source: TOYAMA, PREF. Muddy Water Irrigation Project along the Kurobe River, 1957 ICID Transactions, Vol. III.

1/ without soil dressing

5.2.6 Bentonite application

When clay for dressing is not readily available bentonite is recommended as a dressing material. Bentonite is a clay belonging to the montomorillonite family and is characterized by swelling on absorption of water. On application, particles of bentonite fall among grains of pervious soil and swell, precluding water movement. It is reported (10) that percolation rates in paddy fields decreased remarkably ($\frac{1}{2}$ to 2/5) after bentonite was applied, but no conclusive results were obtained on the effective life of this treatment. However, it should last a long time as bentonite does not dissolve and cannot be leached away.

There are two methods of bentonite application: one is to mix it with upper-top soil (10-15 cm thick) and the other is to embed it between top-soil and subsoil. The former is widely practised in existing leaky paddy fields, whilst the latter is mostly applied to newly reclaimed fields.

5.2.6.1 Mixing method

Bentonite powder spread evenly over the field is ploughed, harrowed and smoothed by puddling operations in accordance with the usual rice cultivation practices. The amount of bentonite to be applied varies according to soil texture and profile, but a rough standard is 7 000 - 10 000 kg/ha. This method is widely practised because (a) the method is very simple and no special labour is needed, (b) mixing it with the topsoil layer (10-15 cm thick) makes it possible to apply an additional amount at a later time if necessary, and (c) cultivation year after year ensures overall mixing.

5.2.6.2 Bedding method

Bentonite mixed with comparatively fine-grained soil is placed between the top and subsoil. The amount applied is almost the same as mentioned above. However, this method creates the following problems:

- An increase in earth-work costs as top-soil must be removed before application of bentonite.
- The layer of bentonite must be placed at a certain depth (i.e. 30 cm) to avoid being turned up or damaged during ploughing operations.

5.2.7 Plastic film sheeting

In paddy fields percolation can be greatly suppressed with vinyl sheeting because it allows very little water leakage. The vinyl cloth is spread all over the fields at a depth of 30-40 cm; it comes in strips which are usually 0.05 cm thick, 1.5 m wide, and is buried about 10 cm overlapped in width.

This method is often practised in newly reclaimed paddy fields, in sand dunes or in volcanic ash soils.

Vinyl film setting

When using this method, attention should be paid to the amount and timing of fertilizer application in order to avoid increasing sulphide and organic acid in the soil, which are both detrimental to root systems.

5.2.8 Control of relief wells in subsurface drainage systems

Subsurface drainage systems are constructed to promote field drainage, thus improving waterlogged fields. They can be used to change the percolation rate during the crop growth period by controlling the water level in the relief well.

6. WETLAND AND UPLAND ROTATION 1/

6.1 Definition

Rice is cultivated every year and paddy fields are usually submerged during the rice growing period. In well drained paddy fields land is drained in the off-season (rice) and planted with wheat, barley and vegetables. However, there are cases where paddy fields are drained for several consecutive years and upland crops are planted. Then the fields are submerged again for the summer months of several consecutive years to grow rice. This pattern is called lowland and upland rotation.

6.2 Effects of wetland and upland rotation

6.2.1 Upland crop yield

In most cases upland and wetland rotation is practised with a view to increasing land productivity and diversifying agriculture, and at the same time saving irrigation water in the irrigation systems. Where wetland is converted to upland, if the water is drained completely, most upland crops can be planted. There is no decrease in crop yields compared with those of permanent upland, except in the case of extremely heavy clay soil paddy fields. In fact, crop yields in converted uplands are often higher than those in permanent upland. In the first year of the upland period, the introduction of tuber crops is not advisable as soils tend to become hardened. As indicated in Tables 6.1 and 6.2, the potato yield in the first year is less than that in the usual upland. The crop yield, however, may increase as the soil takes on the usual characteristics of upland soils.

Table 6.1 Crop yield in converted uplands (8)

Number of years after conversion to upland	Crops	Crop yield kg/ha	Index (crop yield in permanent upland = 100)
1	White potatoes	12 500	67
3	White potatoes	21 900	109
1	Barnyard millet	2 160	133

Table 6.2 Crop yields in converted uplands

Crop sequence	Crop	Crop yields per hectare kg/ha				Ratio to crop yields in ordinary uplands			
		1948	1949	1950	Average	1948	1949	1950	Average
Soybeans -barley	Soybeans	2100	1820	2240	2050	150	130	186	152
	Barley	4540	3980	4670	4400	98	96	128	108
Maize (corn) -barley	Maize	2890	3820	3820	3500	102	101	116	106
	Barley	4800	4260	4490	4520	101	107	124	111

1/ This chapter is introduced particularly to provide information which might be useful when considering crop diversification in mono-rice culture areas.

6.2.2 Rice yield

Rice plants grown in the first year of a paddy field reconverted from the upland are far more vigorous than those in continuous rice cropping fields. Usually the rooting of seedlings after transplantation is very rapid and subsequent plant growth is good. The yield generally shows a considerable increase over that in continuous rice cropping fields. The rate of increase in yield varies with the soil properties, duration of upland period and the kind of upland crops grown. In general, the rate is higher where soil contains much organic matter, the upland period is longer and deep rooted crops or crops requiring deep ploughing are planted. The increase in rate of rice yield in the reconverted paddy field is highest in the first year after reconversion and shows a decreasing trend in the second year and thereafter. The results of experimental studies (8) are shown in Table 6.3.

Table 6.3 Brown rice yields in reconverted lowlands (8)

(kilograms per hectare)

Plot	Years for upland cropping / Upland crops during upland period / Years after reconversion	3 years			2 years			1 year		
		1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Fertilizer application	Soybeans-Wheat	546.0	496.5	441.8	496.5	425.3	410.6	480.8	432.0	391.5
	Sweet potato-Wheat	569.3	482.3	436.5	525.0	453.8	404.6	459.0	414.8	389.3
	Red clover	544.5	504.8	453.8	536.3	453.0	408.0	-	-	-
	Soybeans-Rape seeds	576.0	481.5	438.8	538.5	429.8	408.0	493.5	410.3	374.1
	Sweet potato-Horse beans	566.3	490.5	432.6	544.5	451.5	401.0	522.8	400.5	390.0
	Soybeans-Barley	579.8	489.8	433.8	513.8	453.0	397.5	-	-	-
Non fertilizer application	Soybeans-Wheat	436.5	332.3	247.5	353.3	261.8	217.2	293.3	238.5	196.5
	Sweet potato-Wheat	509.3	324.0	263.3	397.5	279.8	230.6	316.5	246.0	209.6
	Red clover	504.0	350.3	296.7	417.0	251.3	212.3	-	-	-
	Soybeans-Rape seeds	453.8	327.8	255.8	356.3	272.3	216.3	334.5	238.5	194.1
	Sweet potato-Horse beans	510.8	314.3	259.0	426.8	258.8	198.5	404.3	234.8	209.7
	Soybeans-Barley	442.5	314.3	270.3	353.3	268.5	210.8	-	-	-
	Plot	1st	2nd	3rd						
Continuous rice cropping lowland	Fertilizer applied plot	474.8	427.5	404.6						
	Non-fertilizer applied plot	273.8	252.0	217.5						

6.2.3 Yield of winter crops grown in reconverted lowland

Wetland and upland rotation also favourably affects the yield of wheat and barley crops grown in reconverted paddy fields during the winter season. In most cases more healthy crop growth is observed in the converted lowland than in the continuous rice cropping lowland. Table 6.4 gives an example.

Table 6.4 Yield of wheat crops (as succeeding winter crops to rice) grown in reconverted and continuous lowlands (8)

Lowland	In the first year (1951) of reconversion				In the second year (1952) of reconversion			
	Plant height cm	Number of panicles in 50 cm distance	Seed Weight per 10 ha	Index	Plant height cm	Number of panicles in 50 cm distance	Seed weight per 10 ha	Index
Continuous	83	71	264	100	67	96	244	100
Reconverted	87	73	370	140	64	121	251	103

Notes: 1. Upland cropping cycles lasted 3 years.

2. In the case of the reconverted lowland, soybeans and wheat crops were grown during the upland period.

6.2.4 Decrease in weed emergence

Another effect of land rotation is the decrease in weed emergence. Conversion from wetland to upland and vice-versa implies a great change in environmental conditions. The decrease in weed emergence is caused by the death or weakening of hydrophytic weeds during the upland period and mesophic weeds during the lowland period.

6.3 Soil and water management

When wetland is converted to upland and kept in a state of dryness during the summer, the dehydration of soil colloid is accelerated. Usually, the land would not return to normal wetland even if irrigated; the soil becomes less sticky and its moisture holding capacity is decreased. Even after reconversion to wetland, the soil will tend to dry if the water is drained. Table 6.5 shows the soil moisture content after drainage has taken place.

Table 6.5 Soil moisture content one month after drainage (8)

Continuous lowland		44%
Reconverted lowland	1 year upland period	42.0%
	2 year upland period	39.9%

If the upland period lasts longer, small pore spaces or cracks will be created in the soil with the result that soil permeability is increased and downward movement of water in the soil is encouraged. This has favourable effects on the transmission of heat, but adverse effects on water requirements. Consequently, the change in soil permeability plays a key role in determining water use patterns and irrigation practices.

A study on the decrease in permeability of soils converted from permanent upland to lowland showed that the percolation rate was reduced from 1/3 to 1/5 within a few years. During the first year after conversion to lowland paddy fields, the decrease in percolation rate was estimated at about 40 percent, so that after 4-5 years it would reach its original value.

From the water economy viewpoint, the maximum duration for converted upland should be three to five years. This means that if wetland paddy fields were converted to upland fields for less than three to five years (depending upon soil properties and groundwater conditions) there would be no drastic increase in water requirements for the following rice cultivation.

7. LARGE-SCALE PADDY FIELD RECLAMATION
CASE STUDY: HACHIROGATA RECLAMATION PROJECT

7.1 General remarks

The Hachirogata Project is situated in north-eastern Japan covering an area of about 15 700 ha, of which some 13 000 ha are used for paddy fields. The dyke construction was initiated in 1957 and drainage was carried out in 1964. At present more than 50 percent of the total reclaimed area is equipped with irrigation and drainage facilities and other infrastructure for modern mechanized rice cultivation.

The elevation of the land varies from 0 to -4 metres. Annual rainfall is about 1 800 mm. The area is snow-covered from early December to the end of March. The average annual temperature is 10°C. During the irrigation period from May to August the average temperature is 19.2°C (the maximum temperature being 36.4°C and the minimum -1.4°C). During the four month irrigation period the average evaporation is about 500 mm, while the average rainfall is 600 mm. Details of climatic conditions are shown in Table 7.1.

7.2 Farming plan

7.2.1 Basic considerations

The Hachirogata Reclamation Project was planned for the purpose of introducing modern agriculture to farmers so that they could increase appreciably their incomes through high land and labour productivity.

Some of the characteristics of this large scale planned agriculture are as follows:

a) Large scale rice cultivation - 10 ha of reclaimed land is given to a farmer.

b) Cooperative management - Small family units cannot carry out agricultural activities on such a large scale, therefore operations are planned and executed on a cooperative basis, e.g. mechanized direct seeding. Cooperative and coordinated farming operations are also necessary for systematic water application and management.

c) Mechanization: a plan for machine utilization - For the time being only rice is being cultivated in a fully mechanized way utilizing tractors and combines. The following machines are available for every 60 ha of paddy field:

3 Crawler tractors (30-40 HP)
1 Combine (100 HP)
1 Truck
1 Set of farming equipment

The harvested paddy is transported to the local elevator where the paddy is dried and stored. The paddy is husked before being put on the market.

Table 7.1

Climate

Division	Irrigation period					Non-irrigation period									
	May	June	July	Aug.	Total or Mean	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Total or Mean	Yearly
°C. Mean temperature	13.0	17.9	22.2	23.8	19.2	19.0	12.5	6.9	1.4	-1.4	-1.3	1.9	8.1	5.9	10.3
°C. Highest temperature	30.9	33.7	35.3	36.4	36.4	33.9	28.9	23.3	21.4	13.7	13.4	21.0	26.0	33.9	36.4
°C. Lowest temperature	-1.4	4.1	10.2	9.0	-1.4	3.1	-1.4	-4.6	-18.2	-19.8	-24.6	-19.5	-7.2	-24.6	-24.6
mm. Mean evaporation	112.9	122.3	130.5	133.0	498.7	104.3	76.3	53.1	41.5	39.5	43.1	69.5	101.8	529.1	1027.8
mm. Mean amount of precipitation	110.3	132.0	190.3	173.2	605.8	198.3	174.3	188.7	165.2	127.8	103.0	105.3	116.5	1 179.1	1784.9
Mean rain days	14	14	16	13	47	18	18	22	27	27	25	21	15	173	220
m/sec Mean wind velocity	3.7	3.2	2.7	2.7	3.1	2.8	3.1	4.2	5.1	15.3	5.0	4.7	4.3	4.3	3.9
Most frequent wind direction	S.E.	S.E.	S.E.	S.E.	S.E.	S.E.	S.E.	S.E.	N.W.	N.W.	N.W.	S.E.	S.E.	S.E.	S.E.

Division	first day		last day		earliest day		latest day	
	month	date	month	date	month	date	month	date
Frost	10	25	4	28	9	27	5	24
Snow	11	11	4	8	10	21	5	14
Deposited snow	12	4	3	23	11	8	4	20
Continuous snow cover	12	31	3	11	12	2	3	31

Mechanized harvesting

7.2.2 Present situation

Actual farming was started in 1968 and by 1970 there were about 320 settlers. About 3 300 ha of paddy fields have been distributed to 56 agricultural cooperatives and the average yield in 1969 was about 4.5 tons (husked rice) per ha.

7.2.3 Training

Those who wish to settle in the reclaimed area are required to pass an examination given by the Central Government, which is followed by on-the-spot training for 12 months. In 1970 143 farmers received special training and commenced farming in 1971.

7.3 Plot shape (refer to Fig. 7.2)

Each plot is a rectangular shape of 1 000 m x 600 m (an area of 60 ha) and is equipped with irrigation and drainage facilities (including subsurface drainage) to facilitate complete control of the water. A length of 1 000 m was chosen to reduce to a minimum the embankment work of the canal, whilst the 600 m length was decided upon taking into account the effective catchment area of the subsurface drainage network.

A subsurface drainage system consists of a collecting conduit and a water absorption conduit. As a result of practical experiments, it was found that the length of collecting conduits should not be more than 150 m. This means that the secondary drainage canals (which receive drained water) should be set up at intervals of not more than 300 m. As the secondary drainage canals collect drained water from the fields situated on both sides of them, it was decided that the short side of the field should be 600 m.

7.4 Irrigation plan

7.4.1 Water source

One-fifth of the lake (which is about 4 500 ha) has not been reclaimed and its saline water has become fresh water. The water level in this part of the lake is 4 m higher than the reclaimed land surface.

7.4.2 Irrigation system

Twenty intakes were constructed along the embankment. The main irrigation canal runs along the short side of the farm (see Fig. 7.2) commanding both sides by branch irrigation canals set up orthogonally to the main canal.

7.4.3 Irrigation period

Fields are submerged without puddling and direct seeding is done with helicopters.

The irrigation period is as follows:

Table 7.2 Irrigation period

April		May			June			July			August			September		
middle	end	beginning	middle	end	beginning	middle	end	beginning	middle	end	beginning	middle	end	beginning	middle	end
Initial irrigation period			germination period		General irrigation period									Final drainage		

7.4.4 Water requirement

7.4.4.1 Unit water requirement

The water requirement in depth surrounding the polder, having similar characteristics to the reclaimed area, is shown in Table 7.3.

Table 7.3 Unit water requirement mm

		JUNE			JULY			AUGUST		
		beginning	middle	end	beginning	middle	end	beginning	middle	end
Muddy soil	max.	7.3	9.3	8.1	10.0	11.4	9.6	9.8	8.5	7.8
	min.	3.5	3.5	3.5	3.6	2.3	3.6	4.2	4.0	2.5
	mean	5.7	5.7	6.1	6.3	6.7	7.6	6.4	6.3	5.3
sand	max.	11.5	15.0	16.4	22.2	27.8	23.0	25.3	28.6	10.0
	min.	4.6	6.0	6.0	4.8	5.0	7.1	5.0	5.0	2.0
	mean	8.0	9.4	9.9	10.1	10.8	11.3	10.4	10.4	6.3

The water requirement is 8 mm/day for soft silty soil and 10 mm/day for sandy soil. 90 percent of the land consists of soft, silty soil and is formed as follows:

Clay (less than 0.005 mm)	40 - 70%
Silt (0.005 - 0.05 mm)	30 - 60%
Sand (more than 0.05 mm)	almost nil

7.4.4.2 Initial water requirement

More water is required at the beginning of the irrigation period than at other periods, i.e. about 122 mm. One irrigation system is divided into 10 blocks and they are irrigated within a 10 day period.

7.4.4.3 Water requirement in the germination period

In the early germination period the fields are drained twice a week during the day time to encourage healthy growth of roots and to supply oxygen to the root zone, but deep water is left overnight to protect seedlings from late frost and cool weather damage. Later in the germination period this is done once a week.

7.4.4.4 Water requirement for weed and pest control operations

One or two days after chemicals have been applied to the drained fields, they are submerged again. For this purpose each irrigation system is divided into 7 or 10 blocks; each block is drained for two days, chemicals are applied in one day, and two days later the field is irrigated for one day.

7.4.4.5 Water requirement for post mid-summer drainage

Mid-summer drainage takes place after maximum tilling. The water requirement after this operation is estimated at a rate of 20 - 30 mm/day and the rate of percolation is 15 - 20 mm/day.

The water requirement during the various periods is shown in Table 7.4.

Table 7.4 Various water requirements

Division	Water application days	Total water application	Water requirement	Formula	Arranged or mean water requirement	Remarks
	days/s	mm	mm/day		mm/day	
Initial water requirement	10	122	8	$(122 + 8 \times 9) \times \frac{1}{10}$	19.4	
After germination (at beginning)	Once every four days	60		$60 \times \frac{1}{4} \times \frac{24}{14.4}$	25.0	Recovered in 14.4 hrs.
After germination (at end)	Once every seven days	100		$100 \times \frac{1}{7} \times \frac{24}{13.5}$	25.0	Recovered in 13.5 hrs.
During germination (at beginning)			10	$10 \times \frac{3}{4} \times \frac{24}{9.6}$	18.8	
During germination (at end)			10	$10 \times \frac{6}{7} \times \frac{24}{10.5}$	19.6	
Post weed and pest control operations	7	100	10	$(100 + 10 \times 6) \times \frac{1}{7}$	22.9	
Post mid-summer drainage		25			25.0	

7.4.5 Gross water requirement

In order to determine the gross water requirement, the conveyance losses should be added to the net water requirement mentioned above. 15 percent of conveyance losses in design criteria (10 percent in the main canal, 5 percent in the lateral) is used for the project.

The largest irrigation system among the 20 in the project area commands an area of 2 090 ha and its designed water requirement is 7.114 m^3/s. The smallest irrigation system covers an area of 51.5 ha and has a designed water requirement of 0.181 m^3/s.

7.4.6 Intake facilities

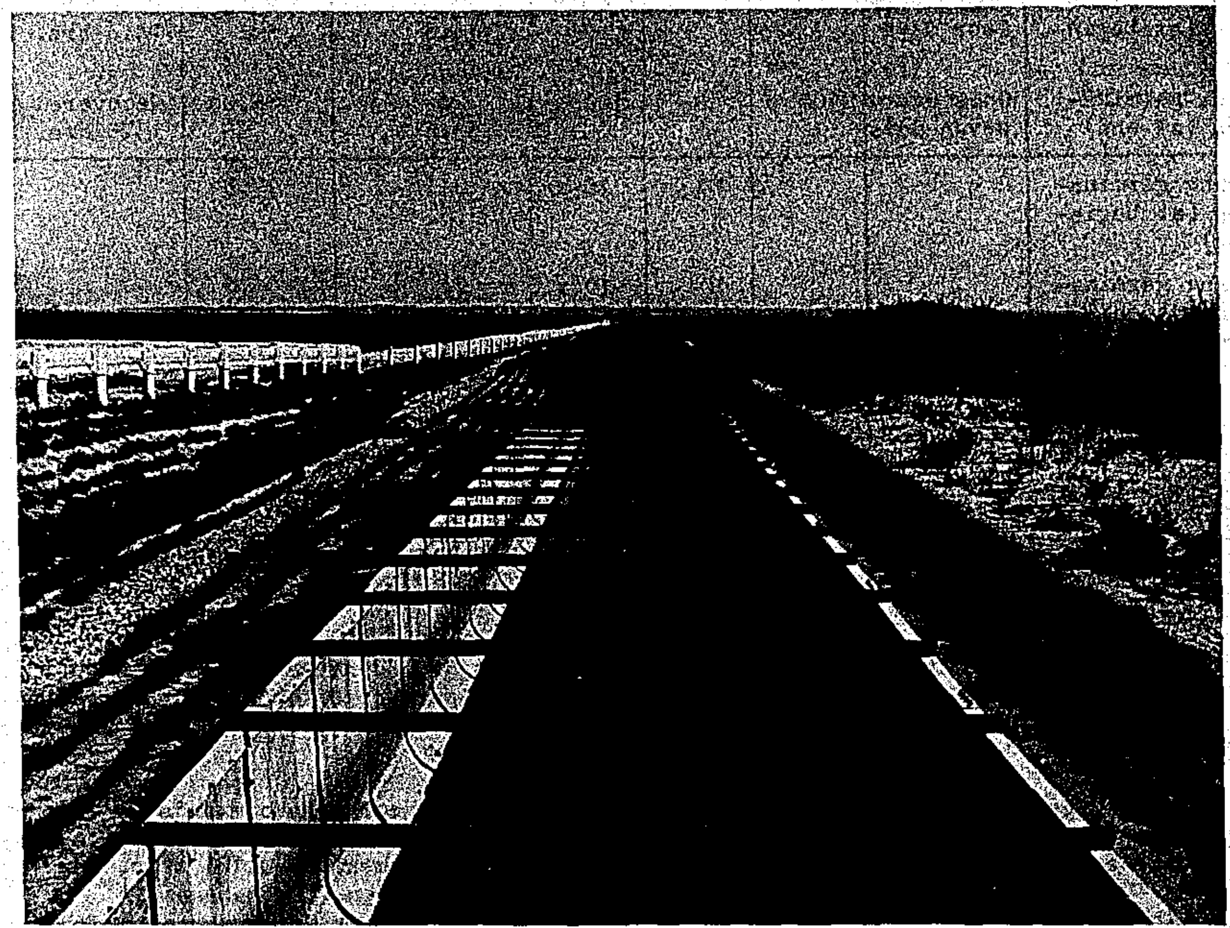
The 8 intakes from the west catch canal are of the conduit type and the 12 intakes from the reservoir and east catch canal are of the syphon type. The locations of the intake facilities are shown in Fig. 7.1.

7.4.7 Main irrigation canals

As most of the soil in the reclaimed area is very soft and has a low bearing capacity, consolidation of banks had to be continued and corrugated material, which is comparatively light in weight, was used to line canals. However, where the soil has a high bearing capacity the usual concrete blocks were used for canal lining.

The water level at a diversion point from a main canal to a tributary or branch canals is planned so that it remains at more than 0.6 m above the field level.

Corrugated flume canal



7.4.8 Tributary canals

Tributary canals 1 km long run from the main canal along the long side of plots and command an area of 30 ha. Their capacity is 0.133 m^3/s, which is sufficient for initial irrigation over a 4 day period. The water level at a diversion point from a tributary canal to a field is planned to remain at more than 0.1 m above the field level. The canals run alongside farm roads made of U-type concrete flumes.

7.5 Drainage plan

7.5.1 Basic considerations

As the water level of the reservoirs surrounding the reclaimed area is much higher than the level of the reclaimed land, the use of pumps is indispensable for drainage. However, complete drainage of such a vast area (15 700 ha) during a short time would require huge investments for pumping facilities and for operation and maintenance. Furthermore, the water drained from the upper reaches of the area would tend to accumulate in the lower part and cause serious flood damage.

In order to overcome these two problems, runoff control conduits were built in each drainage unit/block to control runoff from the higher areas and to spread flood water evenly over the entire area.

7.5.2 Drainage systems

The water drained from the fields and small drainage canal flows into a lateral drainage canal through a control conduit. The drained water then flows into the main drainage canal leading to pumping stations situated at its north and south ends.

7.5.3 Runoff

7.5.3.1 Design rainfall

255 mm/3 days rainfall (75 mm/day) was used for the design rainfall. The probability of such rainfall is once in 30 years.

7.5.3.2 Runoff from a unit area (60 ha)

Assuming that the design rainfall per day falls evenly and the runoff ratio is 100 percent, the unit discharge/2 hours is as follows:

$$\frac{75\ \text{mm}}{24\ \text{hrs}} \times 2\ \text{hrs} \times 60\ \text{ha} \times 100\% = 3\ 750\ \text{m}^3/2\ \text{hrs}$$

As the diameter of the runoff control conduit is 55 cm and its length is 2 m, the maximum flooding depth in fields is estimated at 15.9 cm, which does not cause any serious damage to the paddy. The flooding time is also short. The maximum runoff is estimated at 0.329 m^3/s.

7.5.3.3 Total runoff

Total runoff is calculated from the above figures for the unit area taking into account the time lag for runoff. The maximum runoff from the entire area was thus calculated to be 621 874 m^3 per 2 hrs.

7.5.3.4 Runoff retention capacity of canals

In view of the fact that the maximum discharge capacity of pumps is 40 m^3/sec, a part of the runoff should be stored in drainage canals. It is estimated that the accumulated flood water to be stored in the canals is 418 737 m^3/s which would cause the water level in the canals to be raised by 37 cm.

7.5.4 Small and lateral drainage canals

Small unlined drainage canals are situated along the long side of a unit area at intervals of 300 m.

Lateral drainage canals run along the short side of a unit area at intervals of 2 000 m.

7.5.5 Main drainage canal

In addition to its chief function - to drain runoff at the rate of 40 m^3/sec - the main canal, which runs through the lowest part of the reclaimed area, serves in a flood retention capacity.

7.5.6 Pumping stations

The location of the pumping stations was chosen taking into account these alternative objectives:

a) to drain runoff from the whole area through the main drainage canal, or

b) to drain the area separately (i.e. the higher and the lower part).

The first had the advantage of simplifying the drainage network and systems, but would necessitate the pumps having a larger hydraulic head. The second had the advantage of reducing operation and maintenance costs for pumping due to the comparatively low hydraulic head, but very complicated drainage networks would be required. The former was selected.

Two pumping stations were constructed at the north and south ends of the main canal. Each station has a drainage capacity of 40 m^3/sec.

The specifications of the pumps are as follows:

Two mixed flow pumps (vertical axis)	diameter	2 200 mm
	drainage discharge	12 m^3/s
	lifting head	7.8 m
Two mixed flow pumps (vertical axis)	diameter	1 800 mm
	drainage discharge	8 m^3/s
	lifting head	7.8 m

Drainage facilities

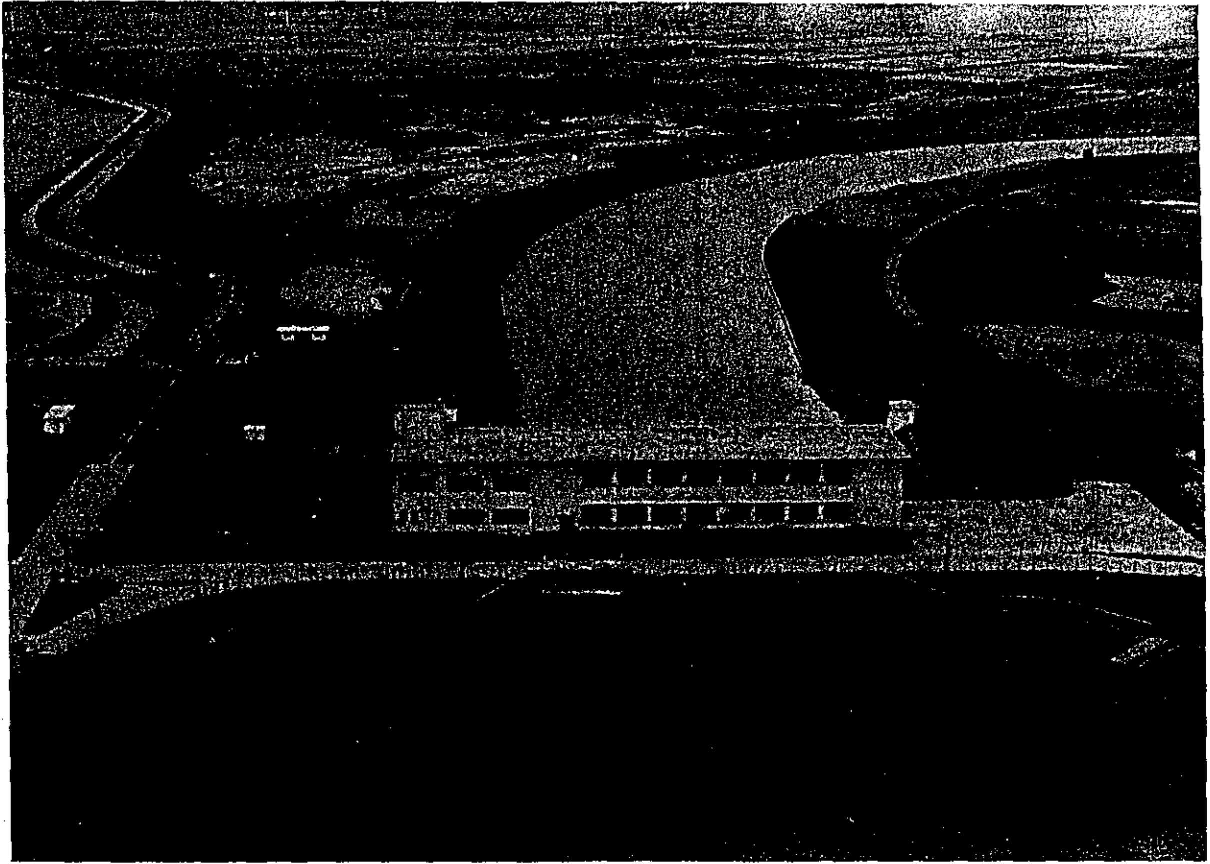


Fig. 7.1 General Plan of Hachirogata Reclamation

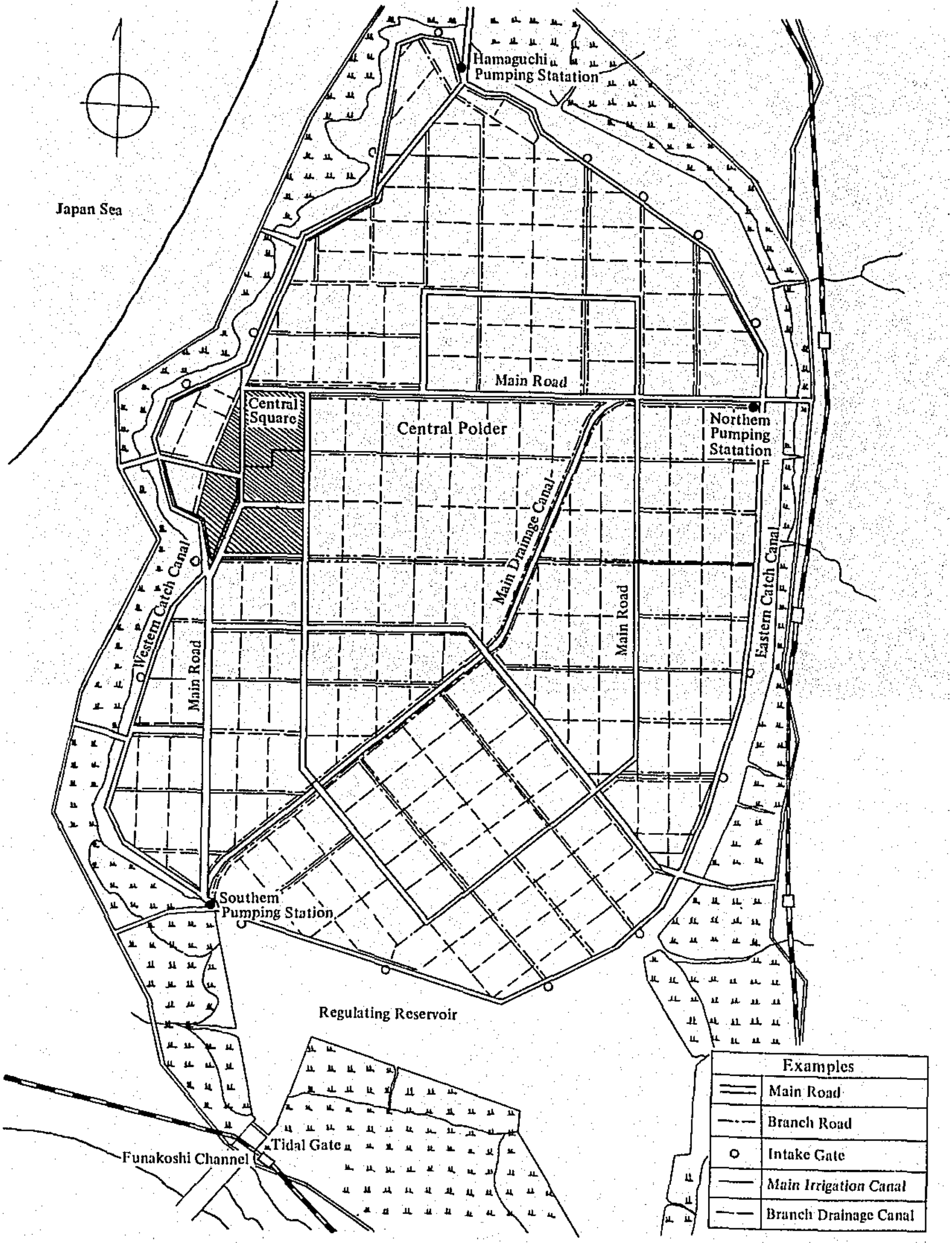
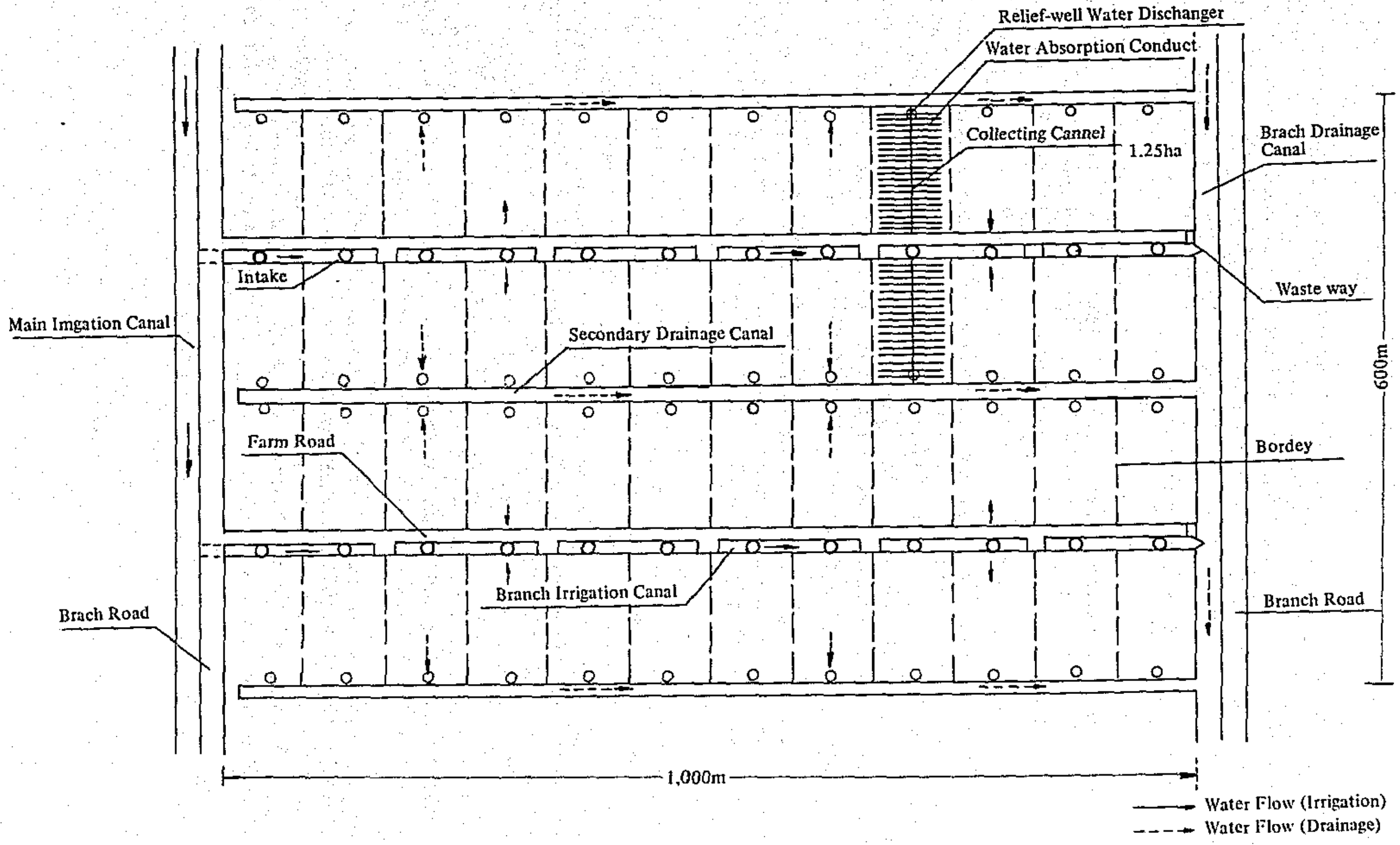


Fig. 7.2 Standard Specification for a Farm (60 ha)



Final remarks

During a long history of irrigation development, appreciable progress was made in the last 100 years and particularly in the last 30. However, greater efforts were directed towards engineering aspects and less attention was paid to the agricultural side, i.e. irrigation practices and water management. In fact, the design and construction of major civil engineering works, such as dams and big canals, received great attention, while water management at the farm level for farmers - who are the direct beneficiaries of irrigation projects - was overlooked.

During Japan's 70 year history of research and experimental work, efforts have been focused on variety improvement and fertilizer application, whilst water management has received less attention. Though it is very necessary, a precise and detailed study and measurement of water requirements would be meaningless, unless farmers use the water properly.

The fact that water management is now receiving worldwide attention indicates an awareness of the importance of and need for effective and intensive use of water at the farm level, without which farmers cannot benefit from the massive investments in irrigation development. It should be noted that parallel with the provision of physical facilities for water management, farmers must be trained to carry out proper water application to their fields - when, how much, how and why water is applied.

Those involved with rice irrigation in Japan have been tackling this important problem for years, but there is still much to be done. This publication, therefore, describes the efforts made so far in Japan and the present status of water management for rice in the country.

As is well known, the principle of irrigation is universal and can be applied to arid and humid zones. However, its application should take into account local characteristics. The authors wish to stress that the application of techniques introduced in this publication requires careful comparative consideration with local features and that a comprehensive study of past experience in irrigation and existing parameters in irrigated areas is essential in order to develop new techniques suitable for respective localities.

Irrigation is a means to an end - not the end in itself. It is hoped, therefore, that readers will foresee the end which is most suitable under the circumstances and develop new and realistic techniques in order to achieve the goal.

Finally, we would like to emphasize that irrigation and drainage are the farmer's means of influencing the availability of water for crop production and preventing harmful effects from drought and excess water, and that an intimate coordination must be maintained in a well balanced manner between irrigation and drainage. This is the reason for our proposing a new word IRRINAGE on the ICID conference in 1973 in Bulgaria.

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