

# EVAPOTRANSPIRATION AND IRRIGATION WATER REQUIREMENTS EVALUATION OF CHINAROK AREA USING ASCE PENMAN- MONTEITH METHOD

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## ABSTRACT

The Koya Directorate of Irrigation (KDI) has a plan to develop the agriculture and launch new agricultural projects in Chinarak area in particular for forestry and orchards plantation. This development requires quantifying the amount of irrigation water and evapotranspiration for the vegetated area. In this paper, these requirements were investigated and evaluated. Chinarak is a rural area located in Kurdistan region north of Iraq. The (KDI) classified the area into three major vegetation types; turfgrass, orchards and forests. Based on the metrological records and plants physical properties, an evapotranspiration (ET) has to be evaluated at the drought summer season, where maximum value is expected. The ET was evaluated for the three vegetation covers by using Penman-Monteith equation which was standardized by the American Society of Civil Engineers and known as ASCE- Penman-Monteith equation which is the most reliable method in estimating ET. It was found that ET values evaluated by Penman-Monteith method showed good agreement with experimental results of ET of a published data. Irrigation water requirement in terms of depth and irrigation frequency were evaluated for the three sectors of vegetation based on soil moisture deficit. In addition, irrigation requirements were calculated in terms of volume and daily water demand. The capacity of ground storage reservoir (or storage pond) was recommended as 5400 m<sup>3</sup> to meet daily water demand. These findings provide a base for the design and operation of proposed irrigation systems in Chinarak.

Keywords: Evapotranspiration, ET, Irrigation, trickle irrigation, Penman- Monteith Method.

الخرجي

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حساب التبخر-النتح ومتطلبات مياه الري لمنطقة جناروك باستعمال طريقة ASCE- بنمان- مونتيث

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المستخلص

لدى مديرية ري كويه (KDI) خطة لتنمية الزراعة واطلاق مشاريع زراعية جديدة في منطقة جناروك وخاصة زراعة البساتين والغابات. ان هذه التنمية تتطلب حساب كمية مياه الري والاستهلاك النباتي للماء (التبخر-النتح) للمساحات الخضراء. في هذا البحث تم دراسة واحتساب هذه الكميات. تتميز منطقة جناروك بانها منطقة ريفية زراعية تقع في اقليم كردستان شمالي العراق. وصنفت (KDI) المنطقة الى ثلاث انواع رئيسية من الغطاء النباتي هي العشب الاخضر, البساتين, والغابات. بالاعتماد على معلومات الارصاد الجوية والخصائص الفيزيائية للنباتات تم احتساب التبخر-النتح (evapotranspiration or ET.) للمنطقة لفصل الصيف الجاف حيث اقصى قيمة متوقعة للاستهلاك. تم احتساب ET للاغطية النباتية الثلاثة باستعمال طريقة ASCE بنمان- مونتيث المقييسة من قبل الجمعية الامريكية للمهندسين المدنيين والمعروفة ب ASCE- Penman- Monteith Equation وهي الطريقة الاكثر وثوقا في تخمين ET. اظهرت قيم ET المحسوبة بطريقة ASCE- Penman- Monteith للاغطية النباتية الثلاثة توافق جيد مع نتائج مختبرية لقيم ET لنفس الاغطية في بحوث منشورة. تم احتساب متطلبات مياه الري بصيغة العمق للاغطية النباتية الثلاثة وكذلك تردد الري (فاصلة الري) على اساس العجز الرطوبي لتربة المنطقة. اضافة الى احتساب متطلبات الري بصيغة الحجم والطلب اليومي لمياه الري. توصي هذه الدراسة بان تكون سعة الخزان الارضي او بركة خزن المياه في منطقة جناروك بحدود 5400 م<sup>3</sup> لكي تلبى الطلب اليومي لمياه الري. ان نتائج هذه الدراسة تعتبر الاساس في تصميم وتشغيل مشروع الري المقترح في منطقة جناروك.

كلمات مفتاحية: التبخر- النتح, ET, الري, الري بالتنقيط, طريقة بنمان- مونتيث.

## INTRODUCTION

Water enters a plant through its roots then moves upward through the plant to the leaves. A very small amount of water taken up is used for plant growth, and the rest of water transpires out of the plant through stomatal pores. This process is called *transpiration*. Water can also be lost from the plant site directly by evaporation from plant leaves or soil surfaces (*i.e.*, the intercepted precipitation on the plant foliage). The water needs of a plant thus consist of transpiration and evaporation and are called *evapotranspiration*, *ET*, or *consumptive use*. ET is measured as a depth per unit time such as (in) or (mm) per day, per week, or per month. Knowledge of consumptive use helps in determining irrigation requirement at the farm. ET can be computed by one of the several methods available for the purpose. These methods range in sophistication from simple temperature correlation such as the Blaney-Criddle formula to equations (such as Penman's equation) which account for radiation energy and weather parameters. Most people in Kurdistan region now live in urban and suburban centers where concrete, steel, glass, asphalt, building, and cars prevail; vegetation directly influences these environments in a positive way. Actively growing vegetative surfaces reduce high summer ground surface temperatures due to transpirational cooling. Turfgrass and other landscape plants reduce discomforting glare and noise. Soil erosion, dust, and fire danger are reduced or eliminated on turfed surfaces. For this purpose, Koya Directorate of Irrigation (KDI) tends to create new green areas in Chinarok region. Chinarok is a rural area located to the east of Koya city in Kurdistan region North of Iraq. The source of irrigation water is Hizob stream which flows through a valley some kilometers to the east of Chinarok. The region is characterized as undulated area with steep slope at some locations. The (KDI) suggests the supply of irrigation water by pumping from Hizob stream and to be stored in Chinarok in ground storage reservoir or in storage pond. The aim is to determine the amount of irrigation water to be transferred by pumping from the stream.

## Chinarok area

Gross area of Chinarok has been estimated as 200 hectares. The classification of this area is decided by (KDI). The decision which was made is to make rural area forming about 25% (50 hectares) for residence, utilities, and water distribution facilities. The rest which is 75% (150 hectares) is of cultivable areas which have been divided into 80 hectares for orchards and 70 hectares for green areas consisting of 62 hectares for forests areas and 8 hectares for turfgrass (lawn grass). The orchards have to be planted with almond with few cherry and pomegranates, while green areas of forests have to be planted with pine trees of slash species where they are locally planted. Because the region is undulated, the (KDI) suggested the following methods of irrigation: the turfgrass area is to be irrigated by sprinkler, while orchards and forests areas by trickle method. The (KDI) was classified the soil of the region as a sandy loam soil. Chinarok is located at longitude 44°33' (44.55°), latitude 36°5' (36.08°) and altitude 610m. In this paper, an irrigation requirement is to be evaluated at the drought summer season. In the recent years maximum air temperature was recorded in August and the (KDI) provides metrological data for the region for 31 days of August with maximum and minimum temperatures recorded at daytime and nighttime respectively. An average values are considered for the month of August, average maximum temperature = 41.5 C°, average minimum temperature = 27.3 C°, average maximum humidity = 41.4%, average minimum humidity = 11.3%, average wind speed = 2.36 m/s, and rainfall = 0. The temperature, humidity, and wind speed were recorded at 5 m above the ground level in Koya metrological station, KDI, 2017 (13).

## Asce penman- monteith method

The American Society of Civil Engineers-Penman- Monteith equation (ASCE-PM) is based on the Penman- Monteith form of the Penman combination equation and is widely accepted as the best- performing method for estimating evapotranspiration (ET) from metrological data, Todorovic, (24). Jensen, Jensen et al. (11) compared 20 methods of computing ET for arid and humid locations. They found that the Penman-Monteith method

was the most accurate for either environment. Because of its reliability, the Penman-Monteith method is used when air temperature, relative humidity, wind speed, and solar radiation data are available or can be reliably estimated. The Penman-Monteith method has been recommended as the primary method for defining grass- reference  $ET_o$ , Allen et al., (3). The basic hypothesis of the Penman-Monteith approach is that transpiration of water through leaves is composed of three serial processes: the transport of water through the surface of the leaves against a surface or canopy resistance, molecular diffusion against a molecular boundary layer, and turbulent transport against an aerodynamic resistance between the layer in the immediate vicinity of the canopy surface and the planetary boundary layer. The ASCE-PM equation for estimating the crop evapotranspiration,  $ET_C$ , from vegetative surfaces where availability of water is not a limiting factor is given by

$$ET_C = \frac{1}{\rho_w \lambda} \left[ \frac{\Delta(R_n - G) + \rho_a c_p \frac{e_s - e_a}{r_a}}{\Delta + \gamma \left(1 + \frac{r_s}{r_a}\right)} \right] \quad (1)$$

Where  $\rho_w$  is the density of water;  $\lambda$  is the latent heat of vaporization of water;  $\Delta$  is the gradient of saturated vapor pressure versus temperature curve;  $R_n$  is the net radiation (solar plus long wave);  $G$  is the soil heat flux;  $\rho_a$  is the density of moist air;  $c_p$  is the specific heat of moist air ( $= 1.013 \text{ kJ}/(\text{kg } ^\circ\text{C})$ );  $e_s$  is the saturation vapor pressure;  $e_a$  is the ambient vapor pressure;  $r_a$  is the aerodynamic resistance to vapor and heat diffusion;  $\gamma$  is the psychrometric constant; and  $r_s$  is the bulk surface resistance. Equation “(1)” is dimensionally homogenous, and any constituent set of units can be used. It is important to keep in mind that Eq.(1) is applicable when the availability of water is not a limiting factor; hence, the evapotranspiration estimated using ASCE-PM equation depends on weather- related and crop parameters only, David, (8). Evapotranspiration of Chinarok area for the three types of vegetation: turfgrass, orchards, and forests at full canopy development stage will investigate carefully for the drought summer.

**Reference- crop evapotran-spiration in grass area:** Reference- crop

evapotranspiration  $ET$  is the rate of evapotranspiration from an area planted with a specific (reference) crop. Reference- crop evapotranspiration is used as a measure of evapotranspiration from a standard vegetated surface. Grass and alfalfa are by far the most commonly used reference crops in hydrologic practices. In this section  $ET$  for standard turfgrass in Chinarok area is evaluated at its maximum value where water is available and temperature is at its maximum. The methods used in estimating the parameters of Eq. (1) for turfgrass are described in the next sections.

#### **Aerodynamic resistance, $r_a$**

There are two principal resistances to evaporation from vegetation: the aerodynamic (controlling interception) and the stomatal (controlling transpiration). The aerodynamic roughness of the vegetation impacts on the role of turbulence and diffusion processes in evaporation. It commonly varies between 10 and  $100 \text{ s m}^{-1}$ , and depends solely on the physical properties of the vegetation cover. Vegetation height will clearly be important since the coefficient of turbulent exchange increases with a change in vegetation height from a short to the tall. The aerodynamic resistance,  $r_a$ , measures the resistance to vapor flow from air flowing over vegetated surfaces.  $r_a$  can be estimated using the relation, Pereira et al., (21):

$$r_a = \frac{\ln \left[ \frac{z_m - d}{z_{om}} \right] \ln \left[ \frac{z_h - d}{z_{oh}} \right]}{k^2 u_z} \quad (2)$$

Where  $z_m$  is the height of wind measurement,  $d$  is the zero-plane displacement height,  $z_h$  is the height of air temperature and humidity measurements,  $z_{om}$  is the roughness length governing momentum transfer,  $z_{oh}$  is the roughness length governing heat and vapor transfers,  $k$  is the von Karman constant, and  $u_z$  is the wind speed measured at height  $z_m$ . Typically for fully covered uniform crops,  $d$  and  $z_{om}$  are related to the crop height,  $h$ , by, Brutsaert, (5):

$$d = \frac{2}{3} h \quad \text{and} \quad z_{om} = 0.123h \quad (3)$$

Since the momentum transfer governs the heat and vapor transfer, the roughness height  $z_{oh}$  is assumed to be a function of  $z_{om}$ , where

$$z_{oh} = a z_{om} \quad (4)$$

For tall and partially covering crops  $a = 1$  and for fully covering crops  $a = 0.1$ , Monteith, (17). The standard grass has a height,  $h$ , of 12cm (0.12m). For the grass, assuming fully covering crop ( $a = 0.1$ ) and taking von Karman constant,  $k$ , as 0.41, David, (8). Average wind speed = 2.36 m/s at height 5 m. By substituting the given data into Eq. (3), Eq. (4), and Eq. (2) we get aerodynamic resistance of grass,  $r_a = 118$  s/m ( $1.37 \times 10^{-3}$  day/m).

#### Surface resistance, $r_s$

The surface resistance,  $r_s$ , describes the resistance to vapor flow through leaf stomatae, and sometimes referred to as the *canopy resistance*. The surface resistance varies as leaf stomatae open and close in response to various metrological conditions and is dependent on the particular plant species. Since stomata are primarily photosynthesis structures, they are extremely sensitive to changes in light intensity. Thus, in the majority of plants there is a diurnal pattern to stomatal movements; they open during the daytime (for photosynthesis) and closed at night when it is dark to avoid unnecessary water loss when photosynthesis would not be taking place. An acceptable approximation for estimating the surface resistance of dense full-cover vegetation is, Allen et al., (3).

$$r_s = \frac{rl}{LAI_{active}} \quad (5)$$

The *stomatal resistance* of a leaf ( $rl$ ), is a physiological resistance in (s/m) imposed by the vegetation itself and  $LAI_{active}$  is the active (sunlight) leaf-area index (dimensionless). On sunny days, the stomatal resistance on exposed leaves decreases rapidly at sunrise, remains at a minimum value all day if the water supply to the leaf is adequate and increases at sunset. The bulk stomatal resistance,  $rl$ , of a single well- illuminated leaf typically has a value in the order of 100 (s/m), and the *leaf area index*,  $LAI$ , is defined as the surface area of the leaves (upper side only) to the projection of the vegetation on the ground surface. The  $LAI$  for grass and alfalfa can be estimated using the following relation, Allen et al., (3):

$$LAI = 24h \quad (6)$$

Where  $h$  is the height of vegetation in meter. A general equation for estimating  $LAI_{active}$  is, Allen et al., (3):=

$$LAI_{active} = 0.5 LAI \quad (7)$$

For the standard turfgrass with 0.12 m height and stomatal resistance,  $rl = 100$  s/m. Equations (6), (7), and (5) give the surface resistance  $r_s = 70$  s/m ( $8.1 \times 10^{-4}$  day/m).

#### Slope of vapor pressure curve, $\Delta$

The slope of vapor-pressure versus temperature curve,  $\Delta$ , can be calculated directly from the air temperature using the relation, David, (8):

$$\Delta = \frac{4098 \left[ 0.6108 \exp \left( \frac{17.27 T}{T + 237.3} \right) \right]}{(T + 237.3)^2} \quad (8)$$

Where  $\Delta$  is in kPa/°C, and  $T$  is the temperature in °C, for daily evapotranspiration,  $ET$ , estimates,  $T$ , is taken as the daily average (34.4°C) of the avg. maximum (41.5°C) and avg. minimum (27.3°C) air temperatures, hence:

$$T = \frac{T_{max.} + T_{min.}}{2} = \frac{41.5 + 27.3}{2} = 34.4 \text{ } ^\circ\text{C}$$

Substituting into expression of  $\Delta$  yields

$$\Delta = 0.302 \text{ kPa/ } ^\circ\text{C}$$

#### The net radiation, $R_n$

The net radiation,  $R_n$ , is equal to the net solar (shortwave) radiation,  $S_n$ , plus the net long wave radiation,  $L_n$ , David, (8) hence;

$$R_n = S_n + L_n \quad (9)$$

A direct measurements of net radiation is not available in the area and is usually difficult to measure because net radiometers are hard to maintain and calibrate, as a consequence, the net radiation is often predicted using empirical equations. The net short wave radiation can be estimated using the equation, David, (8):

$$\begin{aligned} S_n &= (1 - \alpha) \left[ a_s \right. \\ &+ b_s \frac{n}{N} \left[ \frac{1440}{\pi} G_{sc} d_r (\omega_s \sin \phi \sin \delta \right. \\ &\left. \left. + \cos \phi \cos \delta \sin \omega_s) \right] \right] \quad (10) \end{aligned}$$

Where  $\alpha$  is the *albedo* or canopy reflection coefficient, defined as the fraction of shortwave radiation reflected at the surface. Typical *albedos* for various surfaces are given in table (1); the constants  $a_s$  and  $b_s$  are the fractions of extraterrestrial radiation reaching the earth on clear day, the values  $a_s = 0.25$  and  $b_s = 0.5$  are recommended; the solar constant,  $G_{sc}$  is equal to 0.082 MJ/ (m<sup>2</sup>.min);  $d_r$  is the relative distance between the earth and the sun given by the equation, David, (8):

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi}{365} J\right) \quad (11)$$

The Julian day,  $J$ , for mid-August is 227. The solar declination,  $\delta$ , is given by the equation:=

$$\delta = 0.4093 \sin\left(\frac{2\pi}{365} J - 1.405\right) \quad (12)$$

And the sunset- hour angle,  $\omega_s$ , is given by the equation

$$\omega_s = \cos^{-1} [-\tan \phi \tan \delta] \quad (13)$$

**Table 1. Typical Albedos, David, (8).**

Land cover	Albedo, $\alpha$
Open water	0.08
Tall forest	0.11- 0.16
Tall farm crops	0.15- 0.20
Cereal crops	0.20- 0.26
Short farm crops	0.20- 0.26
Grass and pasture	0.20- 0.26
Bare soil	0.10 (wet) - 0.35 (dry)

Using the radian mode in Equations (11), (12), (13) with Julian day = 227, gives  $d_r = 0.976$  and  $\delta = 0.244$  radians. The latitude of the area  $\phi = 36.08^\circ$  (0.63 radians) and substituting in Eq. (13), gives  $\omega_s = 1.753$  radians. The sunshine fraction  $n/N$  (percent of daytime hours) at the mid- August = 0.563, since daytime hours from sun rise (at 5:30 Am) to sunset (7:00 Pm) equals 13.5 hours. From table (1) using *albedo* for grass  $\alpha = 0.23$  and substituting the given and derived values of  $\alpha$ ,  $a_s$ ,  $b_s$ ,  $n/N$ ,  $G_{cs}$ ,  $d_r$ ,  $\omega_s$ ,  $\phi$ , and  $\delta$  into Eq. (10) yields  $S_n = 15.33 \text{ MJ}/(\text{m}^2 \cdot \text{day})$ .

#### Long Wave Radiation, $L_n$

The net long wave radiation,  $L_n$ , is given by the equation, David, (8):

$$\begin{aligned} = L_n = & -\sigma \left( \frac{T_{\max,k}^4 + T_{\min,k}^4}{2} \right) \quad (0.34 \\ & - 0.14 \sqrt{e_a} \left( 1.35 \frac{R_s}{R_{so}} \right. \\ & \left. - 0.35 \right) \quad (14) \end{aligned}$$

=Where  $L_n$  is in  $\text{MJ m}^{-2} \text{ d}^{-1}$ ,  $\sigma$  is the Stefan-Boltzmann constant ( $= 4.903 \times 10^{-9}$ ),  $T_{\max,k}$  and  $T_{\min,k}$  are the maximum and minimum daily temperatures in Kelvin given as 314.7 k ( $=41.5^\circ\text{C}$ ) and 300.5 k ( $=27.3^\circ\text{C}$ ) respectively, average temperature is  $34.4^\circ\text{C}$ ,  $e_a$ , is the actual vapor pressure related to the temperature and humidity by the equation:

$$e_a = \frac{e_s(T_{\max}) \frac{RH_{\max}}{100} + e_s(T_{\min}) \frac{RH_{\min}}{100}}{2} \quad (15)$$

$$e_s(T_{\max}) = 0.6108 \left[ \exp\left(\frac{17.27 T_{\max}}{T_{\max} + 237.3}\right) \right] = 7.98 \text{ kPa} \quad (16)$$

$$e_s(T_{\min}) = 0.6108 \left[ \exp\left(\frac{17.27 T_{\min}}{T_{\min} + 237.3}\right) \right] = 3.63 \text{ kPa} \quad (17)$$

$$e_s(T) = 0.6108 \left[ \exp\left(\frac{17.27 T}{T + 237.3}\right) \right]$$

Substituting the given and derived values of  $e_s$ ,  $RH$ , and  $T$  in ( $^\circ\text{C}$ ) into expression of Eq. (15) yields  $e_a = 1.86 \text{ kPa}$ . The incoming shortwave radiation,  $R_s$ , can be estimated by the relation:

$$R_s = \left( a_s + b_s \frac{n}{N} \right) S_o \quad (19)$$

Where  $S_o$  is the extraterrestrial radiation, substitute the known values of  $a_s$ ,  $b_s$ , and  $n/N$  into relation above gives  $R_s = 0.53 S_o$ , and the clear sky solar radiation,  $R_{so}$ , can be estimated by the equation:

$$R_{so} = [0.75 + 2 \times 10^{-5} z] S_o \quad (20)$$

The altitude of the land surface  $z = 610\text{m}$ , gives  $R_{so} = 0.76 S_o$ , the relative solar radiation,  $R_s/R_{so}$ , indicates the relative cloudiness. Substituting the known values of  $\sigma$ ,  $T_{\max,k}$ ,  $T_{\min,k}$ ,  $e_a$ ,  $R_s$ , and  $R_{so}$  into Eq. (14), yields  $L_n = -3.88 \text{ MJ}/\text{m}^2 \cdot \text{day}$ , the negative value indicates that the net long wave radiation in August is away from the earth. The total available energy,  $R_n$ , in turfgrass area in August is then equal to the sum of  $S_n$  and  $L_n$  and is given by Eq. (9) as:

$$\begin{aligned} R_n = S_n + L_n & = 15.33 - 3.88 \\ & = 11.45 \frac{\text{MJ}}{\text{m}^2 \cdot \text{day}} \end{aligned}$$

#### Soil heat flux, $G$

The soil heat flux,  $G$ , (in  $\text{MJ}/\text{m}^2 \cdot \text{d}$ ) is the energy utilized in heating the soil, and is positive when the soil is warming and negative when the soil is cooling. Averaged value of  $G$  over one day is typically small, but becomes more significant for hourly or monthly time periods. For daily time interval beneath a dense cover of grass surface it can be assumed  $G_{\text{day}} = 0$ , David, (8).

#### Psychrometric constant, $\gamma$

The psychrometric constant,  $\gamma$ , depends on the atmospheric pressure,  $P$ , and the latent heat of vaporization,  $\lambda$ , and is defined as, David, (8):

$$\gamma = 0.0016286 \frac{P}{\lambda} \left( \text{kPa}/^\circ\text{C} \right) \quad (21)$$

The standard atmospheric pressure,  $P$ , is 101.32 kPa. Since latent heat,  $\lambda$ , varies only slightly over normal temperature ranges, a constant value of 2.45 MJ/kg is commonly assumed. Thus the constant  $\gamma$ , will be 0.0674 kPa/°C, David, (8).

#### Air density, $\rho_a$

The density of air,  $\rho_a$ , can vary with atmospheric pressure and air temperature as in equation, David, (8):

$$\rho_a = 3.45 \frac{P}{T + 273} \quad (22)$$

Using standard atmospheric pressure and averaged air temperature in August (34.4°C), yields  $\rho_a = 1.14 \text{ kg/m}^3$ . Taking water density,  $\rho_w$ , as 998.2 kg/m<sup>3</sup>; the latent heat of vaporization,  $\lambda$ , as 2.45 MJ/kg; the specific heat of moist air,  $c_p$ , as  $1.013 \times 10^{-3} \text{ MJ/kg}^\circ\text{C}$ ; and substituting the known and derived values into Penman-Monteith equation (1) yields turfgrass (as standard) evapotranspiration,  $ET_o = 6.5 \times 10^{-3} \text{ m/day}$  (= 6.5 mm/day).

#### Evapotranspiration in orchards and forests area

Crop evapotranspiration,  $ET_c$ , can be derived directly from meteorological and crop data using the Penman-Monteith equation given by Eq. (1) and it can be used to estimate,  $ET$ , for any vegetative surface, David, (8). However, this approach is seldom taken because of the difficulty in estimating such crop parameters as albedo,  $\alpha$ , aerodynamic resistance,  $r_a$ , and surface resistance,  $r_s$ , where these parameters are different from those of reference crops (grass). The more common approach is a crop-coefficient method in which is to first calculate a reference evapotranspiration,  $ET_o$ , assuming either standard grass or alfalfa cover, and then multiply  $ET_o$  by a crop-specific coefficient,  $k_c$ , to estimate the actual crop evapotranspiration,  $ET_c$ , under standard conditions where no limitations are placed on crop growth or evapotranspiration due to water shortage, crop density, etc. Only in recent years, the Penman-Monteith equation has gained a renewed interest to predict crop evapotranspiration in a one-step approach, which could better represent crop water loss than the traditional approach, Isabel et al., (10). In this paper, the evapotranspiration of trees area has to evaluate directly by Penman-Monteith equation and the parameters of Eq. (1) need to be investigated

and determined for orchards and forests trees for the conditions of Chinarok area. Surface resistance,  $r_s$ , is the resistance to vapor flow through leaves stomatae, and is sometimes referred to as canopy resistance,  $r_c$ . It varies as a leaf stomatae opens and closes. Generally the surface resistance of trees is greater than those of shorter vegetation, since trees tend to have stomatal control, while shorter vegetation does not, Olmsted, (19). On the other hand, the aerodynamic resistance,  $r_a$ , for trees is an order of magnitude less than for grass, because trees are not only taller but also present a relatively rougher surface to the wind and so are more efficient in generating the force eddy convection which in most meteorological conditions is the dominant mechanism of vertical water vapor transport, Calder, (6). The main problem lies in the difficulty of obtaining some measurement of the trees vegetation factors, especially  $r_s$  and  $r_a$  which is a complex function of many climatological and plant biological factors. This was admitted by Kelliher, Kelliher et al., (15) when they studied a stomatal control at a plant leaf. He found a maximum stomatal conductance,  $g_{max}$  (the inverse of stomatal resistance  $r_l$ ) for main types of vegetation covers, for deciduous trees  $g_{max} = 4.6 \text{ mm/s}$  and for conifers  $g_{max} = 5.7 \text{ mm/s}$  as it is mentioned by Ward (Ward and Robinson, 2000). Thereafter a stomatal resistance  $r_l$ , is calculated as ( $r_l = 1/ g_{max}$ ) which represent the minimum resistance. For orchards trees (deciduous), stomatal resistance  $r_l$  is  $21.74 \times 10^{-2} \text{ s/mm}$  (= 217.4 s/m) and for pine trees (conifers),  $r_l$  is  $17.54 \times 10^{-2} \text{ s/mm}$  (= 175.4 s/m), then the surface resistance  $r_s$  for trees is evaluated by Eq. (5). Leaf area index LAI for almonds and pine trees have to be investigated carefully. Many researches were conducted to estimate LAI for trees because it is a key parameter for estimating plantation and forests productivity. Jose and his colleagues, Jose et al., (12). were evaluated LAI in almonds orchards by using hemispherical photography technique also called the fisheye photography, the LAI was obtained in mid-season of almonds orchards and ranging from 1.8 to 2.6 m<sup>2</sup>/ m<sup>2</sup>, the mean value of 2.2 m<sup>2</sup>/ m<sup>2</sup> can be adopted to determine  $r_s$ , so Eq. (5) gives  $r_s$  for orchards trees  $\approx 198 \text{ s/m}$  ( $2.3 \times 10^{-3} \text{ day/m}$ ). Carlos and

his colleagues were performed an analysis using loblolly and slash pine LAI data for long-term experiment. Mean annual LAI for slash pine was found as  $2.5 \text{ m}^2/\text{m}^2$ , Carlos et al., (7) and by Eq. (5),  $r_s$  for pine trees  $\approx 140 \text{ s/m}$  ( $1.62 \times 10^{-3} \text{ day/m}$ ). In 1995, Monteith, Monteith, (18) reached a relationship between  $r_s$  and  $r_a$  in trees vegetation and pine forests. He found out the ratio  $r_s/r_a$  was of the order of 10, whereby, this approximation is of most significance in reducing the problem in estimating  $r_a$  when  $r_s$  is known. Using Monteith's ratio ( $r_a = r_s/10$ ),  $r_a$  for almonds trees can be estimated as  $2.3 \times 10^{-4} \text{ day/m}$  and  $r_a$  for pine trees is  $1.62 \times 10^{-4} \text{ day/m}$ . The albedo or canopy reflection coefficient,  $\alpha$ , for forests and crops are given in table (1), and average values can be considered, for forests = 0.14 and for orchards (tall crops) = 0.18, then short wave radiation,  $S_n$  and net radiation,  $R_n$

for forests and orchards are evaluated by Eq. (10) and Eq.(9) respectively. Other parameters of ASCE P-M equation;  $L_n$ ,  $\Delta$ ,  $\rho_a$ ,  $\rho_w$ ,  $\lambda$ ,  $\gamma$ , and  $c_p$  remain constant as those for turfgrass, thereafter evapotranspiration  $ET_c$ , for orchards and forests area are evaluated by Eq. (1). A summary of parameters calculations and results are given in table (2) for the three types of vegetation; turfgrass, orchards, and forests. The results of ASCE-PM equation refer to the average daily evapotranspiration,  $ET$ , based on the averaged maximum weather conditions in summer during August and at maximum leaf conductance (at minimum stomatal resistance).  $ET$ , for turfgrass area is 6.5 mm/d, for orchards area is 8.5 mm/d, and for forests area is 11.5 mm/d. It is clear that  $ET$  for orchards and forests areas is more than that of turfgrass,

**Table 2. Summary of Parameters Evaluation and Results of P-M Equation**

ASCE P-M parameters	Turfgrass	Orchards	Forests
$r_s$ (day/m)	$8.1 \times 10^{-4}$	$2.3 \times 10^{-3}$	$1.62 \times 10^{-3}$
$r_a$ (day/m)	$1.37 \times 10^{-3}$	$2.3 \times 10^{-4}$	$1.62 \times 10^{-4}$
$\Delta$ (kPa/ C°)	0.302	0.302	0.302
$S_n$ (MJ/ m <sup>2</sup> .day)	15.33	16.33	17.12
$L_n$ (MJ/ m <sup>2</sup> .day)	- 3.88	- 3.88	- 3.88
$R_n$ (MJ/ m <sup>2</sup> .day)	11.45	12.45	13.24
$G_{day}$ (MJ/ m <sup>2</sup> .day)	0	0	0
$\gamma$ (kPa/ C°)	0.0674	0.0674	0.0674
$\rho_a$ (kg/ m <sup>3</sup> )	1.14	1.14	1.14
$\rho_w$ (kg/ m <sup>3</sup> )	998.2	998.2	998.2
$\lambda$ (MJ/ kg)	2.45	2.45	2.45
$C_p$ (MJ/ kg C°)	$1.013 \times 10^{-3}$	$1.013 \times 10^{-3}$	$1.013 \times 10^{-3}$
$ET$ ( m/ day)	$6.5 \times 10^{-3}$	$8.5 \times 10^{-3}$	$11.5 \times 10^{-3}$
$ET$ (mm/ day)	6.5	8.5	11.5

this is because of aerodynamic resistance for trees (tall plants) being much less than that for grass (short plants) also because of rough surface of trees (*less albedo*,  $\alpha$ ) in which the net solar energy absorbed by trees ( $R_n = 13.24 \text{ MJ/ m}^2 \cdot \text{day}$ ) is greater compared with that absorbed by grass vegetation ( $R_n = 11.45 \text{ MJ/ m}^2 \cdot \text{day}$ ).

#### Validation of the results

Evapotranspiration have been established for most commonly used warm and cool season turfgrass species in United States. In California, both cool and warm season species are grown in major populated area of the state and  $ET$  for warm season turfgrass has been measured by crop- coefficient approach and

was given in the range 0.24- 0.28 in/ day (6.1- 7.1 mm/day), Ali et al., (2). In California, the almond board of California had measured and recorded  $ET$  for almond trees also by crop-coefficient approach and maximum value of 9.61 in/ month (7.9 mm/d) was recorded in July and 8.59 in/ month (7 mm/d) was recorded in August, Larry, (16). Pine trees  $ET$  has been explored for the slash pine species by the trees planted in a weighted lysimeter in Florida State. The results of the lysimeter study showed that seasonal averages were weighted by the lengths of periods and came to 2.4 mm/day for the autumn months (October, November, December), 1.2 mm/day for the winter months (January, February, March),

and 5.7 mm/day for the spring months (April, May, June) when air temperatures had reached 25°C. Unfortunately equipment failures due to high humidity and lightning storm damage prevented reliable measurement of *ET* for the summer, Riekerk, (22). It is expected that *ET* for the summer months is double of that in spring months (double of 5.7 mm/d). The calculated values of *ET* by P-M equation for the three vegetation covers shown in table 2 showed a good convergence with the measured published data of *ET* for the same covers.

### Net irrigation requirement and irrigation scheduling

Irrigation water requirement refers to the depth of water required to meet evapotranspiration requirement. In other terms, it is the depth of water required to bring soil moisture in root zone of the plant from permanent wilting point to the field capacity. Field capacity ( $F_C$ ) is the moisture content retained in the soil after excess water being removed by drainage. Permanent wilting point ( $PWP$ ) is the lower limit of moisture in the soil at which plant cannot extract water essential for its growth. The amount of moisture content between field capacity and wilting point is termed as available moisture ( $AW$ ). Available Moisture content of soil can also be represented as equivalent depth of water ( $d$ ) or depth of irrigation, Israelsen et al., (9) and is given as:

$$d = \frac{\Delta P_w}{100} \times A_s \times D \quad (23)$$

Where  $\Delta P_w$  is the difference in moisture content (by weight) between field capacity and wetting point ( $F_C - PWP$ ) also called as soil moisture deficit,  $A_s$  is the apparent specific gravity of soil,  $d$ , is a net depth of irrigation, and  $D$ , is the effective root zone depth of plant. Soil moisture near wilting point is not readily available moisture to the plant, Hence, the term readily available moisture has been used to refer to that portion of moisture that is most easily extracted by plants. The suggested depletion of available soil water is 75 percent of the total available moisture, also known as moisture depletion percent,  $P_D$ , Israelsen et al., (9) and net depth of irrigation in Eq. (23) can be modified to:

$$NDI = \frac{\Delta P_w}{100} \times A_s \times D \times P_D \quad (24)$$

It should be noted that, because of the capacity of soil to store water, it is not necessary to apply water to the soil every day even though the evapotranspiration takes place continuously. Soil moisture can vary between the field capacity and the permanent wilting point. The average moisture content will thus depend on the frequency of irrigation and quantity of water applied. Thus frequency of irrigation (irrigation interval) is calculated by dividing the amount of soil moisture which may be depleted within the root-zone soil by the rate of evapotranspiration, Asawa, (4) irrigation frequency is:

$$I.F = \frac{NDI(mm)}{ET(mm/day)} \quad (25)$$

Where,  $I.F$ , is the irrigation frequency (time period) between two successive irrigations in day. In field irrigation practices, the total depth of water applied to the cropped field should include water lost during water application and other factors contribute to large losses of irrigation water which, in turn, reduce irrigation efficiency. Thus gross irrigation requirement is equal to net irrigation requirement plus losses. The gross depth of irrigation,  $GDI$ , is thus expressed in terms of water application efficiency,  $E_a$ , as:

$$E_a = \frac{NDI}{GDI} \quad \text{or} \quad GDI = \frac{NDI}{E_a} \quad (26)$$

Trickle irrigation systems typically apply small amount of water on a frequent basis, maintaining soil water near field capacity, but usually not the entire soil surface is wetted, the system is applying water to each individual plant using one or more emission points per plant, thus in trickle method some modifications are required in the design. The modifications require determining wet area, wetted pattern, and water movement in the soil. In trickle system, typically trees are planted in rows where each trickle lateral pipe irrigates one row of trees. In this paper spacing between trees is denoted as ( $S_p \times S_r$ ) where,  $S_p$ , is spacing between trees and,  $S_r$ , is spacing between rows (or between lateral trickle lines). The (KDI) decided ( $S_p \times S_r$ ) for orchards trees as (4×4 m), and for forests trees by (6×6 m). Hence each one tree would occupy area of ( $S_p \times S_r$ ) m<sup>2</sup>. Figures 1 and 2 show layout and spacing between trees irrigated by trickle system in orchards and forests area. In trickle



system, wetted area depends on soil texture and can be estimated from special tables. Table (3) gives typical diameters of wetted area with different soil texture. From table (3),  $S_w = 3$  m is to be more convenient with the sandy loam soil. Figs. 1 and 2 show the patterns of wetted area along

**Table 3. Diameter of Wetted Area in Trickle Irrigation, Sharil, (23)**

Soil texture	Wet area diameter $S_w$ (m)
Light Sandy Soil	2
Loam Soil	3
Heavy Clay Soil	4.8

the trickle line. It is clear that the radius of wetted area ( $S_w/2 = 1.5$  m) is less than the space ( $S_p/2$ ) between trees and so there is no possible overlap between circles of wetted areas and continuous wetted strip may not developed. Hence the percent of wetted area,  $P_w$ , per one tree can then be calculated, Ahmad and Hakqi, (1), as follow:

$$P_w = \frac{a_w}{S_p \times S_r} \times 100 \% \quad (27)$$

Where  $a_w$ , is the wetted area for tree, equal  $[\pi (S_w)^2 / 4]$  and  $S_w = 3$  m,  $a_w = 7$  m<sup>2</sup>, and ( $S_p \times S_r$ ) is actual area of tree, equal 16 m<sup>2</sup> for orchard tree and 36 m<sup>2</sup> for forest tree. The equation above gives  $P_w$  for orchards and forests as 44% and 20% respectively as they denoted in the plan drawing of figs. 1 and 2. Accordingly, net depth of irrigation in Eq. (24) can be modified for trickle system, Ahmad and Hakqi, (1) to:

$$NDI_{max} = \frac{\Delta P_w}{100} \times A_s \times D \times P_D \times P_w \quad (28)$$

Where  $NDI_{max}$  is the maximum net depth of irrigation in one irrigation cycle and  $P_w$  is the percent of wetted area. In trickle irrigation, water is applied directly to the root zone of plants without coverage of entire area of a field, so the evaporation from soil surface and crops leaves is too small, thus the main component of water consumption in trickle irrigation is transpiration. The daily transpiration rate in trickle system is based on daily  $ET$  and the percent of area shaded (covered) by plant leaves, Ahmad and Hakqi, (1) as given:

$$T_d = U_d [P_s + 0.15(1 - P_s)] \quad (29)$$

Where  $U_d$  (or  $ET$ ) is the daily evapotranspiration in (mm/d),  $P_s$  is the percent of shaded area;  $T_d$  is the daily transpiration in (mm/d). The maximum percent,  $P_s$ , for a mature orchard is usually about  $\pi/4$  ( $=0.785$ ), which is the ratio of a circle (tree canopy area) enclosed by a square area (area occupied tree), (Keller et al., 1990). Similarly irrigation frequency in trickle irrigation is restricted by the maximum limit as in the formula, Ahmad and Hakqi, (1):

$$I. F_{max} = \frac{NDI_{max}}{T_d} \quad (30)$$

And gross irrigation requirement is given as:

$$E_a = \frac{NDI_{max}}{GDI} \quad \text{or} \quad GDI = \frac{NDI_{max}}{E_a} \quad (31)$$

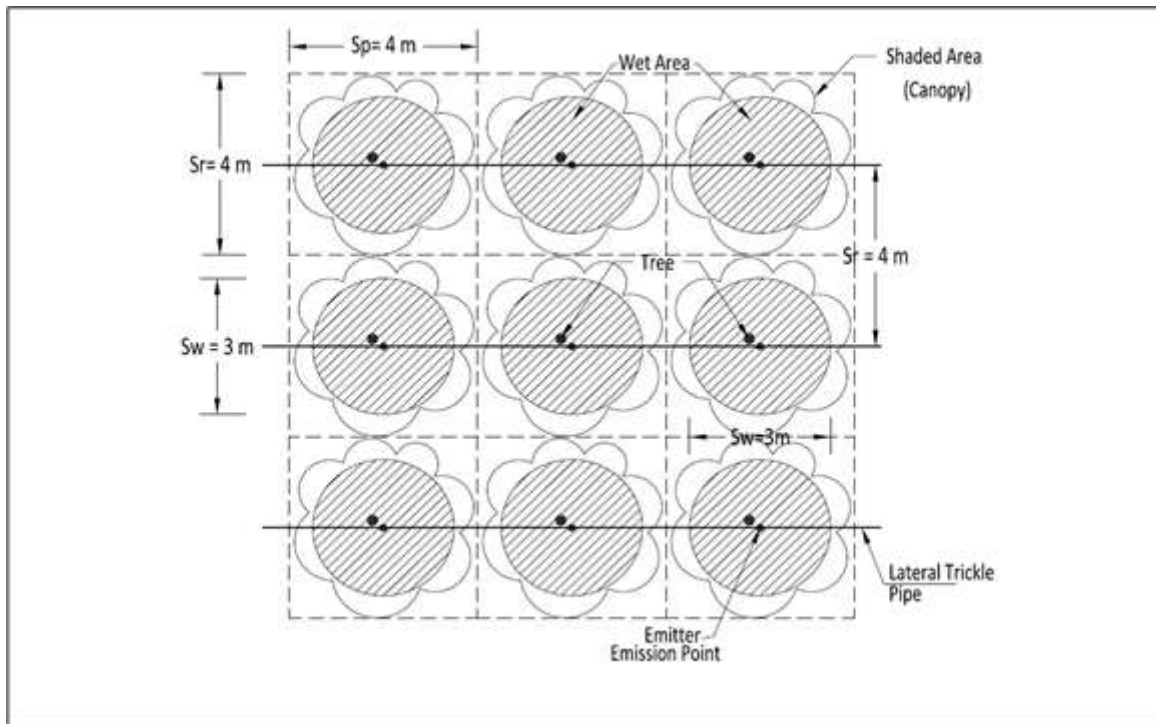


Figure 1. Orchard trees layout in trickle irrigation system with percent of wet area,  $P_W = 44\%$

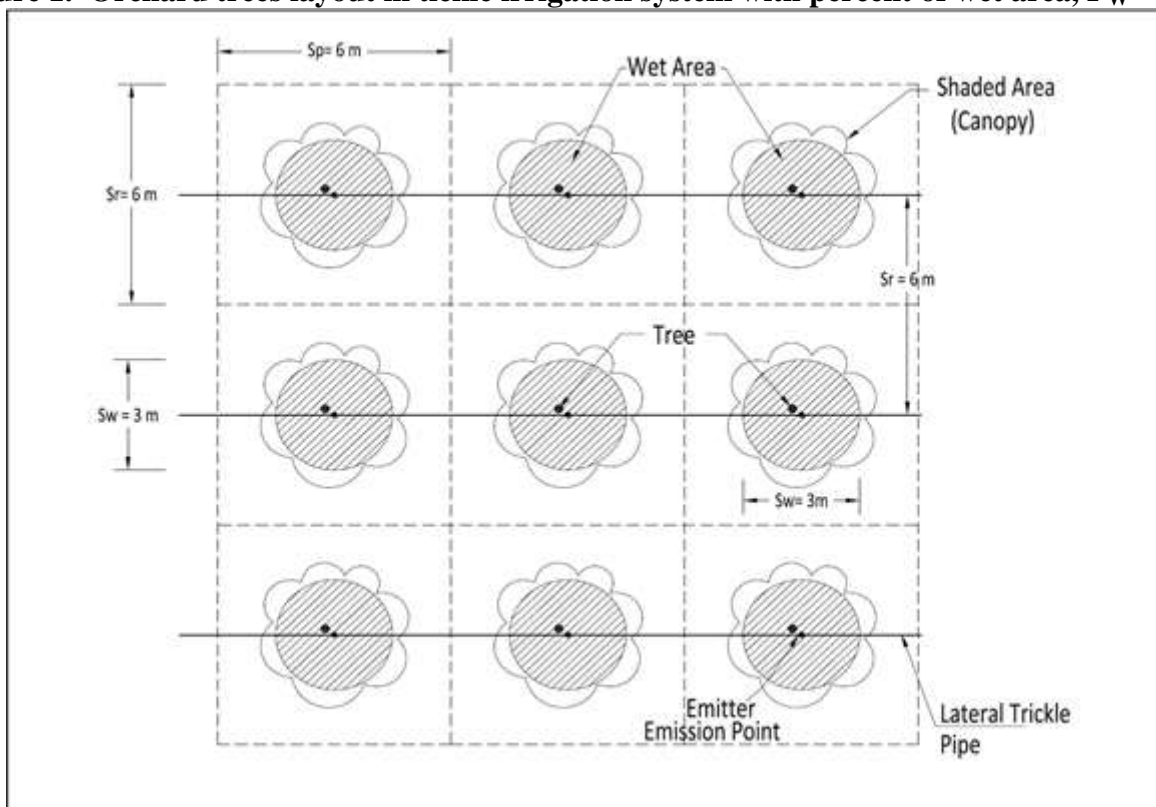


Figure 2. Forest trees layout in trickle irrigation system with percent of wet area,  $P_W = 20\%$

**RESULTS AND DISCUSSION**

Irrigation water requirement and irrigation scheduling for Chinarak area are evaluated by the procedure being described for the three sectors of vegetation; turfgrass, orchards and forests. Chinarak soil was classified as sandy loam soil and a physical properties of such soil are given as  $A_s = 1.5$ ,  $F_C = 14\%$ ,  $PWP = 6\%$ , Israelsen et al., (9). The percent of soil

moisture depletion,  $P_D$ , is recommended as 75%. According to (KDI) instructions, grass area is to be irrigated by Sprinkling and trees areas are to be irrigated by trickle system. In turfgrass area, the depth of root zone,  $D$  is around 15 cm, Ali et al., (2), net depth of irrigation is calculated by Eq.(24) as  $NDI = 1.35$  cm (13.5 mm), with grass  $ET = 6.5$  mm/d and Eq. (25) irrigation frequency is  $I.F = 2$

days. The recommended efficiency of water application in sprinkler system for moderate wind speed is approximately 75%, Ahmad and Hakqi, (1) and gross depth of irrigation for turfgrass is given by Eq.(26) as  $GDI = 1.8 \text{ cm}$ . Wetted area of turfgrass sector,  $A_w$ , equal to the whole area of turfgrass ( $A_1 = 80000 \text{ m}^2$ )

**Table 4. Irrigation Water Requirements and Irrigation Scheduling for Chinarok Area**

Vegetation Cover	ET mm/d	$T_d$ mm/d	NDI cm	I.F day	GDI cm	Wetted area $A_w$ m <sup>2</sup>	Volume m <sup>3</sup> /irrigation cycle
Turfgrass area	6.5	*	1.35	2	1.8	80000	1440
Orchards area	8.5	7	3.2	4.5	4	352000	14080
Forests area	11.5	9.4	2.9	3	3.6	124000	4470

Orchards are to be irrigated by trickle system with design percent of wetted area,  $P_w = 44\%$ . Net depth of irrigation in orchards is given by Eq. (28) as  $NDI_{max} = 3.2 \text{ cm}$  (32 mm). With orchard  $ET = 8.5 \text{ mm/d}$  and percent of shaded area,  $P_s = 0.785$ , Eq. (29) gives daily evapotranspiration in trickle irrigation  $T_d = 7 \text{ mm/d}$ . Maximum irrigation frequency is given by Eq. (30) as  $I.F = 4.5 \text{ days}$ . The most common efficiency of water application in trickle irrigation in undulated area with steep slope is 80 %, Ahmad and Hakqi, (1). Gross depth of irrigation is given by Eq. (31) as  $GDI = 4 \text{ cm}$ . Total wetted area in orchards,  $A_w$ , equal to the total orchard area multiplied by percent of wetted area ( $A_2 \times P_w$ ), where  $A_2$  is  $800000 \text{ m}^2$  then  $A_w = 352000 \text{ m}^2$ . In forests area, active root zone depth,  $D$  of tall trees is around 160 cm (USDA. 1999). Forests is to be irrigated by trickle as well, with the design percent of wetted area  $P_w = 20\%$ . Net depth of irrigation in trickle is given by Eq. (28) as  $NDI_{max} = 2.9 \text{ cm}$  (29 mm). With forests  $ET = 11.5 \text{ mm/d}$  and percent of shaded area,  $P_s = 0.785$ , Eq. (29) gives daily evapotranspiration in trickle irrigation as  $T_d = 9.4 \text{ mm/d}$ . Maximum irrigation frequency is given by Eq. (30) as  $I.F = 3 \text{ days}$ . For the efficiency of water application 80 %, gross depth of irrigation is given by Eq. (31) as  $GDI = 3.6 \text{ cm}$ . Total wetted area in forests,  $A_w$ , equal to the total forests area multiplied by percent of wetted area ( $A_3 \times P_w$ ), where  $A_3$  is  $620000 \text{ m}^2$  then  $A_w = 124000 \text{ m}^2$ . The results of calculations are summarized in table (4). The results refer to, NDI and GDI in orchards is much greater than that in forests. This is due to percent of wetted area, in orchards,  $P_w = 44\%$  while in forests,  $P_w = 20\%$ , but irrigation in

because it is irrigated by sprinkler. In almond orchards area, most root production (about 80%) occurred between 20 and 80 cm soil depth. The majority of active almond roots,  $D$  are present in the 80 cm depth, Patrick et al., (20).

forests sector is more frequent (3 days interval) than that of orchards. This means; apply small depth of water in forests with more frequent irrigations. The volume of irrigation water in one irrigation cycle for the three sectors is calculated by multiplying GDI by wetted area,  $A_w$ , and is given in table (4). For the land irrigation scheduling, it is necessary to find daily water demand. The volume of water needed in each irrigation cycle should provide during period equal I.F (number of days between irrigations). In other words, irrigation is needed when the available water that is present in root zone is depleted. In this manner the volume of water needed in one irrigation cycle is divided by I.F to obtain daily volume demand (m<sup>3</sup>/day). Thus using table (4), in turfgrass area, the daily water demand is (720 m<sup>3</sup>/d), in orchards area, is (3129 m<sup>3</sup>/d), and in forests area, is (1490 m<sup>3</sup>/d). The total daily demand is the sum of all which is equal to 5339 m<sup>3</sup>/d and this represents maximum daily demand during hot summer. The volume of ground storage reservoir (or storage pond) is then can be recommended as 5400 m<sup>3</sup> to meet averaged maximum daily water demand that is evaluated at the drought weather conditions of August. In addition, number of trees in orchards and forests area can be determined by dividing the total area by the space occupied by one tree ( $S_p \times S_r$ ). In orchards area, the number of trees is ( $800000 \div 16 = 50000$  trees) and in forests area is ( $620000 \div 36 = 17222$  trees).

The calculated values of ET by ASCE-PM equation for the three vegetation covers showed a good agreement with the published experimental results of ET, indicating that P-M equation is a reliable tool in evaluating crop

$ET_c$  in addition to reference  $ET_o$  when sufficient weather data and crop physical information are available. The maximum evapotranspiration, maximum irrigation water requirements in terms of depth, volume, and daily water demand are evaluated precisely for Chinarok region for the three vegetation covers. Findings of this study enable (KDI) to design and manage the proposed irrigation project of Chinarok. The management is to apply the correct amount of water at a correct time to optimize water uptake by the roots. Operating the project according to irrigation scheduling will help to reduce the amount of water lost by surface runoff and deep percolation below the root zone, making the project works at the desired efficiency. Because of water supply system of Chinarok is to be by pumping and storage, evaluation of daily water demand is the base in sizing and designing the pipeline and pumping station on Hezob stream.

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