THESIS

EFFECT OF SUPPLEMENTARY IRRIGATION ON THE YIELD OF HYV RICE IN DACCA AREA

ABUL FAZAL MD. SALEH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENGINEERING (WATER RESOURCES)

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DACCA

APRIL, 1981

BANGLADESH UNIVERSITY OF ENGINEERING & TECHNOLOGY

April 28, 1981

WE HEREBY RECOMMEND THAT THE THESIS PREPARED BY ABUL FAZAL MUHAMMAD SALEH ENTITLED EFFECT OF SUPPLEMENTARY IRRIGATION ON THE YIELD OF HYV RICE IN DACCA AREA BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENGINEERING (WATER RESOURCES).

Chairman of the Committee — (Hamidur Rahman Khan)

Member — (Abdul Hannan)

Member — (Md. Shahjahan)

Member — (Kh. Azharul Haq)

Member — (Sohrabuddin Ahmad)

Head of the Department — (Abdul Hannan)

(15)

ABSTRACT

Although Aus and Aman rice cover 89% of the total cropped area and yield 83.7% of the total rice output, these two crops are still grown under 'providence' methods — that is, by impounding rainfall inside the cropped area and depending entirely upon rainfall as a soil moisture source. The high uncertainty involved regarding availability of rainfall during transplanting and during the crop growing periods of these two predominantly rainfed crops has often meant that investments made in these crops were lost, although the mean annual rainfall in the country varies from 1400 mm in Rajshahi to over 5000 mm in Sylhet and 80% of this rainfall occurs during the Aus and Aman crop growing periods.

The present study was aimed at quantifying the amount of supplementary irrigation, determining its effects on the yield and analysing the risks associated with rainfed Aus and Aman cultivations. Experimental plots were taken at the farm of Bangladesh Rice Research Institute, Joydebpur. There were in all five treatments ranging from totally rainfed plots to 25 mm to 50 mm standing water on the plots. The water balance method was applied for determining the crop water requirement with provisions for measuring rainfall, evaporation and seepage and percolation.

From the study, it was observed that with supplementary irrigation increase in yield varying from 8% to 71% over rainfed

condition occured during the study period for different treatments. The amount of supplementary irrigation varied from 69 mm in Aus season to 573 mm in Aman season for the treatment of 25 to 50 mm standing water on the plots. For the saturated plot treatment a 57% higher yield over rainfed condition was observed during the Aman season and required 14.4 mm of water from irrigation. From the analysis of rainfall data it was observed that rainfall during the crop growing period has to be supplemented by irrigation to meet the crop water requirement and to ensure a dependable yield during the Aus and Aman seasons. From probability analysis of rainfall it was found that the Aus crop requires supplementary irrigation in one out of four years and in case of Aman crop the supplementary irrigation is required in three out of four years. The amount of supplementary irrigation required varies from 0 to 67 mm for Aus season and 67 mm to 309 mm for Aman season with rainfall probabilities varying from 50 to 75 percent and 25 to 75 percent for Aus and Aman seasons respectively.

ACKNOWLEDGEMENT

The author gratefully acknowledges his indebtedness to his supervisor Dr. Hamidur Rahman Khan, Professor, Department of Water Resources Engineering, for his able guidance, continuous advice and warm inspiration in making this thesis possible.

The author wishes to express his warm gratitude to other members of his research committee, Dr. A. Hannan, Professor and Head, Department of Water Resources Engineering, Dr. M.Shahjahan, Professor, Department of Water Resources Engineering, Dr.Sohrab-uddin Ahmad, Professor and Head, Department of Civil Engineering and Dr. Kh.Azharul Haq, Head, Division of Agricultural Engineering, BRRI for their valuable comments, criticisms and suggestions which greatly improved the report.

The author is indebted to the officers and field assistants of the Division of Agricultural Engineering, BRRI for their help and cooperation in carrying out the field experiments. Special acknowledgements are due to Mr. Md. Jahirul Islam, Scientific Officer for his sincere help and valuable suggestions.

Finally the author wishes to thank Mr. M. Mofser Ali for his help in neatly typing the thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE

ABBREVIATIONS

BCR	Benefit cost ratio
BRRI	Bangladesh Rice Research Institute
DTW	Deep tubewell
HTW	Hand tubewell
cm	Centimeter
ET	Evapotranspiration
EV	Evaporation
GDP	Gross Domestic Product
HYV	High Yielding variety
IRRI	International Rice Research Institute
Kg	Kilogram
LLP	Low lift pump
m	Meter
mm	Millimeter
MP	Muriate of potash
NPK	Nitrogen, Phosphorus, Potassium
RN	Rainfall
SD	Surface drainage
SFYP	Second Five Year Plan
S & P	Seepage and percolation
STW	Shallow tubewell
T/h	Tons per hectre
TSP	Triple super phosphate
U.S.D.A.	United States Depatment of Agriculture.

CHAPTER - I

INTRODUCTION

1.1 General:

Bangladesh, a flat riverine country, has an area of 14.3 million hectres and a population of almost 90 million thereby giving it a population density of approximately 630 people per square kilometre. Out of the total 14.3 million hectres, 9.43 million hectres (66%) is cultivable land, 2.14 million hectres (15%) is utilized for forest which includes hills and the rest 2.73 million hectres (19%) is covered by rivers, home steads, ponds, beels, haors etc. Agriculture is the dominant sector of the country's economy and accounts for about 56% of GDP and gives employment opportunities to 80% of population (Tarafdar, 1977). The country's warm climate is favourable for crop growth all throughout the year. This permits intensive cultivation and multiple cropping but the intensification is constrained by the fact that about 50% of the cultivable land is not suitable for intensive cultivation all the year round. This area includes about 0.8 million hectre of low lying land which is flooded to a depth of 3.5 to 4.5 metres from June to October and can therefore only be cultivated when the flood recedes in November. Another 2.43 million hectres of cultivable land are annually flooded from 1.0 to 3.5 metres and is used for low yielding rice. Another 1.2 million hectres in the coastal areas are inundated with saline water and can hardly sustain one crop during the rainy season. Thus with little scope left for increasing land area for cultivation and population growing at an annual rate of 3.4% while the food production increasing at a rate of less than 2%, Bangladesh presents itself as a challenge for development.

The Second Five Year Plan (SFYP) of Bangladesh (1980) aims at achieving a projected food grain production target of 20.1 million tons as against bench mark level of 13.5 million tons (Table - 1). Out of the total production target, 17.78 million tons (88%) are expected from the cultivation of rice only. It has also been estimated that the total food grain produced will be enough to feed the projected population of 101 million in 1984-85 at a slightly higher level of consumption (440 grams per day per capita as per FAO estimates) and also allow a disaster relief contingency of 10% (Planning Commission, 1980). This estimated food grain production requires an increased production rate of 7.6% per year and a yield of 1.75 tons per hectre. The production target appears to be an ambitious one when compared with the past performances of the country. In the year 1977-78 the total rice production was 12.76 million tons from 10 million hectres, the average per hectre production being only 1.28 tons.

1.2 Rice Cultivation in Bangladesh

The Principal ingredient of the popular diet in Bangladesh is grain, and rice makes up 95% of the grain output. Agriculture in this country is overwhelmingly dominated by rice, the crop around which the entire economic life gravitates. For the foreseeable future, however, rice production will provide the main source of income and livelihood, the main source of calories in the diet and the main indicator of economic and even political viability of the country. Thus for the country to be able to feed its population by the mid - 1980s and attain self-sufficiency in grain output, as desired in the SFYP requires an increase in rice production as well as its stabilization overcoming the vagaries of nature and technical and institutional drawbacks. The grain production can be considerably improved by the introduction of high yielding varieties (HYV) of rice and application of necessary inputs like irrigation water, fertilizers, pesticides, credits and extension services based on research results suitable to local condition. In addition to the improvement of rice production techniques and their extension among farmers, improvement of social and economic environment of infrastructure such as facilities for supply of production materials or the processing, storage and the marketing of agricultural products is also essential.

Rice in Bangladesh is grown in three seasons - Aus, Aman and Boro and through two general techniques-broadcasting (seeds tossed by hand in the ploughed field) and transplanting (3 to 4 weeks old seedlings transferred to puddled field from seed bed). The varieties of rice grown vary by season and technique and the choice depends on the characteristics of the land-upland and lowland, the resources available to the farmer, the state of technology and alternative cropping possibilities.

Aus (Summer crop): Aus is an upland rice grown both as broadcasted and transplanted crop. It is planted with the advent of the monsoons in April or May and is harvested in July or August. However, the uncertainty of rainfall during the season when Aus is planted prevents the transplanting of the crop in time except where irrigation is available. This delay in transplantation of the seedlings because of uncertainty of rainfall results in a decreased yield due to sensitivity of the crop to photo-period and other crop physiologic changes due to climatic factors like temperature, humidity etc. Moreover delay in transplanting renders the land fallow for the next cultivable season. Aus covers 32% of the total rice growing area and makes up 25.6% of the total rice production (Kroury, 1981). Since Aus is predominantly a rainfed crop, it is expected that there will be some loss in yield due to uncertainty of rainfall during the crop growing period.

Aman (Autumn crop): Aman is the largest rice crop grown and its total yield amounts to two and half times more than that of Aus. The Aman paddy provides 57.8% of the total rice yield and covers 57% of the rice growing area. Aman paddy is also grown both as a broadcasted and a transplanted crop. Broadcast Aman contributes 13% to the total rice production. Because it is grown in deep water areas broadcasted Aman is exposed to early floods and later to early droughts. The broadcast Aman can tolerate moderate flooding and some of the long stemmed types can float in deep water and can grow upto 25 cm in 24 hours. Transplanted Aman, which makes up 45% of the rice production is one of the main crops which is concentrated upon for development; for it is the preferred one, producing the finest quality of rice and providing about 18% more yield than the broadcast varieties (Kfoury, 1981). Aman paddy is predominantly rainfed and provides a good per acre yield of rice and is planted during the peak monsoon period i.e., in July or August and harvested in November or December. The heavy monsoon rains keep the paddies wet, thus providing necessary soil moisture.

Boro (Winter crop): Boro occupies only 11% of the total rice cropped area and provides 16.6% of the total rice yield. The yield per hectre of Boro is highest, 3.95 tons per hectre which is almost twice that of Aus's yield and about 62% higher than Aman's yield. Boro is a transplanted paddy and since it is grown in the dry winter months its survival is heavily dependent upon adequate water supply provided through irrigation. Boro seedlings are transplanted in December to January and harvested in April to May.

1.2.1 Irrigation in Boro season and prospects of achieving food self sufficiency:

Rice, like any other crop requires an adequate supply of water to grow and develop at its maximum potential rate. The water that rice plants require for its growth is normally supplied by rainfall and flood water from rivers. Of the three rice growing seasons the Boro season has the highest yield potential.

This season is also characterized by dry weather with little or no rainfall available to meet the crop water requirement. As a result, crops during the Boro season depend entirely upon irrigation water — the requirement being around 1446 mm (Halim and Khan, 1978). The scarcity of water for irrigation during the Boro season results in limited acreage, although the crop itself has a high yield potential. With widespread annual flooding and average rainfall in excess of 2000 mm (Allison and Jalal, 1974) the country appears to be over endowed with water resources. But the distribution of rainfall is very much skewed with little or no rainfall occuring during the Boro growing period of November to March. The river flows are also significantly less during the winter season, limiting potential for surface water use for irrigation. The most critical of the dry periods are February and March during which the total river flow amounts to 6.35 million hectre metres in comparison to 79.1 million hectre metres during August (Haroun, 1977). Apart from the low flow during winter months the development of surface water resources for irrigation is constrained and complicated by requirements for navigation, domestic use and saline water intrusion problem in the coastal estuary.

Now turning to groundwater as a source of irrigation the utilization of this resource should be limited to the areas where: (1) suitable aquifers with proper water qualities are available, (2) annual replenishment of groundwater equals the total withdrawal of groundwater, (3) withdrawal has a minimum effect on other water uses,(4) depth of water table makes a reasonable cost of pumping etc. Considering all these factors it is estimated that an area of nearly 2.67 million hectres can be brought under irrigation using groundwater as a source (Bhuiyan, 1977). The area estimated to be brought under irrigation in the SFYP using both surface and groundwater as a source amounts to 2.91 million hectres (30% of the cultivable area), which includes 0.40 million hectre to be irrigated by traditional methods. In 1980 the total area under irrigation was 1.44 million hectres including an area of 0.36 million hectre irrigated by traditional method. Since there is no significant increase in the irrigation by traditional methods in the SFYP it is estimated that the 75% increase in the irrigable area will result from the increased installation of deep tubewells (DTW), shallow tubewells (STW) and low-lift pumps (LLP) (N.Alam, 1981). Irrigation by DTW, STW and LLP are constrained by requirements for engines, spare parts, skilled operators,socio-economic factors and last but not the least the cost of fuel. With the many fold increase in the fuel price during the last few years and also with further increase in the years to come, the ambitious plan of doubling the irrigable area by 1985 from the present level is definitely at a stake. Thus, there seems to be a limited scope for increasing the area under Boro cultivation which requires irrigation water at every stage of its growth.

Leaving aside the Boro, the other two crops that fills the country's food requirement are Aus and Aman. Although Aus and

Aman combined cover 8.9 million hectres (89%) of the total cropped area and and yield 10.3 million tons (83.7%) of the total output, these two crops are still grown by 'providence' methods - that is by flooding during high water of rivers or impounding rainfall inside the cropped area. The prospects of developing Aus and Aman crops would be discussed is details later.

Another aspect of achieving the food target is the introduction of new high yielding varieties (HYV) of rice and modern agricultural practices as a realistic technology for agricultural improvement. The introduction of HYV rice of the International Rice Research Institute (IRRI) has greatly improved the harvest of three rice crops. The improved HYV rice, which is usually dwarf, yields two to three times more than the traditional varieties. The Planning Commission in its SFYP has rightly emphasized the importance of switching over to the improved varieties, as in a densely populated country like Bangladesh, HYV and the hybrids have been recognized as the key to survival.

1.2.2 HYV rice cultivation in Bangladesh:

The HYV strains of IRRI which were later improved, modified and adapted to the local conditions by the Bangladesh Rice Research Institute (BRRI) are available for use in all three rice crops. Of the 1.62 million hectres of HYV rice that is grown at present, 0.80 million hectre is HYV Aman, 0.60 million hectre is HYV Boro and 0.20 million hectre is HYV Aus (Kfoury,1981).

The HYV strain possesses certain characteristics for yield improvement: (1) shortness of stem for strength (this characteristic is a disadvantage in flood prone areas), (2) insensitivity to photo-period, (3) enough available soil moisture all throughout the crop growing period, (4) responsiveness to nitrogenous fertilizers, (5) short growing season to allow more than one crop to be grown during the year, (6) resistant to most of the common diseases, pests and stem borers (BRRI, 1978). The first HYV rice introduced in 1966 was IR-8 which possessed all the above listed characteristics and was found suitable as a Boro crop. Its introduction increased the winter crops yield three times from the traditional variety. However increased use of IR-8 has been limited by the slow expansion of irrigation which is necessary to provide water during the dry winter months. Another HYV rice is IR-20, introduced in 1970 for the Aman crop. This variety had all the characteristics of HYV rice but it was found to be slightly sensitive to photo-period. By 1972, 4.7% of all Aman of which 7% was transplanted Aman was HYV. High yielding varieties for the Aus season is less common and in 1972 only 1.6% HYV was used. This is mainly because Aus is broadcasted not transplanted. However, prospects of using HYV for Aus in place of traditional varieties are good. Today 16% of the total rice cultivated area is under HYV and thirteen high yielding varieties invented by the scientists of IRRI and BRRI are in practice. The hybrid progeny lines invented at BRRI are known as BR-1, BR-2 etc. Thus the use of HYV seeds for the Aus, Aman and Boro rice crops has increased significantly the total rice output.

1.2.3 Problems and prospects of rainfed Aus-Aman crops:

Although 59% of the total Boro cultivated area is under HYV rice, the similar area under Aus and Aman is only 6% and 14% of their total areas respectively. The high uncertainty involved regarding availability of moisture during the growing periods of both the Aus and Aman seasons has often meant that investments made in these crops were lost. Studies (Oury, 1972 and Manalo, 1976) show that although annual rainfall in Bangladesh ranges from 1400 mm in Rajshahi area to over 5000 mm in Sylhet (Fig.1) there are 8 months in Rajshahi district and 4 months in Sylhet district with less than 100 mm rainfall (Fig. 2). Months exceeding 200 mm (8 inches) of rainfall considered as 'wet months' are 7 in the district of Sylhet and only 3 in the district of Rajshahi (Fig. 3). Moreover during the wet months also the distribution of rainfall in amount, intensity and duration is very such non-uniform. Thus even during the monsoon or wet months, there are periods of droughts when Aus and Aman crops (which are predominantly rainfed) are damaged due to insufficient rainfall, especially during transplantation and flowering of the plants. Hence the crop that fills 85% of our food requirement and on which the over all food situation of the country is very much dependent is left to the uncertainties of nature for its rearing. A positive step in attaining food self sufficiency lies totally on the ensuring of a good harvest of Aus and Aman crops, and this can be achieved in two ways:

(1) by bringing the total Aus-Aman cultivable area under HYV rice cultivation in phases, so as to increase the overall yield and

(2) by increasing the present yield per hectre with ensured irrigation all throughout the crop growing period.

The cost involved with ensuring irrigation to the Aus and Aman crops would be much less in comparison with the cost of irrigating Boro crop, firstly because Aus and Aman are perdominantly rainfed crops and hence would require much less water from irrigation for the crop growth and secondly the cost of irrigation would also be much less as water for irrigation at that time is readily available both from groundwater and surface water sources. As water is available at very low heads, traditional methods can also be applied for irrigation.

It is, therefore, imperative that a detailed study on the amount of irrigation water required during the Aus and Aman seasons, its need and effect on the yield, climatic and agronomic factors controlling the amount of water to be applied etc. be conducted so as to establish the ideas expressed earlier before proceeding with the development plans of achieving food self sufficiency.

1.3 Review of earlier works:

The development of rice as a staple crop has gone hand in hand with the development of irrigation, as it is primarily a water crop. But Bangladesh does not have a long history of agricultural water use. With excessive rainfall during the monsoon, fertile alluvial soils and year round warm weather the people have been able to feed themselves until the mid fifties without resorting to irrigation. Now that the population growth has overtaken the productivity of traditional agriculture, sufficient food can only be produced in future by making an optimum utilization of the all available resources for crop production.

Irrigated agriculture which is a rather new concept in the agricultural practices of Bangladesh is practised during the dry winter periods for growing Boro, wheat, vegetables etc. Supplemental irrigation which means application of relatively small amount of water for a short duration when crops are suffering from water shortage due to unusual droughts is a completely new concept in this country. In supplementary irrigated crops the major portion of the crop water requirement is supplied by rainfall and irrigation water is supplied from time to time to cover any deficit. The Aus and Aman crops grown under rainfed condition are subjected to the hazards of droughts due to undependable rainfall during the monsoon. Boro crop grown during the dry winter period with little or no rain is reared mainly by irrigation water. But before imparting any further stress on developing Boro crop for reducing the food deficiency with total irrigation, efforts should be made to develop the Aus and Aman crops with supplemental irrigation for obtaining the optimum yield.

Not much research work had been conducted to quantify the amount of supplementary irrigation water and to determine its effects on the yield. Biswas and Ali (1976) in a study on the determination of consumptive use of IR-8, conducted in the Aus season of 1974 found the consumptive use to be 1100 mm. The maximum yield obtained in their study was 7.85 tons/hectre which occured in 100 mm submergence treatment with total water use of 1922 mm.

Khan (1977, 1979) presented a method for determining the probable dates of transplantation and the corresponding risks involved for HYV Aman under rainfed condition using available rainfall, consumptive use and soil data. The study revealed the fact that although rainfall during the crop growing period is more than the crop water requirement there is a need for supplementary irrigation due to erratic distribution of rainfall. It was observed that sufficient moisture for transplanting Aman is available between May to July depending on location and degree of accepted risk. For any given degree of risk, Aman seedling can be transplanted earlier in the eastern part of Bangladesh than in the west because of earlier and longer monsoon in that part. With a statistical approach, the amount of supplementary irrigations at different probabilities were also obtained from the analysis.

Another study was undertaken during the Aman seasons of 1978 and 1979 by the Irrigation and Water Management section of the Division of Agricultural Engineering, BRRI to determine the impact of supplemental irrigation for transplanted Aman. The experimental findings showed that with supplemental irrigation varying from 38 mm to 828 mm the yield varied from 16.6% to 51.8%

higher over the rainfed condition (BRRI, 1980). The higher yield was obtained under a continuous flooding treatment of 50 mm to 76 mm. The study pointed out that with proper management of supplemental irrigation in the transplanted Aman season a significantly higher yield can be obtained.

1.4 Objectivies of the study:

From the analysis of the previous research findings it is apparent that supplementary irrigation is required and has a definite positive effect on the yield of transplanted Aman. But the amount of supplementary irrigation both in magnitude and period of application during the Aus and Aman seasons still deserves attention, No study on the supplementary irrigation requirement of Aus crop was taken, although Aus is also a rainfed crop.

Considering all the above mentioned facts this study has been taken up with the following specific objectives:

(a) To quantify the amount of supplementary irrigation for both Aus and Aman HYV rice crops at different stages of the crop growing periods;

(b) To find the variation of yield with the amount of supplementary irrigation;

(c) To determine the risks associated with the cultivation of HYV Aus and Aman rice under rainfed conditions.

CHAPTER - II

PLANT, SOIL, WATER AND YIELD RELATIONSHIPS IN HYV RICE CULTIVATION

The moisture of the soil is one of the three main elements of plant growth, the other two being the nutrients in the soil solution and solar radiation. For centuries man has tried to control the water content of the soil where and when the natural conditions of the water regime do not permit or are unsatisfactory for agricultural production. Effective control of water environment is essential for maximum utilization of technological development in rice production. Basic to effective control is a thorough understanding of the optimum water environment in relation to rice growth stages and crop yield.

2.1 Rice growth stages:

The life cycle of a rice plant can be divided into three phases, (a) vegetative growth period, (b) reproductive (generative) growth period and (c) ripening period (Fig. 4).

(a) Vegetative growth period: The vegetative phase starts with the sprouting of seed and ends at panicle initiation stage. Following transplantation the vegetative period covers the (1) rooting stage, (2) maximum tillering stage and (3) effective tillering stage. The period between germination of the seed and production of five leaves of the seedling is the seedling stage.

A rice seedling at the five leaf stage is capable of producing tillers.

(b) Reproductive (generative) growth period: This period follows maximum tillering and covers the stages of panicle development, booting, heading and flowering. During the booting stage the panicle axis and branch development are completed. The heading stage begins with the protrution of panicles from the leaf sheath and thereproductive stage ends with pollination and fertilization at flowering.

(c) Ripening period: During the ripening period carbohydrate from leaves and stem is transferred to grains. The grain formation is a step-wise process and is divided into milky, dough, yellow and full ripe stages.

2.2 Field water requirements:

The constituents of water required to grow HYV rice are evapotranspiration (ET), seepage and percolation (S&P) and surface drainage (SD). Only evapotranspiration is the true water requirement for crop growth, but in supplying it, some seepage, percolation and surface drainage is inevitable (Fig.5).

2.2.1 Evapotranspiration (ET):

Evapotranspiration is the amount of water used by the plants plus that evaporated from the surface of the ground. Water that moves through the plants is mostly transpired through the leaves, but some is retained in the plant tissues during crop growth.

There are two measures of ET, potential and actual. Potential ET is the rate of ET when there is no limitation in water availability i.e., the soil can supply all the water demanded by crop and that used in surface evaporation. Actual ET is the amount of water actually evapotranspired, and this is usually less than the potential because the plants are usually unable to get all the water they could use. It has been found that potential ET is about equal to the rate of evaporation from a free water surface. The standard evaporation pan takes advantage of this fact to provide reliable estimates of ET. Actual ET is less than potential but HYV rice grown under flooded condition and even sometimes when it is not (provided the soil is saturated or nearly saturated) has essentially potential ET. Thus ET of flooded rice can be closely approximated by evaporation rate from a standard evaporation pan (Wickham and Sen, 1977). There are other more sophisticated methods of estimating ET, but the advantage of the pan technique of estimation is that it is easy, inexpensive to install and use in any location and sensitive to local conditions similar to those associated with the fields themselves. Well maintained pans give data within 10% of ET for rice (Kampen and Levine, 1970), as long as the crop is at or near potential (flooded) conditions (Fig. 6).

Evapotranspiration is essentially independent of the stages of plant growth (Fig. 7). When the crop is newly planted, plant transpiration is relatively little, but evaporation from the water surface is high. But as the crop grows transpiration increases while the increased shading of the water surface reduces evaporation. The ratio of evaporation and transpiration is mostly a function of leaf area index and fluctuates as the leaf area index rises and falls (De Datta, et al. 1975).

2.2.2 Seepage and percolation (S&P):

Seepage is the lateral sub-surface movement of water and percolation is the sub-surface movement of water in the vertical direction. They are however considered togather, because it is very difficult to artificially seperate them in the field and because they occur simultaneously. Factors that combine to produce a given seepage and percolation rate are type of soil, depth of water table, proximity to drains, slope of surface, poor maintained bunds and depths of standing water. Very little can be done to reduce seepage and percolation from flooded fields apart from keeping the bunds plastered with mud and in good repair.

A simplified method of estimating seepage and percolation in the field is by using an inclined meter. The fall of water level is noted from day to day. The fall is assumed to be the sum of ET and seepage and percolation provided there is no rainfall, irrigation or surface drainage. Seepage and percolation can be estimated by subtracting pan estimates of ET. In practice, data of about half the days of a season must be discarded when surface water flows are met. Lysimetric studies or water balance analysis can also be applied for determination of seepage and percolation.

2.2.3 Surface drainage (SD):

A significant portion of the water available at the fields from rainfall or irrigation runs off the fields into adjacent drains, low lands, creeks etc., as surface drainage. Large surface drainage losses are expected in the wet season when heavy rains often provide more water than can be stored on the fields or used by the crops.

2.2.4 Land preparation:

Land preparation requires considerable more water than is usually recognized and failure to supply it on time results in non-uniform and delayed plantings which tend to reduce the intensity of cropping. At least two weeks prior to puddling, soaking is necessary to allow the weeds and rice stubbles to be decomposed (Valera, 1979). Rice fields require about 100 mm to 150 mm of water for land preparation and puddling operations (De Datta, et al. 1975, Khan, 1979). The water required in nonpuddled field is 50 percent of that required for a puddled field.

2.3 Water requirement at different growth stages:

The demand for water by crops is less during the seedling or juvenile period but increases with the increase of the number of tillers during the vegetative growth. Immediately after transplanting sufficient moisture is required to develop new roots. Drought occuring during this stage causes poor growth and checks tillering resulting in remarkable yield decrease. Subsequent to rooting stage shallow water is preferable during the major part of the vegetative growth. It has been ascertained that the respiration function of the roots is maximum during this stage and therefore, introduction of air into the soil by drying the field is necessary to promote vigorous root growth (Tabbal, 1979).

During the major part of the reproductive stage a large amount of water is consumed. Drought occuring during this period causes damage because it impairs panicle formation, heading, flowering and fertilization leading to sterility and hence in reduced yield.

During the ripening period less water is needed until gradually no water is required after the yellow ripe period. Paddy fields are also being drained during this stage although early drainage may result in immature grains.

2.4 Water requirements and rice yield:

The amount of water needed to grow a crop of rice from transplanting to harvesting has not been definitely quantified because of variations in (a) antecedent moisture in soil, (b) soil type and fertility (c) length of growing period (d) method of cultivation (e) topography (f) variety of rice and (g) others.

Studies at IRRI (Tabbal, 1979) showed that when the water reaching the crop was in the 750 mm to 1000 mm level, there was no significant change in the yield, but when it was below 550 mm essentially no yield was obtained (Fig. 8). Studies in Taiwan revealed a sharp yield reduction when less than 600 mm of water was applied to the crop.

Water requirements are affected by the depth of water since higher the depth the greater is loss due to seepage and percolation. Thus the deeper the depth of water maintained in the field the higher would be the water requirement for the crop.

2.5 Depth of flooding and yield:

Although rice plants are known to be water loving and grown generally with standing water in the field, recent studies however show that rice can be relatively well grown without causing serious yield decrease compared with that obtained under continuous flooding if soils are saturated with water or soil moisture can be maintained very close to saturation point. The highest water use efficiency is attained under these water management practices and seasonal water requirements are 700 mm to 800 mm which is about equal to seasonal evapotranspiration (Tsutsui, 1972). In most rice growing areas, rice fields are submerged continuously throughout the crop growing period, mainly because fields are not provided with adequate watering systems and artificial control of water is neither feasible nor practicable. Apart from that continuous flooding has other advantages such as:

(a) Satisfactory plant growth and rice yield can be obtained.

(b) Helps to eliminate weeds,

(c) Gives better response to timely applications of fertilizers,

(d) Gives better insect and weed control with granular chemicals,

(e) Saves labour for water management.

Shallow water depth on rice fields usually gives favourable results in regard both to the amount of water needed for irrigation and also the rice yield. This is clearly shown in Table-2. But a factor preventing saturation or shallow water application is the problem of weeding.

2.6 Depth of flooding and weed control:

Rice weeds have been serious problems in rice culture. Once weeds have infested the soil they are very difficult to control. Weeds compete with rice plants not only for nutrients, but also for light, space and water. Studies at IRRI (De Datta, <u>et al</u>. 1975 and Tabbal, 1979) have shown that as little as 25 mm of standing water drastically reduces weed population (Fig. 9) and with 150 mm grasses, sedges etc. may be effectively suppressed.

2.7 Method of water application:

There are two methods of applying the required amount of irrigation water to the rice field:

(a) Continuous submergence - the rice field is submerged from transplanting upto about two weeks before harvest.

(b) Intermittent irrigation - the rice field is alternately submerged and drained. The soil surface is allowed to dry prior to the next application of water.

It has been argued that during the monsoon season in Asia, there is plenty of rain water and this is a good justification for use of uncontrolled or continuous submergence. This justification is open to serious doubt. Although continuous flooding gives high yield and has other advantages like better weed control, fertilizer efficiency etc., continuous flooding not only wastes water but also causes serious drainage problems, zinc deficiency etc., either because of poor internal drainage or poor surface drainage (Chow, 1965). Satisfactory rice yields are being obtained under water saving practices in rice cultivation, i.e., intermittent irrigation. Such practices should be encouraged and promoted from the point of view of water economy. Nevertheless, in most rice growing area, this method has not yet been adopted because (a) it requires a complete system of irrigation and drainage involving high cost (b) it needs the services of well trained irrigators and (c) this method can require new farming techniques and soil and water management practices which are new to those who are still accustomed to the continuous flooding farming method.

Considering all factors, when water is readily available, continuous submergence with 50 mm of water is probably best for irrigated rice (Barker, 1972).

2.8 Total submergence and rice yields:

Although the saturation of the root zone and the application and maintenance of a layer of water on the field is not only useful but is an essential feature of rice culture, rice plants when submerged completely, or even partially, for over a certain period of time, yield loss of various magnitudes occurs depending on the stages of growth of crop as well as the duration of submergence. IRRI studies (Bhuiyan, 1979) show that yield loss due to submergence ranged from zero for partially sumerged condition to 100% for fully submerged contitions at 5-day submergence duration. Greatest yield reduction occured for plants fully submerged during the panicle initiation stage for all durations of submergence.

The effect of submergence on rice yield is also dependent on the quality of water submerging the field.

2.9 Water stress effects on growth and yield:

In rainfed rice cultivation, rice fields often become dry and the crop suffers from various degrees of water stress. It was mentioned earlier that rice crop thrives best if the paddy field is always submerged or if the soil is always saturated. When the soil becomes dryer day by day, the rice plant begins to be stressed, and the cumulative amount of stress is reflected in the yield. This had led to the definition of the 'stress day concept' for rice. The point of reckoning is when water disappears from the field's surface. After 3 intervening days stress is being accumulated which is inversely related to yield (Early, 1979). At this stage of water stress initial cracks are developed on the f field. The stress day enumeration system counts the fourth day after water disappears as stress day number one, the fifth day as number two etc.

The effects of moisture stress are widely believed to be more pronounced at some growth stages than others. Water stress reduces crop yield much more when it occurs during these critical stages. Experiments were conducted at IRRI (Okamato,1977) to impose water stress on the growing rice crop at differing growth stages. The results of these experiments indicated that continuous ous flooding (no stress) gave the highest yields followed in order by early stress, stress from the begining of panicle initiation and late stress continuing to harvest (Fig. 10). Early stress was found to be significantly less damaging to yield than either of the late stress periods. Matsushima (1962) reported that rice is most sensitive to water stress from 20 days before heading to 10 days after heading. Similar studies by Wickham and Reys (1973) at the IRRI farm showed that the period of panicle initiation is the critical moisture sensitive stage.

In order to investigate the effects of water deficit in rice field, experiments conducted (Singh and Early, 1979) show that water application rates below 4 mm/day results in practically no yield. The 5 to 7 mm day range was found to be the critical range of sharply declining yields. From 8 mm/day to 9 mm/day application rates, virtually no additional yield increment was obtained (Fig. 11). The yield response to these treatments reveals a water requirement limit below which the yield is sharply reduced.

Current research results (Halim and Khan, 1978) in order to quantify the stress developed, indicate that soil moisture tension as low as 15 centibars was enough to reduce the grain yield of rainfed rice. At a soil moisture tension of 50 centribars (1 bar = 1 dyne/cm^2, 1 atmosphere = 1.0132 bars), the yield of most rice varieties may be as low as 40 percent of that obtained for flooded condition.

2.10 Varieties of HYV rice and water requirement:

The impact of varieties of HYV rice on water requirement was studied at the BRRI (1980). The study indicates that rice variety has no significant impact on water requirement. It is the duration of the crop growing period and not the variety of rice grown that influences the crop water requirement.

2.11 Water management in rice cultivation:

Levine (1970) stated that traditional irrigated systems in southeast Asia tend to supply an overabundance of water ralative to actual needs. The situation is best illustrated in Fig. 12 which shows the relationship between water requirement and the level of water control. The wet season water requirement is assumed to be 650 mm on heavy clay with limited percolation. The quantity in excess of 650 mm in Fig. 12 is identified as losses. The poorer the control of water the higher the system requirement and lower is the water utilization efficiency.

CHAPTER - III

EXPERIMENTAL METHODS AND DATA ANALYSIS

3.1 Experimental site:

The experiment was set-up at the farm of the Bangladesh Rice Research Institute, Joydebpur (24°00.0'N latitude and 90°26.1'E longitude). The area lies in the southern part of the Madhupur tract. Most of the terrace is flat in relief, except where streams have cut across it. The area was selected for its high topography not subjected to the annual flood. Apart from that all the research facilities available at the BRRI were also made available for the study.

3.2 Soil classification:

The soil of the area belongs to the 'Red-Brown Terrace' soil group (UNDP - FAO, 1971). For the determination of the textural characters of the soil, samples were collected from the project area and analysed in the laboratory. The composition of the soil was found to be as follows (Fig. 13):

Percentage of sand = 20

Percentage of silt = 68

Percentage of clay = 12

For the above mentioned percentile composition the soil was identified to be silty loam soil on the basis of textural classification of the U.S.Department of Agriculture (U.S.D.A).

3.3 Experimental treatments:

3.3.1 Aus season:

During the Aus season a total of 8 plots, each measuring 6 m X 8 m in size, were used to represent 4 treatments each treatment having 2 replications. The description of each treatment is as follows:

(a) Treatment T_1: 25 to 50 mm standing water in the plots with application of water whenever the water levels fall below 25 mm.

(b) Treatment T_2: Rainfed, with water application to make the plots saturated at the formation of initial cracks.

(c) Treatment T_3: Rainfed, with water application at a stress of 20 centibars to make the plots saturated. Stress (tension) to be measured with tensiometer.

(d) Treatment T_4: Rainfed condition.

The field layout map of the experimental plots is shown in Fig. 14.

3.3.2 Aman season:

During the Aman season the transplanting date was staggered by 10 days to see the effect of transplanting date on the yield under rainfed conditions. The treatments under the first and second transplant are as follows:

<u>1st Treatment</u>

Treatment T_1: 25 to 50 mm standing water in the plots with application of water whenever the water levels fall below 25 mm.

Treatment T_2: Rainfed, with 25 to 50 mm standing water from the reproductive stage. Water would be applied whenever the water level falls below 25 mm from the reproductive stage. Water would be applied to keep the plots saturated at the formation of initial cracks at the vegetative growth period.

Treatment T_3: Rainfed, with water application to make the plots saturated at the formation of initial cracks.

Treatment T_4: Rainfed condition.

<u>2nd Transplant</u>

All treatments of 1st Transplant except Treatment T_2 were performed.

Two plots (Plots 3 and 4) were kept under 25 to 50 mm standing water without being planted. The field layout map is shown in Figs. 15 and 16. A spacing of 1 metre was kept between the experimental plots and a 2 metre wide spacing was kept in between the rows of plots for conveying irrigation water (Fig. 17). Experimental plots were 6 m X 8 m in size and each treatment was replicated twice.

3.4 Land preparation:

The experimental field was ploughed with heavy harrows 2 weeks prior to transplantation. The clods were broken into small pieces and the stubbles were removed from the field. Puddling was done before dividing the blocks into final treatment plots.

During the Aus season no irrigation water was necessary for the land preparation and puddling. A total of 261 mm of rainfall occured during the 2 week period prior to transplanting at that time. During the Aman season a total of 163.5 mm of rainfall occured during the two week period prior to the 1st transplanting. A total of 62 mm of water was applied on the plots to keep a depth of 50 mm of water at the time of transplanting. No water was necessary for the 2nd transplant because a total of 104 mm occured during the period before transplanting and 70.3 mm on the two two days before transplanting which helped in maintaining a depth of 50 mm on the day of transplantation.

3.5 Fertilizer application:

All the experimental plots with different irrigation treatments were given the same amount of fertilizer and at the same time. The fertilizer application rate was 80:60:40 kg/hectre of Nitrogen, Phosphorus and Potassium (NPK), in the form of Urea, Triple Super Phosphate (TSP) and Muriate of Potash (MP). All the TSP and MP and 50% of the total Urea were applied before transplanting the seedlings. The rest 50% of the Urea was applied in two equal parts and at equal intervals of one month after transplanting.

3.6 Transplantation of seedlings:

The experimental plots of the Aus season were transplanted on the 16th June, 1980 with 26-day-old seedlings of BR-6 (IR-28) variety of HYV rice. During the Aman season BR-4 variety of HYV rice was transplanted on all the experimental plots. The 1st transplantation was completed with 23-day-old seedlings on 2nd August, 1980. For the staggered thansplantation treatment, 22-day-old seedlings were transplanted on 10th August, 1980. At the time of transplanting two seedlings per hill were transplanted with a spacing of 15 cm between hills and 25 cm between rows. In order to establish the seedlings plots of all the treatments of both the Aus and Aman seasons were flooded to a depth of 50 mm after the transplantation. All subsequent applications of water were in accordance with the treatment specifications. A 152 mm high bund was gradually constructed along the periphery of each plot in order to hold the water inside the plot.

3.7 Experimental set-up:

For the purpose of the study, rain gauge and evaporation pan were installed near the experimental site (Fig. 18). Inclined meters (Fig. 19) were installed on all the plots with 25 to 50 mm standing water (Treatment T_1) both during the Aus and Aman seasons. During the Aman season inclined meters were also installed on the plots that were not planted (Plots 3 and 4) (Fig. 20). The inclined meters had a slope of 1:5. Bamboo sticks graduated in centimeters were placed on the plots with treatment T_1 so that water depths can be obtained from them directly and also to facilitate application of water whenever the levels of water fall below 25 mm (Fig. 21). Amount of water applied to the plots was measured with Parshall flume (Fig. 22). Rainfall and evaporation were obtained from the rain gauge and the evaporation pan.

The daily inclined meter reading gave the evapotranspiration, seepage and percolation and surface drainage. Daily rainfall, evaporation and readings of the inclined meters are shown in Table 3 and 4 for the Aus and Aman seasons.

3.8 Other experimental obsservations:

3.8.1 Weed growth: No significant weed growth was observed in any of the experimental plots both during the Aus and the Aman seasons. Removal of weeds from the plots were not necessary during the crop growing seasons. During the Aman season unplanted plots (Plots 3 and 4) had a light growth of weeds (Fig. 20).

3.8.2 Insect and disease attack: During the later part of the vegetative growth period of the Aus season pest (Hispa) attack was observed on all the experimental plots. Accordingly Carbicron was applied on all the plots and it was found to be effective in controlling Hispa. Zinc deficiency was observed in all the plots of the experiment during the vegetative growth period of Aus and Aman seasons. The extent of the deficiency was moderate in plots 1 and 2 of the Aus season and severe in Plots 1 and 2 of the early (1st) transplanted fields of Aman season. During the Aus season Zinc Sulphate was applied on all the plots and was found effective in covering the deficiency. But during the Aman season Zinc Sulphate could not be procured immediately and as such all the plots were drained and dried to reduce the extent of the attack. Zinc Sulphate was applied later on the 10th of September on all the plots. The Zinc deficiency reduced the number of tillers of Plots 1 and 2 significantly which was found to be unrecoverable. At the ripening stage of the 1st transplanted Aman, plots suffered from False Smut (fungal) disease. In a count 12.5% of panicles were found affected and in the panicles, affected grains varied from 2.3 to 5.2%.

3.8.3 Maintenance of bunds:

Bunds constructed along the periphery of each plot required maintenance (re-shaping). It was observed that for rainfall exceeding 25 mm per day, the peripherial bunds were worn down by the rainfall and required maintenance the day after the rainfall. The bunds were reconstructed and reshaped with soils of adjacent areas of the plots. Typical bunds are shown in Fig. 17 and 20.

3.9 Harvesting:

The Aus crop was harvested on the 5th of August, 81 days after transplantation. Prior to harvesting water was drained out from theplots on 24th July in order to initiate maturity. The total life cycle of BR-6 during the Aus season was as follows:

Date	Plant Growth stage	Plant life between stages (days)	Total plant life (days)
20 April	Seeding	-	-
16 May	Transplanting	26	-
5 August	Harvesting	81	107

During the Aman season 1st (early) transplanted crop was harvested on the 8th of December. The 2nd (late) transplanted crop was harvested on 20th December. All water was drained out from the plots on the 16th and 28th of November respectively. The total growing periods of BR-4 during the Aman season were as follows:

1st Transplant

Date	Plant Growth stage	Plant life between stages (days)	Total plant life (days)
9th July	Seeding	-	-
2nd August	Transplanting	23	-
8th December	Harvesting	129	152

2nd Transplant

Date	Plant Growth stage	Plant life between stages (days)	Total plant life (days)
19th July	Seeding	-	-
10th August	Transplanting	22	-
20th December	Harvesting	132	154

After threshing and drying the grains, yield and the corresponding grain moisture content were determined for each of the treatments. The yield was then converted to the standard moisture content percentage (14%) by multiplying with a correction factor. The yield data during the Aus and Aman seasons are shown in Tables 5 and 6.

3.10 Analysis of Data:

3.10.1 Rainfall:

Rainfall data from 1902 to 1974 for the Joydebpur station and 1974 to 1980 from the BRRI weather station were studied in order to quantify the amount of crop water requirement available from rainfall. The probabilities of different amounts of rainfall at Joydebpur during different months of the year were determined (Manalo, 1976). The mean monthly rainfall and the amounts of rainfall and their probabilities are given in Table 7 and Figs. 23 and 24. Study of the figures and tables reveal that probability of 50 mm of rainfall is only 8% in January, which increases to 50% in March and 100% in June, and stays near that level till September and then falls to 9% again in December. Probability of 100 mm of rainfall in January is only 2%, in April 67% and in June 100%, which falls to 7% in November. Still higher rainfall (150 mm to 350 mm) are concentrated during the five months period from May to October.

3.10.2 Evaporation:

Evaporation data were collected from the pan installed near the experimental plots for the Aus and Aman seasons. Observations show that maximum evaporation during the Aus season occured in the month of June (6.03 mm/day). During the Aman season, the maximum evaporation of 4.89 mm/day occured in the month of August. The evaporation decreased to 2.53 mm/day in the month of November (Table 3 and 4).

3.10.3 Seepage and percolation:

Seepage and percolation losses during the Aus and Aman seasons were determined from the daily inclined meter readings. From the water balance approach seepage and percolation was obtained from the equation:

$$S \& P = \frac{WD_{t-1} - WD_t}{Z} + RN - ET$$

where, t refers to the day of measurement

WD = inclined meter reading of the plot

ET = evapotranspiration at time t

RN = rainfall at time t

Z = slope of the inclined meter.

During the Aus season, considering evapotranspiration equal to evaporation, seepage and percolation losses varied from 2.32 mm to 3.68 mm per day (Table 8). For the Aman season seepage and percolation losses were found to vary from 4.68 mm to 5.23 mm per day (Table 9). Seepage and percolation during this period was obtained as follows:

$$S \& P = \frac{WD_{t-1} - WD_t}{Z} + RN - EV$$

where, WD = inclined meter reading of the unplanted plot and

EV = evporation at time t.

3.10.4 Evapotranspitation:

Evapotranspiration during the Aman season was calculated by subtracting seepage and percolation from the inclined meter readings installed on plots with T_1 treatment. Evapotranspiration varied from 2.51 mm to 3.04 mm per day (Table 9) during the crop growing period.

3.10.5 Supplementary irrigation:

Supplementary irrigation water was applied to the plots with different treatments as per conditions specified in the treatment. The amount of water applied to different plots and the corresponding crop growth stages during the Aus and Aman seasons are shown in Tables 10 and 11. During the Aus season two irrigations were required for the treatment T_1, one with 33 mm of water during the vegetative growth and the other with 36 mm of water during the generative (reproductive) growth period. For the treatment T_2, only one irrigation with 4 mm of water was necessary during the vegetative growth period.

During the Aman season the 1st (early) transplanted plots required a total of 203 mm of water for the treatment T_1, 29 mm for the treatment T_2 and 7.2 mm for the treatment T_3. All the treatments required an additional 62 mm of water for land preparation. The 2nd (late)transplanted Aman crop required a total of 572 mm of water for the treatment T_1 and 14 mm of water for the treatment T_2. A total of 389 mm was applied in the plots with treatment T_1 during the drought period of crop's ripening stage.

3.10.6 Water requirements and yields:

From the water balance equation, the water requirement was determined as follows:

$$\text{water requirement} = \text{Rainfall} + \text{Irrigation} = ET + S \,\&\, P + SD + \text{water storage changes.}$$

Assuming that water storage does not change significantly over a season the total water requirement for different treatments for the Aus and Aman seasons are shown in Table 12. The same table also shows the yield in tons/hectre under different treatments and water requirements.

The maximum water requirement of 905 mm for Aus season occured for treatment T_1(25 to 50 mm standing water), but the maximum yield of 3.73 tons/hectre was found for treatment T_2 (rainfed with saturation treatment). For Aman season the maximum water requirement and the maximum yield occured for treatment T_1 (25 to 50 mm standing water). A total of 1253 mm of water was required and a yield of 7.86 tons/hectre was found for this treatment. The yield - water requirement curve for the Aman season is shown in Fig. 25.

CHAPTER - IV

RESULTS AND DISCUSSIONS

4.1 Supplementary irrigation and yield:

4.1.1 Aus season:

Transplanted on 16th May, the crop took 81 days to be harvested, the total life cycle being 107 days. During the Aus season the treatment T_1 (25 to 50 mm standing water) required 69 mm of irrigation water, 33 mm at the vegetative growth period and 36 mm at the generative (reproductive) growth period. The treatment T_2 (saturated) required one single irrigation at the vegetative growth period in which 4 mm of water was applied to keep the plots saturated (Table 10). From Table 5, it is evident that supplementary irrigations of treatments T_1 and T_2 resulted in an increased yield over treatment T_4 which was under rainfed condition, although the percentile increase in yield is not very high (8% and 12.48% respectively). The treatment T_2 gave a higher yield in comparison to T_1, most probably because shallow depth and drainage (but not stress) are preferable after the rootage stage of the vegetative growth period, which occured in the former treatment. The yield of treatments T_1 and T_2 are not significantly higher than T_4 because three days and one day after the application of water in treatments T_1 and T_2 a rainfall of 10 mm occured, which released the stress that was developing in the rainfed plot. The treatment T_3 turned out as a rainfed treatment because during no part of the Aus season a stress of 20 centibars occured.

For the Aus season of the study period the total amount of rainfall was much more and the distribution much uniform than which is expected in a normal year. A total of 842 mm of rainfall occured during the crop growing period which is 1.3 times greater than the normal crop requirement. The amount of rainfall that is expected at 50% probability (1 out of two years) is 812 mm.

4.1.2 Aman Season:

During the Aman season the transplantation date was staggered by 10 days is order to see the effect of late transplanting on the supplementary irrigation water requirements. The two transplantation cases would be discussed seperately:

4.1.2.1 First Transplantation:

Transplanted on 2nd August the crop took 129 days to be harvested, the total life being 152 days (145 to 160 days is the normal range, BRRI, 1978). The treatment T_1 (25 mm to 50 mm standing water) required 265 mm of supplementary irrigation, two in the vegetative growth, one during the revpoductive growth and three in the ripening period (Table 11). The treatments T_2 and T_3 (saturated) required 29 mm and 7.2 mm of irrigation water in addition to the 62 mm required for land preparation. All the treatments of the first transplantion suffered from Zinc deficiency during the vegetative growth period and the attack was severe in the plots with treatment T_1. All the plots were treated with Zinc Sulphate but plots 1 and 2 with treatment T_1 could not recover the deficiency. Tillers were considerably reduced in these plots which ulitmately affected the yield (Table 6). Among the other three treatments the treatment T_3 gave the highest yield of 7.68 tons/hectre. The yield of treatments T_2 and T_4 (rainfed) were somewhat equal.

4.1.2.2 Second Transplantation:

Transplanted 10 days after the first transplantation, the total growing period of the crop was 154 days. The total amount of supplementary irrigation water required for the treatment T_1 (25 to 50 mm standing water) was 572 mm of which one was at the vegetative growth stage, one at the reproductive stage and eleven were at the ripening stage. The treatment T_2(saturated) required 14.4 mm of water to keep the plots saturated during the total growing period.

During the Aman season, no rainfall occured after the 22nd of October when the crop was at the end of the flowering stage. A long drought of sixty days upto the harvesting period resulted in a considerable decrease in yield for the rainfed treatment T_3. From Table 6, it can be observed that a 71% increase in yield resulted in treatment T_1 over the rainfed treatment T_3. For treatment T_2 the increase of yield over T_3 was 57%.

From Table 11 it can be seen that the treatment T_1 (25 to 50 mm standing water) required frequent irrigations during the drought period. This was because of the cracks that were developed on the clay covered bunds constructed along the periphery of the plots due to the long period of drought. Through these cracks excessive amount of applied irrigation water ran off the field.

During the Aman season a total rainfall of 783 mm occured during the 1st transplantation period which is 87.5% of the crop water requirement. For the 2nd transplantation the amount of rainfall was 692 mm which is again 77% of the crop water requirement. The amount of rainfall that is expected during the crop growing period at 50% probability (1 out of 2 years) is 710 mm which is about 79% of the crop requirement during the Aman season.

From the above discussions it is evident that supplementary irrigation is inevitable in order to obtain optimum yield from Aus and Aman crops. The magnitude of increase during the study period varied from 8% to 71% over rainfed condition under different treatments.

4.2 Amount of rainfall and water requirement:

During both the Aus and Aman seasons it was observed that rainfall in excess of 25 mm per day can not be properly retained in the plot and has little use towards crop growth. Figure 26 shows the relation between the amount of ranfall in excess of 25 mm that occured during the Aus and Aman seasons and the corresponding amount of water depleted from the plots. The main reason behind this high loss of water is the excessive rainfall which wears down and washes away the peripherial bunds.

Holes made by earthworms also increases the magnitude of the loss.

Considering the heavy loss that occurs due to excessive rainfall, inclined meter readings for the days with rainfall in excess of 25 mm were discarded for calculating seepage and percolation. With the seepage and percolation losses determined and evaporation assumed equal to evapotranspiration the water requirement for the total growing season and for different months of the growing season for Aus and Aman crops were obtained and are shown in Table 13 and 14. The water requirement for the Aus and Aman seasons were determined as 643.1 mm and 893.8 mm respectively. It was assumed that 101 mm of water is necessary for land preparation and the surface drainage is negligible. The water requirements obtained were studied in detail with different rainfall probabilities as will be discussed later.

4.3 Supplementary irrigation requirement for other years:

All available rainfall data for the Aus and Aman seasons at the BRRI farm area were collected and analysed. Assuming that all the rainfall is available to the corps, the observations are as follows:

(a) Aus season - Out of four years available data from 1974-79, it was observed that supplementary irrigation was required for three years. No irrigation was necessary for the year 1978. The amount of irrigation and the crop growth stage when it was necessary is shown in Table 15 and Figs. 27 to 32. The amount of irrigation varied from 25.4 mm to 228.6 mm.

(b) Aman season - Of the six years (1974-78) analysed data shown in Table 16 supplementary irrigation was required for five years. No irrigation was necessary for the year 1975. The amount of irrigation varied from 51 mm to 178 mm.

The above analysis was done with water budgeting technique, considering the daily rainfall and the corresponding crop water requirement (due consideration being given to crop growth stage) and assuming that the total amount of daily rainfall is available for crop growth. The assumption is not very true (as mentioned in Art. 4.2) since it was experimently determined that most of the water of rainfall in excess of 25 mm runs off the field and is not available for plant growth. Thus in practice the actual amount of irrigation water required for the analysed years would be greater than the calculated values shown in Tables 15 and 16.

4.4 Risks involved with rainfed rice cultivation:

From the analysis of monthly water requirements and the corresponding rainfall probabilities (Table 7, Fig. 24) during the Aus and Aman seasons, the following observations can be made:

(a) Aus season - During the total crop growing period, the rainfall is never sufficient to meet the total crop water requirement. The probabilities of obtaining the monthly water requirements from rainfall increase from 50% in May to 90% in July thereby decreasing the supplementary irrigation requirement from 108.32 mm in May to 17.43 mm in July, the total irrigation amounting to 183.74 mm.

(Table 17 and Fig. 33). The amount of irrigation required during the total growing period at rainfall probabilities of 50% (1 out of 2 years) and 75% (3 out of 4 years) varied from 0 to 66.65 mm and is shown in Fig. 34 and Table 17.

(b) Aman season - Analysis of monthly water requirements and the corresponding rainfall probabilities (Table 18) show that, during this season also rainfall has to be supplemented by irrigation in order to meet the total crop water requirement. The probabilities of rainfall are lower than that of Aus season and still higher supplementary irrigation is necessary for optimum yield. The rainfall probabilities decrease from 70% in August to 15% in November and the total amount of irrigation required for the 1st transplant is 439.96 mm. For the 2nd transplant the rainfall probabilities decrease from 80% in August to 0% in November. Amount of irrigation water required for 2nd transplant is 487.4 mm. Amount of irrigation water required at rainfall probabilities of 25%, 50% and 75% are 67.4 mm, 167 mm and 309 mm for the 1st transplantation, as shown in the Table and Figs. 33 and 34. Amount of irrigation required for the same rainfall probabilities for the 2nd transplant are 137 mm 237 mm and 364 mm respectively.

4,5 Transplantation date and supplementary irrigation:

From both experimental observation and probability analysis it was determined that water stress develops in the rice fields from the later part of the Aman season when the crop is at the end of the flowering stage or at the begining of the maturity stage (from mid October, Table 18) which seriously affects the yield of rainfed crop. If the crop is transplanted earlier (at the end of July or begining of August) then the crop can be saved from the drought occuring at the end of the season. Early transplanted plots may also face water stress at the vegetative growth period but studies have shown that early stress of water is less detrimental to crop yield in comparison to late stress which develops at the ripening stage of the crop growth.

4.6 Prospects of Aus and Aman as rainfed crops:

From rainfall probability analysis of Aus season (Table 17) it is evident that Aus crop can be grown as a rainfed crop with supplementary irrigation required in one out of four years. Although the probability analysis shows that there is only 50% chance of getting the total water requirement during the first month of the crop growing period from rainfall, this early stress will not seriously affect the yield as the probability of getting the the required rainfall increases to 90% during the last months of the crop growth. The need for supplementary irrigation during the Aus season will arise from the land preparation since only 50% of the total water requirement at the initial growing stage can be expected from rainfall.

Aman crop can not be grown as rainfed crop and requires about 440 mm of water (Table 18) from irrigation to meet the water requirement(49% of the water requirement). Probability studies show that Aman crop requires supplementary irrigation in three out of four years. Probability studies also show that by delaying the transplantation enough water for land preparation can be made available from rainfall (70% in August for 1st transplant to 80% for 2nd transplant), but delayed transplantation leads to serious water stress at the ripening stage of crop growth.

CHAPTER - V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions and recommendations:

The following conclusions and recommendations can be made from this study:

(a) Increase in yield of rice varying from 8% to 71% was obtained during the study period for different irrigation treatments over rainfed condition. The percentage of increased yield depends upon the stage of crop growth at which the irrigation is necessary, the percentage being higher for irrigation with late stresses than early stresses.

(b) Aus and Aman cultivation should not be practised under rainfed condition as rainfall probability studies with last 72 years data have shown that rainfall is never sufficient to meet the crop water requirement. Supplementary irrigation can make these crops more reliable and ensure a dependable yield. The amount of supplementary irrigation required varies from 0 to 66.65 mm for Aus season and 67 mm to 309 mm for the Aman season with rainfall probabilities varying from 25% to 75%. The supplementary irrigation required during the study period was 69 mm for Aus season, 203 mm and 572 mm for 1st and 2nd transplantation of Aman season for the treatment of 25 mm to 50 mm standing water on plots.

(c) The seepage and percolation losses per day during the study period varied from 2.32 mm to 5.23 mm, the higher value being observed during the drought period of the Aman season.

(d) The water requirement for the Aus and Aman seasons were found to be 643 mm and 893 mm respectively with negligible loss due to surface drainage. The loss due to surface drainage is a function of the amount and duration of rainfall, the amount of loss being considerably higher for rainfall exceeding 25 mm in a day. Actual water requirement during the study period were 905 mm for Aus season and 1253 mm for Aman season for the treatment of 25 mm to 50 mm standing water in the plots.

(e) Since droughts occur almost invariably at the end of Aman season i.e., November (probability of 50 mm rainfall is only 25%)when the crop is at the begining of ripening stage, transplantation should be made as early as possible in order to save the crop from the late water stress. Early transplantation will also considerably decrease the supplementary irrigation requirement.

(f) Aus rice has a better prospect over Aman rice as a rainfed crop.Aus crop may also face drought during the early part of its growth, but will have a more dependable rainfall during the later part. Early stress has been found to be less detrimental to crop yield than late stress.

(g) The treatment T_2, i.e., rainfed, with water application to make the plots saturated at the formation of initial cracks, gave a yield performance very much close to the standing water treatment, but required a much smaller amount of supplemental irrigation. This treatment can be practised instead of the normal continuous flooding in order to reduce the amount and cost of supplementary irrigation.

5.2 Scope of further study:

Although the need for supplementary irrigation and its importance for an optimum yield during the Aus and Aman seasons have been established, there is still a scope of further studies on the following aspects:

(a) The conclusions made from the study are based on the experimental findings of one season of Aus and Aman crop. In order to establish the findings of the year's observations it is necessary that the whole study be repeated for a few more years and at different hydrological zones in order to arrive at a definite conclusion.

(b) A rigorous economic analysis of the cost of supplemental irrigation and the corresponding return from yield at farmer's level is needed in order to motivate the farmers for applying the supplemental irrigation. This is important because, unless the benefit-cost ratio (BCR) appears feasible to farmers, the concept of supplemental irrigation will not be accepted by them.

(c) The practicable and economic method of supplemental irrigation still remains undetermined. Since Aus and Aman crops are grown during the monsoon season when surface water is readily available and the groundwater level is close to ground level the problem is different from dry season irrigation. All the conventional methods can be studied for finding a reasonable solution. Irrigation by traditional methods or hand tubewell (HTW) may prove to be more economical because Aus and Aman crops are predominantly rainfed and requires a small portion of their water requirements from irrigation.

REFERENCES

1. Allison, S.V. and Jalal, K.F. 1974. Irrigation Development in Bangladesh. American Society of Civil Engineers. Journal of the Irrigation and Drainage Division, Vol. 100, No. IR-1.

2. Barker, R. 1972. Research Relating to the Economics of Irrigation in Rice Production. Irrigation and Drainage. Paper 12. FAO.

3. Bhuiyan, S.I. 1977. Irrigation Water Development and Management in Bangladesh: Problems and Prospects. Proceedings of the National Seminar on Water Management and Control at the Farm Level. Govt. of Bangladesh & FAO.

4. Bhuiyan, S.I. 1979. Drainage Consideration for Agricultural Lands in the Humid Tropics. Engineering and Management Concepts in Irrigation Water Management. IRRI.

5. Biswas, M.R. and Ali, M.F. 1976. Determination of Consumptive Use of Water for IRRI-8 Paddy. Bangladesh Agricultural University.

6. BRRI, 1978. Adhunik Dhaner Chash (Modern Rice Cultivation)

7. BRRI, 1980. Internal Review for 1974-79. Division of Agricultural Engineering (Unpublished).

8. Chow,L. 1965. Rice Irrigation. American Society of Civil Engineers. Journal of the Irrigation and Drainage Division, Vol. 91, No. IR-3.

9. De Datta, S.K. <u>et al</u>. 1975. Water Management Practices in Flooded Tropical Rice. Water Management in Philippine Irrigation Systems: Research and Operations. IRRI.

20. Okamato, M. 1977. Optimal Water Application at Farm Level for Rice Irrigation. Proceedings of the National Seminar on Water Management and Control at the Farm Level. Govt. of Bangladesh & FAO.

21. Oury, B. 1972. Rainfall Analysis. Technical Report No. 23. Bangladesh Land and Water Resources Sector Study. International Bank of Reconstruction and Development. Washington, D.C.

22. Planning Commission. 1980. Draft Second Five-Year-Plan. Government of the People's Republic of Bangladesh.

23. Singh, V.P. and Early, A.C. 1979. Crop Water Yield Relationships. Water Requirements, Agronomic, Soils and Yield Response Concepts in Irrigation Water Management, IRRI.

24. Reyes, R.D. and Wickham, I.H. 1973. The Effect of Moisture Stress and Nitrogen Management at Different Growth Stages on Lowland Rice Yields. Paper presented at the 4th Scientific Meeting of CSSP.

25. Tabbal, D. 1979. Methods of Surface Irrigation. Engineering and Management Concepts in Irrigation Water Management. IRRI.

26. Tarafdar, M.R. 1977. Water Management and Control in Irrigated Agriculture in Bangladesh. Proceedings of the National Seminar on Water Management and Control at the Farm Level. Government of Bangladesh & FAO.

27. Tsutsui, H. 1972. Water Management and Requirements for Rice Cultivation Under Different Irrigation Methods and Cultivation Techniques. Irrigation and Drainage Paper 12, FAO.

28. UNDP-FAO. 1971. Bangladesh Soil Resources. Technical Report 3, Soil Survey Project.

29. Valera, F. 1979. Importance of Land Preparation. Water Requirements, Agronomic, Soils and Yield Response Concepts in Irrigation Water Management. IRRI.

30. Wickham, T.H. and Sen, L.N. 1977. Water Management for Lowland Rice: Water Requirements and Yield Response. Soil and Rice Symposium. IRRI.

APPENDICES

TABLE 1

ACREAGE, PRODUCTION AND YIELD OF FOOD GRAINS

Crops	Benchmark			1984 - 85		
	Area million acres	Yield in tons/ acre	Production million tons	Area million acres	Yield in tons/ acre	Production million tons
Rice:						
1. Aus	7.79	0.34	3.10	8.0	0.60	4.83
2. Aman	14.26	0.52	7.42	14.0	0.68	9.55
3. Boro	2.70	0.82	2.24	3.0	1.13	3.40
Wheat	0.90	0.8	0.71	2.5	0.9	2.25
Barley, Jawar, Maize etc.	0.21	-	0.06	0.15	-	0.07
Total (food grain):	25.87		13.53	27.65		20.10

Source: Draft Second Five-Year-Plan of Bangladesh, May, 1980.

TABLE 2

EFFECT OF WATER MANAGEMENT PRACTICES ON THE YIELD OF RICE, IRRI, 1968 DRY SEASON

Water management practice treatments	Total water use (mm)	Grain yield (T/h)
1. Continous flooding of 75 m.m	850	9.72
2. Continuous flooding of 25 m.m	805	9.54
3. Continuous saturation and flooding (75 m.m) at panicle initiation	780	9.14
4. Deep continuous flooding of 150 m.m	1418	8.96
5. Continuous saturation	647	9.02

Source: Tsutsui, 1972.

TABLE 3

DAILY INCLINED METER READINGS, EVAPORATION AND RAINFALL FOR THE AUS SEASON

Date	Inclined meter readings (mm)		Evaporation (mm)	Rainfall (mm)
	Plot 1	Plot 2		
30 May 1980	10.94	13.34	4.0	2.5
31	6.43	0.75	8.0	27.4
1 June	12.60	26.00	5.0	-
2	10.57	30.77	3.0	11.2
3	10.40	6.40	5.0	-
4	8.60	8.20	7.0	-
5	6.60	8.00	5.0	-
6	3.60	4.00	5.0	-
7	4.21	25.14	5.0	29.2
8	27.12	10.12	11.0	71.1
9	-	37.37	24.0	79.4
10	9.97	15.97	3.0	12.7
11	44.23	46.23	5.0	11.4
12	8.05	6.05	-	6.9
13	4.23	14.32	8.0	20.3
14	19.62	9.62	6.0	7.6
15	16.00	12.00	6.0	-
16	8.80	6.80	5.0	-
17	15.32	25.32	-	71.1
18	38.19	26.39	11.0	12.2
19	17.08	16.88	6.0	5.1
20	+3.52	7.48	5.0	30.5
21	16.60	9.00	10.0	-
22	29.00	9.00	5.0	-
23	9.29	9.40	4.0	6.1
24	0.76	+10.05	7.0	9.1
25	13.20	25.00	5.0	11.7

+ve value indicates an increase in the meter reading

TABLE 3 (Continued)

Date	Inclined meter readings (mm)		Evaporation (mm)	Rainfall (mm)
	Plot 1	Plot 2		
26 June	16.60	6.80	3.0	-
27	16.08	21.68	13.0	-
28	16.60	+6.00	5.0	-
29	15.00	8.00	5.0	-
30	6.60	7.40	5.0	-
1 July	17.40	10.60	5.0	-
2	10.00	18.00	6.0	-
3	5.68	3.68	8.0	11.70
4	1.28	+16.79	1.0	13.20
5	4.23	4.63	3.0	8.60
6	4.90	5.30	4.0	3.30
7	8.65	8.25	8.0	16.20
8	+1.02	2.57	-	20.57
9	4.70	7.70	-	12.70
10	25.51	11.31	-	4.30
11	14.42	13.62	5.0	7.60
12	12.06	17.06	2.0	4.00
13	4.77	9.37	6.0	11.20
14	6.52	10.52	4.0	8.10
15	15.93	12.93	2.0	49.50
16	20.67	21.07	4.0	52.10
17	35.36	26.76	6.0	0.70
18	29.40	29.00	5.0	-
19	5.00	7.00	2.0	-
20	38.15	25.15	3.0	57.10
21	6.60	13.00	2.0	-
22	15.22	32.20	3.0	7.60
23	+16.07	15.33	9.0	49.50
24	10.34	8.14	5.0	2.50

+ve value indicates an increase in the meter reading.

TABLE 4

DAILY INCLINED METER READINGS, EVAPORATION AND RAINFALL, FOR THE AMAN SEASON

Date	Inclined meter readings (mm)						Evaporation (mm)	Rainfall (mm)
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 11	Plot 12		
9 August	9.18	8.88	10.06	9.53			2	7.6
10	15.64	14.71	18.63	16.29			8	12.2
11	8.93	13.42	12.25	12.83			6	7.4
15	6.74	19.60	14.66	29.53			4	-
16	4.85	6.57	7.14	8.86			3	2.0
17	5.22	6.82	4.66	7.52			4	1.7
18	1.25	+9.52	5.81	+11.08			5	12.7
19	4.62	4.04	9.68	12.77			3	1.0
20	4.38	11.36	3.55	14.21			3	-
21	1.88	3.53	2.88	4.37			5	-
22	30.53	39.70	43.49	42.42			6	10.0
23	11.63	25.51	19.87	27.69			3	2.5
24	14.40	+2.07	2.41	+2.56			-	33.5
25	29.97	25.42	29.97	26.96	20.32	20.05	6	30.0
26	14.86	15.19	25.90	21.52	20.81	15.01	8	8.1
27	13.70	10.20	3.11	9.02	10.92	+11.36	4	17.8
28	16.98	4.95	13.17	5.84	15.24	24.34	7	27.2
29	18.00	38.00	28.98	35.64	37.30	31.12	4	0.7
30	0.63	1.26	1.11	1.09	1.26	0.60	4	-
31	55.64	32.14	18.61	19.48	23.67	29.22	-	99.1
1 Sept.	36.05	50.05	60.44	55.50	52.79	63.36	4	-
2	9.87	21.21	20.66	19.68	27.91	8.90	4	-
3	7.59	6.82	21.01	12.50	5.33	16.60	4	1.0
4	4.94	21.23	+6.12	7.87	9.39	6.54	3	4.3
5	18.90	24.53	30.06	13.36	-	24.01	9	7.6
6	13.63	33.33	11.11	25.40	-	24.69	4	-
11	32.55	38.35	23.24	28.23	28.20	27.22	3	38.4
12	7.10	16.91	17.55	26.79	22.08	27.32	5	-
13	4.50	11.61	19.11	19.96	22.58	15.78	5	-
14	3.89	15.91	15.87	6.50	0.76	13.00	4	0.7

+ve value indicates an increase in the meter reading.

TABLE 4 (Continued)

Date	Inclined meter readings (mm)						Evaporation (mm)	Rainfall (mm)
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 11	Plot 12		
15 Sept.	5.79	10.10	2.66	19.1	2.03	24.29	4	-
16	8.29	7.35	8.09	5.54	30.20	4.02	4	6.1
17	10.90	15.42	12.24	10.22	10.65	11.65	2	5.6
18	6.83	+15.73	+ 6.72	+10.47	+6.32	+6.71	4	29.7
19	5.04	6.58	5.87	7.18	5.07	18.73	5	2.5
22	14.22	14.46	16.19	14.65	16.76	14.41	6	11.2
23	2.86	10.37	8.47	5.99	7.36	8.87	3	3.8
24	24.20	+2.30	+3.70	4.75	5.86	+2.23	4	37.8
25	7.00	15.65	11.11	13.67	11.16	12.75	4	-
26	3.77	7.83	19.04	8.92	10.15	7.74	8	1.3
27	31.13	0.58	22.03	33.63	8.92	24.76	4	57.1
28	25.86	35.35	-	2.18	33.50	18.82	2	-
29	5.17	15.15	-	9.29	12.69	9.71	4	-
30	2.97	12.12	-	18.04	10.65	14.57	4	-
1 October	8.59	5.35	8.79	8.94	7.36	12.17	2	8.1
2	7.61	12.93	10.76	10.47	9.39	9.04	6	9.6
3	2.35	4.54	4.22	3.28	2.79	3.03	5	-
4	10.72	5.91	7.78	8.75	9.65	6.64	4	17.8
5	2.66	9.59	6.00	4.92	7.36	12.34	4	-
6	12.13	7.17	8.44	4.38	6.61	0.77	4	17.8
7	6.42	10.60	9.55	11.75	11.16	16.80	4	-
8	26.78	17.70	10.48	7.51	10.95	1.90	-	48.3
9	12.85	23.48	14.00	19.68	22.08	20.24	4	-
10	5.95	7.07	13.33	16.13	8.37	14.97	4	-
11	4.38	13.13	6.66	10.39	7.86	10.12	3	-
12	7.68	9.59	8.22	6.56	7.61	10.12	3	-
13	1.72	+33.83	6.66	+21.05	8.12	14.17	4	-
14	+13.00	40.65	2.44	18.04	7.61	-	2	-
15	11.75	11.86	5.33	14.21	9.89	4.04	3	-
16	3.91	34.84	12.66	28.16	26.39	28.34	5	-
17	2.19	5.80	3.33	1.91	3.23	2.22	5	-
18	14.16	11.73	11.14	14.43	11.45	15.76	3	19.8

+ve value indicates an increase in the meter readings.

TABLE 4 (Continued)

Date	Inclined meter readings (mm)						Evaporation (mm)	Rainfall (mm)
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 11	Plot 12		
19 October	11.27	+0.61	8.79	2.25	0.52	3.48	3	24.1
22	48.37	44.78	45.81	36.91	41.41	43.18	-	57.2
23	18.80	27.27	22.44	25.70	29.94	32.18	5	-
24	5.95	17.42	9.77	15.58	9.89	16.39	3	-
25	5.64	19.94	10.22	15.03	7.61	11.14	3	-
26	3.13	10.10	6.66	7.65	8.12	4.45	2	-
27	3.44	11.11	9.33	6.01	11.42	4.04	2	-
28	9.40	15.15	10.00	27.34	9.13	4.45	1	-
29	3.13	-	10.00	-	5.58	6.07	2	-
30	7.05	29.04	7.77	20.50	8.88	24.29	2	-
31	2.35	8.08	4.44	5.46	5.07	2.02	2	-
1 November	7.83	31.06	12.22	28.71	+1.26	19.63	3	-
2	3.13	22.72	3.33	13.67	7.61	7.69	2	-
3	3.13	12.62	1.11	17.77	20.30	4.04	3	-
4	4.70	6.31	11.77	8.20	10.65	2.02	4	-
5	11.28	3.03	23.55	2.18	10.15	2.02	2	-
6	5.17	+2.02	9.33	22.42	4.56	19.23	4	-
7	9.87	17.92	7.55	16.22	16.24	3.03	2	-
8	13.32	22.72	2.22	25.15	+0.50	13.15	3	-
9	3.13	10.85	11.11	12.30	8.12	4.04	2	-
10	6.26	45.95	17.77	42.38	30.96	30.36	2	-
11		10.85		17.77	16.49	16.19	1	-
12		8.08		13.67	16.49	10.12	2	-
13		32.82		10.93	21.57	18.21	1	-
14		25.25		16.40	15.22	12.14	2	-
15		32.82		27.34	27.91	28.34	2	-
16		11.62		27.34	17.76	14.17	2	-
17		25.25		38.28	19.03	24.29	3	-
18		40.40		24.61	22.08	18.21	3	-

+ve value indicates an increase in the meter reading.

TABLE 4 (Continued)

Date	Inclined meter readings (mm)						Evaporation (mm)	Rainfall (mm)
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 11	Plot 12		
19 November		22.47		14.49	13.95	19.43	3	-
20		19.94		13.39	15.22	19.02	3	-
21		10.60		7.65	11.42	10.12	3	-
22		25.25		31.44	17.76	23.27	3	-
23		15.15		24.61	22.84	25.30	3	-
24		20.20		21.87	10.15	16.19	2	-
25		30.30		32.26	12.69	13.76	3	-
26		15.15		16.95	10.40	14.57	2	-
27		40.40		35.00	15.22	28.34	3	-
28		20.20		28.43	17.76	16.19	3	-

+ve value indicates an increase in the meter reading.

TABLE 5

YIELD PERFORMANCE UNDER DIFFERENT TREATMENTS DURING AUS SEASON

Treatment	Yield (Kg/m^2)	Moisture content (%)	Average yield (14% moisture content) (T/h)	Percent increase over rain-fed condition (T_4)
1. T_1 (25-50 mm standing water)	0.4167	16.1		
2. T_1	0.3167	15.8	3.581	8
3. T_2 (Rainfed with water application to saturation)	0.370	15.7		
4. T_2	0.400	16.8	3.73	12.48
5. T_4 (Rainfed)	0.3167	16.1		
6. T_4	0.370	16.8	3.316	-

TABLE 6

YIELD PERFORMANCE UNDER DIFFERENT TREATMENTS DURING AMAN SEASON

Treatment	Yield (Kg/m^2)	Moisture content (%)	Average Yield (14% moisture content) (T/h)	Percent increase over rain-fed condition (T_4)
1st Transplantation				
1. T_1 (25-50 mm standing water)	0.600	17.0		
2. T_1	0.560	15.4	5.80	-
3. T_2 (Rainfed with 25-50 mm standing water at the reproductive stage)	0.660	15.8		
4. T_2	0.840	17.2	7.27	
5. T_3 (Rainfed with water application to saturation)	0.720	15.6		
6. T_3	0.8760	17.5	7.68	
7. T_4 (Rainfed condition)	0.700	14.6		
8. T_4	0.760	14.8	7.23	
2nd Transplantation				
1. T_1 (25-50 mm standing Water)	0.770	15.6		
2. T_1	0.836	16.1	7.86	71.2%
3. T_2 (Rainfed with water application to saturation)	0.705	16.2		
4. T_2	0.783	17.2	7.21	57%
5. T_3 (Rainfed)	0.591	14.8		
6. T_3	0.344	17.0	4.59	-

TABLE 7 (a)

MEAN MONTHLY AND ANNUAL RAINFALL AT JOYDEBPUR

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Rain fall (mm)	18.5	28.2	60.3	149.8	234.7	368.2	353.3	387.1	266.7	148.7	40.2	13.6	2069.3

Period of record - 1902 - 1974

TABLE 7 (b)

PROBABILITY OF RAINFALL EXCEEDING SPECIFIED AMOUNTS IN ANY MONTH AT JOYDEBPUR

Rainfall (mm)	Probability (%)											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
10	40	66	77	98	100	100	100	100	100	98	76	50
25	20	41	67	90	100	100	98	100	100	94	53	13
50	8	18	50	87	98	100	98	100	98	81	25	9
75	5	10	27	75	95	100	98	98	98	67	15	-
100	2	4	15	67	91	100	98	98	96	56	7	-
125	2	-	10	56	85	96	96	98	88	39	7	-
150				48	75	93	95	95	86	34	2	-
200					54	91	88	88	68	24	-	-
250					41	77	87	83	50	20		
300						62	62	65	40	12		
400						33	37	33	11	8		

Source: Manalo, 1976.

TABLE 8

SEEPAGE AND PERCOLATION (S & P) AND EVAPORATION (EV) FOR AUS SEASON

Stage of growth	Average inclined meter reading (corrected) for planted plots (Treatment T_1) mm/day	Evaporation (EV) mm/day	Seepage and percolation (S & P) mm/day
1. Vegetative growth, 16th May to 15th June	7.67	5.35	2.32
2. Generative (Reproductive) growth, 16th June to 15th July	9.14	5.46	3.68
3. Ripening period 16th July to 5th August	7.44	4.37	3.07

TABLE 9

SEEPAGE AND PERCOLATION, EVAPORATION AND EVAPOTRANSPIRATION FOR AMAN SEASON

Stage of growth	Average inclined meter reading (corrected) for planted plots (Treatment T_1) mm/day	Average inclined meter reading (corrected) for unplanted plots mm/day	Evaporation (EV) mm/day	Seepage and Percolation (S & P) mm/day	Evapotranspiration(ET) mm/day
1. Vegetative growth, 2nd August to 9th September	7.775	9.67	4.6	5.07	2.70
2. Generative growth, 10th September to 19th October	7.720	8.44	3.76	4.68	3.04
3. Ripening period, 20th October to 8th December	7.740	7.71	2.48	5.23	2.51

TABLE 10

STAGES OF GROWTH AND SUPPLEMENTARY IRRIGATION REQUIREMENT FOR AUS SEASON

Date	Stage of growth	Amount of Irrigation water (mm) Treatment T_1	Treatment T_2
26.5.80	Vegetative	33.0	-
27.5.80	Vegetative	-	4.0
30.6.80	Reproductive	36.0	-
	Total:	69.0	4.0

TABLE 11

STAGES OF GROWTH AND SUPPLEMENTARY IRRIGATION REQUIREMENT FOR AMAN SEASON

1st. Transplant		Amount of irrigation water (mm)			
Date	Stage of growth	Treatment T_1	Treatment T_2	Treatment T_3	Treatment T_4
1.8.80	Land preparation	61.96	61.96	61.96	61.96
21.8.80	Vegetative growth	28.11	-	-	-
4.9.80	Vegetative growth	41.79	-	-	-
15.10.80	Reproductive growth	32.34	29.34	-	-
29.10.80	Ripening stage	39.01	-	-	-
1.11.80	Ripening stage	-	-	3.6	-
4.11.80	Ripening stage	29.16	-	-	-
8.11.80	Ripening stage	32.92	-	3.6	-
		Total:265.28	91.30	69.16	61.96
2nd Transplant					
4.9.80	Vegetative growth	62.01	-	-	
15.10.80	Reproductive growth	66.51	3.6	-	
29.10.80	Ripening stage	58.27	3.6	-	
3.11.80	Ripening stage	41.80	-	-	
8.11.80	Ripening stage	26.98	3.6	-	
10.11.80	Ripening stage	56.90	-	-	
14.11.80	Ripening stage	49.15	-	-	
16.11.80	Ripening stage	49.92	-	-	
18.11.80	Ripening stage	34.96	-	-	
19.11.80	Ripening stage	-	3.6	-	
21.11.80	Ripening stage	34.45	-	-	
22.11.80	Ripening stage	37.23	-	-	
24.11.80	Ripening stage	21.66	-	-	
26.11.80	Ripening stage	32.93	-	-	
		Total:572.77	14.4	0.0	

TABLE 12

WATER REQUIREMENT AND YIELD FOR DIFFERENT TREATMENTS OF AUS - AMAN SEASON

Treatment	Water requirement (mm)	Yield (T/h)
Aus season		
1. 25-50 mm standing water (T_1)	905.67	3.58
2. Rainfed with water application for saturation (T_2)	840.67	3.73
3. Rainfed	836.67	3.316
Aman season (1st Transplantation)		
1. 25-50 mm standing water (T_1)	1048.32	5.80
2. Rainfed with standing water at generative growth period (T_2)	874.34	7.27
3. Rainfed with water application for saturation (T_3)	852.20	7.68
4. Rainfed (T_4)	845.00	7.23
(2nd Transplantation)		
1. 25-50 mm standing water (T_1)	1253.00	7.86
2. Rainfed with water application for saturation (T_2)	706.8	7.21
3. Rainfed (T_3)	692.4	4.59

TABLE 13

CALCULATED WATER REQUIREMENT FOR AUS SEASON
(with negligible loss due to surface drainage)

Total water requirement:

May	-	101.60 mm	Land Preparation
(15 days)	-	115.05 mm	Vegetative growth
		216.65 mm	
June	-	115.05 mm	Vegetative growth
(30 days)	-	137.10 mm	Reproductive growth
		252.15 mm	
July	-	137.10 mm	Reproductive growth
(20 days)	-	37.20 mm	Ripening period
		174.30 mm	
Total :		643.10 mm	

Number of days when water is required = 30 (vegetative growth) + 30 (Reproductive growth) + 5)Ripening period) = 65 days.

TABLE 14

CALCULATED WATER REQUIREMENT FOR AMAN SEASON
(with negligible loss due to surface drainage)

Total water requirement: (1st Transplant)

July	-	50.80 mm	Land Preparation
August	-	50.80 mm	Land Preparation
(29 days)	-	233.10 mm	Vegetative growth
		283.90 mm	
September	-	77.70 mm	Vegetative growth
(30 days)	-	154.40 mm	Reproductive growth
		232.10 mm	
October	-	154.40 mm	Reproductive growth
(31 days)	-	85.2 mm	Ripening period
		239.60 mm	
November	-	77.40 mm	Ripening period
(10 days)	-		
		77.40 mm	
	Total:	893.80 mm	

Total water requirement: (2nd Transplant)

August	-	101.60 mm	Land Preparation
(20 days)	-	155.40 mm	Vegetative growth
		257.00 mm	
September	-	155.40 mm	Vegetative growth
(30 days)	-	77.20 mm	Reproductive growth
		232.60 mm	
October	-	231.60 mm	Reproductive growth
(31 days)	-	7.70 mm	Repening period
		239.30 mm	
November	-	147.10 mm	Ripening period
(19 days)	-		
		147.10 mm	

Number of days when irrigation is required = 40 (Vegetative growth)
+ 40 (Reproductive growth)
+ 20 (Ripening period)
= 100 days.

TABLE 15

SUPPLEMENTARY IRRIGATION REQUIREMENT FOR THE YEARS 1974-79 DURING THE AUS SEASON

Year	Amount of supplementary irrigation required at:				Total (mm)
	Land Preparation (mm)	Vegetative growth (mm)	Reproductive growth (mm)	Ripening stage (mm)	
1974	-	No data available			
1975	-	25.4	-	-	25.4
1976	-	25.4	-	-	25.4
1977		No data available			
1978	-	-	-	-	-
1979	101.6	127.0	-	-	228.6

TABLE 17

AMOUNT OF RAINFALL REQUIRED TO MEET THE CROP WATER REQUIREMENT FOR THE DIFFERENT MONTHS OF AUS SEASON, THEIR PROBABILITIES AND THE IRRIGATION REQUIREMENTS UNDER DIFFERENT PROBABILITIES

Months	Amount of rainfall required (mm)	Probability (%)	Amount of irrigation required (mm)	Irrigation requirement at different rainfall probabilities (mm)	
				75%	50%
May	216.65	50	108.32	66.65	-
June	252.15	77	57.99	-	-
July	174.30	90	17.43	-	-
			Total: 183.74	66.65	0.0

TABLE 18

AMOUNT OF RAINFALL REQUIRED TO MEET THE CROP WATER REQUIREMENT FOR THE DIFFERENT MONTHS OF AMAN SEASON, THEIR PROBABILITIES AND IRRIGATION REQUIREMENTS UNDER DIFFERENT PROBABILITIES

Months	Amount of rainfall required (mm)	Probability (%)	Amount of irrigation required (mm)	Irrigation requirement at different rainfall probabilities (mm)		
				75%	50%	25%
1st Transplant						
July	50.80	100	-	-	-	-
August	283.90	70	85.17	15.0	-	-
September	232.10	56	102.12	52.0	-	-
October	239.60	22	186.88	180.0	120.0	40.0
November	77.40	15	65.79	62.0	47.0	27.4
		Total:	439.96	309.00	167.0	67.4
2nd Transplant						
August	257.00	80	51.40	-	-	-
September	232.60	56	102.3	52.0	-	-
October	239.30	22	186.6	180.0	120.0	40.0
November	147.10	0	147.1	132.0	117.0	97.0
		Total:	487.4	364.0	237.0	137.0

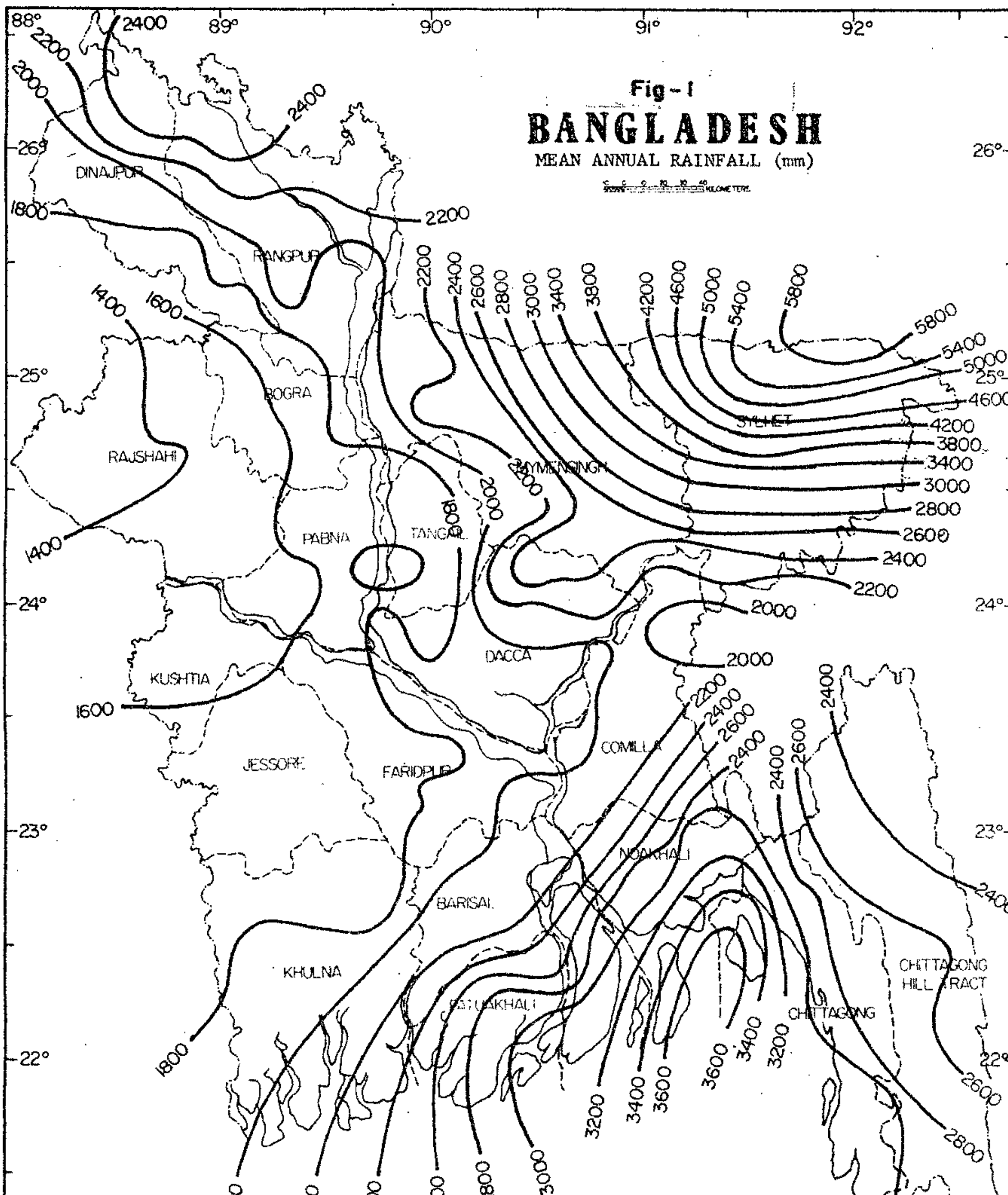


Fig - I
BANGLADESH
MEAN ANNUAL RAINFALL (mm)
DINAJPUR
RANGPUR
BOGRA
RAJSHAHI
PABNA
TANGAIL
MYMENSINGH
SYLHET
KUSHTIA
DACCA
JESSORE
FARIDPUR
COMILLA
NOAKHALI
BARISAL
KHULNA
PATUAKHALI
CHITTAGONG
CHITTAGONG HILL TRACT
88°
89°
90°
91°
92°
26°
25°
24°
23°
22°
21°
EBM/BED '76

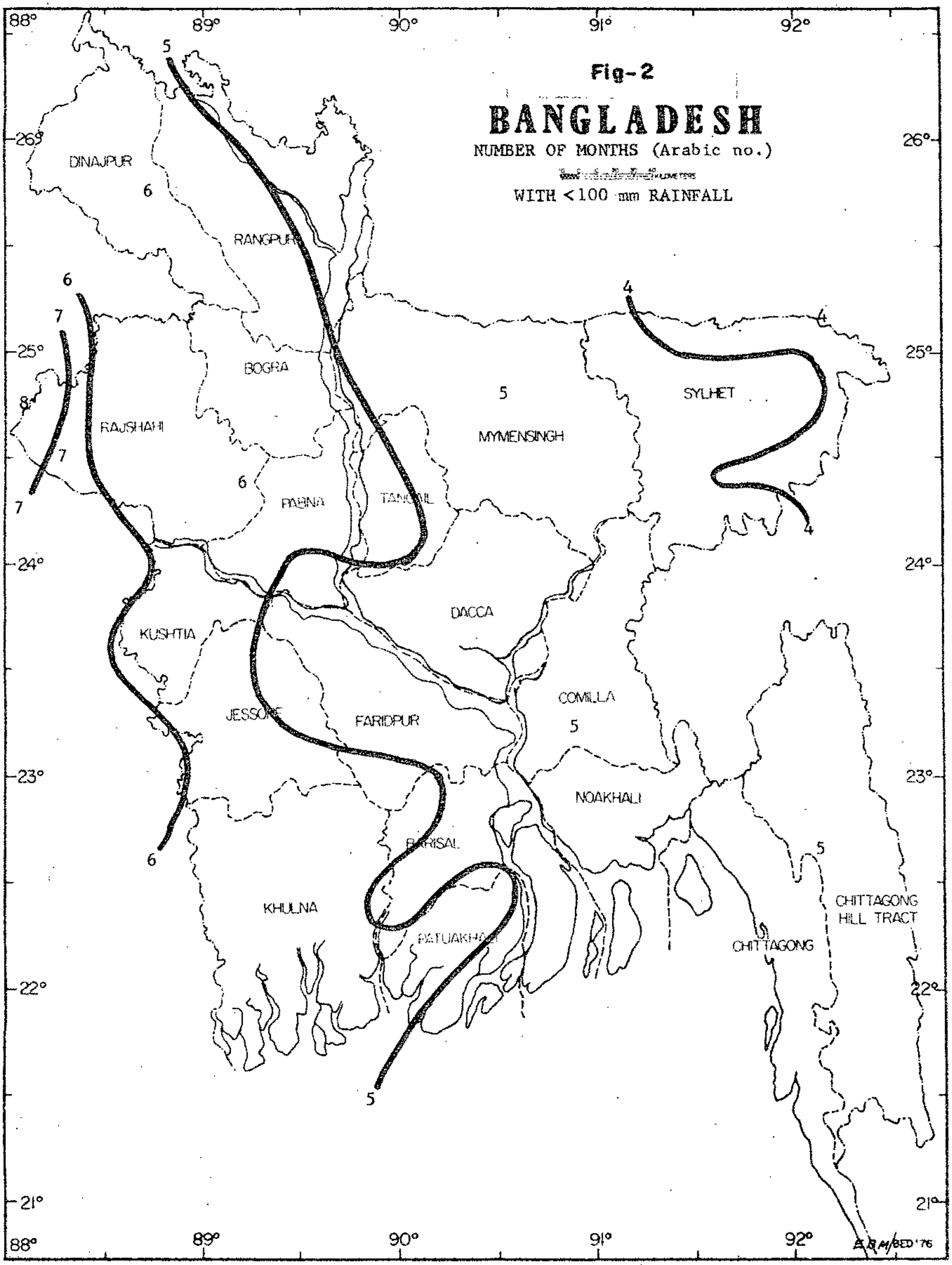


Fig-2
BANGLADESH
NUMBER OF MONTHS (Arabic no.)
WITH <100 mm RAINFALL
88°
89°
90°
91°
92°
26°
25°
24°
23°
22°
21°
DINAJPUR
RANGPUR
BOGRA
RAJSHAHI
PABNA
TANGAIL
MYMENSINGH
SYLHET
KUSHTIA
DACCA
COMILLA
JESSORE
FARIDPUR
NOAKHALI
BARISAL
KHULNA
PATUAKHALI
CHITTAGONG
CHITTAGONG HILL TRACT
4
5
6
7
8
ERM/BED '76

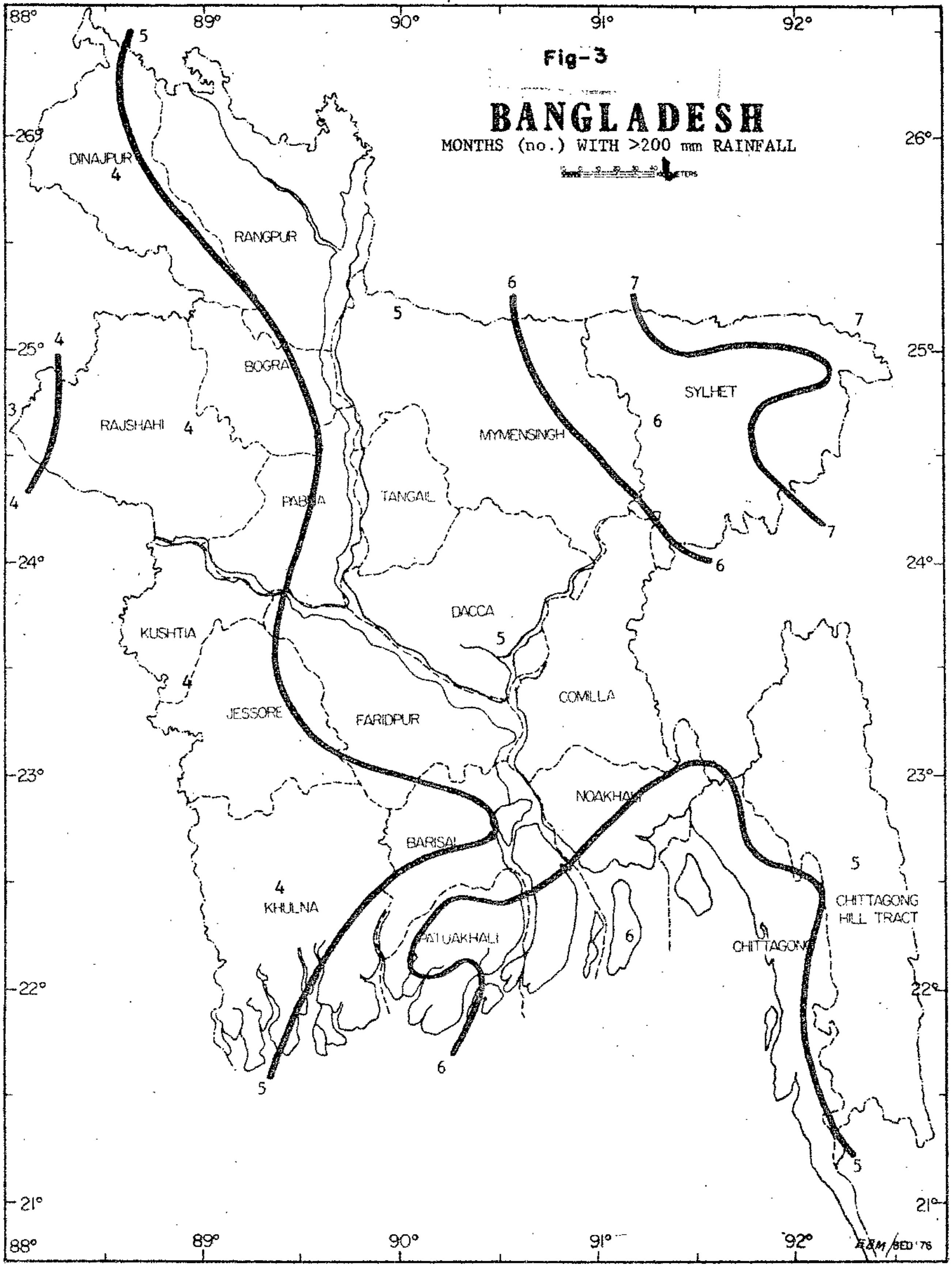


Fig-3
BANGLADESH
MONTHS (no.) WITH >200 mm RAINFALL
88°
89°
90°
91°
92°
26°
25°
24°
23°
22°
21°
DINAJPUR
RANGPUR
BOGRA
RAJSHAHI
PABNA
TANGAIL
MYMENSINGH
SYLHET
KUSHTIA
DACCA
COMILLA
JESSORE
FARIDPUR
NOAKHALI
BARISAL
KHULNA
PATUAKHALI
CHITTAGONG
CHITTAGONG
HILL TRACT
3
4
5
6
7
B&M/BED '76

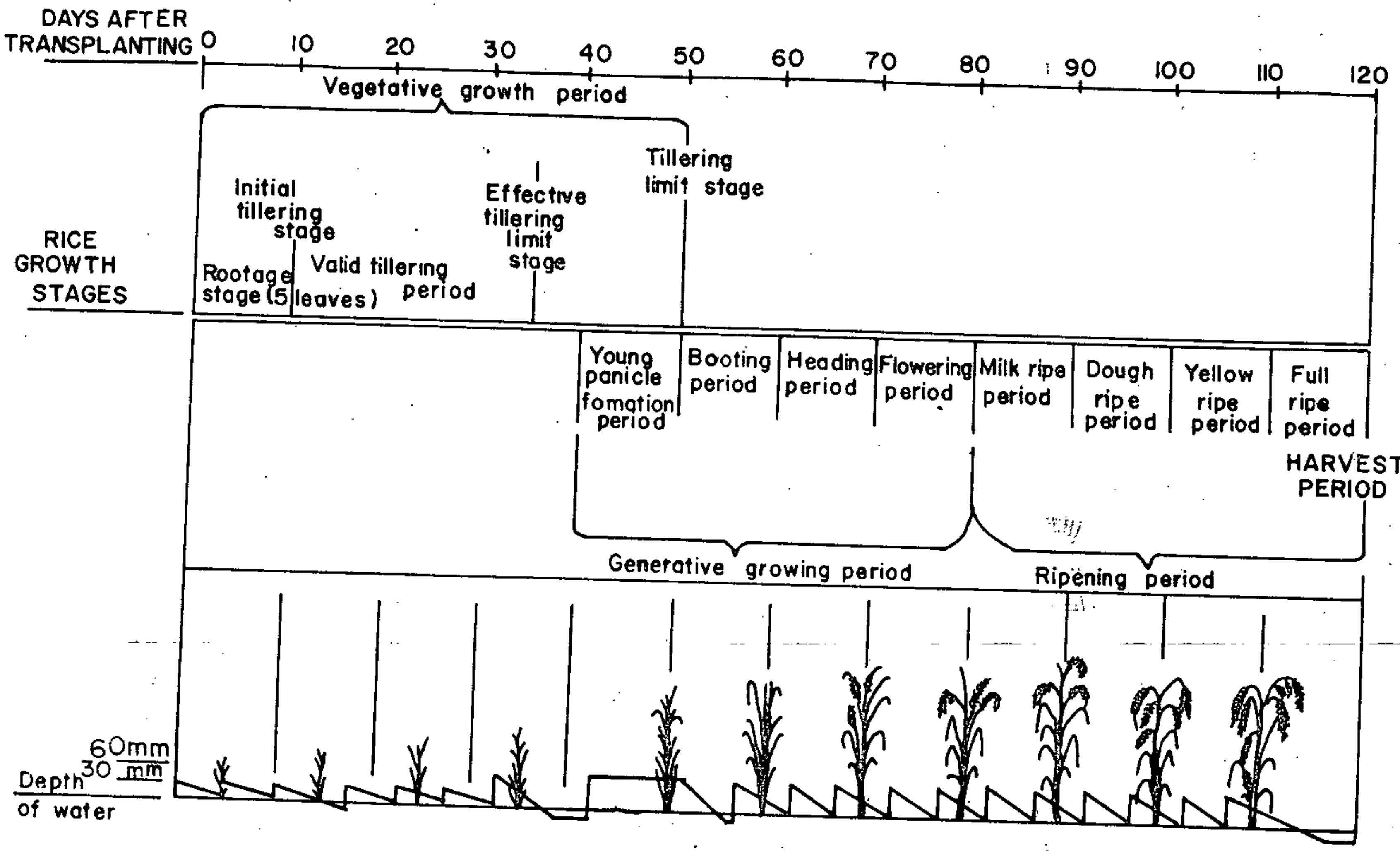


FIG. 4 Rice growing period and water application

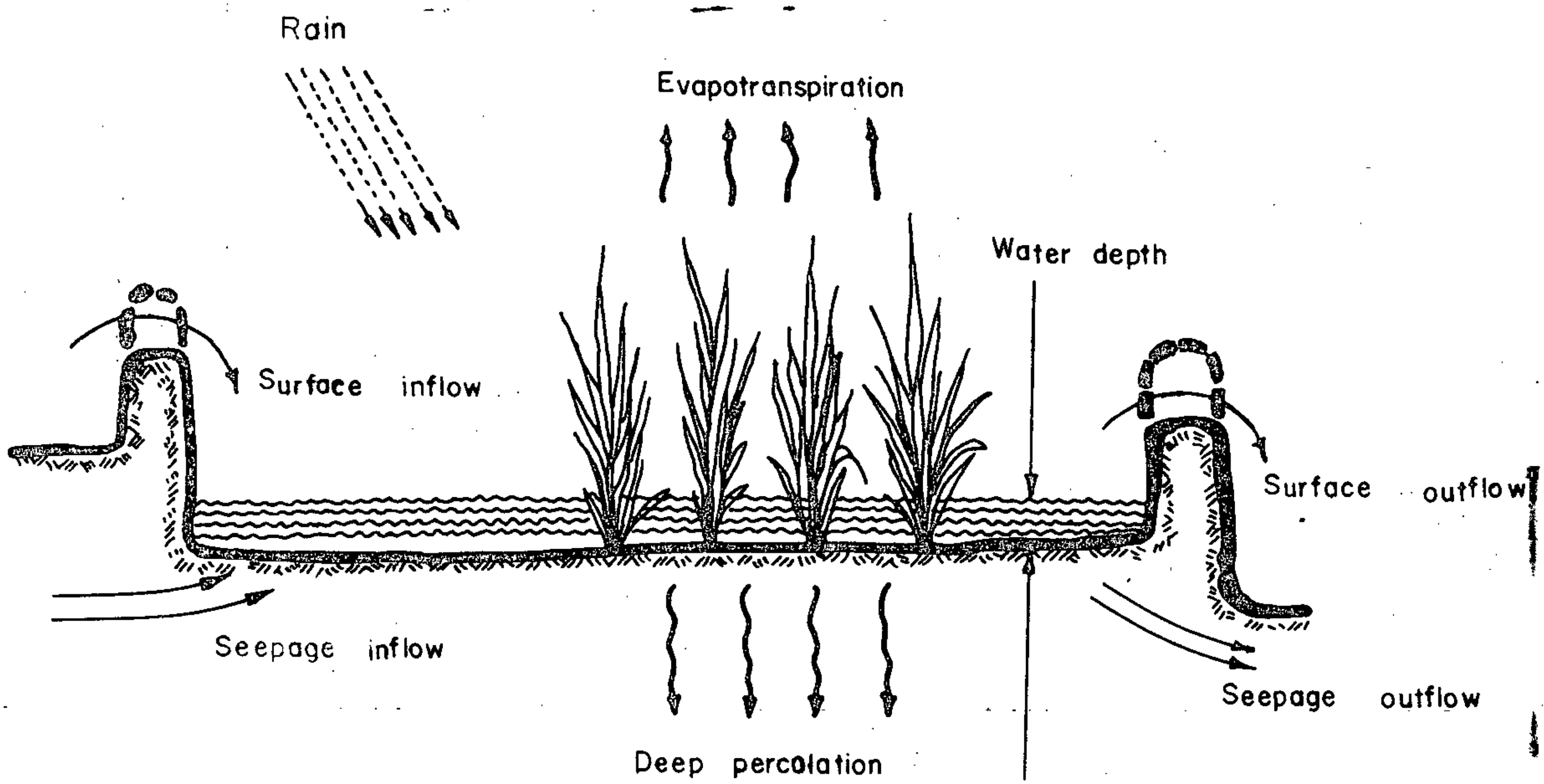


FIG. 5 Water balance in rainfed paddies

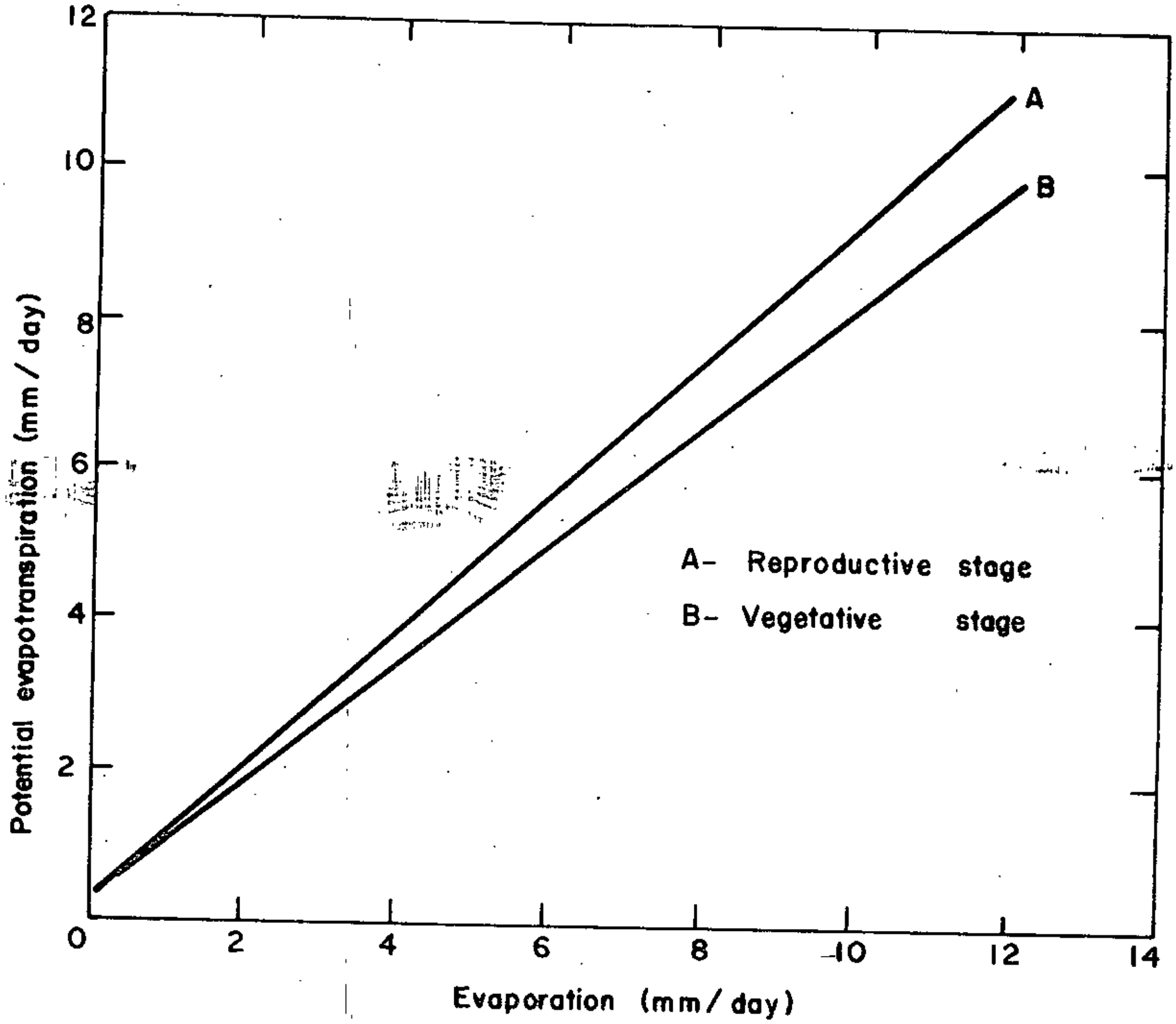
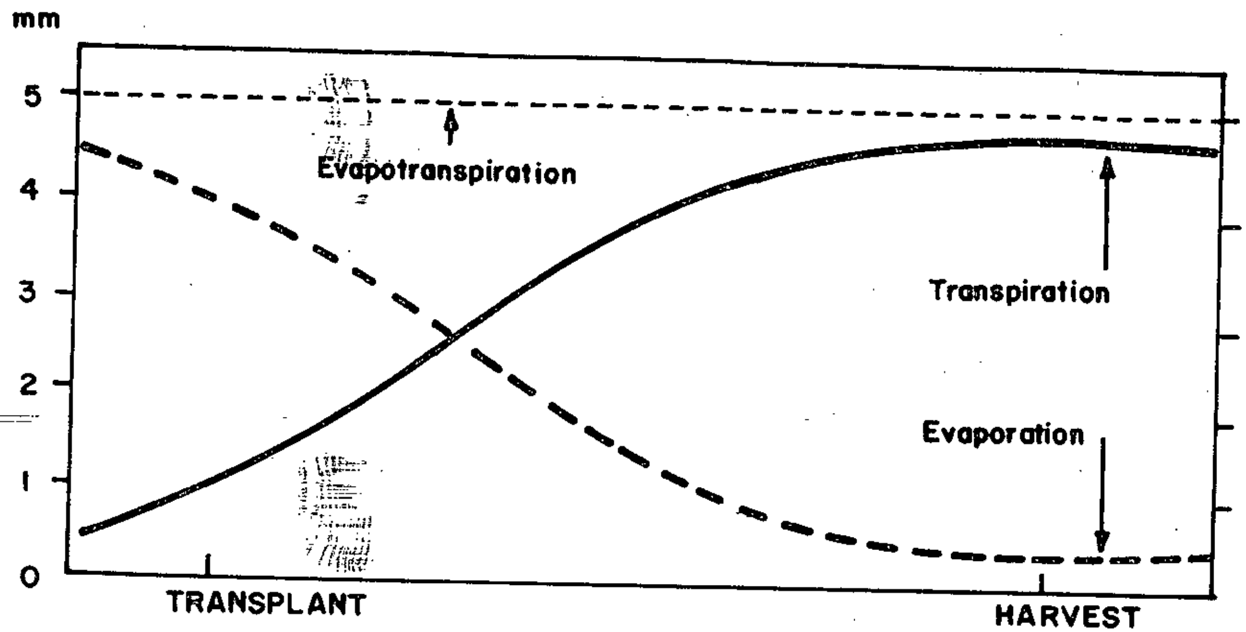


Fig. 6 Evapotranspiration- evaporation relationship using pan evaporation. (Kampen, 1970)



FIG· 7 Relative trends of transpiration, evaporation and evapotranspiration during crop growth ·

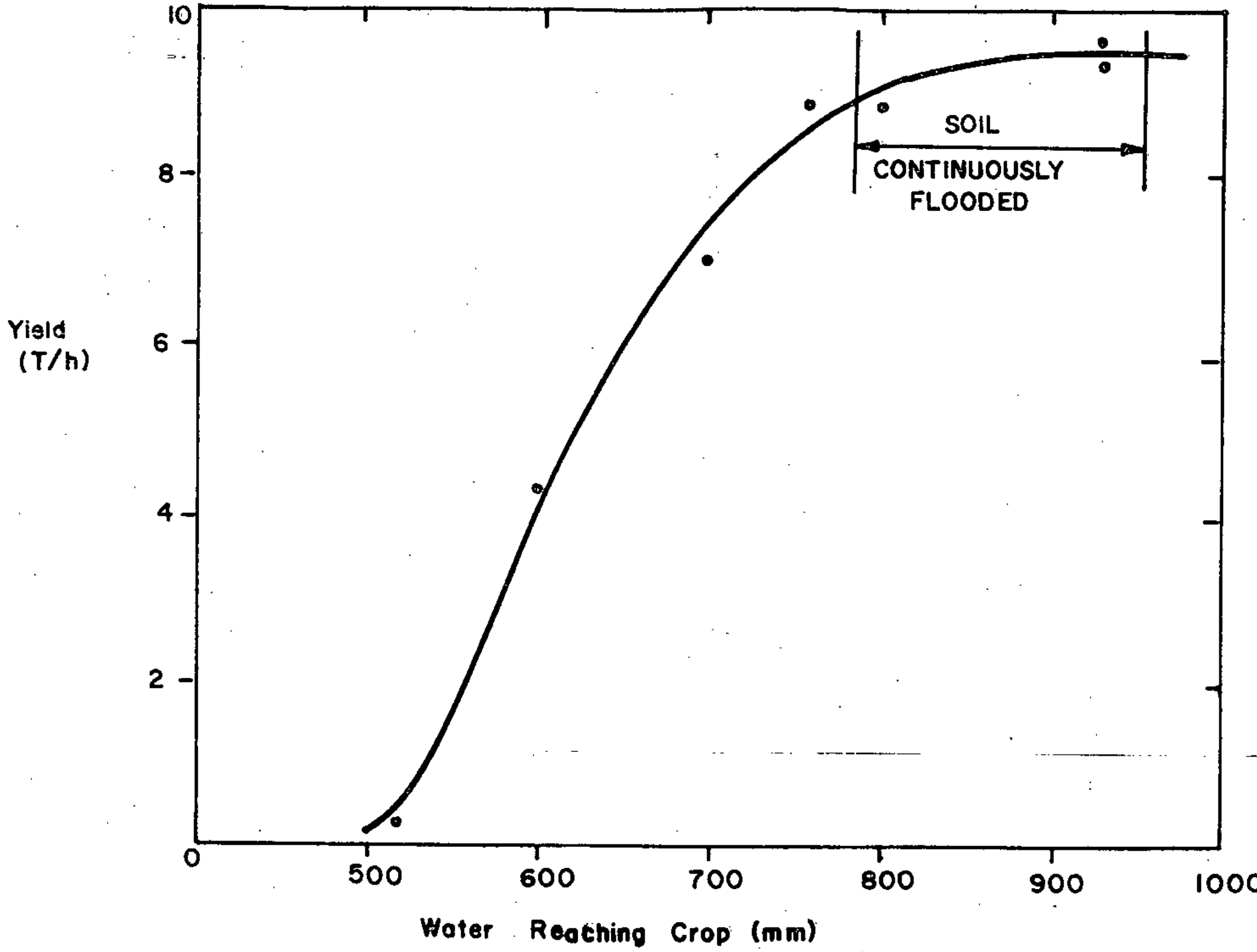


FIG. 8 The yield of rice as a function of applied water. IRRI, 1969.

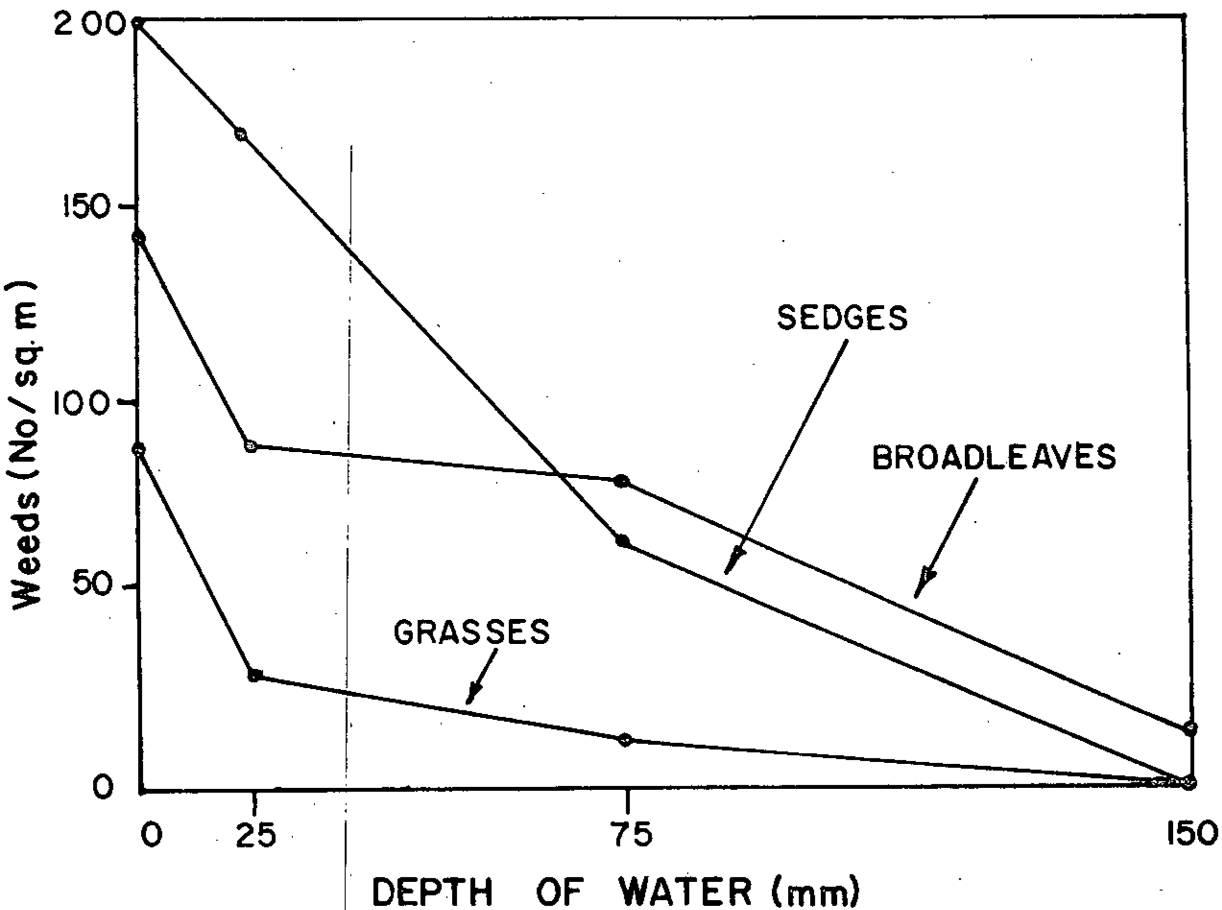


FIG. 9 Effect of depths of water on weed population in rice field. IRRI, 1968 wet season.

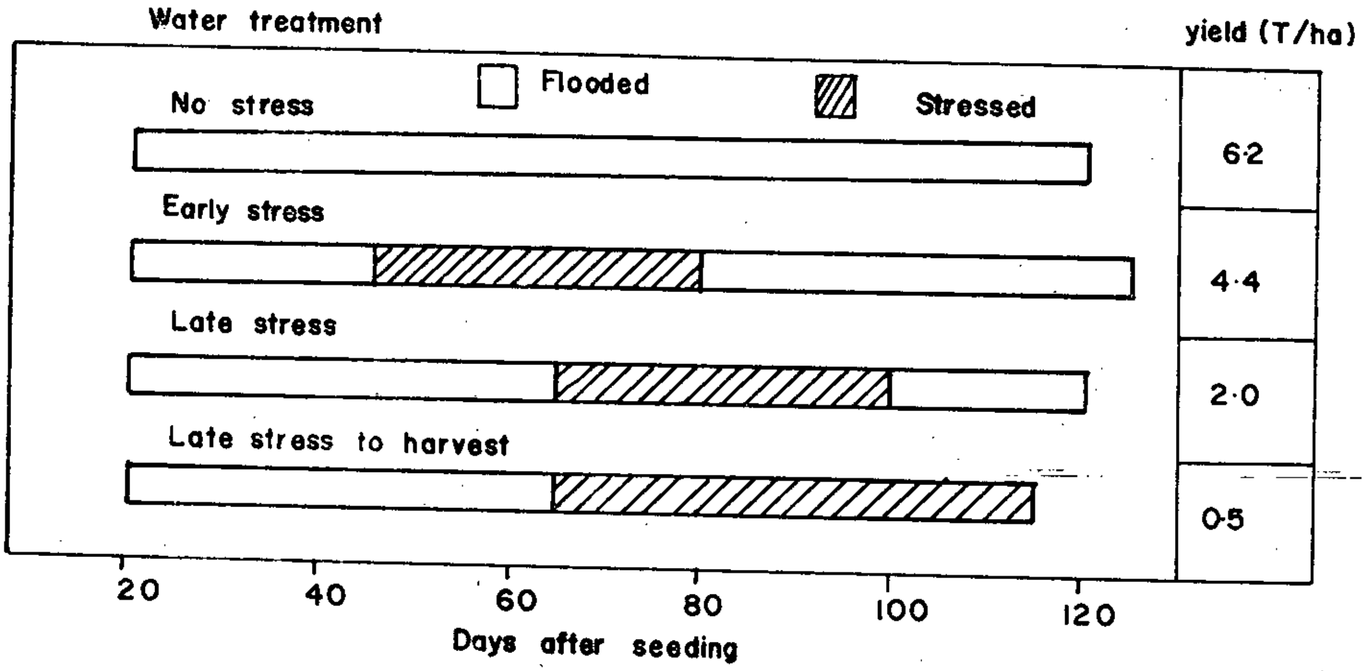


FIG. 10 Grain yield as affected by water stress (IRRI, 1972)

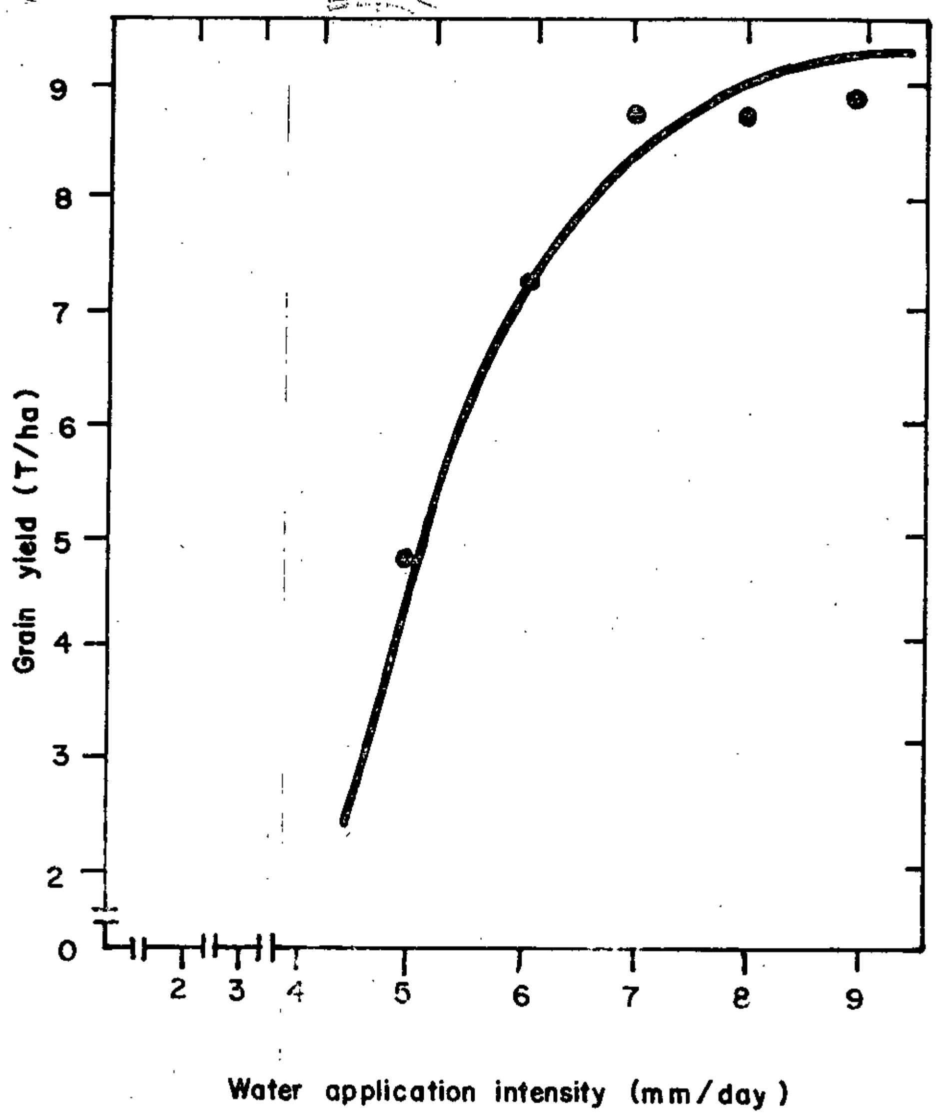


FIG. 11 Yield response to different water application intensity treatments (IRRI, 1970)

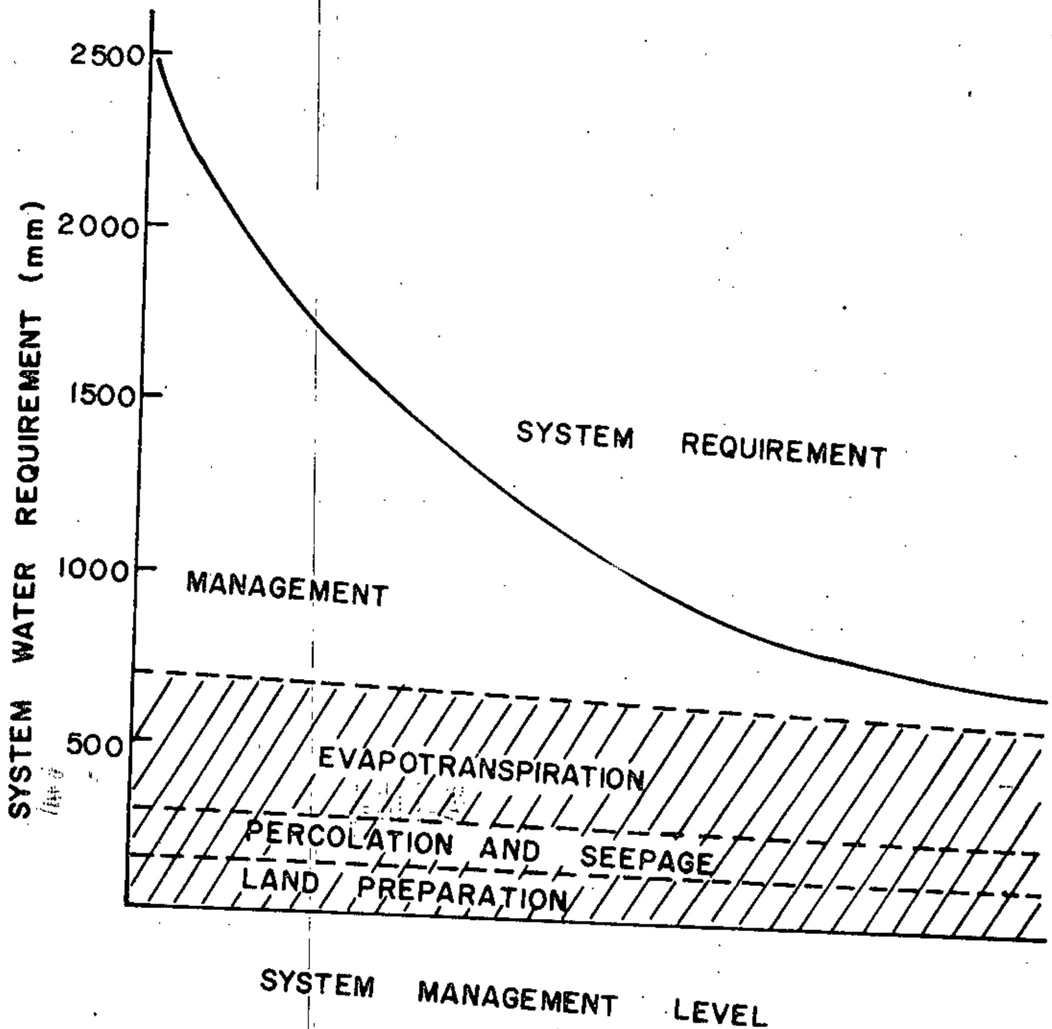


Fig. 12 System water requirement as a function of management level. (G. Levine, 1970)

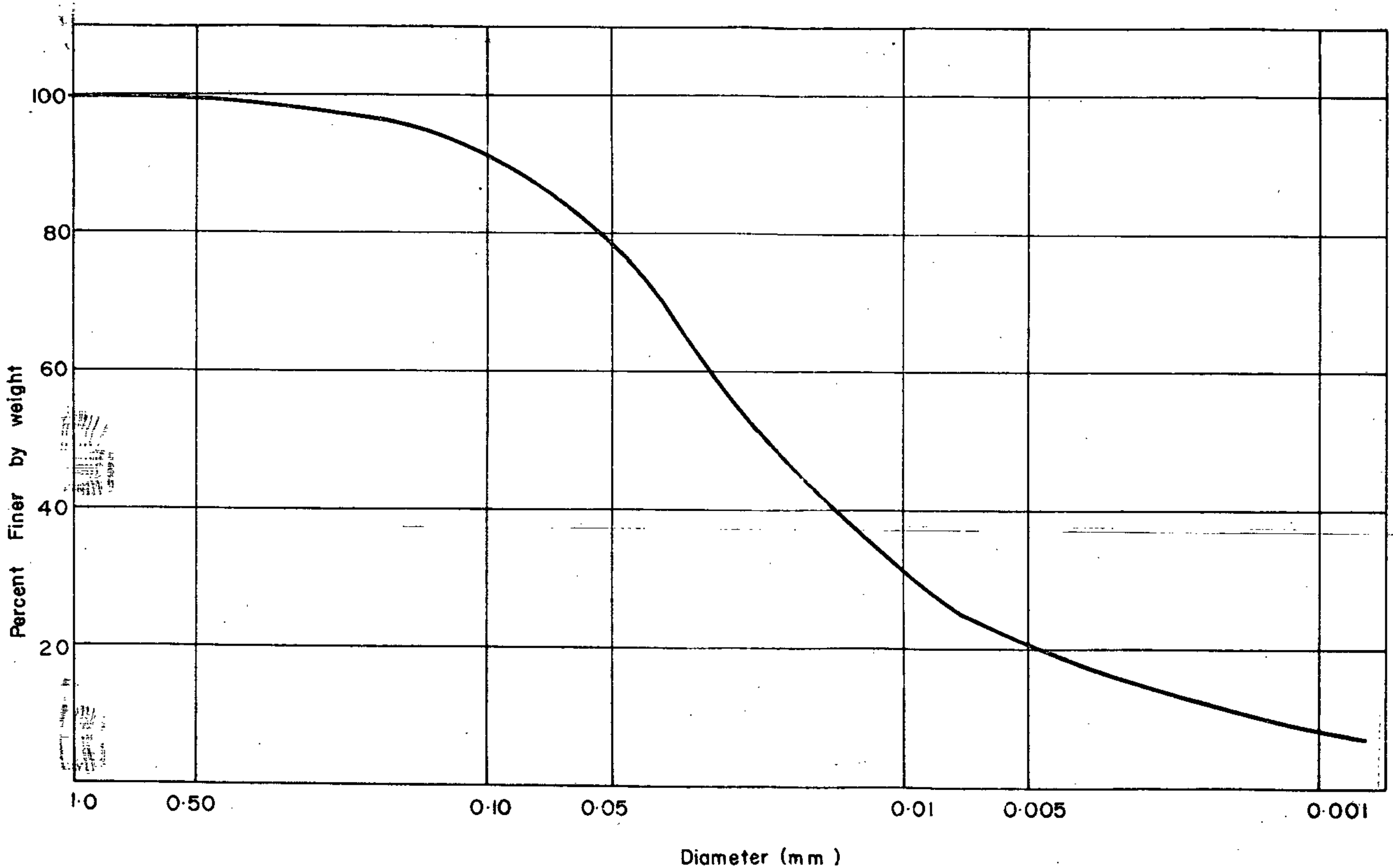


Fig. 13 Grain size distribution of soil taken from BRRI farm, Joydebpur.

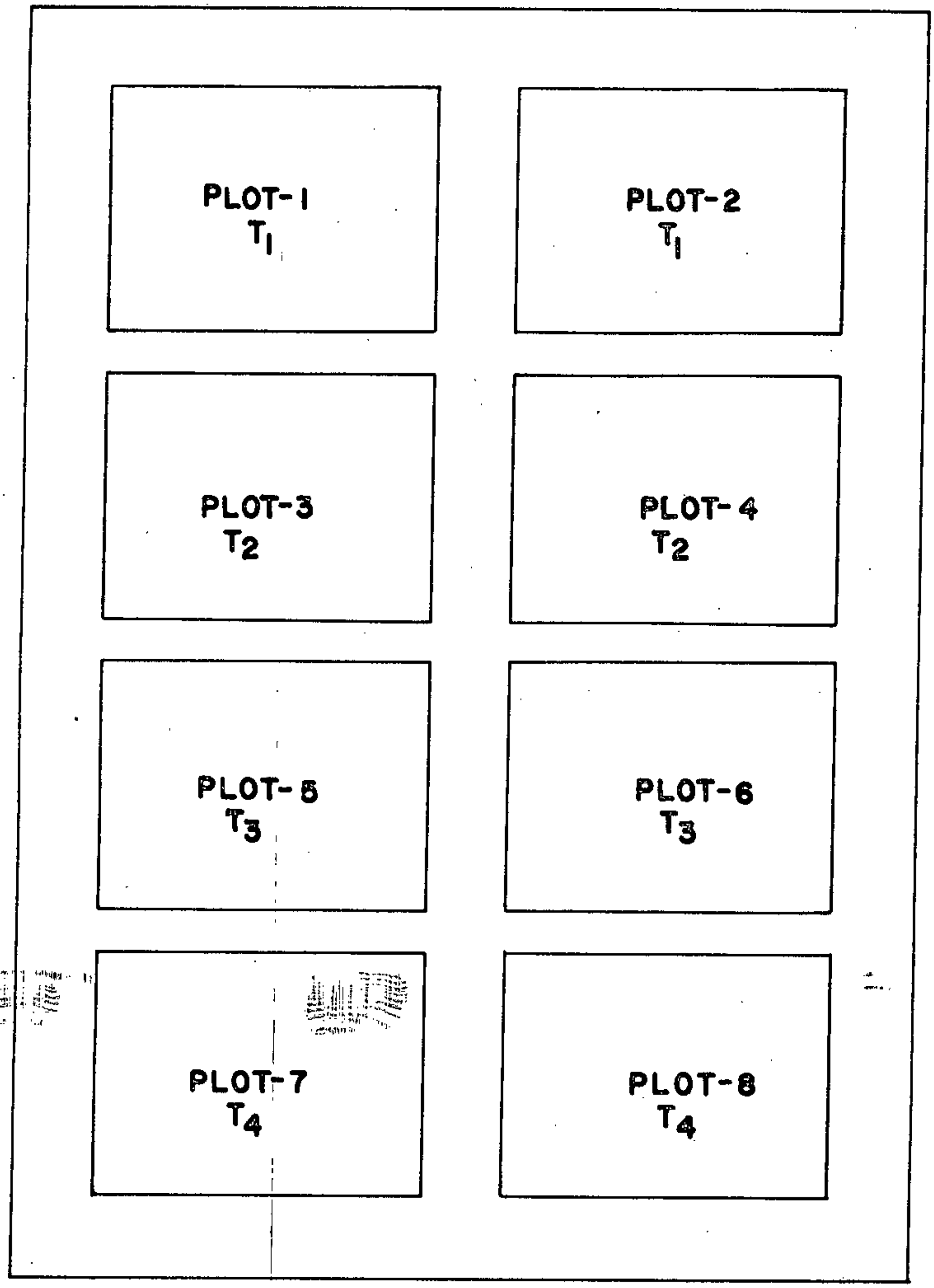


FIG. 14 FIELD LAYOUT MAP OF AUS SEASON
SCALE 1 in = 4 m

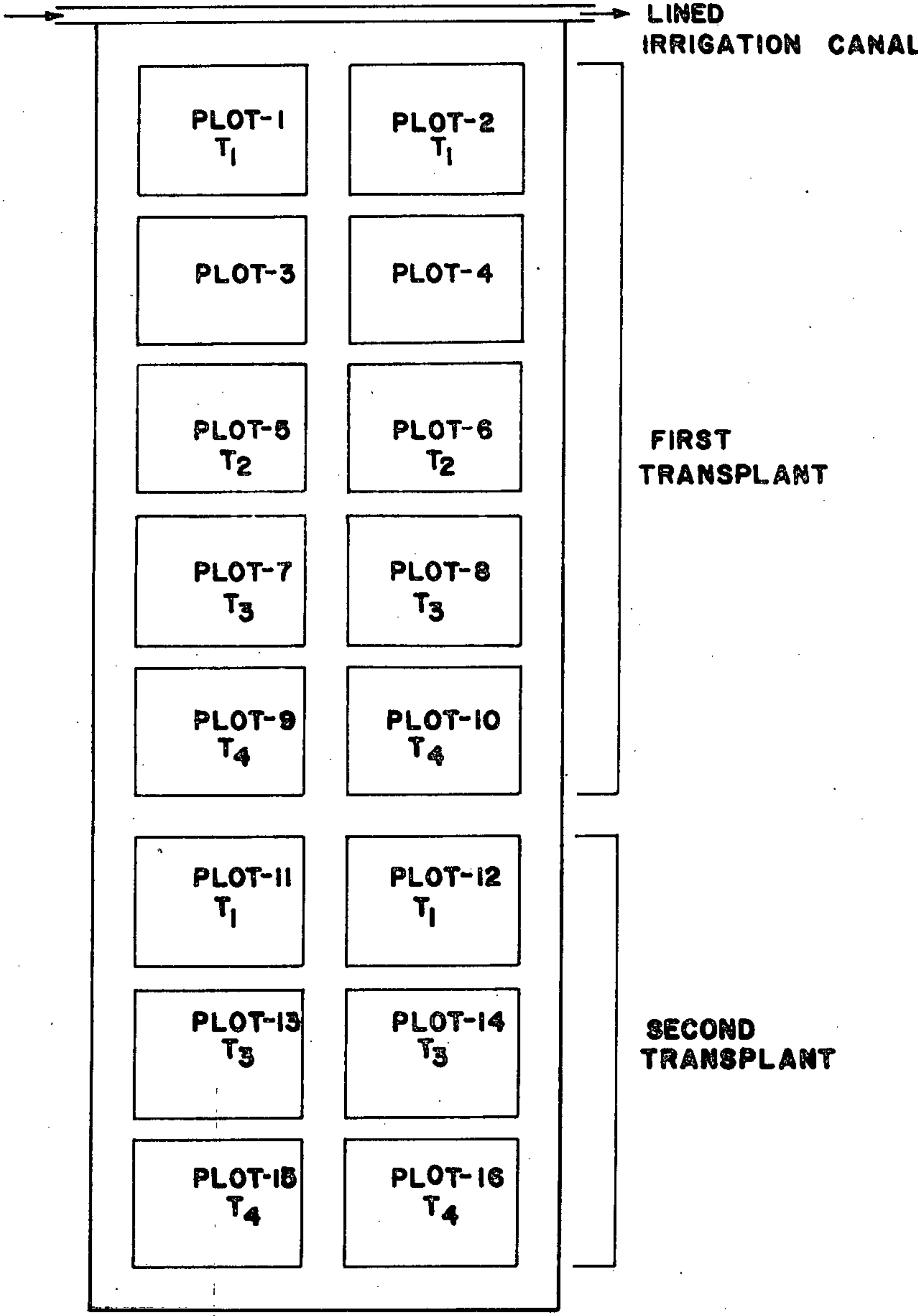


FIG: 15 FIELD LAYOUT MAP OF AMAN SEASON
SCALE: 1in = 6·66m

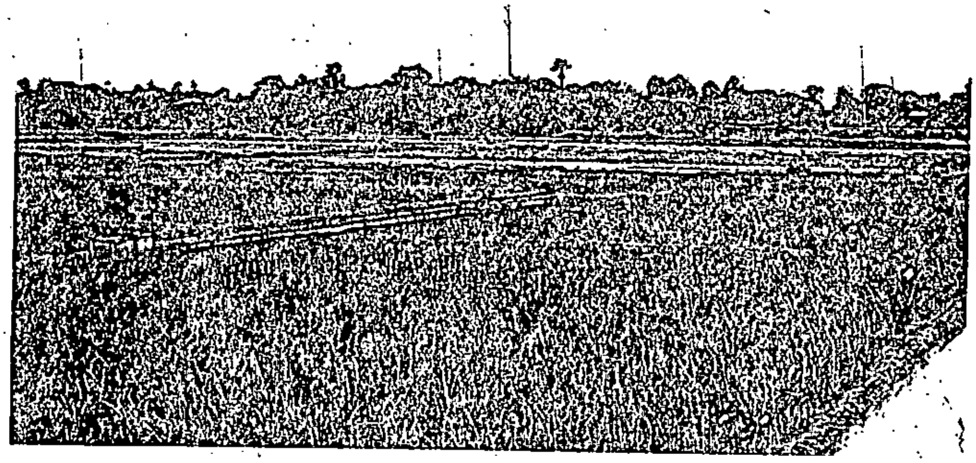


Fig. 16

Experimental plots at the BRRI Farm

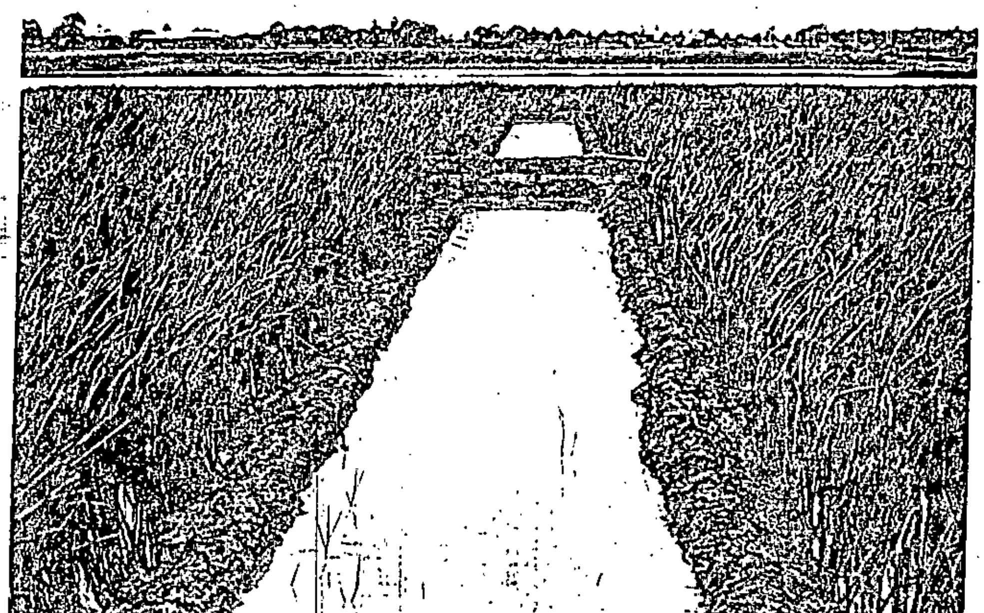
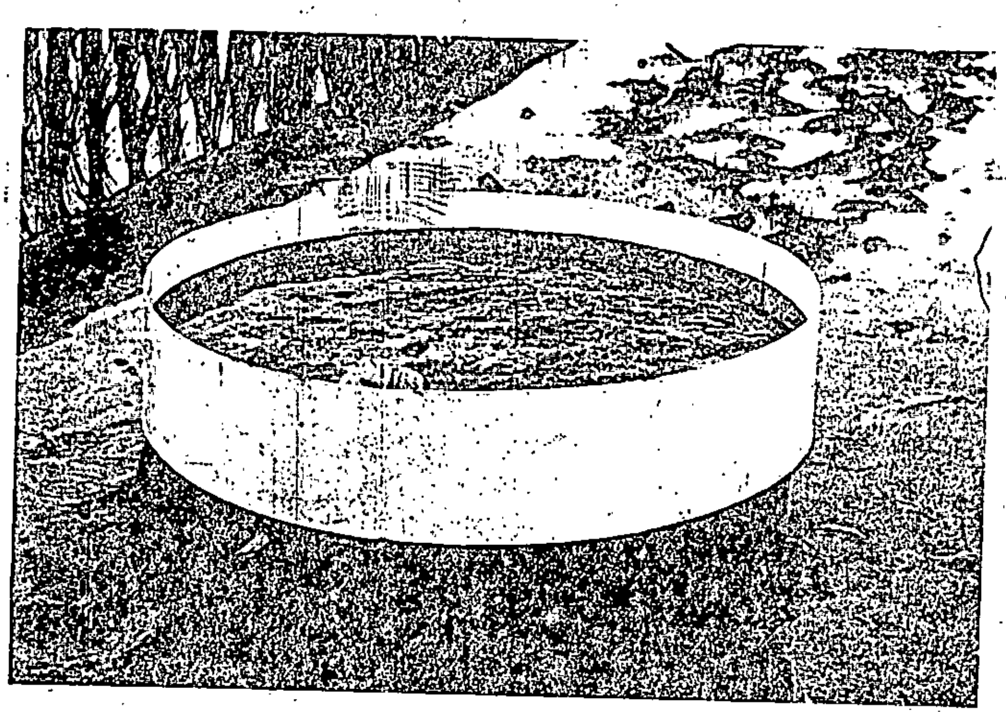


Fig. 17

Spacing between plots and the condition of the bunds after rains

a) Rain gauge



b) Evaporation pan

Fig. 18 Rain gauge and Evaporation pan installed near experimental plots .

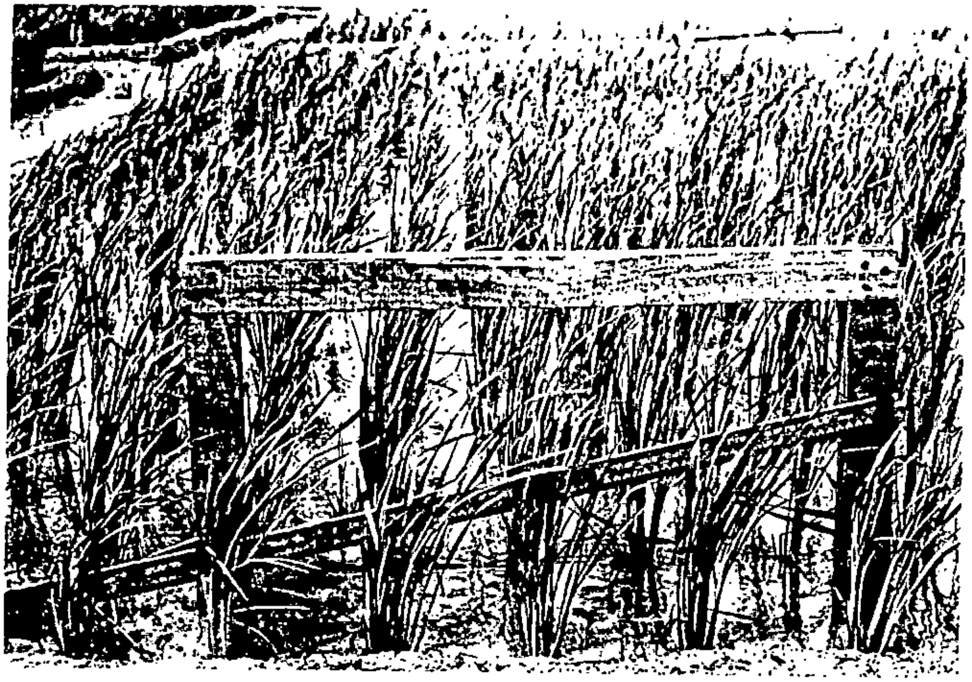


Fig. 19

Inclined meter in a rice field

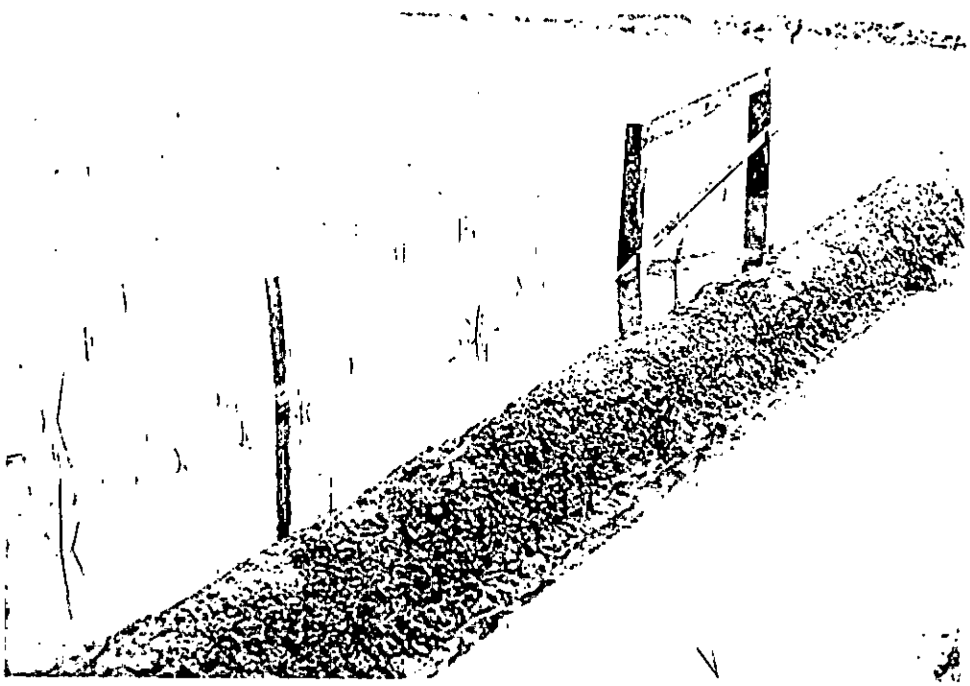


Fig. 20

Inclined meter in unplanted plot

Fig. 21 Graduated bamboo stick for water level measurement

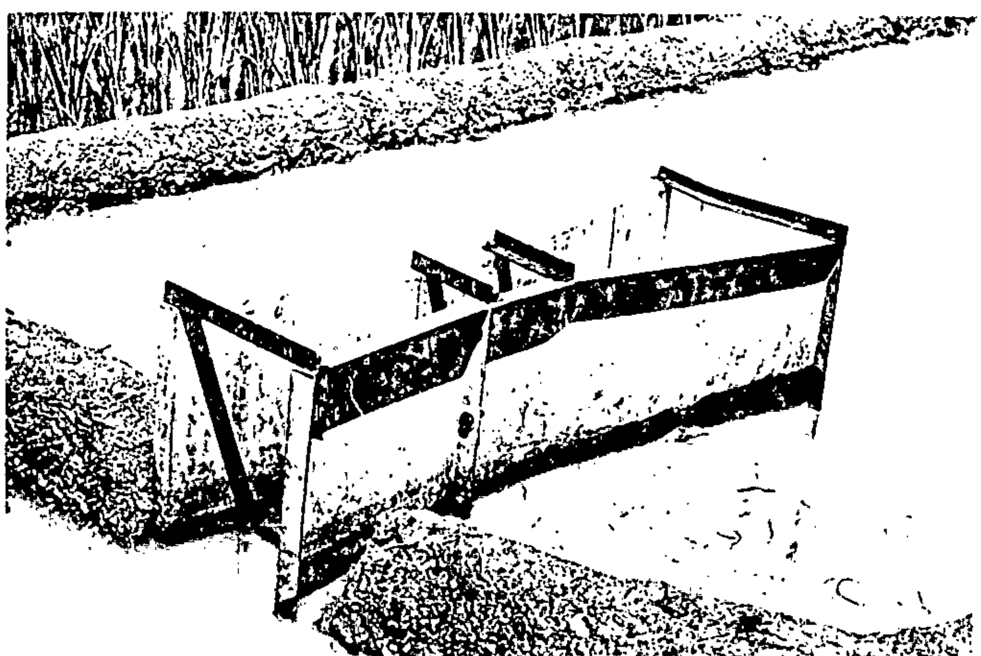
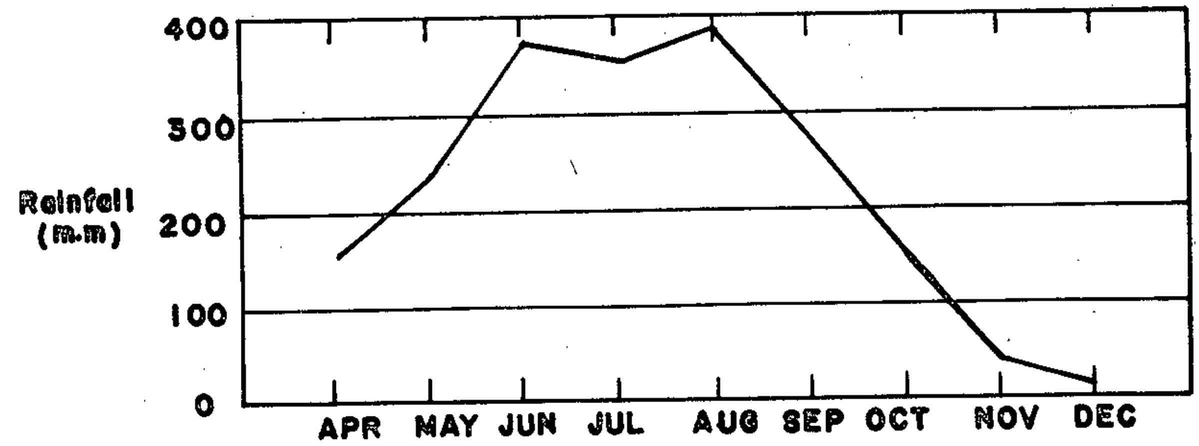
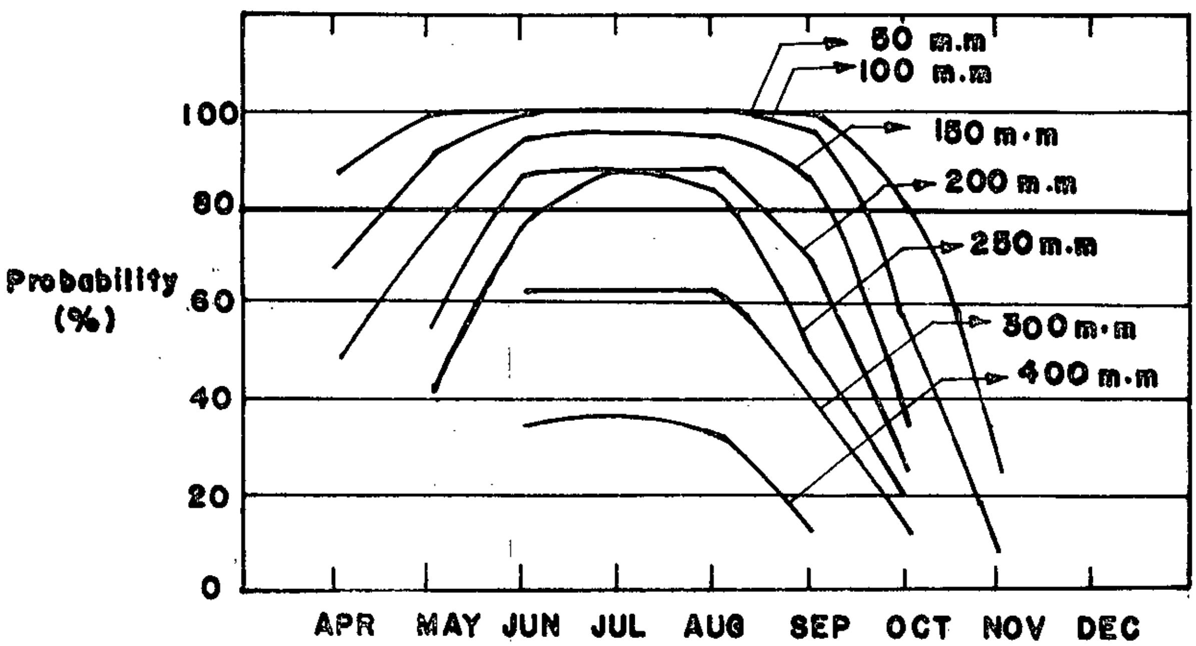


Fig. 22 Parshall flume in the field



FIG·23 Mean monthly rainfall at Joydebpur during the Aus- Aman season ·



FIG· 24 Probability of occurance of different amounts of rainfall during the Aus-Aman season at Joydebpur ·

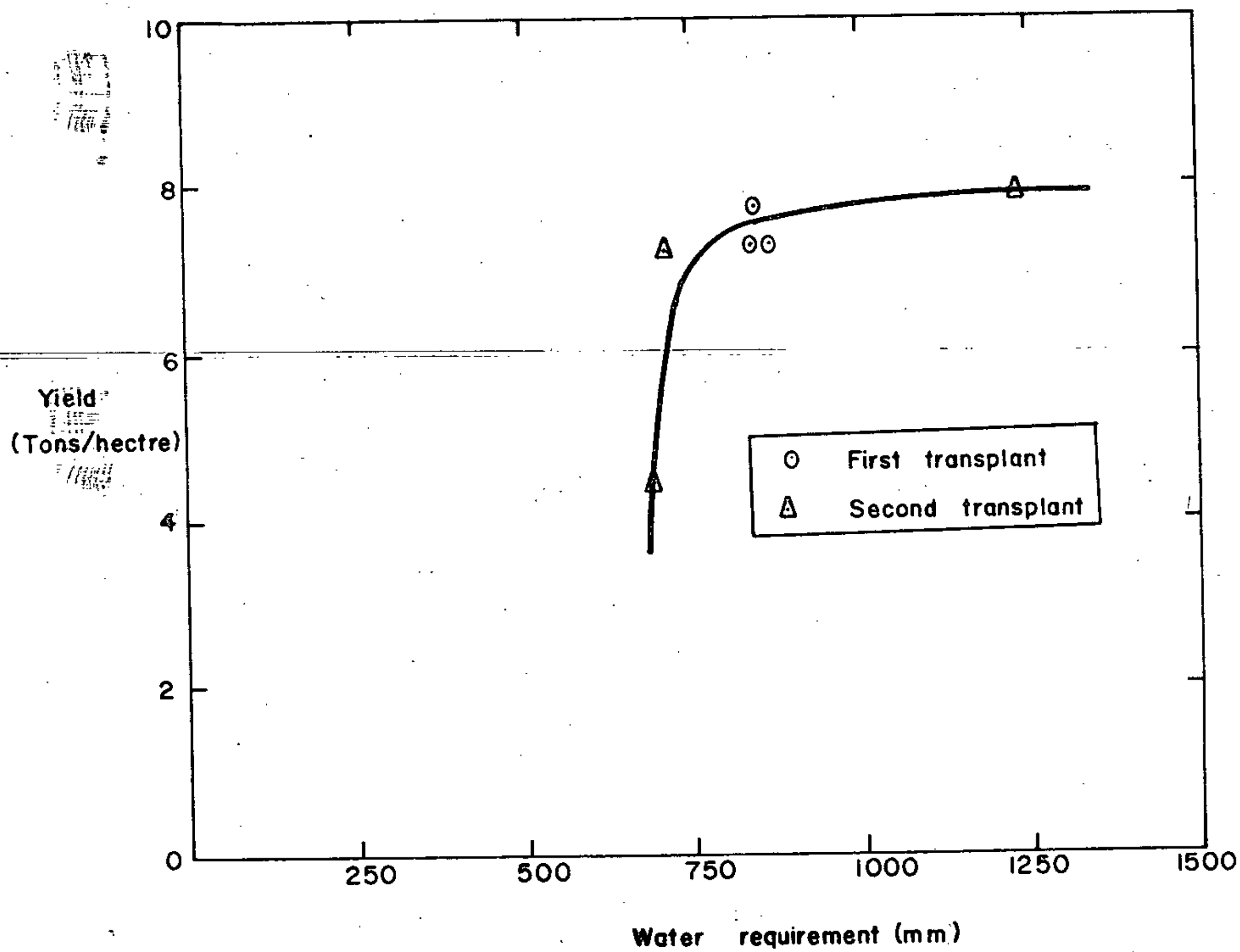


Fig. 25 Yield of rice as a function of water requirement during the Aman season (1980).

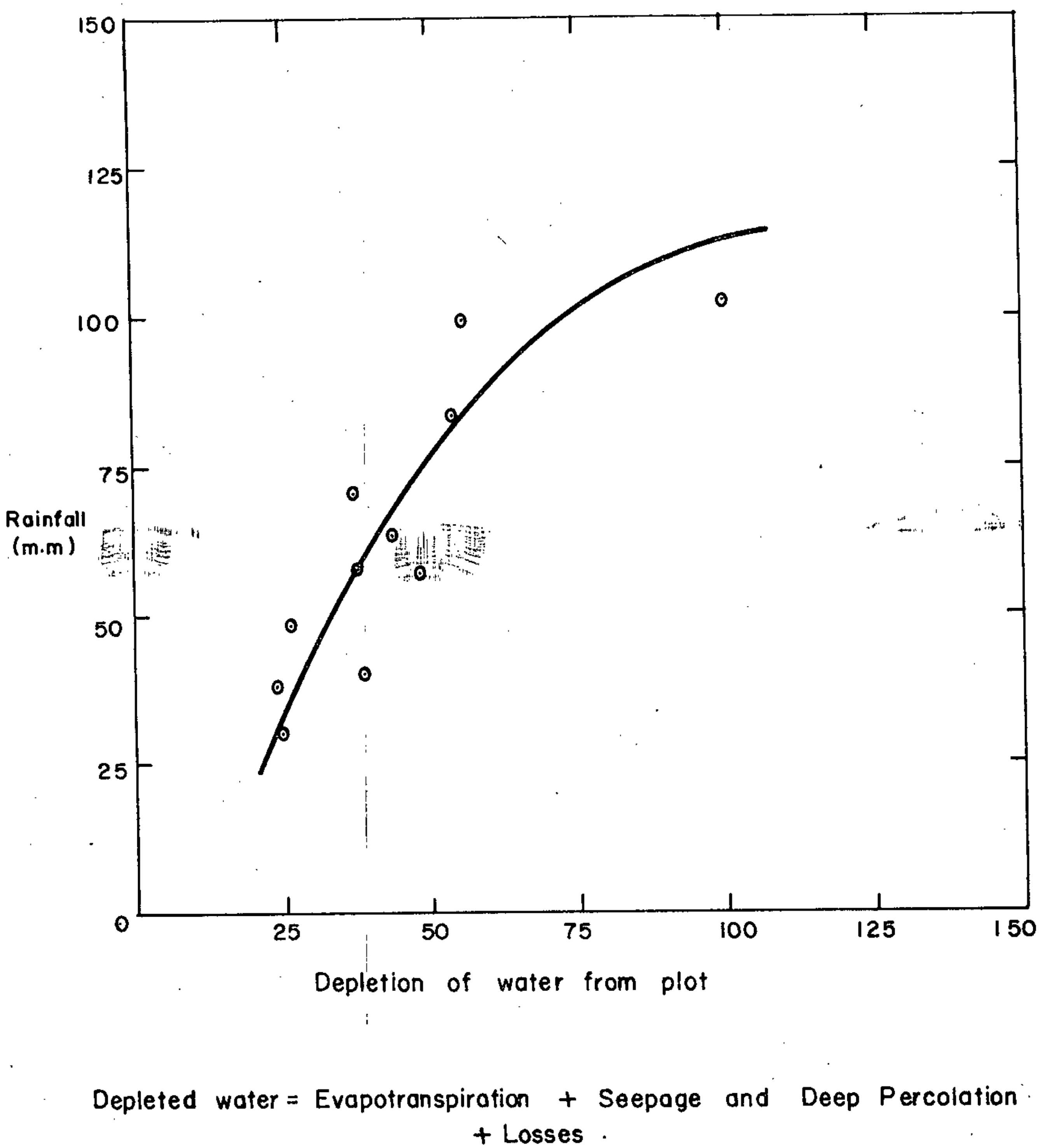


FIG. 26 Depletion of water from plot for rainfall exceeding 25 m.m .

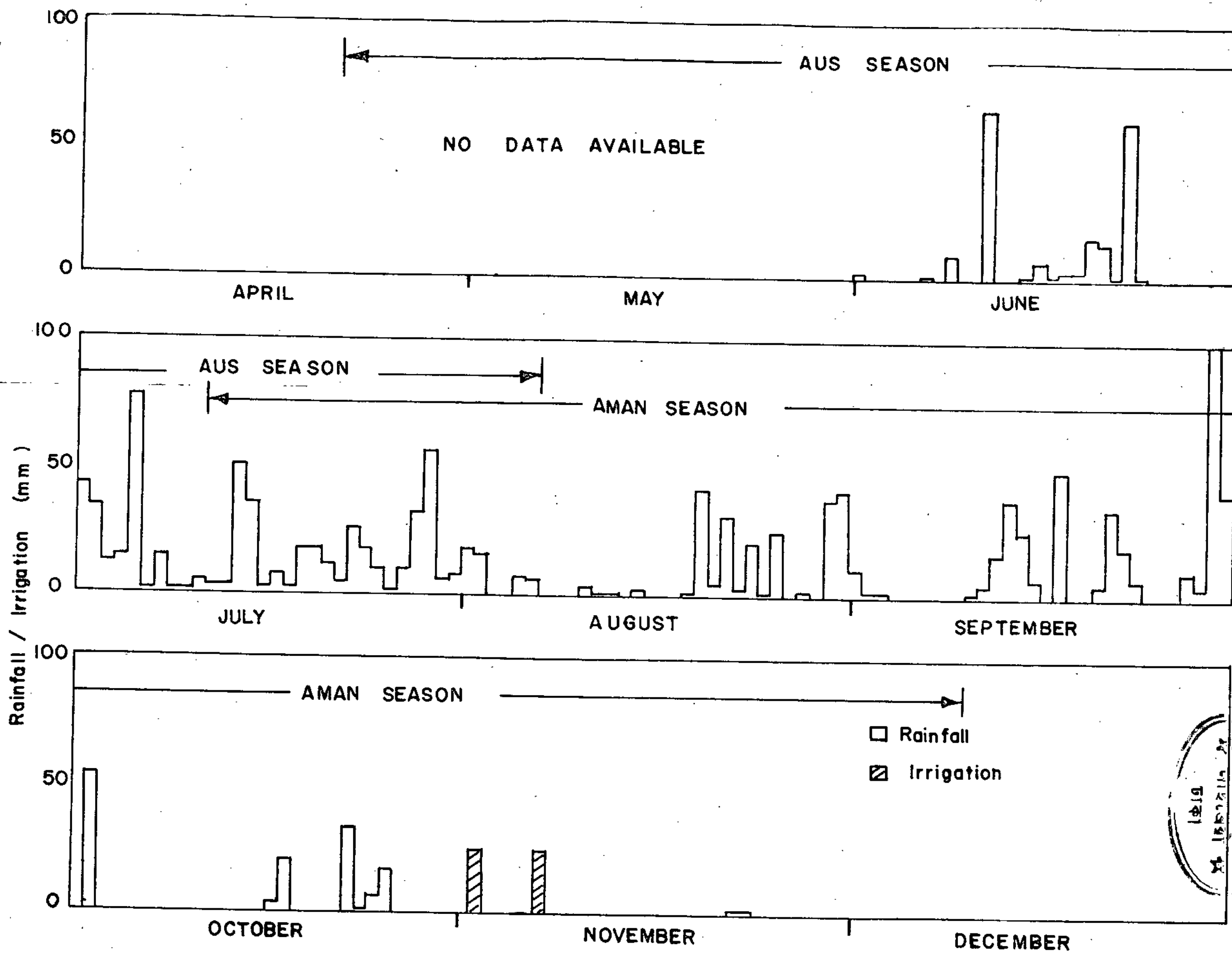


Fig. 27 Rainfall and Supplementary irrigation requirement during the Aus - Aman season for 1974

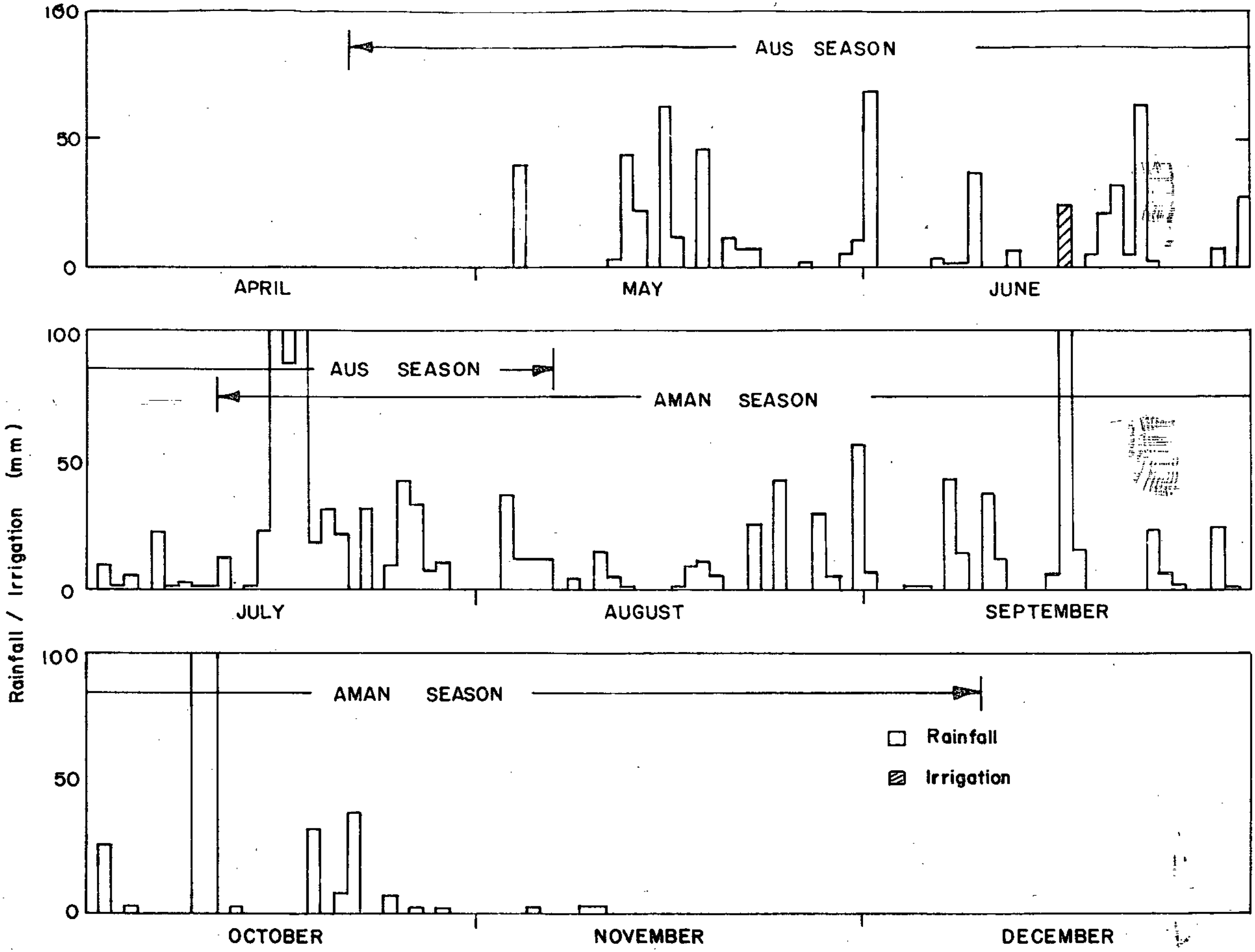


Fig. 28 Rainfall and Supplementary irrigation requirement during the Aus - Aman season for 1975.

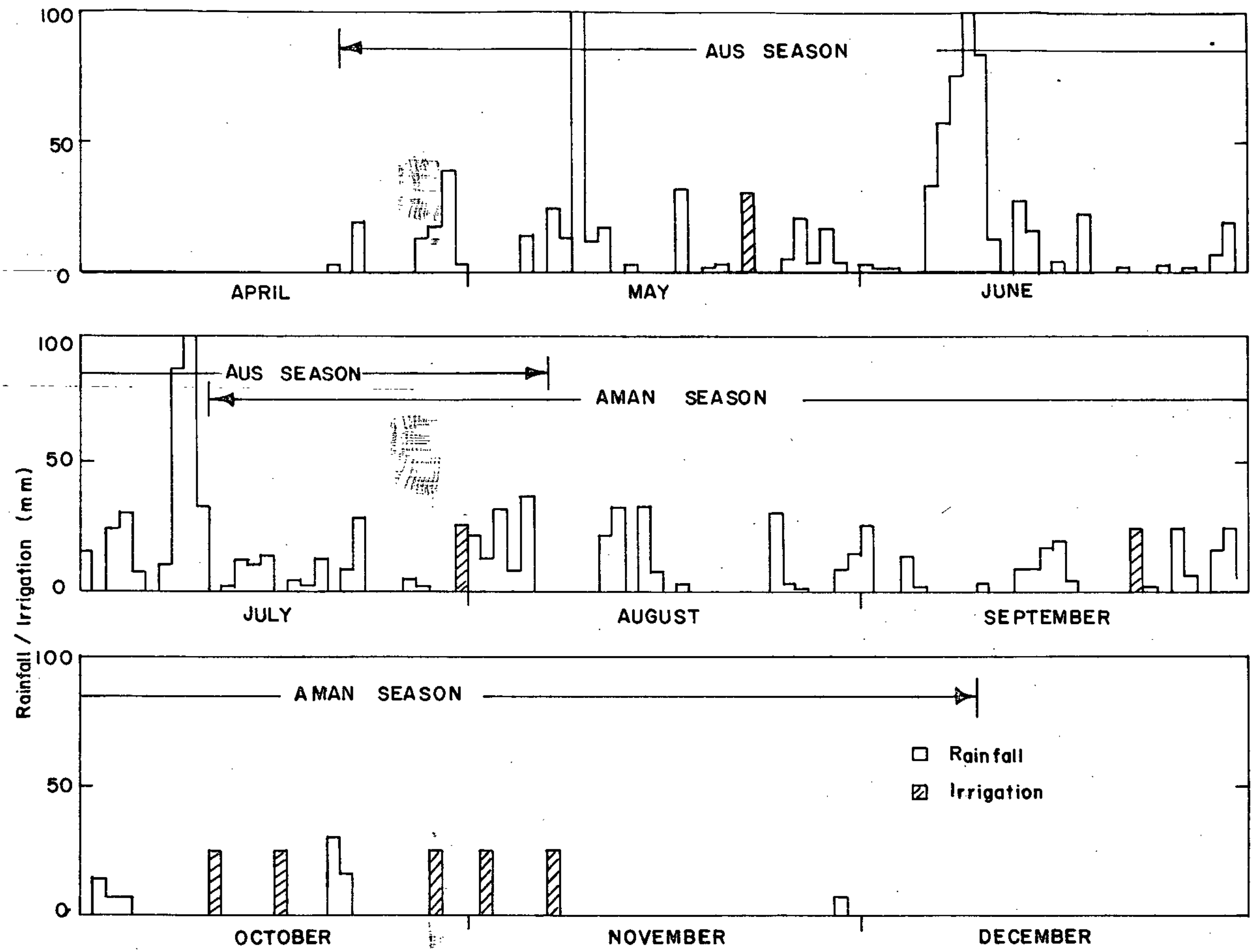


Fig. 29 Rainfall and Supplementary irrigation requirement during the Aus - Aman season for 1976

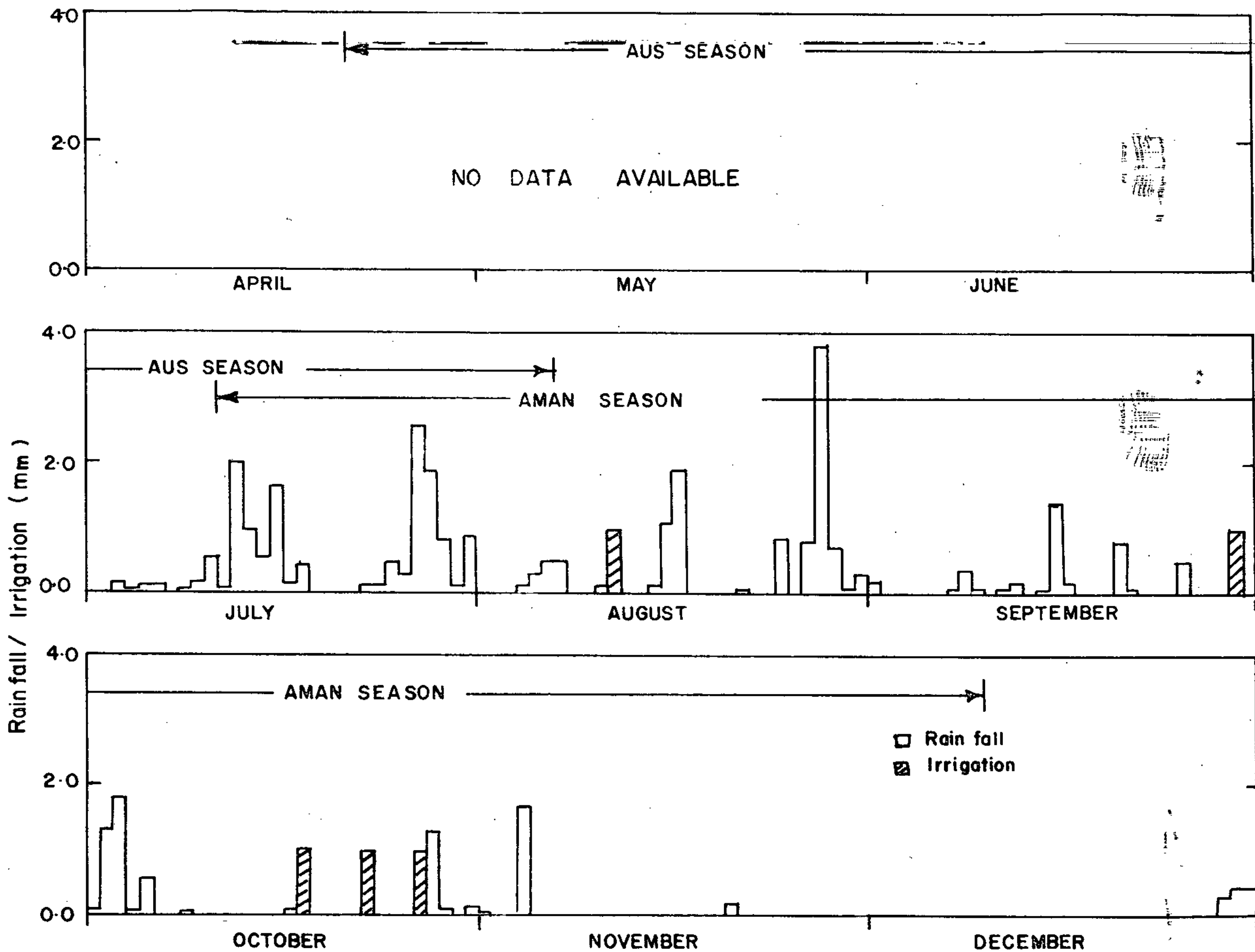


Fig. 30 Rainfall and Supplementary irrigation requirement during the Aus – Aman season for 1977 ·

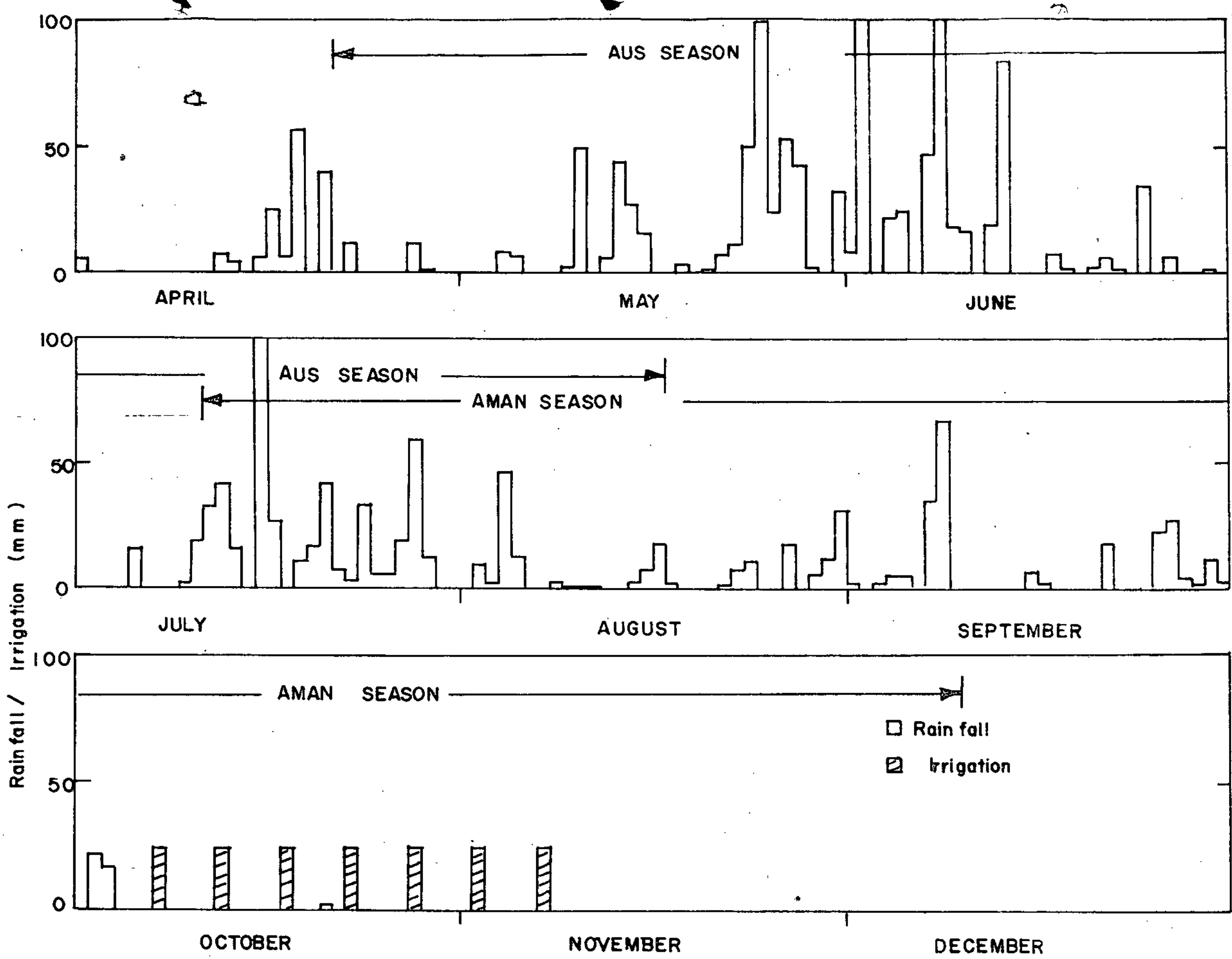


Fig. 31. Rainfall and Supplementary irrigation requirement during the Aus-Aman season for 1978.

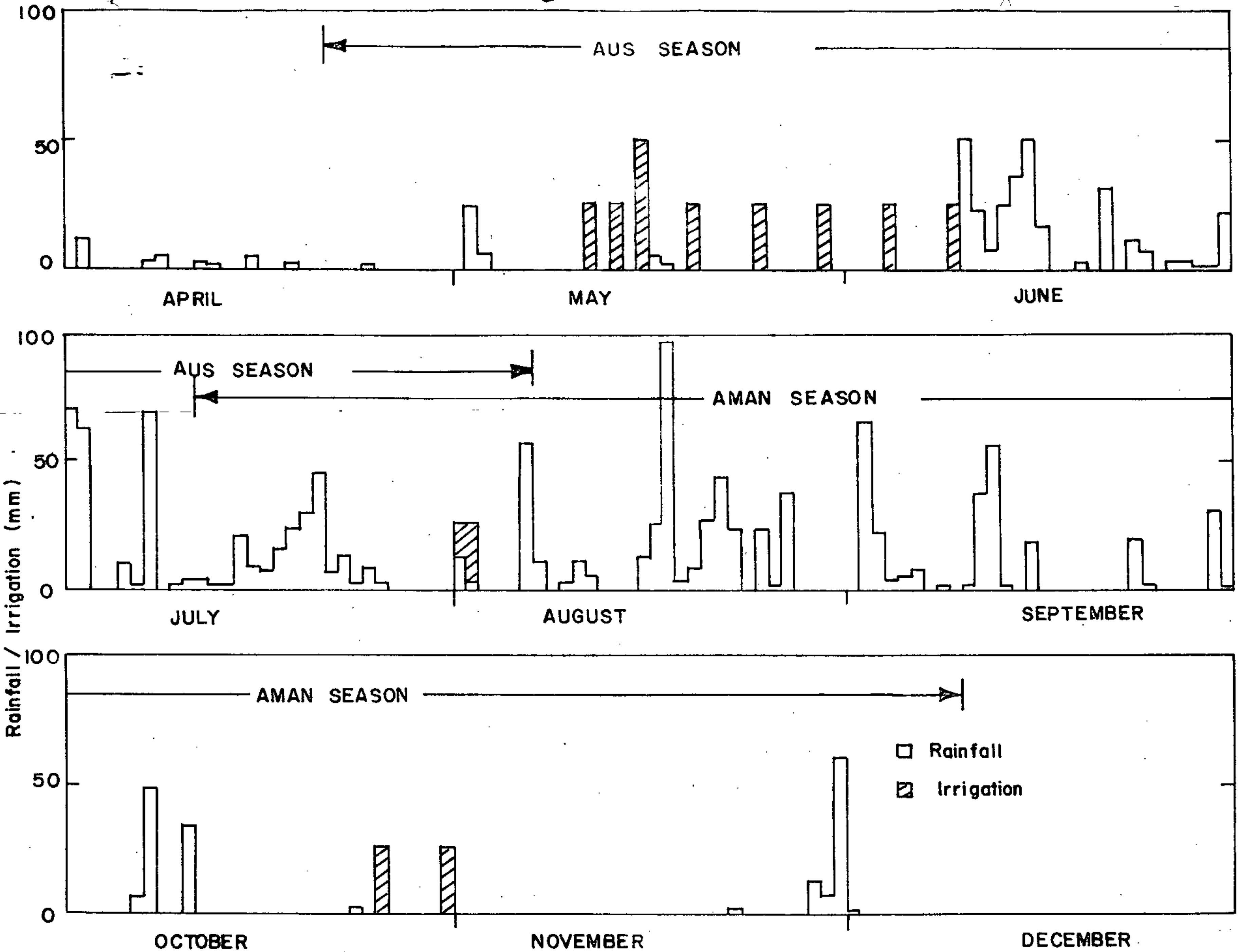


Fig. 32 Rainfall and Supplementary irrigation requirement during the Aus - Aman Season for 1979.

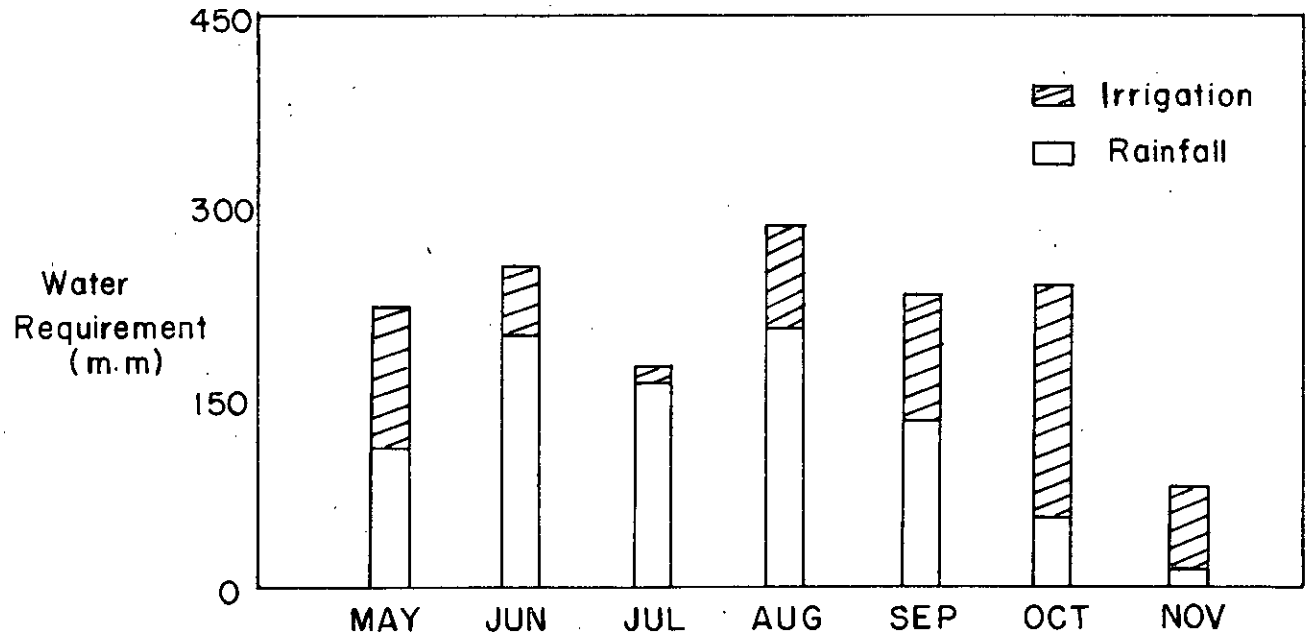


Fig. 33 Supplementary irrigation requirement for different monthsof the Aus-Aman season with no risk on rainfall.

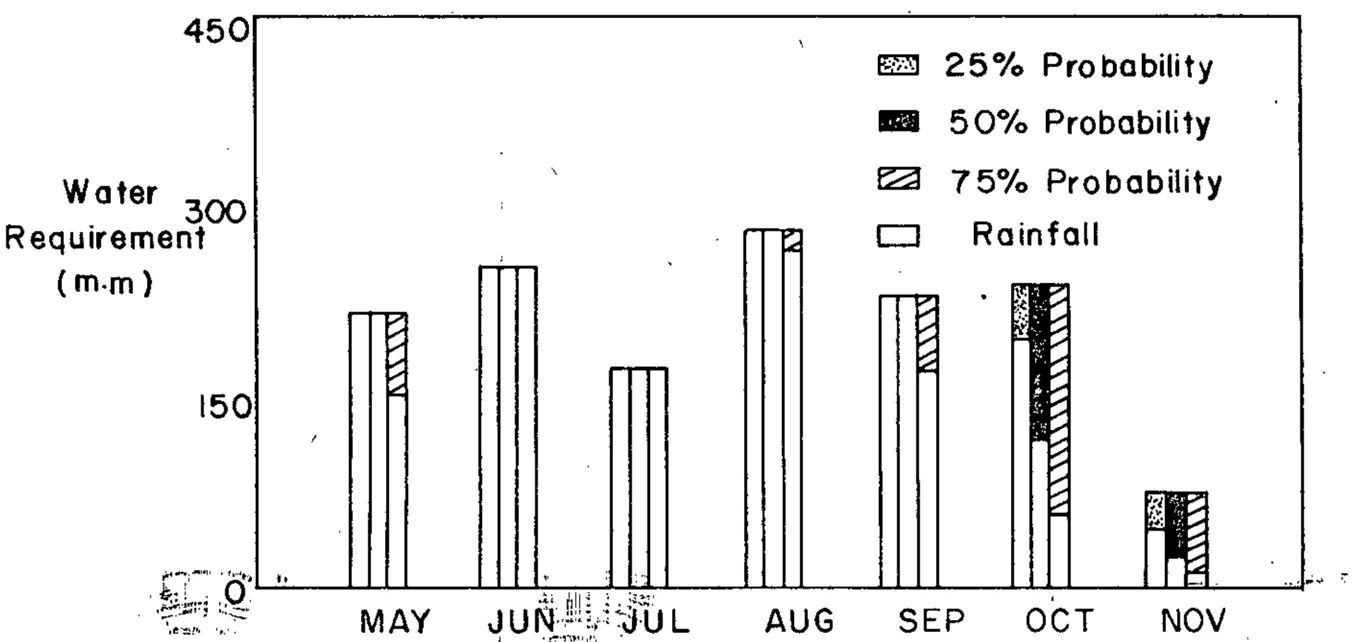


Fig. 34 Supplementary irrigation requirement for different months of the Aus - Aman season at raintall probabilities of 25, 50 and 75 percent .