Optimal Water Application Decisions With Deficit Irrigation

by

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STUDENT'S DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

(Md. Shirazul Islam)

The thesis titled Optimal Water Application Decisions with Deficit Irrigation Submitted by Md. Shirazul Islam, Roll No. Ph.D. 941604P Session 1993-94-95 has been accepted as satisfactory in partial fulfilment of the requirement for the degree of Doctor of Philosophy on 12 December 2004.

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LIST OF SYMBOLS AND ABBREVIATIONS

ASCE	American Society of Civil Engineers
BADC	Bangladesh Agricultural Development Corporation
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
BIADP	Barind Integrated Area Development Project
BMDA	Barind Multipurpose Development Authority
BRRI	Bangladesh Rice Research Institute
cKc	Composite Crop Coefficient
DTW	Deep Tubewell
E_f	System Efficiency
ET	Evapotranspiration
ET_a	Actual Evapotranspiration
ET_c	Crop Evapotranspiration
ET_m	Maximum or Potential Crop Evapotranspiration
ET_o	Reference Evapotranspiration
FAO	Food and Agricultural Organization
GW	Groundwater
GM	Green Manuring
K_c	Crop Coefficient
$K_{c\ ini}$	Crop Coefficient at Initial Stage
$K_{c\ mid}$	Crop Coefficient at Mid Season Stage
$K_{c\ end}$	Crop Coefficient at the End of Late Season Stage
K_y	Yield Response Factor
LAI	Leaf Area Index
LPR	Land Preparation Requirement (Water)
NIR	Net Irrigation Requirement (Water)
P	Percolation (Water)
RH_{min}	Minimum Relative Humidity
SRDI	Soil Resources Development Institute
STW	Shallow Tubewell
Y_a	Actual Yield
Y_m	Maximum or Potential Yield

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ABSTRACT

A linear programming based optimization model was developed for tubewell irrigation system in the high Barind tract area of Bangladesh to maximize profit for wheat and Boro rice from the available land and water supply. The study area comprises four thanas, viz. Tanore of Rajshahi district, Nachole and Gomstapur thanas of Chapai Nawabgonj district and Niamatpur thana of Naogaon district. The area is within a deep tubewell irrigation project and the available land area for irrigation is about 90660 ha. There are 1463 deep tubewells in the study area and the design capacity of each tubewell is about 56 litre per second. Available water for irrigation from 1463 tubewells in the area ranges from 13355 to 14786 ha.m at design discharge during the irrigation season from November to May assuming 16 operating hours a day. At 80% and 60% of design discharge, the water availability varies from 10684 to 11829 ha.m and 8013 to 8871 ha.m, respectively over the irrigation season.

Irrigation equalling full crop water requirement and 10, 20, 30, and 40 percent deficit crop water requirement along with 20, 50 and 80 percent dependable rainfall were considered in the model. Deficit irrigation was applied at vegetative and yield formation stages of Boro rice and wheat. For estimating yields of Boro rice and wheat under different crop water requirements, yield response factors at vegetative and yield formation stages of the crops were determined by field experiments. The values for Boro rice were 1.53 and 0.60 at vegetative stage and 0.29 and 0.28 at yield formation stage, respectively in the first and second years of field experiments. The corresponding values for wheat were 0.21 and 0.18 at vegetative stage and 0.47 and 0.46 at yield formation stage.

The model was first solved without any constraint on land area under Boro rice and wheat using both experimental yields and current farmer's yields. In the solution obtained with experimental yields, all area was covered with wheat whereas with farmer's yields about 98% of the area was covered by wheat, only 2% area being under

Boro rice at full discharge level of tubewells. At 80% and 60% of design discharge of tubewells, all area was found to be under wheat. In this situation, the seasonal profit using experimental yields were found to be 140 to 155% higher than that obtained with farmer's yields.

Next the model was solved with constraints on the maximum and minimum areas under each crop using both experimental and farmer's yields. For Boro rice, the specified maximum and minimum areas were 50000 and 31449 ha, respectively and those for wheat were 60000 and 3613 ha, respectively. At full discharge level, after satisfying the requirement of minimum area under Boro rice, the remaining area was found to be under wheat. At 80% design discharge, the minimum area specified under Boro rice was found to split under 20% and 30% deficit irrigation, the remaining area being under wheat mostly at 40% deficit irrigation. In this case, the seasonal profit using experimental yields were found to be 27 to 71% higher than that obtained with farmer's yields. Comparing the incremental profit with and without any constraint on area under crops, the profit under unrestricted condition was found to be higher. However, all area under wheat, as found in the case of unrestricted situation, may not be acceptable to the farmers who are mostly rice growers.

It seems judicious to consider 80% of the design discharge of tubewells in irrigation planning as the pump efficiency gradually decreases with time thereby reducing the amount of pumping water. Under restricted condition, deficit irrigation appears in solution and keeping Boro area close to the present practice, remaining land area is left for wheat thus encouraging crop diversification. Practicing deficit irrigation, not only the existing farmers of the project will be benefited but also additional farmers will be benefited from BMDA deep tubewells.

CHAPTER I

INTRODUCTION

1.1 Groundwater Irrigation in Bangladesh

Water is one of the most important factors limiting agricultural development. As the importance of irrigation for increased food production is well recognized, huge investments worldwide are directed towards expanding irrigated area and uplifting benefits of the water users. Building new physical systems rather than improving the performance of the existing ones seems to have been the main concern of the planners, practitioners and decision-makers. But poor performance of the irrigation schemes in developing countries demands greater attention to irrigation planning and management rather than building up new physical systems. Under this concept, some emphasis is now being placed on the need to improve the performance of the existing systems (Onta et al., 1995 and Mainuddin et al., 1998). Similar attention is most important for the low efficient irrigation schemes of Bangladesh.

Groundwater irrigation by tubewells covers about 71% of the total irrigation of Bangladesh (BBS, 2000). However, BADC (2002) has found this to be around 75%. Due to the scarcity of surface water bodies in the lean period, tubewell irrigation by groundwater has become most popular in the country. Also, certain useful features have made groundwater more attractive than surface water: it is less susceptible to contamination, it is available closer to the consumer and it involves a mechanism of natural storage that facilitates the withdrawal of this valuable resource throughout the year. These advantages of quality, availability and increased demand of groundwater have led to the development and utilization of the resource in Bangladesh and many other parts of the world during the recent past.

But the wasteful use of groundwater is, often, a common phenomenon in the irrigation schemes of Bangladesh. This inherent situation in irrigation schemes restricts irrigators in achieving optimum command area and net return. Therefore, suitable planning and management policy is required to ensure sustainable development, utilization and maintenance of groundwater for profitable irrigation.

In Bangladesh, groundwater irrigation is accomplished by two systems- farmer-managed system and agency-managed system. In farmer-managed system, individual farmer becomes the owner of the tubewell and uses shallow tubewells for irrigation. The agency-managed system is based on deep tubewells and larger land area is irrigated under the system. In Bangladesh, two wellknown agency-managed groundwater irrigation systems are-Thakurgaon Tubewell Project located in Thakurgaon district and the Barind Multipurpose Development Authority (BMDA) located in the Barind area of greater Rajshahi district.

The Thakurgaon Tubewell Project started functioning early in the 1962 to provide irrigation facilities to 31580 hectare of land from 378 motorized deep tubewells (Sattar, 1983). The discharge capacities of the tubewells ranged from 55 to 115 l/s. Each tubewell was provided with a brick-lined canal. The maximum and the minimum canal lengths were 290 m and 671m, respectively. The project irrigated only 2591 hectares of land compared to the design command area of 31580 hectares in 1973-1974 (Sattar, 1983). Due to improper operation and management, full potential could never be realized from the project. However, the BMDA has, now, taken up initiatives to work in the project area to improve the existing conditions of the project.

The BMDA, on the other hand, is fully operational, more or less systematic in operation and to a large extent, well managed. Thus, considering the functional condition, data availability and working environment, the Barind Project was selected for this study with the objective to increase irrigated area and profit by deficit irrigation. Salient features of BMDA project are discussed in the next section.

1.2 Description of BMDA

In Bangladesh, the High Barind tract, located in the western part of greater Rajshahi district (i.e, Rajshahi, Chapai Nawabgonj and Naogaon districts), is a drought prone area and semi-arid in character (Hunt, 1984) and experiences the highest and the lowest temperatures in the country (Elias, 1986). The principal irrigated crops in the Barind tract are Boro rice and wheat. High yielding varieties of Boro rice and wheat are cultivated, respectively, in about 0.59 million hectares and 0.095 million hectares, the corresponding productions being 1.62 and 0.23 million metric tons (BBS, 2000). Due to inadequate water supply in this drought prone area, only around 33 percent of cultivable area has so far been brought under irrigated agriculture (Rahman, 2003).

To promote agricultural activities through the utilization of groundwater for irrigation, Barind Integrated Area Development Project (BIADP), presently known as Barind Multipurpose Development Authority (BMDA) was established in 1985. The total area of the project is 0.78 million hectares of which 0.58 million hectares are cultivable. Since its establishment, BMDA has installed over six thousand deep tubewells (DTWs) in Barind area for irrigation. To improve the performance of these tubewells, many of the prime movers have been motorized, field channels have been lined and some distribution systems have been converted into buried pipes. These, certainly, have brought about a positive change in the system development, but still there is ample scope for further development in the performance of these DTWs through appropriate water use planning and design, specially, in the in-field water application and management. Thus, it is important to determine an optimal resource allocation policy so that the presently irrigated area could be increased by the available water resource to benefit more farmers in the project area.

1.3 Motivation for Deficit Irrigation

In the determination of an optimal allocation policy and to make it as close to reality as possible, it is desirable to consider the reliability of the resources and the system while modeling the irrigation water requirement. With the advancement of the computer facilities, efficient modeling tools and increased reliability of hydro-meteorological and other data, it is expected that a study in this direction will contribute positively to solve the problem in more realistic ways.

Several considerations may come on the way to manage irrigation water for crop production. The decision as to how much water to be allocated to different cropped areas should get the first preference. It should be based on availability, reliability and profit from crop production. On the basis of these factors, an irrigation schedule should be developed which manages the available water for the maximum profit possible.

There could be two strategies for the application of water to crops. The first is to apply irrigation water at a level that gives maximum yield. The approach may be used when there is no constraint on irrigation supplies. However, when a constraint exists, it is useful to provide alternate levels of irrigation water (less than the full requirement) and thus, cover more area that may result in higher returns. In such cases, farmers may, in actual practice, irrigate more lands than recommended even for maximum production under limited water supply situations This calls for the optimal distribution of water along with the scientific planning of crop cultivation.

Among other options, deficit irrigation can play a vital role in bringing more area under irrigation, increased production and maximum profit per unit of applied water in situations where water supply is limited and or the irrigation costs are high. The concept of deficit irrigation is quite general and it can be applied to any chosen area or irrigation schemes.

Deficit irrigation implies the concept of deliberately under irrigating a crop. It is profitable when irrigation costs are high and water supplies are limited (English et al., 1990). The water saved from one piece of land by deficit irrigation might be used to irrigate additional land thus increasing the farm income. The potential increase in farm income is an opportunity cost of water. If water supply is limited, opportunity cost of water may be the most important consideration in water management. When the land under irrigation is constrained by limited water supply, the economic returns to water is maximized by reducing the depth of irrigation water and increasing the area of land under irrigation. The phenomenon will continue until the marginal profit per hectare multiplied by the number of hectares irrigated just equals the total profit per hectare (English and Orlob, 1978). The optimal level of irrigation, when water is limiting, will also be less than that required for maximizing the yield. At this level of irrigation, designing lower capacity system might also reduce capital costs.

Deficit irrigation accounts for reduced water expenditures and perhaps for energy as well. It is possible to reduce marginal capital costs and opportunity costs by designing irrigation especially for deficit irrigation (English and Nuss, 1982). As the amount of applied water approaches full irrigation, deep percolation increases (Peri et al., 1979; Norum et al., 1979; Shearer, 1978) leading to a less efficient irrigation system. This decline in efficiency is largely associated with variability in applied water, crop characteristics and soil characteristics (English et al., 1986; Peri et al, 1979; Stewart and Hagan, 1969).

A larger land area and increased profit can be obtained by deficit irrigation but care is to be taken so that the deficit occurs at the least damaging period of crop growth (Barret and Skogerboe, 1980). This was further revealed when Onta et al. (1995) found that deficit irrigation in early paddy appeared attractive under favourable hydrologic conditions. Khepar and Chaturvedi (1982) also obtained higher returns from crops for deficit irrigation over full irrigation when they considered the alternative levels of irrigation as 25, 50, 75 and 100 percent of water required for maximum production. Hall and Butcher (1968), however, considered the uniformity of water application along with the deficit irrigation to quantify the net returns.

Deficit irrigation takes into account the function that links the phenomenon of water exchange in the plant-soil-atmosphere system which is influenced by crop-soil-unit, cultivars, weather etc. that produce variations in production (Jensen, 1968; Sudan et al., 1981). Isrelsen and Hansen (1962) described the limited water supply and high water costs as the principal reasons for considering deficit irrigation. To improve crop quality, control disease and regulate maturity of crops, deficit irrigation may be quite helpful and they suggested not imposing this water deficit at the critical growth stages of crops.

Other researchers (Tarjuelo et al., 1996; Hart et al., 1980; Hargreaves and Samani, 1984; James and Lee, 1971; Mainuddin et al., 1998) worked with limited water supply and registered mixed opinions on the feasibility of deficit irrigation for different circumstances.

Research on deficit irrigation within the country is quite limited. Momtaz Uddin (1988) developed a linear optimization model to determine the optimum acreage of different crops for Manu River Project. He applied water based on crop sensitivity to water stress using the equation suggested by Karim et al. (1985) to estimate deficit yields. Among the tested options of his study, diversification of crops was the best option in respect of service area and net return. However, deficit irrigation was found to give higher acreage and net return than that of full irrigation of rice.

Khan (1986) formulated a yield simulation model for rice and it was demonstrated in the drought prone area of Rajshahi region. His findings suggested the normal date of transplanting of Aman rice as on or before July 21 for moderate to heavy textured soils, July 11 for light to moderate textured soils and July 6 for very light textured soils to avoid significant yield losses from shortage of water supply.

From the above discussions it is evident that even deficit irrigation may be profitable because this will help bring more area under irrigation and lead to overall increase in crop production although yield will be somewhat less. Moreover, in context of High Barind Area, where the principal irrigated crops are Boro rice and wheat, deficit irrigation might be of adequate interest to the tubewell owners who sell water to individual farmers.

Thus, under the concept of limited water availability, the present study has been intended to explore the possibility of practicing deficit irrigation in the High Barind tract of Bangladesh considering groundwater supply from the operating deep tubewells of the area.

1.4 Objective of the Study

The objective of this research is to study the different regimes of deficit irrigation for maximizing profit through optimal allocation of available land and irrigation water.

The specific objectives of the study are as follows:

1. to develop a linear optimization model for maximizing profit under different levels of water application
2. to find through field experiments the yield response factors at two growth stages for each of Boro rice and wheat
3. to estimate seasonal profits for the selected levels of irrigation for dry, normal and wet years, and
4. to select the best feasible level(s) of water application for irrigation under different rainfall probabilities in the study area.

The reason for choosing Boro rice and wheat is that these are the two dominant irrigated crops in the Barind tract. Other minor crops grown in the area include oilseeds, vegetables and pulses. Again, each of the selected crops, Boro rice and wheat, has four generalized growth stages, viz. vegetative, flowering, yield formation and ripening stages. Theoretically, deficit irrigation within some tolerable limits can be applied in each of these stages. Flowering stage is very much sensitive to water stress and deficit irrigation at this stage reduces crop yield drastically (Stewart et al., 1976). In ripening stage crop water demand is less than that in either of the vegetative and yield formation stages. As such not much water can be saved applying deficit irrigation in the ripening stage. For these reasons the vegetative and yield formation stages were selected for the application of deficit irrigation in this study.

CHAPTER II

LITERATURE REVIEW

As regards to the theme of this research, the key terms involved are linear programming model in irrigation planning, deficit irrigation, crop production function, reference and potential crop evapotranspiration, crop co-efficient and yield response factor along with crop growth and development stages. In irrigated agriculture, these are considered vital for optimization of the available resources when limited water concept becomes the prominent part of the research. A review of related literature is presented below.

2.1 Linear Programming in Irrigation Planning

The linear programming technique has been used extensively in water resources system analysis and in various fields for solving the problems of limited water resources in optimal way. Among numerous optimization models, linear programming and dynamic models are commonly used by decision makers and policy planners. But, for better utilization of the available resources of irrigation systems, linear programming models are widely used throughout the world due to its linear characteristics, capability of handling very large system and availability of linear programming algorithm as pre-programmed or canned package at most computer installations (Akanda and Saleh, 1989).

Rogers and Smith (1970) formulated a linear programming model to aid in the planning of irrigation projects. They applied the model for conjunctive use of surface and groundwater in East Pakistan. The model accounted for all possible system parameters in realizing the maximum returns from the irrigated agriculture. Also the model considered the flood protection by drainage discharge from the system.

A parametric linear programming model developed by Gisser (1970) estimated the agricultural demand functions for imported water in the Pecos Basin. These functions stored the expected quantities of imported irrigation water that would be demanded at different prices and under a variety of constraints.

A linear programming model was developed by Afzal et al. (1992) to optimize water by alternative irrigation rather than by blending. In a situation of poor quality ground water and limited good quality canal water, the model described how much land to put under each crop and how much groundwater to abstract and apply to each crop in each time period. Also the irrigation system was modeled to maximize the net returns.

Raman et al. (1992) developed a linear programming model to generate optimal cropping patterns from the past drought experience and also from synthetic drought occurrence. These policies together with the knowledge of the experts were incorporated in an expert system. Using this, one can identify the degree of drought in the current situation and its similarity to the identified drought events and be able to get the corresponding management strategy.

Raman and Paul (1992) maximized net return and irrigated area by a linear programming model. They found that optimal allocation of area of each crop changed according to the changes in the net returns. When the cropping pattern was changed, the available water could cover more areas. Again, when the objective was to maximize the area, a total of 19 million m^3 water was left unused for irrigation and when it was run for maximum benefit, this quantity was found 28 million m^3.

Paudyal and Gupta (1990) showed an efficient computer aided planning method to determine an optimal cropping pattern together with an optimal scale of development and monthly water allocation from different sources that would maximize the annual net benefit.

Heady et al. (1973) employed linear programming models to obtain optimal water and land allocation and agricultural water needs for the United States. Using the same technique Soltani-Mohammadi (1972) chose between irrigation methods for a given cropping pattern and Blanks (1975) determined the mix of crops so as to take advantage of the limited resources to maximize economic return. Different combinations of crops and their methods were considered in Blanks' model.

Bari (1985) formulated a linear programming model to determine the cropping pattern and the allocation of irrigation water by month and crop. The effect of changes in crop price and the amount of irrigation water for optimal solution were also studied by parametric linear programming model.

Laxminarayan and Rajagopalan (1977) formulated a linear programming model to determine the optimal cropping pattern and optimal water release policy from canals and tubewells in various months in a year for maximizing the economic returns. Sensitivity analysis was carried out on tubewell capacity, area available for irrigation, operation costs for canals and tubewells and the value of crops. A deterministic situation was assumed and fixed yield approach was adopted to determine the water requirement.

Maji and Heady (1978) developed a chance constrained linear programming model to obtain an optimal cropping pattern and a reservoir management policy for the Mayurakshi Irrigation Project in India. They found that a change in the existing cropping pattern and reservoir management policy was consistent with the maximization of net returns to the project area regardless of an uncertain inflow into the reservoir.

Matanga and Marino (1979) used a linear programming model to determine the optimal crop mix considering the constraints from various levels of irrigation water, land and labour. The maximization of the net economic return was the objective function. A sensitivity analysis was done to study the effect of crop price on the optimal cropping pattern.

Sinha and Charyulu (1980) developed a linear programming model for a set of input data and applied it to the Gomti Kalyani Doab in India. They found that full utilization of surface and groundwater potentials led to more economic benefts and also maintained hydrologic balance.

Kheper and Chaturvedi (1982) applied a linear programming technique to make decisions on optimal cropping pattern and groundwater management alternatives in a canal irrigated area. Various groundwater management alternatives in conjunction with optimum cropping pattern based on water productions were compared. The model also developed ensured optimum utilization of surface water and poor quality groundwater and proper soil conditions for plant growth. Panda and Kheper (1985) also adopted similar techniques to maximize the net return from optimal planning. Both deterministic and chance-constrained linear programming were used.

Akand et al. (1996) developed an irrigation allocation model using multi-period linear programming to allocate canal irrigation water among different irrigated fields in order to maximize net benefit. The model was validated using the soils, crops, canal description, and management data of the Maricopa Agricultural Centre, University of Arizona. The allocation model was used for cotton, barley, wheat and grapes. The model recommended full irrigation for all crops except wheat and barley.

A linear programming technique was used by Salokhe and Paryar (1990) for preparing an optimal farm plan in Nepal. It was shown that the model could produce 280% cropping intensity against the present level of 135% and Rs.7800.00 per annum as profit against only the present value of Rs.2216.00 for a 1.5 ha farm size. Similarly, a farmer with 5 ha farm size who presently received a profit of Rs.7385.00 per annum may increase the cropping intensity from 135% to 214%. And he can expect a profit as high as Rs.19900.00 almost 2.7 times the present value, if he undertakes the farm business as per the optimal plan.

Onta et al. (1991) developed a versatile mathematical tool for generating and evaluating alternative irrigation development plans, mainly in a developing country, based on the conjunctive use of surface and groundwater for irrigation.

Eckert and Wang (1993) developed a linear programming model and applied it to farms situated alternatively on high, medium and low priority irrigation ditches each with and without supplemental pumping from river system. Differences were found in optimum enterprise mixes, net returns, choice of cropping technology, level of marketing and other characteristics in response to variations in the availability of irrigation water.

Mainuddin (1994) developed a linear programming model for maximizing irrigated area and profit for the Sukhothai Groundwater Development Project in Thailand. To account for the uncertainty in water resources availability, the model was solved for three levels of reliability of rainfall and groundwater resources (80%, 50% and 20%). To select the best alternative plan, a multi-objective analysis was carried out using the Analytic Hierarchy Process considering the preference of the decision makers, including the farmers and the irrigation project managers.

2.2 Deficit Irrigation

Deficit irrigation is the practice of deliberately under-irrigating a crop. When water supply does not meet crop water requirements, actual evapotranspiration falls below maximum evapotranspiration. Under such condition, water stress develops in plants and affects crop yields. The effect of amount and timing of water deficit on crop growth and yield is of major importance in irrigation scheduling. Many researchers worked on deficit irrigation and suggested their opinions on the realization of profit and irrigated area. A review of some past research findings on deficit irrigation are presented here:

According to Israelsen and Hansen (1962), the principal reasons for considering deficit irrigation are limited to water supply and high water cost. Also withholding water is sometimes used to improve crop quality, control disease and regulate the maturity of crops. Mild stress at the flowering stage of a crop may be economically advantageous even though this is the most sensitive period with respect to the effect of stress on yield. Water shortage in critical periods will significantly reduce yield.

Hall and Butcher (1968) found that applying deficit irrigation, if the soil moisture conditions are allowed to become less than optimum, a corresponding reduction in crop yield may be obtained. They also found the effects of soil moisture deficits and the situations under which a soil moisture deficit might improve the net returns.

Jensen (1968) and Sudan et al. (1981) found that the solution to the problem of optimizing deficit irrigation cannot ignore those functions which link crop yield to water availability. Such functions, according to them, are determined by the complex phenomenon of water exchange in the plant-soil-atmosphere system which is influenced by many factors such as crop-soil-unit, cultivars, weather etc. These interacting factors give rise to variations in water consumption and production.

Stewart and Hagan (1973) recognized that irrigation programming registers a dual effect on yield. The primary effect is the seasonal water shortage. Any seasonal evapotranspiration deficit is inevitably associated with some minimum fractional reduction in yield below maximum. A secondary effect is that the reduction in yield may result from the timing of ET deficits, with those occurring in the critical growth stages of the crop in question causing a relatively larger decrease in yield. Such losses could be avoided through improved water management practices.

English and Orlob (1978) found that for shortage of irrigation water, additional area might be irrigated through water savings by deficit irrigation. The potential increase in farm income is an opportunity cost of the water. When water supplies are limited, opportunity cost may be the most important consideration in water management. When the amount of land under irrigation is constrained by a limited water supply, the economic returns to water is maximized by reducing the depth of water applied by certain level and increasing the area of land under irrigation.

The economically optimal depth of irrigation, as found by Barret and Skogerboe (1980), depends on the relationship between crop yield and water use. This depth of water would always be in excess of the potential ET of crop increasing slightly with decreasing efficiencies but always less than that giving maximum yield. With methods having low application efficiency, this would result in deficits occurring at the least damaging times. By applying an amount of water less than that necessary to achieve maximum yield, it is quite likely, in fact, that the seasonal efficiency of application will rise, as a higher proportion of the applied water may actually be used by the crop. The lower depth of water application will allow a larger land area to be irrigated and increase profits substantially.

The concept of a system optimal depth of infiltrated irrigation water was developed by Hart et al.(1980) and its application to irrigation was examined. It was assumed that for a single irrigation, the economic losses due to an excess infiltration of water on a fraction of the field and deficit infiltration of water on another fraction of the field are directly proportional to the amount of excess or deficit irrigation.

According to Kumar and Khepar (1980), when water becomes scarcer or the cost of water increases, the farmers would like to adjust the cropping pattern by decreasing the area under crops that demand more water or by applying less water to the crops.

According to Boggess et al. (1981), the problem of developing optimal irrigation schedules, regardless of particular decision criteria, is complicated by the difficulty of predicting the within season relationship of crop response to water deficit.

English and Nuss (1982) found that deficit irrigation could offer significant benefits under some circumstances. These benefits might be largely dependent on system design, as they found, when two distinctly different irrigation systems were designed, one for full irrigation and the other for deficit irrigation. Further, it was determined that the system design for deficit irrigation could lead to increased farm income while substantially reducing energy, water and capital requirements.

Khepar and Chaturvedi (1982) applied 20, 50, 75 and 100% of water required for maximum production for irrigation. It was found that for full irrigation, the returns increased by 21 to 25% and when optimum, rather than maximum was used, the returns increased by 44 to 49%.

James and Lee (1971) found that, under some circumstances, maximum attainable income of an irrigated field can be achieved by deficit irrigation. In order to plan, design or manage irrigation systems for deficit irrigation, the analyst must rely upon crop production function.

Hargreaves and Samani (1984) found that there was a strong interaction between fertility and the optimum amount of water required for maximum yield. High yielding varieties of crops produced under conditions of adequate fertility significantly reduced the probability that deficit irrigation could produce maximum net benefit.

A simulation model capable of predicting the yield response of corn to a limited water supply was developed by Dierckx et al.(1988) from the combination of the mathematical models-SWATRE (Belmans et al., 1983) and SUCROS (Keulen et al., 1982). The primary advantage of using the developed model was its capability of predicting crop yield response to a given irrigation sequence so that economic criteria could be used to schedule irrigation.

English (1990) examined the economics of deficit irrigation for winter wheat. A set of rigorous mathematical expressions for the determination of optimum water use under deficit irrigation was given. These expressions can be used to estimate the range of water use within which deficit irrigation would be more profitable than full irrigation.

English et al. (1990) presented examples of deficit irrigation practices in the Columbia Basin with the aim of developing a better understanding of the practice and economic merits of this irrigation management technique. It was found that farms practicing deficit irrigation achieved lower net incomes per hectare but higher net income per unit of applied water than the fully irrigated farms.

Mannochi and Mecharelli (1994) proposed the theory of mathematical programming to define optimization criteria for the deficit irrigation of an area in the upper Tiber valley in Italy by using a multiplicative Stewart formula. It was possible to determine for various crops the relationships between crop yield and applied water which depend on the deterministic component of the process of water exchange soil-crop-atmosphere. Also a problem of mathematical programming was proposed with the aim of optimizing the use of available water resources in which the above relationship acts as constraints.

Onta et al. (1995) formulated a linear programming based optimization model and a simulation model and applied in a typical diversion type irrigation system for land and water allocation during the dry season. It was found that the existing water allocation policy was not economically efficient. Deficit irrigation in early paddy appeared attractive under favourable hydrologic scenario particularly if accompanied by measures to improve existing system efficiency.

Tarjuelo et al. (1996) developed a model that can be used in areas where water availability is limited. The model can aid in evaluating a system management strategies, economic returns and sensitivities of water availability, fluctuation and cost. It was found that when water availability was unlimited the best profit was obtained from sugar beet, sunflower and corn. On the other hand, when the water was limited, corn was the first crop to disappear from the crop rotation system.

Mainuddin et al. (1998) proposed a linear programming model to maximize benefit and area under full and deficit irrigations. The actual crop yield at different levels of irrigation was calculated using crop water production function given by Doorenbos and Kassam (1979). On an average, the irrigators seemed to prefer the planning alternative corresponding to average (hydrologic) conditions and full irrigation without any deficit. He also found the maximum benefit from deficit irrigation to some crops along with full irrigation.

Juan Reca et al. (2000) proposed an economic optimization model for hydrologic planning in deficit irrigation systems. Irrigation water allocation between agricultural demands was carried out following an economic efficiency criterion with the aim of maximizing the overall economic benefits obtained, allocating available water to each user as a function of the water's profit margin. Water resources constraints were considered in the system. Aggregated economic functions for each irrigation district were generated optimizing the water used for the cropping pattern.

Gorantiwar and Smout (2003) proposed a three stage approach for allocating water from a reservoir optimally based on deficit irrigation approach, using a simulation-optimization model. The allocation that results with a deficit irrigation approach were compared for a single crop (wheat) in an irrigation scheme in India, first with full irrigation and second with the existing fixed depth of water for irrigation. It was found that deficit irrigation enabled the irrigated area and the total crop production in the irrigation scheme used for the case study increased by about 30 to 45% and 20 to 40%, respectively, over the existing rule and by 50 and 45%, respectively, over the adequate irrigation. Allocation of resources also varied with soil types.

2.3 Crop Production Function

For application in planning, design and operation of irrigation schemes, it is possible to analyze the effect of water supply on crop yields. The relationship between crop yield and water supply can be determined when potential crop water requirements and potential crop yield can be quantified, provided the values of yield response factors are known. Water deficit in crop and the resulting water stress in plant have been quantified by the rate of actual evapotranspiration in relation to the rate of maximum evapotranspiration (Doorenbos and Kassam, 1979). Many other researchers have worked on crop production function to relate the amount of water deficits to yield reductions. Some of the research findings using crop production function relating deficit irrigation and yield are presented here.

Stewart and Hagan (1969), Peri et al. (1979), Norum et al. (1979) and Shearer (1978) explained through crop production function that at higher levels of applied water, the crop production function begins to curve over reflecting various water losses as the water use approaches full irrigation. At this point, the deep percolation increases with the increase in applied water but decrease in yield. As a result, the irrigation system will be less efficient at the point.

Tekinel and Kanber (1979), obtained a strong quadratic relation between irrigation water and yield for cotton under deficit irrigation conditions in Turkey. Bastug (1987) found a linear correlation between cotton yield and evapotranspiration.

Among other researchers, Musick and Dusek (1980) and Hanks et al. (1978) found a strong correlation between evapotranspiration and yield of corn under deficit irrigation conditions. Retta and Hanks (1980) obtained similar results from corn and alfalfa.

However, Vance et al. (1980) obtained a linear correlation between transpiration and corn yield. Young et al. (1985) had a similar finding for banana.

Wenda and Hanks (1981) pointed out that shortage of water for irrigation was increasingly becoming an important problem in irrigated areas of the world. For this reason, although the water requirement of crop has been a subject of much study in the past (Rosenberg et al., 1968; Jensen, 1973; Doorenbos and pruitt, 1977), experiments conducted in recent years were focused to obtain the relationship between the crop yield and water (Stewart et al., 1973 and 1976).

Hargreaves et al. (1989) suggested the use of crop-yield models for determining the best way to combine benefits from rainfall and irrigation in places where decisions and/or policies are often required relative to how much land should be irrigated with limited water supplies.

Mannochi and Mecarelli (1988 and !989) suggested using the functional form of crop production function in the multiplicative form in order to take into account the variability of the reduction in yield with the growing stages of crops.

A method was developed by Martin et al. (1989) to determine optimal irrigation strategies for a single season using crop production function incorporating physically based co-efficients. The relationship of yield to evapotranspiration was used to develop the yield-irrigation function. The physical parameters used in the production function can be determined from the field measurements or various types of computer simulations.

Seginer (1978) showed how an optimal application for the whole growing season could be obtained based on straight-line function for yield and water distribution.

One of the pioneering advances in yield-water relationship was given by deWit (1958). He related total dry matter to transpiration by a linear relationship. Other works related to production and transpiration were given by Grimes et al. (1969), Rasmussen and Hanks (1978), Hexem and Heady (1978) and Gulati and Murti (1979).

In the estimation of yields for deficit irrigation using a crop production function, it is important to have an insight into the water exchange phenomenon in plant-soil-atmosphere system as well as the governing parameters and factors regulating the performance of the production function.

When water supply does not meet the crop water requirement, the actual evapotranspiration falls below the maximum evapotranspiration. Under this condition, water stress is developed in the plant that adversely affects the crop growth and ultimately the crop yield. Therefore, it is necessary to predict the actual yield of crop for different levels of water application and this can be done using a crop water production function.

Empirically derived water production functions are usually valid only for a single crop at a single location under conditions of optimal deficit sequence. These functions are usually highly empirical and difficult to generalize. Economic solutions derived from such empirical functions are only useful for specific situations. But Stewart et al. (1977) proposed a simple generalized empirical production function in which the yield and ET variables are contemplated in terms relative to their maximum values.

Stewart's final formula is based on the theory that, considering all other factors of production at their optimum level, it is the water scarcity factor (ET/ET_m) that limits the final yield. For any given situation in which local conditions relating to crop varieties, soil types, prevailing climate and cultural practices enable predetermination of the maximum yield (Y_m) and evapotranspiration values (ET_m), the actual yield (Y) can be estimated for lower values of ET:

$$(Ym - Y)/Y_m = b(\Sigma\, ET_m - \Sigma\, ET)/(\Sigma\, ET_m) \qquad (2.1)$$

The value of b (yield reduction ratio) gives the ratio of the fractional decrease in yield to the fractional ET deficit. A thorough testing of Stewart's model demonstrated its ability to grain and dry matter yields as influenced by irrigation management for many different crops and situations. Stewart et al. (1977) developed a production function which divided the growing season into stages. With the multiplicative formula, Stewart used a different co-efficient for each stage.

When deficits are imposed on particular crop growth stage(s), Stewart's crop production function in the multiplicative form estimates yields better than any other crop production function as it considers, along with other yield regulating factors, the effect of growth stages on yields. Stewart's function is given by

$$\frac{Y_{i,k}}{Y_{m,k}} = \prod_{k=1}^{n}\left[1 - Ky_{i,n}\left(1 - \frac{ETa_{i,k}}{ET_{m,k}}\right)_{n}\right] \qquad (2.2)$$

where, Y= actual crop yield, Y_m = potential yield, K_y = yield response factor, ETa = actual crop evapotranspiration, ET_m = potential crop evapotranspiration, i = crop index, k = level of water application, n = number of crop growth stages.

In the above expression (Eq. 2.2), the potential crop evapotranspiration is an important parameter that needs to be estimated from the knowledge of reference crop evapotranspiration and the crop coefficient. Estimation of ET_m or ET_c are elaborated in the following sections.

2.3.1 Reference Crop Evapotranspiration

Reference crop evapotranspiration (ET_o) is defined as the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water (Doorenbos and Pruitt, 1977).

A large number of empirical methods has been developed over the past 50 years by numerous scientists and specialists worldwide to estimate evapotranspiration from different climatic variables. Relationships were often subject to rigorous local calibrations and proved to have limited global validity. Testing the accuracy of the methods under a new set of conditions is laborious, time consuming and costly, and yet evapotranspiration data are frequently needed at short notice for project planning or irrigation scheduling design. To meet this need, guidelines were developed and published (Doorenbos and Pruitt, 1977). To accommodate users with different data availability, four methods were presented to calculate the reference evapotranspiration (ET_0): the Blaney-criddle, radiation, modified Penman and pan evaporation methods. These climatic methods to calculate ET_0 were all calibrated for ten-day or monthly calculations (Doorenbos and Pruitt, 1977).

Advances in research and more accurate assessment of crop water use have revealed weaknesses in these methodologies. Numerous researchers analyzed the performance of the four methods for different locations. Although the results of such analyses could have been influenced by site or measurement conditions or by bias in weather data collection, it became evident that the proposed methods do not behave the same way in different locations around the world. Deviations from computed to observed values were often found to exceed ranges indicated by FAO. The modified Penman method was frequently found to over estimate ET_0 even by up to 20% for low evaporative conditions. The other FAO recommended equations showed variable adherence to reference crop evapotranspiration standard of grass.

To evaluate the performance of these and other estimation procedures under different climatological conditions, a major study was undertaken under the auspices of the Committee on Irrigation Water Requirements of the American Society of Civil Engineers (ASCE). The ASCE study analyzed the performance of 20 different methods, using detailed procedures to assess the validity of the methods compared to a set of carefully screened lysimeter data from 11 locations with variable climatic conditions. The study proved very revealing and showed the widely varying performance of the methods under different climatic conditions. In a parallel study commissioned by the European Community, a consortium of European research institutes evaluated the performance of various evapotranspiration methods using data from different lysimeter studies in Europe. The studies confirm the overestimation of the Modified Penman method and the variable performance of the different methods depending on their adaptation to local conditions.

In both the ASCE and European studies, the relatively accurate and consistent performance of the Penman-Monteith approach in arid and humid climates has been indicated. Thus, the FAO Penman-Monteith method (Allen, 1998) is recommended as the sole standard method. It is a method with strong likelihood of correctly predicting ET_0 in a wide range of locations and climates and has provision for application in data short situations. The use of older FAO or other reference ET methods is no longer encouraged. The Penman-Monteith equation is discussed in sub-article 2.3.2.

2.3.2 Penman-Monteith Equation

Penman combined the energy balance with the mass transfer method and derived an equation to compute the evaporation from an open water surface from standard climatological records of sunshine, temperature, humidity and wind speed. This so-called combination method was further developed by many researchers and extended to cropped surfaces by introducing resistance factors.

The resistance nomenclature distinguishes between aerodynamic resistance and surface resistance factor. The surface resistance, r_s, describes the resistance of vapour flow through stomata openings, total leaf area and soil surface. The aerodynamic resistance, r_a, describes the resistance from the vegetation upward and involves friction from air flowing over vegetative surfaces. The Penman-Monteith form of the combination equation is (Allen, 1998):

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a C_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma(1 + \frac{r_s}{r_a})} \tag{2.3}$$

where, R_n is the net radiation, G is the soil heat flux, (e_s - e_a) represents the vapour pressure deficit of the air, ρ_a is the mean air density at constant pressure, C_p is the specific heat of the air, Δ represents the slope of the saturation vapour pressure temperature relationship, γ is the psychrometric constant, and r_s and r_a are the (bulk) surface and aerodynamic resistance. The parameters of the equation are defined below:

$$r_a = \frac{\ln\left[(z_w - d)/z_{om}\right]\ln\left[(z_p - d)/z_{ov}\right]}{(0.41)^2 u_z} \tag{2.4}$$

where z_w is the height of the wind measurement, cm, z_p is the height of the humidity and temperature measurements, cm, z_{om} is the roughness length for momentum transfer, cm, z_{ov} is the roughness length for vapour transfer, cm, d is the displacement height for a crop, cm, and u_z is the wind speed at height z_w , m/sec or km/day.

$$z_{om} = h_c / 8.15, \quad z_{ov} = 0.1\, z_{om}$$

$$d = 2/3\, h_c, \; r_s = 100/0.5\, LAI$$

where h_c is the mean height of crop canopy, cm and LAI is the leaf area index (m^2/m^2). LAI is given by –

$$LAI_{active} = 24\, h.$$

From the original Penman-Monteith equation and the equations of the aerodynamic and canopy resistance, the FAO Penman-Monteith Equation is finally derived as (Allen, 1998):

$$ET_o = \frac{0.408\,\Delta\,(R_n - G) + \gamma\,\dfrac{900}{T+273}\,u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,u_2)} \tag{2.5}$$

where, ET_o is the reference evapotranspiration, mm/day and T is the air temperature at 2 m height, $^\circ C$ and rest of the terms have been defined earlier. Once ET_o is estimated, crop coefficient value (K_c) is required to estimate the potential crop evapotranspiration.

2.3.3 Crop Co-efficient

Crop coefficient (K_c) is the ratio of the potential crop evapotranspiration to reference crop evapotranspiration. The value of crop co-efficient varies with the development stages of the crop. For most crops, the K_c value for the total growing period is between 0.85 and 0.90 with the exception of a higher value for banana, rice, coffee and cocoa and a lower value for citrus, grape, sisal and pineapple (Doorenbos and Kassam, 1979). The above K_c values are applicable for crops planted on a fixed date basis. For such planting, the potential crop evapotranspiration can be obtained by equation 2.6.

$$ET_c = ET_o * K_c \tag{2.6}$$

where, ET_c is the potential crop evapotranspiration. The symbols, ET_m of Equation 2.2 and ET_c of Equation 2.6 are synonym. Potential crop evapotranspiration is the quantity of water used by the plants (transpired by the plants plus the amount evaporated from vegetation surface) under no shortage of irrigation requirements. K_c is the crop coefficient or the crop factor that takes up different values in different crop development stages for different crops.

However, if the plantation continues for some days together (staggered plantation), a different crop co-efficient called composite crop coefficient (cK_c) is used. These crop co-efficients for a certain period of crop season are obtained from the knowledge of K_c values for different crop growth stages and the percent area covered for that particular period. Thus, the potential crop evapotranspiration for staggered plantation can be obtained as:

$$ET_c = ET_0 * cK_c \quad (2.7)$$

The standard values of K_c for different development stages of crops are available in FAO publication No.24 (Doorenbos and Pruitt, 1977). However, for local calibration of the standard K_c value, usually, the following procedure as enumerated in FAO Publication No.56 (Allen., 1998) is followed.

2.3.4 Determination of Crop Co-efficient by FAO-56 Guidelines

Single and dual crop co-efficient approaches have been suggested by Allen (1998) to determine location specific crop co-efficients. Among these two approaches, single crop coefficient approach is applicable for irrigation planning and design, irrigation management, basic irrigation schedules and real time irrigation scheduling for non-frequent water applications (surface and sprinkler irrigation). This approach is applicable to irrigation for both daily and ten day time steps. On the other hand, dual crop coefficient approach is suggested for research, real time irrigation scheduling, high frequency water application (micro irrigation and automated sprinkler irrigation), supplemental irrigation and detailed soil and hydrologic water balance studies. This approach is only applicable to irrigation for daily time steps.

In consideration to the nature of research, the single crop coefficient approach seems more appropriate for this study. So, description of the single crop coefficient approach is described here.

2.3.5 Single Crop Co-efficient Approach

In order to estimate potential crop evapotranspiration by Equation (2.6), K_c values for different growth stages of crops are important. Thus the procedure to determine the values of crop co-efficients at initial ($K_{c\ ini,}$), mid ($K_{c\ mid}$) and end ($K_{c\ end}$) times during the crop growth period are described below.

2.3.5.1 Crop Co-efficient for Initial Stage

The crop co-efficient for the initial growth stage can be derived from Figures 2.1 and 2.2 which provide estimates for $K_{c\ ini}$ as a function of the average interval between wetting events, the evaporation power ET_0 and the importance of the wetting event. Figure 2.1 is used for all soil types when wetting events are light having infiltration depths of 10 mm or less. Figure 2.2 is used for heavy wetting with infiltration depths of 40 mm or more and for fine and medium textured soils. The average wetting events of infiltration depths between 10 mm and 40 mm, the value of $K_{c\ ini}$ can be estimated for crops other than rice from figures 2.1 and 2.2 using the following equation:

$$K_{c\ ini} = K_{c\ ini}\ (\text{Fig } 2.1) + (1 - 10) / (40\text{-}10)\ [\ K_{c\ ini}\ (\text{Fig.}2.2) - K_{c\ ini}\ (\text{Fig.}2.1)\ ] \quad (2.8)$$

where, $K_{c\ ini}$ (Fig 2.1) = value for $K_{c\ ini}$ from Figure 2.1, $K_{c\ ini}$ (Fig.2.2) = value for $K_{c\ ini}$ from Figure 2.2 and I = average infiltration depth (mm).

The ET_c of rice during initial stage mainly consists of evaporation from the standing water. Crop co-efficient for the initial stage of rice can be chosen from Table 2.1(Allen et al., 1998).

Table 2.1 Values of K_c of rice for different humidity and wind speed levels

Humidity	Wind Speed		
	Light	Moderate	Strong
Arid-Semi-arid	1.10	1.15	1.20
Sub-humid/humid	1.05	1.10	1.15
Very humid	1.00	1.05	1.10

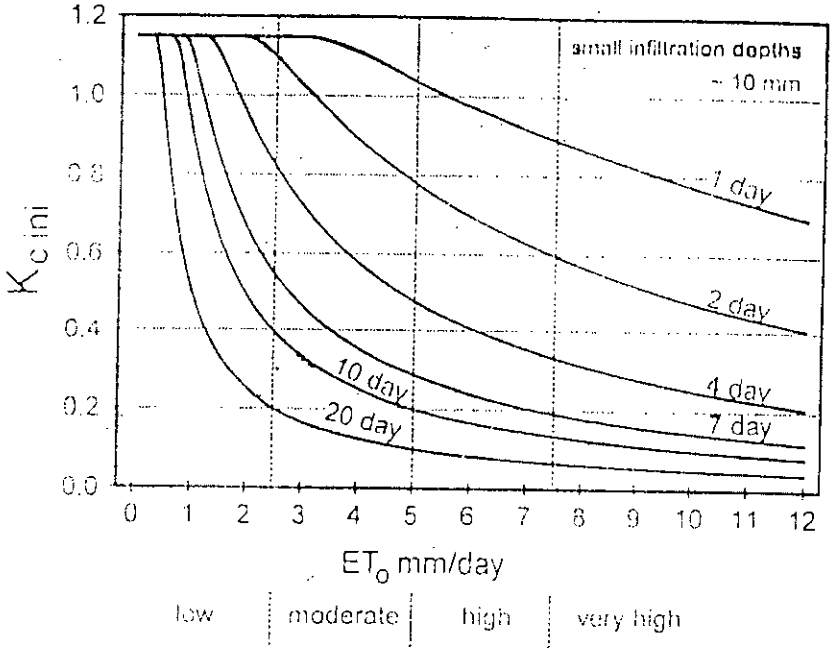


Figure 2.1 Average $K_{c\,ini}$ as related to the level of ET_o and irrigation interval for small depth of infiltration

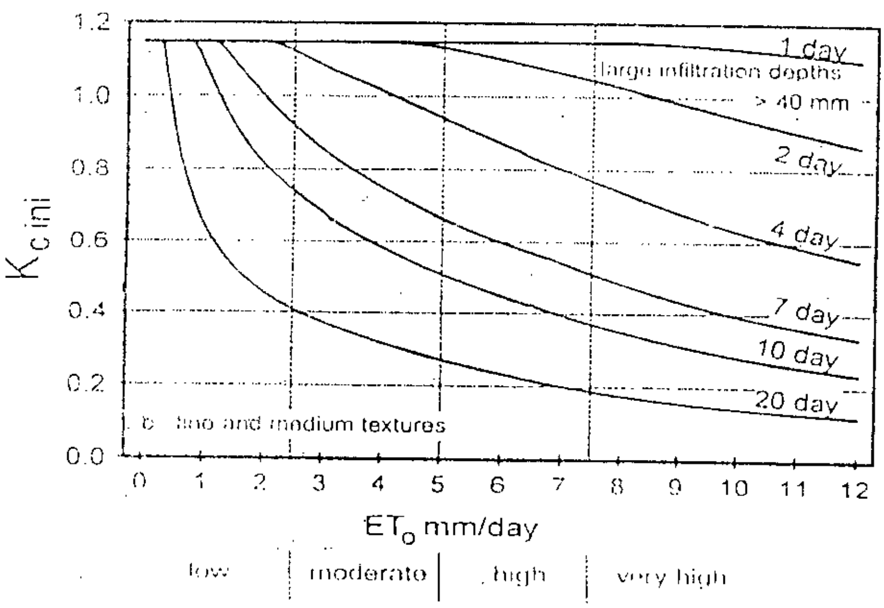


Figure 2.2 Average $K_{c\,ini}$ as related to the level of ET_o and irrigation interval for greater than 40 mm

2.3.5.2 Crop Co-efficient for Mid Season Stage

For specific adjustment in climates where RH_{min} differs from 45% or where mean wind speed at 2.0 m height over grass is larger or smaller than 2.0 m/s , $K_{c\ mid}$ values from Table 2.2 (Allen., 1998) are adjusted as:

$$K_{c\ mid} = K_{c\ mid}\ (\text{Table 2.2}) + [0.04\ (u_2 - 2) - 0.004\ (RHmin - 45)\ ].(h/3)^{0.3} \qquad (2.9)$$

where, u_2 = mean value for daily wind speed at 2 m height over grass during the mid season growth stage (m/s), for 1 m/s $\leq u_2 \leq$ 6 m/s, RH_{min} = mean value for daily minimum relative humidity during the mid season growth stage (%), for 20% $\leq RH_{min} \leq$ 80%, h = mean plant height during the mid season stage (m), for 0.1 m $\leq h \leq$ 10 m.

Table 2.2 Single crop co-efficients and mean maximum plant height for non stressed, well managed crops in sub-humid climates

Crop	$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	Maximum crop ht.(m)
Spring wheat	-	1.15	0.25-0.40	1.0
Winter wheat with non-frogen soil	0.70	1.15	0.25-0.40	1.0
Rice	1.05	1.20	0.90-0.60	1.0

2.3.5.3 Crop Co-efficient at the End of Late Season Stage

$K_{c\ end}$ values in Table 2.2 are typical values expected for average $K_{c\ end}$ under the standard climatic conditions. For specific adjustment in climates where RH_{min} differs from 45% or where wind speed at 2.0 m height (u_2) is larger or smaller than 2.0 m/s, $K_{c\ end}$ values from Table 2.2 are adjusted as:

$$K_{c\ end} = K_{c\ end}\ (\text{Table2.2}) + [0.04\ (u_2 - 2) - 0.004\ (RH_{min} - 45)\ ].(h/3)^{0.3} \qquad (2.10)$$

where, RH_{min} = mean value for daily minimum relative humidity during the late season stage (%), for $20\% \leq RH_{min} \leq 80\%$, h = mean plant height during the mid season stage (m), for $0.1 \text{ m} \leq h \leq 10 \text{ m}$. No adjustment is made when $K_{c\,end}$ obtained from Table 2.2 is less than 0.45 i.e. at this condition the $K_{c\,end}$ equals the tabulated $K_{c\,end}$ value. When crops are allowed to senesce and dry in the field (as evidenced by $K_{c\,end} < 0.45$), u_2 and RH_{min} have less effect on $K_{c\,end}$ and no adjustment is necessary.

2.3.6 Construction of the K_c Curve

Only three point values for K_c are required to describe and to construct the K_c curve. The steps involved are:

1. The growing period of the crop is divided into four general growth stages that describe crop phenology or development (initial, crop development, mid season and late season stages). Then the length of each growing stage is determined and three K_c values that correspond to $K_{c\,ini}$, $K_{c\,mid}$ and $K_{c\,end}$ are identified from Table 2.2.

2. The above K_c values are then adjusted to the frequency of wetting and /or climatic conditions of the growth stages as outlined in sections 2.3.4 through 2.3.5.3.

3. A curve is constructed by connecting straight line segments through each of the four growth stages. Horizontal lines are drawn through $K_{c\,ini}$ in the initial stage and through $K_{c\,mid}$ in the mid season stage. Diagonal lines are drawn from $K_{c\,ini}$ to $K_{c\,mid}$ within the course of crop development stage and from $K_{c\,mid}$ to $K_{c\,end}$ within the course of late season stage. A typical K_c curve is shown in Figure 2.3.

Now, having the reference crop evapotranspiration and the crop coefficient, the potential crop evapotranspiration is obtained using the Equation 2.6 for single dated plantation.

Incorporating the values of potential crop evapotranspiration (ET_m or ET_c), potential yield (Y_m), actual crop evapotranspiration (ET_a) and yield response factor (K_y) in Equation 2.2, the yield for deficit irrigation can be estimated. Detailed discussions about the yield response factors are made in the following section.

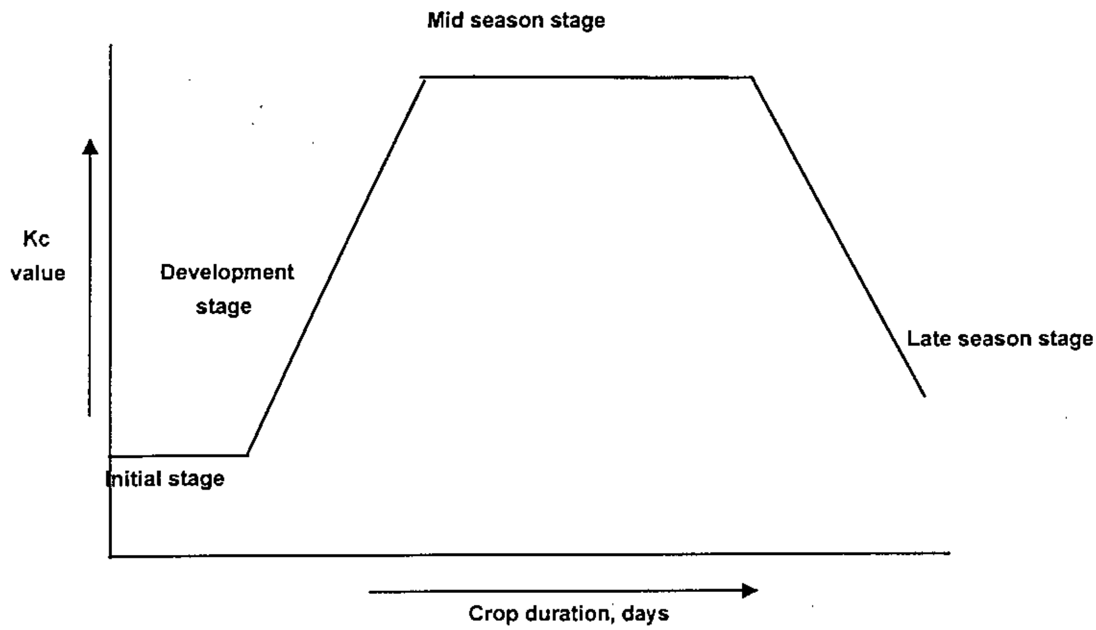


Figure 2.3 A typical Kc curve

2.4 Yield Response Factor

The yield response factor (K_y), as defined by Stewart's formula, is an expression of the sensitivity of a given crop to water deficits (de Juan et al., 1996). Doorenbos and Kassam (1979), in an analysis of a large volume of experimental data, found that representative values of K_y could be expressed for a number of crops.

The response of yield to water supply is quantified through the yield response factor (K_y) which relates relative yield decrease ($1-Y_a / Y_m$) to relative evapotranspiration deficit ($1-T_a/ET_m$). Water deficit of a given magnitude, expressed in the ratio of actual evapotranspiration (ET_a) and maximum evapotranspiration (ET_m), may either occur continuously over the total growing period of the crop or it may occur during any one of the individual growth periods- establishment, vegetative, flowering, yield formation, or ripening (Doorenbos and Kassam, 1979). The magnitude of water deficit in the former refers to the deficit in relation to crop water requirements over the total growing period of the crop and in the latter, the deficit refers to the crop water requirements of the individual growth period. The K_y values for most crops are derived from the assumption that the relationship between relative yield (Y_a / Y_m) and relative evapotranspiration (ET_a / ET_m) is linear and is valid for water deficits of up to 50% (Doorenbos and Kassam, 1979), the Y_a and Y_m being, respectively, the actual and maximum yields. The higher value of K_y, obviously, indicates that the stage is more sensitive to water stress. For both Boro rice and wheat, flowering stage is more water loving than any other stage and is the most critical growth stage for the crops. For any water deficit at this stage, the crops will suffer higher yield losses than those for any other stage. Hence it is most desirable that the water should be saved, if required, from any other growth stage(s) than flowering. It is thus, essential to have adequate knowledge about the growth stages of the selected crops.

2.5 Growth and Development Stages of Boro Rice and Wheat

Understanding and identification of the growth stages of crops are important with respect to each development phase for specific requirements. All who work with crops need to describe the growth stages in an unambiguous and readily understandable way. Use of standard scale describing important growth stages is the usual solution. The best known and most widely used scale for recording the growth stages of cereals such as Boro rice and wheat are probably the scale designed by Feekes as illustrated and amended by Large (1954). The decimal code of Zadocks et al. (1974) is a further development on those proposed by Feekes. Some workers (Puxalkova, 1980, Burns and Crey, 1983), however, defined growth stages and used different scales for indicating stages of development in wheat, but all these are complicated and difficult to correlate with crop growth in on-farm situation. Three broad stages or phases of growth can be distinguished between the developmental events of germination, floral initiation and anthesis to maturity. The phases in question can be conveniently designated as the vegetative, reproductive and ripening phases and can be subdivided by observations. Each phase or stage of growth is considered to differ physiologically from other phases. Such differences may be small and large depending on environmental conditions and crop variety.

2.5.1 Key Growth Stages of Boro Rice

The growth and development stages of rice plants differ under different climatic and cultural conditions (Datta, undated). Based on experience in Texas, Stansel (1975) developed simplified time ranges for each development stage of rice plant. Although the time ranges represent a warm or cool weather combination for the Texas rice belt, the basic time ranges should be applicable in areas with a similar environmental regime.

The development of rice may be divided into three phases (Datta, undated):

a. The vegetative phase, which runs from germination to panicle initiation
b. The reproductive stage, which runs from panicle initiation to flowering
c. A ripening phase, which runs from flowering to full maturity

These main phases, however, may be further divided into physiologically distinct stages or periods. For example, the vegetative stage can be divided into maximum tillering, internode development, elongation and panicle initiation (Datta, undated). Zadoc et al. (1974) proposed a decimal code for the growth stages of cereals that may be applicable to rice with some modifications.

Shiv Raj (1987) suggested the growth stages of rice as germination, active vegetative, lag-vegetative, active reproductive and grain development and ripening. These phases are somewhat generalized and are comparatively easy to follow for irrigation scheduling of rice.

2.5.2 Key Growth Stages of Wheat

Modern techniques of morphological analysis of plants help determine the potential and actual yields of cereal crops (Puxalkova, 1980). Growth and development of bodily organs require to pass through some stages of development. Wheat plants complete their life cycle through 12 stages of development (Kyperman, 1980; Bhuyan and Silotina, 1981; Campbell et al., 1981 and Bhuyan et al., 1987). Each stage plays an important role in the formation of grains on the spike. Salter and Goode (1967) found that wheat was sensitive to moisture condition during shooting to earing stages when the growth of reproductive organs was taking place. Bhuiyan (1992) recognized 12 growth stages from germination to full maturity based on morphological observations. These were- germination and emergence, seedling, crown root, tillering, jointing, shooting, booting, heading, flowering, milk, dough and ripe. Saifuzzaman (1996) described the morphological stages of wheat as the crown root initiation, maximum tillering, booting, heading, flowering, grain watery, grain milky, grain soft dough, grain hard dough and physiological maturity.

2.5.3 Generalized Growth and Development Stages

Sometimes it becomes difficult to demarcate between successive growth stages when these are too many in number. In order to make the stages uniform for all crops and clearly distinguished and easily understandable for irrigation, Doorenbos and Pruitt (1977) and Doorenbos and Kassam (1979) suggested four growth stages and four development stages for all crops. The growth stages include vegetative, flowering, yield formation and ripening stages whereas the development stages include initial, development, mid-season and late season stages.

The vegetative stage of rice comprises maximum tillering, internode development, elongation and panicle initiation, the flowering stage remains as it is, the yield formation stage includes grain formation and development and the ripening stage comprises grain hardening and grain maturity.

Similarly, when the above morphological growth stages of wheat are grouped, the crown root initiation, maximum tillering, booting and heading combine to form vegetative stage. The grain watery, grain milky, grain soft dough and grain hard dough are combined to form yield formation stage and physiological maturity representing the ripening stage, flowering stage remaining unchanged.

For this study, the development stages of Boro rice and wheat were considered as initial, development, mid season and late season stages while the growth stages were considered as vegetative, flowering, yield formation and ripening stages. Generally, crop coefficients are mostly associated with the development stages and the yield response factors with the growth stages. In Bangladesh condition, the lengths of initial, development, mid-season and late season stages of Boro rice are around 20, 40, 30 and 20 days, respectively and those of wheat correspond to 15, 25, 40 and 30 days. The vegetative, flowering, yield formation and ripening stages of Boro rice consist of 45, 15, 30 and 20 days, respectively, whereas those of wheat are 50, 15, 25 and 20 days in the same order. The crop duration of Boro rice (BRRI Dhan 28) from transplanting to maturity and that of wheat from germination to maturity, as learnt from respective crop research institute, is 110 days. However, the duration is subject to vary with climatic changes, management practices and crop variety.

CHAPTER III

DESCRIPTION OF STUDY AREA

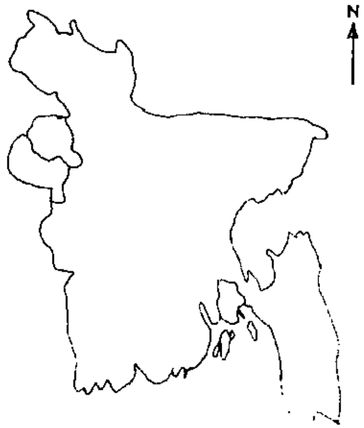
This chapter describes, in brief, the physical location, climate, land and soil type, cropping pattern, groundwater condition etc. of the study area.

3.1 Location

The part of greater Rajshahi, Dinajpur, Rangpur and Bogra districts of Bangladesh and the Maldah district of West Bengal are geographically identified as Barind tract. Rajshahi Barind tract is situated in the north-west region of Bangladesh and comprises mainly the area of Rajshahi, Chapai Nawabganj and Naogaon districts. The tract is located in between 24^0 23′ N to 25^0 15′ N latitudes and 88^0 01′ E to 88^0 57′ E longitudes. The average elevation of the tract from mean sea level is 20 m. The Barind Multipurpose Development Authority (BMDA), as mentioned in Chapter I, includes 25 thanas of these three districts located in Rajshahi Barind tract. Based on soil topography and other physical features, the Barind tract is further divided into three sub-regions: high Barind tract, level Barind tract and north-east terrain. Four thanas, one from Rajshahi, two from Chapai Nawabgonj and one from Naogaon districts, were selected from the high Barind tract area within BMDA for this study. These were, Tanor, Nachole, Gomostapur and Niamatpur (Fig. 3.1). The selected thanas are very much drought prone and suffers from low irrigation coverage. Also, the geophysical features of the selected thanas are almost similar and quite representative of the high Barind Tract area.

3.2 Climate

The climate of the study area does not follow the general climatic pattern of the country. A typical dry climate with comparatively high temperature prevails in the area. The



3.1a Map of Bangladesh

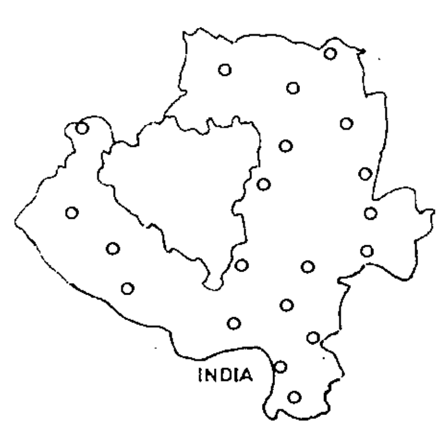


Figure 3.1b BMDA project area

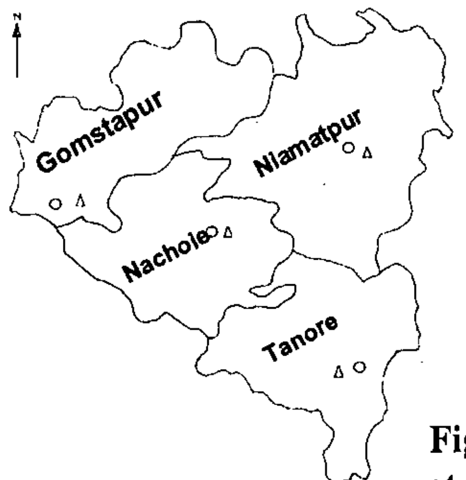


Figure 3.1c Selected thanas of the study area

Figure 3.1 Location map of the study area

mean climatic parameters are shown in Table 3.1. The maximum mean air temperature ranges from 36.27 ^{0}C to 24.67 ^{0}C and the minimum mean from 25.69 ^{0}C to 10.78 ^{0}C. The air temperature goes as high as 45 ^{0}C in May and as low as 6 ^{0}C in January. The mean annual rainfall of the study area is 1363 ± 311mm (Manalo, 1976). The potential evaporation is the maximum (166 mm) in May and the minimum (74 mm) in December. Rainfall greater than 200 mm occurs from mid-June through mid-September. The pre-monsoon (April to mid-June) and post monsoon (mid-September to mid-November) rainfalls are very unreliable with frequent drought. Excessive rainfall during the pre-monsoon period is observed once in three to five years (Bramer, 1988). More than 90% of yearly rainfall occurs from June to September. Due to undulating landscape, the excess water is drained out to the channels.

3.3 Land and Soil Type

Except for a few low lying areas, a single high land soil dominates with clay to silty clay loam textures all over the Barind tract area, the soil colour being grey to mixed grey and brown. The soils are of shallow depth having un-weathered or partially weathered heavy clay (a few low lying areas having Madhupur clay) sub-stratum occurring at about 60-90 cm below the surface. Soil reaction is slightly acidic with p^H values ranging from 5.5 to 7.0. The organic matter content is only about 0.5 – 0.8 % in the fields and about 1.2 % near the homesteads. The natural fertility of the soil ranges from moderate to moderately low (Hunt, 1984). The soil moisture depletion starts from late October and no available soil moisture exists by the end of December.

3.4 Cropping Patterns

Prior to the introduction of irrigation, single transplanted Aman rice was the predominant cropping pattern of the high Barind tract. Cultivation of dry land Aus rice in around 7 to 10 % area was the only practice in early Kharif-I season and the

Table 3.1 Mean climatic parameters of Rajshahi station

Months	Max. temp. (°C)	Min. temp. (°C)	Mean RH (%)	Sunshine hour	Wind speed (Km/hr)	Rainfall (mm)	Evapo-ration (mm)
Jan.	23.03	10.12	76.56	7.60	112	13.83	77.48
Feb.	25.96	12.35	73.25	8.29	134	24.11	91.98
Mar.	30.74	16.48	68.46	8.49	157	34.06	163.25
Apr.	33.67	21.40	69.23	8.29	190	98.44	192.23
May	33.04	23.56	78.39	7.63	213	206.10	197.51
June	32.01	25.09	84.55	5.46	230	465.30	161.96
Jul.	30.82	25.48	87.17	4.35	215	560.20	147.62
Aug.	30.82	25.50	87.06	4.95	196	430.70	150.66
Sep.	30.77	25.23	85.86	5.40	179	485.70	138.25
Oct.	29.96	22.70	82.86	7.52	114	180.90	114.42
Nov.	27.39	17.22	77.69	8.13	115	37.67	88.52
Dec.	24.54	12.05	76.59	8.11	110	11.83	69.17

chickpea, barley, mustard or linseed were grown either as sole or mixed crop after harvest of transplanted Aman rice in years of high rainfall at the late season. In the areas with irrigation facilities, the dominating cropping patters are: Green manuring (GM) – T. Aman – Boro, GM – T.Aman – Wheat and Boro – T.Aman - Mustard. However, wheat cultivation by irrigation has been introduced recently by the Bangladesh Agricultural Research Institute (BARI) and BMDA. Now-a-days, irrigated wheat cultivation is becoming popular to the farmers of the study area.

3.5 Groundwater Availability

Groundwater is the most widely distributed resource for irrigation and drinking purposes in Bangladesh. Due to the scarcity of surface water availability during the dry period, the Barind tract area of the country depends mainly on groundwater for irrigation. Thus, this natural resource is so vital for the area to both irrigation planners and users. The available recharge, abstraction and the useable potentials of groundwater of Rajshahi Barind tract area are given in Table 3.2.

Table 3.2 Thanawise groundwater potential and present use in the Rajshahi Barind area

District	Thana	Available Recharge (MCM)	Usable Recharge (MCM)	Potential Recharge (MCM)	Present Abstraction (MCM)
Naogaon	Atrai	157.75	197.19	262.92	109.67
Naogaon	Badalgachi	52.00	65.00	86.66	61.08
Naogaon	Dhamurhat	78.81	98.52	131.36	72.92
Naogaon	Manda	87.72	109.66	146.21	78.22
Naogaon	Mahadebpur	116.76	145.95	194.60	141.86
Naogaon	Naogaon	106.43	133.04	177.38	95.07
Naogaon	Niamatpur	97.7	122.13	162.84	47.83
Naogaon	Patnitola	81.72	102.16	136.21	90.68
Naogaon	Porsha	73.76	92.21	122.94	32.98
Naogaon	Raninagar	134.13	167.67	223.56	118.03
Naogaon	Shapahar	75.00	93.76	125.01	22.30
Nawabgong	Bholahat	42.55	53.2	70.93	19.11
Nawabgong	Gomstapur	106.79	133.49	177.98	35.53
Nawabgong	Nachol	53.37	66.72	88.96	17.29
Nawabgong	Nawabgong	202.08	252.61	336.81	45.33
Nawabgong	Shibgong	185.30	231.63	308.84	66.73
Rajshahi	Bagha	58.95	73.70	98.26	12.08
Rajshahi	Bagmara	161.59	202.00	269.33	131.9
Rajshahi	Charghat	24.34	30.43	40.53	12.75
Rajshahi	Durgapur	68.11	85.13	113.51	55.18
Rajshahi	Godagari	112.58	140.70	187.60	58.09
Rajshahi	Mohanpur	54.12	67.66	90.21	34.11
Rajshahi	Paba	86.39	107.99	143.98	53.46
Rajshahi	Puthia	50.82	63.52	84.70	37.97
Rajshahi	Tanor	64.75	80.94	107.92	49.40
Total		2333.52	2917.01	3889.25	1499.57

Source: BMDA, Rajshahi

The general trend of groundwater outflow in the BMDA project area is towards the major rivers, streams and low-lying areas at the end of rainy as well as during dry seasons. Most of the area has a water table fluctuation up to 4 m but in the high Barind, it varies from 4-8 m (Jahan and Ahmed, 1997). The groundwater quality in respect of p^H

values, Iron, Chloride, Boron and sodium Chloride contents is good for irrigation purpose and permissible for public health, but the calcium Carbonate content is moderately suitable for irrigation purpose but not suitable for public health. It was learnt from BMDA authority that the DTWs installed in the project area use submersible turbine pump and there was no problem from water pumping due to the fluctuation of groundwater table. Thus, the water available from aquifer seems quite adequate for running the installed DTWs.

CHAPTER IV

LINEAR OPTIMIZATION MODEL FORMULATION

Planning is important in the operation and management of an irrigation system. Its ultimate goal is to obtain maximum economic and social benefit by matching water supply with the demand. Keeping this in view, a linear programming model was formulated to maximize profit from available land and water resources in Tanore, Nachole, Niamatpur and Gomostapur thanas of greater Rajshahi district. In formulating the model some assumptions were made.

4.1 Assumptions of the Model

The model was developed based on the following assumption

i. Prices of crops and water are equal for both full and deficit irrigation
ii. Crop water requirements computed using the Penman-Monteith equation are for the optimum level of crop production
iii. Groundwater is equally available to all wells
iv. All inputs except water are assumed to be available at optimum level
v. The information on yield response factors, crop ET and yields generated through experiments at Shyampur, Rajshahi, is also applicable to the selected thanas viz. Tanore, Nachole, Niamatpur and Gomostapur
vi. The model is to be used on monthly basis

4.2 Problem Statement

An optimal planning and management model involves identification of the decision variables, the constraints and the objective function which are to be maximized or minimized. Given two crops (Boro rice and wheat), three levels of rainfall availability (20, 50 and 80 % probability of rainfall exceedance) and five levels of irrigation water application (full irrigation and 10, 20, 30 and 40% deficit irrigation), area under different crops was determined so that profit is maximized.

4.3 Decision Variables

The decision variables of the proposed model are, A_{ijk}, the area in hectare under crop i, dependable rainfall probability level j and level of irrigation k.

4.4 Objective Function

One of the goals of the BMDA project is to provide financial benefits to the farmers of the project area through irrigation facilities. Therefore, the objective of the model is to maximize profit from the available land and water.

$$Max\ Z = \sum_{i=1}^{l} \sum_{j=1}^{m} \sum_{k=1}^{n} B_{ijk} A_{ijk}$$

where, Z= seasonal profit (Tk./season), B_{ijk}= profit per hectare obtained under crop i, dependable rainfall probability level j and water application level k. A_{ijk} = total irrigated area ha, under crop i, dependable rainfall probability level, j and water application level k. l = total no. of crops, 2 (1 for Boro rice and 2 for Wheat), m = total number of rainfall probability, 3 (1 for 20% probability of rainfall exceedence, 2 for 50% prob. of rainfall exceedence and 3 for 80% probability of rainfall exceedence), n = total number of irrigation regimes, 5 (1 for full irrigation and 2 for 10%, 3 for 20%, 4 for 30% and 5 for 40% deficit of full irrigation).

4.5 Constraints

An irrigation planning model can provide estimates of the resource inputs and their costs that maximize profit. The relationships among these resource inputs are defined by the constraints of the model. The above objective function is subject to the following constraints.

4.5.1 Water Allocation Limitations

The total water requirements for the selected crops at any level of water application in any period should be at most equal to the water supplied from the tubewells in that period i.e.,

$$\sum_{i=1}^{l}\sum_{j=1}^{m}\sum_{k=1}^{n} W_{ijk}^{t} A_{ijk} \le P^{t} \qquad \forall t$$

where, W^t_{ijk} = total water requirement for crop i, dependable rainfall probability level j and water application level k for month t. P^t is the available water per month from the tubewells (i.e., pumped water), ha-m.

4.5.2 Land Area Availability in Different Months

In farmers' fields, all the land areas under a particular crop are not planted at a time. It always takes some days to complete plantation. Therefore, sum of the cropped area in period, t cannot be greater than the total available land for that month.

$$\sum_{i=1}^{l}\sum_{k=1}^{n} \beta_{ijk}^{t} A_{ijk} \le A^{t} \qquad \forall j,t$$

where, β = area co-efficient, β =1, if the crops remain in the field during the whole month, , β = 0, if there is no crop in the field and , β = a fraction, if crops are partly in the field.

4.5.3 Maximum Allowable Area under a Given Crop

To account for enhancing diversified cropping and maintaining market price of a specific crop, limitation on production of that crop is essential.

$$\sum_{j=1}^{m}\sum_{k=1}^{n} A_{ijk} \le A_{i\max} \qquad \forall i$$

where, $A_{i\,max}$ is the maximum area allowable for irrigation under crop i, rainfall probability, j and water application level, k.

4.5.4 Minimum Required Area under a Given Crop

This constraint is needed to fulfil social obligations such as production of certain crop to meet the minimum requirements for that crop.

$$\sum_{j=1}^{m}\sum_{k=1}^{n} A_{ijk} \geq A_{i\,\min} \qquad \forall i$$

where, A_{imin} is the minimum area required for irrigation under crop i,.

4.5.5 Total Available Area for Irrigation

$$\sum_{i=1}^{l}\sum_{j=1}^{m}\sum_{k=1}^{n} A_{ijk} \leq A$$

where, A is the total area available for irrigation in the study area

Non-negativity Requirements

$$A_{ijk}, P^{t} \geq 0$$

Solution of the above model requires a number of parameters. Details of parameter estimation are discussed in chapter 5.

CHAPTER V

DETERMINATION OF MODEL PARAMETERS

For solution of the model formulated in Chapter 4, the required parameters are, monthly irrigation water requirement of the selected crops, pumped water availability, profit per unit area, land area available in different months and maximum and minimum area limits of the selected crops for irrigation. Among these, some were estimated using climatic data, some were collected from BMDA office and the others were determined through two years' field experiments at Shyampur, Rajshahi. Only the maximum area limit was set based on average irrigation water requirement of the selected crops and realization of profit per unit area.

5.1 Estimation of Irrigation Requirement of the Selected Crops

The irrigation requirement of the selected crops was obtained by dividing the net irrigation requirement by system efficiency. The net irrigation requirement was again determined from crop water requirement (crop ET), effective rainfall and seepage and percolation losses whereas crop ET was estimated from reference evapotranspiration and crop co-efficient. Effective rainfall was obtained from dependable rainfall that was predicted by probability analysis of 32 years rainfall records of Rajshahi Meteorological Station. To account for percolation losses in rice field, tests were done to determine percolation rate of the experimental field soil. Further, in estimating monthly irrigation requirement of rice, the water for seedling raise and land preparation requirements were also considered. All these are discussed in details in the following sections.

5.1.1 Reference Evapotranspiration

Having no facility to collect monthly climatic data within the study area, the information on monthly maximum and minimum temperature, monthly average humidity, wind speed and sunshine hours per day were collected from the nearest meteorological station, Rajshahi, to calculate the reference evapotranspiration for the study area. The monthly reference evapotranspiration (ET_o) for the period from 1982 to 1999 were estimated using the software, CropWAT4 version 4.00 Beta based on Penman-Monteith equation described in Chapter 2. The yearwise ET_o calculations are shown in Appendix I. The calculated 18 years reference evapotranspiration and their monthly average values are presented in Table 5.1.

Table 5.1 Monthly reference evapotranspiration (ET_o) in mm/day

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1982	2.79	3.13	4.11	5.78	6.43	4.45	4.68	4.15	4.27	4.10	3.07	2.43
1983	2.69	4.03	5.83	6.46	5.88	5.82	4.74	4.29	4.39	3.50	3.44	2.73
1984	2.50	3.6	5.41	6.30	5.03	3.76	3.48	3.97	3.92	3.45	2.50	2.34
1985	2.46	3.78	5.76	6.36	5.49	4.63	3.87	4.36	4.61	3.86	3.23	2.56
1986	2.71	3.90	5.41	5.98	5.51	5.34	4.22	4.50	3.81	3.40	3.30	2.88
1987	2.87	3.69	4.77	5.77	6.13	4.91	3.52	4.15	3.26	3.90	2.99	2.71
1988	2.70	3.41	4.65	5.58	4.95	4.43	4.00	3.83	4.25	4.07	3.21	2.64
1989	2.63	3.86	5.10	6.32	5.75	4.80	3.93	4.24	3.65	3.74	3.05	2.44
1990	2.47	3.13	4.24	5.79	5.01	4.56	3.84	4.16	3.75	3.22	3.08	2.55
1991	2.54	3.88	4.51	5.60	5.09	4.47	4.30	4.17	3.40	3.30	3.07	2.34
1992	2.41	3.12	5.41	6.53	5.81	5.19	3.88	4.34	4.18	3.79	3.06	2.42
1993	2.25	3.51	4.32	6.41	5.28	4.34	3.81	3.52	3.56	3.62	3.12	2.58
1994	2.38	3.02	4.49	5.24	5.63	4.07	4.33	4.22	4.04	3.79	2.77	2.44
1995	2.38	2.96	4.13	5.64	5.24	3.81	3.69	3.19	3.19	3.78	2.55	2.23
1996	2.45	3.27	5.10	6.22	5.71	4.38	3.94	3.70	4.12	3.46	3.04	2.35
1997	2.46	3.29	4.52	4.63	5.71	5.04	4.05	3.86	3.60	3.71	2.78	2.44
1998	2.04	2.96	4.24	5.14	5.17	4.78	3.73	3.77	3.75	3.51	2.97	2.54
1999	2.56	3.85	5.40	5.41	4.77	4.16	3.85	3.76	3.67	3.59	3.18	2.52
Av.	**2.52**	**3.47**	**4.86**	**5.79**	**5.48**	**4.61**	**3.99**	**4.01**	**3.86**	**3.66**	**3.02**	**2.51**

5.1.2 Crop Co-efficient

Generally, for single dated crops, either standard crop co-efficient values (Doorenbos and Pruitt, 1977) or the location specific crop co-efficient values are used to estimate crop water requirement (crop evapotranspiration). But, for staggered plantation, composite crop co-efficient values (weighted average values) perform better and these are calibrated from standard or location specific values. In this study, field experiments were based on single dated plantation. Thus, the standard and location specific values were used for experimental purposes. In the developed model, on the other hand, staggered plantation was considered for Boro rice and wheat. Therefore, for model use, crop water requirement of the selected crops was estimated using composite crop co-efficients.

5.1.2.1 Determination of Crop Water Requirement Using Standard K_c Values for Single Dated Planting

In the first year of experiment, the standard values (Doorenbos and Pruitt, 1977) of crop co-efficients of Boro rice and wheat were used for the construction of K_c curves. The crop co-efficient values for initial, mid and end of the late seasons were obtained as shown in Table 5.2.

Table 5.2 Crop co-efficient values of Boro rice and wheat in the first year

Crop	Crop development stages		
	Initial	Mid season	End of late season
Boro rice	1.1	1.1	0.95
Wheat	0.3	1.05	0.20

The K_c curves constructed with the above K_c values of rice and wheat are shown in Figures 5.1 and 5.2, respectively. The crop coefficient values obtained from these curves and the ET_0 values of Table 5.1 were used in Equation 5.1 to estimate crop water requirement of the crops.

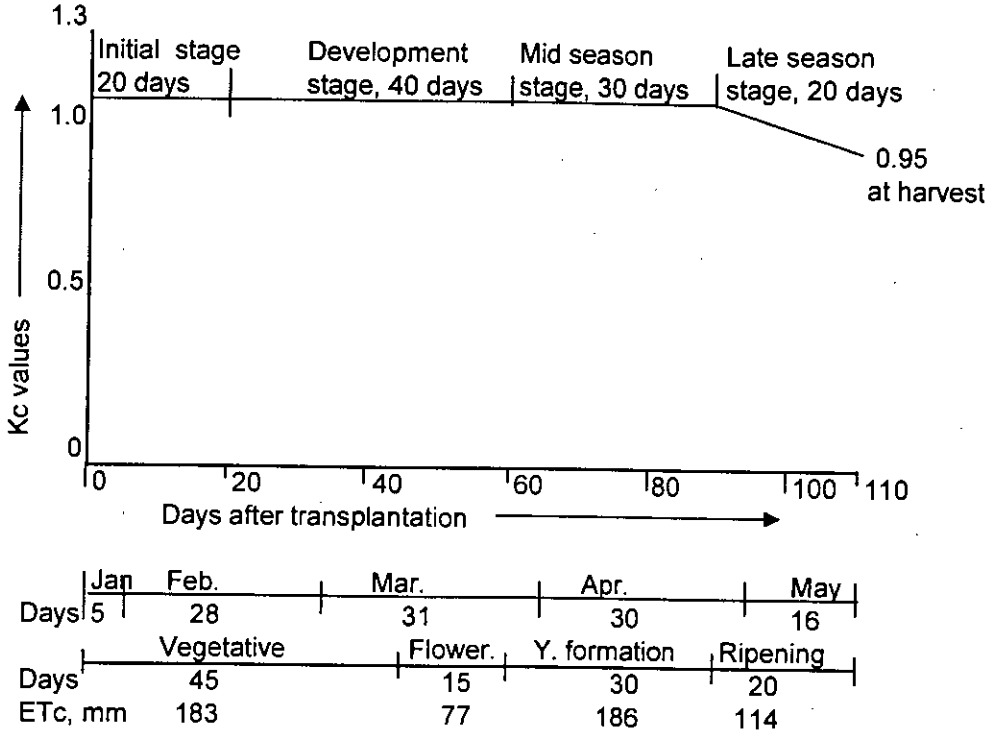


Figure 5.1 Kc curve of Boro rice constructed with standard values

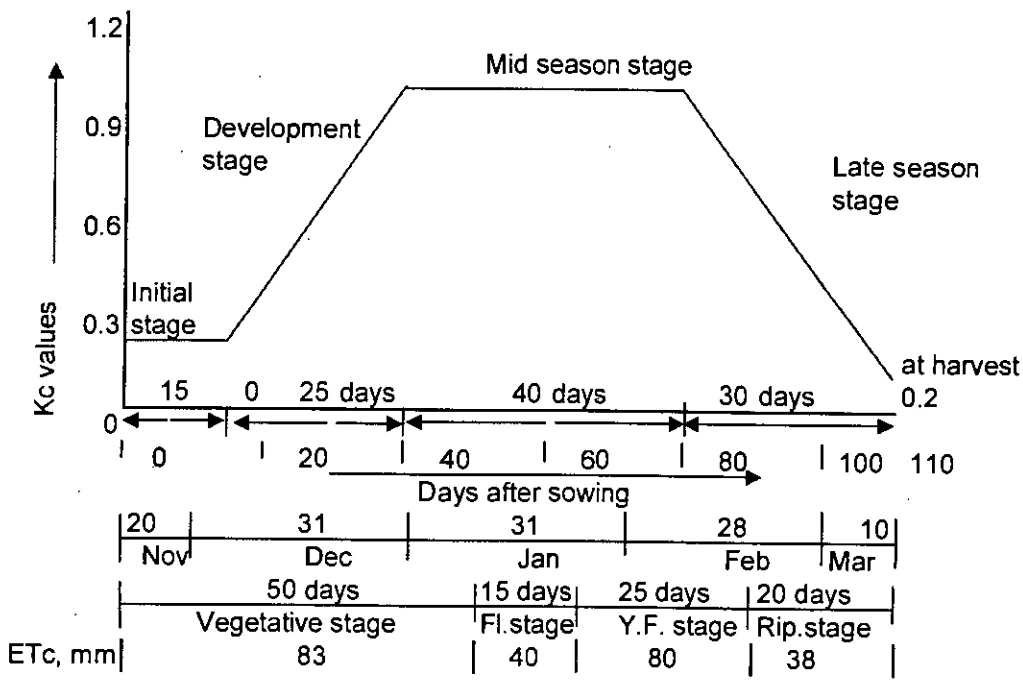


Figure 5.2 Kc curve of wheat constructed with standard values

$$ET_c = ET_0 * K_c * d \quad (5.1)$$

where, d = duration in days for which ET_c and K_c were estimated

5.1.2.2 Determination of Crop Water Requirement Using Location Specific K_c Values for Single Dated Planting

In the second year of study, the standard values of K_c were calibrated for the study location using the guidelines furnished in Chapter 2 and the values are given in Table 5.3. The K_c curves constructed with the above values of rice and wheat are shown in Figures 5.3 and 5.4, respectively. The crop co-efficient value was obtained from the constructed K_c curve and the crop water requirement was then estimated using equation 5.1.

Table 5.3 Crop co-efficients of Boro rice and wheat in the second year

Crop	Crop development stages		
	Initial	Mid season	End of late season
Boro rice	1.1	1.1	0.74
Wheat	0.38	1.15	0.42

5.1.3 Determination of Crop Coefficient Values for Staggered Plantation

The farmers of the study area were found to sow seeds of wheat and to transplant Boro seedlings over a span of time. They usually take 15 to 25 days for plantation of wheat and 20 to more than 30 days for Boro rice. In conjunction with the practical situation, the staggered plantation duration, for this study, were considered 20 days for wheat and 30 days for Boro rice. It was also observed that about 70% of wheat area were covered during the first 10 days and 30% during the last 10 days of sowing. For seedling transplantation of Boro rice, the coverage was 20%, 50% and 30% during the first,

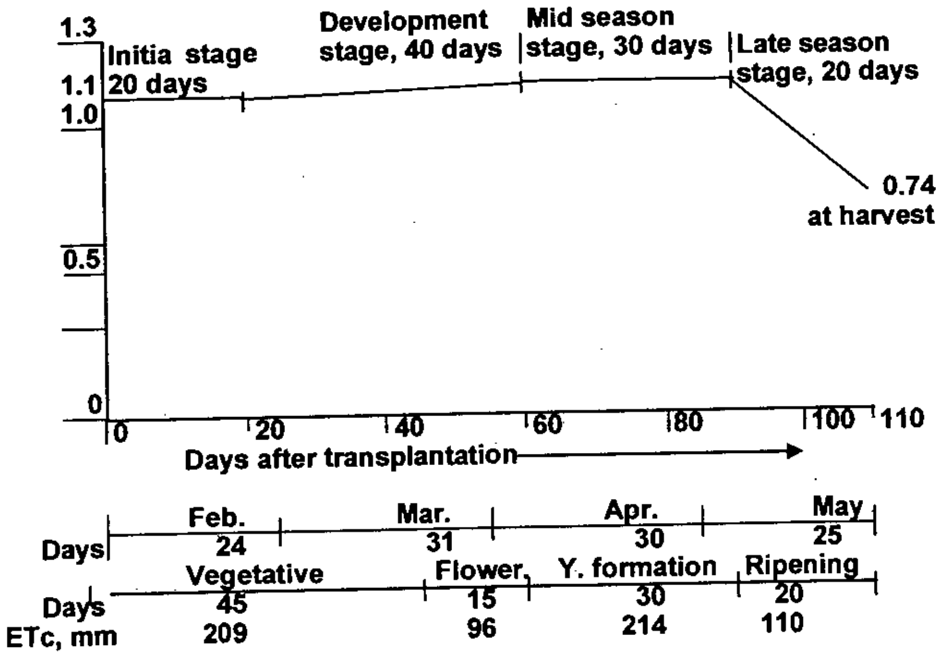


Figure 5.3 Kc curve of Boro rice constructed with location specific values

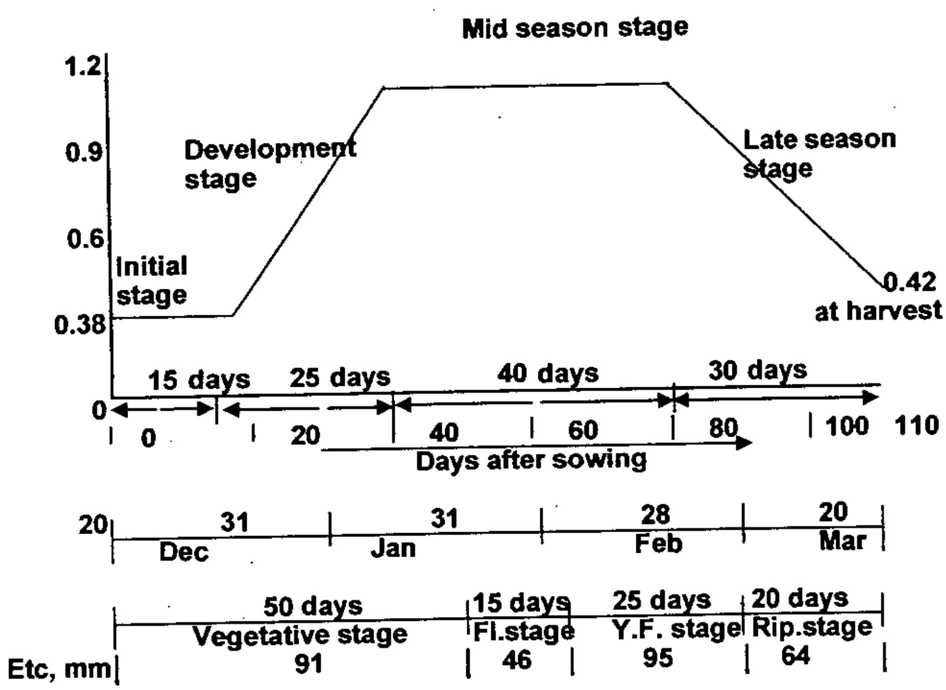


Figure 5.4 Kc curve of wheat constructed with location specific value

second and third decades, respectively. Thus, in a particular month, all the allocated area of Boro rice and wheat could not attain the same growth stage. For computing the monthly potential crop evapotranspiration of Boro rice and wheat, it was, therefore, necessary to compute the areawise weighted average monthly crop coefficient (composite crop coefficient) for each of these crops. So, K_c curves were constructed for staggered plantation with standard (Doorenbos and Pruitt, 1977) and location specific crop coefficient values for both the crops (Figures 5.5 to 5.8). Then using these curves, weighted average monthly composite crop coefficient values were determined.

The calculated monthly composite crop coefficients of the crops are shown in Table 5.4. The detailed calculations are presented in Appendix II.

Table 5.4 Composite crop coefficients of Boro rice and wheat

Crop	Year of study	Months							
		Jan	Feb	Mar	Apr	May	Jun	Nov	Dec
Boro rice	Year 1	0.70	1.1	1.1	1.05	0.53	-	-	-
	Year 2	0.70	1.1	1.1	0.99	0.42	-	-	-
Wheat	Year 1	1.1	0.90	0.27	-	-	-	0.21	0.60
	Year 2	1.12	0.98	0.36	-	-	-	0.27	0.60

5.1.3.1 Stage and Monthwise Potential Evapotranspiration of Boro rice and Wheat for Staggered Plantation

In order to impose water deficit at a particular stage of a crop, it is essential to calculate the stagewise potential crop evapotranspiration. However, monthwise potential evapotranspiration of Boro rice and wheat is needed to estimate their irrigation requirements for the solution of the formulated model on monthly basis. Using the Figures 5.5 to 5.8 and the cK_c values of Table 5.4, both month and stagewise potential

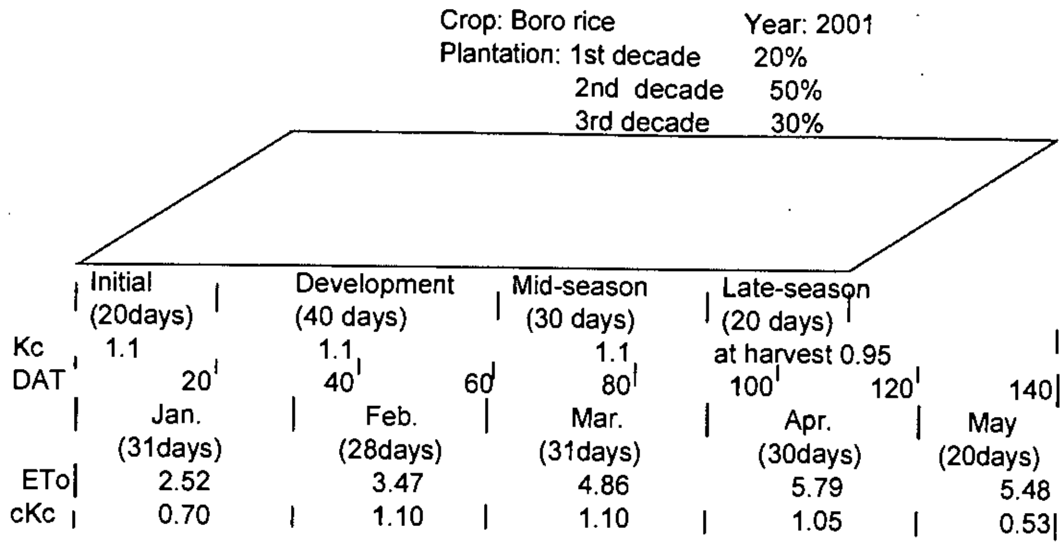


Figure 5.5 Kc curve of Boro rice constructed with standard values for staggered plantation

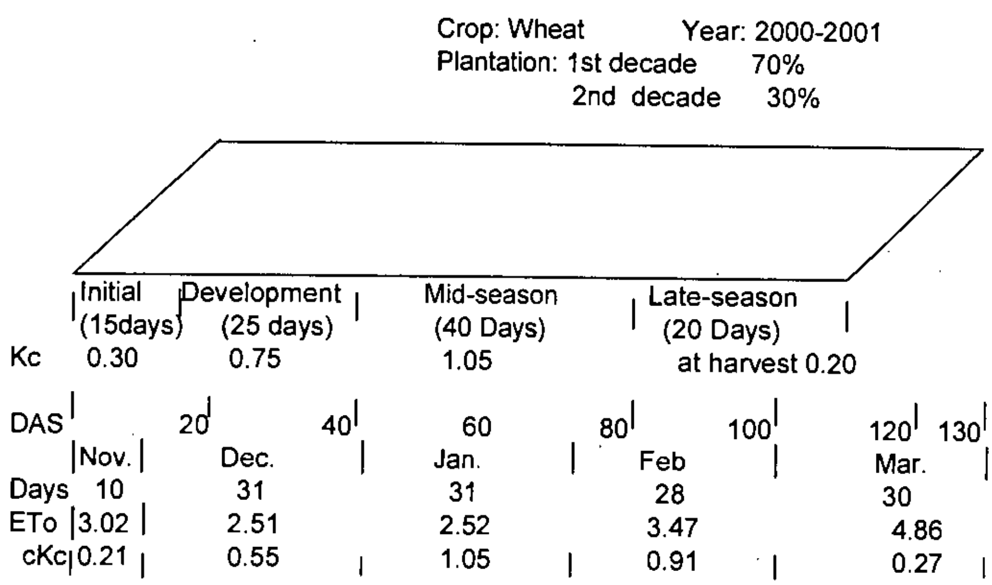


Figure 5.6 Kc curve of wheat constructed with standard values for staggered plantation

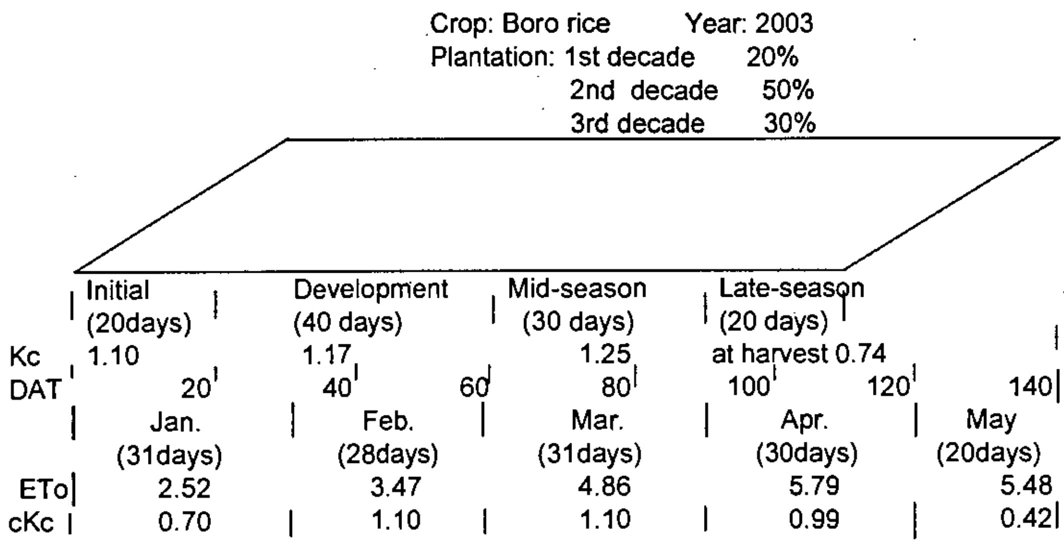


Figure 5.6 Kc curve of wheat constructed with location specific values for staggered plantation

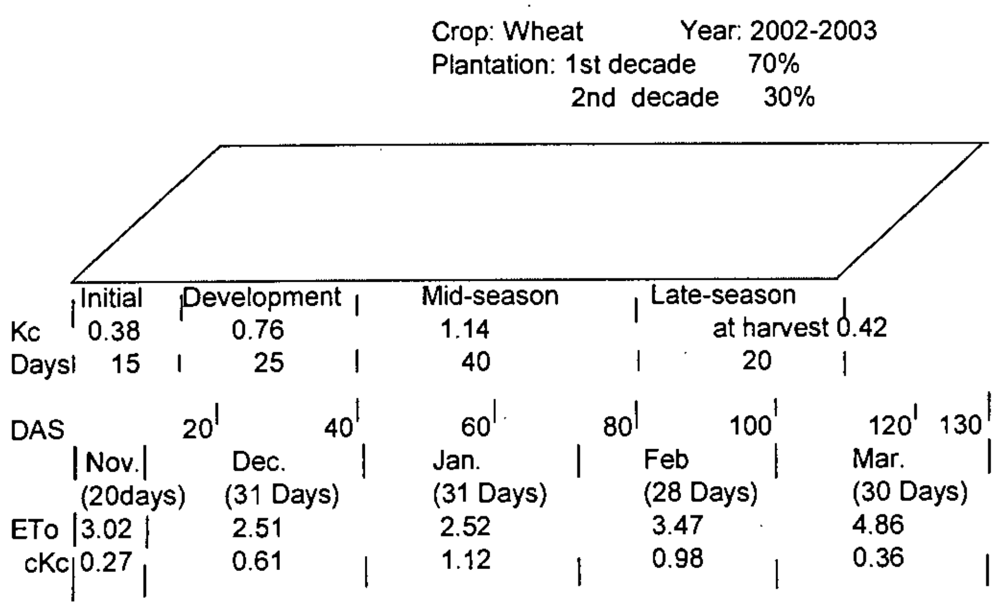


Figure 5.8 Kc curve of wheat constructed with location specific values for staggered plantation

ET of Boro rice and wheat for the study years were calculated. Details are given in Appendices III and IV.

5.1.3.2 Crop Evapotranspiration for Full and Deficit Irrigation for Staggered Planting

The potential crop ET estimated in section 5.1.3.1 was used as a basis for the determination of evapotranspiration of deficit irrigation levels. The deficit ET for 10, 20, 30 and 40% were calculated by multiplying the potential crop ET with 0.90, 0.80, 0.70 and 0.6, respectively. The full and deficit crop ET requirements are presented in Tables 5.5 and 5.6. Once, the crop water requirements of the selected crops are known, the next task is to determine the irrigation requirements of the crops. In doing so, effective rainfall, land preparation requirement, percolation losses etc. are needed to determine. All these are discussed in the following sections starting with dependable and effective rainfall estimation.

Table 5.5 Estimated crop ET for full and deficit irrigation during first year of study for staggered planting

Crop	Irrigation Levels	Evapotranspiration, mm	
		Vegetative Stage	Yield formation stage
Boro rice	Full	172	174
	10% deficit	155	157
	20% deficit	138	139
	30% deficit	120	122
	40% deficit	103	104
Wheat	Full	99	74
	10% deficit	89	67
	20% deficit	79	59
	30% deficit	69	52
	40% deficit	59	44

Table 5.6 Estimated crop ET for full and deficit irrigation during second year of study for staggered plantation

Crop	Irrigation Levels	Evapotranspiration, mm	
		Vegetative Stage	Yield formation stage
Boro rice	Full	172	169
	10% deficit	155	152
	20% deficit	138	135
	30% deficit	120	118
	40% deficit	103	101
Wheat	Full	109	80
	10% deficit	98	72
	20% deficit	87	64
	30% deficit	76	56
	40% deficit	65	48

5.1.4 Dependable and Effective Rainfall for Staggered Plantation

The dependable rainfall is the rainfall which can be expected with a given probability level. It is, for example, the rainfall which will be expected in 7 out of 10 years (70% dependable) or out of 10 years (80% dependable rainfall). Effective rainfall, on the other hand, is the part of dependable or actual rainfall the plant uses to meet up ET demand.

5.1.4.1 Dependable Rainfall

Since there exists a need to determine the types of distribution of rainfall data, there is a need for the graphic presentation of the data. One such graphic presentation is the histogram. Once the histogram has been determined, a theoretical probability distribution can be assigned to the rainfall data (Wanielista et al., 1997). Histograms of 32 years yearly rainfall data of Rajshahi station is shown in Figure 5.9. In the Figure, rainfall versus relative frequency graph is shown. From the graph it is apparent that normal distribution fits the annual rainfall data of Rajshahi station very well.

For further confirmation, 4 probability distributions, Normal, Log-normal, Pearson type-II and III distributions were also checked. Normal distribution was, again, found to fit the rainfall data better than any other tested distribution. Thus, the plotting of rainfall data was done on normal probability paper and is shown in Fig.5.10.

For planning irrigation water supply and management, rainfall data of normal (50% probability of rainfall exceedence), wet (20% probability of rainfall exceedence) and dry (80% probability of rainfall exceedence) years are normally used (Smith, 1992). So, in this study also the rainfall quantities were estimated for dry, normal and wet years by probability analysis of rainfall records. The involved steps in the procedure were:

i. Tabulation of yearly rainfall totals for a given period
ii. Arrangement of data in descending order of magnitude
iii. Calculation of plotting position by

$$P = m / (N+1) * 100 \tag{5.2}$$

where, P = plotting position, m = rank number and N = number of records

iv. Plotting the values on suitable probability paper
v. Selection of the year values at 20 (wet), 50 (normal) and 80 (dry) percent probability from constructed graph
vi. Determination of monthly values for dry, normal and wet years according to the following relationships (Smith, 1992):

$$P_{idry} = P_{iav} * (P_{dry} / P_{av}) \tag{5.3}$$

$$P_{iwet} = P_{iav} * (P_{wet} / P_{av}) \tag{5.4}$$

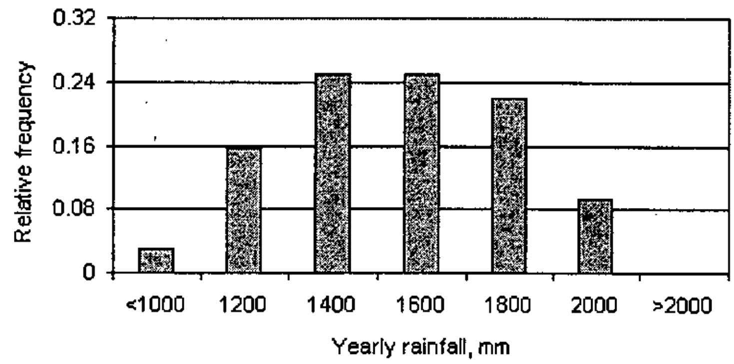


Figure 5.9a Rainfall and frequency relationship

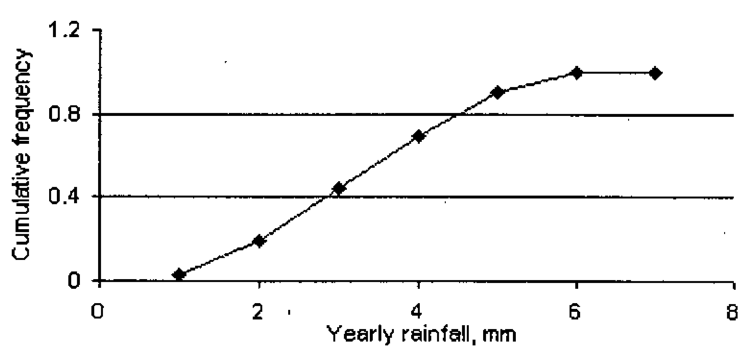


Figure 5.9b Relationship between rainfall and cumulative frequency

Figure 5.9 Histogram of yearly rainfall of Rajshahi meteorological station

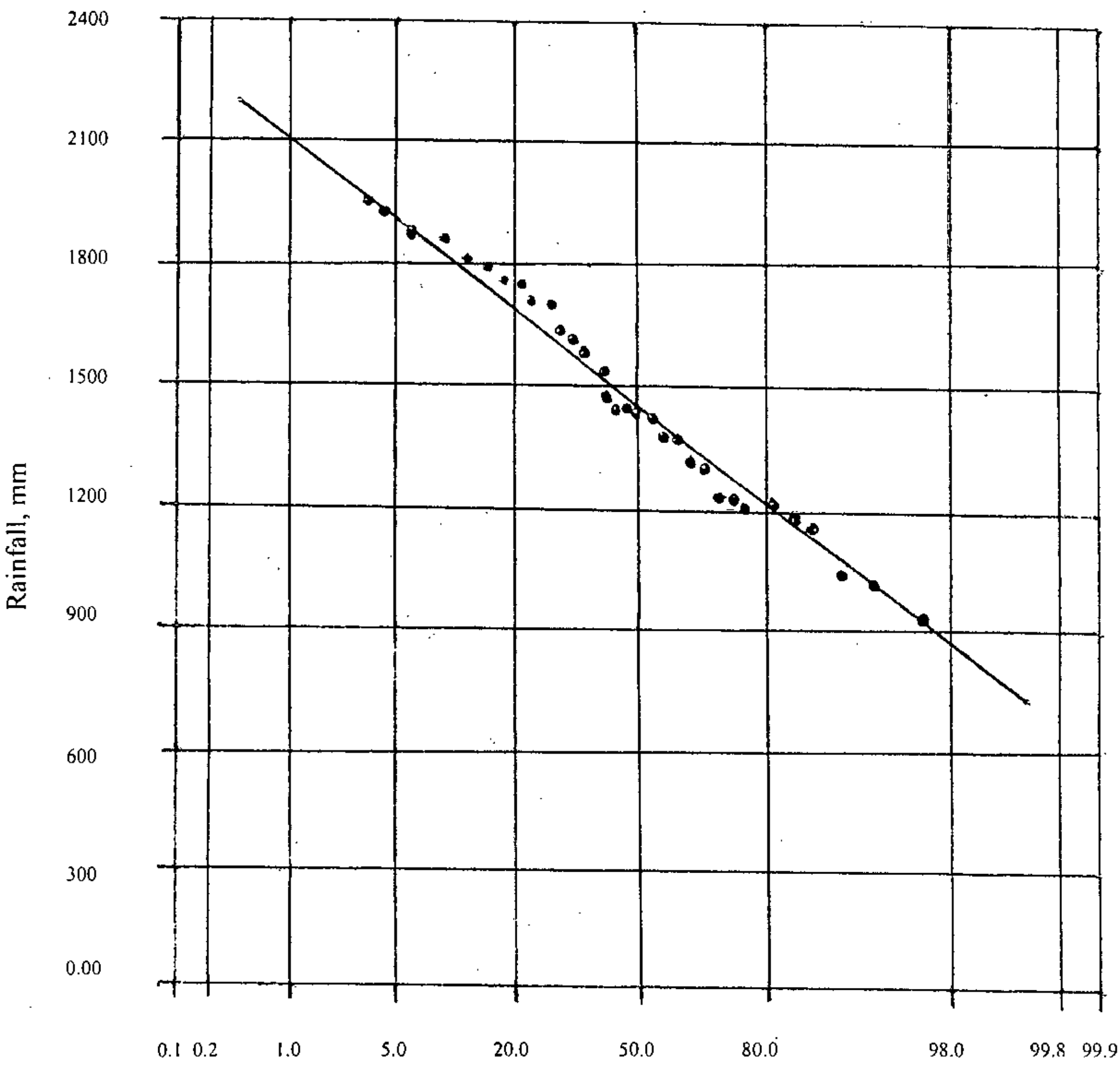


Figure 5.10 Plotting of year rainfall of Rajshahi Station in normal probability paper

where, P_{idry} = monthly dependable rainfall of dry year for month, i, P_{iwet} = monthly dependable rainfall of wet year for month, i, P_{iav} = average monthly rainfall for month, i, P_{av} = average yearly rainfall, P_{dry} = yearly rainfall at 80% probability of exceedence, P_{wet} = yearly rainfall at 20% probability of exceedence. The normal year rainfall is the average values of the data to be analyzed.

The monthly values of dependable rainfalls in normal, dry and wet years i.e., 50, 20 and 80% dependability of the rainfall quantities for normal, dry and wet years, respectively, are presented in Table 5.7.

Table 5.7 Dependable rainfall in normal, dry and wet years

Year category	Jan	Feb	Mar	Apr	May	Oct	Nov	Dec
50% dependability (Normal year)	8.09	13.56	20.72	55.38	125.30	103.30	21.19	6.66
20% dependability (Dry year)	6.75	11.32	17.30	46.24	104.63	86.26	17.69	5.56
80% dependability (Wet year)	9.42	15.80	24.15	64.55	145.70	120.40	24.70	7.76

5.1.4.2 Effective Rainfall

In staggered plantation, wheat was harvested in March and Boro rice in May. Since the dependable rainfalls in dry months, November to March, were found to range from 24.7 to 24.2 mm, the entire quantities of monthly rainfalls were considered effective for both wheat and Boro rice. The predicted dependable rainfalls obtained in April and May were 64 and 136 mm, respectively, during the later part of Boro season. But since the dikes constructed around rice basins by the farmers are, generally, 15 to 18 cm high, it was assumed that the above rainfall could be trapped entirely in the basin within the dikes. So, the total rainfalls of April and May were also considered effective for Boro rice.

5.1.5 Water for Seedling Raise and Land Preparation

From sowing of sprouted seeds to seedling raise, transplanted rice require some water to meet crop water requirement. This water is termed nursery water. After raising seedlings they need suitable land for transplantation. For the purpose, adequate water is required to make the land soft and muddy for seedlings. Upland non-rice crops usually require no water for land preparation except in a few occasions when soil moisture becomes too low for seed germination. Thus, transplanted rice requires a considerable amount of water for seedling raise and land preparation.

Net irrigation requirement of rice is somewhat different from upland non-rice crops because it requires water for land preparation and nursery and for continuous flooding for weed control in addition to crop ET after transplantation. Howard Humphreys (1986) used 200 mm water for land preparation in clay loam soil. Smith (1992) used 180 mm water for land preparation of rice. Doorenbos and Kassam (1979) suggested to use 100 to 300 mm water for land preparation based on soil texture. Mainuddin (1994) used 200 mm water for nursery and land preparation for clay loam soil. However, the scientists of Bangladesh Rice Research Institute, when contacted, suggested 50 mm water for nursery and 150 mm for land preparation. In this study, 200 mm water was considered for land preparation and nursery requirement in both field experiments and in estimating monthly irrigation requirement of Boro rice.

5.1.6 Seepage from Rice Field

Seepage is the lateral subsurface movement of water in the soil. As a process, seepage between two points takes place in response to the difference in the piezometric heads between them. Thus two rice plots having the same ground elevation but with different depths of standing water will have seepage movement across the boundary. Seepage losses in farms with steep slopes, with or without terraces, are generally high. When the fragmented plots of a huge field are irrigated simultaneously, except in a few depressions, practically a little or no water is seeped to the neighbouring plots. But it can occur through bunds downwards if the bunds are not puddled for a long time. In this study, such water loss through bunds was not monitored. Seepage losses can be reduced by (1) land levelling within the farm, (2) maintaining uniform and low depth of water in the field, (3) good maintenance of paddy dikes, enabling them to be less pervious, and (4) more frequent but shallow depths of irrigation supplies (Bhuiyan and Palanisami, 1987).

5.1.7 Percolation from Rice Field

Percolation is the vertical downward movement of water below the crop root zone, which often reaches the water table. Percolated water is not available for use by crops. It is governed by the resistance offered by the soil profile and the water head (depth of standing water) on the field to water movement. It is also related to the structure and texture and the interface between the soil horizons, including hardpans. The depth of water table also influences the percolation losses. In rice irrigation, the consideration of percolation water is important.

According to Wickham and Sen (1978), the presence of soil moisture should not be less than the saturation condition of the soil in rice irrigation, otherwise, serious yield reduction may occur with the stress condition. However, at the ripening stage, the physiological demand of plants becomes the minimum. At maturity (at the end of ripening stage), most of the paddy roots become dead (Doorenbos and Kassam, 1979). Therefore, application of percolation water, at this stage, is nothing but the wastage of water. So, in this study, no percolation was considered for the ripening stage of Boro rice. As there was no information available for the percolation in the experimental field soil, tests were done prior to experimentation for the determination of bare soil percolation rate. Boro field percolation rate was also determined in the course of conducting experiments.

5.1.7.1 Determination of Bare Soil Percolation

Bare soil percolation was used to determine the percolation requirements of Boro rice experimental plots and those determined in Boro rice experimental plots were used to estimate monthwise irrigation requirement of Boro rice for the developed model. These monthly values of irrigation requirement were used for staggered plantation to solve the proposed model. The procedure for the determination of bare soil percolation is given below.

A 4 m x 5 m land area was soaked, puddled and left for 7 days to allow the soil particles settle down. Then water was applied to the plot and a double ring infiltrometer was set in the middle of the plot (Figure 5.11a). A scale was fitted to the inner cylinder to record the water depletion from the cylinder. Both the rings were inserted into the soil up to the depth of 60 cm to avoid seepage loss through the equivalent root zone depth ($\approx$30 cm) of Boro rice and to allow the percolation losses only. The rings were covered with black polythene and trashes were put on it to minimize evaporation from the rings (Figure 5.11b). At the time of scale reading, the polythene was removed, water head was recorded and the depleted water was replenished. During the tests, water depths of 60, 80, 100 and 120 mm were used. The detailed calculations of bare soil percolation tests are presented in Appendix-V. The average rate was obtained 1.96 mm/day. During the first year of experimentation, this average rate was used to compute the total percolation requirement for the irrigation cycles used in the experiment.

Similar tests were also done in the second year. The calculations are presented in same Appendix V. The relationships between water head and percolation rate for the first and second years are given in Figures 5.12a and 5.12b, respectively.

In the second year, the percolation rate for an irrigation cycle was obtained from the head versus percolation rate relationship. The percolation rate was obtained corresponding to crop water requirement (i.e water head) of the cycle from the graph.

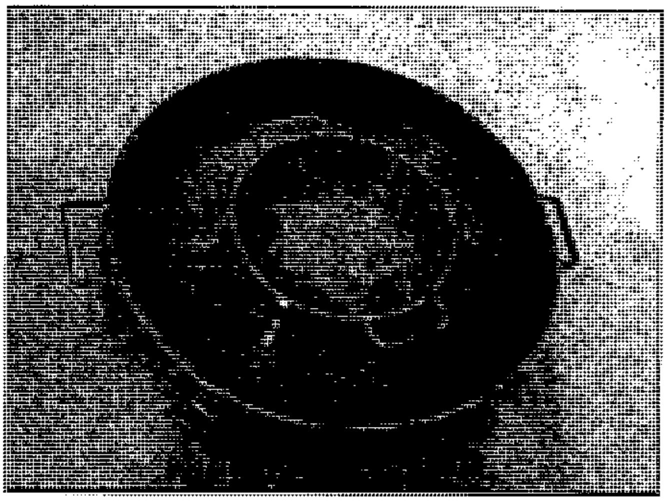


Figure 5.11a Double ring infiltrometer to determine bare soil percolation

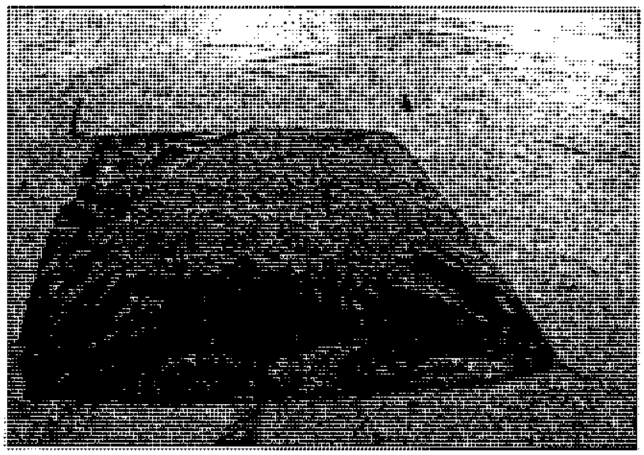


Figure 5.11b Double ring infiltrometer covered with black polythene

Figure 5.11 Double ring infiltrometer set in bare soil

Multiplying this rate by the duration (days) of irrigation cycle, the total percolation requirement for the cycle was calculated. The average percolation in the second year was 1.94 mm/day.

It should be mentioned that the time intervals between two consecutive scale readings in the first year were 1 to 2 days and in the second year 4 to 6 days. The reason for higher interval in the second year was to obtain bigger depletion of water level inside the ring so that scale readings could be taken more accurately with naked eyes.

5.1.7.2 Determination of Boro Field Percolation

Immediately after land preparation and layout formation, lysimeter tanks were set in the experimental field to determine percolation from Boro field. The seedlings were then transplanted in experimental plots including the lysimeter tanks. In the first year, an open lysimeter tank was used to record the water level declination from the scale attached to the inner side of the tank at intervals of 1 to 2 days. The tank was inserted up

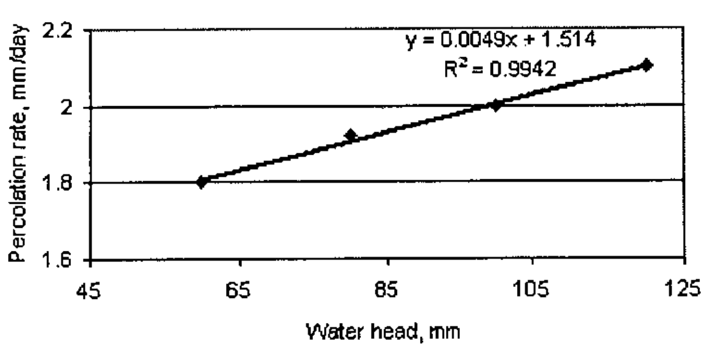


Figure 5.12a Water head-percolation relationship for bare soil in first year

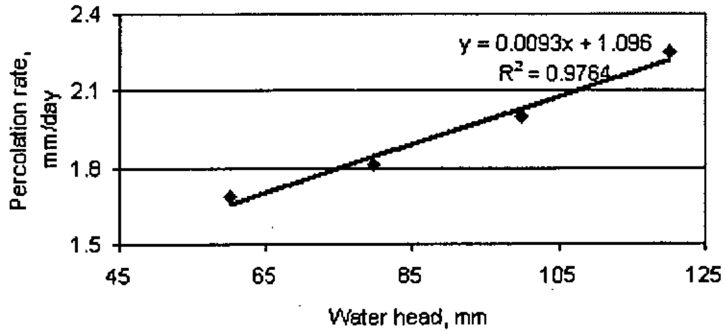


Figure 5.12b Water head-percolation relationship for bare soil in second year

Figure 5.12 Water head-percolation relationship for bare soil in the experimental fields

to 60 cm inside the soil to avoid any seepage from the equivalent root depth of Boro rice. Since the tank had both ends opened, the subsided water level included crop evapotranspiration and percolation for the interval considered. Then subtracting the estimated crop ET for the same period from the above values, the percolation for the interval was obtained in millimeter. Dividing this percolated water depth by the time interval in days, the rate was obtained in mm/day. After each scale reading, the depleted water was replenished. The test was done for the water heads of 60 mm, 80 mm, 100 mm and 120 mm. Then relationship obtained between water head and percolation rate is presented in Figure 5.13a. The calculation procedure is given in Appendix VI. The average percolation rate was 1.99 mm/day in the first year.

In the second year, two lysimeter tanks were used, one with bottom end closed and top end opened and the other with both ends opened. The former recorded the crop ET only while the latter recorded both crop ET and percolation. As in previous year, the tank was inserted up to 60 cm inside the soil to avoid any seepage from the tank. The readings in both the tanks were recorded for the same duration. The difference of these two readings gave the percolation of Boro field for that specified duration. In the second year, the readings were taken at intervals of 3 to 5 days to allow higher depletion of water levels inside the tanks so that the scale readings could be read more accurately with naked eyes. The relationship between water head and percolation rate for the second year is presented in Figures 5.13b. The calculation procedure is furnished in the same Appendix VI. The average percolation rate was 2.04 mm/day in the second year. After estimating potential crop evapotranspiration of Boro rice and wheat (section 5.1.3.1) and effective rainfall (5.1.4.2), the monthly net irrigation requirement of wheat for staggered plantation was calculated using equation 5.5 considering no contribution from groundwater as the static water level of the study site was found to remain at a minimum depth of 3.4 m below ground surface level during the dry season (October to March). For Boro rice, equation 5.6 was used in which water for land preparation and

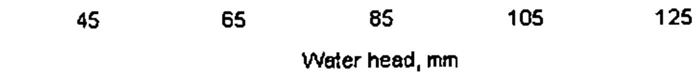


Figure 5.13a Water head-percolation relationship for boro field in fisrt year

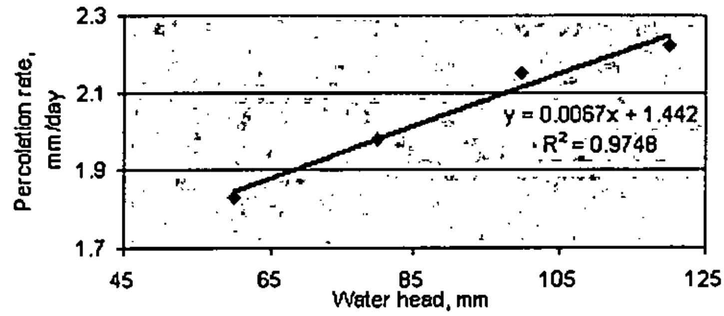


Figure 5.13b Water head-percolation relationship for Boro field in second year

Figure 5.13 Water head-percolation relationship for Boro field

deep percolation were also considered. The effective rainfall was used to estimate net irrigation requirement of the selected crops. It was assumed that for a long-term average, there was no change in stored soil moisture (Mainuddin, 1994). Therefore, the contribution from stored soil water was also considered negligible. The estimated monthly net irrigation requirement of Boro rice and wheat are presented in Appendices VII and VIII, respectively, for the first and second years. Having net irrigation requirement, the gross irrigation requirement (pumping requirement) was obtained by considering the system efficiency. A discussion is made in the following section about the system efficiency and the gross irrigation requirements.

5.1.8 Net Irrigation Requirement

Irrigation supply is the amount of water applied to a crop either to supplement the rainfall or to support fully the water required by the crop. Net irrigation requirement of a crop is calculated using the field water balance. Mathematically,

$$NIR_{non\text{-}rice} = ET_c - R_e - G \quad (5.5)$$

$$NIR_{rice} = ET_c - R_e + LPR + P \quad (5.6)$$

where, NIR = net irrigation requirement of crop, mm, ET_c = potential crop evapotranspiration, mm, G = groundwater contribution to root zone area, LPR = water for land preparation and nursery requirement, mm, P = percolation water, mm.

5.1.9 System Efficiency

It indicates the effectiveness of the irrigation water source for crop production and is measured by the percentage of irrigation water stored in the soil as well as available for consumptive use of crops. When the delivered water is measured at the farm head gate or well, it is called farm irrigation efficiency or the system efficiency (E_f).

Both diesel and electricity operated Deep Tube wells operate in the BMDA project area. According to the BMDA officials, the system efficiencies were different for diesel and electricity operated tube wells, the efficiency for electricity operated tube wells being higher. The system or project efficiency (E_f) comprised two major components, viz. field application efficiency (E_a) and distribution efficiency (E_d).

Rashid et al. (1991) found 84% distribution efficiency and 80% application efficiency for Boro rice at Ukiara deep tubewell scheme in Manikgonj district, thus giving rise to 67% system efficiency. International Institute for Land Reclamation and Improvement (ILRI, 1990) studied the irrigation efficiencies for different countries of the world. The average distribution efficiency was suggested 80%. Hassan and Islam (1997) used 84% application efficiency for Barind area. Considering ILRI distribution efficiency of 80% and the Barind area application efficiency of 84%, the system efficiency becomes 67% for rice. In another study, Alam et al. (1981) found 70 to 90% application efficiency with an average of 80% for open channel in rice field. Considering ILRI distribution efficiency, this scheme has 64% system efficiency. So, in this study, an average system efficiency of 65% was used for rice.

Again, Smith (1992) used 70% application efficiency for upland crops. Considering ILRI distribution efficiency of 80%, the system efficiency becomes 56%. Further, Doorenbos and Pruitt (1977) considered 90% conveyance efficiency, 85% (average) field canal efficiency and 70% application efficiency which gives 54% system efficiency. So, in this study, 55% system efficiency was considered for wheat.

It is worth mentioning here that these rice and wheat efficiencies were used to estimate monthly gross irrigation requirement for staggered plantation and these irrigation requirements were subsequently used for water availability co-efficient in the formulated model.

5.1.10 Gross Irrigation Requirement

Gross irrigation requirement of a tubewell system depends on how efficiently the system is performing. The total amount of water applied through irrigation is termed as 'gross irrigation requirement'. It is the net irrigation requirement plus losses in water application and other losses. The gross irrigation requirement can be determined for a field, for a farm, for an outlet command area or for an irrigation project, depending on the need, by considering the appropriate losses at various stages of crop (Michael, 1986). This is also defined as the total irrigation requirement for a crop at the main intake point from the source and is expressed by equation 5.7. The monthly gross irrigation requirement of Boro rice and wheat are presented in Appendices VII and VIII.

$$\text{Gross irrigation requirement (in field)} = NIR/\ E_f \qquad (5.7)$$

where, E_f = system efficiency

5.2 Water Available for Irrigation

It was learnt from BMDA office that 1463 DTW were in operation during the Rabi season of 2003-2004 in the selected four thanas of the study area and the design discharge of each DTW was 56.6 l/s. According to BMDA official, the tube wells could easily be operated for 16 hours a day without any machine trouble. However, with the pace of time, the efficiency of tubewell might have declined to some extent. Therefore, full, 80% and 60% of design capacities were considered to estimate the available water supply for the model. Under these considerations, the volume of water pumped in each month of the cropping season was estimated. These are shown in Table 5.8.

Table 5.8 Available pumped water for full, 80% and 60% of design DTW capacity

Month	Number of DTWs	Hours pumped per day	Available pumped water (ha-m) at		
			full design capacity	80% design capacity	60% design capacity
November	1463	16	14309	11447	8586
December	1463	16	14786	11829	8871
January	1463	16	14786	11829	8871
February	1463	16	13355	10684	8013
March	1463	16	14786	11829	8871
April	1463	16	14309	11447	8586
May	1463	16	14786	11829	8871

5.3 Estimation of Profit per Unit Area

One of the model parameters is the profit per hectare of Boro rice and wheat. A series of activities were done in the process of profit estimation. These included determination of actual yield and yield response factors (K_y) of Boro rice and wheat by field experiments, prediction of yields for staggered plantation using experimentally determined K_y values and estimation of profit from crop production inputs and outputs.

5.3.1 Yield and Yield Response Factors of Boro rice and Wheat

As mentioned earlier, yield response factor (K_y) plays a very important role in predicting yields under water shortage conditions when used in a crop production function. Doorenbos and Pruitt (1977) recommended standard values of yield response factors for generalized use. But none is available for local condition. So, experiments were conducted to determine the yield response factors for the study location. The research was done at the farm of Bangladesh Agricultural Research Institute, Shyampur, Rajshahi. The field experiments included the selection of irrigation sequence, stage and interval, determination of soil texture of the experimental field, fabrication of water measuring tank and application of irrigation to experimental plots. In addition to K_y determination, checking the locally determined K_y values, developing the soil moisture extraction patterns for wheat and developing the crop production functions for both Boro rice and wheat were also included in the activities.

5.3.1.1 Stages of Deficit Irrigation

In order to save irrigation water, it was decided that deficit should be imposed at vegetative and yield formation stages of the selected crops. Since these two stages consume the maximum of seasonal requirement, larger amount of water could be saved from these stages by deficit irrigation. Moreover, most crops are found highly sensitive to water stress in flowering stage rather than vegetative or yield formation stage (Stewart and Hagan, 1973 and Stewart et al., 1976).

In the first year, the entire amount of stage water deficit was withdrawn from the last irrigation of that particular stage(s). In the second year, the stage water deficit was withdrawn proportionately from individual irrigation of the selected stage(s).

5.3.1.2 Experimental Design

Keeping the above in mind, design for experiments was made to impose water deficit in either vegetative or yield formation stage or in both. In the first year (2000-2001), nine treatments were used in the experiments where the deficits were imposed separately in vegetative and yield formation stages. But to have a cross check of the yields, four additional treatments, each having double stage deficits in both vegetative and yield formation stages were used in the second year (2002-2003). The variety of rice used in the experiment was BRRI Dhan-28 and that of wheat was Protiva. In the first year of experiment, the following treatments were included:

T_1 = Full irrigation at all growth stages (i.e., vegetative, flowering, yield formation and ripening stages)

T_2 = 10% deficit irrigation at vegetative stage and full irrigation at other three growth stages

T_3 = 20% deficit irrigation at vegetative stage and full irrigation at other three growth stages

T_4 = 30% deficit irrigation at vegetative stage and full irrigation at other three growth stages

T_5 = 40% deficit irrigation at vegetative stage and full irrigation at other three growth stages

T_6 = 10% deficit irrigation at yield formation stage and full irrigation at other three growth stages

T_7 = 20% deficit irrigation at yield formation stage and full irrigation at other three growth stages

T_8 = 30% deficit irrigation at yield formation stage and full irrigation at other three growth stages

T_9 = 40% deficit irrigation at yield formation stage and full irrigation at other three growth stages

Since it was decided that the formulated model would be solved considering double stage effect of deficit irrigation, four additional treatments were included in the second year to check the values of K_y determined by field experiments. These additional treatments were:

T_{10} = 10% deficit irrigation at vegetative and yield formation stages and full irrigation at other two growth stages

T_{11} = 20% deficit irrigation at vegetative and yield formation stages and full irrigation at other two growth stages

T_{12} = 30% deficit irrigation at vegetative and yield formation stages and full irrigation at other two growth stages

T_{13} = 40% deficit irrigation at vegetative and yield formation stages and full irrigation at other two growth stages

A statistical design, randomized complete block (RCB), was used in the layout of the experiment. Each treatment was replicated thrice and altogether there were 27 plots for each crop in the first year and 39 plots in the second year. The soil texture of the experimental field was clay loam and it was determined by laboratory tests (section 5.3.1.3). Full irrigation treatment was considered as the basis of comparison among the selected combinations. In the first year, wheat was sown on 20 November 2000 and Boro rice was transplanted on 25 January 2001. In the second year, wheat was sown on 01 December 2002 and Boro rice on 06 December 2003. Thirty two days old rice seedlings were transplanted in the first year and thirty five days old seedlings in the second year. An experimental layout with nine treatments (2000-2001) is shown in Figure 5.14. A similar one with the same statistical design and 13 treatments was used in the second year of study.

The design deficit levels of the treatments as mentioned above were affected to some extent by the Boro field percolation water. However, those for wheat remained unaffected. Discussions on exact water deficit for the design treatments are made in the following section.

5.3.1.3 Determination of Soil Texture of Experimental Fields

Fifteen samples from five spots chosen diagonally on the experimental field were collected at 10, 30 and 50 cm depths and their composite samples were analyzed in laboratory to determine the percentages of sand, silt and clay. Then using the USDA soil textural classification chart (Michael, 1978), soil texture was determined. Texturally, the soil was classified as clay loam. Percentages of sand, silt and clay for each composite sample are given in Table 5.9. The test results agreed to that learnt from the SRDI scientists of Shyampur, Rajshahi. The field capacity of the soil was 28% and bulk density, 1.5 gm/cc on dry basis.

Table 5.9 Textural classification of experimental field soil

Composite sample number	Percentage of			Soil texture
	Sand	Silt	Clay	
1.	40	30	30	Clay loam
2.	28	36	36	Clay loam
3.	25	35	40	Clay loam
4.	32	33	35	Clay loam
5.	35	27	38	Clay loam

5.3.1.4 Exact Water Deficit for the Design Treatments

The most regulating factor for the design deficit levels of the treatments was the water applied for crop evapotranspiration. Since groundwater contribution to crop water requirement was nil, it had no effect on the design deficit levels of the treatments. Rainfall occurred in the growth stage selected for deficit irrigation could have regulated effect to some extent but following each irrigation, the equivalent quantity was subtracted from the subsequent irrigation requirement of the same stage making the regulating effect of rainfall nil on water deficit. In practice, a little amount of rainfall occurred during wheat growing period. Thus, in wheat plots, the design deficit levels could be maintained properly. But, for rice, it was quite difficult to maintain exact deficit level due to application of percolation water. However, determination of the effect of percolation water on deficit levels was beyond the scope of this study.

T_1	T_2	T_9
T_6	T_7	T_5
T_8	T_6	T_7
T_3	T_3	T_4
T_7	T_9	T_1
T_4	T_5	T_8
T_9	T_1	T_2
T_5	T_4	T_6
T_2	T_8	T_3

Figure 5.14 Experimental layout for Boro rice and wheat in the first year of study

5.3.1.5 Irrigation Application and Interval

Two water application techniques were followed for the experimental plots. In the first year, the entire amount of stage water deficit was withdrawn from the last irrigation of that particular stage(s). In the second year, the stage water deficit was withdrawn proportionately from individual irrigation of the selected stage(s).

Regarding the intervals of irrigation for both Boro rice and wheat, a 10-day duration was followed during the first year experiments. This practice was followed to reduce percolation loss by applying smaller quantity of water per irrigation. In the second year, a varying interval of 5 to 10 days was followed for Boro rice and 15 to 20 days for wheat. The reason for increased irrigation interval for wheat in the second year was to reduce the number of irrigation so as to make it close to farmers' practice. However, to maintain irrigation at all the four design growth stages and to protect percolation loss, 6 irrigation were applied to wheat and thus, the number of irrigation could not be restricted to farmers' practice of maximum 4 to 5 in the second year of study.

5.3.1.6 Application of Water to Experimental Plots

In order to apply measured quantity of water to experimental plots, a tank of capacity 1600 litres was fabricated for volumetric measurement of water with the attachments of a manometer tube to read the volume of water and a non-returning valve to control the out flow of water from the tank. The tank was filled with water and then released through a flexible plastic pipe to the experimental plot as per requirements of the treatments. The required depth of irrigation requirement was converted to volume of water. The water measuring tank is shown in Figure 5.15.

Measured quantity of water was applied to each treatment plot. Amount of water for full and deficit irrigation were calculated for the desired stages using Figures 5.1 to 5.4. In estimating water requirement for full irrigation of a particular stage of Boro rice,

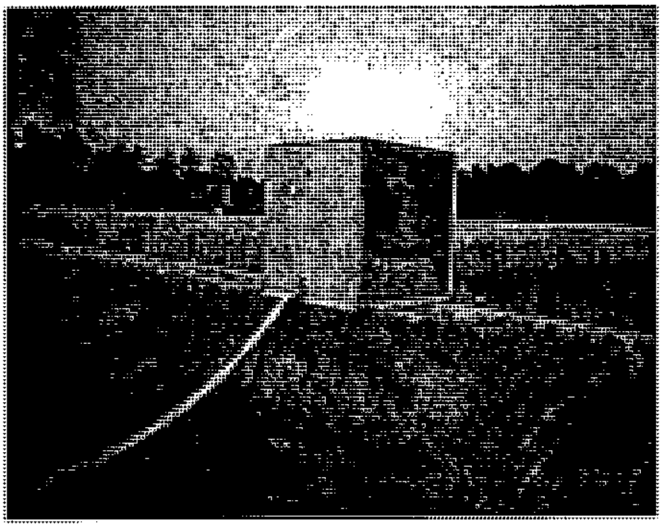


Figure 5.15a Water measuring tank showing delivery pipe

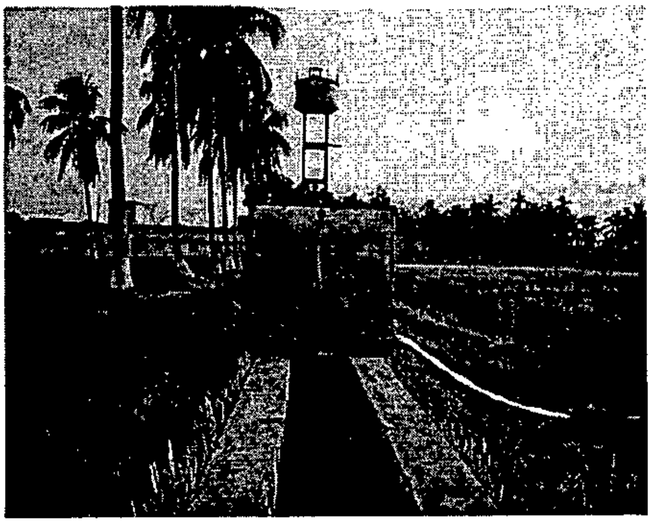


Figure 5.15b Water measuring tank showing graduated **tubing**

Figure 5.15 Water measuring tank placed beside the experimental site groundwater contribution and effective rainfall were considered nil. However, any rainfall occurred during experimentation was adjusted to crop ET. The percolation requirement of Boro rice was fulfilled from the information obtained by bare soil percolation test. The conveyance loss, distribution loss and soil water contribution were considered negligible. The infield water loss was also found negligible because the water application was uniform over the small (3.0 m x 5.0), flat and level plots. So, the system efficiency was considered 100% for the experiments and thus, the gross irrigation requirements equaled net irrigation requirements. The stage-wise ET_c was estimated using equation 5.1.

In estimating water requirement for full irrigation of a particular stage of wheat, the similar considerations were made except that for irrigation requirement no deep percolation was considered. Thus, for full irrigation under no rainfall condition, the crop water requirement (ET_c) of wheat equaled the net irrigation requirement. Detailed estimation of irrigation water requirement for Boro rice and wheat are presented in Appendices IX and X and the treatment-wise estimated crop evapotranspiration of Boro rice are presented in Tables 5.10a and 5.10b and those of wheat in Tables 5.11a and 5.11 b.

Table 5.10a Crop evapotranspiration (mm) of Boro rice in the first year

Treatment	Growth stages of Boro rice			
	Vegetative	Flowering	Yield formation	Ripening
T_1	183	77	186	114
T_2	165	77	186	114
T_3	146	77	186	114
T_4	128	77	186	114
T_5	110	77	186	114
T_6	183	77	167	114
T_7	183	77	149	114
T_8	183	77	130	114
T_9	183	77	112	114

Table 5.10b Crop evapotranspiration (mm) of Boro rice in the second year

Treatment	Growth stages of Boro rice			
	Vegetative	Flowering	Yield formation	Ripening
T_1	209	96	214	110
T_2	188	96	214	110
T_3	167	96	214	110
T_4	146	96	214	110
T_5	125	96	214	110
T_6	209	96	193	110
T_7	209	96	171	110
T_8	209	96	150	110
T_9	209	96	128	110
T_{10}	188	96	193	110
T_{11}	167	96	171	110
T_{12}	146	96	150	110
T_{13}	125	96	128	110

Table 5.11a Crop evapotranspiration (mm) of wheat in the first year

Treatment	Growth stages of wheat			
	Vegetative	Flowering	Yield formation	Ripening
T_1	83	40	80	38
T_2	75	40	80	38
T_3	66	40	80	38
T_4	58	40	80	38
T_5	50	40	80	38
T_6	83	40	72	38
T_7	83	40	64	38
T_8	83	40	56	38
T_9	83	40	48	38

Table 5.11b Crop evapotranspiration (mm) of wheat in the second year

Treatment	Growth stages of wheat			
	Vegetative	Flowering	Yield formation	Ripening
T_1	91	46	95	64
T_2	82	46	95	64
T_3	73	46	95	64
T_4	64	46	95	64
T_5	55	46	95	64
T_6	91	46	86	64
T_7	91	46	76	64
T_8	91	46	67	64
T_9	91	46	57	64
T_{10}	82	46	86	64
T_{11}	73	46	76	64
T_{12}	64	46	67	64
T_{13}	55	46	57	64

5.3.1.7 Yield and Yield Contributing Parameters of Boro rice

Among the yield contributing parameters considered by the agronomists for variety development, only some key parameters were taken into consideration for this study as the nature of the study was quite different. Here, tiller per square metre, panicle per square metre, grains per panicle and 1000 grain weight were considered for the yield contributing parameters. The collected field data were analyzed statistically and are presented in Tables 5.12 a and 5.12b.

From Tables 5.12a and 5.12b it appears that in the first year of study there were significant difference in yield and yield contributing parameters among the treatments. In the second year, no such significant difference was observed for tiller/sq.m and panicle/sq.m. Further, in the first year, the maximum yield (4.7 t/ha.) was much higher than that (3.72 t/ha.) of the second year. A higher rate of yield reduction in deficit irrigation over the full irrigation was observed in the first year except for treatment T_9.

Table 5.12a Yield and yield contributing parameters of Boro rice in the first year

Treatments	Tiller/ sq.m	Panicle/ sq.m	Grains/ panicle	1000 grain wt.(gm)	Grain yield (t/ha)	Reduction of yield (%)
T1	384	382	106	25.17	4.70	-
T2	380	379	94	22.74	4.00	14.89
T3	379	376	91	21.85	3.24	31.06
T4	380	375	84	20.99	2.54	45.96
T5	376	374	75	20.14	1.83	61.06
T6	383	379	97	23.56	4.60	2.13
T7	376	375	94	22.99	4.42	5.96
T8	379	376	86	21.76	4.23	10.0
T9	379	376	85	20.18	4.09	12.98
LSD	8.119	4.78	3.81	1.379	0.155	-
CV(%)	5.90	6.73	10.36	7.57	2.38	-

Table 5.12b Yield and yield contributing parameters of Boro rice in the second year

Treatments	Tiller/ sq.m	Panicle/ sq.m	Grains/ panicle	1000 grain wt.(gm)	Grain yield (t/ha)	Reduction of yield (%)
T1	407	355	96.33	30.00	3.72	-
T2	395	348	95	29.33	3.48	6.45
T3	397	354	94	28.33	3.20	13.98
T4	407	376	92	28.67	3.05	18.01
T5	390	348	89	28.33	3.01	19.09
T6	408	355	96	29.67	3.64	2.15
T7	405	351	91	29.67	3.56	4.30
T8	386	348	86	28.67	3.40	8.60
T9	385	349	81	29.33	3.12	16.13
T10	293	390	90	28.67	3.34	10.22
T11	390	386	82	29.33	3.11	16.40
T12	390	386	79	28.33	2.75	26.08
T13	385	383	79	28.33	2.65	28.76
LSD	-	-	3.46	0.055	0.69	-
CV(%)	4.34	6.89	8.79	9.82	13.10	-

In the first year, plants got adequate water throughout the specified stage of water deficit except with a drastic water shortage amounting to entire stage deficit at the last irrigation of the stage. This phenomenon acted as a severe drought for the deficit treatments and caused sudden water stress in plants of those treatments resulting in greater yield loss. In the second year, the entire stage water deficit was split in proportion to crop ET required for each of the stage irrigation, thus, imposing smaller stress in plants. This resulted in lower rate of yield decrease in the second year. During the first year of study, the winter lasted for a shorter duration and the intensity of cold was much less. So, in first year, the yield of Boro rice was higher (4.7 t/ha). During the second year, the seedlings of Boro rice suffered from prolonged and intensive cold injury and the plant growth was hampered. So, the yield of rice (3.72 t/ha.) in the second year decreased to a considerable extent. The only exception with the treatment T_9 might be due to some sort of nutrient heterogeneity in the plots or some other reasons not known. But since soil nutrient status was not tested, the above assumption is optional.

5.3.1.8 Yield and Yield Contributing Parameters of Wheat

Like Boro rice, collected field data of wheat were also analyzed statistically. The results of analysis are enumerated in Tables 5.5a and 5.5b. The above tables show that unlike Boro rice wheat is more sensitive to water deficits in yield formation stage rather than vegetative stage. The yield for full irrigation was also found to show different trend with higher value (4.10 t/ha.) in the second year than that (3.03 t/ha) in the first year. Wheat is a winter loving crop and the prolonged winter in the second year helped wheat plants grow properly to produce higher yield than that of the first year. The experimental plots with ripened crops are shown in Figures 5.16a and 5.16b.

Table 5.13a Yield and yield contributing parameters of wheat in 2001

Treatments	Spike/ sq.m	Spike length (cm)	Grains/ spike	1000 grain wt.(gm)	Grain yield (t/ha)	Reduction of yield (%)
T1	222	9.00	40	45	3.03	-
T2	220	9.00	39	45	2.98	1.65
T3	211	8.67	39	42	2.91	3.96
T4	205	8.67	37	41	2.82	6.93
T5	210	8.33	38	42	2.74	9.57
T6	213	9.00	40	44	2.90	4.29
T7	212	8.67	38	40	2.75	9.24
T8	205	8.67	37	38	2.59	14.52
T9	202	8.67	36	39	2.40	20.79
LSD	-	-	-	4.008	0.1067	-
CV(%)	5.52	5.67	5.22	5.54	1.78	-

Table 5.13b Yield and yield contributing parameters of wheat in 2003

Treatments	Spike/ sq.m	Spike length (cm)	Grains/ spike	1000 grain wt.(gm)	Grain yield (t/ha)	Reduction of yield (%)
T1	289	10.27	44	35	4.10	-
T2	300	10.27	44	35	4.04	1.46
T3	341	10.30	43	35	3.96	3.42
T4	305	10.40	43	34	3.85	6.10
T5	309	10.10	42	33	3.75	8.54
T6	288	10.13	42	34	3.92	4.39
T7	308	10.07	42	34	3.73	9.02
T8	279	10.43	44	35	3.54	13.66
T9	302	10.00	40	34	3.32	19.02
T10	313	10.20	40	34	3.79	7.56
T11	300	10.17	41	34	3.61	11.95
T12	302	10.27	44	34	3.32	19.02
T13	315	10.20	40	34	3.13	23.66
LSD	49.35	0.615	5.897	8.156	0.433	-
CV(%)	9.63	3.57	8.31	14.18	6.91	-

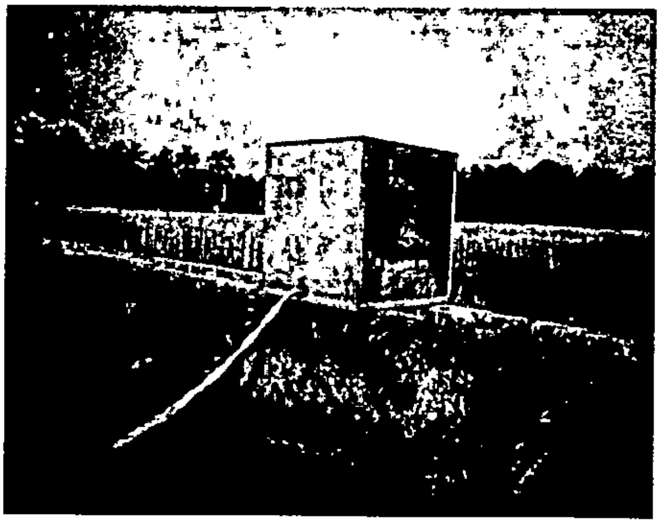


Figure 5.15a Water measuring tank showing delivery pipe

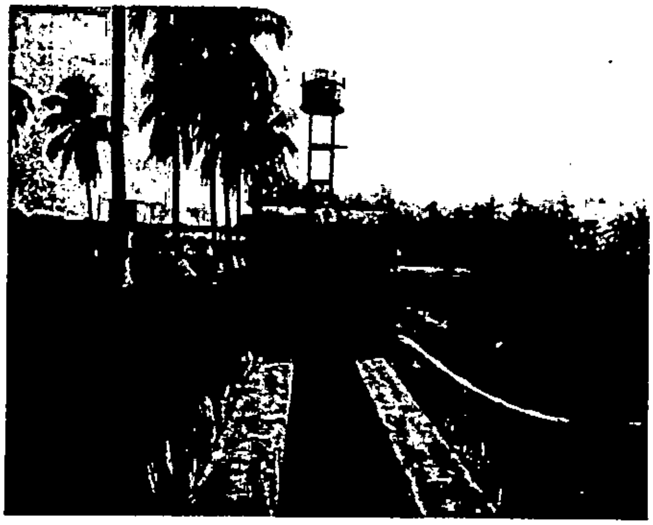


Figure 5.15b Water measuring tank showing graduated **tubing**

Figure 5.15 Water measuring tank placed beside the experimental site

5.3.1.9 Yield Response Factor

Using the known values of applied crop water (ET_a), potential crop water (ET_m), actual crop yield (Y_a) and potential crop yield (Y_m) in Equation 2.2, the yield response factors of Boro rice and wheat were calculated out for vegetative and yield formation stages. Applied crop water implies the water applied in mm as crop ET to different treatments in the specified growth stage and the potential crop water is the estimated maximum crop ET in mm for the crop irrigated. The actual crop yield and the potential crop yield are, respectively, the yields in t/ha obtained from field experiments against full and deficit irrigation. The yield response factors were obtained for both vegetative and yield formation stages of Boro rice and wheat. Detailed calculations for K_y of Boro rice are presented in Tables 5.14 a and 5.14b and those of wheat in Tables 5.15a and 5.15b.

Table 5.14a Yield response factor (K_y) of Boro rice in the first year

Treat-ments	Stage at which deficit was imposed	Crop ET met by irrigation (mm)	Poten-tial crop ET (mm)	Actual yield (t/ha.)	Yield obtained from full irrigation (t/ha)	Yield response factor (K_y)	Av. K_y Value for the stage
T2	Vegetative stage	165	183	4.00	4.70	1.51	1.53
T3		146	183	3.24		1.54	
T4		128	183	2.54		1.53	
T5		110	183	1.83		1.53	
T6	Yield formation stage	167	186	4.60		0.21	0.29
T7		149	186	4.42		0.30	
T8		130	186	4.23		0.33	
T9		112	186	4.09		0.33	

Table 5.14b Yield response factor (K_y) of Boro rice in the second year

Treat-ments	Stage at which deficit was imposed	Crop ET met by irrigation (mm)	Poten-tial crop ET (mm)	Actual yield (t/ha.)	Yield obtained from full irrigation (t/ha)	Yield response factor (K_y)	Av. K_y Value for the stage
T2		188	209	3.48		0.64	
T3	Vegetative	167	209	3.20		0.70	
T4	stage	146	209	3.05		0.60	0.60
T5		125	209	3.01	3.72	0.47	
T6		193	214	3.64		0.22	
T7	Yield	171	214	3.56		0.21	
T8	formation	150	214	3.40		0.29	0.28
T9	stage	128	214	3.12		0.40	

Table 5.15a Yield response factor (K_y) of wheat in the first year

Treat-ments	Stage at which deficit was imposed	Crop ET met by irrigation (mm)	Poten-tial crop ET (mm)	Actual yield (t/ha.)	Yield obtained from full irrigation (t/ha)	Yield response factor (K_y)	Av. K_y Value for the stage
T2		75	83	2.98		0.17	
T3	Vegetative	66	83	2.91		0.19	
T4	stage	58	83	2.82		0.23	0.21
T5		50	83	2.74	3.03	0.24	
T6		72	80	2.90		0.43	
T7	Yield	64	80	2.75		0.46	
T8	formation	56	80	2.59		0.48	0.47
T9	stage	48	80	2.40		0.52	

Table 5.15b Yield response factor (K_y) of wheat in the second year

Treat-ments	Stage at which deficit was imposed	Crop ET met by irrigation (mm)	Poten-tial crop ET (mm)	Actual yield (t/ha.)	Yield obtained from full irrigation (t/ha)	Yield response factor (K_y)	Av. K_y Value for the stage
T2		82	91	4.04		0.15	
T3	Vegetative	73	91	3.96		0.17	0.18
T4	stage	64	91	3.85		0.20	
T5		55	91	3.75	4.10	0.21	
T6		86	95	3.92		0.44	
T7	Yield	76	95	3.73		0.45	0.46
T8	formation	67	95	3.54		0.46	
T9	stage	57	95	3.32		0.48	

Yield RF for T10 to T13 ?

5.3.2 Estimation of Yield for Staggered Planting

Already the potential yield and yield response factors of Boro rice and wheat are obtained from two years study. This information along with the stage wise potential and deficit crop ET for staggered planting were incorporated in Equation 2.2 and the yields for different levels of water application were estimated. It should be mentioned here that the yield response factors of the second year study were only used to estimate yield for staggered planting. Since those for the first year were obtained under some very special conditions of deficit water application, these were not considered. Alongwith the experimental yields, farmers' yields were also considered for estimating deficit yields. The average yields of Boro rice (3.50 t/ha) and wheat (3.0 t/ha) in farmers' field were obtained from personal contact with the personnel of BRRI, BARI and BMDA. These average yields alongwith those obtained from full irrigation in the second year experiments were considered as the potential yields for estimating deficit yields. The detailed yield estimation is presented in Appendix XI.

5.3.3 Checking the Crop ET and Experimentally Determined K_y Values

During the second year of study, lysimeter tank with bottom end closed was set in Boro field. Seedlings of Boro rice was transplanted inside the tank to determine crop ET. Since the ET estimated for Boro rice was calculated from long term average ET_0 and locally determined K_c values, the two values were compared to see the variation in observed and estimated crop ET (Table 5.16). The estimated ET was found not to vary too much.

Table 5.16 Comparison between observed and estimated ET values of Boro rice

Duration	Estimated ET	Observed ET
February 7 to February 11	3.62	3.25
February 14 to February 18	3.82	3.50
February 20 to February 25	3.76	3.20
March 10 to March 14	5.36	5.00
March 16 to March 21	5.36	5.40
March 25 to March 29	5.36	5.50
April 06 to April 11	6.10	6.40
April 14 to April 18	6.10	6.75
April 20 to April 25	6.23	6.60
May 06 to May 09	5.22	5.67

For checking the yield response factor determined experimentally, the predicted yields were compared to those obtained by field experiments. The predicted yields were obtained by incorporating the locally determined K_y values instead of tabulated values into the Stewart's multiplicative crop production function. The yields were calculated out for irrigation up to 10, 20, 30 and 40% deficit levels at vegetative and yield formation stages. The checking was done only for the K_y values determined in the second year of study because the treatments having double stage deficit were not included in the first year. The comparison between actual yields and the predicted yields are presented in Table 5.17. It appears from the table that all the estimated yields marginally differ from the respective actual yields. This indicates that, the values of yield response factors obtained from field experiments are quite reasonable.

Table 5.17 Checking K_y values by comparing actual and predicted yields

Water application level	Stages of water deficit*	Yields of Boro rice, t/ha		Yields of wheat, t/ha	
		Actual	Predicted	Actual	Predicted
10% deficit level	Veg. and Y.form.	3.34	3.40	3.79	3.85
20% deficit level	Veg. and Y.form.	3.11	3.09	3.64	3.59
30% deficit level	Veg. and Y.form.	2.75	2.79	3.32	3.35
40% deficit level	Veg. and Y.form.	2.65	2.51	3.13	3.11

* Veg. is used for Vegetative stage and Y.form is used for Yield formation stage

5.3.4 Profit Estimation for Staggered Planting

Profit from estimated yield was calculated based on information available on crop production inputs and outputs obtained from practical field observation, available reports (BRRI, 1999; BARI, 2000 and BARI, 2001) and consultation with the BRRI and BARI scientists. Among the inputs, land preparation, weeding, fertilization, pest control, irrigation, harvesting, carrying, threshing and cleaning were considered for both Boro rice and wheat. However, for Boro rice, additional operations like seedbed preparation and transplanting were considered in the input items. In output, only the price of main and bi-products were considered.

The parameters like cost of labour for land preparation, seeds, seedling raise, manure and fertilizers and pesticides were considered same for all the selected levels of water application. Labour requirement for seedbed preparation and seedling transplanting of Boro rice were also considered same for all the water application levels. But, some operations like weeding, harvesting, carrying, threshing and cleaning vary with the crop yield. So, these were considered variable as per yields. The cost of irrigation included both water and labour costs. The unit cost of water was obtained from BMDA as Tk.4000/= per ha-m. The labour requirement for irrigation was obtained from the survey conducted among the farmers of the study area. The total water cost per hectare was calculated for a certain water application level based on the gross water applied (ha-m) for that particular application level. The unit labour cost obtained from field survey was used in the study.

The labour requirement per hectare of land for transplanting, weeding, harvesting and carrying of Boro rice were obtained from BRRI Annual Report (1999) and those for wheat from BARI Annual Report (2000 and 2001).

The gross return of the irrigated crop was obtained from the values of main product and the bi-product. For rice, the bi-product was considered 1.16 times the main product (BRRI, 1999) and that for wheat 1.03 times the main product (BARI, 2000). However, depending on situations, this might vary to some extent.

All the inputs and outputs were considered on a hectare basis. Finally, the net return or the profit per hectare was obtained from the difference between the gross return and the total cost of production. Detailed calculations for profit realization from the predicted yields of Boro rice and wheat are presented in Appendices XII and XIII, respectively.

5.4 Land Area Co-efficient

As mentioned in Chapter 4, land area co-efficient (β) depends on the area covered by plants. If plants cover the entire area, the value of land area coefficient becomes 1.0 and if no crop is in the field, the value is 0. Further, if the plants cover the field partially, the value is a fraction. The monthwise land area co-efficients of Boro rice and wheat were determined using the staggered Figures 5.5 to 5.8. Planting of wheat effectively starts on 20 November and continues up to 10 December requiring 20 days for plantation.

During the first 10 days the plantation covers around 70% of the total area and during the second 10 days it covers around 30%. The crop takes 10 days to cover 0% to 70% of the area in November. Thus, the average area covered by plants in November becomes 35%. So, the value of β for the month is 0.35. Now, December has got 31 days of which the first day starts with 70% coverage and ends up on 10th day with 100% coverage, the average being 85% coverage. The remaining days of the month have area coverage of 100% each. So, the average β value for December becomes 95% i.e., average of 85, 100 and 100 percent coverage. In the same way, β values of wheat for other months were calculated. A similar procedure was followed for the determination of land area coefficient of Boro rice. It is important to note that β values are independent of water application levels, sequence of water application and probability of rainfall availability. The values are presented in Table 5.17.

Table 5.18 Land area coefficient of Boro rice and wheat

Month	Boro rice	Wheat
January	0.47	1.00
February	1.00	1.00
March	1.00	0.60
April	0.97	0.00
May	0.35	0.00
November	0.00	0.35
December	0.00	0.95

5.5 Total, Maximum and Minimum Land Area for Irrigation

As per information received from BMDA, the available land area for irrigation is about 90660 ha. in four selected thanas. With 1463 DTWs, presently 31449 ha of Boro rice and 3613 ha of wheat are being irrigated in these thanas. Table 5.18 presents available land area, maximum allowable area and minimum required area of Boro rice and wheat for irrigation. The model was solved for maximum available land area of 90660 ha for irrigation. The lower area limits of Boro rice and wheat were set to 31449 ha and 3613 ha, respectively. The upper limits of the crops were considered 50000 ha for Boro rice and 60000 ha for wheat based on speculations. The upper limit of wheat was set to higher value because the crop needs much smaller quantity of water than rice for the same command area and also the realization of profit per hectare from wheat is quite substantial.

Table 5.19 Available, maximum and minimum land area for irrigation

Month	Total land for irrigation, ha	Area under crops, ha			
		Boro rice		Wheat	
		Maximum	Minimum	Maximum	Minimum
November	90660	50000	31449	60000	3613
December	90660	50000	31449	60000	3613
January	90660	50000	31449	60000	3613
February	90660	50000	31449	60000	3613
March	90660	50000	31449	60000	3613
April	90660	50000	31449	60000	3613
May	90660	50000	31449	60000	3613

CHAPTER VI

MODEL SOLUTION AND RESULTS AND DISCUSSION

In this chapter the linear optimization model formulated in Chapter 4 is solved using the parameters determined in Chapter 5 and results are discussed herein. But before that a brief discussion on the acceptability of some estimated parameters like long term average reference evapotranspiration, yield response factors, relationship between relative yield and ET deficits, Boro field percolation rate, profit per unit area and seasonal profit for various water availability are made.

6.1 Comparison between Estimated Long-term and Specific Year ET_0 Values

As mentioned in Chapter 5, eighteen years monthly ET_0 were estimated from temperature, humidity, sunshine hour and wind speed wherefrom the long-term monthly average ET_0 were calculated for the study region. To predict crop evapotranspiration using these values more accurately, it is desirable that the estimated ET_0 of a specific study year do not deviate significantly from the estimated long-term average value. In order to have a check between the long-term and the specific year values of ET_0 of the study periods (2000-2001 and 2002-2003), a graphical comparison was made (Figure 6.1). From the figure it appears that no abrupt change in ET_0 occurred for the months of November to May between long-term and specific year values. In spite of reduced temperature during the second year, the ET_0 values did not vary so much. This might be due to the fact that ET_0 is not a function of temperature alone, rather, it also depends on humidity, wind speed and sun shine hour for a particular location. Thus, the use of long term average values of monthly reference evapotranspiration was quite reasonable to predict the potential crop evapotranspiration of Boro rice and wheat for the study location.

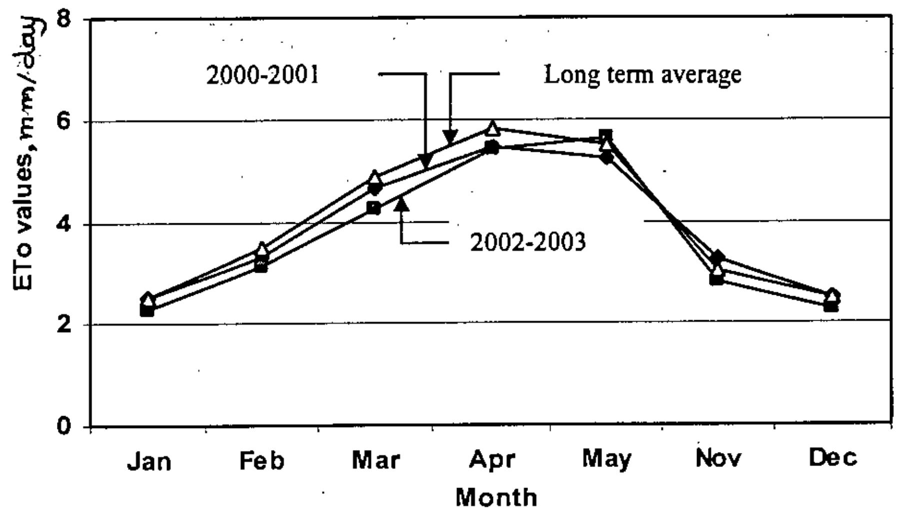


Figure 6.1 Comparison among ETo of 2000-2001, 2002-2003 and long term average values

6.2 Effect of Deficit Irrigation on K_y Values of Boro Rice

From Table 6.1, it is apparent that the values of K_y for a specific crop season maintain, more or less, a definite trend with the level of water application. A little deviation was found at vegetative stage during the second year of study. The value of K_y for 40% deficit irrigation is found somewhat less than what it could be expected for that particular deficit level. This might be due to the residual effect of soil nutrient on growth and yield of the crop. The values of K_y determined experimentally in the first year are found somewhat higher than those obtained in the second year for the same growth stage. This was mainly due to difference in the way of deficit irrigation. During the first year study, the entire stage water deficit was imposed at the last irrigation of the stage while full crop water requirement was met in other irrigations of the stage. Thus, plants received adequate moisture from full irrigations in the first and middle parts of the stage but faced acute shortage of water in the last part of the stage. This phenomenon acted as severe drought for the deficit treatments and resulted in greater yield loss (Table 6.3). Eventually, this drought prone situation led to higher values of yield response factors in the first year. In the second year, the entire amount of stage water deficit was split in proportion to crop ET, thus, imposing smaller stress in plants. So the rate of decrease in yield between full and deficit irrigation treatments was much less. This caused difference in K_y values between the first and second year studies. The higher value of K_y indicates greater yield loss. The K_y values at vegetative stage of Boro rice were found higher than those of yield formation stage in both the years indicating that vegetative stage was more sensitive to water deficit than yield formation stage.

Table 6.1 Yield response factors of Boro rice determined by field experiments

Stage of water deficit	Study year	Treatments	Yield response factor, K_y	Average K_y values for the stage	FAO recommended values of K_y
Vegetative stage	2000-2001	T_2	1.51	1.53	1.14
		T_3	1.54		
		T_4	1.53		
		T_5	1.53		
Yield formation stage		T_2	0.21	0.29	0.26
		T_3	0.30		
		T_4	0.33		
		T_5	0.33		
Vegetative stage	2002-2003	T_2	0.64	0.60	1.14
		T_3	0.70		
		T_4	0.60		
		T_5	0.47		
Yield formation stage		T_2	0.22	0.28	0.26
		T_3	0.21		
		T_4	0.29		
		T_5	0.40		

6.3 Effect of Deficit Irrigation and Sequence on K_y Values of Wheat

In two years study, the K_y values of wheat at vegetative and yield formation stages were found in sequence with the design deficit levels of water application. K_y increased with the increase in deficit level as desired (Table 6.2). At vegetative stage, the values were smaller than those at yield formation stage indicating the vegetative stage less sensitive to water deficit. Further, all that discussed about the sequence of irrigation for Boro rice is also applicable to wheat. The only exception is the smaller rate of yield reduction in wheat (Table 6.3) for deficit irrigation. The difference in K_y values of a particular stage was not found so significant in wheat. But in Boro rice, the difference was prominent. This indicates that wheat was not affected so largely by the way of water application.

Table 6.2 Yield response factors of wheat determined by field experiments

Stage of water deficit	Study year	Treatments	Yield response factor, K_y	Average K_y values for the stage	FAO recommended values of K_y
Vegetative stage	2000-2001	T_2	0.17	0.21	0.20
		T_3	0.19		
		T_4	0.23		
		T_5	0.24		
Yield formation stage		T_2	0.43	0.47	0.50
		T_3	0.46		
		T_4	0.48		
		T_5	0.52		
Vegetative stage	2002-2003	T_2	0.15	0.18	0.20
		T_3	0.17		
		T_4	0.20		
		T_5	0.21		
Yield formation stage		T_2	0.44	0.46	0.50
		T_3	0.45		
		T_4	0.46		
		T_5	0.48		

Table 6.3 Yield reduction rate of deficit irrigation over full irrigation

Treatment	Boro rice		Wheat	
	2000-2001	2002-2003	2000-2001	2002-2003
T_1	-	-	-	-
T_2	14.89	6.45	1.65	1.46
T_3	31.06	13.98	3.96	3.42
T_4	45.96	18.01	6.93	6.10
T_5	61.06	19.09	9.57	8.54
T_6	2.13	2.15	4.29	4.39
T_7	5.96	4.30	9.24	9.02
T_8	10.0	8.60	14.52	13.66
T_9	12.98	16.13	20.79	19.02
T_{10}	-	10.22	-	7.56
T_{11}	-	16.40	-	11.95
T_{12}	-	26.08	-	19.02
T_{13}	-	28.76	-	23.66

6.4 Comparison between Experimentally Determined and Standard Values of Yield Response Factors

As seen from the FAO recommended values (Doorenbos and Kassam, 1979), the yield response factors of Boro rice at vegetative and yield formation stages are, 1.14 and 0.26, respectively. The experimentally determined values when compared to these standard values, it was found that the first year value of K_y at vegetative stage (1.53) was larger while the second year value (0.60) for the same stage was smaller than the standard value (1.14). This was, to a large extent, due to the difference in the way of irrigating the crops. In this study, the K_y values were obtained under field condition whereas the standard values were determined under controlled conditions like lysimeter study. This might have caused the difference between these two values. However, for better prediction of yield, the location specific values are always preferable to standard values. The experimentally determined K_y values at yield formation stage were found 0.29 in the first year and 0.28 in the second year and did not vary significantly from the standard value (0.26).

The values of yield response factors both at vegetative and yield formation stages of wheat obtained during the first and second years of study did not show much difference from the standard values (Table 6.2). This indicates that wheat is neither so sensitive to the levels of deficit irrigation nor the growth stages selected for this study. Unlike Boro rice, the vegetative stage of wheat was found more responsive to water deficit than yield formation stage.

6.5 Relationship between Relative Yield Deficit to Relative Evapotranspiration Deficit

Researchers (De Wit, 1958, Stewart et al., 1977, Doorenbos and Kassam, 1979) have shown a linear relationship between the relative yield deficit to relative ET deficit. In this study, attempt was made to relate the relative yield deficit ($1-Y_a/Y_m$) to relative evapotranspiration deficit ($1-ET_a/ET_m$) to observe the linearity in the relationship. Figures 6.2a to 6.2h present these relationships for vegetative and yield formation stages of the selected crops. All the relationships were found very much linear (r^2 values ranged from 0.9504 to 1.0) indicating a very good harmony between applied ET and observed yield.

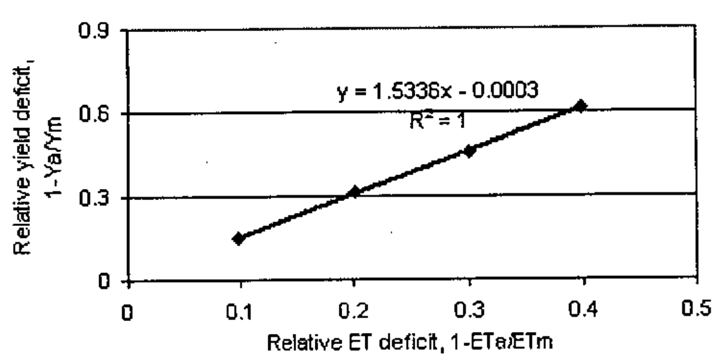


Figure 6.2a Relative yield deficit to relative ET deficit of Bororice for vegetative stage in 2000-2001

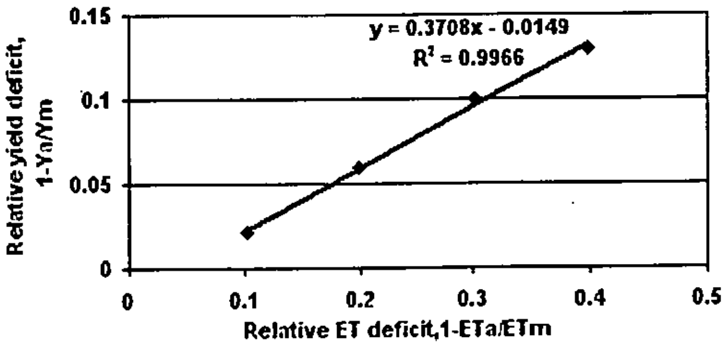


Figure 6.2b Relative yield deficit to relative ET deficit of Boro rice for yield formation stage in 2000-2001

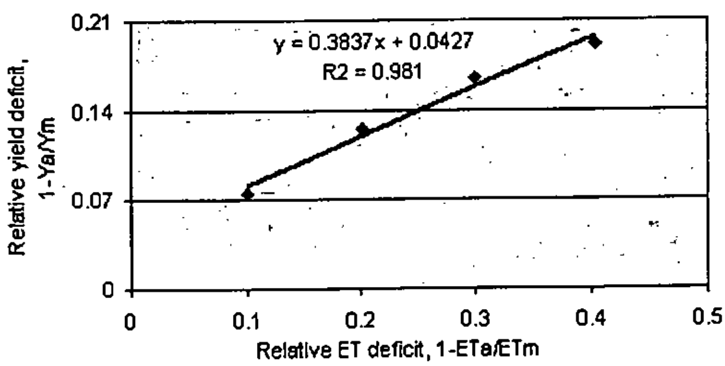


Figure 6.2c Relative yield deficit to relative ET deficit of Boro rice for vegetative stage in 2002-2003

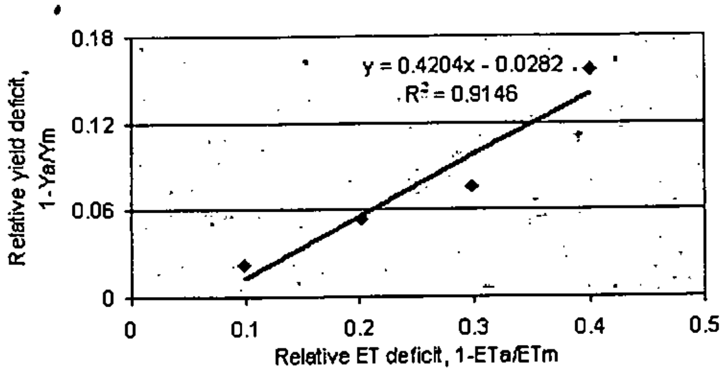


Figure 6.2d Relative yield deficit to relative ET deficit of Boro rice for yield formation stage in 2002-2003

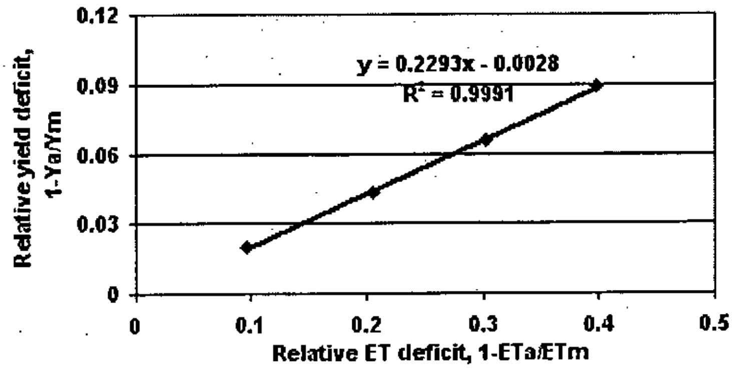


Figure 6.2e Relative yield deficit to relative ET deficit of wheat for vegetative stage in 2000-2001

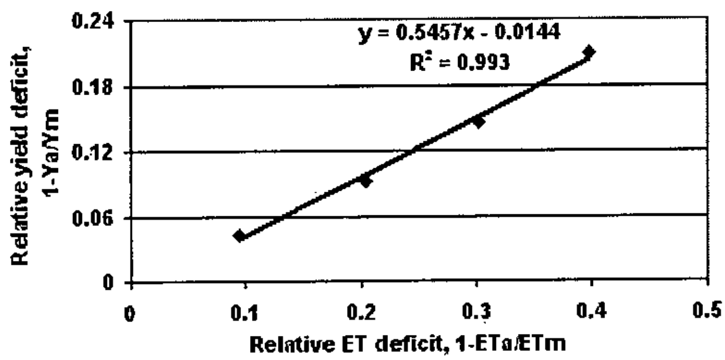


Figure 6.2f Relative yield deficit to relative ET deficit of wheat for yield formation stage in 2000-2001

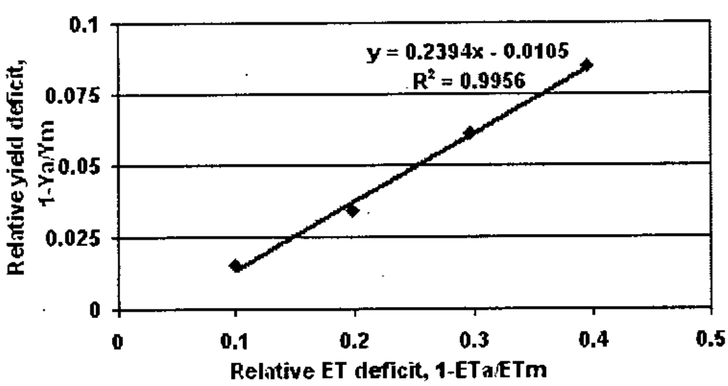


Figure 6.2g Relative yield deficit to relative ET deficit of wheat in vegetative stage in 2002-2003

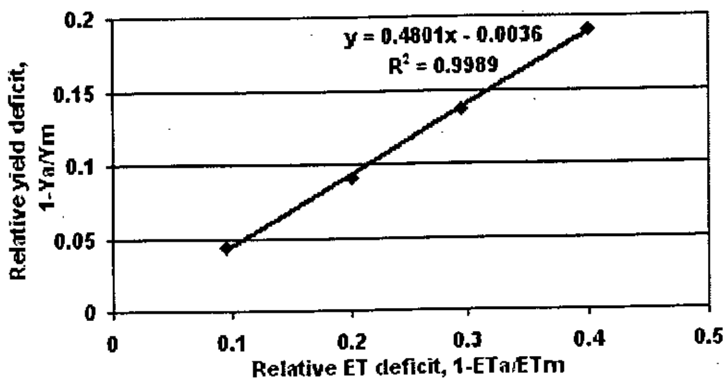


Figure 6.2h Relative yield deficit to relative ET deficit of wheat for yield formation stage in 2002-2003

6.6 Boro Field Percolation

The major factor that controls percolation is the soil texture. Other factors influencing percolation are soil compaction, characteristics of underlying soil stratum, method of ploughing etc. Under this study, the soil texture of the experimental field was clay loam. The land was used to plough by power tillers and tractors that created some sort of plow-pan to a depth of around 20 cm from the soil surface. The percolation determined experimentally in Boro field soil during the first and second years of study were, respectively, 1.99 mm/day and 2.04 mm/day. Howard Hmphreys (1997) used 2.0 mm/day in his model for similar soil. Mainuddin (1998) used 1.0 mm/day for the same soil texture to run his model for maximizing profit and irrigated area. Smith (1992) suggested an average of 1.5 mm/day of percolation for rice field. It has to be mentioned that the bare soil percolation during the first and second year study were 1.96 and 1.94 mm/day, respectively and there was little difference between the bare soil and Boro field percolation. Thus, in estimating Boro field irrigation water, use of bare soil percolation was quite justifiable. Further, use of Boro field percolation in estimating irrigation requirement of Boro rice for staggered plantation was equally feasible.

However, along with percolation of 2.0 mm/day, seepage loss of 2.2 mm/day was also considered for rice irrigation. Thus, to estimate monthly irrigation requirement of rice 4.2 mm/day seepage and percolation was used. Further, it was learnt by personal contract that Mr. M.A. Rashid, a scientist of BRRI has measured seepage and percolation in the Barind area for his Ph.D. study. From his study, also 4.2 mm/day seepage and percolation was determined for Boro rice field.

6.7 Model Solution

The formulated model was solved using the linear programming software package LINDO (Linear, interactive and discrete optimizer), version, 6.01 (Schearge, 1997). LINDO can solve upto 50 constraints, 100 variables and 16000 non-zeros. The formulated model of this study has 30 variables and 19 constraints including 7 water availability constraints each for a month of the cropping season from November to May, 7 land area availability constraints each for a month of the cropping season, 2 constraints for maximum allowable area for the selected crops, 2 constraints for minimum required area under the crops and one for maximum area available for irrigation.

In the solution of the model, water availability at 100, 80 and 60% design capacity of the operating deep tubewells, rainfall amounts for 20, 50 and 80 percent dependability and five levels of water application viz. 10, 20, 30, 40 and 100 % of crop water requirement were used. Crop yields of Boro rice and wheat from second year experiments and the average farmers' yields of the crops were considered to solve the model. The decision variables, objective function coefficients and monthly irrigation water requirements are presented in Appendix XIV.

In the following sections seasonal profit seasonal profit under different crop mix, rainfall dependability, irrigation water availability and levels of water application are discussed. In addition, a comparison of irrigated area and seasonal profit considering farmers' present practice and proposed deficit irrigation, farmers' benefit from deficit irrigation and selection of suitable irrigation level for profit maximization are made in the following sections.

6.7.1 Seasonal Profit under Unrestricted and Restricted Area limits

The formulated model was solved for maximum profit under water availability of full, 80% and 60% of design deep tubewell capacity considering 16 operating hours per day. When the model was run without any restriction from maximum and minimum area, the model gave feasible solution for all the levels of water availability. With the maximum and minimum area limits of Boro rice and wheat, the model gave feasible solution for full and 80% design capacity of the deep tubewells. But at 60% design capacity, the solution was infeasible for both experimental and farmers' yields.

Tables 6.4a and 6.4b present solution with no restriction on maximum and minimum areas under the selected crops whereas Tables 6.5a and 6.5b present solutions with restrictions from maximum and minimum areas under the crops.

Seasonal Profit under Unrestricted Situation

From Tables 6.4a and 6.4b it is apparent that under unrestricted and farmers' yield condition wheat is found in solution for all combinations of water availability and rainfall dependability except for a few acreages of rice at 20 and 80% dependability of rainfall. Under experimental yield condition, wheat appeared in solution with deficit irrigation at water availability of 60 and 80% design supply and 50 to 80% dependability of rainfall but no deficit irrigation is found in solution under farmers' yield condition.

The seasonal profit as obtained from experimental yields is much higher than that of farmers' yields. This was due to higher yield per hectare of both Boro rice and wheat in experimental condition which, eventually, estimated higher profit per hectare as well.

Table 6.4a Area under Boro rice and wheat and seasonal profit obtained using experimental yields considering no area limit under the crops

DTW water availa-bility	Rainfall dependa-bility (%)	Area under selected crops (ha)									Total area under crops (ha).	Profit (10^6 Taka)
		Boro rice				Wheat						
		Full irrigation	10% deficit	20% deficit	30% deficit	Full irrigation	10% deficit	20% deficit	30% deficit	40% deficit		
Full design supply	80	-	-	-	-	90660	-	-	-	-	90660	1295
	50	-	-	-	-	90660	-	-	-	-	90660	1290
	20	-	-	-	-	87288	-	-	-	-	87288	1239
80% design supply	80	-	-	-	-	56297	-	-	-	34363	90660	1073
	50	-	-	-	-	53951	-	-	-	36709	90660	1050
	20	-	-	-	-	69830	-	-	-	-	69830	990
60% design supply	80	-	-	-	-	17587	-	-	-	73073	90660	822
	50	-	-	-	-	16854	-	-	-	73806	90660	812
	20	-	-	-	-	52372	-	-	-	-	52372	743

Table 6.4b Area under Boro rice and wheat and seasonal profit obtained using farmers' yields considering no area limit under the crops

DTW water availa-bility	Rainfall dependa-bility (%)	Area under selected crops (ha)									Total area under crops (ha).	Profit (10^6 Taka)
		Boro rice				Wheat						
		Full irrigation	10% deficit	20% deficit	30% deficit	Full irrigation	10% deficit	20% deficit	30% deficit	40% deficit		
Full design supply	80	1685	-	-	-	88975	-	-	-	-	90660	540
	50	157	-	-	-	90503	-	-	-	-	90660	531
	20	-	-	-	-	87288	-	-	-	-	87288	506
80% design supply	80	-	-	-	-	74194	-	-	-	-	74194	439
	50	-	-	-	-	72680	-	-	-	-	72680	426
	20	-	-	-	-	69830	-	-	-	-	69830	413
60% design supply	80	-	-	-	-	55646	-	-	-	-	55646	329
	50	-	-	-	-	54510	-	-	-	-	54510	319
	20	-	-	-	-	52372	-	-	-	-	52372	304

Table 6.5a Area under Boro rice and wheat and seasonal profit obtained using experimental yields considering maximum and minimum area limit under the crops

DTW water availa-bility	Rainfall dependa-bility (%)	Area under selected crops (ha)									Total area under crops (ha).	Profit (10^6 Taka)
		Boro rice				Wheat						
		Full irrigation	10% deficit	20% deficit	30% deficit	Full irrigation	10% deficit	20% deficit	30% deficit	40% deficit		
Full design supply	80	31449	-	-	-	-	-	-	-	43046	74495	561
	50	31449	-	-	-	-	-	-	-	41788	73237	543
	20	27652	-	-	3797	20878	-	-	-	-	52325	486
80% design supply	80	-	-	13763	17686	-	-	-	-	24676	56125	256
	50	-	-	-	31449	-	-	-	-	27076	58525	237
	20	-	-	-	31449	-	-	-	16148	-	47597	170
60% design supply	80*	-	-	-	-	-	-	-	-	-	-	-
	50*	-	-	-	-	-	-	-	-	-	-	-
	20*	-	-	-	-	-	-	-	-	-	-	-

* Solution is infeasible

Table 6.5b Area under Boro rice and wheat and seasonal profit obtained using farmers' yields considering maximum and minimum area limit under the crops

DTW water availa-bility	Rainfall dependa-bility (%)	Area under selected crops (ha)									Total area under crops (ha).	Profit (10^6 Taka)
		Boro rice				Wheat						
		Full irrigation	10% deficit	20% deficit	30% deficit	Full irrigation	10% deficit	20% deficit	30% deficit	40% deficit		
Full design supply	80	31449	-	-	-	22420	-	-	-	-	77056	393
	50	31449	-	-	-	22420	-	-	-	-	53869	393
	20	20060	-	-	21952	3613	-	-	-	-	52375	384
80% design supply	80	-	16627	-	14822	3613	-	-	-	-	35062	150
	50	-	16627	-	14822	3613	-	-	-	-	35062	150
	20	9497	-	-	21952	3613	-	-	-	-	35062	104
60% design supply	80*	-	-	-	-	-	-	-	-	-	-	-
	50*	-	-	-	-	-	-	-	-	-	-	-
	20*	-	-	-	-	-	-	-	-	-	-	-

* Solution is infeasible

As the yield of wheat is quite substantial and its irrigation requirement is much less than that of rice, the Boro rice could not compete with wheat to appear in solution when the restriction was withdrawn. From the above tables the seasonal profit from experimental and farmers' yield were found to vary from Tk.743 x 10^6 to Tk.1295 x 10^6 and Tk.304 x 10^6 to Tk.540 x 10^6, respectively. This represents an increase of profit by about 140 to 144% over farmers' yield.

Seasonal Profit under Restricted Situation

As seen from Tables 6.5a and 6.5b, under restricted situation, both Boro rice and wheat are found to appear in solution with deficit irrigation under experimental and farmers' yield conditions. When water availability is the maximum, both Boro rice and wheat appear in solution with full irrigation. But as it reduces to full supply and 20% rainfall dependability level, Boro rice is found in solution with deficit irrigation for experimental and farmers' yield conditions. This is quite similar to that the researchers have found in water scarcity situation (Barret and Skogerboe, 1980; Khepar and Chaturvedi, 1982 and Onta et al., 1995). With reduction in water availability to 80% design supply, Boro takes up 30% deficit level and wheat, 30 to 40% deficit levels for experimental yield. However, under farmers' yield condition wheat does not take deficit irrigation. Also the area coverage is less in farmers' yield condition compared to that in experimental yield condition.

Like unrestricted situation, the seasonal profit as obtained from experimental yield is much higher than that of farmers' yield in restricted situation. Under experimental yield condition, the profit earned was Tk. 170 x 10^6 to Tk. 561 x 10^6 and under farmers' yield condition, it was Tk. 104 x 10^6 to Tk. 393 x 10^6. This represents an increase of profit by about 43 to 64% over farmers' yield.

No feasible solution was obtained under restricted situation for water availability of 60% of the design supply. This was due to the fact that the amount of water allocated

6.7.2 Effect of Rainfall on Seasonal Profit

As seen from Tables 6.4a, 6.4b, 6.5a and 6.5b, the rainfall has a tremendous effect on seasonal profit. Since rain water is obtained free of cost, increased quantity of rainfall decreases the irrigation cost thereby increasing the maximum profit. Thus, the seasonal profit becomes the least in dry years for the same quantity of irrigation water availability. In wet years, rainfall is obtained in greater quantity compared to that in normal or dry years and hence, the maximum profit is obtained in wet years.

6.7.3 Comparison of Seasonal Profit under Experimental and Farmers' Yields

Table 6.6a and 6.6b present the seasonal profit realized from experimental and farmers' yield conditions for unrestricted and restricted crop area of Boro rice and wheat, respectively. From Table 6.6a, it is seen that the increase in profit under experimental yield over that of farmers' yield is the maximum (Tk. 1295 x 10^6) for full supply and 80% dependability of rainfall and it is the minimum (Tk. 439 x 10^6) for 60% design supply and 20% rainfall dependability.

Table 6.6a Increased profit under no restriction from experimental and farmers' yields

Available water	Rainfall dependability (%)	Profit (10^6 Taka)			Percent increase of profit
		Experimental yield	Farmers' yield	Increase of profit over farmers' yield	
Full design supply	80	1295	540	755	140
	50	1290	531	759	143
	20	1239	506	733	145
80% design supply	80	1073	439	634	144
	50	1050	429	621	145
	20	990	413	577	140
60% design supply	80	822	329	493	140
	50	812	319	493	155
	20	743	304	439	144

As water availability increases, the irrigated area goes up for both the conditions and since the profit per hectare of the selected crops in experimental yield is higher, the difference also becomes higher.

However, the difference in profit is much lower under restricted conditions, the highest being Tk.168 x 10^6 and the lowest being only Tk. 66 x 10^6. Since no area could be irrigated under water availability of 60% design capacity, no profit could be earned from any of the experimental or farmers' yield conditions for this water supply situation. The reason for low seasonal profit was the limitation from minimum Boro area irrigation as the profit per hectare of Boro rice was much less than that of wheat in the experimental yield condition. Further, after irrigating minimum Boro area there is left inadequate water to bring more area under wheat.

Table 6.6b Incremental profit with restriction from experimental and farmers' yields

Available water	Rainfall dependability (%)	Profit (10^6 Taka)			Percent increase of profit
		Experimental yield	Farmers' yield	Increase of profit over farmers' yield	
Full design supply	80	561	393	168	43
	50	543	393	150	38
	20	486	384	102	27
80% design supply	80	256	150	106	71
	50	237	150	87	58
	20	170	104	66	63
60% design supply	80	-	-	-	-
	50	-	-	-	-
	20	-	-	-	-

6.7.4 Benefiting Additional Farmers by Deficit Irrigation

The present irrigated area of Boro rice is 31449 ha in the project area whereas in unrestricted situation it is almost nil. This will discourage the Boro growers of the study area and it might be very much difficult for them to accept it. Under restricted situation and farmers' yield condition farmers can irrigate marginally the area they are at present irrigating with 80% water availability. But they may irrigate about 7000 to 32000 ha additional area using full design supply. On the other hand, under experimental yield condition they may irrigate about 2500 to 11000 ha additional area for 80% of full supply and about 7000 to 30000 ha of additional area for full supply of water availability. It is most judicious to consider 80% of the full supply of water availability as the pump efficiency gradually decreases with time thereby reducing the amount of pumping water. But to realize the full potential of deficit irrigation, the farmers' have to take adequate measures for increasing the crop yields through appropriate management of irrigation, fertilizer and other intercultural operations.

6.7.5 Selection of the Suitable Irrigation Practice

Referring to above discussions it may be conceived that maximum seasonal profit could be earned from no restriction situation under experimental yield condition. Although, such irrigation practice produces the highest seasonal profit, it does not, in reality, reflect the choice of the farmers of the study area because, in such irrigation practice, the area of Boro rice practically becomes nil. Under restricted situation, profit realization is higher with experimental yield condition over that of farmers' yield condition. In this situation, the Boro area is kept close to the present practice and remaining area is allocated for wheat. Again, the availability of pumped water controls the seasonal profit to a large extent. It is reasonable to assume pumped water availability at 80% design discharge of tubewells. This practice will not only provide adequate profit but also will enhance diversified cropping. By practicing diversified cropping, the excessive withdrawal of groundwater could be protected by proper utilization of this valuable resource. Thus, practicing deficit irrigation, not only the existing farmers of the project will be benefited but also a considerable number of additional farmers will be benefited from BMDA deep tubewells. So, in all respect, this irrigation situation may be desirable for the study area.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

In this study, a procedure has been developed for irrigation planning of Boro rice and wheat under deficit water supply. A linear optimization model was formulated to compute profit from cropping activity under different levels of deficit irrigation. This concept is quite general and can effectively be used for identifying alternate irrigation application levels to maximize seasonal profit. In the present study, the formulated model was solved for irrigable area under available groundwater from deep tubewells operated by BMDA.

It is apparent from model solution that deficit irrigation, applied in proportion to each of the stage irrigation, is profitable for the study area. Under experimental yield condition, a maximum seasonal profit of Tk.543 x 10^6 which is 38% higher than that of farmers' yield could be realized from full deep tubewell supply in normal rainfall year. Even at 80% availability of irrigation water and 50% dependability of rainfall, the seasonal profit may be Tk. 237 x 10^6 which is 58% higher than that of farmers' yield. At 80% availability of water, 31449 ha Boro rice and 27076 ha wheat can be irrigated using deficit irrigation. Such irrigation practices enable the deep tubewell owners to bring about 28000 ha additional area under full supply and about 13500 ha additional area under 80% full water supply in the study area. The seasonal profit was found to vary with the availability of irrigation water and rainfall availability. Irrigation without restriction on maximum and minimum land area reduced Boro rice area sharply with decreased water supply and lower rainfall dependability. The minimum area of Boro rice should be around the present practice of 31449 ha of land. But in no bound situation it goes down to nil allowing only wheat in the solution. Taking into consideration the farmers' choice for growing Boro rice, such irrigation practice is not advocated at this stage of crop cultivation in Barind area. Further, the benchmark survey conducted in the study area, it was learnt that a large number of farmers are facing negative profit from irrigating Boro rice. Practice of deficit irrigation may be an option for them. Irrigating more wheat area and substantial Boro rice area by deficit irrigation, they can, now be benefited adequately. Hopefully, wheat cultivation is gradually increasing in the study area and the farmers are being interested in diversified cropping as was learnt from BMDA officials and field visits. So, in irrigation planning for further development of cropping activity in the study area, deficit irrigation may be considered for Boro rice and wheat in order to increase irrigated area and to protect excessive withdrawal of groundwater.

For the materialization of the above irrigation practice, the BMDA authority should come forward to take initiative for rotational irrigation system in which a group of farmers will be supplied with full irrigation water in one time and specified deficit irrigation water at other time. This practice will help care crop diversification and safe withdrawal of groundwater in addition to benefiting a large number of additional farmers.

7.2 Recommendations

During this research, efforts were made to incorporate possible important activities within the available facilities but still there is scope for further improvement. Under this perspective, the following recommendations are made.

i) In this study, deficit irrigation upto 40% crop evapotranspiration has been found profitable for wheat. So, higher deficit levels for wheat may be studied to see their effects on yield and profit;

ii) Considerations for labour, capital and soil suitability constraints should be incorporated in the model;

iii) The contribution of percolation water to crop ET for deficit irrigations should be determined by field experiments;

iv) In the present study, all lands were considered equally suitable for Boro rice and wheat. In future studies, land suitability should be considered and soil nutrient status should be monitored before planting crops;

v) Further study is also recommended for simulation of the system for management strategy derived from optimization model taking the groundwater as a distributed parameter system

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APPENDICES

Appendix I Eighteen years monthly reference evapotranspiration of Rajshahi region

Year: 1982

Climatic parameters	Months											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.temp. (deg.celsius)	26	26.9	30.6	35.3	37.3	33.3	34.1	32	33.8	32.6	28.3	24
Min.temp. (deg.celsius)	11	12.2	17.1	22.3	25.1	25.5	26.7	26	26.1	22.9	16.5	11
Air humidity (percentage)	69.4	65.75	71.05	68.3	72.75	80.75	81.4	84.4	82.65	75.6	72	77.5
Wind speed (Km/day)	111	93	116	187	200	200	214	249	147	129	133	138
Sun. hours (hrs./day)	8.3	7.5	7.6	8.3	9.3	4.7	5.3	4.9	6.43	8.29	7.2	7.39
ETo (mm/day)	2.79	3.13	4.11	5.78	6.43	4.45	4.68	4.15	4.27	4.10	3.07	2.43

Year: 1983

Climatic parameters	Months											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.temp. (deg.celsius)	24.1	27.1	33.1	34	34	35	33.4	32.5	32.7	31.2	29.5	25.5
Min.temp. (deg.celsius)	12.6	10.6	16	20.5	23.3	25.9	26.3	25.6	25.9	23	17.4	11.6
Air humidity (percentage)	73.5	68	62	65	81	82.5	86	86.5	82	85.5	74	76.5
Wind speed (Km/day)	160	205	240	303	449	512	441	231	245	133	151	160
Sun. hours (hrs./day)	6.7	8.5	8.9	8.1	7.5	6.8	5.5	5.8	6.2	6.9	9	7.9
ETo (mm/day)	2.69	4.03	5.83	6.46	5.88	5.82	7.74	4.29	4.39	3.5	3.44	2.73

Appendix I (continued)

Year: 1984

Climatic parameters	Months											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.temp. (deg.celsius)	23.7	26.1	34.4	37.4	34.6	31.5	31.6	32.8	32.1	32.4	24.9	24.9
Min.temp. (deg.celsius)	10.4	11.7	16.4	23.5	24.7	25.5	25.8	25.8	24.7	23.8	18.2	11.1
Air humidity (percentage)	79.5	74	64.5	70	83	88	90.5	89.5	90.5	90	88	82.5
Wind speed (Km/day)	133	205	174	240	258	360	271	311	271	160	156	107
Sun. hours (hrs./day)	7.5	7.6	9.1	7.9	6.2	3.3	3.2	4.7	6.3	6.4	7.5	8.2
ETo (mm/day)	2.50	3.60	5.41	6.30	5.03	3.76	3.48	3.97	3.92	3.45	2.50	2.34

Year: 1985

Climatic parameters	Months											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.temp. (deg.celsius)	25	28.1	35.2	36.6	33.9	34.4	31.8	32.9	33.4	32	29.6	27.2
Min.temp. (deg.celsius)	11.9	12.1	11.2	23.7	23	25.3	25	25.9	25.7	22.9	16.6	12.2
Air humidity (percentage)	81	73.5	64	68.5	79	82.5	87.5	86.5	70.5	82	75.5	79.5
Wind speed (Km/day)	107	169	200	245	236	218	240	231	191	125	120	111
Sun. hours (hrs./day)	7.6	8.6	7.9	8.3	7.9	5	4.1	5.9	5.4	8.1	8.9	7.9
ETo (mm/day)	2.46	3.78	5.76	6.36	5.49	4.63	3.87	4.36	4.61	3.86	3.23	2.56

Appendix I (continued)

Year: 1986

Climatic parameters	Months											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.temp. (deg.celsius)	24.6	29.2	33.9	35.1	33.4	35.6	33.2	33.9	32.8	30.5	29.4	27.3
Min.temp. (deg.celsius)	10.8	12.8	16.1	22.1	22.1	25.5	25.2	25.2	24.4	22.1	18.7	12.6
Air humidity (percentage)	74.6	71.3	65.3	74.2	79.3	82.4	88.6	88.1	91.2	86.1	77.5	76
Wind speed (Km/day)	138	151	178	271	218	263	285	209	303	111	156	142
Sun. hours (hrs./day)	7.8	9.2	9.4	8.2	8.56	6.6	4.9	6.4	5.4	7.1	8.4	8.8
ETo (mm/day)	2.71	3.90	5.41	5.98	5.51	5.34	4.22	4.50	3.81	3.40	3.30	2.88

Year: 1987

Climatic parameters	Months											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.temp. (deg.celsius)	26.2	29.6	32.7	35.3	35.8	34.9	32.6	32.6	32.2	32.5	30	27.1
Min.temp. (deg.celsius)	9.9	13.6	18.2	21.6	23.2	24.8	25	25.1	25.9	22.5	17.3	12.7
Air humidity (percentage)	79	78	75	71.5	76	87	92	89	92.5	83	85	81.5
Wind speed (Km/day)	138	125	187	191	174	245	191	231	169	125	133	129
Sun. hours (hrs./day)	8.5	9.5	8	8.6	10	6.4	3.4	5.7	4.1	8.2	7.5	9
ETo (mm/day)	2.87	3.69	4.77	5.77	6.13	4.91	3.52	4.15	3.26	3.90	2.99	2.71

Appendix I (continued)

Year: 1988

Climatic parameters	Months											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.temp. (deg.celsius)	25.9	28.8	32.1	37.1	34.1	33.5	32.2	32.5	33.67	33.6	31	26.9
Min.temp. (deg.celsius)	10.8	13.5	17.2	21.6	23.6	24.9	25.7	25.6	25.47	25.5	17.2	14.15
Air humidity (percentage)	74.85	72	71.6	71	84.7	87	87.8	86.8	85.2	88.2	81.3	78.9
Wind speed (Km/day)	107	116	156	129	205	320	200	165	138	116	125	120
Sun. hours (hrs./day)	8.5	7.7	8.3	8.6	7	4.8	4.7	4.4	6.8	8.8	8.2	8.6
ETo (mm/day)	2.70	3.41	4.65	5.58	4.95	4.43	4.00	3.83	4.25	4.07	3.21	2.64

Year: 1989

Climatic parameters	Months											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.temp. (deg.celsius)	23.8	27.4	32.5	37.8	34.5	32.9	32	32.5	32.2	31.6	29.3	24.6
Min.temp. (deg.celsius)	8.9	11.3	15.5	20.4	23.7	24.6	25	25	24.4	22.4	15.1	10.4
Air humidity (percentage)	71.4	71.5	63.8	59.4	76.1	85	85.9	86.3	85.5	81.5	77.5	75.4
Wind speed (Km/day)	107	174	174	165	276	205	151	165	151	107	102	116
Sun. hours (hrs./day)	9.2	9.3	8.6	8.88	7.4	7	4.5	6	4.8	8	8.8	7.9
ETo (mm/day)	2.63	3.86	5.10	6.32	5.75	4.80	3.93	4.24	3.65	3.74	3.05	2.44

Appendix I (continued)

Year: 1990

Climatic parameters	Months											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.temp. (deg.celsius)	25	27.3	29.2	34.3	33.2	33.5	32.7	32.7	32.6	29.6	29.3	26.6
Min.temp. (deg.celsius)	9.3	13	16.3	21.5	22.8	25	25.3	25.2	24.8	20.69	17.6	10.4
Air humidity (percentage)	78	75	74.9	73.8	81.3	84.4	88.2	87.3	88	81.4	77.8	74.5
Wind speed (Km/day)	98	107	169	240	169	209	187	147	169	102	111	102
Sun. hours (hrs./day)	7.6	7.4	8	8.5	7.6	5.6	4	5.8	5.3	6.3	8.5	8.2
Eto (mm/day)	2.47	3.13	4.24	5.79	5.01	4.56	3.84	4.16	3.75	3.22	3.08	2.55

Year: 1991

Climatic parameters	Months											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.temp. (deg.celsius)	25.69	29	32.91	36.2	34.51	33.39	32.55	33.04	32.15	30.98	28.35	24.59
Min.temp. (deg.celsius)	7.9	12.55	18.32	21.3	23.77	24.68	25.31	25.48	24.63	21.95	14.65	10.72
Air humidity (percentage)	85.05	73.9	72.9	67.2	81.6	84.15	86.3	84.65	87.05	83.85	73.55	77.05
Wind speed (Km/day)	107	165	129	138	214	182	205	182	125	111	120	111
Sun. hours (hrs./day)	7.88	8.88	8.23	8.52	6.73	5.51	5.5	5.09	4.22	6.06	8.09	7.22
Eto (mm/day)	2.54	3.88	4.51	5.60	5.09	4.47	4.30	4.17	3.40	3.30	3.07	2.34

Appendix I (continued)

Year: 1992

Climatic parameters	Months											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.temp. (deg.celsius)	23.41	25.63	34	38.15	35.06	35.03	32.3	32.77	32.5	32.03	29.01	24.8
Min.temp. (deg.celsius)	9.8	10.67	17	22	22.1	25	24.64	24.81	24.3	21.32	15.67	10.32
Air humidity (percentage)	77	74.01	59.1	61.7	77.5	82.6	88.5	86.61	84.8	83.27	72.77	75.28
Wind speed (Km/day)	111	111	174	182	209	209	200	147	151	107	102	107
Sun. hours (hrs./day)	7.46	8.17	8.73	9.08	8.56	7.04	4.33	6.4	6.92	8.27	8.6	8.11
ETo (mm/day)	2.41	3.12	5.41	6.53	5.81	5.19	3.88	4.34	4.18	3.79	3.06	2.42

Year: 1993

Climatic parameters	Months											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.temp. (deg.celsius)	23.47	28.7	31.52	34.06	33.4	32.82	32.56	31.97	31.78	31.82	29.21	26.7
Min.temp. (deg.celsius)	7.74	12.9	15.03	20.35	22	23.73	24.82	25.03	24.27	22.35	17.34	12.48
Air humidity (percentage)	74.5	69.5	67.4	74.9	76.5	87.1	89.3	88	87.6	83.5	76.3	75.05
Wind speed (Km/day)	89	125	116	187	200	205	165	156	160	98	111	102
Sun. hours (hrs./day)	6.43	7.74	8.01	8.27	7.4	5.51	4.22	3.56	4.89	7.59	8.82	8.62
ETo (mm/day)	2.25	3.51	4.32	5.41	5.28	4.34	3.81	3.52	3.58	3.62	3.12	2.58

Appendix I (continued)

Year: 1994

Climatic parameters	Months											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.temp. (deg.celsius)	24.85	25.88	32.7	35.5	35.95	33	32.7	32.81	32.36	32	28.7	26
Min.temp. (deg.celsius)	11.1	11.92	17.15	21.8	23.6	24.3	25	24.7	23.63	20.8	16.6	10.5
Air humidity (percentage)	77.46	75.8	69.1	71.5	75.5	87	86.5	86.2	83.6	79.5	77.5	74.5
Wind speed (Km/day)	85	93	111	111	138	142	165	160	133	85	80	89
Sun. hours (hrs./day)	7.6	8.18	8.61	8.47	8.63	4.8	5.85	5.8	6.41	8.61	7.8	8.5
Eto (mm/day)	2.38	3.02	4.49	5.24	5.63	4.07	4.33	4.22	4.04	3.79	2.77	2.44

Year: 1995

Climatic parameters	Months											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.temp. (deg.celsius)	23.38	26.33	32.06	37.7	37.5	33.4	31.8	32.2	32	32.2	28.3	25.8
Min.temp. (deg.celsius)	9.03	12.28	15.72	21.8	25.2	25.25	24.9	25.3	25	23.03	17.3	11.3
Air humidity (percentage)	75.4	78.6	69	63.9	76.6	84.5	87.5	88	88.5	81.5	79	75.5
Wind speed (Km/day)	93	85	89	102	133	111	196	133	160	80	76	71
Sun. hours (hrs./day)	7.96	7.97	8.03	9.2	6.6	3.71	3.6	2.4	3.3	8.4	6.4	7.7
Eto (mm/day)	2.38	2.96	4.13	5.64	5.24	3.81	3.69	3.19	3.19	3.78	2.55	2.23

Appendix I (continued)

Year: 1996

Climatic parameters	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.temp. (deg.celsius)	24	27.7	33.8	36.6	36.2	32.6	32.7	32.1	33.6	31	29.3	25.7
Min.temp. (deg.celsius)	10.2	12	17.92	21.2	23.1	24	25.1	24.7	25.2	21.7	16.1	10.3
Air humidity (percentage)	75	73.5	69.9	64.7	76	85	85	91	85.2	82	74.5	74
Wind speed (Km/day)	107	98	156	200	187	191	196	249	169	89	89	80
Sun. hours (hrs./day)	7.28	8.5	9.43	8.39	7.8	5.5	3.8	4.4	6.01	7.2	9.1	8.4
Eto (mm/day)	2.45	3.27	5.10	6.22	5.71	4.38	3.94	3.70	4.12	3.46	3.04	2.35

Year: 1997

Climatic parameters	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.temp. (deg.celsius)	24.1	27.07	32.4	31.6	36.7	35.9	33.6	32.5	31.2	30.8	28.97	27.5
Min.temp. (deg.celsius)	8.9	11.4	17.6	19.9	23.5	24.2	25.1	25.5	24.5	21.1	17.8	15.2
Air humidity (percentage)	74.4	68.5	69.8	79	78	84.3	88	86.3	88	79.5	81	78.7
Wind speed (Km/day)	111	107	125	142	151	182	187	200	231	102	98	98
Sun. hours (hrs./day)	6.8	8.1	8.36	7.7	8.5	6.5	4.4	4.2	4.86	8.3	7.2	7.1
Eto (mm/day)	2.46	3.29	4.52	4.63	5.71	5.04	4.05	3.86	3.60	3.71	2.78	2.44

Appendix I (continued)

Year: 1998

Climatic parameters	Months											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.temp. (deg.celsius)	21.41	26.48	30.3	33.29	34.51	35.47	32.9	33.04	32.8	32.41	29.84	26.6
Min.temp. (deg.celsius)	10.46	13.45	15.49	21.37	23.74	27	27.8	27.8	27.2	26.65	20.57	14.7
Air humidity (percentage)	80.21	83.5	77.52	76.5	79.5	85.7	87.6	86.6	87.5	83.1	78.18	74.05
Wind speed (Km/day)	110	140	160	190	205	195	189	185	145	108	102	994
Sun. hours (hrs./day)	5.53	6.61	7.77	7.78	6.81	5.93	3.4	3.8	5.22	6.18	7.47	8.6
Eto (mm/day)	2.04	2.96	4.24	5.14	5.17	4.78	3.73	3.77	3.75	3.51	2.97	2.54

Year: 1999

Climatic parameters	Months											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max.temp. (deg.celsius)	24.7	29.43	34.11	34.11	34.35	34.03	31.3	32.2	32.2	30.85	29.82	26.85
Min.temp. (deg.celsius)	11.5	14.38	18.33	18.31	25.6	26.6	25.9	26.3	28	23.95	19.35	15.3
Air humidity (percentage)	77.8	72.1	65.45	65	76.7	82	82.4	85.35	85.1	81.9	77.05	72.2
Wind speed (Km/day)	112	135	165	192	206	190	185	177	160	156	110	94
Sun. hours (hrs./day)	8.2	9.7	9.85	6.4	4.8	3.6	3.6	3.9	4.6	6.6	8.8	7.9
Eto (mm/day)	2.56	3.85	5.40	5.41	4.77	4.16	3.85	3.76	3.67	3.59	3.18	2.52

Appendix II Calculations for composite crop coefficient of Boro rice and wheat

Crop: Boro Year: 2000-2001

Month	Date	Days after 1st transplan.	% cropped area	Average Kc value	Composite Kc value	cKc for the month
	10	10	20	1.1	0.22	
				Sub-total	**0.22**	
	20	20	20	1.1	0.22	
		20	50	1.1	0.55	
January				**Sub-total**	**0.77**	**0.70**
	31	31	20	1.1	0.22	
		31	50	1.1	0.55	
		31	30	1.1	0.33	
				Sub-total	**1.10**	
	10	41	20	1.1	0.22	
		41	50	1.1	0.55	
		41	30	1.1	0.33	
				Sub-total	**1.10**	
	20	51	20	1.1	0.22	
February		51	50	1.1	0.55	**1.10**
		51	30	1.1	0.33	
				Sub-total	**1.10**	
	28	59	20	1.1	0.22	
		59	50	1.1	0.55	
		59	30	1.1	0.33	
				Sub-total	**1.10**	
	10	69	20	1.1	0.22	
		69	50	1.1	0.55	
		69	30	1.1	0.33	
				Sub-total	**1.10**	
March	20	79	20	1.1	0.22	**1.10**
		79	50	1.1	0.55	
		79	30	1.1	0.33	
				Sub-total	**1.10**	
	31	90	20	1.1	0.22	
		90	50	1.1	0.55	
		90	30	1.1	0.33	
				Sub-total	**1.10**	
	10	100	20	1.0625	0.21	
		100	50	1.1	0.55	
		100	30	1.1	0.33	
				Sub-total	**1.09**	
		110	20	0.9875	0.20	
	20	110	50	1.0625	0.53	
April		110	30	1.1	0.33	**1.05**
				Sub-total	**1.06**	
	30	120	20	0.95	0.19	
		120	50	0.9875	0.49	
		120	30	1.0625	0.32	
				Sub-total	**1.00**	
		130	20	0.00	0.00	
	10	130	50	0.95	0.48	
		130	30	0.9875	0.29	
May				**Sub-total**	**0.77**	**0.53**
		140	20	0.00	0.00	
	20	140	50	0.00	0.00	
		140	30	0.95	0.29	
				Sub-total	**0.29**	

Appendix II continued

Crop: Boro Year: 2002-2003

Month	Date	Days after 1st transplan.	% cropped area	Average Kc value	Composite Kc value	cKc for the month
	10	10	20	1.1	0.22	
				Sub-total	**0.22**	
	20	20	20	1.1	0.22	
		20	50	1.1	0.55	
January				**Sub-total**	**0.77**	**0.70**
	31	31	20	1.1	0.22	
		31	50	1.1	0.55	
		31	30	1.1	0.33	
				Sub-total	**1.10**	
	10	41	20	1.1	0.22	
		41	50	1.1	0.55	
		41	30	1.1	0.33	
				Sub-total	**1.10**	
	20	51	20	1.1	0.22	
February		51	50	1.1	0.55	**1.10**
		51	30	1.1	0.33	
				Sub-total	**1.10**	
	28	59	20	1.1	0.22	
		59	50	1.1	0.55	
		59	30	1.1	0.33	
				Sub-total	**1.10**	
	10	69	20	1.1	0.22	
		69	50	1.1	0.55	
		69	30	1.1	0.33	
				Sub-total	**1.10**	
March	20	79	20	1.1	0.22	**1.10**
		79	50	1.1	0.55	
		79	30	1.1	0.33	
				Sub-total	**1.10**	
	31	90	20	1.1	0.22	
		90	50	1.1	0.55	
		90	30	1.1	0.33	
				Sub-total	**1.10**	
	10	100	20	1.019	0.20	
		100	50	1.1	0.55	
		100	30	1.1	0.33	
				Sub-total	**1.08**	
		110	20	0.839	**0.17**	
	20	110	50	1.019	0.51	
April		110	30	1.1	0.33	**0.99**
				Sub-total	**1.01**	
	30	120	20	0.74	0.15	
		120	50	0.839	0.42	
		120	30	1.019	0.31	
				Sub-total	**0.88**	
		130	20	0.00	0.00	
	10	130	50	0.74	0.37	
		130	30	0.84	0.25	
May				**Sub-total**	**0.62**	**0.42**
		140	20	0.00	0.00	
	20	140	50	0.00	0.00	
		140	30	0.74	0.22	
				Sub-total	**0.22**	

Appendix II continued

Crop: Wheat Year: 2000-2001

Month	Date	Days after 1st sowing	% cropped area	Average Kc value	Composite Kc value	cKc for the month
	30	10	70	0.30	0.21	
November				**Sub-total**	**0.21**	**0.21**
	10	20	70	0.34	0.24	
		20	30	0.30	0.09	
				Sub-total	**0.33**	
	20	30	70	0.53	0.37	
December		30	30	0.34	0.10	**0.55**
				Sub-total	**0.47**	
	31	41	70	0.92	0.64	
		41	30	0.65	0.20	
				Sub-total	**0.84**	
	10	51	70	1.05	0.74	
		51	30	0.92	0.28	
				Sub-total	**1.02**	
January	20	61	70	1.05	0.74	**1.05**
		61	30	1.05	0.32	
				Sub-total	**1.06**	
	31	72	70	1.05	0.74	
		72	30	1.05	0.32	
				Sub-total	**1.06**	
	10	82	70	1.05	0.74	
		82	30	1.05	0.32	
				Sub-total	**1.06**	
	20	92	70	0.91	0.64	
February		92	30	1.05	0.32	**0.91**
				Sub-total	**0.96**	
	28	100	70	0.63	0.44	
		100	30	0.91	0.27	
				Sub-total	**0.71**	
	10	110	70	0.34	0.24	
		110	30	0.63	0.20	
				Sub-total	**0.44**	
	20	120	70	0.23	0.16	
March		120	30	0.48	0.14	**0.27**
				Sub-total	**0.30**	
	30	130	70	0.00	0	
	30	130	30	0.21	0.06	
				Sub-total	**0.06**	

Appendix II continued

Crop: Wheat Year: 2002-2003

Month	Date	Days after 1st sowing	% cropped area	Average Kc value	Composite Kc value	cKc for the month
November	30	10	70	0.38	0.27	
				Sub-total	**0.27**	**0.27**
	10	20	70	0.46	0.32	
		20	30	0.38	0.11	
				Sub-total	**0.43**	
December	20	30	70	0.61	0.43	**0.61**
		30	30	0.46	0.14	
				Sub-total	**0.57**	
	31	41	70	0.91	0.64	
		41	30	0.61	0.18	
				1.14	**0.82**	
	10	51	70	1.14	0.80	
		51	30	0.91	0.27	
				Sub-total	**1.07**	
January	20	61	70	1.14	0.80	**1.12**
		61	30	1.14	0.34	
				Sub-total	**1.14**	
	31	72	70	1.14	0.80	
		72	30	1.14	0.34	
				Sub-total	**1.14**	
	10	82	70	1.12	0.78	
		82	30	1.14	0.34	
				Sub-total	**1.12**	
	20	92	70	0.97	0.68	
February		92	30	1.12	0.34	**0.98**
				Sub-total	**1.02**	
	28	100	70	0.73	0.51	
		100	30	0.97	0.29	
				Sub-total	**0.80**	
	10	110	70	0.52	0.36	
		110	30	0.73	0.22	
				Sub-total	**0.58**	
March	20	120	70	0.42	0.29	
		120	30	0.52	0.16	**0.36**
				Sub-total	**0.45**	
	30	130	70	0.00	0.00	
		130	30	0.21	0.06	
				Sub-total	**0.06**	

Appendix III Month and stagewise potential crop ET for staggered plantation of Boro rice

Year: 2000-2001

Stages	Vegetative stage			Flowering stage		Y.formation stage		Ripening stage	
Months	Jan	Feb	Mar	Feb	Mar	Mar	Apr	Apr	May
Days	31	28	31	28	31	31	30	30	20
Eto, mm/day	2.52	3.47	4.86	3.47	4.86	4.86	5.79	5.79	5.48
cKc	0.7	1.1	1.1	1.1	1.1	1.1	1.05	0.99	0.53
% duration	100	88	14	12	36	50	50	50	100
Crop ET, mm	54.68	94.05	23.2	12.83	59.66	82.86	91.19	91.19	58.09
Stage ET, mm			172		73		174		149
Seasonal ET, mm									568

Year: 2002-2003

Stages	Vegetative stage			Flowering stage		Y.formation stage		Ripening stage	
Months	Jan	Feb	Mar	Feb	Mar	Mar	Apr	Apr	May
Days	31	28	31	28	31	31	30	30	20
Eto, mm	2.52	3.47	4.86	3.47	4.86	4.86	5.79	5.79	5.48
cKc	0.7	1.1	1.1	1.1	1.1	1.1	0.99	0.99	0.42
% duration	100	88	14	12	36	50	50	50	100
Crop ET, mm	54.68	94.05	23.2	12.83	59.66	82.86	85.98	85.98	46.03
Stage ET, mm			172		73		169		132
Seasonal ET, mm									546

Appendix IV Month and stagewise potential crop ET for staggered plantation of wheat

Year: 2000-2001

Stages	Vegetative stage			Flowering stage		Y.formation stage			Ripening stage	
Months	Nov	Dec	Jan	Jan	Feb	Jan	feb	Mar	Feb	Mar
Days	10	31	31	31	28	31	28	30	28	30
ETo	3.02	2.51	2.52	2.52	3.47	2.52	3.47	4.86	3.47	4.86
cKc	0.21	0.55	1.05	1.05	0.91	1.05	0.91	0.27	0.91	0.27
% duration	100	100	61	35	15	4	76	8.5	9	91.5
Crop ET	6.34	42.80	50.04	28.71	13.26	3.28	67.20	3.35	7.96	36.02
Stage ET			99		42			74		44
Seasonal ET										259

Year: 2002-2003

Stages	Vegetative stage			Flowering stage		Y.formation stage			Ripening stage	
Months	Nov	Dec	Jan	Jan	Feb	Jan	feb	Mar	Feb	Mar
Days	10	31	31	31	28	31	28	30	28	30
ETo	3.02	2.51	2.52	2.52	3.47	2.52	3.47	4.86	3.47	4.86
cKc	0.27	0.61	1.12	1.12	0.98	1.12	0.98	0.36	0.98	0.36
% duration	100	100	61	35	15	4	76	8.5	9	91.5
Crop ET, m	8.15	47.46	53.37	30.62	14.28	3.50	72.36	4.46	8.57	48.03
Stage ET, mm			109		45			80		57
Seasonal ET										291

Appendix V Bare soil percolation test

Year: 2000-2001

A. Test for water depth of 60 mm

Date	Clock time (hr.:min.)	Scale reading mm	Differential clocktime, day	Differential scale reading	Percolation, mm/day
3/11/02	10:00 AM	250	0.0	0.0	0.00
5/11/02	10:00 AM	247	2.0	3.0	1.50
6/11/02	10:00 AM	248	1.0	2.0	2.00
7/11/02	10:00 AM	248	1.0	2.0	2.00
9/11/02	10:00 AM	247	2.0	3.5	1.75
			Average for the duration		1.81

B. Test for water depth of 80 mm

Date	Clock time (hr.:min.)	Scale reading mm	Differential clocktime, day	Differential scale reading	Percolation, mm/day
12/11/02	9:00 AM	260	0.0	0.0	0.00
13/11/02	9:00 AM	258	1.0	2.0	2.00
16/11/02	9:00 AM	255	3.0	5.0	1.67
17/11/02	9:00 AM	257	1.0	3.0	2.00
18/11/02	9:00 AM	258	1.0	2.0	2.00
			Average for the duration		1.92

C. Test for water depth of 100 mm

Date	Clock time (hr.:min.)	Scale reading mm	Differential clocktime, day	Differential scale reading	Percolation, mm/day
22/11/02	9:30 AM	280	0.0	0.0	0.00
23/11/02	9:30 AM	277	1.0	2.0	2.00
24/11/02	9:30 AM	278	1.0	2.0	2.00
25/11/02	9:30 AM	278	1.0	2.0	2.00
26/11/02	9:30 AM	278	1.0	2.0	2.00
			Average for the duration		2.00

D. Test for water depth of 120 mm

Date	Clock time (hr.:min.)	Scale reading mm	Differential clocktime, day	Differential scale reading	Percolation, mm/day
1/12/02	9:30 AM	280	0.0	0.0	0.00
3/12/02	9:30 AM	275	2.0	5.0	2.50
4/12/02	9:30 AM	278	1.0	2.0	2.00
5/12/02	9:30 AM	278	1.0	2.0	2.00
8/12/02	9:30 AM	274	3.0	6.0	2.00
9/12/02	9:30 AM	275	2.0	2.0	2.00
			Aerage for the duration		2.10

Average bare soil percolation rate : 1.96 mm/day

Appendix V continued

Year: 2002-2003

A. Test for water depth of 60 mm

Date	Clock time (hr.:min.)	Scale reading mm	Differential time, day	Differential scale reading	Percolation, mm/day
20/11/2002	9:30 AM	240	0.0	0.0	0.00
24/11/2002	9:30 AM	232	4.0	8.0	2.00
28/11/2002	9:30 AM	234	4.0	6.0	1.50
2/12/02	9:30 AM	234	4.0	6.0	1.50
6/12/02	9:30 AM	233	4.0	7.0	1.75
			Average for the duration		1.69

B. Test for water depth of 80 mm

Date	Clock time (hr.:min.)	Scale reading mm	Differential clocktime, day	Differential scale reading	Percolation, mm/day
8/12/02	9:00 AM	260	0.0	0.0	0.00
12/12/02	9:00 AM	253	4.0	7.0	1.75
16/12/2002	9:00 AM	252	4.0	8.0	2.00
20/12/2002	9:00 AM	252	4.0	8.0	2.00
24/12/2002	9:00 AM	254	4.0	6.0	1.50
			Average for the duration		1.81

C. Test for water depth of 100 mm

Date	Clock time (hr.:min.)	Scale reading mm	Differential clocktime, day	Differential scale reading	Percolation, mm/day
25/12/02	9:20 AM	280	0.0	0.0	0.00
29/12/02	9:20 AM	272	4.0	8.0	2.00
2/1/03	9:20 AM	273	4.0	7.0	1.75
6/1/03	9:20 AM	272	4.0	8.0	2.00
10/1/03	9:20 AM	271	4.0	9.0	2.25
			Average for the duration		2.00

D. Test for water depth of 120 mm

Date	Clock time (hr.:min.)	Scale reading mm	Differential clocktime, day	Differential scale reading	Percolation, mm/day
11/1/03	9:30 AM	300	0.0	0.0	0.00
15/1/2003	9:30 AM	290	4.0	10.0	2.50
19/1/2003	9:30 AM	292	4.0	8.0	2.00
23/1/2003	9:30 AM	290	4.0	10.0	2.50
27/1/2003	9:30 AM	292	4.0	8.0	2.00
			Average for the duration		2.25

Average bare soil percolation rate: 1.94 mm/day

N.B. The depleted water was replinished after each scale reading

Appendix: VI Boro field percolation determination

Year: 2000-2001

Boro field P and ET

Water head in open bottom cylinder: 120 mm

Dates	Clock time	Differential time,day	Scale reading, mm	Differential scale reading, mm	P and ET of Boro rice field, mm/day
2/2/01	10:10 A.M	0	200	0	0
3/2/01	10:10 A.M	1	194	6	6
9/2/01	09:30 A.M	0	200	0	0
10/2/01	09:30 A.M	1	193	7	7
17/2/01	10:30 A.M	0	200	0	0
18/2/01	10:30 A.M	1	192	8	8
25/2/01	10:30 A.M	0	200	0	0
26/2/01	10:30 A.M	1	192	8	8

Boro field P rates

Water head in open bottom cylinder: 120 mm

Dates	P and ET of Boro rice,mm/day	Boro rice ET, mm/day (estimated)	Boro field P rates, mm/day
2/2/01	0	0	0
3/2/01	6	3.82	2.18
9/2/01	0	0	0
10/2/01	5	3.82	1.18
17/2/2001	0	0	0
18/2/2001	7	3.82	3.12
25/2/2001	0	0	0
26/2/2001	6	3.82	2.18
		Average	2.17

Boro field P and ET

Water head in open bottom cylinder: 100 mm

Dates	Clock time	Differential time,day	Scale reading, mm	Differential scale reading, mm	P* and ET of Boro rice field, mm/day
4/3/01	10:10 A.M	0	200	0	0
5/3/01	10:10 A.M	1	195	5	5
11/3/01	09:30 A.M	0	200	0	0
12/3/01	09:30 A.M	1	193	7	7
17/3/2001	10:30 A.M	0	200	0	0
18/3/2001	10:30 A.M	1	195	5	5
27/3/2001	10:30 A.M	0	200	0	0
28/3/2001	10:30 A.M	1	192	8	8

Appendix VI (continued)
Year: 2000-2001
Boro field P rates
Water head in open bottom cylinder: 100 mm

Dates	P and ET of Boro rice,mm/day	Boro rice ET, mm/day (estimated)	Boro field P rates, mm/day
4/3/01	0	0	0
5/3/01	7	5.15	1.85
11/3/01	0	0	0
12/3/01	8	5.15	2.85
17/3/2001	0	0	0
18/3/2001	7	5.15	1.85
27/3/2001	0	0	0
28/3/2001	7	5.15	1.85
		Average	2.10

Boro field P and ET
Water head in open bottom cylinder: 80 mm

Dates	Clock time	Differential time,day	Scale reading, mm	Differential scale reading, mm	P and ET of Boro rice field, mm/day
5/4/01	10:10 A.M	0	200	0	0
6/4/01	10:10 A.M	1	193	7	7
12/4/01	09:30 A.M	0	200	0	0
14/4/2001	09:30 A.M	2	183	17	8.5
19/4/2001	10:30 A.M	0	200	0	0
20/4/2001	10:30 A.M	1	192	8	8
27/4/2001	10:30 A.M	0	200	0	0
29/4/2001	10:30 A.M	2	183	17	8.5

Boro field P rates
Water Head: 80 mm

Dates	P and ET of Boro rice,mm/day	Boro rice ET, mm/day (estimated)	Boro field P rates, mm/day
5/4/01	0	0	0
6/4/01	8	6.37	1.63
12/4/01	0	0	0
14/4/2001	8.5	6.37	2.23
19/4/2001	0	0	0
20/4/2001	8	6.37	1.63
27/4/2001	0	0	0
29/4/2001	8.5	6.37	2.23
		Average	1.93

Appendix VI (continued)
Year: 2000-2001
Boro field P and ET
Water head in open bottom cylinder: 60 mm

Dates	Clock time	Differential time,day	Scale reading, mm	Differential scale reading, mm	P and ET of Boro rice field, mm/day
2/5/01	10:00 A.M	0	200	0	0
3/5/01	10:00 A.M	1	193	7	7
10/5/01	09:30 A.M	0	200	0	0
11/5/01	09:30 A.M	1	192	8	8
16/5/01	10:30 A.M	0	200	0	0
18/5/01	10:30 A.M	2	185	15	7.5
24/5/01	10:00 A.M	0	200	0	0
25/5/01	10:00 A.M	1	193	7	7

Boro field P rates
Water head in open bottom cylinder: 60 mm

Dates	P and ET of Boro rice,mm/day	Boro rice ET, mm/day (estimated)	Boro field P rates, mm/day
2/5/01	0	0	0
3/5/01	7	5.62	1.38
10/5/01	0	0	0
11/5/01	8	5.62	2.38
16/5/2001	0	0	0
18/5/2001	7.5	5.62	1.88
24/5/2001	0	0	0
25/5/2001	7	5.62	1.38
		Average	1.76

Average of all heads 1.99 mm/day

Appendix: VI (continued)
Year: 2002-2003
Boro field ET
Water head in closed bottom cylinder: 120 mm

Dates	Clock time	Differential time,day	Scale reading, mm	Differential scale reading, mm	ET of Boro rice in crop field, mm/day
7/2/03	10:00 A.M	0	120	0	0
11/2/03	10:00 A.M	4	107	13	3.25
14/2/03	10:30 A.M	0	120	0	0
18/2/03	10:30 A.M	4	106	14	3.5
20/2/03	10:00 A.M	0	120	0	0
25/2/03	10:00 A.M	5	103	16	3.20

Boro field P and ET
Water head in open bottom cylinder: 120 mm

Dates	Clock time	Differential time,day	Scale reading, mm	Differential scale reading, mm	P and ET of Boro rice field, mm/day
7/2/03	10:05 A.M	0	120	0	0
11/2/03	10:05 A.M	4	98	22	5.5
14/2/03	09:30 A.M	0	120	0	0
18/2/03	09:30 A.M	4	98	22	5.5
20/2/03	10:30 A.M	0	120	0	0
25/2/03	10:30 A.M	5	92	28	5.6

Boro field P rates
Water head: 120 mm

Dates	P and ET of Boro rice,mm/day	Boro rice ET, mm/day	Boro field P rates, mm/day
7-11/2/03	5.5	3.25	2.25
14-18/2/03	5.5	3.50	2.00
20-25/2/03	5.6	3.20	2.40
		Average	2.22

Appendix VI (continued)

Year: 2002-2003

Boro field ET

Closed bottom cylinder: Water Head: 100 mm

Dates	Clock time	Differential time,day	Scale reading, mm	Differential scale reading, mm	ET of Boro rice in crop field, mm/day
10/3/03	10:00 A.M	0	100	0	0.00
14/3/2003	10:00 A.M	4	80	20	5.00
16/3/03	9:30 A.M	0	100	0	0.00
21/3/03	9:30 A.M	5	73	27	5.40
25/3/03	9:00 A.M	0	100	0	0.00
29/3/03	9:00 A.M	4	78	22	5.50

Boro field P and ET

Open bottom cylinder: water Head: 100 mm

Dates	Clock time	Differential time,day	Scale reading, mm	Differential scale reading, mm	P and ET of Boro rice field, mm/day
10/3/03	10:30 A.M	0	100	0	0.00
14/3/2003	10:30 A.M	4	70	30	7.50
16/3/03	10:00 A.M	0	100	0	0.00
21/3/03	10:00 A.M	5	62	38	7.60
25/3/03	10:00 A.M	0	100	0	0.00
29/3/03	10:00 A.M	4	71	29	7.25

Boro field Percolation

Water Head: 100 mm

Dates	P and ET of Boro rice,mm/day	Boro rice ET, mm/day	Boro field P rates, mm/day
10-14/3/03	7.5	5	2.50
16-21/3/03	7.6	5.4	2.20
25-29/3/03	7.25	5.5	1.75
		Average	2.15

Appendix VI (continued)
Year: 2002-2003
Boro field ET
Closed bottom cylinder: water Head: 80 mm

Dates	Clock time	Differential time,day	Scale reading, mm	Differential scale reading, mm	ET of Boro rice in crop field, mm/day
6/4/03	10:35 A.M	0	80	0	0.00
11/4/03	10:35 A.M	5	48	32	6.40
14/4/03	09:35 A.M	0	80	0	0.00
18/4/03	09:35 A.M	4	53	27	6.75
20/4/03	10:30 A.M	0	80	0	0.00
25/4/03	10:30 A.M	5	47	33	6.60

Boro field P and ET
Open bottom cylinder: water Head: 80 mm

Dates	Clock time	Differential time,day	Scale reading, mm	Differential scale reading, mm	P and ET of Boro rice field, mm/day
6/4/03	10:35 A.M	0	80	0	0.00
11/4/03	10:35 A.M	5	38	42	8.40
14/4/03	09:35 A.M	0	80	0	0.00
18/4/03	09:35 A.M	4	46	34	8.50
20/4/03	10:30 A.M	0	80	0	0.00
25/4/03	10:30 A.M	5	36	44	8.80

Boro field Percolation
Water Head: 80 mm

Dates	P and ET of Boro rice,mm/day	Boro rice ET, mm/day	Boro field P rates, mm/day
6-11/4/03	8.4	6.4	2.00
14-18/4/03	8.5	6.75	1.75
20-25/4/03	8.8	6.6	2.20
		Aver	1.98

Appendix VI continued
Year: 2002-2003
Boro field ET
Water head in closed bottom cylinder: 60 mm

Dates	Clock time	Differential time,day	Scale reading, mm	Differential scale reading, mm	ET of Boro rice in crop field, mm/day
6/5/03	10:10 A.M	0	60	0	0.00
9/5/03	10:10 A.M	3	43	17	5.67

Boro field P and ET
Water head in open bottom cylinder: 60 mm

Dates	Clock time	Differential time,day	Scale reading, mm	Differential scale reading, mm	P and ET of Boro rice field, mm/day
6/5/03	10:10 A.M	0	60	0	0.00
10/5/03	10:10 A.M	4	30	30	7.50

Boro field P rates
Water Head: 60 mm

Dates	P and ET of Boro rice,mm/day	Boro rice ET, mm/day	Boro field P rates, mm/day
6-10/5/03	7.50	5.67	1.83
		Percolation r	1.83

Average of all heads 2.04 mm/day

Appendix VII Monthwise net and gross irrigation requirement
Crop: Boro rice Probability level: 20%

Month	Irrigation levels	LP water mm	Crop ET mm	Effective rainfall, mm	Perco-lation, mm	Net irrig. water mm	System eff., %	gross reqmnt. mm	Gross irrig.req. m
November (4 days)	Full	15	0	3	0	12	0.65	18	0.018
	10% def.	15	0	3	0	12	0.65	18	0.018
	20% def.	15	0	3	0	12	0.65	18	0.018
	30% def.	15	0	3	0	12	0.65	18	0.018
	40% def.	15	0	3	0	12	0.65	18	0.018
December (31 days)	Full	185	0	8	0	177	0.65	272	0.272
	10% def.	185	0	8	0	177	0.65	272	0.272
	20% def.	185	0	8	0	177	0.65	272	0.272
	30% def.	185	0	8	0	177	0.65	272	0.272
	40% def.	185	0	8	0	177	0.65	272	0.272
January (31 days)	Full	0	55	9	130	176	0.65	270	0.270
	10% def.	0	50	9	130	171	0.65	263	0.263
	20% def.	0	44	9	130	165	0.65	254	0.254
	30% def.	0	39	9	130	160	0.65	246	0.246
	40% def.	0	33	9	130	154	0.65	237	0.237
February (28 days)	Full	0	107	16	118	209	0.65	322	0.322
	10% def.	0	96	16	118	198	0.65	305	0.305
	20% def.	0	87	16	118	189	0.65	291	0.291
	30% def.	0	75	16	118	177	0.65	273	0.273
	40% def.	0	64	16	118	166	0.65	256	0.256
March (31 days)	Full	0	166	24	130	272	0.65	418	0.418
	10% def.	0	149	24	130	255	0.65	392	0.392
	20% def.	0	133	24	130	239	0.65	368	0.368
	30% def.	0	116	24	130	222	0.65	342	0.342
	40% def.	0	100	24	130	206	0.65	317	0.317
April (30 days)	Full	0	172	65	126	233	0.65	358	0.358
	10% def.	0	155	65	126	216	0.65	332	0.332
	20% def.	0	138	65	126	199	0.65	306	0.306
	30% def.	0	120	65	126	181	0.65	278	0.278
	40% def.	0	103	65	126	164	0.65	252	0.252
May (20 days)	Full	0	46	94	84	36	0.65	55	0.055
	10% def.	0	46	94	84	36	0.65	55	0.055
	20% def.	0	46	94	84	36	0.65	55	0.055
	30% def.	0	46	94	84	36	0.65	55	0.055
	40% def.	0	46	94	84	36	0.65	55	0.055

Appendix VII (continued)

Crop: Boro rice Probability level: 50%

Month	Irrigation levels	LP water mm	Crop ET mm	Effective rainfall, mm	Perco-lation, mm	Net irrig. water mm	System eff., %	gross reqmnt. mm	Gross irrig.req. m
November (4 days)	Full	15	0	3	0	12	0.65	18	0.018
	10% def.	15	0	3	0	12	0.65	18	0.018
	20% def.	15	0	3	0	12	0.65	18	0.018
	30% def.	15	0	3	0	12	0.65	18	0.018
	40% def.	15	0	3	0	12	0.65	18	0.018
December (31 days)	Full	185	0	7	0	178	0.65	274	0.274
	10% def.	185	0	7	0	178	0.65	274	0.274
	20% def.	185	0	7	0	178	0.65	274	0.274
	30% def.	185	0	7	0	178	0.65	274	0.274
	40% def.	185	0	7	0	178	0.65	274	0.274
January (31 days)	Full	0	55	8	130	177	0.65	272	0.272
	10% def.	0	50	8	130	172	0.65	265	0.265
	20% def.	0	44	8	130	166	0.65	255	0.255
	30% def.	0	39	8	130	161	0.65	248	0.248
	40% def.	0	33	8	130	155	0.65	238	0.238
February (28 days)	Full	0	107	14	118	211	0.65	325	0.325
	10% def.	0	96	14	118	200	0.65	308	0.308
	20% def.	0	87	14	118	191	0.65	294	0.294
	30% def.	0	75	14	118	179	0.65	275	0.275
	40% def.	0	64	14	118	168	0.65	258	0.258
March (31 days)	Full	0	166	21	130	275	0.65	423	0.423
	10% def.	0	149	21	130	258	0.65	397	0.397
	20% def.	0	133	21	130	242	0.65	372	0.372
	30% def.	0	116	21	130	225	0.65	346	0.346
	40% def.	0	100	21	130	209	0.65	322	0.322
April (30 days)	Full	0	172	55	126	243	0.65	374	0.374
	10% def.	0	155	55	126	226	0.65	348	0.348
	20% def.	0	138	55	126	209	0.65	322	0.322
	30% def.	0	120	55	126	191	0.65	294	0.294
	40% def.	0	103	55	126	174	0.65	268	0.268
May (20 days)	Full	0	46	81	84	49	0.65	75	0.075
	10% def.	0	46	81	84	49	0.65	75	0.075
	20% def.	0	46	81	84	49	0.65	75	0.075
	30% def.	0	46	81	84	49	0.65	75	0.075
	40% def.	0	46	81	84	49	0.65	75	0.075

Appendix VII (continued)

Crop: Boro rice Probability level: 80%

Month	Irrigation levels	LP water mm	Crop ET mm	Effectiv rainfall, mm	Perco-lation, mm	Net irrig. water mm	System eff., %	gross reqmnt. mm	Gross irrig.req. m
	Full	15	0	2	0	13	0.65	20	0.020
November	10% def.	15	0	2	0	13	0.65	20	0.020
(4 days)	20% def.	15	0	2	0	13	0.65	20	0.020
	30% def.	15	0	2	0	13	0.65	20	0.020
	40% def.	15	0	2	0	13	0.65	20	0.020
	Full	185	0	6	0	179	0.65	275	0.275
December	10% def.	185	0	6	0	179	0.65	275	0.275
(31 days)	20% def.	185	0	6	0	179	0.65	275	0.275
	30% def.	185	0	6	0	179	0.65	275	0.275
	40% def.	185	0	6	0	179	0.65	275	0.275
	Full	0	55	7	130	178	0.65	274	0.274
	10% def.	0	50	7	130	173	0.65	266	0.266
January	20% def.	0	44	7	130	167	0.65	257	0.257
(31 days)	30% def.	0	39	7	130	162	0.65	249	0.249
	40% def.	0	33	7	130	156	0.65	240	0.240
	Full	0	107	11	118	214	0.65	329	0.329
	10% def.	0	96	11	118	203	0.65	312	0.312
February	20% def.	0	87	11	118	194	0.65	298	0.298
(28 days)	30% def.	0	75	11	118	182	0.65	280	0.280
	40% def.	0	64	11	118	171	0.65	263	0.263
	Full	0	166	17	130	279	0.65	429	0.429
	10% def.	0	149	17	130	262	0.65	403	0.403
March	20% def.	0	133	17	130	246	0.65	378	0.378
(31 days)	30% def.	0	116	17	130	229	0.65	352	0.352
	40% def.	0	100	17	130	213	0.65	328	0.328
	Full	0	172	46	126	252	0.65	388	0.388
	10% def.	0	155	46	126	235	0.65	362	0.362
April	20% def.	0	138	46	126	218	0.65	335	0.335
(30 days)	30% def.	0	120	46	126	200	0.65	308	0.308
	40% def.	0	103	46	126	183	0.65	282	0.282
	Full	0	46	68	84	62	0.65	95	0.095
	10% def.	0	46	68	84	62	0.65	95	0.095
May	20% def.	0	46	68	84	62	0.65	95	0.095
(20 days)	30% def.	0	46	68	84	62	0.65	95	0.095
	40% def.	0	46	68	84	62	0.65	95	0.095

Appendix VIII Monthwise net and gross irrigation requirement
Crop: Wheat Probability level: 20%

Month	Irrigation levels	Crop ET, mm	Effective rains, mm	Net irrigation, mm	System efficiency	Gross irri. req., mm	Gross irri. req., m
	Full	8	8	0	0.55	0	0.000
	10% deficit	7	8	0	0.55	0	0.000
November	20% deficit	6	8	0	0.55	0	0.000
(10 days)	30% deficit	6	8	0	0.55	0	0.000
	40% deficit	5	8	0	0.55	0	0.000
	Full	48	8	40	0.55	73	0.073
	10% deficit	43	8	35	0.55	64	0.064
December	20% deficit	38	8	30	0.55	55	0.055
(31 Days)	30% deficit	34	8	26	0.55	47	0.047
	40% deficit	29	8	21	0.55	38	0.038
	Full	88	9	79	0.55	144	0.144
	10% deficit	79	9	70	0.55	127	0.127
January	20% deficit	70	9	61	0.55	111	0.111
(31 Days)	30% deficit	62	9	53	0.55	96	0.096
	40% deficit	53	9	44	0.55	80	0.080
	Full	95	16	79	0.55	144	0.144
	10% deficit	86	16	70	0.55	127	0.127
February	20% deficit	76	16	60	0.55	109	0.109
(28 Days)	30% deficit	67	16	51	0.55	93	0.093
	40% deficit	57	16	41	0.55	75	0.075
	Full	53	16	37	0.55	67	0.067
	10% deficit	48	16	32	0.55	58	0.058
March	20% deficit	42	16	26	0.55	47	0.047
(20 Days)	30% deficit	37	16	21	0.55	38	0.038
	40% deficit	32	16	16	0.55	29	0.029

Appendix VIII (continued)
Crop: Wheat Probability level: 50% Year: 2002-2003

Month	Irrigation levels	Crop ET, mm	Effective rains, mm	Net irrigation, mm	System efficiency	Gross irri. req., mm	Gross irri. req., m
	Full	8	7	1	0.55	2	0.002
	10% deficit	7	7	0	0.55	0	0.000
November	20% deficit	6	7	0	0.55	0	0.000
(10 days)	30% deficit	6	7	0	0.55	0	0.000
	40% deficit	5	7	0	0.55	0	0.000
	Full	48	7	41	0.55	75	0.075
	10% deficit	43	7	36	0.55	65	0.065
December	20% deficit	38	7	31	0.55	56	0.056
(31 Days)	30% deficit	34	7	27	0.55	49	0.049
	40% deficit	29	7	22	0.55	40	0.040
	Full	88	8	80	0.55	145	0.145
	10% deficit	79	8	71	0.55	129	0.129
January	20% deficit	70	8	62	0.55	113	0.113
(31 Days)	30% deficit	62	8	54	0.55	98	0.098
	40% deficit	53	8	45	0.55	82	0.082
	Full	95	14	81	0.55	147	0.147
	10% deficit	86	14	72	0.55	131	0.131
February	20% deficit	76	14	62	0.55	113	0.113
(28 Days)	30% deficit	67	14	53	0.55	96	0.096
	40% deficit	57	14	43	0.55	78	0.078
	Full	53	13	40	0.55	73	0.073
	10% deficit	48	13	35	0.55	64	0.064
March	20% deficit	42	13	29	0.55	53	0.053
(20 Days)	30% deficit	37	13	24	0.55	44	0.044
	40% deficit	32	13	19	0.55	35	0.035

Appendix VIII (continued)
Crop: Wheat   Probability level: 80%

Month	Irrigation levels	Crop ET, mm	Effective rains, mm	Net irrigation, mm	System efficiency	Gross irri. req., mm	Gross irri. req., m
	Full	8	6	2	0.55	4	0.004
	10% deficit	7	6	1	0.55	2	0.002
November	20% deficit	6	6	0	0.55	0	0.000
(10 days)	30% deficit	6	6	0	0.55	0	0.000
	40% deficit	5	6	0	0.55	0	0.000
	Full	48	6	42	0.55	76	0.076
	10% deficit	43	6	37	0.55	67	0.067
December	20% deficit	38	6	32	0.55	58	0.058
(31 Days)	30% deficit	34	6	28	0.55	51	0.051
	40% deficit	29	6	23	0.55	42	0.042
	Full	88	7	81	0.55	147	0.147
	10% deficit	79	7	72	0.55	131	0.131
January	20% deficit	70	7	63	0.55	115	0.115
(31 Days)	30% deficit	62	7	55	0.55	100	0.100
	40% deficit	53	7	46	0.55	84	0.084
	Full	95	11	84	0.55	153	0.153
	10% deficit	86	11	75	0.55	136	0.136
February	20% deficit	76	11	65	0.55	118	0.118
(28 Days)	30% deficit	67	11	56	0.55	102	0.102
	40% deficit	57	11	46	0.55	84	0.084
	Full	53	11	42	0.55	76	0.076
	10% deficit	48	11	37	0.55	67	0.067
March	20% deficit	42	11	31	0.55	56	0.056
(20 Days)	30% deficit	37	11	26	0.55	47	0.047
	40% deficit	32	11	21	0.55	38	0.038

Appendix IX Irrigation water calculations of Boro rice for field experiment

Year: 2000-2001

Date of irrigation	Irrigation cycle, days	Treatments	Etc for the cycle, mm	Percolation for the cycle, mm	Effective rainfall, mm	Net Irrigation water, mm
26/01/2000 Vegetative stage	10	T1	33	19	0	52
		T2	33	19	0	52
		T3	33	19	0	52
		T4	33	19	0	52
		T5	33	19	0	52
		T6	33	19	0	52
		T7	33	19	0	52
		T8	33	19	0	52
		T9	33	19	0	52
5/2/2002 Vegetative stage	10	T1	38	19	2	55
		T2	38	19	2	55
		T3	38	19	2	55
		T4	38	19	2	55
		T5	38	19	2	55
		T6	38	19	2	55
		T7	38	19	2	55
		T8	38	19	2	55
		T9	38	19	2	55
15/02/02 Vegetative stage	10	T1	38	19	0	57
		T2	38	19	0	57
		T3	38	19	0	57
		T4	38	19	0	57
		T5	38	19	0	57
		T6	38	19	0	57
		T7	38	19	0	57
		T8	38	19	0	57
		T9	38	19	0	57
25/02/01 Vegetative stage	15	T1	74	29	0	103
		T2	56	29	0	85
		T3	37	29	0	66
		T4	19	29	0	48
		T5	1	0	0	1
		T6	74	0	0	74
		T7	74	0	0	74
		T8	74	0	0	74
		T9	74	0	0	74

Appendix IX (continued)

Year: 2000-2001

Date of irrigation	Irrigation cycle, days	Treatments	Etc for the cycle, mm	Percolation for the cycle, mm	Effective rainfall, mm	Net Irrigation water, mm
12/3/2001 Flowering stage	10	T1	51	19	0	70
		T2	51	19	0	70
		T3	51	19	0	70
		T4	51	19	0	70
		T5	51	19	0	70
		T6	51	19	0	70
		T7	51	19	0	70
		T8	51	19	0	70
		T9	51	19	0	70
22/03/01 Flowering stage	5	T1	26	0	2	24
		T2	26	0	2	24
		T3	26	0	2	24
		T4	26	0	2	24
		T5	26	10	2	34
		T6	26	0	2	24
		T7	26	0	2	24
		T8	26	0	2	24
		T9	26	0	2	24
27/03/01 Yield formation stage	10	T1	58	19	0	77
		T2	58	19	0	77
		T3	58	19	0	77
		T4	58	19	0	77
		T5	58	19	0	77
		T6	58	19	0	77
		T7	58	19	0	77
		T8	58	19	0	77
		T9	58	19	0	77
6/4/2001 Yield formation stage	10	T1	64	19	0	83
		T2	64	19	0	83
		T3	64	19	0	83
		T4	64	19	0	83
		T5	64	19	0	83
		T6	64	19	0	83
		T7	64	19	0	83
		T8	64	19	0	83
		T9	64	19	0	83

Appendix IX (continued)

Year: 2000-2001

Date of irrigation	Irrigation cycle, days	Treatments	Etc for the cycle, mm	Percolation for the cycle, mm	Effective rainfall, mm	Net Irrigation water, mm
16/04/01 Yield formation stage	10	T1	64	19	0	83
		T2	64	19	0	83
		T3	64	19	0	83
		T4	64	19	0	83
		T5	64	19	0	83
		T6	45	19	0	64
		T7	27	19	0	46
		T8	8	19	0	27
		T9	0	19	0	19
26/04/01 Ripening stage	10	T1	58	0	0	58
		T2	58	0	0	58
		T3	58	0	0	58
		T4	58	0	0	58
		T5	58	0	0	58
		T6	58	0	0	58
		T7	58	0	0	58
		T8	58	0	0	58
		T9	58	0	0	58
6/5/2001 Ripening stage	10	T1	56	0	0	56
		T2	56	0	0	56
		T3	56	0	0	56
		T4	56	0	0	56
		T5	56	0	0	56
		T6	56	0	0	56
		T7	56	0	0	56
		T8	56	0	0	56
		T9	56	0	0	56

N.B. No percolation water was applied in ripening stage

Appendix IX (continued)

Year: 2002-2003

Date of irrigation	Irrigation cycle, days	Treatments	Etc for the cycle, mm	Percolation for the cycle, mm	Effective rainfall, mm	Net Irrigation water, mm
7/2/2003 Vegetative stage	10	T1	38	17	0	55
		T2	34	17	0	51
		T3	30	17	0	47
		T4	27	17	0	44
		T5	23	16	0	39
		T6	38	17	0	55
		T7	38	17	0	55
		T8	38	17	0	55
		T9	38	17	0	55
		T10	34	17	0	51
		T11	30	17	0	47
		T12	27	17	0	44
		T13	23	16	0	39
17/02/03 Vegetative stage	10	T1	38	17	2	53
		T2	34	17	2	49
		T3	30	17	2	45
		T4	27	17	2	42
		T5	23	16	2	37
		T6	38	17	2	53
		T7	38	17	2	53
		T8	38	17	2	53
		T9	38	17	2	53
		T10	34	17	2	49
		T11	30	17	2	45
		T12	27	17	2	42
		T13	23	16	2	37
27/2/03 Vegetative stage	10	T1	48	18	11	55
		T2	43	17	11	49
		T3	38	17	11	44
		T4	34	17	11	40
		T5	29	17	11	35
		T6	48	18	11	55
		T7	48	18	11	55
		T8	48	18	11	55
		T9	48	18	11	55
		T10	43	17	11	49
		T11	38	17	11	44
		T12	34	17	11	40
		T13	29	17	11	35

Appendix IX (continued)

Year: 2002-2003

Date of irrigation	Irrigation cycle, days	Treatments	Etc for the cycle, mm	Percolation for the cycle, mm	Effective rainfall, mm	Net Irrigation water, mm
9/3/2003 Vegetative stage	7	T1	39	12	0	51
		T2	35	12	0	47
		T3	31	12	0	43
		T4	27	12	0	39
		T5	23	11	0	34
		T6	39	12	0	51
		T7	39	12	0	51
		T8	39	12	0	51
		T9	39	12	0	51
		T10	35	12	0	47
		T11	31	12	0	43
		T12	27	12	0	39
		T13	23	11	0	34
16/03/03 Vegetative stage	5	T1	46	9	25	30
		T2	41	9	25	25
		T3	37	9	25	21
		T4	32	8	25	15
		T5	28	8	25	11
		T6	46	9	25	30
		T7	46	9	25	30
		T8	46	9	25	30
		T9	46	9	25	30
		T10	41	9	25	25
		T11	37	9	25	21
		T12	32	8	25	15
		T13	28	8	25	11
21/03/03 Vflowering stage	8	T1	51	14	20	45
		T2	51	14	20	45
		T3	51	14	20	45
		T4	51	14	20	45
		T5	51	14	20	45
		T6	51	14	20	45
		T7	51	14	20	45
		T8	51	14	20	45
		T9	51	14	20	45
		T10	51	14	20	45
		T11	51	14	20	45
		T12	51	14	20	45
		T13	51	14	20	45

Appendix IX (continued)

Year: 2002-2003

Date of irrigation	Irrigation cycle, days	Treatments	Etc for the cycle, mm	Percolation for the cycle, mm	Effective rainfall, mm	Net Irrigation water, mm
29/03/03 Flowering stage	7	T1	45	12	20	37
		T2	45	12	20	37
		T3	45	12	20	37
		T4	45	12	20	37
		T5	45	12	20	37
		T6	45	12	20	37
		T7	45	12	20	37
		T8	45	12	20	37
		T9	45	12	20	37
		T10	45	12	20	37
		T11	45	12	20	37
		T12	45	12	20	37
		T13	45	12	20	37
5/4/2003 Yield formation stage	8	T1	58	15	0	73
		T2	58	15	0	73
		T3	58	15	0	73
		T4	58	15	0	73
		T5	58	15	0	73
		T6	52	14	0	66
		T7	46	14	0	60
		T8	41	14	0	55
		T9	35	14	0	49
		T10	52	14	0	66
		T11	46	14	0	60
		T12	41	14	0	55
		T13	35	14	0	49

Appendix IX (continued)

Year: 2002-2003

Date of irrigation	Irrigation cycle, days	Treatments	Etc for the cycle, mm	Percolation for the cycle, mm	Effective rainfall, mm	Net Irrigation water, mm
13/4/03 Yield formation stage	8	T1	58	15	0	73
		T2	58	15	0	73
		T3	58	15	0	73
		T4	58	15	0	73
		T5	58	15	0	73
		T6	52	14	0	66
		T7	46	14	0	60
		T8	41	14	0	55
		T9	35	14	0	49
		T10	52	14	0	66
		T11	46	14	0	60
		T12	41	14	0	55
		T13	35	14	0	49
21/04/03 Yield formation stage	7	T1	51	12	0	63
		T2	51	12	0	63
		T3	51	12	0	63
		T4	51	12	0	63
		T5	51	12	0	63
		T6	46	12	0	58
		T7	41	12	0	53
		T8	36	12	0	48
		T9	31	12	0	43
		T10	46	12	0	58
		T11	41	12	0	53
		T12	36	12	0	48
		T13	31	12	0	43
28/04/03 Yield formation stage	7	T1	47	12	0	59
		T2	47	12	0	59
		T3	47	12	0	59
		T4	47	12	0	59
		T5	47	12	0	59
		T6	42	12	0	54
		T7	38	12	0	50
		T8	33	12	0	45
		T9	28	12	0	40
		T10	42	12	0	54
		T11	38	12	0	50
		T12	33	12	0	45
		T13	28	12	0	40

Appendix IX (continued)

Year: 2002-2003

Date of irrigation	Irrigation cycle, days	Treatments	Etc for the cycle, mm	Percolation for the cycle, mm	Effective rainfall, mm	Net Irrigation water, mm
7/5/2003 Ripening stage	10	T1	62	0	0	62
		T2	62	0	0	62
		T3	62	0	0	62
		T4	62	0	0	62
		T5	62	0	0	62
		T6	62	0	0	62
		T7	62	0	0	62
		T8	62	0	0	62
		T9	62	0	0	62
		T10	62	0	0	62
		T11	62	0	0	62
		T12	62	0	0	62
		T13	62	0	0	62
17/05/03 Ripening stage	10	T1	48	0	0	48
		T2	48	0	0	48
		T3	48	0	0	48
		T4	48	0	0	48
		T5	48	0	0	48
		T6	48	0	0	48
		T7	48	0	0	48
		T8	48	0	0	48
		T9	48	0	0	48
		T10	48	0	0	48
		T11	48	0	0	48
		T12	48	0	0	48
		T13	48	0	0	48

N.B. No percolation water was applied in ripening stage

Appendix X Irrigation water calculations of wheat for field experiment

Year: 2000-2001

Date of irrigation	Irrigation cycle, days	Treatments	Etc for the cycle, mm	Effective rainfall, mm	Net Irrigation water, mm
20/11/00 Vegetative stage	10	T1	8	0	8
		T2	8	0	8
		T3	8	0	8
		T4	8	0	8
		T5	8	0	8
		T6	8	0	8
		T7	8	0	8
		T8	8	0	8
		T9	8	0	8
30/11/00 Vegetative stage	10	T1	10	0	10
		T2	10	0	10
		T3	10	0	10
		T4	10	0	10
		T5	10	0	10
		T6	10	0	10
		T7	10	0	10
		T8	10	0	10
		T9	10	0	10
10/12/2000 Vegetative stage	10	T1	15	0	15
		T2	15	0	15
		T3	15	0	15
		T4	15	0	15
		T5	15	0	15
		T6	15	0	15
		T7	15	0	15
		T8	15	0	15
		T9	15	0	15
20/12/00 Vegetative stage	10	T1	23	0	23
		T2	23	0	23
		T3	23	0	23
		T4	23	0	23
		T5	23	0	23
		T6	23	0	23
		T7	23	0	23
		T8	23	0	23
		T9	23	0	23

Appendix X (continued)
Year: 2000-2001

Date of irrigation	Irrigation cycle, days	Treatments	Etc for the cycle, mm	Effective rainfall, mm	Net Irrigation water, mm
30/12/00 Vegetative stage	10	T1	27	0	27
		T2	19	0	19
		T3	10	0	10
		T4	2	0	2
		T5	0	0	0
		T6	27	0	27
		T7	27	0	27
		T8	27	0	27
		T9	27	0	27
9/1/2001 Flowering stage	15	T1	40	0	40
		T2	40	0	40
		T3	40	0	40
		T4	40	0	40
		T5	40	0	40
		T6	40	0	40
		T7	40	0	40
		T8	40	0	40
		T9	40	0	40
24/1/01 Yield formation stage	15	T1	48	0	48
		T2	48	0	48
		T3	48	0	48
		T4	48	0	48
		T5	48	0	48
		T6	48	0	48
		T7	48	0	48
		T8	48	0	48
		T9	48	0	48
8/2/2001 Yield formation stage	10	T1	32	0	32
		T2	32	0	32
		T3	32	0	32
		T4	32	0	32
		T5	32	0	32
		T6	24	0	24
		T7	18	0	18
		T8	8	0	8
		T9	0	0	0

Appendix X (continued)

Year: 2000-2001

Date of irrigation	Irrigation cycle, days	Treatments	Etc for the cycle, mm	Effective rainfall, mm	Net Irrigation water, mm
		T1	38	0	38
		T2	38	0	38
		T3	38	0	38
18/2/01	20	T4	38	0	38
Ripening		T5	38	0	38
stage		T6	38	0	38
		T7	38	0	38
		T8	38	0	38
		T9	38	0	38

Appendix X (continued)

Year: 2002-2003

Date of irrigation	Irrigation cycle, days	Treatments	Etc for the cycle, mm	Effective rainfall, mm	Net Irrigation water, mm
1/12/2002 Vegetative stage	20	T1	20	0	20
		T2	18	0	18
		T3	16	0	16
		T4	14	0	14
		T5	12	0	12
		T6	20	0	20
		T7	20	0	20
		T8	20	0	20
		T9	20	0	20
		T10	18	0	18
		T11	16	0	16
		T12	14	0	14
		T13	12	0	12
20/12/02 Vegetative stage	20	T1	42	0	42
		T2	38	0	38
		T3	34	0	34
		T4	29	0	29
		T5	25	0	25
		T6	42	0	42
		T7	42	0	42
		T8	42	0	42
		T9	42	0	42
		T10	38	0	38
		T11	34	0	34
		T12	29	0	29
		T13	25	0	25
9/1/2003 Flowering stage	15	T1	29	0	29
		T2	26	0	26
		T3	23	0	23
		T4	20	0	20
		T5	17	0	17
		T6	29	0	29
		T7	29	0	29
		T8	29	0	29
		T9	29	0	29
		T10	26	0	26
		T11	23	0	23
		T12	20	0	20
		T13	17	0	17

Appendix X (continued)
Year: 2002-2003

Date of irrigation	Irrigation cycle, days	Treatments	Etc for the cycle, mm	Effective rainfall, mm	Net Irrigation water, mm
		T1	46	0	46
		T2	46	0	46
		T3	46	0	46
		T4	46	0	46
		T5	46	0	46
24/1/03	15	T6	46	0	46
Yield		T7	46	0	46
formation		T8	46	0	46
stage		T9	46	0	46
		T10	46	0	46
		T11	46	0	46
		T12	46	0	46
		T13	46	0	46
		T1	95	4	91
		T2	95	4	91
		T3	95	4	91
		T4	95	4	91
		T5	95	4	91
8/2/2003	20	T6	86	4	82
Yield		T7	76	4	72
formation		T8	67	4	63
stage		T9	57	4	53
		T10	86	4	82
		T11	76	4	72
		T12	67	4	63
		T13	57	4	53
		T1	64	13	51
		T2	64	13	51
		T3	64	13	51
		T4	64	13	51
		T5	64	13	51
		T6	64	13	51
1/3/2003	20	T7	64	13	51
Ripening		T8	64	13	51
stage		T9	64	13	51
		T10	64	13	51
		T11	64	13	51
		T12	64	13	51
		T13	64	13	51

Appendix XI Estimation of yield for different crop evapotranspirations

Crop: Boro rice   Potential yield: Experimental yield

Deficit level, %	Growth stage	Available ETa, mm	Potential crop ET, Etm	F= Eta/Etm	(1-F)	Ky	1-Ky(1-F)= Ya/Ym	Ya/Ym for combined stages	Potential yield, t/ha	Estimated crop yield t/ha
10	vegetative	155	172	0.90	0.10	0.60	0.94			
10	y.formatio	152	169	0.90	0.10	0.28	0.97	0.91	3.72	**3.40**
20	vegetative	138	172	0.80	0.20	0.60	0.88			
20	y.formatio	135	169	0.80	0.20	0.28	0.94	0.83	3.72	**3.09**
30	vegetative	120	172	0.70	0.30	0.60	0.82			
30	y.formatio	118	169	0.70	0.30	0.28	0.92	0.75	3.72	**2.79**
40	vegetative	103	172	0.60	0.40	0.60	0.76			
40	y.formatio	101	169	0.60	0.40	0.28	0.89	0.67	3.72	**2.51**

Crop: Boro rice   Potential yield: Average of Farmers' yield

Deficit level, %	Growth stage	Available ETa, mm	Potential crop ET, Etm	F= Eta/Etm	(1-F)	Ky	1-Ky(1-F)= Ya/Ym	Ya/Ym for combined stages	Potential yield, t/ha	Estimated crop yield t/ha
10	vegetative	155	172	0.90	0.10	0.60	0.94			
10	y.formatio	152	169	0.90	0.10	0.28	0.97	0.91	3.82	**3.49**
20	vegetative	138	172	0.80	0.20	0.60	0.88			
20	y.formatio	135	169	0.80	0.20	0.28	0.94	0.83	3.82	**3.18**
30	vegetative	120	172	0.70	0.30	0.60	0.82			
30	y.formatio	118	169	0.70	0.30	0.28	0.92	0.75	3.82	**2.86**
40	vegetative	103	172	0.60	0.40	0.60	0.76			
40	y.formatio	101	169	0.60	0.40	0.28	0.89	0.67	3.82	**2.57**

Appendix XI continued

Crop: Wheat   Potential yield: Experimental yield

Deficit level, %	Growth stage	Available ETa, mm	Potential crop ET, Etm	F= Eta/Etm	(1-F)	Ky	1-Ky(1-F)= Ya/Ym	Ya/Ym for combined stages	Potential yield, t/ha	Estimated crop yield t/ha
10	vegetative	98	109	0.90	0.10	0.18	0.98			
10	y.formatio	72	80	0.90	0.10	0.46	0.95	0.94	4.10	**3.84**
20	vegetative	87	109	0.80	0.20	0.18	0.96			
20	y.formatio	64	80	0.80	0.20	0.46	0.91	0.88	4.10	**3.59**
30	vegetative	76	109	0.70	0.30	0.18	0.95			
30	y.formatio	56	80	0.70	0.30	0.46	0.86	0.82	4.10	**3.34**
40	vegetative	65	109	0.60	0.40	0.18	0.93			
40	y.formatio	48	80	0.60	0.40	0.46	0.82	0.76	4.10	**3.10**

Crop: Wheat   Potential yield: Average of Farmers' yield

Deficit level, %	Growth stage	Available ETa, mm	Potential crop ET, Etm	F= Eta/Etm	(1-F)	Ky	1-Ky(1-F)= Ya/Ym	Ya/Ym for combined stages	Potential yield, t/ha	Estimated crop yield t/ha
10	vegetative	98	109	0.90	0.10	0.18	0.98			
10	y.formatio	72	80	0.90	0.10	0.46	0.95	0.94	3.00	**2.81**
20	vegetative	87	109	0.80	0.20	0.18	0.96			
20	y.formatio	64	80	0.80	0.20	0.46	0.91	0.88	3.00	**2.63**
30	vegetative	76	109	0.70	0.30	0.18	0.95			
30	y.formatio	56	80	0.70	0.30	0.46	0.86	0.82	3.00	**2.45**
40	vegetative	65	109	0.60	0.40	0.18	0.93			
40	y.formatio	48	80	0.60	0.40	0.46	0.82	0.76	3.00	**2.27**

Appendix XII Estimation of profit of Boro rice at different rainfall probabilities and levels of water application

Irrigation level: Full Probability: 20% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	40	70	2800
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.713	4000	6852
	Labour	Number	10	70	700
Harvesting	Labour	Number	25	70	1750
Carrying	Labour	Number	12	70	840
Threshing	Labour	Number	16	70	1120
Cleaning	Labour	Number	16	70	1120
Variable cost					28773
2. Returns					
Main product	Rice	Mtons	3.72	8500	31620
Bi-product	Straw	Mtons	4.32	1000	4315
Gross return					35935
Profit/hectare					7162

Appendix XII (continued)

Irrigation level: Full Probability: 50% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed preparation for seedling rea:500 sq.m)	Plough	Number	1	375	375
	Seeds	Kg.	50	15	750
	Manure	Kg.	250	0.5	125
	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land preparation	Labour	Number	30	70	2100
	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	40	70	2800
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.761	4000	7044
	Labour	Number	10	70	700
Harvesting	Labour	Number	25	70	1750
Carrying	Labour	Number	12	70	840
Threshing	Labour	Number	16	70	1120
Cleaning	Labour	Number	16	70	1120
Variable cost					28965
2. Returns					
Main product	Rice	Mtons	3.72	8500	31620
Bi-product	Straw	Mtons	4.32	1000	4315
Gross return					35935
Profit/hectare					6970

Appendix XII (continued)

Irrigation level: Full Probability: 80% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	40	70	2800
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.81	4000	7240
	Labour	Number	10	70	700
Harvesting	Labour	Number	25	70	1750
Carrying	Labour	Number	12	70	840
Threshing	Labour	Number	16	70	1120
Cleaning	Labour	Number	16	70	1120
Variable cost					29161
2. Returns					
Main product	Rice	Mtons	3.72	8500	31620
Bi-product	Straw	Mtons	4.32	1000	4315
Gross return					35935
Profit/hectare					6774

Appendix XII (continued)

Irrigation level: 10% deficit Probability: 20% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
.rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	37	70	2590
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.637	4000	6548
	Labour	Number	9	70	630
Harvesting	Labour	Number	23	70	1610
Carrying	Labour	Number	11	70	770
Threshing	Labour	Number	15	70	1050
Cleaning	Labour	Number	15	70	1050
Variable cost					27839
2. Returns					
Main product	Rice	Mtons	3.40	8500	28900
Bi-product	Straw	Mtons	3.94	1000	3944
Gross return					32844
Profit/hectare					5005

Appendix XII (continued)

Irrigation level: 10% deficit Probability: 50% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	37	70	2590
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.685	4000	6740
	Labour	Number	9	70	630
Harvesting	Labour	Number	23	70	1610
Carrying	Labour	Number	11	70	770
Threshing	Labour	Number	15	70	1050
Cleaning	Labour	Number	15	70	1050
Variable cost					28031
2. Returns					
Main product	Rice	Mtons	3.40	8500	28900
Bi-product	Straw	Mtons	3.94	1000	3944
Gross return					32844
Profit/hectare					4813

Appendix XII (continued)

Irrigation level: 10% deficit Probability: 80% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	37	70	2590
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.733	4000	6932
	Labour	Number	9	70	630
Harvesting	Labour	Number	23	70	1610
Carrying	Labour	Number	11	70	770
Threshing	Labour	Number	15	70	1050
Cleaning	Labour	Number	15	70	1050
Variable cost					28223
2. Returns					
Main product	Rice	Mtons	3.40	8500	28900
Bi-product	Straw	Mtons	3.94	1000	3944
Gross return					32844
Profit/hectare					4621

Appendix XII (continued)

Irrigation level: 20% deficit Probability: 20% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	33	70	2310
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.514	4000	6056
	Labour	Number	9	70	630
Harvesting	Labour	Number	21	70	1470
Carrying	Labour	Number	10	70	700
Threshing	Labour	Number	13	70	910
Cleaning	Labour	Number	13	70	910
Variable cost					26577
2. Returns					
Main product	Rice	Mtons	3.09	8500	26265
Bi-product	Straw	Mtons	3.58	1000	3584
Gross return					29849
Profit/hectare					3272

Appendix XII (continued)

Irrigation level: 20% deficit Probability: 50% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	33	70	2310
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.61	4000	6440
	Labour	Number	9	70	630
Harvesting	Labour	Number	21	70	1470
Carrying	Labour	Number	10	70	700
Threshing	Labour	Number	13	70	910
Cleaning	Labour	Number	13	70	910
Variable cost					26961
2. Returns					
Main product	Rice	Mtons	3.09	8500	26265
Bi-product	Straw	Mtons	3.58	1000	3584
Gross return					29849
Profit/hectare					2888

Appendix XII (continued)

Irrigation level: 20% deficit Probability: 80% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	33	70	2310
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.658	4000	6632
	Labour	Number	9	70	630
Harvesting	Labour	Number	21	70	1470
Carrying	Labour	Number	10	70	700
Threshing	Labour	Number	13	70	910
Cleaning	Labour	Number	13	70	910
Variable cost					27153
2. Returns					
Main product	Rice	Mtons	3.09	8500	26265
Bi-product	Straw	Mtons	3.58	1000	3584
Gross return					29849
Profit/hectare					2696

Appendix XII (continued)

Irrigation level: 30% deficit Probability: 20% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	30	70	2100
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.484	4000	5936
	Labour	Number	9	70	630
Harvesting	Labour	Number	19	70	1330
Carrying	Labour	Number	9	70	630
Threshing	Labour	Number	12	70	840
Cleaning	Labour	Number	12	70	840
Variable cost					25897
2. Returns					
Main product	Rice	Mtons	2.79	8500	23715
Bi-product	Straw	Mtons	3.24	1000	3236
Gross return					26951
Profit/hectare					1054

Appendix XII (continued)

Irrigation level: 30% deficit Probability: 50% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	30	70	2100
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.53	4000	6120
	Labour	Number	9	70	630
Harvesting	Labour	Number	19	70	1330
Carrying	Labour	Number	9	70	630
Threshing	Labour	Number	12	70	840
Cleaning	Labour	Number	12	70	840
Variable cost					26081
2. Returns					
Main product	Rice	Mtons	2.79	8500	23715
Bi-product	Straw	Mtons	3.24	1000	3236
Gross return					26951
Profit/hectare					870

Appendix XII (continued)

Irrigation level: 30% deficit Probability: 80% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed preparation for seedling rea:500 sq.m)	Plough	Number	1	375	375
	Seeds	Kg.	50	15	750
	Manure	Kg.	250	0.5	125
	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land preparation	Labour	Number	30	70	2100
	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	30	70	2100
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.579	4000	6316
	Labour	Number	9	70	630
Harvesting	Labour	Number	19	70	1330
Carrying	Labour	Number	9	70	630
Threshing	Labour	Number	12	70	840
Cleaning	Labour	Number	12	70	840
Variable cost					26277
2. Returns					
Main product	Rice	Mtons	2.79	8500	23715
Bi-product	Straw	Mtons	3.24	1000	3236
Gross return					26951
Profit/hectare					674

Appendix XII (continued)

Irrigation level: 40% deficit Probability: 20% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed preparation for seedling rea:500 sq.m)	Plough	Pairs	1	375	375
	Seeds	Kg.	50	15	750
	Manure	Kg.	250	2	500
	Urea	Kg.	5	9	45
	TSP	Kg.	10	8	80
	MP	Kg.	5	7	35
	Labour	Number	4	70	280
Land preparation	Labour	Number	30	70	2100
	Plough	Number	4	375	1500
	Cowdung	M.Ton	4	500	2000
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	200	10	2000
	Mp	Kg.	150	6	900
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	27	70	1890
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.397	4000	5588
	Labour	Number	8	70	560
Harvesting	Labour	Number	17	70	1190
Carrying	Labour	Number	8	70	560
Threshing	Labour	Number	11	70	770
Cleaning	Labour	Number	11	70	770
Variable cost					26885
2. Returns					
Main product	Rice	Mtons	2.51	8500	21335
Bi-product	Straw	Mtons	2.91	1000	2912
Gross return					24247
Profit/hectare					-2638

Appendix XII (continued)

Irrigation level: 40% deficit Probability: 50% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Pairs	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	2	500
rea:500 sq.m)	Urea	Kg.	5	9	45
	TSP	Kg.	10	8	80
	MP	Kg.	5	7	35
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	4	500	2000
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	200	10	2000
	Mp	Kg.	150	6	900
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	27	70	1890
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.453	4000	5812
	Labour	Number	8	70	560
Harvesting	Labour	Number	17	70	1190
Carrying	Labour	Number	8	70	560
Threshing	Labour	Number	11	70	770
Cleaning	Labour	Number	11	70	770
Variable cost					27109
2. Returns					
Main product	Rice	Mtons	2.51	8500	21335
Bi-product	Straw	Mtons	2.91	1000	2912
Gross return					24247
Profit/hectare					-2862

Appendix XII (continued)

Irrigation level: 40% deficit Probability: 80% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Pairs	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	2	500
rea:500 sq.m)	Urea	Kg.	5	9	45
	TSP	Kg.	10	8	80
	MP	Kg.	5	7	35
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	4	500	2000
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	200	10	2000
	Mp	Kg.	150	6	900
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	27	70	1890
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.503	4000	6012
	Labour	Number	8	70	560
Harvesting	Labour	Number	17	70	1190
Carrying	Labour	Number	8	70	560
Threshing	Labour	Number	11	70	770
Cleaning	Labour	Number	11	70	770
Variable cost					27309
2. Returns					
Main product	Rice	Mtons	2.51	8500	21335
Bi-product	Straw	Mtons	2.91	1000	2912
Gross return					24247
Profit/hectare					-3062

Appendix XII (Continued)

Irrigation level: Full   Rainfall probability: 20%   Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Pairs	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	1.5	375
rea:500 sq.m)	Urea	Kg.	5	6	30
	TSP	Kg.	10	10	100
	MP	Kg.	5	8	40
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	Kg.	1250	1.5	1875
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	41	70	2870
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.713	4000	6852
	Labour	Number	10	70	700
Harvesting	Labour	Number	26	70	1820
Carrying	Labour	Number	12	70	840
Threshing	Labour	Number	16	70	1120
Cleaning	Labour	Number	16	70	1120
Variable cost					28609
2. Returns					
Main product	Rice	Mtons	3.82	8500	32470
Bi-product	Straw	Mtons	4.43	1000	4431.2
Gross return					36901.2
Profit/hectare					8292

Appendix XII (continued)

Irrigation level: Full Rainfall probability: 50% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Pairs	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	1.5	375
rea:500 sq.m)	Urea	Kg.	5	6	30
	TSP	Kg.	10	10	100
	MP	Kg.	5	8	40
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	Kg.	1250	1.5	1875
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	41	70	2870
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.761	4000	7044
	Labour	Number	10	70	700
Harvesting	Labour	Number	26	70	1820
Carrying	Labour	Number	12	70	840
Threshing	Labour	Number	16	70	1120
Cleaning	Labour	Number	16	70	1120
Variable cost					28801
2. Returns					
Main product	Rice	Mtons	3.82	8500	32470
Bi-product	Straw	Mtons	4.43	1000	4431.2
Gross return					36901.2
Profit/hectare					8100

Appendix XII (continued)

Irrigation level: Full   Rainfall probability: 80% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Pairs	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	1.5	375
rea:500 sq.m)	Urea	Kg.	5	6	30
	TSP	Kg.	10	10	100
	MP	Kg.	5	8	40
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	Kg.	1250	1.5	1875
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	41	70	2870
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.81	4000	7240
	Labour	Number	10	70	700
Harvesting	Labour	Number	26	70	1820
Carrying	Labour	Number	12	70	840
Threshing	Labour	Number	16	70	1120
Cleaning	Labour	Number	16	70	1120
Variable cost					28997
2. Returns					
Main product	Rice	Mtons	3.82	8500	32470
Bi-product	Straw	Mtons	4.43	1000	4431.2
Gross return					36901.2
Profit/hectare					7904

Appendix XII (continued)

Irrigation level: 10% deficit Probability: 20% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	Kg.	1250	1.5	1875
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	37	70	2590
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.637	4000	6548
	Labour	Number	10	70	700
Harvesting	Labour	Number	24	70	1680
Carrying	Labour	Number	11	70	770
Threshing	Labour	Number	15	70	1050
Cleaning	Labour	Number	15	70	1050
Variable cost					27354
2. Returns					
Main product	Rice	Mtons	3.49	8500	29665
Bi-product	Straw	Mtons	4.05	1000	4048
Gross return					33713
Profit/hectare					6359

Appendix XII (continued)

Irrigation level: 10% deficit   Probability: 50%   Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	Kg.	1250	1.5	1875
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	37	70	2590
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.685	4000	6740
	Labour	Number	10	70	700
Harvesting	Labour	Number	24	70	1680
Carrying	Labour	Number	11	70	770
Threshing	Labour	Number	15	70	1050
Cleaning	Labour	Number	15	70	1050
Variable cost					27546
2. Returns					
Main product	Rice	Mtons	3.49	8500	29665
Bi-product	Straw	Mtons	4.05	1000	4048
Gross return					33713
Profit/hectare					6167

Appendix XII (continued)

Irrigation level: 10% deficit Probability: 80% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	Kg.	1250	1.5	1875
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	37	70	2590
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.733	4000	6932
	Labour	Number	10	70	700
Harvesting	Labour	Number	24	70	1680
Carrying	Labour	Number	11	70	770
Threshing	Labour	Number	15	70	1050
Cleaning	Labour	Number	15	70	1050
Variable cost					27738
2. Returns					
Main product	Rice	Mtons	3.49	8500	29665
Bi-product	Straw	Mtons	4.05	1000	4048
Gross return					33713
Profit/hectare					5975

Appendix XII (continued)

Irrigation level: 20% deficit Probability: 20% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	34	70	2380
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.514	4000	6056
	Labour	Number	9	70	630
Harvesting	Labour	Number	22	70	1540
Carrying	Labour	Number	10	70	700
Threshing	Labour	Number	13	70	910
Cleaning	Labour	Number	13	70	910
Variable cost					26717
2. Returns					
Main product	Rice	Mtons	3.18	8500	27030
Bi-product	Straw	Mtons	3.69	1000	3689
Gross return					30719
Profit/hectare					4002

Appendix XII (continued)

Irrigation level: 20% deficit Probability: 50% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	34	70	2380
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.61	4000	6440
	Labour	Number	9	70	630
Harvesting	Labour	Number	22	70	1540
Carrying	Labour	Number	10	70	700
Threshing	Labour	Number	13	70	910
Cleaning	Labour	Number	13	70	910
Variable cost					27101
2. Returns					
Main product	Rice	Mtons	3.18	8500	27030
Bi-product	Straw	Mtons	3.69	1000	3689
Gross return					30719
Profit/hectare					3618

Appendix XII (continued)

Irrigation level: 20% deficit Probability: 80% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	34	70	2380
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.658	4000	6632
	Labour	Number	9	70	630
Harvesting	Labour	Number	22	70	1540
Carrying	Labour	Number	10	70	700
Threshing	Labour	Number	13	70	910
Cleaning	Labour	Number	13	70	910
Variable cost					27293
2. Returns					
Main product	Rice	Mtons	3.18	8500	27030
Bi-product	Straw	Mtons	3.69	1000	3689
Gross return					30719
Profit/hectare					3426

Appendix XII (continued)

Irrigation level: 30% deficit Probability: 20% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	31	70	2170
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.484	4000	5936
	Labour	Number	9	70	630
Harvesting	Labour	Number	20	70	1400
Carrying	Labour	Number	9	70	630
Threshing	Labour	Number	12	70	840
Cleaning	Labour	Number	12	70	840
Variable cost					26037
2. Returns					
Main product	Rice	Mtons	2.86	8500	24310
Bi-product	Straw	Mtons	3.32	1000	3318
Gross return					27628
Profit/hectare					1591

Appendix XII (continued)

Irrigation level: 30% deficit Probability: 50% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	31	70	2170
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.53	4000	6120
	Labour	Number	9	70	630
Harvesting	Labour	Number	20	70	1400
Carrying	Labour	Number	9	70	630
Threshing	Labour	Number	12	70	840
Cleaning	Labour	Number	12	70	840
Variable cost					26221
2. Returns					
Main product	Rice	Mtons	2.86	8500	24310
Bi-product	Straw	Mtons	3.32	1000	3318
Gross return					27628
Profit/hectare					1407

Appendix XII (continued)

Irrigation level: 30% deficit Probability: 80% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	31	70	2170
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.579	4000	6316
	Labour	Number	9	70	630
Harvesting	Labour	Number	20	70	1400
Carrying	Labour	Number	9	70	630
Threshing	Labour	Number	12	70	840
Cleaning	Labour	Number	12	70	840
Variable cost					26417
2. Returns					
Main product	Rice	Mtons	2.86	8500	24310
Bi-product	Straw	Mtons	3.32	1000	3318
Gross return					27628
Profit/hectare					1211

Appendix XII (continued)

Irrigation level: 40% deficit Probability: 20% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	28	70	1960
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.397	4000	5588
	Labour	Number	8	70	560
Harvesting	Labour	Number	18	70	1260
Carrying	Labour	Number	8	70	560
Threshing	Labour	Number	11	70	770
Cleaning	Labour	Number	11	70	770
Variable cost					25059
2. Returns					
Main product	Rice	Mtons	2.57	8500	21845
Bi-product	Straw	Mtons	2.98	1000	2981
Gross return					24826
Profit/hectare					-233

Appendix XII (continued)

Irrigation level: 40% deficit Probability: 50% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	28	70	1960
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.453	4000	5812
	Labour	Number	8	70	560
Harvesting	Labour	Number	18	70	1260
Carrying	Labour	Number	8	70	560
Threshing	Labour	Number	11	70	770
Cleaning	Labour	Number	11	70	770
Variable cost					25283
2. Returns					
Main product	Rice	Mtons	2.57	8500	21845
Bi-product	Straw	Mtons	2.98	1000	2981
Gross return					24826
Profit/hectare					-457

Appendix XII (continued)

Irrigation level: 40% deficit Probability: 80% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
1. Cost items					
Seedbed	Plough	Number	1	375	375
preparation	Seeds	Kg.	50	15	750
for seedling	Manure	Kg.	250	0.5	125
rea:500 sq.m)	Urea	Kg.	6	9	54
	TSP	Kg.	3	8	24
	MP	Kg.	3	7	21
	Labour	Number	4	70	280
Land	Labour	Number	30	70	2100
preparation	Plough	Number	4	375	1500
	Cowdung	M.Ton	5	500	2500
	Gypsum	Kg.	36	4.5	162
	TSP	Kg.	60	8	480
	Mp	Kg.	60	6.5	390
Transplanting	Labour	Number	30	70	2100
Weeding	Labour	Number	28	70	1960
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Pest Control	Pesticides	Lump sum			600
	Labour	Number	7	70	490
Irrigation	Water	Ha-m	1.503	4000	6012
	Labour	Number	8	70	560
Harvesting	Labour	Number	18	70	1260
Carrying	Labour	Number	8	70	560
Threshing	Labour	Number	11	70	770
Cleaning	Labour	Number	11	70	770
Variable cost					25483
2. Returns					
Main product	Rice	Mtons	2.57	8500	21845
Bi-product	Straw	Mtons	2.98	1000	2981
Gross return					24826
Profit/hectare					-657

Appendix XIII Estimation of profit of wheat at different rainfall probabilities and levels of water application

Irrigation Level: Full Probability: 20% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	50	70	3500
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.428	4000	1712
	Labour	Number	7	70	490
Harvesting	Labour	Number	30	70	2100
Carrying	Labour	Number	12	70	840
Threshing	Labour	Number	35	70	2450
Cleaning	Labour	Number	20	70	1400
Variable cost					26837
Main product	wheat	Mtons	4.1	9000	36900
Bi-product	Straw	Mtons	4.22	1000	4223
Gross return					41123
Profit/hectare					14286

Irrigation Level: Full Probability: 50% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	rice (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	50	70	3500
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.442	4000	1768
	Labour	Number	7	70	490
Harvesting	Labour	Number	30	70	2100
Carrying	Labour	Number	12	70	840
Threshing	Labour	Number	35	70	2450
Cleaning	Labour	Number	20	70	1400
Variable cost					26893
Main product	wheat	Mtons	4.1	9000	36900
Bi-product	Straw	Mtons	4.22	1000	4223
Gross return					41123
Profit/hectare					14230

Appendix XIII (continued)

Irrigation Level: Full Probability: 80% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	50	70	3500
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.452	4000	1808
	Labour	Number	7	70	490
Harvesting	Labour	Number	30	70	2100
Carrying	Labour	Number	12	70	840
Threshing	Labour	Number	35	70	2450
Cleaning	Labour	Number	20	70	1400
Variable cost					26933
Main product	wheat	Mtons	4.1	9000	36900
Bi-product	Straw	Mtons	4.22	1000	4223
Gross return					41123
Profit/hectare					14190

Irrigation Level: 10% deficit Probability: 20% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	47	70	3290
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.376	4000	1504
	Labour	Number	6	70	420
Harvesting	Labour	Number	28	70	1960
Carrying	Labour	Number	11	70	770
Threshing	Labour	Number	33	70	2310
Cleaning	Labour	Number	19	70	1330
Variable cost					25929
Main product	Wheat	Mtons	3.84	9000	34560
Bi-product	Straw	Mtons	3.96	1000	3955
Gross return					38515
Profit/hectare					12586

Appendix XIII (continued)

Irrigation Level: 10% deficit Probability: 50% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	47	70	3290
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.389	4000	1556
	Labour	Number	6	70	420
Harvesting	Labour	Number	28	70	1960
Carrying	Labour	Number	11	70	770
Threshing	Labour	Number	33	70	2310
Cleaning	Labour	Number	19	70	1330
Variable cost					25981
Main product	Wheat	Mtons	3.84	9000	34560
Bi-product	Straw	Mtons	3.96	1000	3955
Gross return					38515
Profit/hectare					12534

Irrigation Level: 10% deficit Probability: 80% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	47	70	3290
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.401	4000	1604
	Labour	Number	6	70	420
Harvesting	Labour	Number	28	70	1960
Carrying	Labour	Number	11	70	770
Threshing	Labour	Number	33	70	2310
Cleaning	Labour	Number	19	70	1330
Variable cost					26029
Main product	Wheat	Mtons	3.84	9000	34560
Bi-product	Straw	Mtons	3.96	1000	3955
Gross return					38515
Profit/hectare					12486

Appendix XIII (continued)

Irrigation Level: 20% deficit Probability: 20% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	44	70	3080
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.322	4000	1288
	Labour	Number	5	70	350
Harvesting	Labour	Number	26	70	1820
Carrying	Labour	Number	11	70	770
Threshing	Labour	Number	31	70	2170
Cleaning	Labour	Number	18	70	1260
Variable cost					25083
Main product	Wheat	Mtons	3.59	9000	32310
Bi-product	Straw	Mtons	3.70	1000	3698
Gross return					36008
Profit/hectare					10925

Irrigation Level: 20% deficit Probability: 50% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	44	70	3080
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.335	4000	1340
	Labour	Number	5	70	350
Harvesting	Labour	Number	26	70	1820
Carrying	Labour	Number	11	70	770
Threshing	Labour	Number	31	70	2170
Cleaning	Labour	Number	18	70	1260
Variable cost					25135
Main product	Wheat	Mtons	3.59	9000	32310
Bi-product	Straw	Mtons	3.70	1000	3698
Gross return					36008
Profit/hectare					10873

Appendix XIII (continued)

Irrigation Level: 20% deficit Probability: 80% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	44	70	3080
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.347	4000	1388
	Labour	Number	5	70	350
Harvesting	Labour	Number	26	70	1820
Carrying	Labour	Number	11	70	770
Threshing	Labour	Number	31	70	2170
Cleaning	Labour	Number	18	70	1260
Variable cost					25183
Main product	Wheat	Mtons	3.59	9000	32310
Bi-product	Straw	Mtons	3.70	1000	3698
Gross return					36008
Profit/hectare					10825

Irrigation Level: 30% deficit Probability: 20% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	41	70	2870
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.274	4000	1096
	Labour	Number	5	70	350
Harvesting	Labour	Number	24	70	1680
Carrying	Labour	Number	10	70	700
Threshing	Labour	Number	29	70	2030
Cleaning	Labour	Number	16	70	1120
Variable cost					24191
Main product	Wheat	Mtons	3.34	9000	30060
Bi-product	Straw	Mtons	3.44	1000	3440
Gross return					33500
Profit/hectare					9309

Appendix XIII (continued)

Irrigation Level: 30% deficit Probability: 50% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	41	70	2870
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.287	4000	1148
	Labour	Number	5	70	350
Harvesting	Labour	Number	24	70	1680
Carrying	Labour	Number	10	70	700
Threshing	Labour	Number	29	70	2030
Cleaning	Labour	Number	16	70	1120
Variable cost					24243
Main product	Wheat	Mtons	3.34	9000	30060
Bi-product	Straw	Mtons	3.44	1000	3440
Gross return					33500
Profit					9257

Irrigation Level: 30% deficit Probability: 80% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	41	70	2870
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.3	4000	1200
	Labour	Number	5	70	350
Harvesting	Labour	Number	24	70	1680
Carrying	Labour	Number	10	70	700
Threshing	Labour	Number	29	70	2030
Cleaning	Labour	Number	16	70	1120
Variable cost					24295
Main product	Wheat	Mtons	3.34	9000	30060
Bi-product	Straw	Mtons	3.44	1000	3440
Gross return					33500
Profit/hectare					9205

Appendix XIII (continued)

Irrigation Level: 40% deficit Probability: 20% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	38	70	2660
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.222	4000	888
	Labour	Number	4	70	280
Harvesting	Labour	Number	23	70	1610
Carrying	Labour	Number	9	70	630
Threshing	Labour	Number	26	70	1820
Cleaning	Labour	Number	15	70	1050
Variable cost					23283
Main product	Wheat	Mtons	3.1	9000	27900
Bi-product	Straw	Mtons	3.19	1000	3193
Gross return					31093
Profit					7810

Irrigation Level: 40% deficit Probability: 50% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	38	70	2660
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.235	4000	940
	Labour	Number	4	70	280
Harvesting	Labour	Number	23	70	1610
Carrying	Labour	Number	9	70	630
Threshing	Labour	Number	26	70	1820
Cleaning	Labour	Number	15	70	1050
Variable cost					23335
Main product	Wheat	Mtons	3.1	9000	27900
Bi-product	Straw	Mtons	3.19	1000	3193
Gross return					31093
Profit/hectare					7758

Appendix XIII (continued)

Irrigation Level: 40% deficit Probability: 80% Crop yield: Experimental field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	38	70	2660
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.248	4000	992
	Labour	Number	4	70	280
Harvesting	Labour	Number	23	70	1610
Carrying	Labour	Number	9	70	630
Threshing	Labour	Number	26	70	1820
Cleaning	Labour	Number	15	70	1050
Variable cost					23387
Main product	Wheat	Mtons	3.1	9000	27900
Bi-product	Straw	Mtons	3.19	1000	3193
Gross return					31093
Profit/hectare					7706

Irrigation Level: Full Probability: 20% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	37	70	2590
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.428	4000	1712
	Labour	Number	7	70	490
Harvesting	Labour	Number	22	70	1540
Carrying	Labour	Number	9	70	630
Threshing	Labour	Number	26	70	1820
Cleaning	Labour	Number	15	70	1050
Variable cost					24177
Main product	Wheat	Mtons	3.0	9000	27000
Bi-product	Straw	Mtons	3.09	1000	3090
Gross return					30090
Profit/hectare					5913

XIII

Appendix XIV (Continued)

Irrigation Level: Full Probability: 50% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	37	70	2590
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.442	4000	1768
	Labour	Number	7	70	490
Harvesting	Labour	Number	22	70	1540
Carrying	Labour	Number	9	70	630
Threshing	Labour	Number	26	70	1820
Cleaning	Labour	Number	15	70	1050
Variable cost					24233
Main product	Wheat	Mtons	3.0	9000	27000
Bi-product	Straw	Mtons	3.09	1000	3090
Gross return					30090
Profit/hectare					5857

Irrigation Level: Full Probability: 80% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	37	70	2590
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.456	4000	1824
	Labour	Number	7	70	490
Harvesting	Labour	Number	22	70	1540
Carrying	Labour	Number	9	70	630
Threshing	Labour	Number	26	70	1820
Cleaning	Labour	Number	15	70	1050
Variable cost					24289
Main product	Wheat	Mtons	3.0	9000	27000
Bi-product	Straw	Mtons	3.09	1000	3090
Gross return					30090
Profit/hectare					5801

Appendix XIII (continued)

Irrigation Level: 10% deficit Probability: 20% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	35	70	2450
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.376	4000	1504
	Labour	Number	6	70	420
Harvesting	Labour	Number	21	70	1470
Carrying	Labour	Number	8	70	560
Threshing	Labour	Number	24	70	1680
Cleaning	Labour	Number	14	70	980
Variable cost					23409
Main product	Wheat	Mtons	2.81	9000	25290
Bi-product	Straw	Mtons	2.89	1000	2894
Gross return					28184
Profit/hectare					4775

Irrigation Level: 10% deficit Probability: 50% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	35	70	2450
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.389	4000	1556
	Labour	Number	6	70	420
Harvesting	Labour	Number	21	70	1470
Carrying	Labour	Number	8	70	560
Threshing	Labour	Number	24	70	1680
Cleaning	Labour	Number	14	70	980
Variable cost					23461
Main product	Wheat	Mtons	2.81	9000	25290
Bi-product	Straw	Mtons	2.89	1000	2894
Gross return					28184
Profit/hectare					4723

Appendix XIII (continued)

Irrigation Level: 10% deficit Probability: 80% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	35	70	2450
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.401	4000	1604
	Labour	Number	6	70	420
Harvesting	Labour	Number	21	70	1470
Carrying	Labour	Number	8	70	560
Threshing	Labour	Number	24	70	1680
Cleaning	Labour	Number	14	70	980
Variable cost					23509
Main product	Wheat	Mtons	2.81	9000	25290
Bi-product	Straw	Mtons	2.89	1000	2894
Gross return					28184
Profit/hectare					4675

Irrigation Level: 20% deficit Probability: 20% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	32	70	2240
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.322	4000	1288
	Labour	Number	5	70	350
Harvesting	Labour	Number	19	70	1330
Carrying	Labour	Number	8	70	560
Threshing	Labour	Number	23	70	1610
Cleaning	Labour	Number	13	70	910
Variable cost					22633
Main product	Wheat	Mtons	2.63	9000	23670
Bi-product	Straw	Mtons	2.71	1000	2709
Gross return					26379
Profit/hectare					3746

Appendix XIII (continued)

Irrigation Level: 20% deficit Probability: 50% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	32	70	2240
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.335	4000	1340
	Labour	Number	5	70	350
Harvesting	Labour	Number	19	70	1330
Carrying	Labour	Number	8	70	560
Threshing	Labour	Number	23	70	1610
Cleaning	Labour	Number	13	70	910
Variable cost					22685
Main product	Wheat	Mtons	2.63	9000	23670
Bi-product	Straw	Mtons	2.71	1000	2709
Gross retum					26379
Profit/hectare					3694

Irrigation Level: 20% deficit Probability: 80% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	32	70	2240
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.347	4000	1388
	Labour	Number	5	70	350
Harvesting	Labour	Number	19	70	1330
Carrying	Labour	Number	8	70	560
Threshing	Labour	Number	23	70	1610
Cleaning	Labour	Number	13	70	910
Variable cost					22733
Main product	Wheat	Mtons	2.63	9000	23670
Bi-product	Straw	Mtons	2.71	1000	2709
Gross return					26379
Profit/hectare					3646

Appendix XIII (continued)

Irrigation Level: 30% deficit Probability: 20% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land preparation	Labour	Number	30	70	2100
	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	30	70	2100
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.274	4000	1096
	Labour	Number	5	70	350
Harvesting	Labour	Number	18	70	1260
Carrying	Labour	Number	7	70	490
Threshing	Labour	Number	21	70	1470
Cleaning	Labour	Number	12	70	840
Variable cost					21951
Main product	Wheat	Mtons	2.45	9000	22050
Bi-product	Straw	Mtons	2.52	1000	2524
Gross retum					24574
Profit/hectare					2623

Irrigation Level: 30% deficit Probability: 50% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land preparation	Labour	Number	30	70	2100
	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	30	70	2100
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.287	4000	1148
	Labour	Number	5	70	350
Harvesting	Labour	Number	18	70	1260
Carrying	Labour	Number	7	70	490
Threshing	Labour	Number	21	70	1470
Cleaning	Labour	Number	12	70	840
Variable cost					22003
Main product	Wheat	Mtons	2.45	9000	22050
Bi-product	Straw	Mtons	2.52	1000	2524
Gross return					24574
Profit/hectare					2571

Appendix XIII (continued)

Irrigation Level: 30% deficit Probability: 80% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
Land preparation	Plough	Number	3	375	1125
	Labour	Number	30	70	2100
	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	30	70	2100
Top dressing of fertilizer	Labour	Number	8	70	560
	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.3	4000	1200
	Labour	Number	5	70	350
Harvesting	Labour	Number	18	70	1260
Carrying	Labour	Number	7	70	490
Threshing	Labour	Number	21	70	1470
Cleaning	Labour	Number	12	70	840
Variable cost					22055
Main product	Wheat	Mtons	2.45	9000	22050
Bi-product	Straw	Mtons	2.52	1000	2524
Gross return					24574
Profit/hectare					2519

Irrigation Level: 40% deficit Probability: 20% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
Land preparation	Plough	Number	3	375	1125
	Labour	Number	30	70	2100
	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	28	70	1960
Top dressing of fertilizer	Labour	Number	8	70	560
	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.222	4000	888
	Labour	Number	4	70	280
Harvesting	Labour	Number	17	70	1190
Carrying	Labour	Number	7	70	490
Threshing	Labour	Number	20	70	1400
Cleaning	Labour	Number	11	70	770
Variable cost					21323
Main product	Wheat	Mtons	2.27	9000	20430
Bi-product	Straw	Mtons	2.34	1000	2338
Gross return					22768
Profit/hectare					1445

Appendix XIII (continued)

Irrigation Level: 40% deficit Probability: 50% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	28	70	1960
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.235	4000	940
	Labour	Number	4	70	280
Harvesting	Labour	Number	17	70	1190
Carrying	Labour	Number	7	70	490
Threshing	Labour	Number	20	70	1400
Cleaning	Labour	Number	11	70	770
Variable cost					21375
Main product	Wheat	Mtons	2.27	9000	20430
Bi-product	Straw	Mtons	2.34	1000	2338
Gross return					22768
Profit/hectare					1393

Irrigation Level: 40% deficit Probability: 80% Crop yield: Farmers' field data

Activities	Inputs	Units	Quantity	Price (Tk/unit)	Value (Tk.)
	Plough	Number	3	375	1125
Land	Labour	Number	30	70	2100
preparation	Seeds	Kg	120	10	1200
	Urea	Kg.	200	9	1800
	TSP	Kg.	160	8	1280
	MP	Kg.	50	6.5	325
	Cowdung	Mtons	4	1500	6000
Weeding	Labour	Number	28	70	1960
Top dressing	Labour	Number	8	70	560
of fertilizer	Urea	Kg.	120	9	1080
Irrigation	Water	Ha-m	0.248	4000	992
	Labour	Number	4	70	280
Harvesting	Labour	Number	17	70	1190
Carrying	Labour	Number	7	70	490
Threshing	Labour	Number	20	70	1400
Cleaning	Labour	Number	11	70	770
Variable cost					21427
Main product	Wheat	Mtons	2.27	9000	20430
Bi-product	Straw	Mtons	2.34	1000	2338
Gross retum					22768
Profit/hectare					1341

Appendix XIV Decision variables and parameters of LP model

Decision variables under different crops

Crop	Rainfall probability	Irrigation level	Irrigated area, ha
i = 1	j = 1	k = 1	A_{111}
		k = 2	A_{112}
		k = 3	A_{113}
		k = 4	A_{114}
		k = 5	A_{115}
	j = 2	k = 1	A_{121}
		k = 2	A_{122}
		k = 3	A_{123}
		k = 4	A_{124}
		k = 5	A_{125}
	j = 3	k = 1	A_{131}
		k = 2	A_{132}
		k = 3	A_{133}
		k = 4	A_{134}
		k = 5	A_{135}
i = 2	j = 1	k = 1	A_{211}
		k = 2	A_{212}
		k = 3	A_{213}
		k = 4	A_{214}
		k = 5	A_{215}
	j = 2	k = 1	A_{221}
		k = 2	A_{222}
		k = 3	A_{223}
		k = 4	A_{224}
		k = 5	A_{225}
	j = 3	k = 1	A_{231}
		k = 2	A_{232}
		k = 3	A_{233}
		k = 4	A_{234}
		k = 5	A_{235}

Appendix XIV (continued)

Objective Function Coefficients (Profit per hectare)

B_{ijk} = profit (Tk./ha) for crop i under rainfall probability j and irrigation level k

Where, i = 1, 2, j = 1, 2, 3, k = 1, 2, 3, 4, 5

Experimental yield

Crop	Rainfall probability	Irrigation level	Profit per ha, Bijk, (Tk./ha)	Value of Bijk, Tk./ha.
i = 1	j = 1	k = 1	B_{111}	7162
		k = 2	B_{112}	5005
		k = 3	B_{113}	3272
		k = 4	B_{114}	1054
		k = 5	B_{115}	-2638
	j = 2	k = 1	B_{121}	6970
		k = 2	B_{122}	4813
		k = 3	B_{123}	2888
		k = 4	B_{124}	870
		k = 5	B_{125}	-2862
	j = 3	k = 1	B_{131}	6774
		k = 2	B_{132}	4621
		k = 3	B_{133}	2696
		k = 4	B_{134}	674
		k = 5	B_{135}	-3062
i = 2	j = 1	k = 1	B_{211}	14286
		k = 2	B_{212}	12586
		k = 3	B_{213}	10925
		k = 4	B_{214}	9309
		k = 5	B_{215}	7810
	j = 2	k = 1	B_{221}	14230
		k = 2	B_{222}	12534
		k = 3	B_{223}	10873
		k = 4	B_{224}	9257
		k = 5	B_{225}	7758
	j = 3	k = 1	B_{231}	14190
		k = 2	B_{232}	12486
		k = 3	B_{233}	10825
		k = 4	B_{234}	9205
		k = 5	B_{235}	7706

Appendix XIV (continued)

Farmers' yield

Crop	Rainfall probability	Irrigation level	Profit per ha, Bijk, (Tk./ha)	Value of Bijk, Tk./ha.
i = 1	j = 1	k = 1	B_{111}	8292
		k = 2	B_{112}	6359
		k = 3	B_{113}	4002
		k = 4	B_{114}	1591
		k = 5	B_{115}	-233
	j = 2	k = 1	B_{121}	8100
		k = 2	B_{122}	6167
		k = 3	B_{123}	3618
		k = 4	B_{124}	1407
		k = 5	B_{125}	-457
	j = 3	k = 1	B_{131}	7904
		k = 2	B_{132}	5975
		k = 3	B_{133}	3426
		k = 4	B_{134}	1211
		k = 5	B_{135}	-657
i = 2	j = 1	k = 1	B_{211}	5913
		k = 2	B_{212}	4775
		k = 3	B_{213}	3746
		k = 4	B_{214}	2623
		k = 5	B_{215}	1445
	j = 2	k = 1	B_{221}	5857
		k = 2	B_{222}	4723
		k = 3	B_{223}	3694
		k = 4	B_{224}	2571
		k = 5	B_{225}	1393
	j = 3	k = 1	B_{231}	5801
		k = 2	B_{232}	4675
		k = 3	B_{233}	3646
		k = 4	B_{234}	2519
		k = 5	B_{235}	1341

Appendix XIV (continued)

Monthly Irrigation Water Requirement under Different Water Application Levels and Rainfall Probabilities

W^t_{ijk} = irrigation water (m) requirement for crop i, under rainfall probability j and irrigation level k for month t.

Month: November (t=1)

Crop	Rainfall probability, j	Irrigation level, k	Irrigation water, (W_{ijk}), m	Depth of irrigation water (W_{ijk}), m
i = 1	j = 1	k = 1	W_{111}	0.018
		k = 2	W_{112}	0.018
		k = 3	W_{113}	0.018
		k = 4	W_{114}	0.018
		k = 5	W_{115}	0.018
	j = 2	k = 1	W_{121}	0.018
		k = 2	W_{122}	0.018
		k = 3	W_{123}	0.018
		k = 4	W_{124}	0.018
		k = 5	W_{125}	0.018
	j = 3	k = 1	W_{131}	0.020
		k = 2	W_{132}	0.020
		k = 3	W_{133}	0.020
		k = 4	W_{134}	0.020
		k = 5	W_{135}	0.020
i = 2	j = 1	k = 1	W_{211}	0.00
		k = 2	W_{212}	0.00
		k = 3	W_{213}	0.00
		k = 4	W_{214}	0.00
		k = 5	W_{215}	0.00
	j = 2	k = 1	W_{221}	0.00
		k = 2	W_{222}	0.00
		k = 3	W_{223}	0.00
		k = 4	W_{224}	0.00
		k = 5	W_{225}	0.00
	j = 3	k = 1	W_{231}	0.00
		k = 2	W_{232}	0.00
		k = 3	W_{233}	0.00
		k = 4	W_{234}	0.00
		k = 5	W_{235}	0.00

Appendix XIV (continued)

Month: December (t=2)

Crop	Rainfall probability, j	Irrigation level, k	Irrigation water, (W_{ijk}), m	Depth of irrigation water (W_{ijk}), m
i = 1	j = 1	k = 1	W_{111}	0.272
		k = 2	W_{112}	0.272
		k = 3	W_{113}	0.272
		k = 4	W_{114}	0.272
		k = 5	W_{115}	0.272
	j = 2	k = 1	W_{121}	0.274
		k = 2	W_{122}	0.274
		k = 3	W_{123}	0.274
		k = 4	W_{124}	0.274
		k = 5	W_{125}	0.274
	j = 3	k = 1	W_{131}	0.275
		k = 2	W_{132}	0.275
		k = 3	W_{133}	0.275
		k = 4	W_{134}	0.275
		k = 5	W_{135}	0.275
i = 2	j = 1	k = 1	W_{211}	0.073
		k = 2	W_{212}	0.064
		k = 3	W_{213}	0.055
		k = 4	W_{214}	0.047
		k = 5	W_{215}	0.038
	j = 2	k = 1	W_{221}	0.075
		k = 2	W_{222}	0.065
		k = 3	W_{223}	0.056
		k = 4	W_{224}	0.049
		k = 5	W_{225}	0.040
	j = 3	k = 1	W_{231}	0.076
		k = 2	W_{232}	0.067
		k = 3	W_{233}	0.058
		k = 4	W_{234}	0.051
		k = 5	W_{235}	0.042

Appendix XIV (continued)

Month: January (t=3)

Crop	Rainfall probability, j	Irrigation level, k	Irrigation water, (W_{ijk}), m	Depth of irrigation water (W_{ijk}), m
i = 1	j = 1	k = 1	W_{111}	0.270
		k = 2	W_{112}	0.263
		k = 3	W_{113}	0.254
		k = 4	W_{114}	0.246
		k = 5	W_{115}	0.237
	j = 2	k = 1	W_{121}	0.272
		k = 2	W_{122}	0.265
		k = 3	W_{123}	0.255
		k = 4	W_{124}	0.248
		k = 5	W_{125}	0.238
	j = 3	k = 1	W_{131}	0.274
		k = 2	W_{132}	0.266
		k = 3	W_{133}	0.257
		k = 4	W_{134}	0.249
		k = 5	W_{135}	0.240
i = 2	j = 1	k = 1	W_{211}	0.144
		k = 2	W_{212}	0.127
		k = 3	W_{213}	0.111
		k = 4	W_{214}	0.096
		k = 5	W_{215}	0.080
	j = 2	k = 1	W_{221}	0.145
		k = 2	W_{222}	0.129
		k = 3	W_{223}	0.113
		k = 4	W_{224}	0.098
		k = 5	W_{225}	0.082
	j = 3	k = 1	W_{231}	0.147
		k = 2	W_{232}	0.131
		k = 3	W_{233}	0.115
		k = 4	W_{234}	0.100
		k = 5	W_{235}	0.084

Appendix XIV (continued)

Month: February (t = 4)

Crop	Rainfall probability, j	Irrigation level, k	Irrigation water, (W_{ijk}), m	Depth of irrigation water (W_{ijk}), m
i = 1	j = 1	k = 1	W_{111}	0.322
		k = 2	W_{112}	0.305
		k = 3	W_{113}	0.291
		k = 4	W_{114}	0.273
		k = 5	W_{115}	0.256
	j = 2	k = 1	W_{121}	0.325
		k = 2	W_{122}	0.308
		k = 3	W_{123}	0.294
		k = 4	W_{124}	0.275
		k = 5	W_{125}	0.258
	j = 3	k = 1	W_{131}	0.329
		k = 2	W_{132}	0.312
		k = 3	W_{133}	0.298
		k = 4	W_{134}	0.280
		k = 5	W_{135}	0.263
i = 2	j = 1	k = 1	W_{211}	0.144
		k = 2	W_{212}	0.127
		k = 3	W_{213}	0.109
		k = 4	W_{214}	0.093
		k = 5	W_{215}	0.075
	j = 2	k = 1	W_{221}	0.147
		k = 2	W_{222}	0.131
		k = 3	W_{223}	0.113
		k = 4	W_{224}	0.096
		k = 5	W_{225}	0.078
	j = 3	k = 1	W_{231}	0.153
		k = 2	W_{232}	0.136
		k = 3	W_{233}	0.118
		k = 4	W_{234}	0.102
		k = 5	W_{235}	0.084

Appendix XIV (continued)

Month: March (t = 5)

Crop	Rainfall probability, j	Irrigation level, k	Irrigation water, (W_{ijk}), m	Depth of irrigation water (W_{ijk}), m
i = 1	j = 1	k = 1	W_{111}	0.418
		k = 2	W_{112}	0.392
		k = 3	W_{113}	0.368
		k = 4	W_{114}	0.342
		k = 5	W_{115}	0.317
	j = 2	k = 1	W_{121}	0.423
		k = 2	W_{122}	0.397
		k = 3	W_{123}	0.372
		k = 4	W_{124}	0.346
		k = 5	W_{125}	0.322
	j = 3	k = 1	W_{131}	0.429
		k = 2	W_{132}	0.403
		k = 3	W_{133}	0.378
		k = 4	W_{134}	0.352
		k = 5	W_{135}	0.328
i = 2	j = 1	k = 1	W_{211}	0.067
		k = 2	W_{212}	0.058
		k = 3	W_{213}	0.047
		k = 4	W_{214}	0.038
		k = 5	W_{215}	0.029
	j = 2	k = 1	W_{221}	0.073
		k = 2	W_{222}	0.064
		k = 3	W_{223}	0.053
		k = 4	W_{224}	0.044
		k = 5	W_{225}	0.035
	j = 3	k = 1	W_{231}	0.076
		k = 2	W_{232}	0.067
		k = 3	W_{233}	0.056
		k = 4	W_{234}	0.047
		k = 5	W_{235}	0.038

Appendix XIV (continued)

Month: April (t = 6)

Crop	Rainfall probability, j	Irrigation level, k	Irrigation water, (W_{ijk}), m	Depth of irrigation water (W_{ijk}), m
i = 1	j = 1	k = 1	W_{111}	0.358
		k = 2	W_{112}	0.322
		k = 3	W_{113}	0.306
		k = 4	W_{114}	0.278
		k = 5	W_{115}	0.252
	j = 2	k = 1	W_{121}	0.374
		k = 2	W_{122}	0.348
		k = 3	W_{123}	0.322
		k = 4	W_{124}	0.294
		k = 5	W_{125}	0.268
	j = 3	k = 1	W_{131}	0.388
		k = 2	W_{132}	0.362
		k = 3	W_{133}	0.335
		k = 4	W_{134}	0.308
		k = 5	W_{135}	0.282
i = 2	j = 1	k = 1	W_{211}	0.0
		k = 2	W_{212}	0.0
		k = 3	W_{213}	0.0
		k = 4	W_{214}	0.0
		k = 5	W_{215}	0.0
	j = 2	k = 1	W_{221}	0.0
		k = 2	W_{222}	0.0
		k = 3	W_{223}	0.0
		k = 4	W_{224}	0.0
		k = 5	W_{225}	0.0
	j = 3	k = 1	W_{111}	0.0
		k = 2	W_{112}	0.0
		k = 3	W_{113}	0.0
		k = 4	W_{114}	0.0
		k = 5	W_{115}	0.0

Appendix XIV (continued)

Month: May (t = 7)

Crop	Rainfall probability, j	Irrigation level, k	Irrigation water, (W_{ijk}), m	Depth of irrigation water (W_{ijk}), m
		k = 1	W_{111}	0.055
		k = 2	W_{112}	0.055
	j = 1	k = 3	W_{113}	0.055
		k = 4	W_{114}	0.055
		k = 5	W_{115}	0.055
		k = 1	W_{121}	0.075
		k = 2	W_{122}	0.075
i = 1	j = 2	k = 3	W_{123}	0.075
		k = 4	W_{124}	0.075
		k = 5	W_{125}	0.075
		k = 1	W_{131}	0.095
		k = 2	W_{132}	0.095
	j = 3	k = 3	W_{133}	0.095
		k = 4	W_{134}	0.095
		k = 5	W_{135}	0.095
		k = 1	W_{211}	0.0
		k = 2	W_{212}	0.0
	j = 1	k = 3	W_{213}	0.0
		k = 4	W_{214}	0.0
		k = 5	W_{215}	0.0
		k = 1	W_{221}	0.0
		k = 2	W_{222}	0.0
i = 2	j = 2	k = 3	W_{223}	0.0
		k = 4	W_{224}	0.0
		k = 5	W_{225}	0.0
		k = 1	W_{111}	0.0
		k = 2	W_{112}	0.0
	j = 3	k = 3	W_{113}	0.0
		k = 4	W_{114}	0.0
		k = 5	W_{115}	0.0