Literature Review

CHAPTER-3

LITERATURE REVIEW

General information about crop water requirements, available methods for measurement of evaporation, transpiration and evapotranspiration, methods for estimating evapotranspiration, limitations of the available methods, and need for research is discussed in this chapter. The problem of research undertaken is also analysed.

3.1 IMPORTANT TERMINOLOGY :

3.1.1 Evaporation

Evaporation of water from the soil is a process by which water is changed from liquid or solid state into the gaseous state through the transfer of heat energy; i.e.,the difference of temperature gradients in the atmosphere and in the soil surface. It is the total water vapour loss from a given area over a given time period. It may be expressed as the total or the mean rate in units of mass or volume per unit area or as an equivalent depth of water for the period concerned. The factors that affect the rate of evaporation are the nature of the evaporating surface and the difference in vapour pressure as determined by temperature, wind and atmospheric pressure.

3.1.2 Transpiration

The water in vapour form is transffered from a wet surface to the atmosphere by means of a turbulent exchange process. The wet surface may be a free water surface or a partially free surface as formed by the stomata in plant leaves.

The transformation of the liquid phase in the plant into gaseous phase is transpiration. Transpiration takes place on the moist surface of mesophyllous cell from where water vapours diffuses into the intracellular spaces of the leaves and from there into the atmosphere. The volume of water transpired by plants depends in part on the water at their disposal and also on temperature and humidity of the air, wind movement, intensity, and duration of sunlight, stage of development of the plant, type of foliage and nature of the leaves. The size and number of stomata in leaves vary according to the species, but all plants have the ability to vary their stomata size, and hence the evaporation rate, by the operation of quard cells, which operate when the leaf turgor falls. Units are identical with the evaporation as in (i) above.

3.1.3 Potential Evaporation

It is the evaporation from a given surface when all surface atmospheric interfaces are wet (saturated)so that there is no restriction due to either biological control or soil water content on the water vapour loss from the surface area.

Evaporation from a crop soil unit comprises evaporation from the soil surface and transpiration through the plant via leaves. If the crop completely covers the ground surface, evaporation takes place entirely through the plants and if the roots can absorb water at a sufficiently high rate, the vapour transfer is controlled by the climate alone. This rate of moisture use is reffered to as the potential evapotranspiration rate and is a function of the energy available to vaporise the water in conjuction with the rate of removal of vapour from the leaf surface. (Ref. B Withers and S Vipond)

3.1.4 Consumptive use of water :

Consumptive use of water for transpiration is the amount of the water consumed by the plant for its assumed development in the vegetation period for physiological processes in the given climatic conditions and for securing all growth factors. It is the amount of water used by growing plant in transpiration and building of plant fissures and that evaporated from adjacent soils or from intercepted precipitation on the plant foliage in any specified time. Consumptive use is usually expressed in metre cube per hectare or centimetres cube per hectare or in depth units as millimetres or centimetres.

3.1.5 Transpiration Coefficient

It is the ratio of weight of water consumed by crop during the growing season to weight of dry matter harvested (Dry matter is the plant matter dried at 105° C). It is also known as transpiration ratio. The values varies from 200 to

1000 and for sugarcane 250 to 1500.

3.1.6 Evapotranspiration (ET)

The total sum of both components of water vapour loss, i.e. evaporation and transpiration from a vegetated surface over a given time period is evapotranspiration. The maximum value of evapotranspiration at optimal moisture conditions for plants is termed as potential evapotranspiration. Units are same as in (i) above for evaporation. The terms evapotranspiation and consumptive use are frequently used interchangeably. However they are synonymous only if evapotranspiration is used to indicate the amount of water consumed in evaporation and transpiration in raising plants. Diversion of water from one watershed to another is considered to be consumptively used eventhough it is not evaporated or transpired. Thus the two terms do not always have the same meaning.

3.1.7 Crop Water Requirements

Crop Water Requirements are defined as the total depth of water needed to meet the water loss through evapotranspiration from planting to harvest, of a given 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.

3.1.8 Reference Crop Evapotranspiration (ETo)

The effect of the climate on crop water requirement is given by the reference crop evapotranspiration. The evapotranspiration from a given well-adopted crop selected for comparative purposes under given weather conditions and with adequate fetch and for a standardised watering regime appropriate for this crop and the region concerned.

Alternatively FAO-24 describes it as the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall green grass cover of uniform height actively growing, completely shading the ground and not short of water.

3.1.9 Optimal Evapotranspiration

It is evapotranspiration from a particular crop under given weather and fetch conditions when the crop has been watered optimally for a specified agronomic or economic purpose .

3.1.10 Equilibrium or Limiting Evapotranspiration

A basic limiting value of evapotranspiration, given for practical purposes by the radiation term of the combination equation towards which evapotranspiration coverages as uniform fetch increases. Near surface air humidity changes downwind toward equilibrium with the underlying surface wetness (which is not saturated in most cases) or the equivalent surface resistance. The resulting equilibrium evapotranspiration becomes in all cases equal to the net radiation term due to interaction of the aerodynamic component and the other terms in the combination equation.

3.1.11 Fetch

The distance the air travels over similar vegetation and soil water conditions upwind from the site in question measured in the direction of the prevailing wind which should be specified.

3.1.12 Combination Equation

It is simpler form of equation for estimating evapotranspiration that combines energy balance and vapour flow relationships so that atmosphere gradients and surface temperature are eliminated as parameters. By including a surface or crop canopy resistance, the method can be used to estimate evapotranspiration for various crops and soil water conditions.

3.1.13 Net Irrigation Requirements

The depth of irrigation water, exclusive of precipitation, stored soil moisture or ground water (capillary)contribution that is required consumptively for crop production and for purposes such as leaching and percolationlosses inevitable in case of some crops. In other words in normal soils (without leaching requirement) and for crops other than paddy (where standing water results in percolation losses) it is the amount or the depth of water required to bring the soil moisture level in the effective root zone to field capacity from the soil moisture content before applying irrigation water.

3.1.14 Crop Coefficient

Crop coefficient relates reference crop evapotranspiration to crop evapotranspiration or consumptive use. It accounts for the effect of crop charactristics on crop water requirements. Crop coefficient value takes into account the sowing time, crop development stages, crop characteristics and climate.

3.2 CROP WATER REQUIREMENTS - HISTORICAL DEVELOPMENTS

3.2.1 A knowledge of the rate of wateruse by crops is fundamental in design of water supply system and scheduling of the irrigation scheme. The problem of estimating or determining water requirements for irrigation has been studied for more than 100 years. The work on water requirement of crops was started as early as 1850 at Rothamsted. But the term was actually defined by Hellregel, who conducted investigations in pots to determine the water requirements of the crops in 1883. Simultaneously in the first decade of the century very systematic investigations were undertaken in the great plains area in the United States of America and the Indo-Gangetic plains of India. Investigations in the Great plains area in the year 1910 and 1911 proved that drought resistance and water requirements were two distinct features of the crop plants.

Water requirements, worked out in pots had a limited applicability. Besides the effect of pot-bound root system, water distribution, excessive evaporation and transpiration produced results not in toto comparable to field grown crops. With a view to arriving at a more scientific basis of irrigation, the investigations/experiments were conducted in the field. Initially techniques were not much refined as information on the movement of soil moisture, the physiology or water absorption and the transpiration was limited. Now better assessment of water needs of the crops is possible in relation to weather conditions, soil fertility and the source of water supply.

3.2.2 Since the beginning of the century considerable amount of work has been done on soil water plant relationship and on computation and determination of evapotranspiration for different crops. The emphasis was given in these studies to the need of developing useful concepts and different methods which could be reliably used based on the knowledge gained in one climatic zone to another climatic zone. During the 25 years following 1920, considerable emphasis was placed on the development of procedures for estimating seasonal evapotranspiration. Cummings and Richardson (1927) proposed the theoretical method based on energy balance formula. Experiments were carried by Blaney H. F., Taylor C. A. et al in 1930 at California on soil moisture sampling approach. Evapotranspiration was determined from measurements of irrigation water and seasonal fluctuations in the water table in California by Harding S. T. (1927-30). The approach of Bowen's ratio was also presented by Richardson in 1931. The Thornthwaite equation developed in North America in 1931 is based on an exponential relationship between mean monthly temperature and mean monthly consumptive use. In 1931 Carl Rohwer developed an equation based on barometric pressure, wind velocity and vapour pressure deficit. Formula based on vapour pressure deficit and wind velocity was proposed by Meyer in 1942. Lowry - Johnson (1942) developed an equation based on the temperature of the application area. Blaney and Morin (1942) proposed an empirical formula for evapotranspiration. Thornthwaite (1948) correlated mean monthly temperature with evapotranspiration as determined by water balance studies.

3.2.3 After 1950 considerable attention was given to physical law governing the evapotranspiration process. Two theoretical approaches to the problem were investigated, namely the mass transfer and the energy balance. Theoretical approach was considered in predicting evaporation from water surfaces before being applied to the cropped surface. The influence of temperature, humidity, wind velocity, vapour pressure and solar radiation on consumptive use has been studied by several researchers. Penman H.L., in England, has made the most complete analysis using several climatic variables. He carried out experiments at Rothmasted in meteorological enclosure during 1944-45. He combined two theoretical concepts into an equation for estimating evaporation from a free water surface and then applied empirical coefficient to adopt the values obtained for the evapotranspiration. Penman (1948) used clipped grass similar to a lawn to develpe his version of the combination equation. In testing the Penman formula Makkink (1957) found that the height of the grass did have an influence on the evapotranspiration rate. An earlier digest of the Penman, Blaney-Criddle and other methods was prepared by Criddle in ASCE paper 1507 (1958). Olivier in 1953 stated that evaporation could be described as the integration of periodic variations of environmental climate and is influenced by temperature, humidity and wind. Papadakis (1961) and Harbeck (1962) proposed an equation based on saturation vapour pressure. Temperature has been used as the principal variable to obtain an index to consumptive use by Blaney and Criddle (1950) in the arid Western United States. Blaney and

Criddle (1966) modified the Blaney-Morin (1942) formula by omitting the humidity term. Jensen and Haise (1963) used temperature and solar radiation to estimate the consumptive use of a reference crop as did Hargreaves (1956) for grass as a reference crop. Denmead and Shaw (1962) and later Holmes and Robertson (1963) studied evapotranspiration in detail and found that as the soil moisture decreases, evapotranspiration rate declines and this decline begins at a higher moisture content when the atmospheric demand rate is high.

3.2.4 Christiansen (1960), Christiansen and Low (1970) developed a formula for estimating class A pan evaporation from extra terrestrial radiation and climatic data based on data from Northen Utah. Later he and his collegue developed a more general formula based on data from Western United States and Texas (Christiansen and Patil 1961). This study was later expanded to include data from the other countries. Grassi (1964) developed three equations for estimating actual evapotranspiration for several cropes using data furnished by Jensen and Haise (1963). These studies were continued using data furnished by Pruitt and Angus (1960). These studies were reprinted in a paper by Christiansen and Hargreaves (1970). Christiansen and Hargreaves developed three formulae for estimating evapotranspiration using data from Pruitt for rye grass from a twenty feet diameter lysimeter. Jensen et al (1970) defined alternate definition of evapotranspiration widely used in Western United States.

3.2.5 Priestley and Taylor reported (1972) that out of the total solar energy available at the soil or plant surfaces, some 80 to 90 percent is utilized to provide energy for the liquid to vapour conversion of water, if water is readily available. Wiegand and Taylor (1961) analysed that the flux of water vapour is largely limited by one or more requirements. Several researchers viz. Tanner (1957), Goodell (1966), Penman et al (1967), Grey (1970), Campbell (1977) and Eagleson (1978) have provided good descriptions of the primary variables which determined evapotranspiration rates. They provided an extensive mathematical review which integrated the principles of evapotranspiration into hydrologic predictions.

3.2.6 Some investigators in the Western United States have used the evapotranspiration from a well watered crop like alfalfa with 30 to 50 cm growth and 100 m of fetch as representing potential evapotranspiration (Jensen 1974). Because of the ambiguities involved in the interpretation of evapotranspiration J. Doorenbos and W. O. Pruitt (FAO Irrigation and Drainage paper-24, 1977) defined the term reference crop evapotranspiration (ETo). The California department of water resources selected class A pan evaporation as the means of estimating evapotranspitration and carried out experiments in 1974. A comprehensive evaluation of common evapotranspiration equations was made, comparing 18 methods for estimating ETo using lysimetric measurements from 10 world wide locations, by the technical committee on irrigation water requirements of the irrigation and drainage division of ASCE (M E Jensen 1974). Ritchie (1972), Tanner and Tury (1976) used models that separate evapotranspiration into evaporation and transpiration components.

3.2.7 Crop evapotranspiration related to evaporation was measured with pans by Pruitt (1966). Generalised maps of class A pan and pond evaporation are available to estimate average conditions. Kohler et al (1959) and Nodenson (1962) provided maps and seasonal distributions. Morton (1979) provides an estimation methods of lake evaporation based on temperature and radiation. Climatic observations as an index to consumptive use is given by USDA, SCS technical release number 21 (1970). G. H. Hargreaves (1977) carred out work on water requirements for irrigated crops and rainfed agriculture. He used the climatic mean values of temperature and estimated radiation from data published by WMO to estimate evapotranspiration for 644 world wide locations.

3.2.8 Francis Idike et al (1981) analysed soil moisture data under corn for a field location in southwest Minnesota to develop relationship for ET as a function of soil moisture content, crop stage and weather. Sun F Shih (1984), using optimum ridge regression analysis, reported that a model based on two variables of air temperature and solar radiation can provide a satisfactory estimation of ET. Hargreaves and Samani (1985) used the equation given by Hargreves et al (1985) for comparision with grass lysimeter ET at three sites and with the Penman method at various locations. They concluded that the temperature method provided a better fit of the measured lysimeter data in nearly all cases. P. K. Jain and Gideon Sinai (1985) modified the Thornhwaite equation coefficient for semi arid regions. Subramanium and Rao (1985) compared the weekly evapotranspiration estimates by the Penman method for three semi arid and one dry subhumid climatic locations in India for five crops (Rice, Wheat, Maize, Cotton and Groundnut) with lysimeter observations for a period of two years. They reported that the estimated evapotranspiration was in close aggrement for most of the crops. Samani and Pessarikli (1986) compared field measurements of ET at Mesa, Arizona with estimated ET using three different methods and concluded that a temperature related method was one of closest methods to actual ET. Soliman A et al (1987) selected 23 empirical methods for estimating ET and used for ET estimates under extremely arid conditions of central Saudi Arabia and found that Jensen Haise and class A pan methods gives results nearest to actual measurements. The Penman equations for estimating hourly ETo of an alfalfa was calibrated for both day time and night time conditions by Micheal et al (1988). The analysis of data from four lysimeter and class A pan sites in California by Hargreaves (1989) indicates that the temperature range equations estimates ET resonably well in a large diversity of climates.

3.2.9 Muluneh Yitayew (1990) used remote sensing technique for estimating regional ET and concluded that the technique requires extrapolation of instantaneous values for long term regional ET. He developed extrapolation coefficients based on earth-sun geometry. Kizer et.al. (1990) used the Penman equation for estimating hourly ET for both day time and night time conditions in Southwestern Oklahoma, USA and found good correlation with field measurements. Improved equations are presented by Richard Allen and W. O. Pruitt (1991) for calculating correction factors for the method given in FAO-24. S Mohan (1991) compared four methods with Penman for Tamilnadu in India and found good correlation between the values. An equation is developed by A. Dong et al (1992) for hourly net radiation over well watered grass from meteorological data. R. L. Snyder and W. O. Pruitt has reported in ASCE (1992) for electronic weather statins and telephone data transfer to a control computer used to collect hourly weather data and estimate ETo in California Department of Water Resources. Allen R G et. al. (1994) redefined the reference crop evapotranspiration with a clipped grass surface.

3.3 METHODS OF MEASUREMENTS

3.3.1 Measurement of Evaporation

The methods of measurements and estimation of evaporation are described briefly as under

(1) Evaporation Pans

The evaporation pan is the most widely used instruments for evaporation measurements. Several types of pans are commonly used.

The measurement by evaporation pans is affected by many variables including vapour pressure difference, wind movement, pan diameter, water temperature, air pressure, rim height, colour of pan, and depth of pan. These variables were correlated by Hickox with the experimental results which he obtained from a small pan under controlled conditions.

Many studies were also made to determine reliable relation between pan evaporation and meteorological factors. Some results so obtained have been incorporated in various methods of evaporation determination. Some of the relation so developed involve the substitution of air temperature for water temperature, with a resultant seasonal and geographic bias. Thus use of air temperature is more practical for design purpose. Penman proposed such a method through simultaneous solution of an empirical mass transfer equation and energy balance equation. Observations indicate that pan evaporation is also affected by the sensible-heat transfer across the pan walls in either direction and by advection to and by the energy storage in the reservoir or lake. Such effects have been analysed through the use of the Bowen ratio and energy balance concept.

(2) Atmometers

The atmometer is instrument for measuring or estimating different intensities of evaporativity. Various types are as under

(a) Livingston atmometer

(b) Bellani atmometer

(c) Piche atmometer

(3) Empirical Evaporation Equations

Many empirical or semiempirical equations have been developed to estimate evaporation from free-water surfaces. Most of them are based on Dalton's law, with modifications for factors affecting evaporation. The equation developed have the common feature that the energy factor is the difference in vapour pressure between water and air. Their application is difficult because it may not be possible to obtain the information needed for their solution. Most of the quantities used are average values, whereas, in fact, evaporation depends upon the total quantity of incoming energy and the average may not represent the total. The relative humidity, or vapour-pressure deficit, measured in early morning and other measurement in late afternoon may give averges that do not indicate the total quantities needed to determine evaporation.

(4) Water-Balance Method

The water-balance or Water-budget method is a measurement of continuity of flow of water. This holds true for any time interval and applies to any drainage basin and to the earth as a whole. According to Horton, the water-balance equation may be written as

$$E = I - O - S$$

Where E is the evaporation

I is the inflow, or precipitation

O is the outflow, or total runoff

S is the change in reservoir contents

Theoretically this method can be used but practically it is difficult to use because of the effects of errors in measuring the various items. Evaporation as determined by this method is a residual and therefore may be subject to considerable error if it is small compared with other items.

(5) Energy-Balance Method

This method is similar to the water-balance method except that it deals with continuity of flow of energy instead of water. This method was applied to obtain estimates of annual evaporation from the oceans and lakes. This method is complicated by the difficulties of evaluating the needed items as atmospheric radiation, long-wave radiation from the body of water, energy storage, and conduction of sensible heat to or from the body of water for the solution of the energy-balance equation. With the energy-balance equation, it is possible to obtain the sum of energy conducted as sensible heat and energy utilized by evaporation. The ratio of these two terms is known as Bowen's ratio. According to Anderson, the energy-balance equation applied to a body of water with free-water surfaces may be expressed as

$$Qs - Qr - Qb - Qh - Qe = Qo - Qv$$

where Qs = Solar radiation incident to water surface

Qr = Reflected solar radiation

Qb = Net energy lost by body of water through the exchange of long-wave radiation between atmosphere and body of water

Qh = Energy conducted from body of water to atmosphere as sensible heat

Qe = Energy utilised for evaporation

Qo = Increase in energy stored in body of water

Qv = Net energy advected into body of water

This equation assumes the principle of conservation of energy but neglects items of small magnitude such as heat transformed from kinetic energy, heating due to chemical and biological processes, and conduction of heat through the bottom. From the above equation, the evaporation can be derived using density of water, latent heat of evaporation and Bowen ratio.

(6) Mass-transfer Method

Based on the concepts of discontinuous and continuous mixing applied to mass transfer in the boundary layer, a mass-transfer theory has been developed to derive evaporation equations.

3.3.2 Measurements of Transpiration

For a small plant the transpiration may be measured for short periods by placing the plant in a closed container and computing the changes in humidity in the container. The excessive humidity thus produced can be reduced by use of a drying agent placed inside the container but the computed transpiration must be corrected for the moisture absorbed by the drying agent.

A phytometer provides a practical method for measuring transpiration. This is a large vessel filled with soil in which one or more plants are rooted. The soil surface is sealed to prevent evaporation so that the only escape of moisture is by transpiration which can be determined from the loss in weight of plant and vessel. This method gives satisfactory results provided the simulated testing condition is comparable with the natural environment under investigation.

Transpiration may also be determined by watershed studies. This method studies the effect of removing the vegetative cover from the watershed. Transpiration can also be expressed in terms of depth of water consumed annually by the plant and such depths for various plants were evaluated. The transpiration ratio and transpiration depth do not represent a true measure of field conditions and they may mislead unless the exact conditions under which the measurements made are fully specified.

The amount of transpiration depends on many variable. Its precise determination cannot be easily obtained and no accurate single value can be assigned to any crop without specifying all the variables. Therefore the estimated transpiration may be extremely unreliable, serving only as a measure of the relative water use by plants under similar conditions. This is the reason why so much effort has been made to correlate climatic factors to evapotranspiration. Thus the measurements in one locality under known evapotranspiration conditions may be applied to another in which the environmental conditions affecting use of water can be measured.

3.3.3 Direct Measurement of Evapotranspiration

The principal methods for direct measurement of evapotranspiration are as under.

1. Soil-moisture Sampling
2. Lysimeter Measurements
3. Inflow-outflow Measurements
4. Integration Method
5. Energy Balance
6. Vapour Transfer

7. Ground Water Fluctuations

These methods yield very reliable values of evapotranspiration provided elaborate installation and precise measurements are made. The methods are however costly, laborious and time consuming. A brief dęscription of direct methods is given as under.

1. Soil-Moisture Sampling

This method is usually suitable for irrigated field plots where soil is fairly uniform and the depth of ground water is such that it willnot influence soil moisture fluctuations within the root zone. Soil samples are taken in the area before and after each irigation, and their moisture contents are detemined by standard laboratory practices. From the moisture percentage obtained in the laboratory, the quantity of water in acre-inches per acre removed by evapotranspiration from each foot of soil is computed by

$$D = PVd/100$$

where P is the moisture percentage of the soil by weight

V is the apparent specific gravity of the soil

d is the depth of soil

D is the equivalent depth of water lost by the soil

The losses may be plotted against time and use of water curve for the season is obtained. This method usually requires a large number of measurements covering representative locations in order to obtain desired accuracy. The soilsampling should represent the full depth of soil occupied bythe roots. The area of sample should be large, so as to avoid border effect. The place of sampling should be some distance from the outside rows of plants, to prevent undue influence from advected energy. A free water surface within the reach of roots precludes use of the soil sampling method in the field.

2. Lysimeter Measurements

This method is commonly used to determined evapotranspiration of individual crops and natural vegetation, by growing the plants in tanks, or lysimeter, and then measuring the losses of water necessary tomaintain the growth satisfactorily.

An excellent review of the history of evaporation research and experimental methods is found in Brutsaert (1982). Historical accounts of evapotranspiration research, in particular lysimeter developments, are found in Kohnke et.al. (1940), Harrold and Dreibelbis (1951, 1958 and 1967), Tanner (1967) and Aboukhaled et.al. (1982). Soileau and Hauck (1987) reviewed lysimetry research with an emphasis on percolate water quality and Bergstrom (1990) discussed lysimetry application for pesticide leaching research.

Probably the most accurate measurement of evapotraspiration is obtained by the use of lysimeters. A lysimeter is a device that is hydrologically isolated from the surrounding soil. This device contains a known volume of soil, usually planted to the crop under study and has some means to directly measure the consumptive use of water. Lysimetry establishes a datum for evapotranspiration calculations because it is the only method of measuring evapotranspiration where the investigator has complete knowledge of all the terms of water balance equation.

Lysimeters are constructed in three forms :

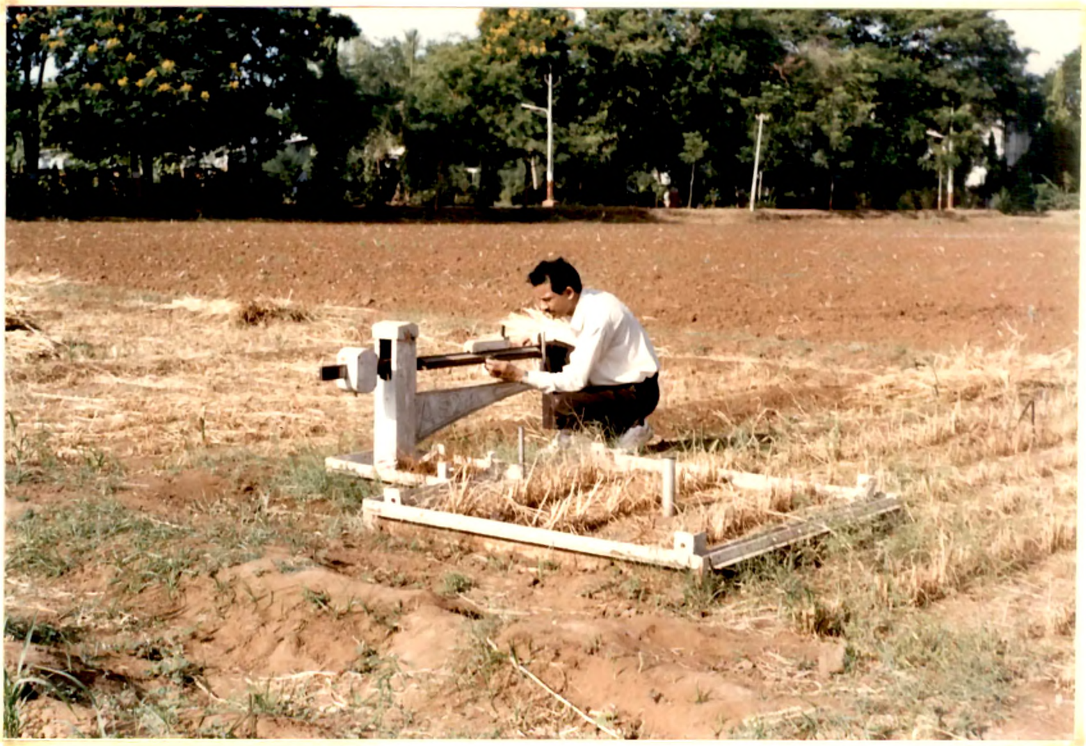
(a) The non-weighing lysimeter where, assuming soil moisture storage capacity remains constant, crop water use is the difference between applied and drainage water. (b) The weighing lysimeter in which crop water use is found by the loss in weight between water applications. (c) The water table lysimeter where the crop water use is measured by the amount of the water required to maintain the water table at a constant depth below the soil surface.

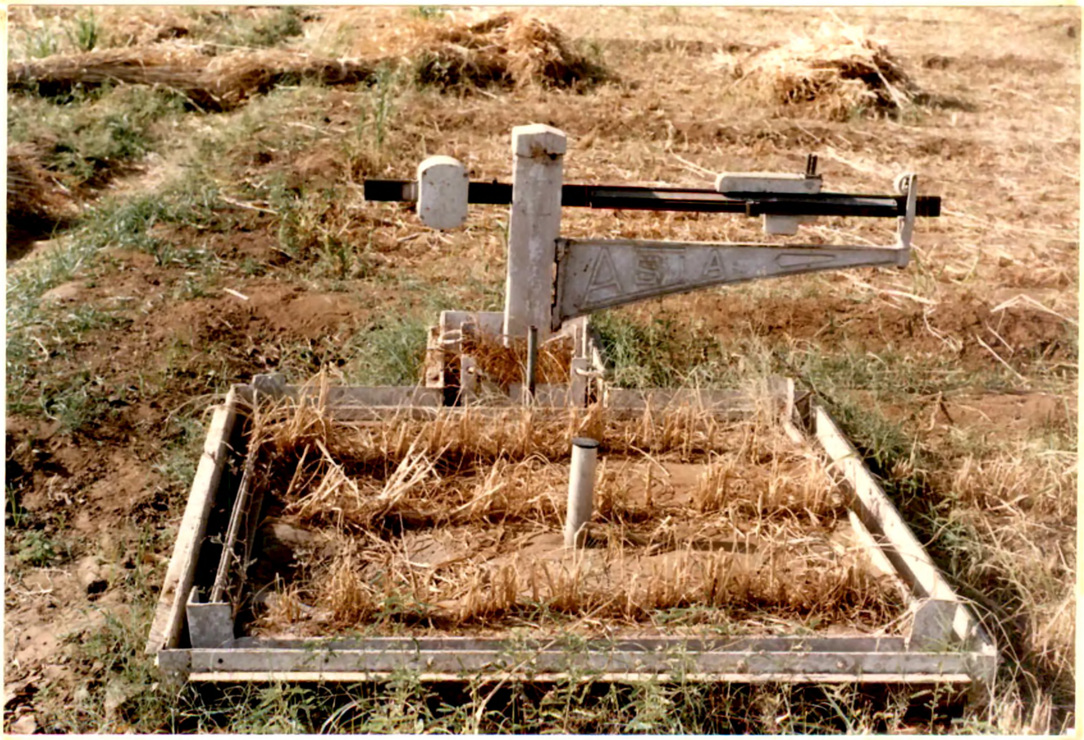
Weighing lysimeter may be desirable for precise research. A hydraulic weighing lysimeter, usually planted to deep rooted crops, such as alfalfa or corn. Figure 3·1 shows the weighing type lysimeter. Photo 3·1 to 3·3 shows the lysimeter installed at Anand agricultural college. Lysimeters, though provide the means of precise and direct measurement of the amount of water supplied to and lost by the crop, often encounter a number of problems. The major limitations are the reproduction of physical conditions, such as temperature, water-table, soil texture and density within the lysimeter, comparable to those outside in the field. To obtain accurate results in lysimetry, the plants growing in the container must be identical in all respect to the crop being studied and must be subjected to the same physiological and climatological conditions.

The soil moisture conditions must be similar and therefore the amount and time of water applications must be the same. Other management practices such as similar planting times, equal supply of fertilizer and the leaching of any accumulation of salts must be identical. It is necessary to ensure that water applied to the lysimeter travels through the soil and not between the sides and soil.

A circular lysimeter is suitable for grass and other close-rooted crops. A square lysimeter is needed for row crops. Filling the lysimeter obviously disturbs the structure. Non-granular soils should ideally be encased insitu by the container. Care should be taken to maintain the original soil profile, similar soil moisture conditions and rooting densities. If the overall condition in the tank may not closely simulate the field condtions, the result thus obtained may not be converted reliably to an acreage basis for a much larger area under consideration.

3.1 Weather Station At Anand





3.2 Lysimeter Installed At Anand

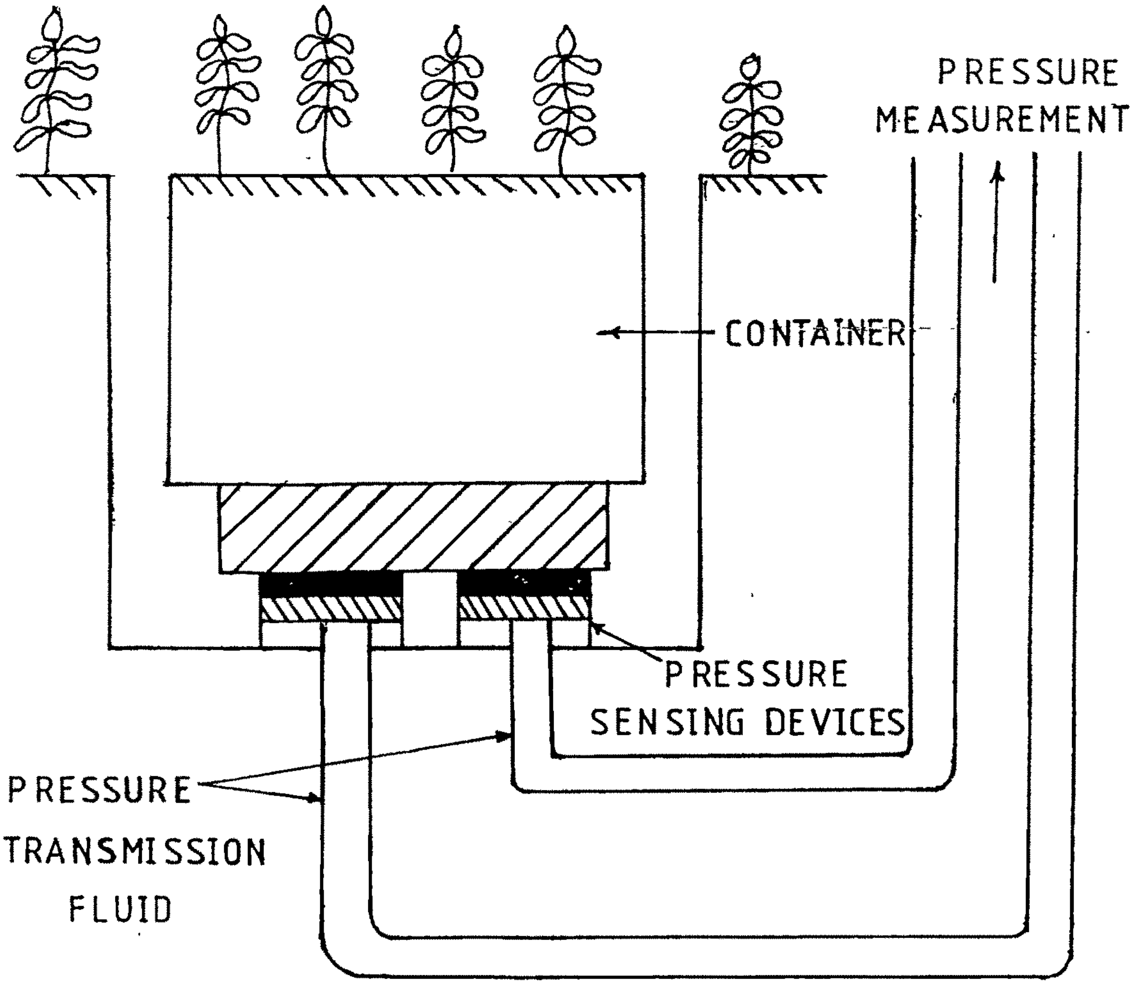


FIG:3·1 THE HYDRAULIC WEIGHING LYSIMETER

3. **Inflow-Outflow Measurements**

This method involves the applications of the water balance principal to large land areas. The amount of water entering a known area of land during a certain period is measured and compared with the recorded precipitation on the area for the same period. The difference between these two items and the amount flowing out of the area adjusted by the change in ground water storage during the same period will be a major of losses by evapotranspiration for the period. The difference of storage of water at the beginning and at the end of the period is usually considered to be negligible. This method usually present difficulties in determining the flow quantities to a desired accuracy.

4. **Integration Method**

This method determines evapotranspiration by the summation of products of evapotranspiration for each crop times its area plusthe evapotranspiration of natural vegetation times its area plus water surface evaporation times water surface area plus evaporation from bare land times its area. In applying this method, of course, it is necessary to know unit evapotranspiration and the areas of various classes of agricultural crops, natural vegetations,bare land, and water surfaces.

5. **Energy Balance**

This method assumed that the energy received by a surface through radiation equals the energy used for evaporation and heating the air and the soil plus any extraneous or advective energy. For short period, such as daily and monthly balances the energy for heating the soil and the advective energy may be neglected. This method isbased on the simple principle of energy balance. Its application to cropped land and the instrumentation necessary for measuring the energy items are discussed by Tanner and Levine.

6. Vapour Transfer

This method uses the Thornthwaite -Holzman equation for evapotranspiration estimation by modifications suggested by Pasquill. The method requires strict adherence to boundary conditions and to the limitations imposed by the sensitivity of the instrumentation. This requirèments will usually put the method beyond most facilities available for the measurement of evapotranspiration.

7. Groundwater Fluctuations

Daily rise and fall of the water table give an indication of evapotranspiration losses. The evapotranspiration overlying vegetation can therefore be computed on the basis of diurnal measurements of the ground water table fluctuations in observation wells. This method has been used by the U.S. Geological Survey with success.

3.4 ESTIMATING EVAPOTRANSPIRATION

3.4.1 General

There are many methods of estimating evapotranspiration and potential evapotranspiration, but no one can be applied generally for all purposes. Most methods for estimating evapotranspiration apply also to estimate potential evapotranspiration, provided the area under observation has sufficient water at all times. All methods, however, may fall into three general categories : theoretical approaches based on the physics of the evap otranspiration process, analytical approaches based on energy or water amounts and empirical approaches based on the regional relation between the measured evapotranspiration and the climatic conditions. Several methods are available for estimating evapotranspiration or potential evapotranspiration, out of which some are in vouge and some of them are widely used. The widely used methods are given as follows.

3.4.2 Empirical Expressions

Various methods for ascertaining evapotranspiration are in vogue. However the methods viz: water balance method, micro-climatic method; are complex and time consuming. Empirical methods are therefore employed in irrigation practice. They mostly consist in obtaining the value of evapotranspiration from measured meteorological values, the type and development stage of the vegetation. Confidence is developing in the practical utility of ET equations that require weather records. This confidence comes from comparisions of calculated daily and longer period ET values with water balance methods, especially those from weighing lysimeters. Many methods of estimating ET have been proposed by several researchers. The methods may be broadly classified as those based on combination theory, humidity data, radiation data, temperature data and miscellaneous methods which usually involved multiple correlation of ET and various climatic data.The most frequently used empirical methods are covered briefly under the discussions are (i) Blaney Criddle method (ii) Radiation method (iii) Penman method (iv) Pan evaporation method (v) Hargreaves method (vi) Jensen Haise method (vii) Thornthwaite method. Many other formulae for calculating evapotranspiration on climatological approach are in existance. Some of them are those given by Alptayev, Tore, Shanov and Shaumyan. Their use however has been limited because of the limited number of factors considered and the particular set of environment in which they were developed. Detailed analysis, tables and graphs and application of various methods are given in FAO Irrigation and Drainage paper 24.

(1) Lowry-Johnson

Lowry and Johnson (1942) developed a procedure for estimating water requirements for irrigation projects which is applicable to an entire valley, but does not to an individual farm. This method is essentially an empirical procedure based on the temperature of the application area. A linear relationship is assumed between effective heat and consumptive use. Effective heat is defined as the accumulation in degree days of maximum daily growing season temperature above 32°F. The approximate relationship can be written as

$$U = 0.8 + 0.000156\ H$$

Where

U = Consumptive use in feet

H = Effective heat in thousands of day-degrees(Farenheit)

(2) Blaney - Morin

Blaney and Morin (1942) proposed an empirical formula for estimating either evaporation or evapotranspiration, which is,

$$E = K * T * P (114 - H)$$

Where

E = Monthly evaporation or evapotranspiration in inches

K = Monthly coefficient

T = Mean monthly temperature in °F

P = Monthly percent of annual day time hours

H = Mean monthly humidity, expressed decimally.

(3) Blaney-Criddle Method

Blaney and Criddle (1966) modified Blaney and Morin formula (1942) by ommiting the humidity term. The relationship was initially developed and intended for seasonal estimates. The principal assumption is that evapotranspiration varies directly with the sum of the products of mean monthly air temperature and monthly percentage of day time hours of the year. Expressed mathematically as

$$u = K * F$$

Where

u = Consumptive use of a crop in inches for a given period

K = empirical crop coefficient

F = Sum of consumptive use factor for the period
= p * t / 100

t = mean temperature in degree ferenheit

p = percentage day time hours of the year occuring during the period

Further attemps were made by researchers to develop formulae which would depend less on the judgement of the users. The formula attains following shape in metric system with 't' expressed in °C and 'U' in millimeters.

$$U = o.254 (1.8 * t + 32) * p * K$$

The original Blaney-Cridle equations involves calculation of the consumptive factor (f) from mean temperature (T) and Percentage of total day light hours (p). For a better definition of the effect of climate on crop water requirements, but still employing the temperature and day length factor, a modified method is presented by FAO-24 paper. The recommended relationship is;

$$ETo = C [P (0.46T+8)] \text{ mm/day}$$

ETo = Reference crop evapotranspiration in mm/day for the month considered

T = Mean daily temperature in °C over the month considered

P = Mean daily percentage of total annual day time hours obtained from Table 1- FAO 24 for a given month and latitude

C = Adjustment factor which depends on minimum relative humidity, sunshine hours and daytime wind estimates

(4) Radiation Method

This method is suitable where available climatic data includes measured air temperature and sunshine,cloudiness or radiation but not measured wind and humidity. Wind and humidity are to be estimated using published weather descriptions from nearby areas or local sources. This method may be more reliable and can be used near equatorial regions, on small island or at high altitudes and in coastal areas. The recommended relationship is expressed as

$$ETo = C \times (W \times RS) \text{ mm/day}$$

Where

ETO = Reference crop evapotranspiration in mm/day

Rs = Solar radiation in equivalent evaporation in mm/day

Rs = (a + b x (n / N)) x Ra

W = Weighting factor which depends on temperature and altitude (Table 4 FAO 24)

C = Adjustment factor which depends upon mean humidity and daytime wind conditions.

n/N = Ratio between actual measured bright sunshine hours and maximum possible sunshine hours.

n = Actual measured bright sunshine hours

N = Maximum possible sunshine hours (Table 3 FAO-24)

Ra = Amount of radiation received at the top of the atmosphere (Table 2 FAO-24)

The values of 'a' and 'b' may be taken as 0.25 and 0.50 for practical purposes. The values of 'a' and 'b' can be calculated by a regression off mean monthly values of R against n/N or otherwise the values can be taken from the table for the region under consideration.

The ETo values can also be obtained from relation

$$ETo = b \times W \times Rs - 0.3 \quad \text{mm/day}$$

The values of 'b' as a function of RHmean and mean day-time wind can be obtained from Table given in FAO-24.

(5) **Penman method**

The Penman method first introduced in 1948 and later simplified was the first of several combination equations derived from a combination of energy balance and a mass transfer aerodynamic term.

Compared to other methods Penman relationship is likely to provide most satisfactory results as it is based on physics or combining the vertical radiation budget with terbulent boundary flow over the land surface. Based on studies of the climatic and measured grass evapotranspiration data from various research stations in the world, Doorenbos and Pruitt proposed a modified Penman's method for estimating reference crop evapotranspiration and gave tables to facilitate the necessary computations. The prediction equations and its terms are defined as under.

$$ETo = C \{ \underbrace{W.Rn}_{\text{Radiation term}} + \underbrace{(1-W) \times f(u)\ (ea-ed)}_{\text{Aerodynamic term}} \}$$

Where

ETo = Reference crop evapotranspiration in mm per day

W = Temperature and elevation related weighing factor

Rn = Net radiation in equivalent evaporation in mm/day

= Rns-Rnl

Rns = Net incoming short-wave solar radiation

Rnl = Difference between outgoing and incoming longwave radiation.

$Rns = (1 - \alpha)\ Rs$

$Rs = Ra\ (0.25 + .50\ n/N)$

α = Reflection coefficient = .25 for most of the crops

Rnl = f (T, ed, n / N)

f(T) = σ Tk'

f(ed) = 0.34 - 0.044 $\sqrt{ed}$

f(n/N) = 0.1 + 0.9 n/N

f(u) = Wind related function = 0.27 (1 + U / 100)

U = 24 hr. wind run in km/day at 2 m height

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

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

Meaning of ETo,Rs,T,n/N are as in 3.3.1 and 3.3.2

(6) Pan Evaporation Method

The relationship of evapotranspiration to pan evaporation has been used in the computation of irrigation requirements. Many research stations are now reporting consumptive use data by relating evapotranspiration to pan evaporation. This relationship is available for some crops from many diverse parts of the world such as Israel, Phillippines, United States and India.

Evaporation pans provide a measurement of the integrated effect of radiation, wind, temperature,and humidity on evaporation from a specific open water surface. The plants also responds to the same climatic variables. Several major factors such as reflection of solar radiation, storage of heat, water loss differece from pans and crops, heat transfer through pans etc. produce significant difference in loss of water. Doorenbos and Pruitt (1977) relate pan evaporation to ETo using empirically derived coefficient (Kp) which take into account the climate, pan environment and crop type.

ETo = Kp * Epan

Where

Epan = Pan evaporation in mm/day and represents the mean daily value of the period considered.

Kp = Pan coefficient which take into account climate and pan environment, values are given in Table 18 and 19 (FAO-24)

The Kp 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 is placed in agricultural area.

In selecting the appropriate value of Kp to relate class A pan data to ETo, it is necessary to consider the ground cover of the pan station itself, that of the surrounding and general wind and humidity data. Wind is reflected as total 24-hour wind run in km/day.

(7) Thornthwaite Method

Thornthwaite (1948) assumed that an exponential relationship existed between mean monthly temperature and mean consumptive use. He corrected mean monthly air temperature with evapotranspiration as determined by water balance studies with adequate soil moisture. An empirical equation was obtained for estimating potential evapotranspiration. The relationship was largely based on experience in the Central Eastern United

States. No allowance was made for different crops or other land use. The formula was originally developed for the purpose of rational classification of broad climatic patterns of the world. Suitable coefficient should, therefore, be developed locally for reliable estimation of crop evapotranspiration values. The Thornthwaite equation would not give accurate estimation in arid and semi-srid areas.

$$e = 16 \left(10\ t/I \right)^{a}$$

e = Unadjusted potential evapotranspiration mm/month

t = Mean monthly air temperature in degree centigrade

I = Annual or seasonal heat Index

=the summation of 12 values of monthly heat indices (i)

i = monthly heat index which is = $(t/5)^{1.514}$

a = an empirical exponent

$$= (6.75 \times 10^{-7} \times I^3) - (7.71 \times 10^{-5} \times I^2) + (1.792 \times 10^{-2} \times I) + 0.49239$$

The unadjusted values of 'e' are corrected for actual daylight hours and days in a month. The correction factors are given in Table 3.1.

Table 3.1

Correction Factors for Thornthwaite Method

LAT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
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
25	0.93	0.89	1.03	1.06	1.15	1.14	1.17	1.12	1.02	0.99	0.91	0.91
26	0.92	0.88	1.03	1.06	1.15	1.15	1.17	1.12	1.02	0.99	0.91	0.91
27	0.92	0.88	1.03	1.07	1.16	1.15	1.18	1.13	1.02	0.99	0.90	0.90
28	0.91	0.88	1.03	1.07	1.16	1.16	1.18	1.13	1.02	0.98	0.90	0.90

The Thornthwaite formula gives a resonable estimate of ETo in the temperate, continental climate of North America, where the formula was originally derived, because there the temperature and radiation are correlated.

(8) Hargreaves Method

Hargreaves (1956) proposed a formula to estimate evaporation and evapotranspiration by using class A pan as a climatic index and basis for estimating evapotranspiration.

$$Et = K * Ev$$

where

Et = Evapotranspiration in mm

K = Crop factor which depends on the crop growth and month

Ev = Class A Pan evaporation

$= 17.4 * D * Tc \ (1.0 - Hn)$

D = monthly day time coefficient, which is the ratio of the mean day length for the month to 12 hours times the ratio of number of days in the month to a mean value (365 / 12)

Tc = mean monthly temperature in °C

Hn = mean monthly relative humidity at noon expressed decimally

This formula could be improved by modifying the humidity factor (1 - Hn) and incorporating factors for wind, sunshine and elevation. The modified equation can then be written as

$$Ev = 17.4 * D * Tc * Fh * Fw * Fs * Fe$$

Where

$Fh = 0.59 - 0.55 * Hn^2$

$Fw = 0.75 + 0.125 * Wkh^{0.5}$

$Fs = 0.478 + 0.58 * S$

$Fe = 0.95 + .0001 * E$

Wkh = mean wind velocity in km/hr at a height of 2 meters

S = Sunshine percentage, expressed decimally.

E = elevation in meters.

Hargreaves (1975) developed a simple empirical method requiring only temperature and radiation data for estimation of ETo for Alta Fescue grass used as the reference crop and climatic data from Davis, California. Hargreaves work is based on data from grass Lysimeter.This equation has been extensively used in Latin America. The equation is

$ETo = 0.0075 * Rs * T$

ETo = Potential Evapotranspiration in mm/day

Rs = Incident or Global radiation in mm/day

T = Mean temperature for the period in degree °F

Or

$Etp = 1.2 \times 0.0135(T+17.78)Rs$

Where

ETp and Rs are in langleys/day and T in degree centigrade

Hargreaves and Samani (1985) evaluated the equation with several world wide lysimeter experiments and found that the equation closely predicts measured evapotranspiration. The equation has been used to provide monthly estimate for many of the developing countries and for some regions for 5, 10, and 15 days intervals. A primary limitation of the use of the above equation is the lack of accurate and reliable measurements of solar radiation. Hence, Hargreaves have developed useful equation for estimating solar radiation from other parameters.

For locations for which mean maximum and minimum temperatures are available, Rs can be estimated from the equation :

$$Rs = Kt * Ra * TD^{0.5}$$

Where,

TD = Difference between mean maximum and mean minimum temperatures

Ra = Extra terrestrial radiation mm/day, from FAO-24

In the above equation, Kt is a coefficient that require local calibration. For most continental climates, Kt for °C is usually within the range of 0.15 to 0.18. Values of Kt are generallylower near mountains when there is significant resultant night-time cooling and higher near the ocean due to the moderating effect of the large body of water.

Combining above two equations and calibrating using the Alta Fescus grass lysimeter ET from Davis, California and the available solar radiation data for India, Africa, Brazil and the United States, results in the equation :

$$ETo = (0.0023 * Ra) (T + 17.8) * TD^{0.5}$$

(9) Jensen Haise Method

Jensen and Haise used observations of consumptive use from the Western USA and developed a relationship for estimating potential evapotranspiration using solar radiation and mean temperature. The method is the result of about 3000 measurements of ET over 35 year period. The equation can be written as

$$ETp = Ct\ (T - Tx)\ Rs$$

Where

ETp = Potential evapotranspiration in mm/day

Ct = an air temperature coefficient which is constant for a given area

T = mean daily average temperature in °C

Tx = Intercept on the temperature axis, can be determined by calibration (plotting Et/Rs versus mean air temperature)

Rs = Incident solar radiation expressed as the equivalent depth of evaporation

When calibration data are not available, then for common farm crops the temperature coefficient, Ct, can be estimated using the general equation,

$$Ct = 1/(\ C1 + C2.Ch\ )$$

Where

$$C1 = 38 - \frac{[\ 2 \times Elevation\ (m)\ ]}{305}$$

$$C2 = 7.6 \text{ degree celcius}$$

$$Ch = 50\ mb\ /\ (\ e_2 - e_1\ )$$

$$Tx = -\ 2.5 - 0.14\ (e_2 - e_1) - Elevation\ (m)\ /\ 550$$

e_2 and e_1 are saturation vapour pressure in mb available for Tmax & Tmin during the month that had highest values.

This method has been used to calculate ETp on a day to day basis, it should be considered as reliably representing values for longer time periods (5 to 7 days), when effects of fluctuations in wind and humidity levelare averaged out. This method performs reliably for semi-arid to arid conditions.

(10) Linacre Method

Linacre (1967) proposed a formula for estimating potential evapotranspiration which is

$$Etp = \frac{Rs\ [4.7\ Tc + 110\ (e_a - e_d)/Tc - 9.6\ (1 + 4\ S)]}{(\ 6\ Tc + 75\ )}$$

Where

Etp = Potential Evapotranspiration in mm/day

Rs = Incoming solar radiation in mm/day

e_a = Saturation vapour pressure at the average daily maximum temperature of month in millibars

e_d = Saturation vapour pressure at the temperature of dew point in millibars

(11) **Christiansen and Hargreaves Method**

Christiansen and Hargreaves (1969) developed three formulas for estimating potential evapotranspiration using data from Pruitt for rye grass from a 20 feet diameter weighing lysimeter.

Their first formula, using measured pan evaporation, Ev as a base was

$$Etp = 0.755\ Ev.Ct.Cw.Ch.Cs$$

Where,

Ev = measured class A pan evaporation

$Ct = 0.862 + 0.179\ (\ Tc\ /\ Tco\ ) - 0.041\ (\ Tc\ /\ Tco\ )^2$

Tc = mean temperature in °C and Tco = 20 °C

$Cw = 1.189 - 0.24 (W / Wo) + 0.051 (W / Wo)^2$

W = mean wind velocity at 2 m above the ground level in km/day and Wo = 6.7 km/day

$Ch = 0.499 + 0.62 (Hm / Hmo) - 0.119 (Hm / Hmo)^2$

Hm = mean relative humidity, expressed decimally and Hmo =0.6

The second formula, using extraterrestrial radiation, Rt, as a base was

$$Etp = 0.324\ Rt \cdot Ctt \cdot Cwt \cdot Cht \cdot Cst \cdot Ce$$

Where

$Ctt = 0.468 + 0.425 (Tc / Tco) + 0.112 (Tc / Tco)^2$

$Cwt = 0.672 + 0.406 (W / Wo) - 0.078 (W / Wo)^2$

$Cht = 1.035 + 0.24 (Hm / Hmo) - 0.275 (Hm / Hmo)^2$

$Cst = 0.34 + 0.856 (S / So) - 0.196 (S / So)^2$

S = mean sunshine hour in percentage, expressed decimally and So = 0.8

$Ce = 0.97 + 0.3 (E / Eo)$

Tc, Tco, W, Wo, Hm and Hmo are the same as defined above.

The third formula using measured incoming radiation, Rs, as a base was

$$Etp = 0.492\ Rs \cdot Ctt \cdot Cwt \cdot Cht$$

Where Ctt, Cwt and Cht are the same as defined above.

(12) Papadakis Formula

Papadakis (1961) computed potential evapotranspiration for more than 2400 stations by using his equation which can be written as

$$E = 5.625 (e_{ma} - e_d)$$

Where

E = Monthly potential evapotranspiration (mm);

e_{ma} = Saturation vapour pressure of average daily maximum temperature of the month in millibars;

e_d = Average vapour pressure for the month in millibars

The advantages of the formula are its simplicity and its requiring only readily available routine meteorological data.

(13) **Hamon's formula**

Hamon (1961) gave the formula

$$E = 0.055 D^2 . Pt$$

Where

E = Average potential evapotranspiration (in/day)

D = Day length in units of 12 hours;

Pt = Saturation absolute humidity (g / m^3).

The formula requires only latitude, converted to day length, and mean temperature converted to saturation vapour density.

(14) **G.S.Benton and J.Dominatz** have suggested the equation for the estimation of reference crop evapotranspiration for an arbitrary time interval and region and is given as

$$Er = P + F + dn \quad (gm / cm^2)$$

Where

Er = evapotranspiration

P = precipitation

F = net outflow of atmospheric water vapour (outflow-inflow)

dn = change in precipitable water content of the atmosphere

The Hedke equation (1930) is based on a method by which the evapotranspiration, or water use, is estimated by summating for the growing season the values of available heat, expressed in degree-days above the germinating or minimum growing temperature. Considerable judgement is required in selecting the coefficient since only limited data are available. The equation is,

$$U = k * H$$

Where U = evapotranspiration for a given period in feet;

k = annual or seasonal consumptive use coefficient

H = accumulated degree-days above minimum growing temperature for growing season.

(15) David (1936) proposed equation based on saturation deficit as

$$ET = 0.5 (e_1 - e_2)$$

Where ET = evapotranspiration in mm/day

e_1 = saturation pressure in mb at mean air temperature

e_2 = saturation pressure in millibars.

(16) Alpat'ev (1954) developed similar equation based on saturation pressure as

$$ET = B * e_d$$

Where ET = evapotranspiration in mm/day

e_d = average daily vapour deficit in millibars

B = hydrometric coefficient = 0.56 for clover

(17) Halstead (1951) suggested

$$ET = c * d_L \, (Qmax - Qmin)$$

Where Qmax and Qmin are saturation absolute humidities corresponding to maximum and minimum temperatures.

d_L = fraction of annual daylight hours

c = 1 when ET is in millimeters per month.

(18) Makkink (1957) estimated ET in mm/day over 10 days periods for grass under the cool climatic conditions of the Netherlands as

$$ET = 0.61 \frac{\Delta}{\Delta + \gamma} \frac{Rs}{58.5} - 0.12$$

Where net radiation is Rn = 0.6 Rs . Hansen (1984) applied this equation to determine potential and agricultural evapotranspiration from agricultural crops in Denmark.

(19) Turc Method : Under general climatic conditions of Wesrern Europe, Turc (1961) computed ET in mm/day for 10 day periods as

$$ET = 0.013 \frac{T}{T + 15} (Rs + 50)$$

for relative humidity RH > 50 % and

$$ET = 0.013 \frac{T}{T + 15} (Rs + 50) \left(1 + \frac{50 - RH}{70} \right)$$

for relative humidity RH < 50 %

Where T = average temperature in degree Celcius

Rs = solar radiation in langleys per day.

3.5 LIMITATIONS OF AVAILABLE METHODS

3.5.1 Nearly all of these methods are empirical in form and depend upon the establishment of known correlations between evapotranspiration and one or more measured climatic variables such as evaporation, temperature, radiation, humidity, wind speed and percent of sunshine. The accuracy of estimates computed from these methods depends primarily on the ability of the equation being used to describe the physical laws governing the processing in an area different from the area of the calibration.

It is already discussed under introductory para 1.8 and 1.9 that the prediction methods often need to applied under climatic and agronomic conditions vary different from those under which they were originally developed. Table 1.1 shows large variations amongst the results of various methods. The choice of method must be based on the type of climatic data available and on the accuracy and limitations of each method. A comprehensive evaluation of common ETo equations was made by the technical committee on irrigation water requirements, ASCE (1974). They concluded that "no single adjusting methods using meteorological data is universally adequate under all climatic regimes especially for tropical areas and for high elevations, without some local or regional calibration. Observed evapotranspiration rates for a given crop and growth stage depends on climatic conditions. Water use rates observed at one location may not apply elsewhere.

3.5.2 Limitations of various methods are as under :

(a) The modified Penman method would offer the best results with possible error of plus or minus 10 % in summer, and upto 20 percent under low evaporative conditions. The principal limitations of penman approach is the lack of sufficient weather measurements in most localities. only a few climatological stations record the needed data. The absence of humidity data is often cited as a reason for not using combination equation. Hence the formula eventhough quite reliable have some practical limitations. Another fact to remember in use of the Penman equation is that the coefficients should be calibrated for the specific locations to better fit the relative importance of advaction and solar energy.

(b) The Pan method can be graded next with possible error of 15 percent, depending on the location of the pan.

(c) The radiation method in the extreme conditions involves a possible error of upto 20 percent in summer.

(d) The Blaney Criddle method should only be applied for periods of one month or longer. It has a serious limitation in representing consumptive use for shorter time periods than one month due to use of temperature as only variable. In humid, windy, mid latitude winter conditions an over and under prediction of upto 25 percent has been noted. Blaney and Criddle developed the formulae for arid western portion of the United States. According to Doorenbos and Pruitt, the Blaney Criddle formula is not suitable for use in

(i) equitorial regions where air temperature remains fairly constant but other weather parameter change .

(ii) small islands where air temperature is affected by the surrounding sea temperature showing little response to seasonal change in radiation.

(iii) high altitude where day time radiation is practically independent of night temperature.

(iv) climates with a high variability in sunshine hours during transition months.

(e) Jensen and Haise used observations from the western United States. Jensen-Haise equation can only be applied in well watered irrigated fields located in semi-arid and arid areas. There is some evidence that the elevation adjustments may be excessive and should be used with caution, particularly at higher elevations (1500 to 2000 m and more).

(f) The Thornthwaite formula gives a reasonable estimate of ETo in the temperate, continental climate of North America where the formula was originally developed. Thornthwaite equation would not be expected to give accurate estimates in arid and semi-arid areas. The limitations of the formula are (i) temperature alone is not a good indication for the energy available for evapotranspiration (ii) it does not consider the effectof warm and cool air on the temperature of a place.

(g) Hargreaves based his work on data from grass lysimeters. It has been used extensively in Latin America. Hargreaves method does not have any adjustments for site specific conditions of elevation or humidity.

3.6 NEED FOR RESEARCH

3.6.1 As reported, the available prediction methods are site specific and needs verification for local area. All methods of estimating evapotranspiration from climatic data involved empirical relationship to some extent. Even the combination equation, the penman method utilizes an empirical wind function, which account for many local conditions. Before calculating ET crop a review should be made of specific studies carried out on crop water requirements in the area and available measured climatic data. Meteorological and research stations should be visited and environment, types of instruments, observations and recording practices should be appraised to evaluate accuracy of available data. Data relevant to crop type, crop development stages and agricultural practices should be collected from available information for different prediction methods, it is clear that the methods are developed for various regions and shows large variation.

3.6.2 Above discussion emphasize a need for following research for Gujarat Region.

(i) Analysis of agro climatic data of selected stations of Gujarat, to evaluate the variation and distribution pattern of them throughout year and for various areas.

(ii) Determination of potential evapotranspiration by various predictions methods and comparision of methods over regions under consideration.

(iii) Comparision of evapotranspiration observed by lysimeters established in area under study with evapotranspiration calculated with empirical methods.

(iv) To develop relationship based on local principal climatic variables best suited for the region under consideration. The aim of developing such equation is to give a simple, one or two variable based regional equation.

(v) Verification of such developed equation with directly observed data and/or various estimation methods.