PREDICTION OF CROP WATER REQUIREMENT: A REVIEW

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ABSTRACT

Method of prediction of water requirement is important due to the difficulty in obtaining accurate field measurement. The methods of prediction often need to be applied under climatic and agronomic conditions quite different from those under which they were developed. Testing the accuracy of the prediction methods under new conditions is time consuming and costly, and yet crop water requirement data are frequently needed at short notice for project planning. In this paper, prediction methods are reviewed to evaluate water requirement of crops under different climatic and agronomic conditions. present study reveals that the modified Penman method offers the best results with minimum possible error of plus or minus 10 percent in summer, and -up to 20 percent under low evaporative condition followed by the Pan method with an error of 15 percent, depending on the location of the pan.

Keywords: Irrigation, Methods, Prediction, Requirement, Water.

I. INTRODUCTION

Crop water requirements are referred as the depth of water needed to meet the water loss through evapo-transpiration of a disease-free crop growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment. There are various factors which affect water requirement of crops.

1.1 The Effect Of Climate On Crop Water Requirements

The effect of climate on crop water requirements is given by the reference crop evapo-transpiration "ETo" which can be defined as the rate of evapo-transpiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water. It is expressed in mm per day. To evaluate ETo using the mean daily climatic data, four methods namely, the Blaney-Criddle, Radiation, Penman and Pan Evaporation method, are used.

1.2 The Effect Of The Crop Characteristics On Crop Water Requirements

The effect of the crop characteristics on crop water requirements is given by the crop coefficient "kc" which presents the relationship between reference (ETo) and crop evapo transpiration (ETcrop). The value of "kc" varies with the crop, its stage of growth, growing season and the prevailing weather conditions. ETcrop can be determined in mm per day as mean over the same 30- or 10-day periods.

1.3 The Effect Of Local Conditions And Agricultural Practices On Crop Water Requirements

The effect of local conditions and agricultural practices on crop water requirements includes the local effect of variations in climate over time, distance and altitude, size of fields, advection, soil water availability, salinity, method of irrigation and cultivation methods and practices, for which local field data are required.

1.4 Reference Crop Evapo-Transpiration (Eto)

Based on meteorological data available and accuracy required prediction method is selected to calculate ETo and then climatic and crop data are collected and evaluated.

1.5 Crop Coefficient (Kc)

Cropping pattern determines time of planting or sowing, rate of crop development, length of crop development stages and growing period are selected. Then "kc" for given crop and stage of crop development under prevailing climatic conditions is selected. Then ETcrop for each 30- or 10-day period:

ETcrop = kc . ETo. (2)

1.6 Factors Affecting Et_{crop} Under Prevailing Local Conditions

The effect of climate and its variability over time and area is determined. Then the effect of soil water availability together with agricultural and irrigation practices is evaluated.

1.7 Potential Impact Of Climate Change

Major climatic factors influencing crop water needs are shown in Fig.1.The increase in greenhouse gas concentrations in the atmosphere has led many scientists to predict that the earth's temperature will increase by several degrees over the next century [5,8,7]. with some saying that the effect of the increase in anthropogenic greenhouse gas on global climate is already evident [10]. Convention on Climate change seeks only to stabilize emission from developed countries [11], it appears likely that atmospheric levels of greenhouse gases will continue to rise. If they do, warming of the climate is highly likely. If climate change is inevitable, then it is probably also inevitable that the sea level will rise, agricultural production will change, runoff and water supply will change, and the location of forests and other terrestrial vegetation will shift poleward and to higher altitudes [6,9].

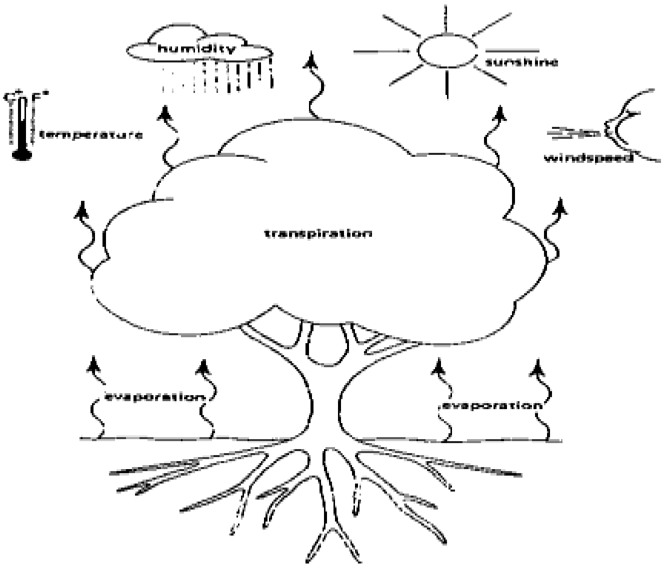

Fig. 1 Major Climatic Factors Influencing Crop Water Needs

II. WATER REQUIREMENT PREDICTORS

Crop water requirement is an important parameter in the calculation of the equilibrium of water and soil resources and the design, operation, and management of the irrigation projects [4]. Many methods of measuring and estimating crop water requirement have been proposed in the world. Four methods namely, the Blaney-Criddle, Radiation, Penman and Pan Evaporation method, are reviewed herein for predicting water requirement of crops.

2.1 Blaney-Criddle Method

This method is suggested for areas where available climatic data cover air temperature data only. The Blaney-Criddle equation (1950) involves the calculation of the consumptive use factor (f) from mean temperature (T) and percentage (p) of total annual daylight hours occurring during the period being considered. An empirically determined consumptive use crop coefficient (K) is then applied to establish the consumptive water requirements (CU).

$$CU = K.f = K(p.T/100) \qquad (3)$$

Where T is in °F.

Consumptive use is referred as 'the amount of water potentially required to meet the evapo-transpiration needs of vegetative areas so that plant production is not reduced by shortage of water.

2.2 Radiation Method

The Radiation Method is essentially an adaptation of the Makkink formula (1957). This method is suggested for areas where available climatic data include measured air temperature and sunshine, cloudiness or radiation, but not measured wind and humidity. Knowledge of general levels of humidity and wind is required,and these are to be estimated using published weather descriptions, extrapolation from nearby areas or from local sources. Relationships are given between the presented radiation formula and reference crop evapo-transpiration (ETo). In fact, in equatorial zon.es, on small islands, or at high altitudes, the Radiation method may be more reliable even if measured sunshine or cloudiness data are not available; in this case solar radiation maps prepared for most locations in the world should provide the necessary solar.radiation data.

To calculate solar radiation (Rs) from sunshine duration or cloudiness data, to determine the weighting factor (W) from temperature and altitude data and to select the appropriate adjustment as given by the relationship between W.Rs and ETo for different mean humidity and daytime wind conditions, the following procedure is suggested.

Solar radiation (Rs)

The amount of radiation received at the top of the atmosphere (Ra) is dependent on latitude and the time of year only. Part of Ra is absorbed and scattered when passing through the atmosphere. The remainder, including some that is scattered but reaches the earth's surface, is identified as solar radiation (Rs). Rs is dependent on Ra and the transmission through the atmosphere, which is largely dependent on cloud cover. Radiation is expressed in several units; converted into heat it can be related to the energy required to evaporate water from an open water surface. The unit equivalent evaporation in mm/day is employed herein. Rs can be measured directly but is frequently not available for the area of investigation. In this case, Rs can also be obtained from measured sun.shine duration records as follows:

$$Rs = (0.25 + 0.50\, n/N)\, Ra \qquad (4)$$

where n/N is the ratio between actual measured bright sunshine hours and maximum possible sunshine hours..Data for n, for instance using the Campbell Stokes sunshine recorder, should be available locally. Both n and N are expressed as mean daily values, in hours. Rs is obtained in mean equivalent evaporation in nun/day for the period. considered.

2.3 Penman Method

For areas where measured data on temperature, humidity, wind and sunshine duration or radiation are available, an adaptation of the Penman method (1948) is suggested; compared to the other methods presented it is likely to provide the most satisfactory results. The original Penman equation predicted evaporation losses from an open water surface (Eo). Experimentally determined crop coefficients ranging from 0.6 in winter months to 0.8 in summer months related Eo to grass evapo-transpiration for the climate in England. The Penman equation consisted of two term's: the energy (radiation) term and the aerodynamic (wind and humidity) term. The relative importance of each term varies with climatic conditions. Under calm weather conditions the aerodynamic term is usually less important than the energy term. In such conditions the original Penman Eo equation using a crop coefficient of 0.8 has been given to predict ETo closely, in cool, humid and very hot regions, and semi-arid regions.

2.4 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. In a similar fashion the plant responds to the same climatic variables but several major factors may produce significant differences in loss of water. Reflection of solar radiation from a water surface is only 5-8 percent, from most vegetative surfaces 20-25.percent. Storage of heat within the pan can be appreciable and may cause almost equal evaporation during night and day; most crops transpire only during daytime. Also the difference in water losses from pans and from crops can be caused by differences in turbulence, temperature and humidity of the air immediately above the surfaces. Heat transfer through the sides of the pan can occur, which may be severe for sunken pans. Also the colour of the pan and the use of screens will affect water losses. Notwithstanding these deficiencies, with proper use of pans to predict crop water requirements for periods of 10 days or longer is still warranted. From the many different types of pans, the use of the 13 . S. Class A pan and the Colorado sunken pan is presented here1in. To relate pan evaporation (Epan) to reference crop evapo transpiration (ETo) empirically derived coefficients (Kp) are given which 'take into account climate and pan environment.

III. MODIFICATION OF WATER REQUIREMENT PREDICTORS

For the better prediction in widely varied climatic conditions, Blaney-Criddle, Radiation, Penman and Pan Evaporation method are modified as under:

3.1 Modification Of Blaney-Criddle Method

The effect of climate on crop water requirements is, insufficiently defined by temperature and day length; crop water requirements will vary widely between climates having similar values of T and p. Consequently the consumptive use crop coefficient (K) will need to vary not only with the crop but also very much with climatic conditions. For a better definition of the effect of climate on crop water requirements, but still employing the Blaney-Criddle temperature and day length related f factor, a method is presented to calculate reference crop evapo-transpiration (ETo). The use of crop coefficients (K) used in the original Blaney-Criddle approach needs to be modified because of the following:

(i) the original crop coefficients are heavily dependent on climate, and the wide variety of k values reported in literature makes the selection of the correct value difficult;

(ii) the relationship between p(0.46T + 8) values and ETo can be adequately described for a wide range of temperatures for areas having only minor variation in RHmin, n/N and U; and

(iii) once ETo has been determined, the crop coefficients (kc) presented herein can be used to determine ETcrop.

The modified relationship is expressed as:

ETo = c[p(0.46T + 8)] mm/day (5)

where: ETo = reference crop evapo transpiration in mm/day for the month considered

T = mean daily temperature in oC over the month considered

p = mean daily percentage of total annual daytime hours for a given month and latitude

c = adjustment factor which depends on minimum relative humidity, sunshine hours and daytime wind estimates

After determining ETo, ETcrop can be predicted using the appropriate crop coefficient (kc).

Since the empiricism involved in any ET prediction method using a single weather factor, this method should be used in equatorial regions where temperatures remain fairly constant, for small islands ,and coastal areas where air temperature is affected by the sea temperature having little response to seasonal change in radiation, at high altitudes due to the fairly low mean daily temperatures and in climates with a wide variability in sunshine hours during transition months (e.g. monsoon climates, mid-latitude climates during spring and autumn). Calculation of mean daily ETo should be made for periods no shorter than one month. Since for a given location climatic conditions and consequently ETo may vary greatly from year to year, ETo should preferably be calculated for each calendar month for each year of record rather than by using mean temperatures based on several years records. At high latitudes (550 or more) the days are relatively long but radiation is lower as compared to low and medium latitude areas having the same day length values. This results in an undue weight being given to the day length related p factor. Calculated ETo values should be reduced by up to 15 percent for areas at latitudes of 550 or more. Concerning altitude, in semiarid and arid areas ETo values can be adjusted downwards some 10 percent for each 1 000 m altitude change above sea level.

3.2 Modification Of Radiation Method

The relationship is expressed as:

ETo = c(W:Rs) mm/day (6)

where: ETo = reference crop evapo-transpiration in mm/day for the periods considered

Rs = solar radiation in equivalent evaporation in mm/day

W= weighting factor which depends on temperature and altitude

c= adjustment factor which depends on mean humidity and daytime wind conditions

Calculations should preferably be made for each month or period for each year of record rather than using mean radiation and mean temperature data based on several years of record. A value of ETo can then be obtained to ensure that water requirements will be met with a reasonable degree of certainty.

3.3 Modification Of Penman Method

A slightly modified Penman equation is suggested here to determine ETo, involving a revised wind function term. The method uses mean daily climatic data; since day and night time weather conditions considerably affect the level of evapo-transpiration, an adjustment for this is included.

The form of the equation used in this method is modified to:

ETo = c[W.Rn + (1-W).f(u).(ea-ed)] **(7)**

radiation aerodynamic

term term

where, ETo reference crop evapo-transpiration in mm/day temperature-related weighting factor

Rn = net radiation in equivalent evaporation in mm/day

f(u) = wind-related function

(ea-ed) difference between the saturation vapour pressure at mean air temperature and the mean actual vapour pressure of the air, both in mbar

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

Description of variables and their method of Calculation

Vapour pressure (ea-ed)

Air humidity affects ETo. Humidity is expressed here as saturation vapour pressure deficit (ea-ed): the difference between the mean saturation water vapour pressure (ea) and the mean actual water vapour pressure (ed).

Wind function f(u)

The effect of wind on ETo has been studied for different climates and revised wind function is defined as:

f(u) = 0.27(1 + U/100) **(8)**

where U is 24-hr wind run in km/day at 2m height.

Weighting factor (1-W)

(1-W) is a weighting factor for the effect of wind and humidity on ETo.

Net radiation (Rn)

Net radiation (Rn) is the difference between incoming and outgoing radiation. It can be measured, but such data are seldom available. Rn can be calculated from solar radiation or sunshine hours (or degree of cloud cover), temperature and humidity data.

Adjustment factor (c)

The Penman equation given assumes the most common conditions where radiation is medium to high, maximum relative humidity is medium to high and moderate daytime vrind about double the night time wind. However, these conditions are not always met. For such conditions correction to the Penman equation is required

IV. MODIFICATION OF PAN EVAPORATION METHOD

Reference crop evapotranspiration (ETo) can be obtained from:

ETo = Kp . Epan **(9)**

where: Epan = pan evaporation in mm/day and represents the mean daily value of the period considered

Kp = pan coefficient

Values for Kp are given in standard Table for the Class A pan

In selecting the appropriate value of Kp to relate Class A, it is necessary to consider the ground cover of the pan station itself, that of the surroundings and general wind and humidity conditions.

When the pan is located at a station with very poor grass cover, dry bare soil or, undesirably, a concrete or asphalt apron, air temperatures at pan level may be 2 to 5°C higher and relative humidity 20 to 30 percent lower. This will be most pronounced in arid and semi-arid climates during all but the rainy periods. This effect has been accounted for in the figures of Tables 18 and 19. However, in areas with no agricultural development a-nd extensive areas of bare soils - as are found under desert or semi-desert conditions - the values of Kp given for arid, windy areas may need to be reduced by up to 20 percent; for areas with moderate levels of wind, temperature and relative humidity by 5 to 10 percent; no or little reduction in Kp is needed in humid, cool conditions.

4.1 Selection of crop coefficient

The four aforesaid methods described predict the effect of climate on reference crop evapotranspiration (ETo). To account for the effect of the crop characteristics on crop water requirements, crop coefficien.ts (kc) are presented to relate ETo to crop evapotranspiration (ETcrop). The kc value relates to evapotranspiration of a disease-free crop grown in large fields under optimum soil water and fertility conditions and achieving full production potential under the given growing environment. ETcrop can be found by:

ETcrop = kc . ETo **(10)**

Each of the four methods predicts ETo and only one set of crop coefficients is required. Procedures for selection of appropriate kc values are given, which take into account the crop characteristics, time of planting or sowing, and stages of crop development and general climatic conditions. Factors affecting the value of the crop coefficient (kc) are mainly the crop characteristics, crop planting or sowing data, rate of crop development, length of growing season and climatic conditions. Particularly during the early growth stage of crop, the frequency of rain or irrigation is important. The crop planting or sowing date will affect the length of the growing season, the rate of crop development to full groundcover and onset of maturity. For instance, depending on climate, sugar beets can be so-urn in autumn, spring and summer with a total growing season ranging from 230 to 160 days. For soybeans, the growing season ranges from 100 days in warm-tow altitude areas, to 190 days at 2 500 m altitudes and for maize 80 to 240 days respectively. Crop development will also be at a different pace; for example for sugar beets, the time needed to reach full development or maximum water demand varies from up to 60 percent of the total growing season for an autumn sown crop to about 35 percent for an early summer sowing. In selecting the appropriate kc value for each period or month in the growing season for a given crop, the rate of crop development must be considered. Transpiration and evaporation are governed by different physical processes. However, since for the crop growing. season, Esoil forms part of ETcrop, and for the sake of simplicity, the coefficient relating ETo and Esoil is given herein by the appropriate crop factor (kc). T'he value of kc largely depends on the level of ETo and the frequency with which the soil is wetted by rain and or irrigation. ETcrop is the sum of transpiration by the crop and evaporation from the soil surface. During full groundcover, evaporation is negligible; just following sowing and during the early growing period evaporation from the soil surface (Esoil) may be considerable, particularly when the soil surface is wet for most of the time from irrigation and rain.

V. CONCLUSION

The conclusions drawn from present study are as under:

The modified Penman method would offer the best results with minimum possible error of plus or minus 10 percent in summer, and -up to 20 percent under low evaporative conditions. The Pan method can be graded next with possible error of 15 percent, depending on the location of the pan. The Radiation method, in extreme conditions, involves a possible error of up to 20 percent in summer. The Blaney-Criddle method should only be applied for periods of one month or longer; in humid, windy, mid-latitude winter condition.- an over and under prediction of up to 25 percent has been noted

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