RELATIONSHIP BETWEEN OBSERVED AND ESTIMATED EVAPOTRANSPIRATION OF RICE

BY

Md. Nuruddin Molla

In partial fulfilment of the requirements for the Degree of Master of Engineering (Water Resources)

DEPARTMENT OF WATER RESOURCES ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DHAKA, BANGLADESH

June, 1995

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF WATER RESOURCES ENGINEERING

We hereby recommend that the project prepared by Md. Nuruddin Molla entitled "Relationship between Observed and Estimated Evapotranspiration of Rice" be accepted as fulfilling this part of the requirements for the degree of Masters of Engineering (Water Resources).

Chairman of the Committee ____________________ Professor M. A. Halim

Member ____________________ Professor A. Hannan

Member ____________________ Professor A. Nishat

Head of the Department ____________________ Professor M. Monowar Hossain

CERTIFICATE

This is to certify that this work has been done by me and neither this project nor any part thereof has been submitted elsewhere for the award of any degree or diploma.

Countersigned

Professor M. A. Halim

Signature

Md. Nuruddin Molla

ABSTRACT

Seasonal evapotranspiration of BR-3 variety of rice has been calculated by five predictions methods, namely the modified Penman, the Hargreaves, the Thornthwaite, the pan evaporation and the Blaney-Criddle methods by using three years climatological data from the Amla farm, Kushtia and compared with the observed evapotranspiration. The accuracy of prediction has been tested by determining the correlation coefficient, the coefficient of efficiency and the root mean square of each method. Also the t-test for mean difference has been performed.

Considering the seasonal evapotranspiration values obtained by different methods, the numerical values of the correlation coefficient, coefficient of efficiency, root mean square and t-statistic, and the climatic data requirement, the modified Penman method and the Hargreaves method seem to provide the best estimate of the evapotranspiration of BR-3 Boro rice for the climatic conditions considered. The daily evapotranspiration of BR-3 Boro rice during the entire growing season (December to May) varies from 5.13 mm/day to 5.80 mm/day and the mean daily evapotranspiration is 5.63 mm/day. The consumptive use requirement for BR-3 Boro variety of rice is maximum in the month of April when the crop is in the reproductive phase.

ACKNOWLEDGEMENT

The author expresses his profound gratitude and indebtness to Dr. M. A. Halim, Professor of Water Resources Engineering and Chairman of the Committee in M.Engineering for his sincere help, encouragement, guidance and cooperation in preparation of the project work. His active interest in this work and valuable direction and advice were the source of the authors inspiration.

The author deeply indebted to Dr. M. Mirjahan Miah for his sincere help and encouragement and many valuable suggestions.

The author extends his deep appreciation to Dr. M. Monowar Hossain , Professor and Head of the Department of Water Resources Engineering for his sincere help and guidance.

The author expresses his sincere appreciation to the Dr. A. Nishat and Dr. A. Hannan, Professors of Water Resources Engineering and the member of Committee of Project work.

The author indebted to Mr. Fakir, Deputy Chief Agronomist, BWDB, Kustia for his sincere help of data collection. The author expresses his appreciation to Mr. B. R. Khan, senior scientific officer BARI, Joydebpur for his sincere co-operation.

The author expresses his sincere indebtness to the Director, Hydrology Section, BWDB, Dhaka for his sincere help for supplying Hydrological Data.

The author thanks to Mr. M.A. Mannan Khan and Mr. M. Mofser Ali for their official assistance and typing of the project thesis.

THE AUTHOR

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOL

Symbol	Meaning
B_H	Hygrometric coefficient
C	Adjustment factor
C_e	Coefficient of efficiency
D	Mean monthly depression of the wet bulb
e_a	Vapor pressure in air
E_L	Evaporation from lake
ET_0	Reference crop evapotranspiration
EV	Evaporation
e_w	Water vapor pressure
f	Monthly consumptive use factor
f(u)	Wind related function
I	Annual or seasonal heat index
K_c	Crop coefficient
K_p	Pan coefficient
p	Percent daylight hours
r	Correlation coefficients
R_a	Extraterrestrial solar radiation
R_n	Net radiation
w	Temperature-related weighing factor
w_f	Water requirement constant for months and latitude
Δ	Slope of the saturation vapor pressure-temperature curve
γ	Stephens - Boltzman constant.

LIST OF ABBREVIATIONS

BBS	=	Bangladesh Bureau of Statistics
BRRI	=	Bangladesh Rice Research Institute
BWDB	=	Bangladesh Water Development Board
BUET	=	Bangladesh University of Engineering and Technology
EPWAPDA	=	East Pakistan Water and Power Development Authority
FPCO	=	Flood Plan Coordination Organisation
G-K	=	Ganges-Kobadak
IBRD	=	International Bank for Reconstruction and Development
IECO	=	International Engineering Company
IRRI	=	International Rice Research Institute

CHAPTER I

INTRODUCTION

Bangladesh is predominantly an agricultural country having 8.18 million ha of net cropped land for a population of about 111 million with decreasing land-man ratio (BBS, 1993). The food grain production has been increasing day by day but fails to meet up the national demand caused by the rapid increase in population makes the country as one of the food-deficit regions of the world. During the fiscal year 1992-93 the food deficit stood at 1.24 million metric tons (Food Situation Report, 1993). This acute problem can be overcome by increasing food production per unit area per unit time which is directly associated with agricultural water management, because the scope of increasing the amount of land per capita is limited.

Rice, the main agricultural crop of Bangladesh, occupies about 80 percent of the total cropped area of the country. The total area irrigated by various methods is 3.02 million ha and the area covered by Boro rice is near about 2.60 million ha of which 2.12 million ha are irrigated (BBS, 1993). Of all the rice growing seasons in Bangladesh, the Boro season is characterized by dry weather with a little or no effective rainfall to meet the consumptive use requirements. As a result, crops during the Boro season depend almost entirely upon irrigation water.

In the past three decades, a number of high-yielding rice varieties were released by Bangladesh Rice Research Institute (BRRI) for the Aus, Aman and Boro seasons. A series of HYV varieties such as BR-1 (Chandina), BR-2 (Mayna), BR-3 (Biplob), BR-14 (Gazi), BR-15 (Mohini), BR-16 (Shahi Balam), BR-17 (Hasi), BR-18 (Shahjalal) and BR-19 (Mongol) have been recommended by BRRI for cultivation in Bangladesh. The BR-3 variety of rice created a tremendous impact on the rice-farming of Bangladesh because of its high yield per ha, broad spectrum of disease resistance and wide adaptability for all rice seasons. This is why BR-3 has been recommended for a large scale commercial production in Bangladesh with immediate effect as Boro, Aus and Aman crops.

Knowledge of water requirements of different crops is essential for efficient planning, design and operation of an irrigation project. In Bangladesh, sufficient systematic studies have not been undertaken to determine the water requirements of various important crops and, as such, specific research data on this vital aspect of irrigation are limited.

The three constituents of water requirement to grow rice are evapotranspiration (ET), seepage and percolation and surface drainage. Of them only evapotranspiration is the true water requirement for crop growth, but in supplying it, some seepage and percolation and surface drainage are inevitable. Evapotranspiration can be measured directly or can be predicted indirectly. The lysimeter is the only direct method in which the experimenter can obtain accurate and continuous measurements of evapotranspiration. The other direct methods are soil moisture depletion studies and the water balance method. Direct methods are laborious, time-consuming and expensive. Prediction methods for evapotranspiration are often used in irrigation planning owing to the difficulty of obtaining accurate field data. The prediction methods use meteorological parameters for estimating evapotranspiration. Several methods are available for computation of evapotranspiration. Primarily, the choice of a method depends upon the meteorological data available and the needed accuracy of estimation. Such formulae have often been used under agro-climatic conditions, different from those for which they are originally developed. However, it is necessary to test the adaptability of these formulae by correlating with actual measurement of evapotranspiration under a new sets of conditions.

Of the several prediction methods available for estimating reference crop evapotranspiration, three approaches have been used by different investigators in Bangladesh (Saleh and Fatema, 1988). These are (1) the Blaney - Criddle method, (2) the radiation method, and (3) the modified Penman method. Saleh and Fatema (1988) made a comparative study of these methods for estimating evapotranspiration of rice using climatological data from 10 stations in Bangladesh by using the coefficient of efficiency of each method. The results of the study showed that of the three methods, the modified Penman method gives the best prediction followed by the radiation and the Blaney-Criddle methods. Halim (1992) made a comparative study of eighteen empirical and semi-empirical equations from 18 stations by using correlation coefficient, coefficient of efficiency and root mean square. The results showed that the Papadakis method, the Makkink method, the Stephens-Steward method, the Penman method and the Blaney-Criddle method modified by FAO are suitable for estimating ET_0 for the climatic conditions of Bangladesh. The above authors compared between the ET-values obtained by different prediction methods but did not compare their results with the ET obtained by direct methods.

The aim of the present study is to estimate the ET of BR-3 variety of rice using climatological data and compare the estimated ET with measured ET. Thus, the present study will give an insight into the relationship between measured and estimated ET of rice and it will provide a guideline for using empirical equations to estimate ET of rice. The specific objectives of the present study are to

(1) estimate the ET of BR-3 variety of rice in the Boro season by five prediction methods, namely, the modified Penman, the Hargreaves, the Thornthwaite, the pan evaporation and the Blaney-Criddle methods,

(2) study the relationship between measured and estimated ET of rice, and

(3) find out the equation which gives the best estimate of ET of rice.

CHAPTER II

REVIEW OF LITERATURE

2.1 Water Balance in an Irrigated Field

Irrigation is the controlled application of water to arable lands to supply crop requirements not satisfied by natural precipitation (Houk, 1960). After the occurrence of a heavy rainfall or heavy application of irrigation water to a field having the water table at a considerable depth below the soil surface, only a small amount of water is evaporated from the soil or water surface and from the wet surface of the vegetation. The remaining portion infiltrates into the upper soil layers and occupies the larger pore spaces. This water, commonly known as the soil moisture, is used up in three ways. A portion, commonly known as the gravity water, percolates downward to the groundwater. Another portion moves laterally across the boundaries of the irrigated plot and is commonly referred to as the side or lateral seepage loss. The third portion of soil moisture is dispersed into the smaller pore spaces of soil and is known as the capillary moisture which is gradually drawn up and evaporated from the soil surface. Plants supplement this process by drawing capillary water from the soil and passing it to the air in the process of transpiration (Hobba, 1964).

2.2 The Evaporation Phenomenon

Evaporation (EV) from natural surfaces, such as open water, bare soil or vegetative cover, is a diffusive process by which water in the form of vapor is transferred from the underlying surface to the atmosphere. The essential requirements in evaporation process are:

(1) the source of heat to vaporise the liquid water, and

(2) the presence of a gradient of concentration of water vapor between the evaporating surface and the surrounding air.

The source of energy for evaporation may be solar energy, the air blowing over the surface or the underlying surface itself. Evaporation can, however, occur only when the vapor concentration at the evaporating surface exceeds that in the overlying air. The fundamental principle of evaporation from a free surface was enunciated by Dalton (1802) who stated that evaporation is a function of the difference in the vapor pressure of the water and the vapor pressure of the overlying air.

Factors affecting evaporation include the difference in vapor pressure at the water surface and in the air above, air and water temperatures, wind, atmospheric pressure, and quality of water. Also nature of the evaporating surface such as soil surfaces, vegetation, snow and ice influences the rate of evaporation.

Evaporation is proportional to the difference between the vapor pressure of the water (e_w) and the vapor pressure in the air (e_a) above the water surface, and continues until $e_a = e_w$. The higher the temperature of water, the greater the energy of the water molecules. Evaporation does increase with the temperature of the water surface.

Evaporation increases with the increase of wind speed but decreases as some high value of wind speed is approached. The rate of evaporation is less for salt water than for fresh water and decreases as the specific gravity of water increases. The evaporation rate decreases about 1 percent for each 1 percent increase is specific gravity until crushing takes place, usually at a specific gravity of about 1.30 (Linsley et al., 1985)

2.3 The Transpiration Phenomenon

Transpiration is the process by which water vapor leaves the living plant body and enters the atmosphere. It involves continuous movement of water from the soil into the roots, through the stem and out through the leaves to the atmosphere. However, unlike evaporation from a water surface, transpiration is modified by plant structure and stomatal behavior operating in conjunction with the physical principles governing evaporation.

Transpiration is the dominant factor in plant-water relations. This is because evaporation of water produces the energy gradient which causes the movement of water between the leaf and the bulk air outside and constitutes the driving force which is responsible for the movement of water vapor in transpiration from the leaf into the air (Kramer, 1972). As water vapor escapes from the leaf into the air, a diffusion pressure deficit or tension is set up in the spongy cells of the leaf which is passed on down through the xylem to the root tips. When a greater tension exists in the root cells than in the soil the roots absorb water. This water moves upward from root to stem to petiole and thence to the leaf (Lull,1964). Most water vapor escapes through the stomata when they are open because the resistance to flow is relatively low in the pathway. When the stomata close, transpiration continues slowly through the epidermal cells and cuticle but at a much lower rate than the evaporative power of the air.

The climate, the soil and the plant factors influence the transpiration. The important climatic factors affecting transpiration are light intensity, atmospheric vapor pressure, temperature and wind. The soil factors are those governing the water supply to the roots. The plant factors include the extent and efficiency of root systems in moisture absorption, the leaf area, leaf arrangement and structure and stomatal behavior. Transpiration obviously has some important effects on the physiology and behavior of plants (Meyer, 1952).

2.4 BR-3 Variety of Rice

The BR-3 (Biplob) variety of rice was recommended by BRRI as a high-yielding variety of rice in 1973. This variety was developed from the cross between IR-506-1-133 (IRRI, Philipines) and Latisail (Bangladesh). It is a drought-resistance variety and has the highest yield-potential amongst all of the high-yielding varieties of rice in Bangladesh. It is resistant to all the prevalent diseases except the sheath blight to which it is moderately susceptible (BRRI, 1974).

2.5 The Consumptive Use of Water

The consumptive use of water or the evapotranspiration (ET) denotes the quantity of water transpired by plants during their growth or retained in the plant tissues plus the moisture evaporated from the surface of the soil and the vegetation. According to Doorenbos and Pruitt (1977), the reference crop evapotranspiration (ET_0) is defined as the rate of evapotranspiration for 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. The term consumptive use is used to designate the losses due to evapotranspiration and the water that is used by the plant for its metabolic activities. Since the water used in the actual metabolic processes is insignificant (less than 1% of ET), the term consumptive use is generally taken equivalent to ET.

The consumptive use of water is affected by many factors which operate either singly or in combination. Some factors are man-made while others are related to natural influences and the environment (Blaney, 1952). The important natural factors are the climatic factors which include precipitation, solar radiation, temperature, humidity and wind movement. In general, low values of consumptive use are registered on days which are rainy, humid, cloudy and calm, whereas high values are registered on dry, sunny and windy days (Doorenbos and Pruitt, 1977). The amount of water that the ground will absorb and make available for consumptive use of the plants varies widely with the soil type (Criddle,1952).

The effects of all the factors mentioned earlier on the consumptive use of water are not necessarily constant but are likely to fluctuate from farm to farm, season to season and day to day. The amount of water used increases with plant growth, reaches a peak during some stage of the growth period and then tapers off during harvest time. Nevertheless, for optimum production at a specific location, a specific crop does require a fairly definite amount of water during the growing season (Erie et al., 1965).

2.6 Direct Determination of ET for Rice

Of the several methods for direct determination of ET, the lysimetric technique is the most reliable. A field study was carried out in Kottamparomba, Kerala, India for estimating water requirements for the Culture 20 and Pattanbi-20 varieties of rice by using microlysimeter and the total water requirements were found to be 1250 mm and 1300 mm, respectively (Rao et al., 1988). The ET of direct-sown rice CVDR 92 was measured by a floating type lysimeter during the wet season of 1984 in western Orissa, India and the water requirement and water use efficiency was 668 mm and 35 kg/cm, respectively. (Taha et al., 1988).The actual ET of rice CVRD-25 was determined by using lysimeter method, at Bangkok, Thailand in 1983 and daily seasonal average of actual ET was found 8.68 mm (Shaha et al., 1986). The ET of Samridhi rice was studied in central India with two volumetric lysimeters in the centre of each field and ET was found 645 mm (Sastri et al., 1985).

The first ever study in the area of water requirements for rice in Bangladesh was initiated by FAO in 1958 at the Amla experimental station of the G.K. Project (Huang, 1963). This study was continued up to 1962 and it involved 9 trials -- 1 for Aus, 5 for Aman and 3 for Boro. The seasonal consumptive use of water for Aus was 500 mm, the daily water consumption rate being 8.38 mm. For Aman, the seasonal consumptive use values varied from 800 mm to 1122 mm whereas the daily consumptive use values varied from 7.62 mm to 10.67 mm. For Boro, the seasonal and daily consumptive use values ranged from 864 mm to 1513 mm and 8.12 mm to 11.68 mm, respectively.

Another tank study was made at the Amla experimental station during the period 1965-67 to determine the consumptive use of Aus (Dharial), Aman (Nizersail) and Boro (Khoyaboro) varieties of rice (Huq et al., 1970). The average seasonal consumptive use of water for Aus, Aman and Boro varieties of rice were found to be 881 mm, 903 mm and 965 mm, respectively, and the average daily ET for these varieties were found to be about 11.17 mm, 8.38 mm and 8.12 mm, respectively.

A field lysimeter study conducted in 1974 on the loamy soil of Bangladesh Agricultural University farm reported that the ET of IR-8 variety of rice during the Aus season was 1110 mm and the average daily rate of ET was 9.90 mm. The percolation loss was found to range from 38 mm to 140 m per week on the loam soil (Biswas and Ali, 1976). A lysimeter study was conducted at BRRI farm and the ET for the BR-3 variety of rice was found to be 1110 mm for the period April-July and the ratio ET/EV was 2.41 (Halim, 1977).

2.7 Prediction of Evapotranspiration Using Climatic Data

There is a series of equations for predicting ET of different crops based on readily available climatic data. These methods are grouped according to the involved climatic data and shown in Table 2.1.

Table 2.1 Classification of estimating methods based on climatic data (After Jensen, 1973)

Classification	Method
Combination	Kohler, Nordenson and Fox (1954) Penman (1948, 1963) van Bavel-Businger (1956, 1966)
Humidity	Ivanov (1954) Ostromecki (1965) Papadakis (1966)
Miscellaneous	Behnke-Maxey (1969) Christiansen (1968) Olivier (1961) Makkink (1957) Stephens-Stewart (1963, 1965) Turc (1961)
Temperature	Blaney-Criddle (1967) Thornthwaite (1948, 1955)

The Blaney-Criddle and the Thornthwaite methods are discussed in detail in Articles 2.10.4 and 2.10.6, respectively. The other methods quoted in Table 2.1 are discussed briefly in the following sections.

2.7.1 Kohler, Nordenson and Fox Method

The equation for this method is given by (Kohler, Nordenson, and Fox (1954))

$$E_L = 0.7\,\frac{[R_n\Delta + \gamma_L E_a]}{\Delta + \gamma_L}$$

$$= 0.7\left[\frac{R_n\Delta}{\Delta+\gamma_L} + \frac{\gamma_L}{\Delta+\gamma_L}E_a\right] \tag{2.1}$$

where,

E_a = $(e_z^o - e_z)^{0.88}(0.37 + 0.0041w)$

E_L = evaporation from lake in inches

$e_z^o - e_z$ = vapor pressure deficit in inches Hg

w = wind speed in mile/day

R_n = net radiation expressed as the equivalent depth of evaporation in inches

2.7.2 Penman Method

The original Penman equation (Penman, 1948) is given by

$$ET_o = \frac{\Delta}{\Delta + \alpha} H + \frac{\gamma}{\Delta + \gamma} E_a \tag{2.2}$$

where,

ET_0 = reference crop evapotranspiration in mm/day

H = $R_A(1-r)(0.18+0.56n/N) - \sigma T_a^4 (0.56 - 0.92\sqrt{e_d})(0.10+0.90\frac{n}{N})$

(0.10 + 0.90 n/N)

Δ = slope of the saturation vapor pressure-temperature curve, mm Hg/^{0}F

γ = constant of wet and dry bulb hygrometer equation

E_a = wind-related function

= $0.35\ (e_a - e_d)\ (1 + 0.0098\ U_2)$ mm/day

R_A = angot value of short wave radiation from sun and sky, mm/day

r = albedo or reflection coefficient of the surface

n/N = ratio between actual and possible hours of sunshine

γ = Stephens-Boltzman constant

= 2.01×10^{-9} mm/day/$^0K^4$

T_a = temperature of air, ^{0}K

e_d = saturation vapor pressure at dew-point temperature, mm Hg

e_a = saturation vapor pressure at T_a, mm Hg

U_2 = mean wind velocity at 2 metre height, miles/day.

2.7.3 Van Bavel-Businger Method

The Van Bavel-Businger equation (Van Bavel-Businger, 1966) is given by

$$E_p = \frac{\Delta}{\Delta+\gamma}(R_n+G) + \frac{\gamma}{\Delta+\gamma}\frac{0.622\lambda\rho k^2}{p}\frac{u_z}{(\ln z/z_o)^2}(e_z^o - e_z) \tag{2.3}$$

where,

$\frac{\Delta}{\Delta+\gamma}$ = weighting parameters

R_n = net radiation in cal $cm^{-2}t^{-1}$

G = heat conducted to the soil surface in cal cm^{-2} t^{-1}

$e_z^o - e_z$ = vapor saturation deficit

2.7.4 Ivanov Method

The equation is given by (Ivanov, 1954)

$$E = 0.0018\ (25 + T)^2\ (100 - r.h.) \tag{2.4}$$

where,

E = evapotranspiration in mm/month

T = temperature in ^{0} C

and r.h.= $\frac{e_z}{e_z^o} \times 100$

2.7.5 Ostromecki Equation

The Ostromecki equation is given by (Ostromecki, 1965)

$$E_t = \beta_H\ d_a \tag{2.5}$$

where,

E_t = evapotranspiration in mm/day

d_a = average daily vapor pressure deficit in mb

β_H = hygrometric coefficient

2.7.6 Papadakis Method

Papadakis (1966) proposed the equation

$$E_{tp}=0.5625\,(e^{o}_{max}-e_{z}) \qquad (2.6)$$

where,

E_{tp} = monthly potential E_t in cm,

e^{o}_{max} = saturation vapor pressure corresponding to average daily maximum temperature in mb

e_z = the average vapor pressure for the month in mbr.

2.7.7 Behnke - Maxey Method

Behnke - maxey method (1969) is given by

$$E_t=\frac{t}{1.9}w_{\Phi} \qquad (2.7)$$

where,

$\frac{T}{1.9}$ = the simulated wet bulb depression in ^{0}C,

T = mean air temp in ^{0}C

$w\Phi$ = Water requirement constant for months and latitude.

2.7.8 Christiansen Method

Christiansen (1968) developed an equation for estimating USWB Class A pan evaporation from which potential E_t can be estimated. The equation is given by

$$E_{tp} = 0.755\ E_v\ C_{T2}\ C_{w2}\ C_{H2}\ C_{s2} \qquad (2.8)$$

where,

E_v = measured class A pan evaporation

T = mean air temperature in ^{0} F

w = mean wind velocity 2m above the ground in mile/day

H = mean relative humidity in percent

S = possible sunshine in percent.

2.7.9 Olivier Method

Olivier (1961) proposed an equation for monthly potential evapotranspiration based on the average depression of the wet bulb temperature and a radiation latitude factor based on clear sky values of solar radiation by latitudes and months. The equation is given by

$$E_{t\phi} = DW_{\phi} \tag{2.9}$$

where,

$E_{t\phi}$ = Basic water requirement in mm/day at latitude Φ,

D = mean monthly depression of the wet bulb in ^{0}C

W_{ϕ} = water requirement constant for months and latitude.

2.7.10 Makkink Method

Makkink (1957) presented an equation for estimating E_t for grass over 10-day periods under cool climatic condition of the Netherlands which is given by

$$E_g = 0.61 \frac{\Delta}{\Delta+\gamma} \cdot \frac{R_s}{58.5} - 0.12 \tag{2.10}$$

where, E_g = evapotranspiration rate in mm/day (R_n = 0.6 R_s) and other symbols are as previously defined.

2.7.11 Stephens - Stewart Method

Stephens (1965) developed the equation

$$E_{tp} = (0.014T - 0.37) \frac{R_s}{1500} \tag{2.11}$$

where,

E_{tp} = evapotranspiration in inch/day

T = mean air temperature in ^{0} F

R_s = solar radiation at land surface in mm/day.

2.7.12 Turc Method

Turc (1961) gave the following two equations for potential evapotranspiration for 10-day periods under climatic conditions of western Europe.

For r.h. > 50

$$E_{tp}=0.013\frac{T}{T+15}(R_s+50) \qquad (2.12a)$$

For r.h. <50

$$E_{tp}=0.013\frac{T}{T+15}(R_s+50)(1+\frac{50-r.h.)}{70} \qquad (2.12b)$$

where,

T = average temperature in ^{0}C

R_s = solar radiation in langleys/day.

2.8 Use of Prediction Methods for Estimating Evapotranspiration in Bangladesh

Of the several prediction methods available for estimating reference crop evapotranspiration,three approaches have been used by different investigators in Bangladesh(Saleh and Fatema, 1988). These are:

(1) the Blaney-Criddle method

(2) the radiation method, and

(3) the modified Penman method.

The Blaney-Criddle method was used for the calculation of ET in the Water Master Plan of East Pakistan (IECO, 1964). The method was also used for the calculation of ET of rice in G.K. Project (EPWAPDA, 1968). Jenkins (1981) calculated the ET for different regions of Bangladesh by using the radiation method. He also recommended its use for rice and other crops. The modified Penman method has been widely used for the calculation of ET in different regions of Bangladesh (Acres International Overseas Ltd., 1970; IBRD, 1972). Karim and Akand (1982) also used the modified Penman method for computing water requirements of different crops. Master Plan Organization (MPO, 1984) has used the estimate of Karim and Akand (1982) for crop water requirements. The modified Penman method was used for estimating the crop water requirement of rice in the Teesta Barrage Project (BUET and BWDB, 1987). FPCO (1993) used the Penman-Monteith approach for predicting the reference crop evapotranspiration for Jamalpur priority project study.

2.9 Studies on Estimated vs. Observed Evapotranspiration of Rice

Sufficient studies have not yet been undertaken to compare between estimated and observed ET of rice. A relationship study was undertaken between observed and estimated ET of rice by using five empirical equations, namely the modified Penman, the pan evaporation, the modified radiation, the modified Blaney-Cridle and the Jensen-Haise methods in Thailand (Qurban et al., 1990). The best performance was obtained by the modified Penman method as it possessed a real correlation between estimated and observed ET. Sastri et al. (1985) showed that the ET/EV ratio varied from 1.78 to 1.24.

Saleh and Fatema (1988) made a comparative study of three methods namely, the Blaney-Criddle, the radiation and the modified Penman method for estimating evapotranspiration of rice for 10 stations in Bangladesh by comparing the coefficient of efficiency of each method. The actual ET_0 - values were estimated from pan evaporation data. The results of this study showed that the modified Penman method gave the best prediction followed by the radiation and the Blaney-Criddle methods.

Halim (1992) computed mean monthly reference crop evapotranspiration by using eighteen empirical and semi-empirical equations and compared the computed ET_0-values with actual ET_0- values obtained from the pan evaporation. The accuracy of prediction has been tested by considering the correlation coefficient, the coefficient of efficiency and the root mean square of each method. The Papadakis method, the Makkink method, the Stephens-Stewart method, the Blaney-Criddle method modified by FAO and the Penman method have been found suitable for estimating ET_0 for the climatic conditions of Bangladesh.

2.10 The Prediction Methods Considered

2.10.1 General

As stated earlier, there are many methods of estimating reference crop evapotranspiration (ET_0) of different crops. The choice of a method depends upon the meteorological data available and the needed accuracy of estimation. In the present study, five different prediction methods have been used to compute ET_0 of the BR-3 Boro rice based on readily available climatic data. These methods are

i. the modified Penman method

ii. the Hargreaves method

iii. the Thornthwaite method

iv. the pan evaporation method, and

v. the Blaney-Criddle method.

The methods considered in this study are grouped according to their climatic data requirements in Table 2.2 and presented in the following sections. The minimum time period used for the calculation of ET_0 by the prediction methods considered is given in Table 2.3.

Table 2.2 Climatic data required by different methods

Method	Temperature	Humidity	Wind	Sunshine	Radiation	Evaporation
Modified Penman	+	+	+	+	(+)	
Hargreaves	+				+	
Pan evaporation		*	*			+
Blaney-Criddle	+			*		
Thornthwaite	+					

\+ data used directly to compute ET_0

* data used to compute coefficients, correction factors etc.

(+) data to be used if available but not necessary

Table 2.3 Minimum time periods for the selected methods

Method	Recommended minimum time period	Remarks
Modified Penman	Daily	Penman used daily values to obtain coefficients, but evaluated the equation over 10-day periods
Hargreaves	Daily	
Pan evaporation	Daily or hourly	
Blaney-Criddle	Seasonal (monthly if locally calibrated)	
Thornthwaite	Monthly	

2.10.2 Modified Penman Method

Based on intensive studies of the climatic and measured grass evapotranspiration data from various research stations in the world and the available literature on prediction of ET or ET_0, Doorenbos and Pruitt (1977) proposed a modified Penman method, which is given by

$$ET_0 = C\,[W.R_n + (1-W)\,f(u)\,(e_a-e_d)] \qquad (2.13)$$

where,

ET_0 = reference crop evapotranspiration in mm/day

W = temperature-related weighing factor

R_n = net radiation in equivalent evapotranspiration in mm/day

$f(u)$ = wind related function

$(e_a - e_d)$ = difference between the saturation vapor pressure at mean air temperature and the mean actual vapor pressure of air in mbar

C = adjustment factor to compensate for the effect of day and night weather conditions.

The modified Penman method is a combination approach in which both energy-balance and aerodynamic terms appear explicitly in a single relationship. This method has been used extensively in England by government agencies and private companies who are providing computerized irrigation scheduling services for farmers. Due to the interdependence of the variables composing the equation, the correct use of units in which variables need to be expressed is important. However, it is far more readily applied than either the energy-budget or the aerodynamic equations from which it was derived; so evapotranspiration equation of the modified Penman or combination type is amongst the most widely used in hydrology today (Thom and Oliver, 1977).

2.10.3 Hargreaves Method

The Hargreaves equation is given by (Hargreaves, 1985)

$$ET_0 = 0.0023\ R_a\ (T_{av} + 17.8)\ T_D^{0.5} \tag{2.14}$$

where,

ET_0 = reference crop evapotranspiration in mm/day

R_a = extraterrestrial solar radiation in mm

T_{av} = average of minimum and maximum temperatures in ^0C

T_D = difference between maximum and minimum temperatures in ^0C

This method has been used extensively in Latin America to estimate crop water requirements. This method does not have any adjustments for site specific conditions of elevation or humidity as does other combination methods.

2.10.4 Thornthwaite Method

Thornthwaite (1948) assumed that an exponential relationship existed between mean monthly temperature and mean monthly consumptive use. The formula was originally developed for the purpose of a rational classification of the broad climatic patterns of the world. Thornthwaite proposed the following formula for potential evapotranspiration for a month of 30 days:

$$ET_o = 1.6\left[\frac{10t}{I}\right]^a \qquad (2.15)$$

where,

ET_0 = 30-day value of estimated ET_0 in cm

t = mean monthly air temperature in ^0C

I = annual or seasonal heat index being equal to the summation of 12 values of monthly heat indices i

i = $(t/5)^{1.514}$

a = an empirical exponent computed by the equation

$$a = 0.0000000675I^3 - 0.0000777I^2 + 0.01792I + 0.49239$$

Equation (2.15), however, gives only unadjusted rates of reference crop evapotranspiration. Since the number of days in a month varies from 28 to 31 and since the number of hours in the day between the onset of evapotranspiration in the morning and its termination in the evening varies with the season and with latitude, it becomes necessary to reduce or increase the unadjusted rates by a factor which varies with the month and the latitude. These factors are given in Table 2.4.

Table 2.4 The adjusting factor for reference crop evapotranspiration computed by the Thornthwaite equation*

Latitude, deg	J	F	M	A	M	J	J	A	S	O	N	D
0	1.04	0.94	1.04	1.01	1.04	1.01	1.04	1.04	1.01	1.04	1.01	1.04
10	1.00	0.91	1.03	1.03	1.08	1.06	1.08	1.07	1.02	1.02	0.98	0.99
20	0.95	0.90	1.03	1.05	1.13	1.11	1.14	1.11	1.02	1.00	0.93	0.94
30	0.90	0.87	1.03	1.08	1.18	1.17	1.20	1.14	1.03	0.98	0.89	0.88
35	0.87	0.85	1.03	1.09	1.21	1.21	1.23	1.16	1.03	0.97	0.86	0.85
40	0.84	0.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	0.96	0.83	0.81
45	0.80	0.81	1.02	1.13	1.28	1.29	1.31	1.21	1.04	0.94	0.79	0.75
50	0.74	0.78	1.02	1.15	1.33	1.36	1.37	1.25	1.06	0.92	0.76	0.70

*** Source: Criddle (1958)**

The Thornthwaite formula gives a reasonable estimate of ET_0 in the temperate, continental climate of North America where the formula was originally derived. The drawbacks of the formula as enumerated by Chang (1968) are as follows:

i) Temperature alone is not a good indication of the energy available for evapotranspiration.

ii) Air temperature of a place lags behind radiation.

iii) According to this formula, ET will cease when the mean temperature falls below 0 ^{0}C which by no means is true, although the amount of evaporation will be very small.

iv) The formula does not take into account the wind effect which might be an important factor in some areas.

v) It also does not consider the effect of warm and cool air on the temperature of a place.

The Thornthwaite method, despite its obvious limitations, has enjoyed considerable success in humid climates throughout the world (Bruce and Vipond, 1988).

2.10.5 Pan Evaporation Method

Evaporation pans provide a measurement of the integrated effect of radiation, wind, temperature and humidity on evaporation from a specific open water surface. Sharma and Dastance (1968) suggested that the standard United States Weather Bureau Class A open pan evaporimeter or the sunken screen open pan evaporimeter be used for the measurement of evaporation. The relationship between reference crop evapotranspiration and the pan evaporation suggested by Doorenbos and Pruitt (1977) is

$$ET_0 = K_p . E_{pan} \qquad (2.16)$$

where,

ET_0 = reference crop evapotranspiration in mm/day

E_{pan} = pan evaporation in mm/day and represents the mean daily value of the period considered

K_p = pan coefficient which depends on wind speed, mean relative humidity, type of the pan used and windward distance of green crops or dry fallow from the pan.

Values for K_p are given in Table 2.5. The K_p-values relate to pans located in an open field with no crops taller than 1 m within some 50 m of the pan. The pan station is placed in an agricultural area. The pan is unscreened. In selecting the appropriate value of K_p to relate Class A pan data to ET_0 , it is necessary to consider the ground cover of the pan station itself, that of the surroundings and general wind and humidity conditions.

The pan coefficients given in Table 2.5 apply to galvanized pans annually painted with aluminium. Little difference in E_{pan} will show when inside and outside surfaces of the pan are painted white. An increase in E_{pan} of up to 10 percent may occur when they are painted black. The material from which the pan is made may account for variations of only a few percent.

Table 2.5 Pan coefficient (K_p) for Class A pan for different groundcover and levels of mean relative humidity and 24 hour wind

Class A pan	Case A: Pan placed in short green cropped area				Case B*: Pan placed in dry fallow area			
RH_{mean}%		low <40	medium 40-70	high >70		low <40	medium 40-70	high >70
Wind km/day	Windward side distance of green crop (m)				Windward side distance of dry fallow (m)			
Light <175	1	.55	.65	.75	1	.7	.8	.85
	10	.65	.75	.85	10	.6	.7	.8
	100	.7	.8	.85	100	.55	.65	.75
	1000	.75	.85	.85	1000	.5	.6	.7
Moderate 175-425	1	.5	.6	.65	1	.65	.75	.8
	10	.6	.7	.75	10	.55	.65	.7
	100	.65	.75	.8	100	.5	.6	.65
	1000	.7	.8	.8	1000	.45	.55	.6
Strong 425-700	1	.45	.5	.6	1	.6	.65	.7
	10	.55	.6	.65	10	.5	.55	.65
	100	.6	.65	.7	100	.45	.5	.6
	1000	.65	.7	.75	1000	.4	.45	.55
Very strong >700	1	.4	.45	.5	1	.5	.6	.65
	10	.45	.55	.6	10	.45	.5	.55
	100	.5	.6	.65	100	.4	.45	.5
	1000	.55	.6	.65	1000	.34	.4	.45

For extensive areas of bare-fallow soils and no agricultural development, reduce K_p by 20% under hot, windy conditions and by 5-10% for moderate wind, temperature and humidity conditions

Source: Doorenbos and Pruitt (1977)

2.10.6 Blaney-Criddle Method

Blaney and Criddle (1950) observed that the amount of water consumptively used by the crops during their growing seasons was closely correlated with mean monthly temperatures and daylight hours. The relationship developed by Blaney and Criddle in FPS units may be stated as

$$ET = \sum kf = \sum \frac{ktp}{100} \tag{2.17}$$

where,

ET = seasonal consumptive use of water by the crop for the given period in inches

k = empirical consumptive use crop coefficient for the month

f = monthly consumptive use factor for the growing season

t = mean monthly temperature in ^{0}F

Doorenbos and Pruitt (1977) recommended the following relationships for f in mm/day in the Blaney-Criddle formula:

$$f = 25.4\ (p \times t)/100 \tag{2.18a}$$

when t is in ^{0}F, and

$$f = p(0.46\ t + 8.13) \tag{2.18b}$$

when t is in ^{0}C.

Using Eq. (2.18b) in Eq. (2.17), the Blaney-Criddle formula can also be expressed as

$$ET_0 = p(0.46t + 8.13) \tag{2.19}$$

where,

ET_0 = reference crop evapotranspiration in mm/day for the month considered

p = monthly daylight hours expressed as percent of daylight hours of the year divided by 100

t = mean monthly temperature in ^{0}C

Doorenbos and Pruitt (1977) pointed out that the Blaney- Criddle method to calculate the mean daily reference evapotranspiration (ET_0) should normally be applied for periods not shorter than one month and for each calender month for each year of record, instead of using mean temperature from several years of record.

Blaney and Criddle (1950) developed a simplified formula using temperature and daytime hours for the arid western portion of the United States. Their formula has been used extensively by the Soil Conservation Service of the United States Department of Agriculture wherein considerable data have been collected to determine the values of the coefficients to be used for various crops. The Blaney-Criddle formula has a serious limitation in representing consumptive use for shorter time periods than one month due to the use of temperature as the only climatological variable. However, this formula has been used very extensively. In some instances, the monthly crop coefficients have been recalculated to better fit observed crop water use in a particular region. It is an empirical formula developed to fit arid conditions and will give good estimates of seasonal water needs under these conditions.

2.11 Testing of Accuracy of Different Prediction Methods

Several types of statistics such as standard deviation, mean deviation, coefficient of variance, Kolmogorov - Smirnov test, D-test, χ^2-test, correlation coefficient, coefficient of efficiency, root mean square and the t-test provide useful numerical measures of the degree of agreement between recorded (observed) and predicted quantities. Out of them, 4 statistical approaches, viz. the correlation coefficient (r), the coefficient of efficiency (C_e), the root mean square (rms) and the t-test for the mean difference have been used for comparing between the observed and the estimated evapotranspiration of rice and they are presented in the following sections.

2.11.1 Correlation coefficient

The correlation coefficient, r, is defined as (Haan, 1977)

$$r = \frac{Cov\ (S,R)}{S_s S_R} \tag{2.20}$$

where,

Cov (S,R) = covariance between predicted and recorded series

S_s, S_R = standard deviations of the predicted and recorded series, respectively.

A high correlation coefficient closer to 1 indicates closer agreement between the two series and a zero correlation coefficient indicates no agreement.

2.11.2 Coefficient of efficiency

The coefficient of efficiency, C_e, is defined as (James and Burges, 1982)

$$C_e = \frac{\sum_{i=1}^{N} [(S_i - R_i)/R_i]^2}{\sum_{i=1}^{N} (R_i/M_R - 1)^2} \tag{2.21}$$

where,

S_i and R_i = items in the predicted and recorded series, respectively.

M_R = mean of the series R_i

N = no. of observations.

The value of C_e should approach zero as the two series reach complete agreement.

2.11.3 Root mean square

The root mean square (rms) is given by (Jensen, 1973)

$$\text{rms} = \sqrt{(R_i - S_i)^2/N} \tag{2.22}$$

Like C_e, it should be equal to zero when the measured and the predicted values are in complete agreement.

2.11.4 t-test for mean difference

The t-test statistic has been determined to show whether the difference between the mean observed and estimated ET are significant or not. The t-test statistic is given by (Zaman et al., 1982).

$$t = \frac{\bar{X}_1 - \bar{X}_2}{S\sqrt{1/n_1 + 1/n_2}} \tag{2.23}$$

with, $n_1 + n_2 - 2$ degrees of freedom, where,

$\overline{X}_1$ = mean of the first sample (i.e. observed ET)

$\overline{X}_2$ = mean of the second sample (i.e. estimated ET)

n_1 = sample size of the first sample (i.e. observed ET)

n_2 = sample size of second sample (i.e. estimated ET)

S = combined standard deviation of the two samples

$$= \sqrt{\frac{(n_1-1)S_1^2+(n_2-1)S_2^2}{n_1+n_2-2}}$$

When $n_1 = n_2 = n$ $S = \sqrt{0.5(S_1^2+S_2^2)}$ (2.21)

If the calculated value of t is less than its tabulated value at 1% or 5% level of significance, then the hypothesis is accepted and the difference is insignificant. If the calculated value is greater than the tabulated value, the hypothesis is rejected and the difference is significant.

CHAPTER III

METHODOLOGY

3.1 Data Collection

3.1.1 Site selection

A set of 16 lysimeters, each having a volume of 1 cubic meter, has been constructed by Bangladesh Water Development Board (BWDB) at the Amla experimental farm, Kustia. The layout plan of the Amla experimental farm is shown in Fig. A.1 of Appendix-A. This farm is located in the G.K. project area, about 15 km west of Kustia city and lies approximately at $23^0 53'$ N latitude and $89^0 8'$ E longitude. The total area of the farm is 56 ha. A good number of experiments were conducted at the Amla experimental farm to determine the water requirements of crops with simultaneous collection of climatic data from the adjacent climatological station.

3.1.2 Collection of observed ET and climatological data

Various types of experiments such as water requirements of different local and HYV varieties of rice, effect of fertilizer dozes on the production of rice, integrated pest management, etc. were conducted by BWDB at Amla farm in Kustia. An experiment was conducted at Amla farm to ascertain water requirement of BR-3 variety of rice in the Boro season on lysimetric condition in G.K. area for the years 1987-88, 1988-89, and 1989-90, respectively (Fakir, 1990). The procedure for determining the water requirement of BR-3 rice is as follows:

The soil of each lysimeter was brought to the field capacity soil-moisture status and then a measured amount of water was added in the lysimeter to puddle the surface soil. The BR-3 rice seedlings were transplanted to the lysimeter pan at the rate of two seedings per hill with 20 cm x 20 cm spacing. About 2.5 cm standing water was maintained for 25 days for seedling establishment. After 25 days of transplantation, water was drained out from the lysimeter until it reached the field capacity level. The amount of water added (including rain water) minus the percolating water is considered to be the ET or consumptive use of water for the establishment period. In a similar way, the observed ET for other periods (mostly for 15-day period) during the growing season of the crop was calculated. The observed ET-values for different irrigation treatments are shown in Table 3.1 through Table 3.9.

Lysimetric data on ET of BR-3 rice for the period from 1987- 88 to 1989-90 have been collected from the Amla farm. The climatological data such as temperature, solar radiation, wind velocity, relative humidity, pan evaporation and rainfall for the same period have also been collected from the same station and are given in Appendix-A.

Table 3.1 **Irrigation requirement of BR-3 Boro rice under different levels for the year 1987-88**

Date	Treatments	Irrigation (cm)	Rainfall (cm)	Percolation (cm)	Water consumed (cm)
26.12.87 to 5.5.88	T_1	101.27	18.55	43.25	76.57
	T_2	67.19	18.55	33.97	51.77
	T_3	26.82	18.55	15.82	29.55
	T_4	59.71	18.55	31.54	46.72

T_1 = Continuous standing water (2.50 to 5.0 cm)

T_2 = Always saturated condition

T_3 = Rainfed condition

T_4 = Saturation for a period of 10 days and then allowed to dry upto hair-cracking and then added water to saturation and maintained saturation again for 10 days and then dried again and so on.

Table 3.2 **Effect of irrigation treatments on the growth and yield of BR-3 Boro for the year 1987-88**

Treatment	Date of Trans-planting	Date of maturity	Total growing periods (days)	Plant height (cm)	No. of effective tillers	Length of panicle (cm)	No.of fertile grain/ panicle	Yield (ton/ha)	Grain straw ratio	Reduction in yield over max. (%)
T_1	26.12.87	9.5.88	177	78.5	23.50	23.37	124.0	6.46	1:2.3	-
T_2	26.12.87	9.5.88	177	72.0	16.75	22.25	111.25	4.0	1:2.7	28.79
T_3	26.12.87	2.6.88	201	40.75	7.25	13.25	23.75	0.41	1:21.7	93.65
T_4	26.12.87	9.5.88	177	72.0	18.50	22.25	110.75	4.18	1:2.8	38.29

Table 3.3 Irrigation requirement of BR-3 Boro rice under different irrigation levels for the year 1988-89

Date	Treatments	Irrigation (cm)	Rainfall (cm)	Percolation (cm)	Water Consumed (cm)
18.12.88 to 11.5.89	T_1	132.98	1.03	51.88	82.13
	T_2	109.78	1.03	45.01	65.8
	T_4	103.05	1.03	41.38	62.7

Table 3.4 Effect of irrigation treatments on growth and yield contributing characters of Boro rice for the year 1988-89

Date of Trans-planting	Date of maturity	Treatments	Plant height (cm)	No.of effective tillers	Length of panicle (cm)	No. of fertile grain/ panicle	Yield (ton/ha)	Grain straw ratio	Reduction in yield over max. (%)
18.12.88	14.5.89	T_1	77.09	15.25	22.37	93.75	4.51	1:2.6	-
18.12.88	14.5.89	T_2	72.25	11.50	21.75	84.25	3.17	1:3.2	29.71
18.12.88	14.5.89	T_3	71.25	11.50	21.75	81.75	2.7	1:3.53	40.13

Table 3.5 Irrigation requirement of BR-3 Boro rice under different irrigation levels for the year 1989-90

Date	Treatments	Irrigation (cm)	Rainfall (cm)	Percolation (cm)	Water Consumed (cm)
19.12.89 to 10.5.90	T_1	114.65	29.2	66.10	77.75
	T_2	69.89	29.2	50.89	48.20

Table 3.6 Effect of irrigation treatments on the growth and yield contributing characters of BR-3 Boro rice for the year 1989-90

Date of trans-planting	Date of maturity	Treatment	Plant height (cm)	No. of tillers	Length of panicle (cm)	No. of filled grain/ panicle	Yield (ton/ha)	Grain straw ratio	Reduction in yield over max. (%)
19.12.89	12.5.90	T_1	73.34	19.08	20.84	82.08	9.0	1:1.33	-
19.12.89	12.5.90	T_2	70.37	15.58	20.84	79.32	7.3	1:1.67	35.21

Table 3.7 Seasonal irrigation requirement, percolation, rainfall and water consumed for the year 1987-88

Date	Irrigation (cm)	Rainfall (cm)	Percolation (cm)	Water Consumed (cm)
26.12.87 to 19.1.88	11.02	-	6.57	1.45
20.1.88 to 3.2.88	10.88	-	6.46	1.42
1.2.88 to 18.2.88	10.21	-	5.10	1.81
19.2.88 to 1.3.88	9.09	3.48	5.61	8.07
5.3.88 to 19.3.88	9.01	1.95	1.69	9.27
20.3.88 to 3.1.88	11.12	0.53	5.55	9.10
1.1.88 to 18.1.88	22.18	-	1.30	17.88
19.1.88 to 5.5.88	13.32	9.59	1.67	18.21
Grand Total (cm)	101.27	18.55	13.25	76.57

Table 3.8 **Seasonal irrigation requirement, percolation, rainfall and water consumed for the year 1988-89**

Date	Irrigation (cm)	Rainfall (cm)	Percolation (cm)	Water Consumed (cm)
18.12.88 to 11.1.89	12.82	-	5.72	7.10
12.1.89 to 26.1.89	11.23	-	6.25	4.98
27.1.89 to 10.2.89	11.89	-	4.66	7.23
11.2.89 to 25.2.89	13.39	0.75	5.77	8.37
26.2.89 to 12.3.89	14.66	-	5.92	8.74
13.3.89 to 27.3.89	16.42	-	7.05	9.37
28.3.89 to 11.4.89	14.15	0.15	3.64	10.66
12.4.89 to 26.4.89	20.7	-	7.35	13.35
27.4.89 to 11.5.89	17.72	0.13	5.52	12.33
Grand Total (cm)	132.98	1.03	51.88	82.13

Table 3.9 **Seasonal irrigation requirement, percolation, rainfall and water consumed for the year 1989-90**

Date	Irrigation (cm)	Rainfall (cm)	Percolation (cm)	Water Consumed (cm)
19.12.89 to 12.1.90	11.74	2.1	8.74	5.10
13.1.90 to 27.1.90	8.57	-	5.42	3.15
28.1.90 to 11.2.90	13.31	-	7.46	5.85
12.2.90 to 26.2.90	6.25	6.6	7.92	4.93
27.2.90 to 13.3.90	7.81	6.80	6.77	7.84
14.3.90 to 28.3.90	16.33	-	6.63	9.70
29.3.90 to 12.4.90	15.08	6.30	7.79	13.59
13.4.90 to 27.4.90	20.26	3.10	7.40	15.96
28.4.90 to 10.5.90	15.30	4.30	7.97	11.63
Grand Total (cm)	114.65	29.20	66.10	77.75

3.2 Data Analysis

3.2.1 Estimation of evapotranspiration

The modified Penman, the Hargreaves, the Thornthwaite, the pan evaporation and the Blaney-Criddle methods have been used to estimate the ET_0 of BR-3 Boro rice for the same period for which the observed ET and the climatological data are available. The detail procedure for estimating ET_0 is given in Appendix-B.

The reference crop evapotranspiration, ET_0, obtained by different methods has been multiplied by the crop coefficient (K_c) of rice to obtain the actual evapotranspiration ET. The crop coefficient of rice for different months is taken from Doorenbos and Pruitt (1977) and is given in Table 3.10. Karim and Akand (1984), Saleh and Fatema (1988) and Halim (1992) also used the same crop coefficient of rice.

Table 3.10 Crop coefficient (K_c) of rice for different months (Doorenbos and Pruitt, 1977)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
K_c	1.15	1.25	1.0	1.10	1.15	1.30	1.0	1.10	1.15	1.30	1.0	1.10

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 General

As stated earlier, five methods, namely the modified Penman, the Hargreaves,the Thornthwaite, the pan evaporation and the Blaney-Criddle methods, have been used to determine the evapotranspiration of BR-3 rice in the G.K. project area using climatological data for the crop season December to May of the years 1987-88 to 1989-90. In order to study the effectiveness of these methods, the predicted ET has been compared with the actual ET. The accuracy of prediction has been tested by the statistical approaches such as correlation coefficient (r), coefficient of efficiency (C_e), root mean square (rms) and t-statistics for the test of mean difference. The results of the present study are presented and discussed in the following sections.

4.2 Comparison between Observed and Estimated ET

The actual (observed) ET for BR-3 Boro variety of rice for the crop season December to May of the years 1987-88 to 1989-90 is given in Table 4.1. From this table it is seen that the actual ET of BR-3 Boro crop for the entire growing season varies from 76.57 cm to 82.13 cm. The lengths of growing season in 1987-88, 1988-89 and 1989-90 are 132, 145 and 143 days, respectively.

Table 4.1 Observed evapotranspiration of BR-3 Boro variety of rice

Growing season	Length of growing season (days)	Observed ET during the growing season (cm)	Mean daily ET during the growing season (mm/day)	Mean daily ET for 3 growing seasons (mm/day)
26.12.87 to 5.5.88	132	76.57	5.80	
18.12.88 to 11.5.89	145	82.13	5.66	5.63
19.12.89 to 10.5.90	143	77.75	5.43	

From these values, the average daily ET during the entire growing season is found to range from 5.43 mm/day to 5.80 mm/day, the mean daily ET for the three growing seasons being 5.63 mm/day. It is seen that the difference between the mean daily ET of BR-3 Boro variety of rice in the three growing seasons is practically insignificant and well within 4% of its average value of 5.63 mm/day.

The mean daily values of ET in different months obtained by different methods for the crop season December to May of the years 1987-88 to 1989-90 are given in Table 4.2 and the comparisons between the observed ET and that computed by the five methods for different dates are presented in Tables 4.3, 4.4, 4.5, 4.6 and 4.7, respectively.

Table 1.2 Monthly mean daily ET (mm/day) by different methods for the years 1987-88 to 1989-90

Method	Year	Mean daily T (mm/day) in the month of						Mean daily ET for the growing season (mm/day)	Mean daily ET for 3 growing seasons (mm/day
		Dec	Jan	Feb	Mar	Apr	May		
Modified Penman	1987-88	2.61	1.41	1.27	1.33	6.38	6.15	1.79	1.92
	1988-89	3.22	3.21	5.12	5.63	8.07	8.56	5.58	
	1989-90	2.95	3.27	1.68	1.15	6.10	7.23	1.10	
Har-greaves	1987-88	3.06	3.70	1.97	5.09	6.88	6.11	5.12	5.05
	1988-89	1.20	3.55	5.12	5.66	7.39	7.92	5.18	
	1989-90	2.78	3.31	1.85	1.11	5.85	6.72	1.57	
Thornth-waite	1987-88	1.53	1.21	2.31	3.37	7.71	7.62	3.69	3.67
	1988-89	2.78	0.81	1.90	3.18	8.19	12.21	1.23	
	1989-90	1.08	1.11	2.29	2.83	5.62	7.28	3.09	
Pan evapora-tion	1987-88	1.18	1.51	1.93	2.92	1.31	1.18	2.67	2.81
	1988-89	1.60	1.70	2.32	2.76	1.53	1.15	2.80	
	1989-90	1.35	1.13	1.61	2.32	3.23	3.00	2.13	
Blaney-Criddle	1987-88	1.11	1.31	5.60	5.21	6.87	7.30	5.19	5.53
	1988-89	1.60	1.31	5.60	5.21	7.00	7.93	5.61	
	1989-90	3.92	1.13	5.71	5.07	6.58	7.31	5.50	

Table 4.3 Datewise comparison between observed ET (mm/day) and ET (mm/day) estimated by the modified Penman method

1987-88			1988-89			1989-90		
Date	ET_{obs}	ET_{est}	Date	ET_{obs}	ET_{est}	Date	ET_{obs}	ET_{est}
26.12.87 to 19.1.88	1.78	3.98	18.12.88 to 11.1.89	2.84	3.32	19.12.89 to 12.1.90	2.04	3.10
20.1.88 to 3.2.88	2.95	4.38	12.1.89 to 26.1.89	3.90	3.24	13.1.90 to 27.1.90	2.10	3.27
4.2.88 to 18.2.88	3.23	4.27	27.1.89 to 10.2.89	4.82	4.69	28.1.90 to 11.2.90	3.90	4.30
19.2.88 to 4.3.88	5.38	4.29	11.2.89 to 25.2.89	5.58	5.42	12.2.90 to 26.2.90	3.29	4.68
5.3.88 to 19.3.88	6.18	4.33	26.2.89 to 12.3.89	5.83	5.58	27.2.90 to 13.3.90	5.23	4.48
20.3.88 to 3.4.88	6.27	4.74	13.3.89 to 27.3.89	6.25	5.63	14.2.90 to 28.3.90	6.47	4.45
4.4.88 to 18.4.88	11.92	6.38	28.3.89 to 11.4.89	7.11	7.41	29.3.90 to 12.4.90	9.06	6.01
19.4.88 to 5.5.88	10.73	6.30	12.4.89 to 26.4.89	8.90	8.07	13.4.90 to 27.4.90	10.64	6.40
			27.4.89 to 11.5.89	8.22	8.40	28.4.90 to 10.5.90	8.95	6.10
Mean	5.80	4.79		5.66	5.58		5.43	4.40
% diff.	-17.41			-1.41			-18.96	

Table 4.1 Datewise comparison between observed ET (mm/day) and ET (mm/day) estimated by the Hargreaves method

1987-88			1988-89			1989-90		
Date	ET_{obs}	ET_{est}	Date	ET_{obs}	ET_{est}	Date	ET_{obs}	ET_{est}
26.12.87 to 19.1.88	1.78	3.54	18.12.88 to 11.1.89	2.84	3.91	19.12.89 to 12.1.90	2.04	3.03
20.1.88 to 3.2.88	2.95	3.97	12.1.89 to 26.1.89	3.32	3.55	13.1.90 to 27.1.90	2.10	3.31
4.2.88 to 18.2.88	3.23	5.15	27.1.89 to 10.2.89	4.82	4.59	28.1.90 to 11.2.90	3.90	4.43
19.2.88 to 4.3.88	5.38	5.13	11.2.89 to 25.2.89	5.58	5.12	12.2.90 to 26.2.90	3.29	4.85
5.3.88 to 19.3.88	6.18	5.09	26.2.89 to 12.3.89	5.83	5.55	27.2.90 to 13.3.90	5.23	4.49
20.3.88 to 3.4.88	6.27	5.45	13.3.89 to 27.3.89	6.25	5.66	14.3.90 to 28.3.90	6.47	4.45
4.4.88 to 18.4.88	11.92	6.88	28.3.89 to 11.4.89	7.11	6.92	29.3.90 to 12.4.90	9.06	5.57
19.4.88 to 5.5.88	10.73	6.64	12.4.89 to 26.4.89	8.90	7.39	13.4.90 to 27.4.90	10.64	5.85
			27.4.89 to 11.5.89	8.22	7.77	28.4.90 to 10.5.90	8.95	6.52
Mean	5.80	5.12		5.66	5.48		5.43	4.57
% diff.	-11.72			-3.18			-15.83	

Table 4.5 Datewise comparison between observed ET (mm/day) and ET (mm/day) estimated by the Thornthwaite method

1987-88			1988-89			1989-90		
Date	ET_{obs}	ET_{est}	Date	ET_{obs}	ET_{est}	Date	ET_{obs}	ET_{est}
26.12.87 to 19.1.88	1.78	1.28	18.12.88 to 11.1.89	2.84	1.91	19.12.89 to 12.1.90	2.04	1.10
20.1.88 to 3.2.88	2.95	1.43	12.1.89 to 26.1.89	3.32	0.81	13.1.90 to 27.1.90	2.10	1.14
4.2.88 to 18.2.88	3.23	2.34	27.1.89 to 10.2.89	4.82	1.53	28.1.90 to 11.2.90	3.90	1.98
19.2.88 to 4.3.88	5.38	2.61	11.2.89 to 25.2.89	5.58	1.90	12.2.90 to 26.2.90	3.29	2.29
5.3.88 to 19.3.88	6.18	3.37	20.2.89 to 12.3.89	5.83	3.16	27.2.90 to 13.3.90	5.23	2.75
20.3.88 to 3.4.88	6.27	4.24	13.3.89 to 27.3.89	6.25	3.48	14.3.90 to 28.3.90	6.47	2.83
4.4.88 to 18.4.88	11.92	7.71	28.3.89 to 11.4.89	7.11	7.15	29.3.90 to 12.4.90	9.06	5.06
19.4.88 to 5.5.88	10.73	7.68	12.4.89 to 26.4.89	8.90	8.49	13.4.90 to 27.4.90	10.64	5.62
			27.4.89 to 11.5.89	8.22	11.24	28.4.90 to 10.5.90	8.95	6.89
Mean	5.80	3.69		5.66	4.23		5.43	3.09
% diff.	-36.38			-25.26			-43.09	

Table 4.6 Datewise comparison between observed ET (mm/day) and ET (mm/day) estimated by the pan evaporation method

1987-88			1988-89			1989-90		
Date	ET_{obs}	ET_{est}	Date	ET_{obs}	ET_{est}	Date	ET_{obs}	ET_{est}
26.12.87 to 19.1.88	1.78	1.52	18.12.88 to 11.1.89	2.84	1.64	19.12.89 to 12.1.90	2.04	1.38
20.1.88 to 3.2.88	2.95	1.62	12.1.89 to 26.1.89	3.32	1.70	13.1.90 to 27.1.90	2.10	1.43
4.2.88 to 18.2.88	3.23	1.93	27.1.89 to 10.2.89	4.82	2.11	28.1.90 to 11.2.90	3.90	1.56
19.2.88 to 4.3.88	5.38	2.19	11.2.89 to 25.2.89	5.58	2.32	12.2.90 to 26.2.90	3.29	1.61
5.3.88 to 19.3.88	6.18	2.92	26.2.89 to 12.3.89	5.83	2.67	27.2.90 to 13.3.90	5.23	2.22
20.3.88 to 3.4.88	6.27	3.20	13.3.89 to 27.3.89	6.25	2.76	14.3.90 to 28.3.90	6.47	2.32
4.4.88 to 18.4.88	11.92	4.31	28.3.89 to 11.4.89	7.11	4.06	29.3.90 to 12.4.90	9.06	3.03
19.4.88 to 5.5.88	10.73	4.27	12.4.89 to 26.4.89	8.90	4.53	13.4.90 to 27.4.90	10.64	3.21
			27.4.89 to 11.5.89	8.22	4.25	28.4.90 to 10.5.90	8.95	3.04
Mean	5.80	2.67		5.66	2.80		5.43	2.13
% diff.	-53.96			-50.53			-60.77	

Table 1.7 Datewise comparison between observed ET (mm/day) and ET (mm/day) estimated by the Blaney-Criddle method

1987-88			1988-89			1989-90		
Date	ET_{obs}	ET_{est}	Date	ET_{obs}	ET_{est}	Date	ET_{obs}	ET_{est}
26.12.87 to 19.1.88	1.78	4.29	18.12.88 to 11.1.89	2.84	4.47	19.12.89 to 12.1.90	2.04	4.16
20.1.88 to 3.2.88	2.95	4.59	12.1.89 to 26.1.89	3.32	4.31	13.1.90 to 27.1.90	2.10	4.43
4.2.88 to 18.2.88	3.23	5.60	27.1.89 to 10.2.89	4.82	5.17	28.1.90 to 11.2.90	3.90	5.36
19.2.88 to 4.3.88	5.38	5.49	11.2.89 to 25.2.89	5.58	5.60	12.2.90 to 26.2.90	3.29	5.71
5.3.88 to 19.3.88	6.18	5.21	26.2.89 to 12.3.89	5.83	5.31	27.2.90 to 13.3.90	5.23	5.15
20.3.88 to 3.4.88	6.27	5.54	13.3.89 to 27.3.89	6.25	5.24	14.3.90 to 28.3.90	6.47	5.87
4.4.88 to 18.4.88	11.92	6.87	28.3.89 to 11.4.89	7.11	6.53	29.3.90 to 12.4.90	9.06	6.27
19.4.88 to 5.5.88	10.73	6.99	12.4.89 to 26.4.89	8.90	7.00	13.4.90 to 27.4.90	10.64	6.58
			27.4.89 to 11.5.89	8.22	7.68	28.4.90 to 10.5.90	8.95	7.16
Mean	5.80	5.49		5.66	5.61		5.43	5.50
% diff.	-5.34		-0.88			+1.29		

From Table 4.2, it is seen that the seasonal ET-value computed by different methods vary considerably. The ET-values predicted by the pan evaporation method are the lowest and those predicted by the Blancy-Criddle method are the highest. The ET- values given by the modified Penman, the Hargreaves and the Blaney-Criddle methods seem to be near to one another. The Thornthwaite and the pan evaporation methods give ET-values which are considerably lower than those predicted by the other three methods.

From Table 4.3, it is readily seen that the observed ET varies from 1.78 mm/day to 11.92 mm/day and the estimated ET calculated by the modified Penman method varies from 3.10 mm/day to 8.07 mm/day. For the entire growing season, the daily mean observed ET varies from 5.43 mm/day to 5.80 mm/day and the daily mean ET estimated by the modified Penman method varies from 4.40 mm/day to 5.58 mm/day. This method overestimates the actual ET during first two months of its growing season and underestimates the actual ET during the rest of the growing season. The modified Penman method tends to underestimate the observed ET in all the years, the percentage of underestimation being 17.41, 1.40 and 18.96 in the years 1987-88, 1988-89 and 1989-90, respectively. This method as a whole underestimates the observed ET by 12.59%.

From Table 4.4, it is seen that the ET computed by the Hargreaves method varies from 3.03 mm/day to 7.77 mm/day. The mean ET estimated by the Hargreaves method varies from 4.57 mm/day to 5.48 mm/day. This method overestimates the actual ET for more than two months after transplanting of the rice plants and underestimates the actual ET for the rest of the growing season upto the maturity stage. The Hargreaves method tends to underestimate the observed ET in all the years, the percentage of underestimation being 11.72, 3.18, 15.83 in the years 1987-88, 1988-89 and 1989-90, respectively. This method as a whole underestimates the observed ET by 10.24%.

From Table 4.5, it is seen that the ET computed by the Thornthwaite method varies from 0.81 mm/day to 11.24 mm/day. The mean ET estimated by the Thornthwaite method varies from 3.09 mm/day to 4.23 mm/day. This method underestimates the actual ET more than three months after transplanting of rice plants and overestimates the actual ET during rest of the growing period. The Thornthwaite method tends to underestimate the observed ET considerably in all the years, the percentage of underestimation being 36.38, 25.26, 43.09 in the years 1987-88, 1988-89, 1989-90, respectively. This method as a whole underestimates the observed ET by 34.91%.

From Table 4.6, it is seen that the ET computed by the pan evaporation method varies from 1.38 mm/day to 4.53 mm/day and the mean daily ET for the entire growing season varies from 2.13 mm/day to 2.80 mm/day. This method underestimates the actual ET during entire growing season. The pan evaporation method tends to underestimate the observed ET in all the years considerably, the percentage of underestimation being 53.96, 50.53, 60.77 in the years 1987-88, 1988-89, 1989-90, respectively. This method as a whole underestimates the observed ET by 55.02%.

From Table 4.7, it is seen that the ET computed by the Blaney-Criddle method varies from 4.16 mm/day to 7.68 mm/day and the mean daily ET for the whole growing season varies from 5.50 mm/day to 5.61 mm/day. The

Blaney-Criddle method tends to underestimate the observed ET slightly in the years, 1987-88 and 1988-89, the percentage of underestimation being 5.34 and 0.88, respectively and overestimate the actual evapotranspiration by 1.29% in the year 1989-90. This method as a whole underestimates the observed ET by 1.64%.

From the results presented in Tables 4.3 through 4.7, it is apparent that all the five methods, viz. the modified Penman, the Hargreaves, the Thornthwaite, the pan evaporation and the Blaney- Criddle methods, underestimate the actual or observed ET, the percentage of underestimation as a whole for the growing seasons being 12.59, 10.24, 34.91, 55.02 and 1.64, respectively. Thus, comparing between the actual ET and the ET computed by the five prediction methods, the Blaney-Criddle method seems to be best, followed by the Hargreaves and the modified Penman methods. The ET-values obtained by the Hargreaves and the modified Penman methods are very near to one another. The ET-values obtained by the Thornthwaite and the pan evaporation methods are considerably lower than the actual ET-values.

The variation of actual and estimated ET by different methods with time of the growing season have been shown in Figs. 4.1 to 4.3 for the years 1987-88 to 1989-90, respectively. From these figures, it is apparent that the rate of water consumption of BR-3 rice plants depends upon its stage of growth. Initially, right after transplanting, the water needs of the rice plants are relatively low because of limited leaf area and lower physiological activities of the rice plants at that time. As the growth continued,the consumptive use needs of the plants increased gradually and reached a maximum value in the booting stage when the vegetative growth of the rice plants was also maximum. In the entire reproductive phase, the rate of water consumption was very high compared to the vegetative phase (tillering phase). After the heading stage, the water needs of the crop reduced gradually in the ripening phase.

From Table A.1 through Table A.3 of Appendix-A and Figs. 4.1 to 4.3, it is found that the water requirement for BR-3 Boro rice is maximum in the month of April. It is stated earlier that in our country the Boro season is characterized by dry weather having a little or no effective rainfall. Due to dry climate and high wind velocity in the month of April, water loss due to transpiration is extremely high. For BR-3, the month of April becomes more critical because it coincides with the booting and heading stages (reproductive phase) of the rice plants. Hence any moisture stress in this month will cause considerable damage to the BR-3 Boro crop resulting in substantial decrease in grain yield.

4.3 Accuracy of prediction

The correlation coefficient (r), the coefficient of efficiency (C_e), the root mean square (rms) and the t-static for the different methods are presented in Table 4.8. From this table, it is seen that the average value of the correlation coefficient (r) of all the methods is high, equal to or greater than 0.90. However, in terms of this coefficient, the ranking of the different methods are (1) the pan evaporation method (r = 0.97), (2) the modified Penman method (r = 0.95), (3) the Hargreaves method (r = 0.93), (4) the Thornthwaite method (r = 0.92) and (5) the Blaney-Criddle method (r = 0.90).

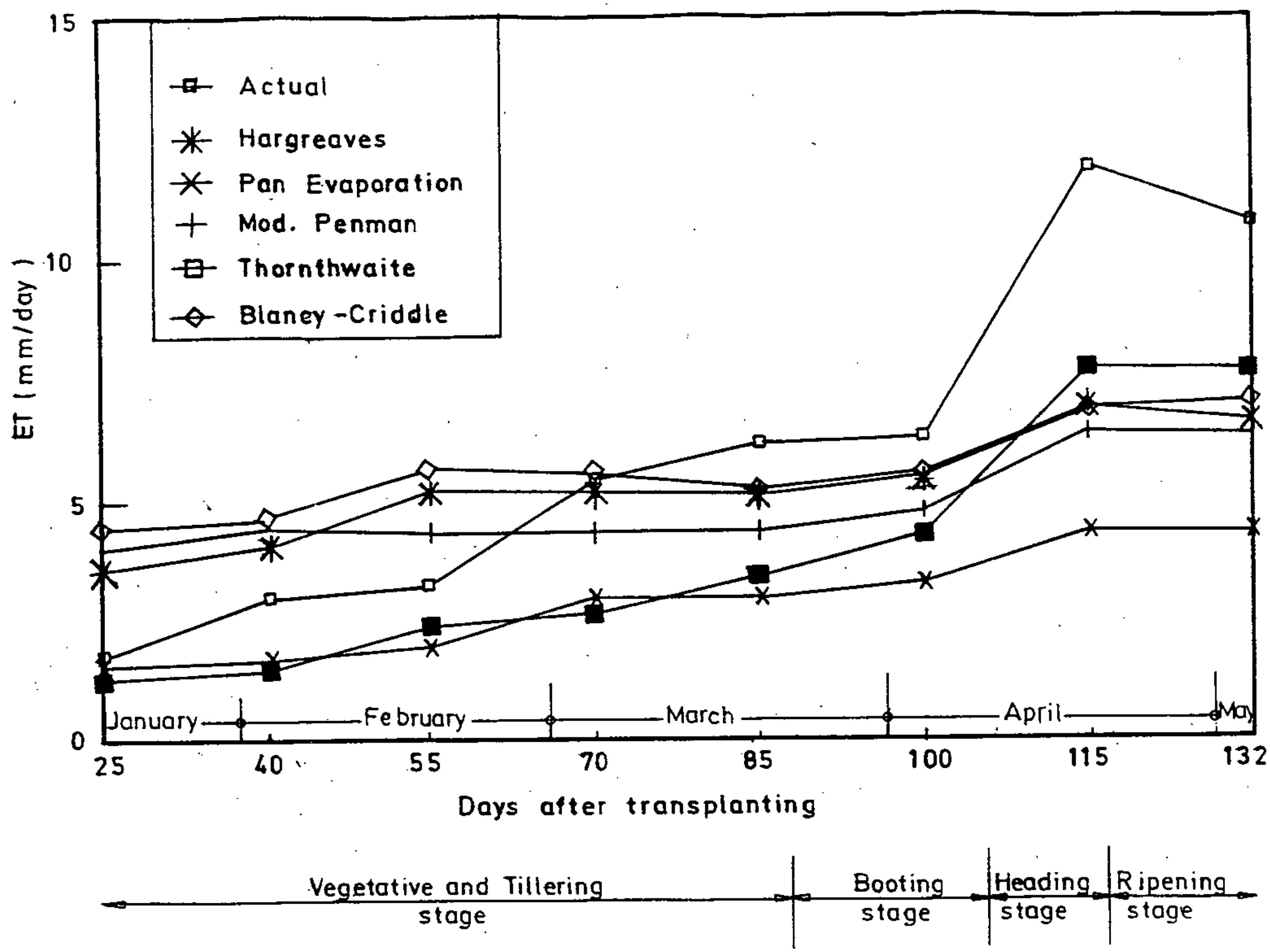


Fig. 4.1 Variation of Crop Evapotranspiration with Time of Season for the Year 1987 - 88

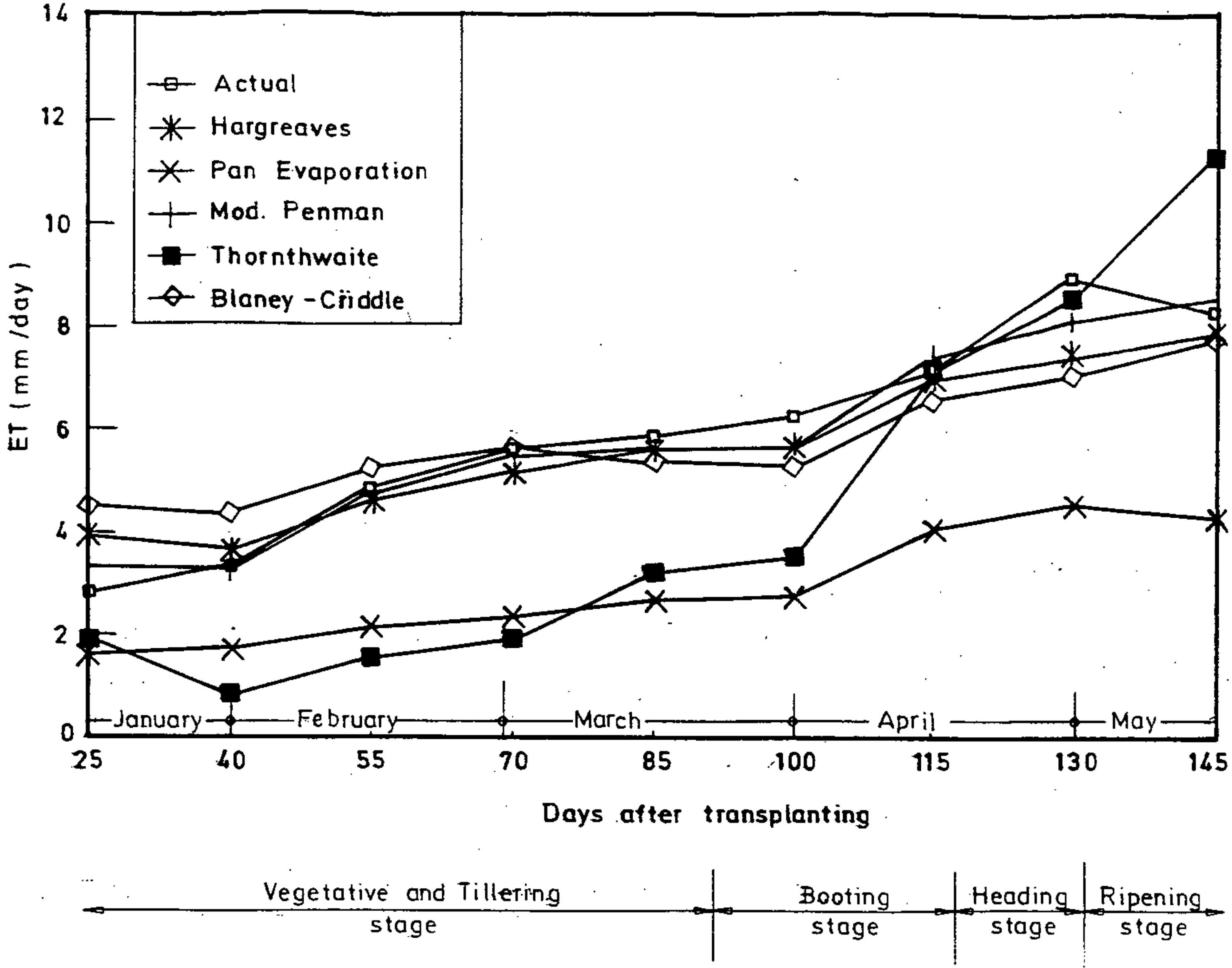


Fig. 4.2 Variation of Crop Evapotranspiration with Time of Season for the Year 1988-89

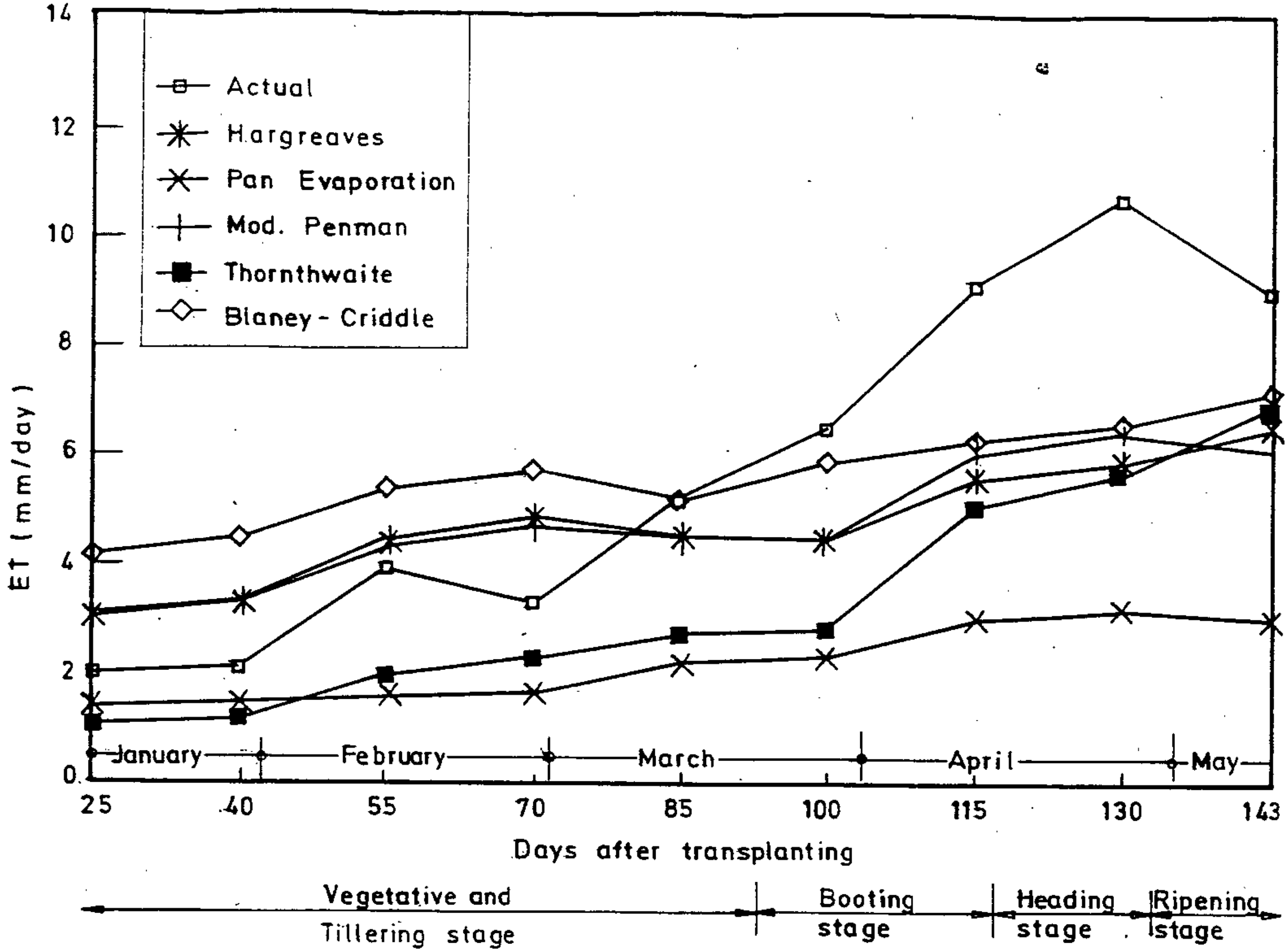


Fig. 4.3 Variation of Crop Evapotranspiration with Time of Season for the Year 1989 - 90

Table 4.8 Correlation coefficient (r), coefficient of efficiency (C_e), root mean square (rms) and t-statistic of different methods

Method	Year	Correlation coefficient (r)	Coefficient of efficiency (C_e)	Root mean square (rms)	t-statistic		
					t_{cal}	t_{tab}	Remarks
Modified Penman	1987-88	0.94	0.88	2.85	1.34	2.14	**
	1988-89	0.98	0.08	0.40.	0.07	2.12	**
	1989-90	0.94	0.88	2.22	0.89	2.12	**
Hargreaves	1987-88	0.94	0.65	2.54	0.50	2.14	**
	1988-89	0.97	0.20	0.69	0.21	2.12	**
	1989-90	0.88	0.48	2.37	0.75	2.12	**
Thornthwaite	1987-88	0.96	0.43	2.50	0.95	2.14	**
	1988-89	8.87	2.17	2.48	0.96	2.12	**
	1989-90	0.93	1.03	2.81	1.72	2.12	**
Pan evaporation	1987-88	0.97	0.72	4.08	1.16	2.14	**
	1988-89	0.95	2.39	3.13	3.69	2.12	*
	1989-90	0.98	.62	4.24	3.00	2.12	*
Blaney-Criddle	1987-88	0.92	1.14	2.63	0.23	2.14	**
	1988-89	0.93	0.52	1.01	0.05	2.12	**
	1989-90	0.85	1.18	2.29	0.05	2.12	**

* = Significant
** = Not significant

The coefficient of efficiency of different methods, as found in Table 4.8, varies from as low as 0.08 (the modified Penman method) to 2.39 (the pan evaporation method). Considering the average value of this coefficient for the three growing seasons, the Hargreaves method (C_e = 0.44) and the modified penman method (C_e = 0.61) seem to be better than the Blaney-Criddle (C_e = 1.15), the Thornthwaite (C_e = 1.21) and the pan evaporation (C_e = 1.24) methods.

As it is seen in Table 4.8, the root mean square (rms) value of different methods varies over a wide range from 0.40 to 4.24. In terms of the mean rms value, the modified penman method (rms = 1.82) and the Hargreaves method (rms = 1.87) and the Blaney- Criddle method (rms = 1.98) seem to be better than the Thornthwaite (rms = 2.60) and the pan evaporation (rms = 3.82) methods.

The t-values for the mean test has been presented in the same table to show the existence of statistical difference between the actual ET and the estimated ET by different methods for the three years. It is seen that no statistical difference exists between the observed and the estimated ET except the result obtained by the pan evaporation method.

4.4 Best Prediction Method for Bangladesh

Considering the seasonal ET obtained by different methods, the numerical values of r, C_e, rms,and the t-statistic and the climatic data requirements, the following two prediction methods seem to be satisfactory for the climatic conditions of Bangladesh:

1. The modified Penman method

2. The Hargreaves method

The modified Penman method requires air temperature, relative humidity, wind velocity and solar radiation (or sunshine hours) for predicting evapotranspiration. In fact, most of the climatic parameters which have influence on the rate of evaporation are included in the modified Penman method and this is the reason why the modified Penman method provides the best prediction of ET. This method has been widely used all over the world and the applicability of this method for predicting evaporation and evapotranspiration from a surface regardless of its size, shape and climatic location is beyond any doubt. As stated earlier, this method has also been widely used in Bangladesh.

The main attraction of the Hargreaves method may be that it requires air temperature and solar radiation (or sunshine hours) only for predicting evapotranspiration and thus it is comparatively simple in its application. As stated earlier, the Blaney-Criddle, the radiation and the modified Penman method have been used by the different organizations in Bangladesh for computing ET of different crops. The radiation method has not been considered in the present study. The works of Saleh and Fatema (1988) and Halim (1992) established that this method is far less satisfactory than the modified Penman method for estimating ET of rice. The results of the present study seem to indicate that the Blaney-Criddle method is satisfactory so far as the prediction of ET is concerned. However, in terms of correlation coefficient, coefficient of efficiency and root mean square, this method is not as satisfactory as the modified Penman and the Hargreaves methods.

4.5 Possible Sources of Error

One possible source of error in this study might be the water loss by leakage through the concrete tank. The lysimeter of Amla farm is old and due to lack of proper maintenance the loss might occur. However, the seasonal consumptive use values do not suggest any appreciable source of error of this kind.

The error of observation, if any, was supposed to be very small, because such an error would be random and in both directions (positive and negative). Such errors are also expected to be somewhat self-compensatory in nature.

On the whole, it may be concluded that no substantial error has been involved in the experiment and the results obtained seem satisfactory.

CHAPTER V

CONCLUSIONS AND SUGGESTIONS FOR FURTHER STUDY

5.1 Conclusions

The following conclusions could be drawn from this study on the relationship between observed and estimated evapotranspiration of BR-3 Boro variety of rice.

1. The modified Penman method and Hargreaves method seem to be the best methods for predicting the evapotranspiration of BR-3 Boro variety of rice.

2. The daily evapotranspiration of BR-3 Boro variety of rice during the entire growing season (December to May) varies from 5.43 mm/day to 5.80 mm/day and the mean daily ET is 5.63 mm/day.

3. The rate of water consumption of BR-3 rice plants depends upon its stage of growth. After transplanting, the water needs of the rice plants increase as the vegetative growth of the plant continues and reaches the maximum at the booting and heading stages (reproductive phase).

4. The consumptive use requirement for BR-3 Boro rice is maximum in the month of April which coincides with the booting and heading stages (reproductive phase) of the crop.

5.2 Suggestions for further study

The present study is limited to the prediction of evapotranspiration for one crop, one location and one season only. Consequently, the following suggestions are made as to the determination of consumptive water needs of different crops:

1. Similar study may be undertaken for a number of seasons to obtain results representative of average climatic conditions.

2. Similar study may be repeated for different locations of Bangladesh to obtain results representative of the climatic conditions of the country.

3. The study may be extended for Aus and Aman seasons.

4. The study may be undertaken for other crops like jute, wheat, pulses, potato, etc.

5. There are a variety of methods for predicting evapotranspiration of crops. The study may be extended to determine the evapotranspiration by other methods not considered in the present study.

6. The present study has been undertaken to determine the evapotranspiration only. The study may be extended to determine the irrigation water requirements of different crops in different months.

REFERENCES

1. Acres International Overseas Ltd., 1970, Crop consumptive use in East Pakistan, Dhaka.

2. Bangladesh Bureau of Statistics, 1993, Statistical Yearbook of Bangladesh, Ministry of Planning, Government of Bangladesh.

3. Bangladesh Rice Research Institute, 1974, BR-3 a new rice cultivar of Bangladesh, Joydebpur, Dhaka.

4. Blaney, H.F., 1952, Definition, methods and research data, A symposium on consumptive use of water, ASCE Transactions, Vol. 117, Paper No. 25244.

5. Blaney,H.E. and Criddle, W.D., 1950, Determining water requirements in irrigated areas from climatological and irrigation data, U.S. Dept. Agri., SCS-TP 96.

6. Biswas, M. R. and Ali, M. F.,1976, Determination of the consumptive use of water for IRRI-8 Paddy, Department of Irrigation and Water Management, Bangladesh Agricultural University,Mymensingh.

7. Bruce, W. and Stanley, V., 1988, Irrigation : Design and Practice, BT Batsford limited, London.

8. BUET and BWDB, 1987, Report on the study of water availability and irrigation water requirement of Teesta Project, Submitted to Bangladesh Water Development Board.

9. Criddle, W.D., 1952, Irrigated Crops, A Symposium on consumptive use of water, ASCE Transactions, Vol.117, Paper No.2524.

10. Criddle,W.D., 1958, Methods of computing consumptive use of water, Proc. ASCE., J. Div. Irrigation and Drainage, Vol. 84, IRI, 1-77.

11. Chang, J., 1968, Climate and Agriculture --- an Ecological Survey. Aldine Publishing Co., Chicago.

12. Christiansen, J.E., 1968, Pan evaporation and evapotranspiration from climatic data, J. Irrig. and Drain. Div., ASCE, Vol. 94, 243-265.

13. Doorenbos, J. and Pruitt, W.O., 1977, Crop water requirements, FAO Irrigation and Drainage paper 24, FAO, Rome.

14. EPWAPDA, 1968, Consumptive use of water by rice and other crops in the G.K. Project area, Directorate of land and water use.

15. Erie, K.J., French, O.F. and Harris, K., 1965, Consumptive use of water by crops in Arizona. Technical Bulletin No. 169. University of Arizona.

16. Fakir, M.A., 1990, Annual report of Amla experimental farm, BWDB, Kustia.

17. Flood Plan Coordination Organisation, 1993, Jamalpur Priority Project Study, Final Feasibility Report, Peoples Republic of Bangladesh, Ministry of Irrigation, Water Development and Flood Control.

18. Food Situation Report, 1993, Food Planning and Monitoring Unit, Ministry of Food, Government of Bangladesh.

19. Haan, C.T., 1977, Statistical Methods in Hydrology, Iowa State University Press, Ames.

20. Halim, M.A., 1977, Water Requirement for BR-3 variety of rice, M.Sc. Engineering Thesis, Department of Water Resources Engg., BUET, Dhaka.

21. Halim, M.A., 1992, A comparative study of some methods of estimating reference crop evapotranspiration using climatic data form different locations of Bangladesh, Bangladesh Journal of Water Resource Research, Vol. 13, 1-20.

22. Hargreaves, G.H., 1985, Crop water requirements, Lecture Notes presented in a training program on Groundwater Investigations held at Bangladesh Rice Research Institute, Gazipur, April 1-28.

23. Hendricks, J.M.H., Vinn, N.H, and Fayinne, T., 1986, Water requirement for irrigated rice in semi arid region in West Africa, Journal of Agricultural Water Management, 75-90.

24. Hobba, R.L., 1964, Hydrology of Forest lands and Rangelands, Section 22, Handbook of Applied Hydrology, McGraw-Hill Book Company, New York.

25. Houk, I.E., 1960, Irrigation Engineering, Vol. I., John Wiley and Sons, New York.

26. Huang, C.H., 1963, Water requirements of rice by tank experiments. Findings and recommendations, FAO of UN, Dhaka.

27. Huq, A.K.M.F., Khan, S.H. and Qasem, M.A., 1970, Consumptive use coefficient (K) determination of T. Aus, Aman and Boro rice for the Ganges-Kobadak area of East Pakistan, Pakistan Journal of Soil Science, Vol. VI, No.2.

28. Hussain, Q., Mushabbir, P.M. and Christoph, F., 1990, Relationship between observed and estimated crop evapotranspiration and climate variations., AMA , Vol. 2, No.3, 61-65.

29. IBRD, 1972, Bangladesh land and water resources sector study, Vol.3, Water Resources, Washington.

30. IECO, 1964, EPWAPDA Master Plan, Supplement B, Agriculture.

31. James, L.D. and S.J. Burges, 1982, Selection, Calibration and Testing of Hydrologic Models, in Hydrologic Modeling of Small Watersheds, ASAE Monograph No.5.

32. Jenkins, D., 1981, Irrigation water distribution systems for tubewells and low lift pumps in Bangladesh, CARE-USAID.

33. Jensen, M.E. (ed.), 1973, Consumptive Use of Water and Irrigation Water Requirements, Report by the Technical Committee on Irrigation Water Requirements, Irrigation and Drainage Division, American Society of Civil Engineers, New York.

34. Karim, Z. and Akand, N.A., 1982, Net irrigation requirement of rice and evapotranspiration of wheat and potato for different locations of Bangladesh, BARC, Dhaka.

35. Khan, B.R., Mainuddin, M., Miah, M.A.A., Molla, M.N. and Maniruzzaman, M., 1992, Evapotranspiration from lentil, Bangladesh Journal of Agricultural Engineering, Vol. 6, Nos. 1 and 2, 63-68.

36. Kohler, M.A., Nordenson, T.J., and Fox, W.E., 1955, Evaporation from pans and lakes, U.S. Department Com. Weather Bur., Res. Paper 38, 1-21.

37. Krammer, P.J., 1972, Plant and Soil Water Relationship: a Modern Synthesis, Tata McGraw-Hill Publishing Co. Ltd., New Delhi.

38. Linsley, R.K.,Kohler, M.A. and Paulhus, L.H. J., 1975, Applied Hydrology, Tata Mcgraw-Hill Publishing Company Ltd., New Delhi.

39. Lull, H.W., 1964, Ecological and silvicultural aspects, Section 6, Handbook of Applied Hydrology. Mcgraw-Hill Book Co., New York.

40. Meyer, B.S. and Anderson D.B., 1952, Plant Physiology, V. Dan Nostrand Company, New York.

41. MPO, 1984, National Water Plan Project, Vol. VI, Agriculture.

42. Oliver, H., 1961, Irrigation and Climate, Edward Arnold, Ltd., London.

43. Ostromecki, 1965, Remarks on methods of computation of water requirements of fields and grass lands, Translated from Polish, U.S. Dept. Int., TT. 67-56052.

44. Papadakis, J., 1966, Climates of the world and their agricultural potentialities, Buenos Aires, Argentina.

45. Pati, B.P., Bal, A.S. and Prabhudesai, S.S., 1989, Evapotranspiration and deep percolation loss of water in summer rice on lateritic soil, International Rice Research Newsletter, Vol. 14(3).

46. Penman, H.L., 1948, Natural Evaporation from open water, bare soil and grass, Proc. Roy. Soc., Ser.A, No. 193, 120- 146.

47. Penman, H.L., 1963, Vegetation and Hydrology, Techn. Comm. No. 53, Commonwealth Bureau of Soils, Harpenden, England.

48. Rao, A.S., Thomas, R. and Prabha, H., 1988, Evapotranspiration rates of rice varieties Culture - 20 and Pattanbi-20 in a humid tropical climate, Mausam, Vol. 39, No.1.

49. Saleh, M and Fatema, K., 1988, A Comparative study of the commonly used methods for calculation of evapotranspiration of rice, Bangladesh Journal of Water Resource Research, Vol. 9, No.1, 63-72.

50. Sastri, A.S.R.A.S., Chandrakar, B.L and Chandrawanshi B.R., 1985, Evapotranspiration and water use of rice in central India, International Rice Research Newsletter, No., 30-31.

51. Shah, M.H., Bhatti, M.A. and Jensen J.R., 1986, Crop coefficient over a rice field in the central plain of Thailand, Journal of Field Crop Research, Vol. 13, No. 3, 25-256.

APPENDIX - A
(DATA)

Table A.1 **Meterological parameters during the period Dec'87 to May '88 at Amla experimental farm**

Month	Dec/87	Jan/88	Feb/88	Mar/88	Apr/88	May/88
Av.Max.Temp.(°C)	27.00	25.59	28.81	31.66	36.59	33.35
Av.Min.Temp.(°C	14.11	11.14	14.08	17.54	22.51	24.08
Rainfall (cm)	1.67	-	3.47	6.55	9.60	27.30
Evaporation, (cm)	5.72	5.92	6.38	11.29	14.66	14.10
Av.wind speed (miles/hr.)	0.65	5.46	0.53	1.16	1.95	2.90
Av. Sunshine hrs	8.45	9.01	8.56	8.29	9.16	7.63
Av. Humidity (%)	72	68	66	72	70	81

Table A.2 **Meterological parameters during the period Dec'88 to May '89 at Amla experimental farm**

Month	Dec/88	Jan/89	Feb/89	Mar/89	Apr/89	May/89
Av.Max.Temp.(°C)	34.24	23.92	27.95	33.47	38.09	39.19
Av.Min.Temp.(°C)	14.01	9.21	12.28	16.18	22.05	26.06
Rainfall (cm)	-	-	0.75	0.15	-	28.06
Evaporation (cm)	6.22	5.74	7.44	12.25	18.22	16.64
Av.wind speed (miles/hr.)	2.36	2.41	3.22	2.98	6.06	7.51
Av. Sunshine hrs.	8.25	8.77	9.37	8.48	9.48	7.91
Av. Humidity(%)	77	70	59	50	68	73

Table A.3 **Meterological parameters during the period Nov '89 to May '90 at Amla experimental farm**

Month	Nov/89	Dec/89	Jan/90	Feb/90	Mar/90	Apr/90	May/90
Av.Max.Temp.(°C)	28.70	24.19	23.65	27.57	29.14	33.05	33.79
Av.Min.Temp.(°C)	17.12	12.15	11.66	14.08	17.75	22.05	24.15
Rainfall (cm)	-	2.10	-	7.90	7.25	10.40	10.60
Evaporation (cm)	7.50	5.98	5.52	6.43	9.01	13.74	13.32
Av.wind speed (miles/hr.)	1.82	2.29	2.27	1.95	2.74	6.83	4.96
Av. Sunshine hrs	8.83	8.16	8.25	8.01	7.15	8.84	8.25
Av. Humidity (%)	72	64	72	66	74	77	77

BANGLADESH WATER DEVELOPMENT BOARD

Surface Water Hydrology

Dhaka

Daily Evaporation (mm) & Statistics

Station : 1 Amla   sub div : PB   Year : 1987 - 88

Day	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1	4.3	3.8*	6	4.3	1.2	2.6*	3	1.8	2.1	1.8	2.5	1.8
2	5.3	1.4	5	4.1	3.9	2.8	2.8	2.1	2	1.4	2.5	2.5
3	4.3	4.6	2.5	3*	.4	2.5	3.2	2.1	1.8	1.8	2.5	2.8
4	5.7	1.4	2.1	3.9	1.8	2.8	3.6	1.8	1.8	1.8	2.5	2.5
5	6	2.8	1.1	4.3	2.5	1.4	3.4	1.8	1.4	1.8	2.3	2.8
6	6	3.2	2.5	4.3	2.8	3	3.6	2.1	1.8	1.8	2.1	3.2
7	5.3	3.2	2.8	3.7	2.7*	2.8	3	2.5	1.6	1.4	2	3.6
8	6	2.8	3.2	2.1	4.3	3.2	2.5	2.5	2	1.8	2.1	3.7
9	6.4	3.2	1.8	3.6	3.9	2.8	2.5	2.1	1.8	1.4	2.1	3.6
10	4.8	3.6	3.4	2.3	3.4	2.1	2.5	2.5	2	1.1	2.5	2.8
11	4.6	3.8*	1.4	2.1	2.1	2.6*	2.8	2.8	1.8	1.4	2.5	3.2
12	4.6	3.6	2.8	2.5	1.4	1.2	1.8	2.8	1.2	1.6	2.5	5.2
13	4.3	3.6	4.3	3*	2	3.7	2.8	2.8	1.8*	1.8	2.5	2.7
14	5	5.3	4.3	2.8	2.8	3.2	2.8	2.8	.4	1.8	2.5	3.6
15	3.6	5	4.4	2.8	2.8	3.9	2.1	1.4	1.8	1.8	2.3	3.2
16	5.7	4.6	4.3	1.4	3.2	2.1	2.8	.4	2.1	1.4	2.1	3.6
17	5.3	5	4.4	2.7	2.8	3.2	2.5	1.4	2.1	1.4	1.8	3.6
18	5.3	5	4.1	2.7	2.5	4.3	2.8	2.5	1.8	2.5	2.5	2.8
19	5.7	5.3	2.8	3.4	3.9	3.2	3	2.7	1.4	2.5	2.5	4.4
20	4.7*	5	5.2	2	3.7	2.6*	2.8	2.1	1.4	2.1	2.5	2
21	4.6	5	3.6*	2.8	2.7*	1.8	2.8	2.1	1.8	2.3	2.8	2.8
22	5	4.6	3.9	3.7	2.7	2.8	3.2	1.8	1.8	2.5	3.2	3.6
23	5	3.8*	1.1	2.8	2.3	1.8	3.2	1.8	2.1	2.5	2.4*	5
24	4.7*	2.5	3.2	2.8	2.5	1.6	3.4	2.1	2.1	2.5	3	4.6
25	0#	3.8*	5	3*	3.2	2.1	2.8	2.1	1.8	2.1	1.4	4.6
26	4.4	3.9	4.8	3.2	2.7*	2	3	2.3	2	1.8	2.5	3.7
27	2.8	4.3	5	2.5	3.6	2.5	3.2	2.5	2.1	2.1	2.8	4.3
28	4.8	3.6	5.3	2.1	3.2	2.5	3	3	2.1	2.1	2.5	4.8
29	2.5	3.6	3.9	3*	1.8	2.5	2.7	2.5	2.1	2.1	--	5.3
30	3.6	3.6	4.6	4.3	2	2.8	2.8	2.1	1.8	2.1	--	5.7
31	--	4.3	--	3*	2.8	--	2.5	--	1.8	2.3	--	5.7
Td 1	54.1	30	30.4	35.6	26.9	26	30.1	21.3	18.3	16.1	23.1	29.3
Td 2	48.8	46.2	38	25.4	27.2	30	26.2	21.7	15.8	18.3	23.7	34.3
Td 3	37.4	43	40.4	33.2	29.5	22.4	32.6	22.3	21.5	24.4	22.4	50.1
Mtot	140.3	119.2	108.8	94.2	83.6	78.4	88.9	65.3	55.6	58.8	69.2	113.7

Total evaporation : 1076

Legend : $ >> Missing data: estimated : # >> Negative data; estimated

* >> Eva. exceeded max. eva. of non-rainy day; estimated: NA >> Not available

BANGLADESH WATER DEVELOPMENT BOARD
Surface Water Hydrology
Dhaka
Daily Evaporation (mm) & Statistics

Station : 1 Amla | sub div : PB | Year : 1989 - 90

Day	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1	4.6	5.3	4.3	1.6	1.9	3.2	2.5	2.5	2.1	2.1	2.5	2.1
2	4.6$	4.5	3.5	3.2	2.5	3.6	3.2	2.8	2.1	1.8	2.8	3.1
3	5	6	4.6	.4	2.4	2.8	2.1	3.2	2.5	1.8	3.2	2.3
4	5.7	6.4	4.4	1.8	3.2	4.3	2.5	3.2	2.5	1.4	3.2	2.5
5	6.4	6	2.8	2.5	1.9	3	3.2	2.8	2.5	1.8	2.1	2.8
6	6.4	6.4	2.5	2.3	2.5	2.8	2.5	2.5	2.3	1.8	2	3.5
7	6.8	6	4.2	3.5	2.7	3.6	3.5	3.2	2.1	1.8	1.8	1.1
8	5.7	5.7	3.8	2.8	3.2	3.2	2.5	2.8	1.8	1.8	2	2.5
9	5.'	8.2	2.5	2.5	3.[illegible]	2.8	1.3	3.2	2.1	1.8	1.8	2.5
10	5.3	9.2	2.8	2.8	3.3*	3.9	2.7*	2.8	1.8	2	2	2.3
11	6	7.8	4.3	3.6	3.2	3.3	2.7*	3.2	1.4	2.1	1.8	2.7
12	5.7	7.1	3.2	3.8	4.6	3.2	2.8	2.5	1.4	2.1	2.1	2.8
13	5.3	8.5	2.7	1.6	3.2	1.7	2.8	2.8	1.4	2.1	2.1	3.4
14	6	5.4	2.5	4.3	3.2	2.1	3.9	2.5	1.4	1.4	2.1*	1.4
15	6.4	5.3	1.3	3.2	3.2	3.6	4.3	2.5	1.8	1.4	.7	2.1
16	6.2	4.2	.7	3.5	2.1	3.9	2.8	2.1	2.1	1.8	1.1	2.1
17	5.4	5.8	4.3	2.1	2.5	4.3	2.7*	2.8	2.5	1.8	1.8	1.8
18	6.4	3.1	3.6	2.8	4.2	3.9	.7	1.8	2.1	1.8	2.1	2.1
19	6.4	2.6	3.2	3.9	4.3	1.4	1.4	2	1.8	1.8	2.1*	2.8
20	6.4	4.3	3.2	3	4.3	2.9	2.7*	2.1	2.1	1.8	2.1	3.2
21	6.8	5	1	3.4	1.8	1.4	2.8	1.8	1.8	1.1	2.5	5
22	6.8	5.3	4.3	2.8	3.2	2.7	3.9	2.1	1.4	1.1	2.5	3.2
23	7.1	5	4.2	4.6	3.6	2.5	3.6	2.1	1.8	1.1	2.5	3.2
24	6.8	5	3.9	4.3	3.6	3.2	3.2	2.5	.7	1.1	2.5	3.9
25	6.6	3.7	4.3	1.7	3.6	2.1	1.8	1.8	1.4	1.4	2.5	4.6
26	6.8	3.5	5	3.6	4.6	3.5	2.8	2.1	1.8*	1.8	2	3.6
27	6.8	4.8	4.3	3.9	3.6	.6	2.5	2.1	1.8*	2.1	1.1	3.6
28	6	2.7	4.3	1.4	3.9	3	2.5	2.3	1.4	1.1	1.8	5.3
29	5.3	0#	2.8	3.7	4.3	2.5	2.1	2.1	1.8	2.5	--	2.1
30	5.7	2.1	1	1.7	4.6	1.1	2.8	2.5	2	3.2	--	2.8
31	--	5.3	--	2.1	3.5	--	2.8	--	1.4	2.8	--	3.6
Td 1	56.2	63.7	35.4	23.4	27.5	33.2	26	29	21.8	18.1	23.4	24.7
Td 2	61.2	54.1	29	31.8	34.8	30.3	26.8	24.3	18	18.1	18	24.4
Td 3	64.7	42.4	35.1	33.2	40.3	22.6	30.8	21.4	17.3	19.3	17.4	40.9
Mtot	182.1	160.2	99.5	88.4	102.6	86.1	83.6	74.7	57.1	55.5	58.8	9[illegible]

Total evaporation : 1138.6

Legend : $ >> Missing data; estimated : # >> Negative data; estimated
* >> Eva. exceeded max. eva. of non-rainy day; estimated; NA >> Not available

BANGLADESH WATER DEVELOPMENT BOARD

Surface Water Hydrology

Dhaka

Daily Evaporation (mm) & Statistics

Station : i · Amla   sub div : PB   Year : 1990 - 91

Day	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1	6	4.6	1.6	2.7*	2.5	5.3	2.9*	3.6	2.5	1.8	2.5	1.8
2	4	5	3.9	1.5	5.3	3.5*	2.8	2.1	2.8	1.8	1.8	3.2
3	3.9	4.2	4.9	2.7*	4.4*	3.6	0#	1.8	3.9	1.8	1.8	3.2
4	1.7	6	4.3	2.7*	4.8	3.5*	2.9*	2.1	2.8	1.8	2.7	3.4
5	3	2.6	5.7	2.6	4.7	3.5*	1.4	2.6*	3.6	2.5	1.4	2.8
6	3.9	3.6	5.4	2.2	5.6	5.3	1.8	1.4	2.8	1.4	1.8	2.8
7	2.8	4.3	3.9	1.8	2.5	3.2	3.6	1.3	3.2	2.1	1.8	3.2
8	4.3	5.7	3.9	4.6	3.2	3.6	1.8	1.8	2.5	1.8	2.1	3.2
9	3.6	5.3	4.9	.1	3.6	3.6	.7	3.2	2.1	1.8	2.8	3.4
10	4.6	5.7	4.1	0#	4.6	3.5*	2.2	3.6	3.2	1.8	2.5	3.6
11	5	4.4	3.6	1.5	5	3.5*	2.7	2.5	2.1	1.1	2.1	3.6
12	5	3.9	3.4	3.6	0#	3.1	1.8	2.6*	3.2	.7	2.5	3.2
13	5	3.3	3.6	2.1	3.3	3.6	3.7	1.8	2.8	1.8*	2.1	3.2
14	3.9	3.1	3.6	3.2	4.4*	4.1	4.6	3.6	2.5	1.4	2.5	3.6
15	5	2.7	3.2	3.6	5.9	4.9	4.3	3.6	2.1	2.1	3.6	4.3
16	6	3.2	2.7	4.6	5	3.2	1.8	4.3	2.5	1.8	3.2	3.6
17	5.3	3.6	3.2	2.8	4.2	.6	2.5	3.2	1.4	2.1	3.6	3.9
18	5.7	4.3	5	3.1	6.7	2.5	3.2	3.2	1.4	2.1	3.2	5.3
19	6	4.6	4.3	3.4	3.9	3.5*	3.6	3.2	1.8	2.1	2.1	5.7
20	7.1	4.6	3.2	2.7*	4.3	3.5*	3.6	1.8	2.8	1.8	2.5	5
21	5.7	5	4.3	2.8	4.3	3.6	4.6	2.5	2.8	2.1	3.2	5
22	5.3	4.6	2.1	4.6	4.6	3.6	4.3	2.8	2.5	1.8	2.8	3.6
23	5.7	4.8	3.2	3.2	6.8	3.2	3.9	1.8	2.5	1.8	3.2	4.3
24	6.4	4.6	1.7	4.3	7.1	2.8	3.6	2.1	1.8	1.4	3.6	2.4
25	3.9	4.3	3.2	2.8	5.3	3.8	3.6	2.5	1.4	2.1	2.5	2.8
26	3.6	5.3	3.2	3.4	3	3.7	2.5	3.9	1.4	2.1	2.8	3.9
27	3.9	2.3	2.4	3.6	4.9	2.2	3.6	2.5	1.8	2.1	3.2	4.3
28	4.3	4.3	2.8	1	3.6	3.5*	2.5	3.6	1.4	2.1	3.6	4.3
29	3.3	3	2.8	1.6	4.6	3.5*	3.6	2.1	1.2	1.8	--	5
30	3.6	3.9	3.6	1.8	5	3.5*	3.6	2.5	1.8	2.1	--	5
31	--	3.6	--	3.5	3.6	--	3.6	--	1.4	1.8	--	3.9
Td 1	37.8	47	42.6	20.9	41.2	38.6	20.1	23.5	29.4	18.6	21.2	30.6
Td 2	54	37.7	35.8	30.6	42.7	32.5	31.8	29.8	22.6	17	27.4	41.4
Td 3	45.7	45.7	29.3	32.6	52.8	33.4	39.4	26.3	20	21.2	24.9	44.5
Mtot	137.5	130.4	107.7	84.1	136.7	104.5	91.3	79.6	72	56.8	73.5	116.5

Total evaporation : 1190.6

Legend : $ >> Missing data; estimated : # >> Negative data; estimated

* >> Eva. exceeded max. eva. of non-rainy day; estimated; NA >> Not available

BANGLADESH WATER DEVELOPMENT BOARD

Surface Water Hydrology   Date of retrieval:28-05-1994

Daily Rainfall in mm

Station: 214 Amla   Sub.Div. : PB   Year: 1987-88

Date	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1	0.0	36.1	0.0	0.0	14.5	59.4	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	44.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	12.7	0.0	57.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	3.8	2.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	4.1	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	1.5	8.4	9.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	53.8	0.0	9.1	0.0	0.0	0.0	0.0	0.0	2.0
10	4.1	0.0	8.4	11.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	3.8	0.0	0.0	0.0	59.9	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	2.5	6.4	5.6	0.0	0.0	0.0	0.0	10.7
13	0.0	0.0	0.0	16.0	1.8	15.5	0.0	0.0	16.8	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	30.7	11.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	6.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47.5
20	2.0	0.0	16.0	1.8	38.4	15.7	0.0	0.0	0.0	0.0	0.0	5.3
21	0.0	0.0	63.0	0.0	90.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	16.8	6.4	21.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	1.0	17.0	2.5	0.0	6.4	0.0	0.0	0.0	0.0	0.0	17.8	0.0
24	58.9	0.0	20.8	0.0	0.0	1.3	0.0	0.0	0.0	0.0	17.0	0.0
25	7.4	15.2	0.0	25.4	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	11.4	0.0	0.0	15.7	109.5	1.8	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	137.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	10.9	0.0	0.0	1.0	26.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	20.8	0.0	0.0	0.0	0.0	0.0	0.0	--	0.0
30	0.0	0.0	0.0	15.2	1.5	0.0	0.0	0.0	0.0	0.0	--	0.0
31	--	0.0	--	69.9	0.0	--	0.0	--	0.0	0.0	--	0.0

Ten Daily Total

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Td1	4.1	48.8	11.9	131.3	72.2	74.6	0.0	0.0	0.0	0.0	0.0	2.0
Td2	2.0	3.8	46.7	36.9	44.7	97.5	5.6	0.5	16.8	0.0	0.0	63.5
Td3	89.6	32.2	103.1	154.4	395.3	3.1	0.0	0.0	0.0	0.0	34.8	0.0

Monthly Total

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Mtot	95.7	84.8	161.7	322.6	512.2	175.2	5.6	0.5	16.8	0.0	34.8	65.5
Rday	7	5	9	16	16	10	1	1	1	0	2	4

Depth Duration Data

Dday	1	2	3	5	7	10	15	20	30	60	90	120
Rmax	137.2	246.7	272.1	275.1	368.4	432.2	493.1	499.2	595.8	843.9	1141.0	1185.1

Annual rainfall : 1475.4   Annual rainy days : 72

BANGLADESH WATER DEVELOPMENT BOARD

Surface Water Hydrology   Date of retrieval:28-05-1994

Daily Rainfall in mm

Station: 214 Amla   Sub.Div. : PB   Year: 1988-89

Date	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1	0.0	0.0	0.0	0.0	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	1.6	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	2.0	6.5	0.0	15.5	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	33.0	0.0	1.0	19.7	0.0	0.0	0.0	0.0	0.0
6	0.0	0.5	0.0	60.0	0.0	6.5	0.0	49.5	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	10.0	19.0	2.0	2.0	0.0	0.0	0.0	0.0	0.0
8	0.0	2.5	0.0	45.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	19.6	72.0	0.0	51.5	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	55.9	0.0	16.5	4.0	12.8	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	7.6	26.6	5.0	24.3	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	78.7	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	2.0	54.9	0.0	18.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	41.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	10.2	42.4	0.0	26.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	21.6	2.0	0.0	7.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	104.9	24.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	4.0	6.5	0.0	2.5	0.0	0.0	0.0	7.5	0.0
20	0.0	0.0	0.0	0.0	6.5	21.3	0.0	0.0	0.0	0.0	0.0	0.0
21	2.5	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	26.9	21.1	0.0	10.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	36.8	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	16.5	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	53.8	15.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	9.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	3.8	43.0	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	12.7	17.8	17.8	0.0	21.6	0.0	0.0	43.0	0.0	0.0	---	0.0
30	0.0	0.0	6.9	0.0	0.0	0.0	0.0	56.0	0.0	0.0	---	1.5
31	---	19.1	---	9.5	32.0	---	0.0	---	0.0	0.0	---	0.0

Ten Daily Total

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Td1	0.0	58.9	19.6	245.1	61.0	73.8	43.2	49.5	0.0	0.0	0.0	0.0
Td2	0.0	138.7	252.1	34.1	69.5	51.6	2.5	0.0	0.0	0.0	7.5	0.0
Td3	95.9	75.5	81.8	64.0	73.7	0.0	0.0	99.0	0.0	0.0	0.0	1.5

Monthly Total

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Mtot	95.9	273.1	353.5	343.2	204.2	125.4	45.7	148.5	0.0	0.0	7.5	1.5
Rday	4	12	13	17	16	8	5	3	0	0	1	1

Depth Duration Data

Dday	1	2	3	5	7	10	15	20	30	60	90	120
Rmax	104.9	133.6	175.5	225.5	263.1	271.7	300.5	354.0	598.0	839.4	1022.3	1211.2

Annual rainfall : 1598.5   Annual rainy days : 80

BANGLADESH WATER DEVELOPMENT BOARD

Surface Water Hydrology Date of retrieval:28-03-1994

Daily Rainfall in mm

Station: 214 Amla Sub.Div. : PB Year: 1989-90

Date	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1	0.0	0.0	0.0	5.3	6.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	12.0	6.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	6.0
3	0.0	1.0	0.0	30.0	9.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	1.5	6.3	18.5	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	7.3	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.5
7	0.0	0.0	5.0	1.5	9.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	39.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	1.0	3.0	0.0	8.5	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	28.9	0.0	12.5	0.0	0.0	0.0	0.0	13.0
11	0.0	0.0	0.0	0.0	1.5	18.5	4.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	41.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	12.0	12.0	1.0	5.0	1.0	0.0	0.0	0.0	0.0	42.0
14	0.0	26.0	29.0	62.0	2.5	5.0	0.0	0.0	0.0	0.0	32.0	0.0
15	0.0	0.0	8.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0
16	0.0	39.0	3.5	3.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	58.0	1.0	7.0	0.0	0.0	46.0	0.0	0.0	0.0	0.0	0.0
18	0.0	12.5	0.0	0.0	4.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0
19	0.0	2.5	2.0	16.7	0.0	4.0	0.0	0.0	0.0	0.0	32.0	0.0
20	0.0	0.0	3.0	14.0	0.0	23.0	56.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	4.5	31.3	26.9	3.5	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	29.0	0.0	0.0	13.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	57.6	0.0	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	2.5	0.0	0.0	1.5	3.0	0.0	0.0	18.0	0.0	13.0	0.0
27	0.0	27.2	0.0	0.0	0.0	5.5	0.0	0.0	3.0	0.0	0.0	0.0
28	0.0	40.5	0.0	6.0	0.0	15.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	4.5	83.0	0.0	0.0	0.0	0.0	0.0	0.0	--	4.0
30	0.0	1.0	5.5	5.0	0.0	0.0	0.0	0.0	0.0	0.0	--	6.0
31	--	0.0	--	3.5	1.0	--	0.0	--	0.0	0.0	--	0.0

Ten Daily Total

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Td1	0.0	13.0	50.0	53.3	63.9	19.5	25.0	0.0	0.0	0.0	0.0	20.5
Td2	0.0	138.0	58.5	156.7	11.0	55.5	111.0	0.0	0.0	0.0	66.0	42.0
Td3	0.0	128.8	49.5	134.3	29.4	40.0	0.0	0.0	21.0	0.0	13.0	10.0

Monthly Total

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Mtot	0.0	279.8	158.0	344.3	104.3	115.0	136.0	0.0	21.0	0.0	79.0	72.5
Rday	0	12	16	21	16	12	9	0	2	0	4	6

Depth Duration Data

Dday	1	2	3	5	7	10	15	20	30	60	90	120
Rmax	83.0	97.0	115.0	135.5	138.0	188.0	265.8	291.0	354.9	567.1	834.5	892.9

Annual rainfall : 1309.9 Annual rainy days : 98

BANGLADESH WATER DEVELOPMENT BOARD

Surface Water Hydrology   Date of retrieval:28 05-1994

Daily Rainfall in mm

Station: 214 Amla   Sub.Div. : PB   Year: 1990-91

Date	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1	3.5	0.0	10.9	69.7	0.0	0.0	11.0	0.0	0.0	0.0	0.0	1.1
2	23.5	0.0	0.0	25.0	5.0	65.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	4.5	5.0	69.5	25.0	0.0	39.2	0.0	0.0	0.0	0.0	0.0
4	3.5	0.0	0.0	101.5	15.0	13.3	50.0	4.0	0.0	0.0	13.0	0.0
5	3.3	19.0	0.0	24.0	7.2	52.3	0.0	16.6	0.0	0.0	0.0	0.0
6	0.0	0.0	8.8	23.4	41.0	5.5	0.0	0.0	0.0	0.0	0.0	0.0
7	19.7	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	21.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	4.5	6.8	0.0	0.0	53.8	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	14.5	60.0	0.0	90.0	2.1	0.0	0.0	0.0	0.0	0.0
11	0.0	21.0	0.0	5.2	0.0	40.5	1.3	0.0	0.0	0.0	0.0	0.0
12	0.0	0.5	14.0	0.0	44.5	12.1	0.0	31.0	0.0	0.0	0.0	0.0
13	0.0	23.0	0.0	0.0	52.4	0.0	18.5	0.0	0.0	8.9	0.0	0.0
14	0.0	10.0	0.0	2.5	29.1	14.0	4.1	0.0	0.0	0.0	0.0	0.0
15	0.0	10.5	0.0	0.0	15.5	9.5	8.2	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	14.0	0.0	7.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	2.0	2.0	5.0	30.9	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	7.0	15.1	0.0	0.0	0.0	2.0	0.0	0.0	0.0
19	0.0	0.0	0.0	15.0	5.6	35.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	4.5	38.0	0.0	65.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	1.5	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	4.0	4.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5
25	31.0	0.0	0.0	5.0	5.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	1.5	0.0	15.0	7.3	16.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	2.5	8.0	0.0	10.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	3.0	40.0	0.0	76.0	0.0	0.0	0.0	0.0	0.0	0.0
29	19.5	13.5	0.0	4.3	0.0	122.0	0.0	0.0	0.0	0.0	--	0.0
30	0.0	0.0	0.0	0.0	0.0	35.0	0.0	0.0	0.0	0.0	--	0.0
31	--	0.0	--	3.5	0.0	--	0.0	--	0.0	0.0	--	0.0

Ten Daily Total

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Td1	53.5	23.5	43.7	401.2	93.2	226.1	186.1	25.0	0.0	0.0	13.0	1.1
Td2	0.0	65.0	34.5	69.7	174.9	257.0	32.1	31.0	2.0	8.9	0.0	0.0
Td3	50.5	17.5	19.5	73.9	22.3	276.9	0.0	0.0	0.0	0.0	0.0	4.5

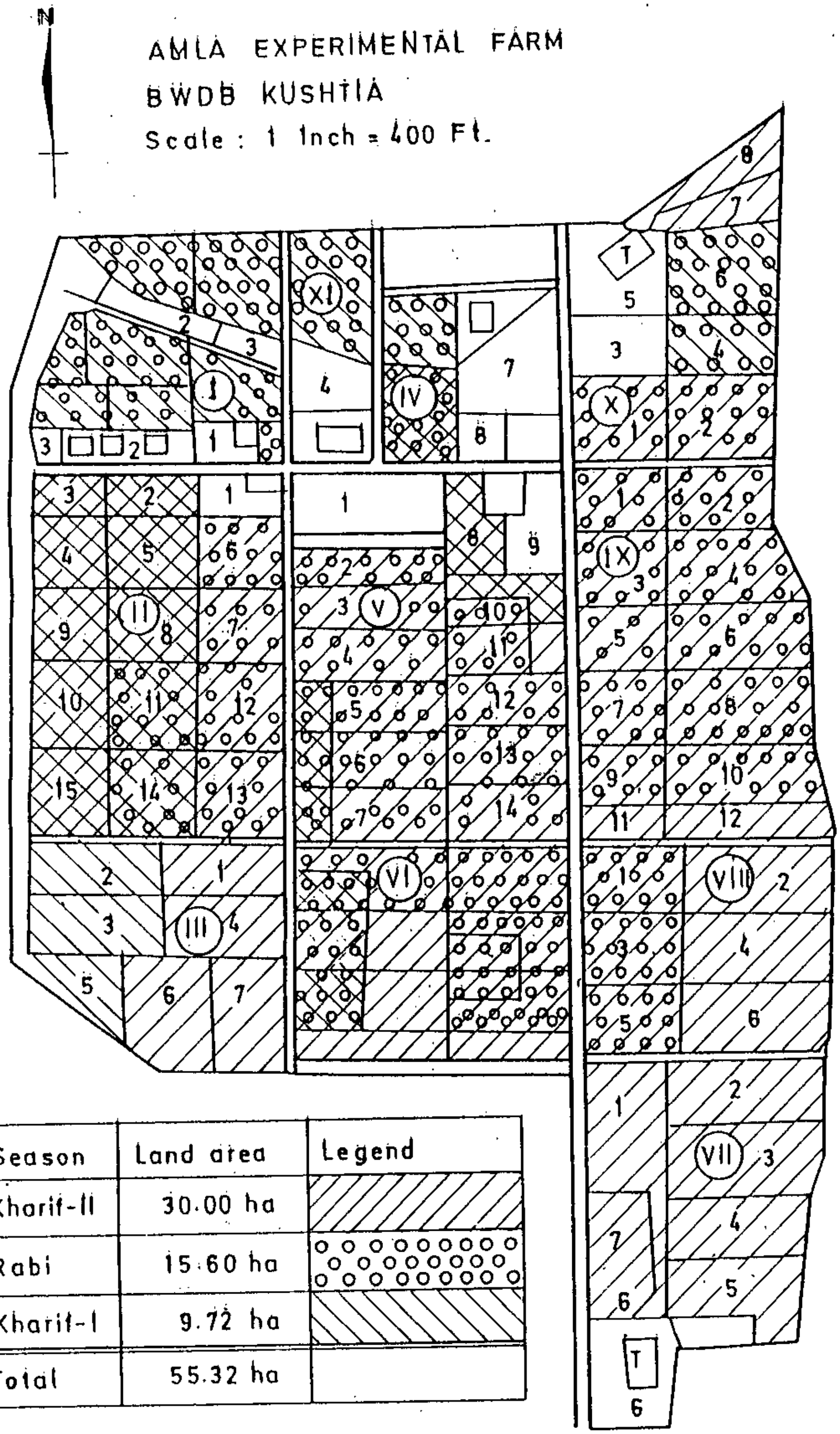
Monthly Total

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Mtot	104.0	106.0	97.7	544.8	290.4	760.0	218.2	56.0	2.0	8.9	13.0	5.6
Rday	7	10	13	22	16	19	9	4	1	1	1	2

Depth Duration Data

Dday	1	2	3	5	7	10	15	20	30	60	90	120
Rmax	122.0	198.0	233.0	289.7	363.2	401.2	507.1	597.5	811.9	1143.3	1500.5	1841.1

Annual rainfall : 2206.6   Annual rainy days : 105



Season	Land area	Legend
Kharif-II	30.00 ha	
Rabi	15.60 ha	
Kharif-I	9.72 ha	
Total	55.32 ha	

FIG. LAYOUT PLAN OF AMLA EXPERIMENTAL FARM

APPENDIX-B
(DETAIL PROCEDURE OF ESTIMATING CROP EVAPOTRANSPIRATION)

Table B.1 ET calculated by the Modified Penman of BR-3 Rice for the year 1987-88

Month	T_{mean} (°C)	RH_{mean} (%)	e_a (mbar)	e_d (mbar)	e_a-e_d (mbar)	Wind speed (km/day)	f(u)	(1-w)	w	R_a	n	N	n/N	R_s	R_{ns}	R_{nl}	R_n	$W.R_n$	ET_o (mm/day)	K_c	ET (mm/day)
Dec/87	20.50	72	24.15	17.39	6.76	25	0.33	0.32	0.68	9.70	8.45	10.68	0.79	6.25	4.70	1.90	2.80	1.90	2.61	1.0	2.61
Jan/88	18.37	68	21.12	14.36	6.76	211	0.84	0.34	0.66	10.20	9.01	10.76	0.83	6.78	5.07	2.17	2.90	1.91	3.84	1.15	4.41
Feb/88	21.44	66	25.56	16.87	8.69	20	0.32	0.30	0.70	11.90	8.56	11.34	0.75	7.40	5.54	1.84	3.70	2.59	3.42	1.25	4.27
Mar/88	24.60	72	30.94	22.28	8.66	45	0.39	0.27	0.73	13.90	8.29	12.0	0.69	8.20	6.15	1.46	4.69	3.42	4.33	1.0	4.33
Apr/88	29.55	70	41.36	28.96	12.40	75	0.47	0.22	0.78	15.40	9.16	12.70	0.72	9.40	6.05	1.25	5.80	4.52	5.80	1.10	6.38
May/88	28.72	81	39.46	31.96	7.50	112	0.57	0.23	0.77	16.40	7.63	13.26	0.57	8.78	6.59	0.92	5.67	4.37	5.35	1.15	6.15

Table B.2 ET calculated by the Modified Penman of BR-3 Rice for the year 1988-89

Month	T_{mean} (°C)	RH_{mean} (%)	e_a (mbar)	e_d (mbar)	e_a-e_d (mbar)	Wind speed (km/day)	f(u)	(1-w)	w	R_a	n	N	n/N	R_s	R_{ns}	R_{nl}	R_n	$W.R_n$	ET_o (mm/day)	K_c	ET (mm/day)
Dec/88	24.17	77	30.00	23.20	6.80	91	0.53	0.27	0.73	9.70	8.25	10.68	0.77	6.16	4.62	1.48	3.14	2.29	3.22	1.0	3.22
Jan/89	16.56	70	18.80	13.16	5.64	93	0.52	0.35	0.65	10.20	8.77	10.70	0.81	6.68	5.01	2.25	2.76	1.79	2.82	1.15	3.24
Feb/89	20.10	59	23.30	13.90	9.60	124	0.60	0.32	0.68	11.90	9.37	11.34	0.83	7.91	5.93	2.23	3.70	2.50	4.34	1.25	5.42
Mar/89	24.82	50	31.36	15.68	15.68	115	0.58	0.26	0.74	13.90	8.48	12.0	0.70	8.34	6.25	1.83	4.42	3.27	5.63	1.0	5.63
Apr/89	30.30	68	43.15	29.34	13.81	234	0.90	0.22	0.78	15.40	9.48	12.70	0.75	9.62	7.21	1.30	5.91	4.61	7.34	1.10	8.07
May/89	32.62	73	49.27	35.97	13.30	290	1.05	0.20	0.80	16.40	7.91	13.26	0.59	8.94	6.71	0.87	5.83	4.66	7.45	1.15	8.56

Table B.3 ET calculated by the Modified Penman of BR-3 Rice for the year 1989-90

Month	T_{mean} (°C)	RH_{mean} (%)	e_a (mbar)	e_d (mbar)	e_a-e_d (mbar)	Wind speed (km/day)	f(u)	(1-w)	w	R_a	n	N	n/N	R_s	R_{ns}	R_{nl}	R_n	$W.R_n$	ET_o (mm/day)	K_c	ET (mm/day)
Dec/89	18.17	64	20.83	13.33	7.50	88	0.50	0.34	0.66	9.70	8.83	10.68	0.82	6.40	4.80	2.27	2.53	1.67	2.95	1.0	2.95
Jan/90	17.65	72	20.18	14.53	5.65	87	0.50	0.35	0.65	10.20	8.16	10.70	0.76	6.42	4.81	1.95	2.86	1.86	2.85	1.15	3.27
Feb/90	20.82	66	24.63	16.25	8.37	75	0.47	0.31	0.69	11.90	8.25	11.34	0.72	7.26	5.44	1.75	3.67	2.53	3.75	1.25	4.68
Mar/90	23.44	74	28.85	21.35	7.50	105	0.55	0.28	0.72	13.90	8.01	12.0	0.66	8.06	6.04	1.44	4.59	3.30	4.45	1.0	4.45
Apr/90	27.55	77	36.75	28.29	8.45	262	0.97	0.24	0.76	15.40	7.15	12.70	0.56	8.16	6.12	1.03	5.80	3.86	5.82	1.10	6.40
May/90	28.97	77	40.00	30.80	9.20	190	0.78	0.22	0.78	16.40	8.84	13.26	0.67	9.60	7.20	1.15	6.04	4.71	6.29	1.15	7.23

Table B.4 ET calculated by the Hargreaves method for the year 1987-88

Month	Dec/87	Jan/88	Feb/88	Mar/88	Apr/88	May/88
R_a	9.70	10.20	11.90	13.90	15.40	16.40
T_{mean} (^{0}C)	20.50	18.37	21.44	24.40	29.55	28.72
$T_{diff.}$ (^{0}C)	12.89	14.15	14.73	14.12	14.08	9.27
ET_0 (mm/day)	3.06	3.22	4.12	5.09	6.29	5.34
K_c	1.00	1.15	1.25	1.00	1.10	1.15
ET (mm/day)	3.06	3.70	5.15	5.09	6.88	6.14

Table B.5 ET calculated by the Hargreaves method for the year 1988-89

Month	Dec/88	Jan/89	Feb/89	Mar/89	Apr/89	May/89
R_a	9.70	10.20	11.90	13.90	15.40	16.40
T_{mean} (^{0}C)	24.17	16.56	20.10	24.82	30.30	32.62
$T_{diff.}$ (^{0}C)	20.14	14.71	15.67	17.29	15.59	13.13
ET_0 (mm/day)	4.20	3.09	4.10	5.66	6.72	6.89
K_c	1.00	1.15	1.25	1.00	1.10	1.15
ET (mm/day)	4.20	3.55	5.12	5.66	7.39	7.92

Table B.6 ET calculated by the Hargreaves method for the year 1989-90 at Amla farm

Month	Dec/89	Jan/90	Feb/90	Mar/90	Apr/90	May/90
R_a	9.70	10.20	11.90	13.90	15.40	16.40
T_{mean} (^{0}C)	18.17	17.65	20.82	23.44	27.55	28.97
$T_{diff.}$ (^{0}C)	12.04	11.99	13.49	11.39	11.00	9.64
ET_0 (mm/day)	2.78	2.88	3.88	4.44	5.32	5.85
K_c	1.00	1.15	1.25	1.00	1.10	1.15
ET (mm/day)	2.78	3.31	4.85	4.44	5.85	6.72

Table B.7 ET calculated by the Thornthwaite method for the year 1987-88 at Amla experimental farm

Month	Dec/87	Jan/88	Feb/88	Mar/88	Apr/88	May/88	Jun/88	Jul/88	Aug/88	Sep/88	Oct/88	Nov/88
T_{mean} (°C)	20.50	18.37	21.44	24.60	29.55	28.72	30.30	28.91	28.85	29.22	27.30	25.20
i	10.80	7.22	9.06	11.16	14.74	14.10	15.31	14.23	14.19	14.47	13.11	11.54
I			148.00									
(i)												
a			3.64									
ET_o unadjust, (mm/month)	52.37	35.13	61.00	101.71	198.24	178.71						
Correction factor	0.91	0.93	0.89	1.03	1.06	1.15						
ET_o adjust, (mm/month)	47.61	32.67	54.29	104.76	210.13	205.51						
K_c	1.00	1.15	1.25	1.00	1.10	1.15						
ET (mm/month)	47.61	37.57	67.86	104.76	231.43	236.33						
ET (mm/day)	1.50	1.21	2.34	3.37	7.71	7.62						

Table B.8 ET calculated by Thornthwaite method for the year 1988-89 at Amla experimental farm

Month	Dec/88	Jan/89	Feb/89	Mar/89	Apr/89	May/89	Jun/89	Jul/89	Aug/89	Sep/89	Oct/89	Nov/89
T_{mean}, °C	24.17	16.56	20.10	24.82	30.30	32.62	29.00	28.61	29.08	28.72	27.72	22.91
i	10.86	6.13	8.21	11.31	15.30	17.10	14.30	14.00	14.37	14.10	13.51	10.00
I			148.19									
(i)												
a			3.69									
ET_o unadjust, (mm/month)	95.00	23.51	48.06	105.00	218.54	287.00						
Correction factor	0.91	0.93	0.89	1.03	1.06	1.15						
ET_o adjust, (mm/month)	86.45	21.87	42.77	108.15	231.65	330.00						
K_c	1.00	1.15	1.25	1.00	1.10	1.15						
ET (mm/month)	86.45	25.15	53.46	108.15	254.81	379.50						
ET (mm/day)	2.78	0.81	1.90	3.48	8.49	12.24						

Table B.9 ET calculated by the Thornthwaite method for the year 1989-90 at Amla experimental farm

Month	Dec/89	Jan/90	Feb/90	Mar/90	Apr/90	May/90	Jun/90	Jul/90	Aug/90	Sep/90	Oct/90	Nov/90
T_{mean} (°C)	18.17	17.65	20.82	23.44	27.55	28.97	29.49	28.51	28.24	28.80	28.46	22.72
I (i)			140.75									
a			3.28									
ET_o unadjust (mm/month)	36.97	33.16	57.78	85.24	144.81	170.76						
Correction factor	0.91	0.93	0.89	1.03	1.06	1.15						
ET_o adjust (mm/month)	33.64	30.83	51.42	87.79	153.50	196.37						
K_c	1.00	1.15	1.25	1.00	1.10	1.15						
ET (mm/month)	33.64	35.46	64.27	87.79	168.85	225.82						
ET (mm/day)	1.80	1.14	2.29	2.83	5.62	7.28						

Table B.10 ET calculated by the Pan Evaporation method for the year 1987-88 at Amla experimental farm

Month	Dec/87	Jan/88	Feb/88	Mar/88	Apr/88	May/88
RH_{mean}	High	Medium	Medium	High	High	HIgh
Wind (km/day)	Light	Moderate	Light	Light	Light	Light
K_p	0.80	0.70	0.70	0.80	0.80	0.80
E_{Pan} (mm/day)	1.85	1.91	2.28	3.65	4.90	4.55
ET_o (mm/day)	1.48	1.34	1.60	2.92	3.92	3.64
ET_o (mm/month)	45.88	41.54	44.80	90.52	117.60	112.84
K_c	1.0	1.15	1.25	1.0	1.10	1.15
ET (mm/month)	45.88	47.71	56.00	90.52	129.36	129.76
ET (mm/day)	1.48	1.54	1.93	2.92	4.31	4.18

Table B.11 ET calculated by the Pan Evaporation method for the year 1988-89 at Amla experimental farm

Month	Dec/88	Jan/89	Feb/89	Mar/89	Apr/89	May/89
RH_{mean}	High	High	Moderate	Moderate	Moderate	High
Wind (km/day)	Light	Light	Light	Light	Moderate	Moderate
K_p	0.80	0.80	0.70	0.70	0.68	0.70
E_{Pan} (mm/day)	2.80	1.85	2.66	3.95	6.07	5.16
ET_o (mm/day)	1.60	1.48	1.86	2.76	4.12	3.61
ET_o (mm/month)	49.68	46.00	52.08	85.56	123.60	111.97
K_c	1.0	1.15	1.25	1.0	1.10	1.15
ET (mm/month)	49.60	52.90	65.10	85.56	135.96	128.76
ET (mm/day)	1.60	1.70	2.32	2.76	4.53	4.15

Table B.12 ET calculated by the Pan Evaporation method for the year 1989-90 at Amla experimental farm

Month	Dec/89	Jan/90	Feb/90	Mar/90	Apr/90	May/90
RH_{mean}	Medium	High	Medium	High	High	HIgh
Wind (mm/day)	Light	Light	Light	Light	Moderate	Moderate
K_p	0.70	0.80	0.70	0.80	0.70	0.70
E_{Pan} (mm/day)	1.93	1.79	2.30	2.90	4.58	4.30
ET_0 (mm/day)	1.35	1.43	1.61	2.32	3.21	3.00
ET_0 (mm/month)	41.85	44.33	45.10	72.00	96.30	93.00
K_c	1.0	1.15	1.25	1.0	1.10	1.15
ET (mm/month)	45.88	47.71	56.00	90.52	129.36	129.76
ET (mm/day)	1.48	1.54	1.93	2.92	4.31	4.18

Table B.13 ET calculated by the Baney Criddle method for the year 1987-88 at Amla experimental farm

Month	Dec/87	Jan/88	Feb/88	Mar/88	Apr/88	May.88
T_{mean} (°C)	20.50	18.37	21.44	24.60	29.55	28.72
P	0.24	0.24	0.26	0.27	0.29	0.30
ET_0 (mm/day)	4.18	3.95	4.65	5.21	6.26	6.36
K_c	1.00	1.15	1.25	1.00	1.10	1.15
ET (mm/month)	128.34	134.54	162.68	161.51	206.10	226.60
ET (mm/day)	4.18	4.34	5.81	5.21	6.87	7.31

Table B.14 ET calculated by the Blaney-Criddle method for the year 1988-89 at Amla experimental farm

Month	Dec/88	Jan/89	Feb/89	Mar/89	Apr/89	May/89
T_{mean} (°C)	24.17	16.56	20.10	24.82	30.30	32.62
P	0.24	0.24	0.26	0.27	0.29	0.30
ET_0 (mm/day)	4.59	3.75	4.48	5.24	6.36	6.90
K_c	1.00	1.15	1.25	1.00	1.10	1.15
ET (mm/day)	4.59	4.31	5.60	5.24	7.00	7.93
ET (mm/month)	142.29	133.61	156.80	162.44	210.00	245.83

Table B.15 ET calculated by the Blaney-Criddle method for the year 1989-90 at Amla experimental farm

Month	Dec/89	Jan/90	Feb/90	Mar/90	Apr/90	May/90
T_{mean} (°C)	18.17	17.65	20.82	23.44	27.55	28.97
P	0.24	0.24	0.26	0.27	0.29	0.30
ET_0 (mm/day)	3.92	3.86	4.57	5.07	5.99	6.39
K_c	1.00	1.15	1.25	1.00	1.10	1.15
ET (mm/month)	121.52	137.33	160.00	157.17	197.40	227.54
ET (mm/day)	3.92	4.43	5.71	5.07	6.58	7.34