IRRIGATION SCHEDULING OF PALM TREES IN THE UNITED ARAB EMIRATES

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ABSTRACT

A computer model is developed to determine irrigation needs of palm trees on the basis of fixed quantity at different times (calendars). The model is based on the computation of reference evapotranspiration, crop coefficient, water holding capacity of the soil, ground cover, effective contact volume of the root zone, leaching requirements, irrigation efficiency and daily soil water crop yield. It is developed for different tree ages and soil types. The model used has been shown to produce reliable estimate of soil water balance. The predictions are sensitive to the accuracy of the input data measured on the farm. The model is intended to improve water management practices by the farmers. Preliminary test showed that irrigation water could be decreased from 130m^3 to 74m^3 per year at Dhaid in the Central Region of UAE.

INTRODUCTION:

The objectives of irrigation management are well stated in Huygen et al., 1995: "Maximize net return... minimize irrigation cost...maximize yield...optimally distribute a limited water supply...minimize ground water pollution". To achieve these goals, it is necessary to schedule irrigation accordingly, in other words, when to irrigate and how much to irrigate. It is well known that over or under irrigation has a negative effect on quantitative and qualitative yield.

Timing and depth criteria for irrigation scheduling (Huygen et al., 1995) can be established by using several ways based on soil water measurements, soil water balance estimates and plant stress indicators, in combination with simple or complex models. These require knowledge on crop water requirements and yield responses to water, irrigation methods and equipments, and the limitation of water supply.

In the United Arab Emirates (UAE), 53.4% of the cultivated land are covered by palm trees. It consumes 63.2% of the irrigation water. Improper irrigation water management leads to some physiological disorders and/or diseases. Fruits quality can also be affected. Over irrigation will cause some diseases at Rutab stage. It has a major effect on nitrogen leaching from the root zone especially in sandy soils.

The objectives of this study are to adopt an appropriate irrigation scheduling method for palm in UAE could lead to increase in yield, significant water savings, reduce environmental impact of irrigation and improve sustainability of irrigated agriculture.

MEASUREMENTS AND CALCULATIONS

Soil moisture balance method for irrigation scheduling is used to accurately determine when and how much to irrigate. This method sums daily crop water requirements and subtracts this quantity from the water holding capacity in the effective root zone. When the water holding capacity drops down to a predetermined level, then it is time to apply water by refilling the effective root zone to the field capacity.

This method needs knowledge of daily water requirements, water holding capacity of the soil, effective root zone volume, management allowable depletion, times and amounts of precipitation.

1- Crop Water Requirements:

The effects of radiation, temperature, humidity, wind speed, available soil water, size of tree canopy and time during the year on water requirements are well stated by many authors. Fortunately, technologies have made the collection and the calculation of crop water requirements values available. The meteorology section of the water and soil department at the Ministry of Agriculture and Fisheries in the UAE is currently collecting weather data information in more than 24 locations.

Reference crop evapotraspiration (ETref) was estimated using modified Penman (Doorenbos and Pruitt, 1977, FAO) instead of Penman - Montieth equation (Allen et al., 1994). A comparison of ETref estimation by different methods indicated that Penman - Montieth equation under estimated ETref values by at least 25% for five different zones in the UAE. These variations may be caused by the choice of the constants values for the surface resistance in Penman Montieth equation.

Modified Penman Equation is:

$$ETref = C[W . Rn + (1-W) . f(u) . (es - ea)] \qquad (1)$$

Where:

ETref is reference crop evapotranspiration, mm

C is a correction factor

$$W = \Delta / (\gamma + \Delta) \qquad (2)$$

Δ is the slope of the saturation vapor pressure – air temperature, mbar/°C

γ is psychrometric constant mbar/°C

Rn is net radiation, mm/day

f(u) is a function of wind speed

es is saturated vapor pressure, mbar

ea is actual vapor pressure, mbar

Effective Rainfall:

As input of monthly rainfall, the average, dependable or actual rainfall data can be given. Careful consideration should be taken in selecting the appropriate values for dependable rainfall. To account for the losses due to surface runoff and deep percolation the effective rainfall was calculated using the USDA Soil Conservation Method (Allen et al., 1994) as follow:

$$Peff = Ptot\ (125 - 0.2Ptot) / 125 \quad \text{for } Ptot < 250mm \qquad (3)$$

$$Peff = 125 + 0.1\ Ptot \quad \text{for } Ptot > 250mm \qquad (4)$$

Where:

Peff is effective rainfall in mm.

Ptot is the monthly rainfall in mm

2- CROP

Crop Coefficient (KC):

Crop coefficient is mainly controlled by the crop characteristics namely the resistance to transpiration of different plants. To maintain good growth and high yields of good quality a regular water supply is needed throughout the year with a possible exception just prior and during harvest and at winter time. Water deficiencies during early April to late July have been shown to hasten ripening but reduce volume and quality of the fruits.

The crop coefficient was determined by the following equation (Hess, 1996)

$$KC = (KCb \cdot KS) + Ke \qquad (5)$$

Where:

KCb is the basal crop coefficient when the water is not a limiting factor for plant growth. KCb is set equal to 0.8 (Doorenbos and Pruitt, 1977).

KS is a soil water availability factor (0 - 1). KS is equal to 0.9 for the period from mid January to late March, 1.0 from late March to late July and 0.7 from late July to mid January for the most common varieties in UAE.

Ke is soil water evaporation coefficient. Ke was equal to 0.1 from experimental data measuring soil evaporation under the canopy at different locations.

For the period from mid January to late March KC is:

$$KC = (0.8 \times 0.9) + 0.1 = 0.82$$

For the period from late March to late July, KC is:

$$KC = (0.8 \times 1.0) + 0.1 = 0.9$$

For the period from late July to mid January, KC is:

$$KC = (0.8 \times 0.7) + 0.1 = 0.66$$

After mid July, the fruits reach the Rutab stage for the most common varieties. At this stage the water content of the fruits is maximum. During this stage the water content of the fruits will be decreased. Therefor, it is necessary to expose the tree to a mild stress. This is very important practice especially in the humid regions in order to have a good fruit quality.

Ground Cover:

The canopy of palm trees intercepts only a portion of the incoming solar radiation. The amount of the interception depends on the size of the canopy and varies with age of the palm tree.

A reduction factor, Kr, will be used to correct water requirement calculations. The reduction factor is calculated from the ground cover value (GC). It is defined as the fraction of the total surface area actually covered by the foliage of the trees when viewed directly from above. In order to calculate the GC, it is necessary to measure the ground cover by the leaves (LC). Large numbers of LC measurements were made for different varieties of palms at different ages. Figure (1) shows the relationship between the LC and palm tree age for the most common varieties in UAE. The LC varies from 0.6 to 3.0m for the age one to seven years. The statistical analysis indicated significant increases in the LC from the first to sixth year of the offshoot planting. After the sixth year no significant increases in the LC value were recorded.

Logistic function was used to express the relationship between LC and palm tree age as follow:

$$LC = \frac{LCm}{1 + b\ e^{cA}} \qquad (6)$$

Where:

LC is ground cover by the leaves (the distance from the stem to the end of the shaded area), m

LCm is the maximum ground cover by leaves at maturity, m. It is equal to 3.1m for the most common varieties in UAE.

b and c are statistical parameters and equal to 19.3 and -1.112, respectively.

A is the age of palm trees, year.

The correlation coefficient (r) was 0.99

The ground cover is calculated by dividing the actual surface area covered by the foliage on the total ground area according to the spacing between trees.

The reduction factor (Kr) is estimated using Killer and Karmeli (1974) equation as follow:

$$Kr = GC/ 0.85 \qquad (7)$$

Effective Root Zone Volume (Contact Volume):

The effective crop rooting zone volume refers to the volume of the soil at which roots extract 80% of the water utilized by the tree. Though the actual rooting volume is greater, the effective rooting volume should be used in irrigation scheduling. It is well known that the root growth is genetically controlled but environmentally modified. Root zone volume varies with palm tree age, physical properties of the soil and irrigation method. Root depth and distribution patterns for palm trees from planting the offshoot to maturity have been determined by the excavation method at different

Locations in UAE for different varieties. Figures (2 & 3) show the effective vertical and horizontal root distributions at different ages of palm trees. The statistical analysis indicated significant increases in both vertical and horizontal root distributions from planting the offshoot to the seventh year. No significant increases in root distribution after the seventh year. It should be stated that the soils varied from sandy to loamy sand. The hardpan was at least 2.3m from the soil surface. The irrigation system was bubbler. The irrigated area around the tree varied in diameter from 1.0 to 4.5m according to the age of the tree.

Logistic function is used to express the relationships between the effective root distributions and palm tree age as follow:

$$RLv = \frac{RLvm}{1 + b\, ec^{cA}} \qquad (8)$$

Where

RLv is the effective vertical root length, m

RLvm is the maximum effective vertical root length, m. It is equal to 1.3m.

b and c are statistical parameters and equal to 9.5 and -0.79, respectively.

A is the age of the palm tree, year.

The correlation coefficient (r) was 0.966.

For the horizontal root distribution the equation is:

$$RLh = \frac{RLhm}{1 + b\, e^{cA}} \qquad (9)$$

Where:

RLh is the effective horizontal root distribution from the stem, m.

RLhm is the maximum effective horizontal root distribution from the stem, m.

b and c are statistical parameters and equal to 15.1 and -0.89, respectively.

The correlation coefficient (r) was 0.963.

Equations 8 & 9 made it possible to determine the volume of the effective root zone in order to calculate the exact amount of the water application without any over irrigation.

3- FIELD

Water Holding Capacity:

The water holding capacity (WHC) of the soil is defined as the amount of soil water content held between the field capacity (FC) and the wilting point (WP). It is determined as follow:

$$WHC = (FC - WP) \,.\, Pd \,.\, 10 \,.\, 1.0m \qquad (10)$$

WHC = mm/1.0m depth of soil or liter/ m^3 of soil

Where:

FC is the water content at field capacity on weight basis, %
WP is the water content at the wilting point on weight basis, %
Pd is the bulk density of soil, g/ cm^3

The percentage of WHC that can be used by the crop without loss of yield or quality will vary with stage of crop development and ETref. The maximum fraction of WHC that a crop can extract without loss of yield or quality is called Management Allowable Depletion (MAD). It should be considered when calculating the net water requirements (NWR). For palm trees, the MAD is set equal to 0.5 at flowering, pollination and fruits formation to Rutab stage. This Period is from mid

January to late July. During the rest of the year, MAD is equal to 0.65. For young palm trees, it is necessary to keep water at optimum conditions throughout the year (MAD = 0.5).

The maximum amount of water uptake that the palm tree can absorb from the root zone without any decrease is calculated as follow:

$$EASW = WHC.\ ERV.\ MAD \qquad (11)$$

Where:

EASW is the easily available soil water, liter.

ERV is the effective root zone volume, m^3.

WHC is water holding capacity, liter/m^3

Actual Evapotranspiration (Eta):

Easily available soil water decreases as the palm tree uses water. The daily water use by palm tree is calculated as follow:

$$ETa = ETref\ .\ KC\ .\ Kr.\ Ar \qquad (12)$$

Where:

ETa is actual daily water use by the palm tree in liter.

Ar is the area specified for each tree, m^2.

The daily water use by the palm tree (ETa) is subtracted from EASW. When EASW reaches close to zero, irrigation will start again to refill the root zone back to field capacity. Attempting to store water beyond field capacity can increase the occurrence of leaching valuable plant nutrients below the root zone. The EASW is equal to the net amount of the applied water (NAW). To calculate the gross amount of the applied water (GAW), it is necessary to know the application efficiency (AF) of the irrigation system and leaching requirements (LR).

The application efficiency includes both distribution uniformity and uniformity coefficient. The leaching requirements are calculated using Hoffman and van Genuchten (1983) approach.

The GAW is calculated as follow:

$$GAW = (NAW / AF)(1 + LR) \quad \text{in liters} \qquad (13)$$

4- YIELD WATER RELATIONSHIP:

The manner in which water deficit affects crop growth and yield varies with crop species and growth period. In order to quantify this effect of water stress on yield, Doorenbos and Kassam (1979) equation was used. The equation is:

$$(1 - Ya/Ym) = ky\ (1 - ETa/ ETm) \qquad (14)$$

Where

Ya and Ym are actual and maximum harvested yield.

ETa and ETm are actual and maximum evapotranspiration.

ky is yield response factor.

In this program the soil water is at optimum conditions from mid January to late July. Hence, fruit yield is always maximum.

5- Testing the Model:

The model was tested for six months period. Soil water content was measured in both vertical and horizontal directions from the stem to cover the effective root zone. Reasonable agreement was obtained between measured and calculated data in the soil water balance system. The model needs to be test for longer time.

CONCLUSIONS:

Simple model was developed to calculate irrigation needs for palm trees. The model is reliable and intended to promote easy and ready adoption of improving water management practices by the farmers. The model gave a close estimation of the irrigation water needed by palm trees throughout the season that improve yield and quality. The calendar is simple and could be used by any person. Further information and help in using the calendar can be found at your local Ministry of Agriculture and Fisheries Cooperative Extension Office in your region.

Flowchart of the Program

- ETref
  - Station Identification
  - Input Data
    - Rs, T, U, RH, n, P
  - Calculate ETref
    - Pen77
    - Pen-Mon
  - Calculate effective Rainfall
    - USDA Equation
- Crop
  - Palm
  - Input Data
    - Spacing Between Trees
    - Age of the Tree
    - MAD
  - Calculate Crop Coefficient
  - Calculate Contact Volume of the Root
    - Horizontal Distribution of the Root
    - Vertical Distribution of the Root
  - Calculate Ground Cover
  - Calculate Reduction Factor
- Field
  - Input Data
    - FC, WP, Pd, LR, AF
  - Calculate Water Holding Capacity
  - Calculate Easily Available Soil Water
- Irrigation Scheduling
  - Calculate ETa
  - Calculate Yield Reduction
  - Calculate Irrigation Intervals
  - Calculate Gross Applied Water

EXAMPLE

Soil Moisture Balance Sheet for Checkbook Irrigation Scheduling

Field No: *10* Region: *Central*

Farmer Name: *MAF*

Date Palm Cultivar: *Mixed* Age of Trees: *7*

Effective Rooting Depth Volume m^3: *20* m^3

Water Holding Capacity of the Soil: *1400 liters/ 20*m^3

Reduction Factor: *0.55*

Water Quality:*1000 ppm*

Spacing Between Trees: *8m x 8m*

Irrigation System: Two Bubblers per Tree (Bubbler Emission is 360 liter/ hr)

Month	Day	Water Use Liter/Day	Rainfall	Net Irrigation Liter	Soil Moisture Liter
Jan.	1	70	0	0	1400
	2	70			1330
	3	70			1260
	4	70			1190
	5	70			1120
	6	70			1050
	7	70			980
	8	70			910
	9	70			840
	10	70			770
	11	70		700	1400

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Irrigation System: Two Bubblers per Tree (Bubbler Emission is 360 liter/ hr)

FARM 10 Region: Central

700 liters / Irrigation

MONTH	DAY
JAN	1, 11, 21, 31
FEB	7, 14, 21, 28
MARCH	5, 10, 15, 20, 25, 30
APRIL	3, 7, 11, 15, 19, 23, 27
MAY	1, 4, 7, 10, 13, 16, 19, 22, 25, 28, 31
JUNE	2, 5, 7, 10, 12, 15, 17, 20, 22, 25, 27, 30
JULY	2, 5, 7, 10, 12, 15, 17, 20, 22, 25, 27, 30
AUGUST	3, 7, 10, 14, 17, 20, 24, 27, 31
SEPT	4, 8, 12, 16, 20, 24, 28
OCT	3, 8, 13, 18, 23, 28
NOV	2, 9, 16, 23, 30
DEC	7, 14, 21, 28

NO. of Irrigation is 87

Net Irrigation $61m^3$ / season

Gross Irrigation $74m^3$

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Sheet1 Chart 1

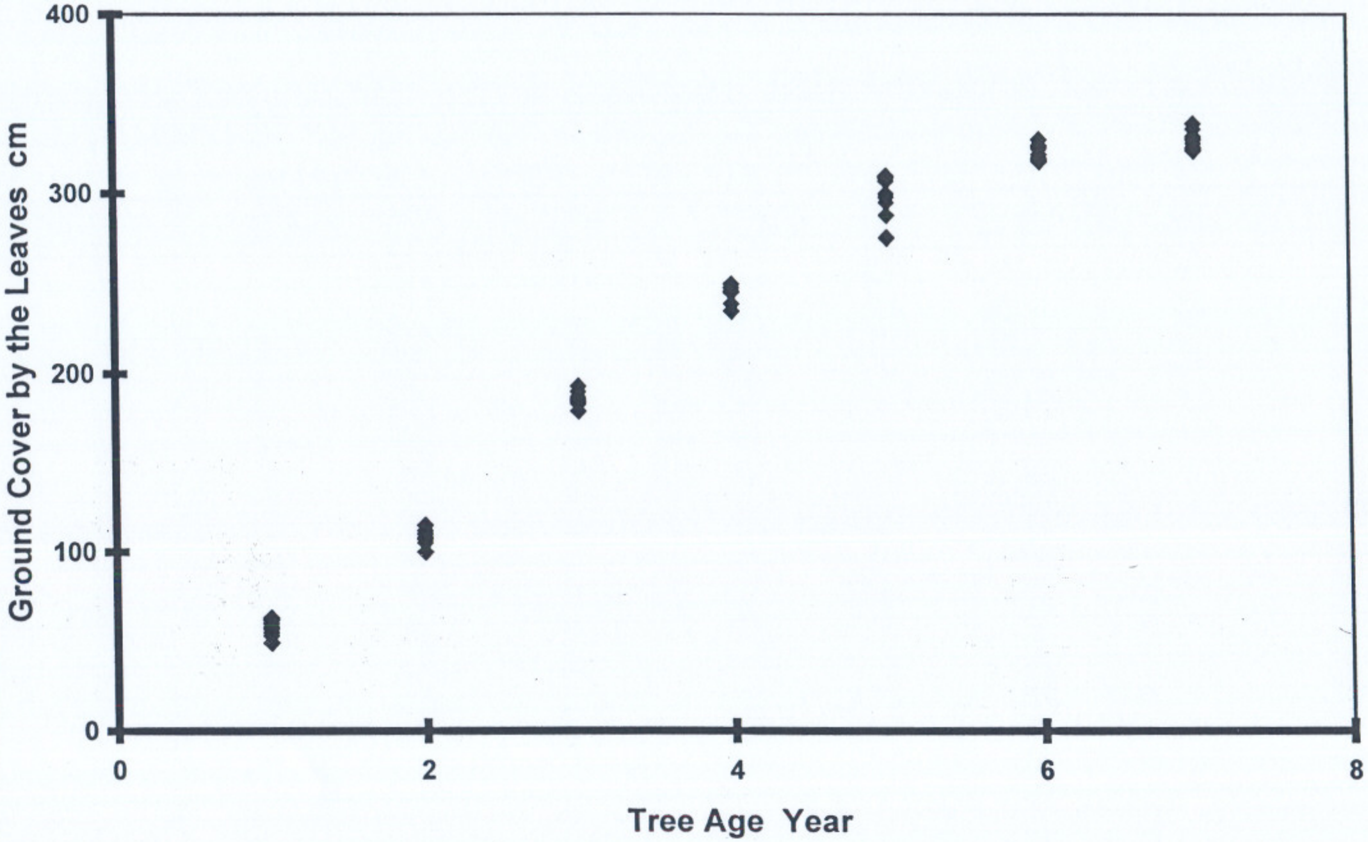

Fig. (1). Ground Cover by the Leaves at Different Ages of the Palm Tree

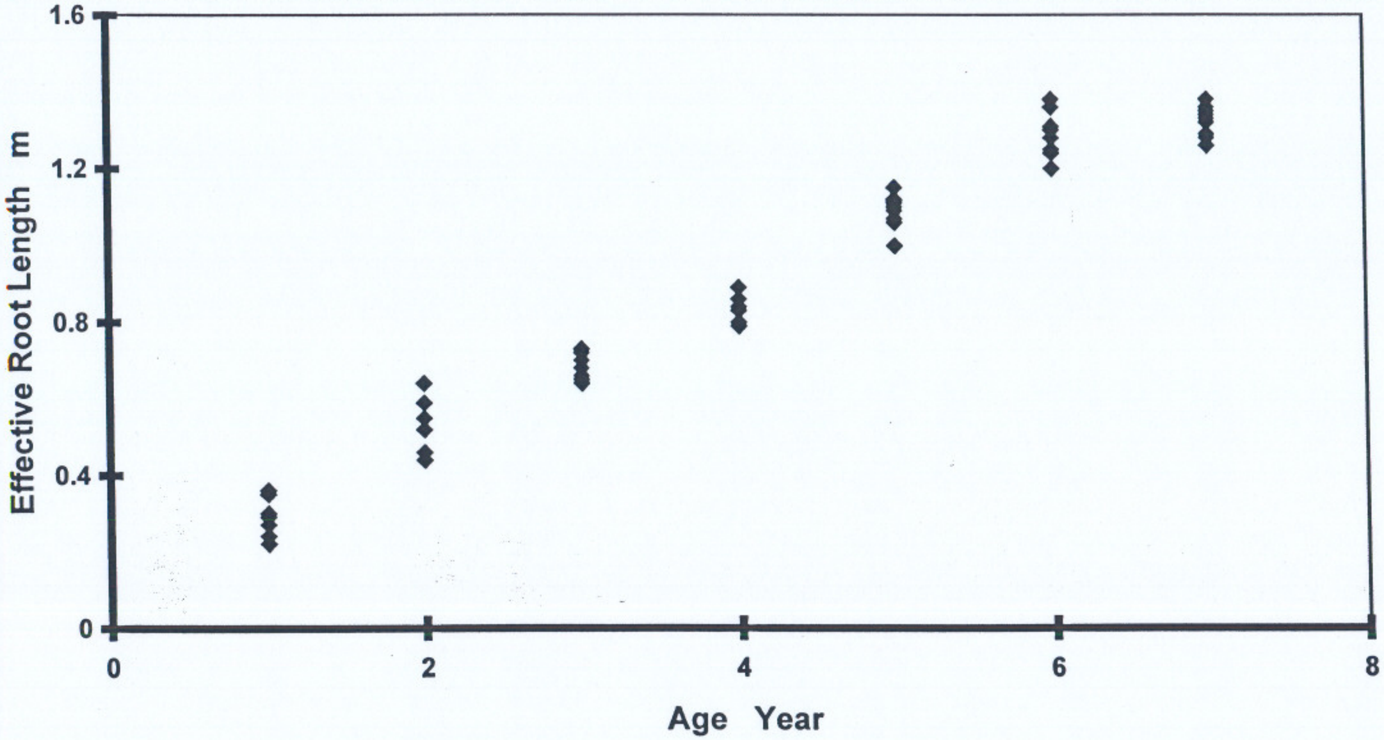

Fig. (2). Effective Vertical Root Length of Palm Tree at Different Ages

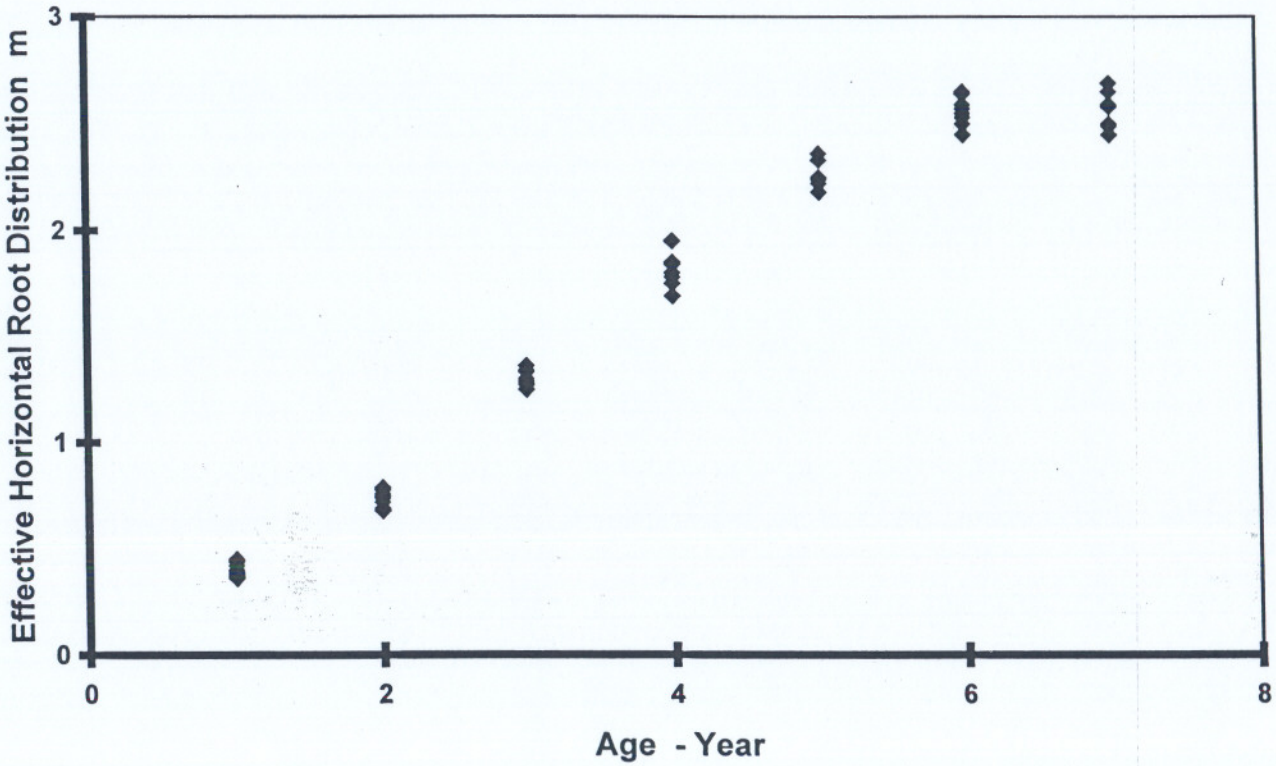

Fig. (3). Effective Horizontal Root Distribution from the Stem for Palm Tree at Different Ages