FERTIGATION TECHNIQUE MANAGEMENT BASED ON EXPERT SYSTEM

BY

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B.Sc. (Agricultural Mechanization), Faculty of Agriculture,
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Approval Sheet

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Contents

List of Symbols

A	Evaporating surface area, m^2
ASCE	American Society of Civil Enginers
ASMD	Alowable soil moisture depletion, %
AVHRR	Advanced very high resolution radiometer
AW	Available soil water content, %
AWDi	Allowable soil water depletion at day i, mm
awd	Min allowable soil water depletion, mm
Cd	Salt concentration of drainage water, kg. m^{-3}
Cf	Crop factor (for the horizontal root extension), %
Ci	Salt concentration of irrigation water, kg. m-3
Co	Level of soil salinity above which the yield is zero, dS m^{-1}
Cp	Specific heat capacity of air, cal cm-3. °K^{-1}
Ct	Threshold of soil salinity, dS. m^{-1}
CWSI	Crop water stress index
D	Semiempirical constant depends of climatology and the crop structure
d	Zero plane displacement (0.7 hc. m. where hc is the crop heigh)
DAP	Number of days after planting, days
dawd	Difference between awd at day i and at day i-1, mm
D_{cd}	Constant daily depth of irrigation water to be applied, mm day^{-1}
DDBM	Daily data based model for irrigation scheduling
D_{fi}	Depletion fraction of soil water at day i, %
Di	Irrigation water requirement, for salinity control, mm day-1
di	Depth of irrigation application, mm
dia	Actual plant water requirement, mm day-1
Dr	Volme of water drained below the root zone, m3
Ds	Drainage water salinity (soil salinita at the root zone), dS. m^{-1}
Ds1	Drainage water salinity for yield level = 95 %
D_{ti}	Irrigation water requirement for salinity control, L. day^{-1} .plant^{-1}
DTM	Number of days to maximum root depth, days
D_{wd}	Daily amount of water to be applied, liter day^{-1} plant^{-1}
E	Evaporation, mm day^{-1}
e_a	Measured vapor pressure, bar or KPa
EC	Electronic Conductivity, dS m^{-1}
EC_{ec}	Economic electronic conductivity in the root zone, dS. m^{-1}
Ed	Volume of water lost by evaporation, m^3

E_i	Irrigation application efficiency, %
ER	Energy balance residual, W. m^{-2}
Es	Volume of water evaporated from soil, m^3
es	Saturated vapor pressure at air temperature, bar or KPa
esd	Saturated vapor pressure at dew point temperature of air, mbar
ET	Evapotranspiration, mm. day^{-1} or MJ. m^{-2} .day^{-1}
ET_a	Actual evapotranspiration, mm. day^{-1}
ET_c	Crop evapotranspiration, mm. day^{-1}
ETo or ETr	Reference evapotranspiration, mm. day-1
fc	Soil field capacity, vol %
F (Ui)	Wind function, m. s^{-1}
G	Soil heat flux, MJ. m^{-2} .day^{-1}
h	Height above the sea level, m
H	Sensible heat flux, MJ.m^{-2} .day^{-1}
hc	Crop height, m
hp	Maximum crop height, m
i	Irrigation intervals, days
I s	Irrigation water salinity, dS. m^{-1}
K	Van karman constant (0.41)
Kc	Crop coefficient, %
Kcadj	Adjusted crop coefficient, %
Kcb	Basal crop coefficient, %
Kc dev	Crop coefficient of vegetation development stage, %
Kc end	Crop coefficient of vegetation end stage, %
Kc mid	Crop coefficient of vegetation mid-season stage, %
Ke	Soil water evaporation coefficient, %
Kp	Unsaturated permeability of the root zone, mm .day^{-1}
Ks	Water stress coefficient, %
LAI	Leaf area index
LE	Latent heat, cal .gram^{-1}
LEf	Latent heat flux, W. m^{-2}
ARC	Agricultural research center in cairo
ls	Loamy sand soil
n	Mean daily sunshine hours, hour
N	Mean daily max sunshine hours, hour
No	Number of trees (Plants) per hectare, plants
NOAA	National oceanic and atmospheric Administration

P	Allowable soil moisture depletion, %
Pc	Crop production, kg
pa	Air pressure, bar
PDi	ETo for the ith hour, mm.h^{-1}
PDi´	Daily reference evapotranspiration, mm. day^{-1}
pef	Effective Precipitation, mm. day^{-1}
Pi	Depth of water in effective root zone at day i, mm
ptot	Total precipitation, mm. day^{-1}
Qd	Daily volume of drainage water, m^{3} .day^{-1}
Qi	Irrigation water requirement of salinity control, m^{3} .day^{-1}
R	Volume of water lost by runoff, m^{3}
Ra	Daily extraterrestrial radiation, mm. day^{-1} or MJ. m^{-2} .day^{-1}
ra	Aerodynamic resistance, s .m^{-1}
RAW	Readily available soil water, %
rc	Canopy resistance, s .m^{-1}
rcp	Canopy resistance at ETp, s .m^{-1}
ri	Single leaf resistance to vapor transfer, s. m^{-1}
RH	Relative air humidity, %
RHmin.	Minimum relative air humidity, %
Rn	Net radiation, mm .day^{-1} or MJ .m^{-2}.day^{-1}
Rnd/ Rni	Mean annual of ratio between daily and mid-day value of Rn, MJ. m^{-2} .d^{-1}
rpl	Crop resistance for water flow, bar day .mm^{-1}
rs	Surface resistance, s. m^{-1}
Rs	Observed solar radiation, mm. day^{-1} or MJ .m^{-2} .day^{-1}
Rso	Clear day solar radiation, mm .day^{-1} or MJ .m^{-2} .day^{-1}
S	Percent yield decrease per unit of salinity above the threshold, %
Sa	Available soil water content, %
Sd	Salt leached from soil by rain or irrigation, dS. m^{-1}
Sfc	Soil water content at field capacity, %
Si	Addition of salt to the soil due to irrigation of saline water, dS. m^{-1}
So	Original salt content in the soil before irrigation, dS .m^{-1}
stl	Sandy clay loam soil
Su	Soil factor ~1/5 of soil hydraulic conductivity, cm .day^{-1}
Swp	Soil water content at wilting point, %
T4	Brightness temperature in channel 4 of AVHRR instrument, °C
T5	Brightness temperature in channel 5 of AVHRR instrument, °C

Ta or T	Air surface temperature, °C
TAW	Total available soil water content, %
Tc	Volume of water transpired by crop, m^3
DDBM	Daily data based model for irrigation scheduling
Tm	Mean minimum air temperature, °C
TM	Mean maximum air temperature, °C
Ts	Crop surface temperature, °C
Tw	Volume of water transpired by weeds, m^3
U2	Wind speed at 2 m height, $m .s^{-1}$
Uz	Wind speed at height Zm, $m .s^{-1}$
VC	Vegetation cover, %
W	Volume of applied water, m^3
Wp	Soil water content at permanent wilting point, vol %
Wra	Actual plant water requirement, $mm .day^{-1}$
Wras	Irrigation requirement for salinity control, $mm .day^{-1}$
WUEag	Agronomic efficiency of water use, $kg. m^{-3}$
Zm	Height of the wind measurement (2 m), m
Zr	Effective root depth, cm
Zri	Effective root depth at day i, cm
Zrm	Maximum root depth of the crop, cm
sin (rad)	Angle in radiant
Q fc	Soil moisture content at –33 KPa, %
Q wp	Soil moisture content at –1500 KPa, %
γ	Psychometric Constant

INTRODUCTION

1. INTRODUCTION

Fertigation is a technique of fertilizer application through the water of irrigation. With the use of modern water irrigation systems, such as drip and sprinkler systems, fertigation will be a promising technique. There are some advantages of fertigation which include easy application, use in adverse conditions, low hazards, conservation of proper soil structure, possible control of pests and weeds and decreasing the adverse effect of salinity. However, the disadvantages of this system include increases in capital expenditure, incidents of orifices clogging, salinity build-up and need for technical handling **(Charles, 2007).**

The agricultural sector in Egypt consumes more than about 81 percent from total available water and about 1.25 million tons of fertilizer annually **(FAO, 2005).** This problem forces the scientists to find out a new technique to overcome reasons of such problem. One of these techniques is using the fertigation system to increase the efficiency of both fertilization and irrigation.

The expert system (ES) is a computer program designed to simulate the problem simulating behavior of an expert in a narrow domain or discipline **(Rafea, 1998).** The advantages of ES programs are minimizing or avoiding errors in complex tasks, protecting the perishable knowledge of experts and making it available and where required, systematically considering all possible alternatives, displaying unbiased judgment, available for use unlike human experts and less expensive to consult than human experts **(Awady *et al*., 1997 Kabany, 2003 and Dent *et al*., 1989).**

The objective of this research is to design an expert system to provide farmers by the sound decisions on the management of irrigation and fertilization (fertigation). There are also some specific objectives of this study which can be summarized in the following:

1 - Improving the efficiency of fertilizer and water use.

2 - Finding out the best sources of nutrients, optimum rates of fertilization, optimum water requirement, suitable timing and proper of fertilizer placement.

REVIEW
OF
LITERATURE

2. REVIEW OF LITERATURE

2.1. Water Resources in Egypt and Associated Problems

Egypt has a desert climate and is dependent on the water of the Nile, which is Egypt's most important water source. At present, supplying the country with almost all of its water requirements for human, municipal, and agricultural use, i.e. 97 % of water needs and the development of additional water resources in the near future is not likely **(Anonymous, 1995; Seckler and Altaf, 1997).** Although the area under cultivation with wheat (which is a major food crop in all countries) was about 1,000,000 ha with production of about 6,200,000 t, Egypt imports about 50 % of the total local food consumption **(Rayan *et al.*, 1999).**

It is estimated that already, for the year 2000, the total water use approached 70 milliard. m^3 $year^{-1}$, which was more than the actual water availability **(FAO, 1997; Attia *et al.*, 1995).** "The study of the Water Master Plan revealed requirement of 73 milliard. m^3 year $^{-1}$ in the year 2000 in Egypt" **(Bishay, 1993).**

The irrigated area (95 % irrigated from the Nile) is 3,246,000 ha, with 93.8 % surface irrigation; 3.6 % sprinkler irrigation; and 2.6 % micro-irrigation). The total actual surface water resources are 55.5 milliard. m^3 representing Egypt’s annual share from the Nile water of which 47.4 milliard. m^3 $year^{-1}$ (i.e. 85.4 % of total water) is water withdrawal for agriculture therefrom 2 milliard. m^3 $year^{-1}$ are estimated loss due to evaporation from 31,000 km of canals **(FAO, 1997).** In addition, 0.2 milliard. m^3 $year^{-1}$ is reused treated wastewater and 4.7 milliard. m^3 $year^{-1}$ is reused agricultural drainage water. **Abu-Zeid (1990)** stated that “reused water will increase gradually to 7.0 milliard. by the year 2000 plus 2.3 milliard. m^3 $year^{-1}$ available ground water”.

According to criteria of water scarcity, Egypt was classified by **Seckler *et al*. (1998)** in a group of countries which will have to divert water from irrigation to supply their domestic and industrial needs and will need to import more food, and have no sufficient water resources to satisfy their requirements in 2025. Yet according to results obtained by **Salam and El-Shennawy (1999)** who examined the awareness of rural women to the water resources problem “the women were generally unaware of the national limitation on water availability”. The study used 10 groups involving 240 women in four Egyptian governorates.

“Many of the newly developed agricultural areas in Egypt (mainly sandy soils) where flood irrigation is used have problems with high water demand, high energy costs, intensive use of labour, spread of weeds under fruit trees, and stunted growth of fruit trees due to salinity” **(El-Kadi *et al*., 1997).** Most of the irrigation and drainage canals in the Western Delta of Egypt are affected and covered with floating weeds. These weeds greatly retard the velocity of flow and increase the seepage loss; subsequently they cause soil salinity and soil waterlogging.

According to the results obtained by **El-Noby *et al*. (1999)** “the occurrence of floating weeds is strongly related to the seepage loss”. In the Western Nile Delta, the high amounts of floating weeds in drainage canals (62,775 kg fresh weight) and in irrigation canals (203,400 kg fresh weight) resulted in an increased seepage loss (563,147 m^3 $year^{-1}$ for drainage canals and 546,170 m^3 $year^{-1}$ for irrigation canals).

2.2. Egypt's Efforts towards Overcoming Water Scarcity Problem

The water balance figures for Egypt as estimated in 2000 show that available water supply may in the near future not be sufficient to satisfy the demand. To overcome this critical situation, the main options must be taken into account are:

i) Developing new sources of water;

Blending saline water with fresh water for irrigation "enables improvement of the water quality, and has the potential to save significant quantities of good quality water to enlarge available water resources and increase the benefits of irrigation" **(Leskys *et al*., 1999).**

"Drainage water in the Nile Delta is collected in the drainage canals and is partly diverted to coastal lakes and the Mediterranean Sea. At 21 locations, government pump stations lift water from the drainage canals into irrigation canals where it is mixed with fresh Nile water and is reused for irrigation” **(Project Team, 1989).**

“The total quantity of generated drainage water amounts to about 70 % of the total supply of irrigation water to the crops in the Eastern Nile Delta, while the quantity of drainage water used in irrigated land amounts to 30 % of the quantity of supplied water to the crops” **(Willardson *et al.*, 1997).**There are some aquifers in the Nile Valley alluvial, which are recharged by percolation from the river Nile, the main sources of recharge for these aquifers being the Rosetta and Damietta branches of the Nile, the irrigation canals, and seepage from irrigated fields. Although during low flow conditions the aquifers feed water into the Nile branches, the major outlet of water from these Delta aquifers is seepage into the Mediterranean Sea.

According to **Hammad (1986)** estimates suggested that each year about 740 mills. Cubic meters flow unused from the aquifers into the Mediterranean Sea. ”Pumped wells scattered throughout the Nile Delta take water from these aquifers and reduce these losses effectively” **(Beaumont, 1993).**

However, there are concerns about environmental impacts of heavy metals resulting from drainwater reuse in irrigation **(El -Hawary *et al*., 1998; Helal *et al*., 1998; Grieve *et al*., 1999).** In Bahariya Oasis, Egypt "the ground water is contaminated with iron, manganese, lead, nickel and zinc which exceed the recommended critical limits of these elements in irrigation water where the data showed that use of such groundwater in irrigation increases the heavy metals content in the soil surface" **(Shahin *et al*., 1996).**

ii) Increasing water use efficiency and reducing water losses;

Aziz *et al*. (1995) reported that "improving the water use efficiency of Egypt's irrigation system offers the best solution to its problem of how to increase food production". Therefore, enhancement of the water use efficiency become a necessity nowadays.

It is important that water losses due to percolation or evaporation from the distribution net should be restricted. "The use of pipe-lines instead of open canals to deliver water to irrigation systems was investigated as a means of ensuring more efficient use of water resources" **(Hussien *et al*., 1997).** Egypt is lining canals and local water courses (mesqas) to improve water delivery efficiency. Several kinds of canal linings have successfully been used. "The channels lining is extensively used in the newly developed area, but has been limited in the established irrigation area" **(Aziz *et al*., 1995).**

In North Delta, Egypt, **El-Mowelhi *et al*. (1998)** studied the effect of three land levelling practices and two levels of tillage on seed cotton production. The results showed that land leveling with 0.1 % slope resulted in the highest seed cotton yield and recorded the highest values of water utilization efficiency compared to the other treatments (i. e. flat and traditional land leveling).

Barros and Hanks (1993) found that mulch on the surface reduced soil water evaporation by 45 mm and increased transpiration of beans *(Phaseolus vulgaris L.)* by the same amount. The effect of mulching the soil on soil moisture status in Egypt was investigated by **Ghali and Nakhlla (1996). and Abu-Awwad, (1999) who reported that** water use efficiency in the covered soil was the highest, where onion yield was significantly higher than in open surface treatments at low water level; a similar result was obtained by **Gajera *et al.* (1998).** In India, the fruit yield of tomato increased with mulch treatment from 16.63 ton ha^{-1} to 23.25 ton ha^{-1}, both under drip irrigation compared to 11.95 ton ha^{-1} under surface irrigation without mulching **(Raine *et al*., 1999).**

iii) Reducing or suppressing water uses of low priority" **(Attia *et al.,* 1995).**

2.3. Water Use Efficiency (WUE)

A widely applicable expression of efficiency is the agronomic or crop water-use efficiency, which has been defined by **Viets (1962)** as "the amount of vegetative dry matter produced per unit volume of water taken up by the crop from the soil", while the net amount of water added to the root zone divided by the amount of water taken from some source, was defined as "irrigation or technical efficiency" **(Hillel, 1997)**.

The overall agronomic efficiency of water use, WUE_{ag}, can be expressed according to **Hillel *et al*., (1998) as:**

$$\mathbf{WUE_{ag} = P_c / W} \qquad \text{Eq. 1}$$

Where P_c is the crop production and W is the volume of water applied. Since only a fraction of the applied water is actually absorbed and utilized by the crop, the various components of the W must be defined as follows:

$$\mathbf{W = R + D_r + E_d + E_s + T_w + T_c} \qquad \textbf{Eq. 2}$$

where R is the volume of water lost by runoff from the field, D_r the volume drained below the root zone (by deep percolation), E_d the volume lost by evaporation during delivery and application to the field, E_s the volume evaporated from the soil, T_w the volume transpired by weeds, T_c the volume transpired by the crop. All of these volumes pertain to the same unit area and the same time period, therefore,

$$\mathbf{WUE_{ag} = P_c / (R + D_r + E_d + E_s + T_w + T_c)} \qquad \textbf{Eq. 3}$$

Clearly, WUE_{ag} can be maximized by decreasing the denominator and/or by increasing the numerator. “It requires both that growth be maximized by using high-yielding varieties well adapted to local soil and climate, and that water be conserved by avoidance of waste (runoff, seepage, evaporation and transpiration by weeds). But the one component of the field water balance that generally should not be reduced is transpiration by the crop” **(Hillel *et al.*, 1998).**

WUE in crop production is important from both economic and environmental points of view, because over-irrigation accounts for water losses by deep percolation, potential fertilizer, underground water pollution and partial root anoxia **(Clothier and Green, 1994; Al -Kaisi *et al.*, 1999).** On the other hand “under-irrigation causes a restricted wetted soil volume, which may fail to supply total plant evapotranspiration needs, and can create conditions for salt intrusion into the crop-rooting soil volume” **(Curovich, 1999).**

2.4. Reference-Evapotranspiration, Crop Evapotranspiration and Irrigation Requirements

2.4.1. Reference-Evapotranspiration (ET o)

One way to improve WUE and optimize plant production is to provide crops only with the water they need based on the climate-plant-soil relationship. Therefore, the concept of evapotranspiration (ET) is the base for the right amount of irrigation water that should be applied.

“Evaporation” and “Transpiration”occur simultaneously and there is no easy way of distinguishing between the two processes. The evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface” **(Withers and Vipond, 1978).** This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more of the ground area. When the crop is small, water is predominantly lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process.

"At sowing, nearly 100 % of ET comes from evaporation, while at full crop cover more than 90 % of ET comes from transpiration" **(Hillel, 1987).** The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as Crop Water Requirement. Although the values for crop evapotranspiration and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be applied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration. "The Irrigation Water Requirement basically represents the difference between the crop water requirement and effective precipitation" **(Doorenbos and Pruitt, 1975)**. The irrigation water requirement also includes additional water for leaching of salts and for compensating for non-uniformity of water application.

According to **Al-Ghobari (2000),** the potential evapotranspiration is defined as the rate at which water would be removed from wet soil or plant surfaces (expressed as the rate of latent heat transfer per unit area, or as a depth of water per unit time), while the reference evapotranspiration is defined as the rate at which water would be re-moved from the soil and plant surfaces (expressed as the rate of latent heat transfer per unit area, or as a depth of water per unit time) and transpired from a reference crop. So, the use of reference evapotranspiration (= evapotranspiration from the reference crop) for a specified crop surface has largely replaced the use of the more general potential evapotranspiration.

The potential evapotranspiration depends only on climatic driving forces and the potential rate of evaporation from the fraction of the soil surface and is presumed to equal the potential energy available **(Pereira *et al*., 1996; Allen *et al*., 1996).**

"The use of a reference evapotranspiration permits a physically Float istic characterization of the effect of the microclimate of a field on the evaporative transfer of water from the soil-plant system to the atmospheric air layers overlying the field" **(Wright, 1996).** When selecting a reference (standard) method to estimate crop evapotranspiration it is necessary to consider a reference crop with standard height, albedo, an aerodynamic resistance (from the wind speed) and an average surface resistance (results from the stomatal regulation and canopy structure as influenced by the climate). Adequate data are already available for clipped grass and alfalfa, allowing the definition of a general reference evapotranspiration, ET_o (**Pereira *et al*., 1996).** In the current investigation we will use the concept of reference evapotranspiration (ET_o) which has been defined as the rate of evapotranspiration from a hypothetical reference crop.

For calculation of (actual) crop evapotranspiration (ET_c), the crop coefficient (K_c) that acts as an aggregation of the physical and physiological difference between crops must be available in addition to the reference evapotranspiration (ET_O). Actual crop evapotranspiration can be calculated by multiplication of K_c by ET_O ($ET_c = ET_o \times K_c$).

2.4.2. Crop Coefficient, (K_c)

“The crop coefficient, K_c, is basically the ratio of the crop evapotranspiration to the reference evapotranspiration, and it represents an integration of the effects of four primary characteristics that distinguish the crop from reference grass" **(Achtnich, 1980).** These characteristics are:

Albedo (reflectance) of the crop-soil surface that influences the net radiation of the surface.

- The albedo is affected by the fraction of ground covered by vegetation and by the soil surface wetness and color.
- Crop height influences the aerodynamic resistance, r_a, and the turbulence of vapor from the crop into the atmosphere.
- "Canopy resistance, is the resistance of the crop to vapor transfer and it is affected by leaf area (number of stomata), leaf age and condition. The canopy resistance influences the surface resistance, r_s" **(Alves, 1995).**
- Crops such as pineapples, that close their stomata during the day, have a very small crop coefficient.

For many crops K_c increases as wind speed increases and as relative humidity decreases, herewith more arid climates and conditions of greater wind speed will have higher values for K_c , and vice versa. Three stages are recommended for the calculation of the crop evapotranspiration ET_c: The first is the effect of climate on crop water requirements, the second is the effect of the crop characteristics on crop water requirements, and the third is the effect of local condition and agricultural practices on crop water requirements. The first is given by the reference evapotranspiration ET_o and the second is given by the crop coefficient K_c, which represents the relationship between ET_o and ET_c, **(Doorenbos and Pruitt, 1977);**

$$\mathbf{ET_c = ET_O . K_c} \qquad \textbf{Eq. 4}$$

Allen *et al.* (1998) classified the crop coefficients into two types as follows:

1) One Single Crop Coefficient (K_c), where the effects of crop evapotranspiration and soil evaporation are combined; its time step is daily, every 10 days or monthly;

2) Or a Dual Crop Coefficient, which can be split into two factors (K_{cb} + K_e), where K_{cb} is the Basal Crop Coefficient to describe plant transpiration and defined as the ratio of ET_c to ET_O when the soil surface is dry but transpiration is occurring at a potential rate. It represents the baseline potential K_C in the absence of the additional effects of soil wetting by irrigation or precipitation. “The basal crop coefficient provides improved estimates of K_C on a daily basis where the effects of a wet soil surface are explicitly considered”**.**

A similar conclusion was reported by **Hunsaker (1999).** K_e is the Soil Water Evaporation Coefficient, to describe evaporation from the soil surface. If the soil is wet following rain or irrigation, K_e may be large, and becomes smaller as the soil surface becomes drier. The estimation of K_e requires a daily calculation of the soil water content remaining in the upper topsoil. The Dual Coefficient requires more numerical calculations, and the time step for it is daily. Changes in vegetation and ground cover mean that the crop coefficient varies during the growing period. The trends in K_c during the growing period are represented in the Crop Coefficient Curve. Only three values for K_c are required to describe and construct the crop coefficient curve: Those during the initial stage ($K_{c\ ini}$), the mid-season stage ($K_{c\ mid}$), and at the end of the late season stage ($K_{c\ end}$). The constructing of the crop coefficient curve allows one to determine K_c values for any period during the growing period.

2.4.2.1. Adjusted Crop Coefficient, $K_{c\ adj}$

According to the recommendation of **Allen *et al*. (1996), Neale *et al.* (1996) and ASCE (1996),** the values of $K_{c\ mid}$ and $K_{c\ end}$ of **Doorenbos and Pruitt**

(1977) should be modified, as they are for a subhumid climate (RH min ~ 45%) with moderate wind speed (averaging 2 m s^{-1}). For more humid or arid conditions or for more or less windy conditions, they should be modified as follows:

$$K_{c\ mid\ adj} = K_{c\ mid\ (table)} + [0.04(U_2 - 2) - 0.004\ (RH_{min} - 45)]\ (h_p / 3)^{0.3} \quad \text{Eq. 9}$$

$$K_{c\ end\ adj} = K_{c\ end\ (\ table\ )} + [\ 0.04\ (U_2 - 2\ ) - 0.004\ (\ RH_{min} - 45\ )\ ]\ (\ h_p / 3\ )^{0.3} \ \text{Eq. 10}$$

Where h_p is the maximum plant height (m). When $K_{cend\ (table)} < 0.45$, no adjustment is made

When crops are allowed to ripen and dry in the field (as evidenced by $K_{cend} < 0.45$), U_2 and RH_{min} have less effect on $K_{c\ end}$ and no adjustment is necessary. When $K_{c\ end} < 0.4$, **ASCE (1996)** produced an adjustment as:

$$K_{c\ end} = K_{c\ end\ (table)} + 0.001\ (RH_{min} - 45.0) \ \text{Eq. 11}$$

Accordingly, as the research area is under arid condition, adjustments are made for $K_{c\ mid}$ and $K_{c\ end}$ in the following.

2.4.3. Some Evapotranspiration-Calculation Methods

Estimation of evapotranspiration can be based on the hydrologic cycle or on climatological data. The first type requires measurements of soil water and thus it is subject to sampling error, or use of a lysimeter which also incurs problems, a long period of time and cost. Hence, other methods of estimating evapotranspiration have been sought that are simpler and faster. There is considerable interest in methods based on climatic measurements (**Hanks and Ashcroft, 1980; Milivojevic *et al*., 1996**):

1- The climatic variables apply to a wider scale than spot soil sampling.

2- Where average climatological data are available, these methods can be used for prediction.

2.4.3.1. Hargreaves Equation

The monthly ET_O can be calculated using **Hargreaves *et al*. (1985)** as follows:

$$ET_o = 0.0023 R_a (T + 17.8) d^{0.5} \quad \textbf{Eq. 12}$$

Where Ra = daily extraterrestrial radiation in the same units (usually) as ET_o; $T = (T_M + T_m)/2$ (C°); TM and Tm are the mean maximum and minimum temperature (C°), respectively; and $d = T_M - T_m$ (C°). **Hargreaves (1994)** recommended the Hargreaves equation for general use for computing values of ET_o. Due to its simplicity and reliability, the equation requires only measured values of maximum and minimum temperatures, and correlates well with results from the Penman combination equations.

2.4.3.2. Penman-Monteith Equation

Attempting to better characterize water loss by plants, **Monteith (1965)** introduced some modifications, resulting in the now well-known Penman-Monteith equation. The Penman-Monteith formula is the most suitable method for estimating crop evapotranspiration and for the reference evapotranspiration **(Allen *et al.*, 1989 & 1996; Jensen *et al.*, 1990; Hargreaves, 1994)**. The PM equation for ET_c is (see Eq. 19):

$$ET_c = \frac{\Delta (R_n - G) + P_a \, C_p \, \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma \left[1 + \frac{r_s}{r_a}\right]}$$ **Eq. 13**

The Penman-Monteith equation has gained a renewed interest, especially to predict crop evapotranspiration in a one-step approach, without the use of a crop coefficient it has been currently used for the last 20 years. But to do so and for the Penman-Monteith equation to be used predictively, methodologies for determining aerodynamic resistance and canopy surface resistance must be available **(Alves *et al.*, 1996; Smith *et al.*, 1996).**

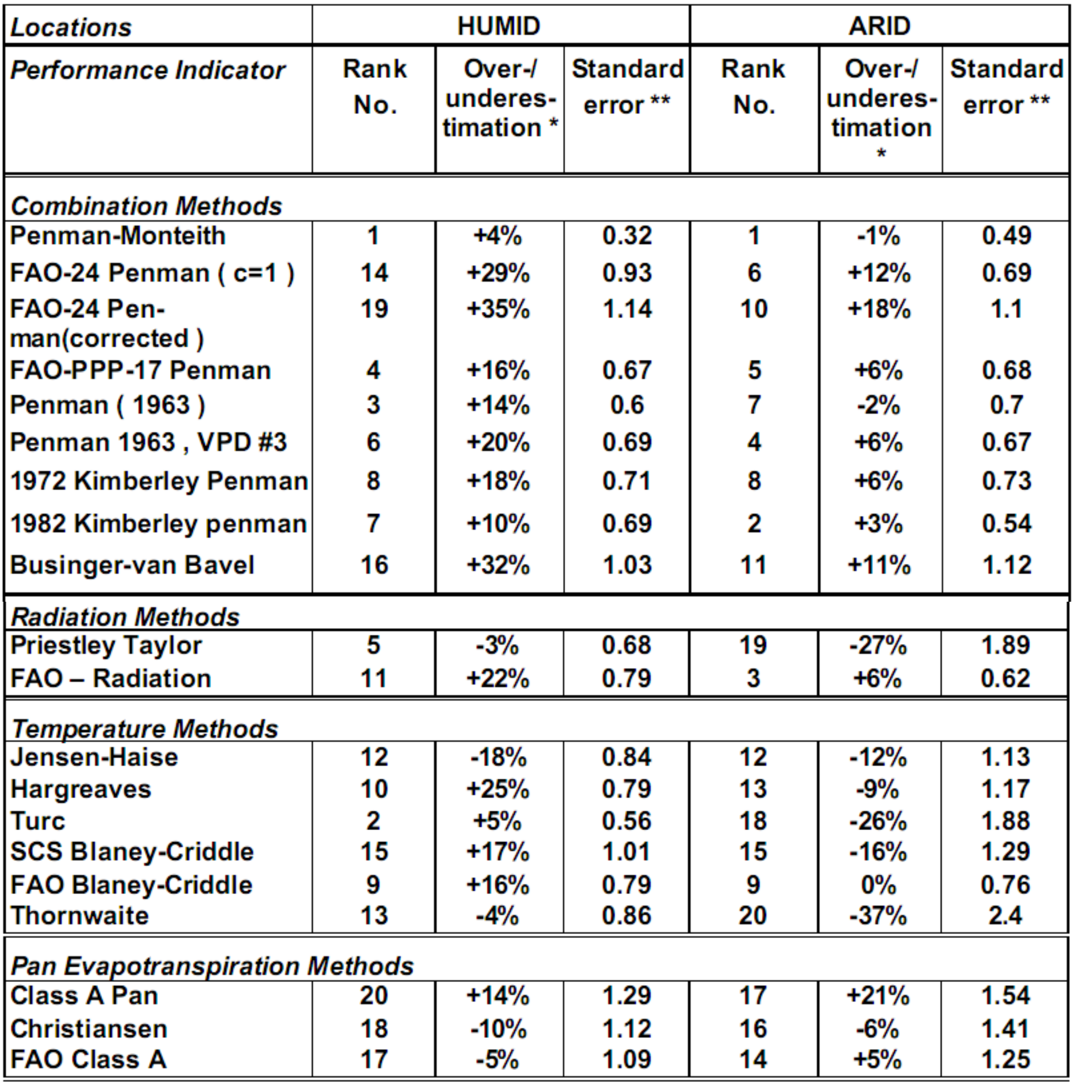
“Also one important advantage in using the PM equation with an abstract reference crop is that it offers the opportunity to have a model that applies everywhere and does not need any local calibration” **(Steduto *et al.*, 1996).** Relationships were often subject to rigorous local calibrations and proved to have limited global validity. Special attention was focused on the PM equation as a potential standard for ETo estimate throughout the Mediterranean region and has been generally the most stable form of the Penman combination ET equation used around the world (**Howell, 1996; Steduto *et al.*, 1996; Simon *et***

***al*., 1998; Vidal *et al*., 1999; Ventura *et al*., 1999; Michael and Bastiaanssen, 2000).**

The American Society of Civil Engineers (ASCE) study reported by **Jensen *et al*., 1990 (quoted by Smith, 1993)** analyzed the performance of 20 different methods, using very detailed procedures to assess the validity of the methods compared to a set of carefully screened lysimeter data from 11 locations with variable climatic conditions.The study proved very revealing and showed the widely varying performance of the methods under different climatic conditions for humid and arid regions (see: Table 2-1).

“In a study commissioned by the European Community, a Consortium of European Research Institutes evaluated the performance of various evapotranspiration methods using data from different lysimeter studies in Europe” **(Choisnel *et al*., 1992).** The studies confirm the overestimation of the modified Penman introduced in FAO-No. 24 **(Doorenbos and Pruitt, 1984)**, and the variable performance of the different methods depending on their adaption to local conditions. The comparative studies may be summarized as follows **(Smith *et al*., 1996):**

Table (2-1): Performance of various ET o methods (after Jensen et al., 1990)



Locations	HUMID			ARID		
Performance Indicator	Rank No.	Over-/ underes-timation *	Standard error **	Rank No.	Over-/ underes-timation *	Standard error **
Combination Methods						
Penman-Monteith	1	+4%	0.32	1	-1%	0.49
FAO-24 Penman (c=1)	14	+29%	0.93	6	+12%	0.69
FAO-24 Penman(corrected)	19	+35%	1.14	10	+18%	1.1
FAO-PPP-17 Penman	4	+16%	0.67	5	+6%	0.68
Penman (1963)	3	+14%	0.6	7	-2%	0.7
Penman 1963 , VPD #3	6	+20%	0.69	4	+6%	0.67
1972 Kimberley Penman	8	+18%	0.71	8	+6%	0.73
1982 Kimberley penman	7	+10%	0.69	2	+3%	0.54
Businger-van Bavel	16	+32%	1.03	11	+11%	1.12
Radiation Methods						
Priestley Taylor	5	-3%	0.68	19	-27%	1.89
FAO – Radiation	11	+22%	0.79	3	+6%	0.62
Temperature Methods						
Jensen-Haise	12	-18%	0.84	12	-12%	1.13
Hargreaves	10	+25%	0.79	13	-9%	1.17
Turc	2	+5%	0.56	18	-26%	1.88
SCS Blaney-Criddle	15	+17%	1.01	15	-16%	1.29
FAO Blaney-Criddle	9	+16%	0.79	9	0%	0.76
Thornwaite	13	-4%	0.86	20	-37%	2.4
Pan Evapotranspiration Methods						
Class A Pan	20	+14%	1.29	17	+21%	1.54
Christiansen	18	-10%	1.12	16	-6%	1.41
FAO Class A	17	-5%	1.09	14	+5%	1.25

× Over- or underestimation as percentage from 11 lysimeter data locations, corrected for reference type.
×× Weighted standard error of estimates, mm day^{-1}.

- The Penman methods require local calibration of the wind function to achieve satisfactory results.
- The radiation methods show good results in humid climates where the aerodynamic term is relatively small, but performance in arid conditions is erratic and underestimates evapotranspiration.
- Temperature methods remain empirical and require local calibration in order to achieve satisfactory results. A possible exception is the Hargreaves method **(Hargreaves and Samani, 1985)** which has shown reasonable ET_O results with a global validity.
- Pan Evapotranspiration methods clearly reflect the shortcomings of predicting crop evapotranspiration from open water evaporation. The methods are susceptible to the microclimatic conditions under which the pans are operating and their performance proves erratic.
- The excellent performance of the Penman-Monteith approach both in humid and arid climates (only very slight over- and underestimates +4 % and –1 %, and negligible standard error 0.32 and 0.49 resp.) is

convincingly shown both in the ASCE study and European study.

The main reason to recommend the use of different ET_o methods has been the limiting availability of the full range of climatic data as, in particular, sunshine, humidity or wind data are often lacking.

“The consultation of experts organized by FAO in May 1990 in Rome recommended the adoption of the Penman-Monteith combination method as a consistent and a new globally-valid standard for reference evapotranspiration and advised procedures for calculation of the various parameters **(Hargreaves, 1994).**

According to **Baselga and Allen (1996),** the crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance and air resistance factors in the PM approach as follows:

$$ET_c = \frac{\Delta\,(R_n - G) + P_a\,C_p\,\dfrac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left[1 + \dfrac{r_s}{r_a}\right]}$$

Eq. 14

Where ET_c is the crop evapotranspiration (mm day^{-1}), R_n is the net radiation at the crop surface (MJ m^{-2} d^{-1}) (it is the difference between the incoming net shortwave radiation R_{ns} and the outgoing net long wave radiation R_{nl}). It can be calculated according to **Doorenbos and Pruitt (1977)** as follows:

$$R_n = 0.75\,R_s - 2.0(10)^{-9}(T_a + 273.16)^4\left(0.34 - 0.044\sqrt{e_s}\,\right)\left[-0.35 + 1.8\frac{R_s}{R_a}\right] \quad \textbf{Eq. 15}$$

This equation had been modified by **Pair,(1983)** as:

$$R_n = 0.75\,R_s - 2.0(10)^{-9}(T_a + 273.16)^4\left(0.31 - 0.044\sqrt{e_{sd}}\,\right)\left[-0.35 + 1.35\frac{R_s}{R_{so}}\right] \quad \textbf{Eq.16}$$

Where R_s is observed solar radiation (mm day^{-1}), R_a is extraterrestrial solar radiation (mm day^{-1}), R_{so} is solar radiation on a clear day (mm day^{-1}), e_s is the saturated vapor pressure (mbar) at average air temperature T_a (C°) and e_{sd} is saturated vapor pressure at dew point temperature of air (mbar).

The relative shortwave radiation is the ratio of the actual solar radiation (R_s) to the clear day solar radiation (R_{so}). This ratio is a way to express the cloudiness of the atmosphere; the cloudier the sky, the smaller the ratio. In the absence of a direct measurement of the net radiation R_n, the relative shortwave radiation is used in the computation of the net radiation as showed in equation 21. The actual (observed) short wave radiation R_s can be estimated as **(Doorenbos and Pruit, 1977):**

$$R_s = (0.25 + 0.5\frac{n}{N})R_a \quad \textbf{Eq. 17}$$

Where n is the mean daily sunshine hours and N is the mean daily maximum sunshine hours. G is the Soil heat flux, it is the energy that is utilized in heating the soil. G is positive when the soil is warming and negative when the soil is cooling. Although the soil heat flux is small compared to R_n and may often be ignored, the amount of energy gained or lost by the soil in this process should theoretically be subtracted or added to R_n when estimating evapotranspiration. G is small compared to R_n , particulary when the surface is covered by vegetation and calculation time steps are 24 hours or longer. For day and ten-day periods, soil heat flux is relatively small, it may be ignored (G day ~ 0), but for monthly periods, assuming a constant soil heat capacity of 2.1 MJ m^{-3} $°C^{-1}$ and an appropriate soil depth, G (MJ m^{-2} d^{-1}) can be calculated as follows **(Smith, 1993):**

$$G_{month,i} = 0.07(T_{month,i+1} - T_{month,i-1}) \quad \textbf{Eq. 18}$$

Where $T_{month,\ i-1}$ is the mean air temperature (C°) of the previous month and $T_{month\ ,\ i+1}$ is the mean air temperature of the next month. As stated by **Nakamura *et al.* (1996),** the daytime soil heat flux can be estimated using the following equation which includes daytime net radiation (R_n) and vegetation coverage (VC, %):

$$G = (0.174 - 0.00086\,VC)R_n$$ **Eq. 19**

The standard error of estimation in this equation is 0.46 MJ m^{-2} d^{-1}. Soil heat flux and net radiation can be measured directly with net radiometers and soil heat flux disks. Δ is the slope of the relationship between saturation vapor pressure and temperature, Kp_a /°C, it had been calculated in (mbar $°C^{-1}$) according to Bosen's equation as follows:

$$\Delta = 2.00(0.00738\,T + 0.8072)^7 - 0.00116$$
Eq. 20

It can be also computed as **(Allen, 1991):**

$$\Delta = 4098\frac{e_s}{(T_a + 273.3)^2}$$ **Eq. 21**

Where e_s is the saturation vapor pressure in KP_a and T_a is the air temperature, γ is the Psychrometric Constant (KP_a/C°), and can be calculated according to **James (1988)** as:

$$\gamma = \frac{1615\,P_a}{2.49\,(10)^6 - 2.13(10)^3\,T_a}$$ **Eq. 22**

where P_a is air pressure (mbar), T_a average air temperature (C°). P_a can be calculated as:

$$P_a = 1013 - 0.1152\,(h) + 5.44(10)^{-6}h^2$$

Eq. 23

$$\gamma = \frac{P_a\ C_p}{\varepsilon\ \ LE}$$ **Eq. 24**

Where P_a is the air pressure; C_p is the specific heat capacity of air; ε is the ratio of the molecular weight of air to water, 0.622 (= 18 g/28.9 g), and LE is the latent heat of vaporization.

In the PM equation (Eq. 14), (e_s - e_a) is the vapor pressure deficit of the air (KP$_a$), r_a is the mean air density at constant pressure, C_p is the specific heat of the air, r_s and r_a are the surface and aerodynamic resistance.

According to (**FAO, 1998)**, the saturation vapour pressure (es) can be calculated from

The following relationship:

$$e^o(T) = 0.6108 \exp\left[\frac{17.27T}{T + 237.3}\right]$$ **Eq.25**

Where

e°(T) saturation vapour pressure at the air temperature T [kPa],
T air temperature [°C],
exp[..] 2.7183 (base of natural logarithm) raised to the power [..].

The saturation vapour pressure at the mean daily maximum and minimum air temperatures for that period:

$$e_s = \frac{e^{\circ}(T_{max}) + e^{\circ}(T_{min})}{2} \quad \textbf{Eq.26}$$

Where:

$e^{\circ}(T_{max})$ saturation vapour pressure at the air temperature T_{max} [kPa],$e^{\circ}(T_{min})$ saturation vapour pressure at the air temperature T_{mjn} [kPa],

Where humidity data are lacking or are of questionable quality, an estimate of actual vapour pressure, ea, can be obtained by the following equation:

$$ea = es \times {RH}/{100} \quad \textbf{Eq. 27}$$

As there is still a considerable lack of information for different crops, the PM method is used for the estimation of the standard reference crop to determine its evapotranspiration rate. According to **Smith *et al*. (1996)** the adaption of fixed values for crop surface resistance and crop height required an adjustment of the concept of reference evapotranspiration which was redefined as “the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height (12 cm), a fixed crop surface resistance (70 s/m) and albedo (0.23) closely resembling the evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and with adequate water”. Thus, the PM equation used for 24-hour calculations of reference evapotranspiration using daily or monthly mean data can be defined as:

$$ET_o = \frac{0.408\,\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 U_2)}$$ **Eq.28**

Where, U_2 is wind speed at 2 m height (m/s).

FAO-PM equation can be adapted to hourly ET_o calculations, of relevance in detailed research studies and for automatic weather stations, by replacing the conversion factor 900 in the equation by 37 equal to 900/24 **(Smith *et al.*, 1996).**

According to **El- Beltagy, *et. al.*,(2004)**, the green cover can be calculated from the following relations

Eq.29

$$gc_{int\ stage} = \frac{(100 \times 0.05 + GrowthInDays \times 100 \times 0.5)}{Inti\ stage}$$

Where:

gc $_{int\ stage}$ = the percentage of green cover in the intial stage, %.

GrowthInDays = plant age in the day of irrigation, days, and

Inti stage = the number of days of intial stage, days.

$$gc_{ve\ stage} = \frac{100 \times 0.55 + (GrowthInDays - IntiStage\ ) \times 100 \times 0.4}{Dev\ Stage}$$ **Eq.30**

Where:

gc$_{ve\ stage}$ = the percentage of green cover in vegtable stage, %.

Dev stage = the total number of days for development stage, days.

$$gc_{fl\ stage} = \frac{100 \times 0.95 + (GrowthInDays - Inti\ Stage - Dev\ Stage) \times 100 \times 0.05}{Mid\ Stage}$$ **Eq. 31**

Where:

Gc$_{fl\ stage}$ = the percentage of green cover in flowering stage, %.

Mid stage = the total number of days for mid stage, days.

According to **Keller and Bliesner, 1990**, the crop evapotranspiration for drip irrigation can be calculated from the following relations:

$$ET_c = ET_o\,(Kc/100)\ Kr$$ Eq.32

$$Kr = 0.1\sqrt{gc} \text{ Eq.33}$$

Where:

gc = the percentage of green cover, %.

Kr= reduction factor.

Kc = crop coefficient.

2.5. Irrigation Scheduling

The irrigation performance can be improved either by means of developing new application systems (drip, sprinkler, etc.) or by a more accurate irrigation scheduling. “For any crop, schedule implies the determination of time and volume of water application to meet a specified management objective. So an irrigation schedule handles two key elements in irrigation: The limiting of irrigation (when to irrigate?) and the amount of irrigation (how much water should be applied?)” **(Howel, 1996).** These two elements are not independent of each other and are consequently dealt with jointly, by means of a method for scheduling irrigation on the basis of plant water requirement and weather and soil conditions.

Because scheduling is an important element in improving water use efficiency, several new plant and water sensor technologies have direct implications for improving irrigation management. “Methods based on direct measurements of plant water status have always attracted the attention of irrigation research as a tool for irrigation timing, but getting accurate and representative data for these parameters has always been very difficult” **(Cremona *et al.*, 2000).**

2.5.1. Irrigation Scheduling Options

Irrigation scheduling research priorities are recommended to focus on the evapotranspiration (ET) estimation method, on improved understanding of the spatial variation of ET and irrigation application, on identifying the water balance components in typical irrigated agriculture, and on integrating various sensing technologies into irrigation scheduling models and controls. Irrigation scheduling was defined by **Jensen (1981)** as: “A planning and decision-making activity that the farm manager or operator of an irrigation farm is involved in before and during most of the growing season for each crop that is grown”. He further indicated four types of data needed for irrigation decision making:

1- Current level and expected change in available soil water for each field over the next 5 to 10 days.

2- Current estimates of the probable latest date of the next irrigation on each field to avoid adverse effects of plant water stress.

3- The amount of water that should be applied to each field, which will achieve high irrigation efficiency.

4- Some indication of the adverse effects of irrigation a few days early or late.

For an optimal irrigation the irrigation depth will bring soil moisture content back to field capacity, thus equal to the depleted soil moisture in the root zone. As the depletion in the root zone will normally vary over the growing season with changing root depth and allowable depletion levels, the application doses may vary substantially over the season.

The irrigation scheduling schemes should take into account the soil properties that affect soil moisture-holding capacity. **James *et al*. (1982)** reported that “the irrigation scheduling with a soil of low water-holding capacity would have to be more frequent with smaller amounts applied each time for best efficiency”.

The crop water requirements, defined as the daily water needs of crops, have been calculated previously from climatic data (ET_O) and crop data (K_c, length of growth stages). They represent the daily uptake of soil moisture from the root zone due to ET of the crop. **Smith (1992)** classified the scheduling options into two different categories as follows:

a) Timing options - related to WHEN irrigation is to be applied:

1- Each irrigation defined by user; this type is used to evaluate irrigation practices and to simulate any alternative irrigation schedule.

2- Irrigation at critical depletion (100 % depletion of readily available soil moisture). Resulting in minimum irrigations, but irregular and therefore unpractical irrigation intervals.

3- Irrigation below or above critical depletion (% depletion of readily available soil moisture). Useful to set a safety level above critical soil moisture or allow a critical stress level.

4- Irrigation at fixed intervals per stage, suitable in particular in a gravity system with rotational water distribution, may result in some over-irrigation in the initial stages and under-irrigation in the peak season.

5- Irrigation at given ETc reduction (%).

6- Irrigation at given yield reduction (%).

7- No irrigation, only rainfall.

b) Application options - HOW MUCH water is to be given per irrigation turn:

1- Each irrigation depth is defined by user, as determined from field or simulated data.

2- Refill soil to field capacity, to bring soil moisture content back to field capacity, thus equal to the depleted soil moisture in the root zone, as the depletion in the root zone will normally vary over the growing season with changing root depth and allowable depletion levels.

3- Refill below or above field capacity. Useful to allow for leaching for salinity control (above field capacity) or to accommodate possible rainfall (below field capacity).

The scheduling method that will be suggested in this work is mixed from a/2 (but with other critical depletion values), b/2 and b/3.

2.5.2. Water Supply Requirements

The supply requirements methods at the field level that are commonly used by many investigators are determined by the depth and interval of irrigation. According to the required data are primarily determined by **Doorenbos *et al*. (1986)**

I) The total available soil water ($S_a = S_{fc} - S_{wp}$), where S_{fc} is the soil water content at field capacity and S_{wp} is the soil water content at wilting point,

II) The fraction of the available soil water (*p*) permitting unrestricted evapotranspiration and/or optimal crop growth, and

III) The rooting depth, Z_r.

The depth of irrigation application (d_i) including application losses is:

$$d_i = \frac{(p\ S_a)\ Z_r}{E_i} \qquad \textbf{Eq. 34}$$

Where E_i is the application efficiency (%). The frequency of irrigation expressed as irrigation intervals of the individual field, i (days), is:

$$i = \frac{(p\ S_a)\ Z_r}{ET_c} \qquad \textbf{Eq. 35}$$

Since *p*, Z_r and ETc will vary over the growing season, the depth in mm and interval of irrigation in days will vary.

Rojas and Rolda'n (1996) in their study on Olive trees, produced the following equation to calculate the daily amount of water to be applied (D_{wd}, liter day plant):

$$D_{wd} = \frac{D_{cd}\ 10{,}000}{N_o} \qquad \textbf{Eq. 36}$$

Where D_{cd} is the constant daily depth of irrigation water to be applied (mm day^{-1}) and N_o is the number of trees per hectare.

Particularly for drip systems is to be considered: As the drip system applies water only to the plant's rooting area, the crop factor C_f can be used, thereby reducing the area irrigated for some crops: 0.9 for vegetable and 0.7 for berries **(Moon and Van der Gulik, 1996).**

2.5.3. Total available soil moisture content (TAW) and effective root depth

The total Available Soil Water content (TAW) is defined as the difference in soil moisture content between soil field capacity (f_c) and wilting point (W_P). It represents the ultimate amount of water available to the crop and depends on the texture, structure and organic matter content of the soil. As the water content above field capacity cannot be held against the forces of gravity and will drain and as the water content below wilting point cannot be extracted by plant roots, the total available water in the root zone can be calculated as follows **(Hanks and Ashcroft, 1980):**

$$TAW = 1000(\theta_{fc} - \theta_{wp})Z_r \qquad \textbf{Eq. 37}$$

where *TAW* is the total available soil water in the root zone (mm), is the water content at field capacity (m^3/m^3), is the water content at wilting point (m^3/m^3), and Z_r is the root depth (m). *TAW* is the amount of water that a crop can extract from its root zone, and its magnitude depends on the type of soil and the root depth.

Root depth growth with time can be calculated using the procedure described by **Borg and Grimes (1986)** and it reads as follows:

$$Z_r = Z_{rm}\left[0.511 + 0.511\, Sin_{(rad)}\left[3.03\frac{DAP}{DTM} - 1.47\right]\right] \quad \textbf{Eq. 38}$$

Where the angle is in radiant, Z_r is the root depth in cm; Z_{rm} is the maximum root depth of the crop in cm, DAP is number of days after planting, and DTM is the number of days to maximum root depth. “The root depth growth rate is 1.2 mm day^{-1} , for grass and 1.5 mm day^{-1} for other crops until maximum effective root depth has been reached” **(Plauborg *et al*., 1996).** The maximum effective root depth is determined by both crop and soil type.

2.5.4. Readily available water (RAW) and depletion fraction

As the soil water content decreases, water becomes more strongly bound to the soil matrix and it is more difficult to extract. When the soil water content drops below a threshold value, soil water can no longer be transported quickly enough towards the roots to respond to the transpiration demand and the crop begins to experience stress. The fraction of total available water TAW that a crop can extract from the root zone without suffering water stress is the Readily Available Water (RAW):

$$RAW = P * TAW \quad \textbf{Eq. 39}$$

Where P is an average fraction of the total available soil water (TAW) that can be depleted from the root zone before moisture stress (reduction in ET) occurs (P ranges from 0 to 1). The allowable depletion is a function of the evaporation power of the atmosphere where first drought stress occur affecting evapotranspiration and crop production. At low rates of ET_c, the p values are higher than at higher rates of ET_c. The P values are expressed as a fraction of TAW with lower values taken for sensitive crops with limited root systems under high evaporative conditions, and higher values for deep and densely rooting crops and low evaporation rate **(Doorenbos *et al.*, 1986).**

2.5.5. Soil water depletion fraction and crop production

The efficiency of current irrigation design and techniques requires assessment to identify an irrigation system that will minimize deep percolation. “To prevent the development of a shallow water table and subsequent soil salinity and water logging, many researchers aimed at developing systems also to minimize the deep percolation" **(Tracy *et al.,* 1997).**

Curtius and Bohne (1997) found that to prevent the leaching of nitrate excessive irrigation must be avoided and an irrigation adapted to soil properties and plant requirements is necessary.

The results of *Zea mays L.* showed that the higher water applications that lead to reduced yields were associated with higher N leaching for a given N appl ication amount **(Pang *et al.,* 1997).**

In Egypt, a study of the water use efficiency for onion, cropped in Mallawi, found that bulb weight produced per unit of water consumed increased from 278.3 kg/cm ET (Evapotranspiration) in the wet treatment (irrigation at 25 % available soil moisture depletion, ASMD) to 316.9 kg/cm ET in the dry treatment, 75 % ASMD **(Koriem *et al.,* 1994). Mohamed (1994)** studied the effect of soil moisture depletion of 35 %, 60 % or 85 % on water use efficiency for wheat under different soil salinity. He found that the water use efficiency was highest with irrigation at 85 % ASMD under low and medium soil salinity and with irrigation at 60 % ASMD at high soil salinity. **Khedr *et al.* (1996)** found that the irrigation at 25 % and 50 % water depletion gave similar yields, which were significantly higher than irrigation at 75 % depletion. WUE water use efficiency was highest with irrigation at 50 % water depletion; similar results were obtained by **Gaafar *et al.* (1993).**

2.6 Concept of Fertigation

Fertigation involves two aspects of operations in crop management: (1) fertilization and (2) irrigation, hence the term is "fertigation". This is simply application of plant nutrients through irrigation water.

Bucks *et al.* (1979) stated that the process of applying chemicals through irrigation water is referred to as "chemigation" and when such chemicals are fertilizers, the term is "fertigation". Application of chemical fertilizers through irrigation water is a practice which has been in use on a commercial scale for about the past forty years **(Nilay *et al.* 2000).** Systems of irrigation such as sprinkler, and drip (trickle) are more suited to the use of fertigation. Hence it is not surprising that the use of drip and sprinkler irrigation systems to transport chemicals to plants came under evaluation almost as soon as these modern irrigation systems began to be investigated in a systematic way.

Fertilizers were probably the first chemicals to be added to water of modern irrigation systems of drip and sprinkler or injected into such waters **(Goldberg and Shmueli, 1970).** Since the initial application of fertgation such many types of chemicals have been used and injected into irrigation systems. Such chemicals include herbicides **(Phene *et al*., 1979),** fungicides and insecticides **(Phene *et al*., 1979)**, nematicides **(Overman, 1978)**, growth regulators **(Bryan and Duggins, 1978),** and fumigants **(Overman, 1976).** Acids and other chemicals which control clogging have also been used **(Ford, 1976 and Bucks *et al*., 1979).**

The maintenance of nutrients and water at optimum levels within the rhizosphere is very important to achieve high crop yield and better quality of produce as well as to increase fertilizer and water use efficiencies. Therefore, application of fertilizers through the irrigation stream became a common practice in modern irrigated agriculture **(Bresler, 1977; Elfving, 1982; Hairstne *et al.*, 1981; Phene and Beale, 1976; Phene and Sanders, 1976; Papadopoulos, 1988a and Threadgll, 1991; Nilay *et al.*, 2000 and Neilsen *et al.*, 2002).**

Fertigation may be used with different systems of irrigation **(Phene and Beale, 1976; Corrijo etal, 1983; Keng etaL, 1979; Koo, 1981; Mikkelsen, 1989; Gascho, 1991; Rubeiz *et al.*, 1989 and Bar-Yosef *et al.*, 1989).** However, the systems involved in fertigation are mainly the closed systems of ordinary sprinkler systems or the center-pivot sprinkler ones, as well as the drip (trickle) systems (whether with surface dripper or subsurface drippers). Also fertigation may be practiced with the open systems such as the lined or unlined open ditches, the gated pipes, and the furrow or flood surface irrigation.

2.7 Systems of applying Fertigation

The most widely used systems for fertigation application through drip or sprinkler irrigations are two systems the venturi system and the pressure tank system; other system, such as the displacement pumps may also be used **(Eliades and Hadgiloucas 1985, Aboukhaled 1991 and Serhal 1991).**

2.8 Chemical materials used in fertigation

Chemical fertilizers providing plant nutrients in readily soluble forms, are the most appropriate materials for use in fertigation. Such materials should also not be subjected to precipitation forming insoluble salts when reacting with each other (when mixed in tanks) and should also not form insoluble salts when reacting with other constituents present in irrigation water. Table (2-2) shows the soluble fertilizers materials most widely used in fertigation. Fertilizers which are most often used, are those providing nitrogen; however, application of phosphorus and potassium is common especially for vegetables and tree crops that have high fertilization requirements and application of micronutrients through fertigation is not widely practiced **(Boswell, 1990).**

Table (2-2): Some of the most widely used chemical fertilizer materials utilized in fertigation.

Fertilizer	**N %**	**P_2O_5%**	**K_2O %**	**Reference**
Ammonium nitrate	34	-	-	Boswell, 1990; Mattered/., 1991
Ammonium sulphate	21	-	-	Albasel, 1977; Boswell, 1990.
Calcium nitrate	15.5	-	-	Boswell, 1990
Urea	45-46	-	-	Rolston £×«/., 1979
Mono ammonium	11	20.2-23.1		Lauer, 1988; Boswell, 1990;
Diammonium phosphate	16	19.3-20.2	-	Boswell, 1990
Phosphoric acid	-	21.0- 22.2	-	Boswell, 1990
Potassium nitrate	13		36.1-37.2	Rolston et al, 1979 and Boswell,
Potassium sulphate			39.4-42.6	Rolston etal, 1979
Potassium chloride			49.2-50.8	Rolston et al, 1979 Boswell, 1990

2.9 Suitability of chemical fertilizers as fertigation materials and solution properties.

Choice of the fertilizer material suitable for application through ferigation depends on a number of considerations which include the form of plant nutrient, the purity of the chemical fertilizer, the solubility of the fertilizer, and the cost of fertilizer.

Since most of the cases using fertigation are based mainly on using closed irrigation systems such as drip and sprinkler irrigation, particularly in newly reclaimed lands of sandy soils, therefore considerations governing the appropriate use of chemicals for fertigation would take this into account. Preparation of stock solution of fertilizers is very important in order to obtain the full benefit of fertigation

2.9.1 Form of plant nutrient:

The presence of the needed nutrient should be in sufficient concentration and in a readily available form, easily absorbed by plant roots; or readily convertible to easily absorbed forms. For example, nitrogen fertilizers should contain N in sufficient concentration, such as ammonium NH_4 - N) and nitrate ($N0_3$-N); and urea ($(NH_2)_2CO$). These forms are totally soluble and easily available and are absorbed by plant roots. Besides, urea and NH4-N undergo transformation leading to $N0_3$-N which is easily available to plants.

2.9.2 Purity of the chemical fertilizers:

Acceptable purity of the chemical fertilizer material should be viewed so that no other unacceptable constituents are present in concentration which may adversely affect plant roots. I"or examples, some urea materials may contain rather high contents of biurett $(NH_2\ CO)_2NH$ which is toxic to plants if present in concentration exceeding 1 % in the urea solid material **(Russell, 1978).**

2.9.3 Solubility of the fertilizer:

None -Existence of constituents which may cause clogging or plugging of emitters or orifices of the irrigation lines should be observed. Usually, N materials such as ammonium nitrate and urea are free of such problems since constituents of each material are not involved in clogging reactions. However, the use of some materials containing P, Ca, and Mg, macronutrients may lead to clogging, unless certain precautions are taken. The quality of irrigation water may call for some considerations in using materials which may cause irrigation orifice clogging. Also, analysis of water for its pH, as well as its contents of Ca^{2+}, Mg^{2+}, Fe^{2+}, $C0_3^{2'}$ and $HC0_3^-$ is of great importance for predicting chemical precipitation problems. The risk of precipitation (and therefore the risk of clogging) increases with increasing the concentration of such constituents in water particularly with high water pH. The problem of P precipitation in emitters may be overcome by using soluble organic P forms rather than mineral P forms. **Rolston *et al.* (1975)** used six organic P compounds on a clay loam soil and found that P moved for about 12 cm within the soil in comparison with 2 to 3 cm for inorganic sources. Using acids or acidic materials as fertilizers for fertigation (e.g. using phosphoric acid as a source of P) would reduce clogging risks. Injecting acids in the irrigation system along with the fertilizer material may be added to avoid chemical precipitation of insoluble salts and therefore increases solubility of the fertilizers particularly when the irrigation water is high in pH. **Randall *et al.* (1985)** stated that with high Ca and Mg concentrations in irrigation water, application of P fertilizers through drip or sprinkler systems is not recommended because of possible precipitation of insoluble Ca and Mg in the form of phosphates. Formation of dicalcium phosphates may occur due to using most soluble P fertilizer through drip systems utilizing high Ca water.

2.9.4. Cost of the fertilizers

Fertilizer materials vary in their costs. Consideration must take into account the cost per unit weight of plant nutrient. The associated constituents should be viewed in terms of their effect.

2.9.5. Solution preparation:

The preparation of the stock solution should be precise. The stock solution is rather a concentrated solution of the fertilizer salt (salts). Solutions which are injected into the irrigation systems are derived from the stock solution after dilution. The concentration of solutions of the stock nature amount to between 200 to 250 g of soluble salt materials/L of water **(Sonneveld, 1982).** Solubility of the used fertilizer salts varies according to the salt. Some materials such as magnesium nitrate have very high solubility approaching 2400 g/L (at 20 °C) while other such as urea have solubility of 510 g/L **(Boswell 1990).**

According to **Sonneveld (1982)** practical concentration of stock solution is limited by the quantity of salt which can be fully dissolved in water; and since there is a cooling effect due to dissolution of meanly all fertilizers, water may be added by up to 20 % in excess.

2.10. Important precautions in fertigation management

The followings are precautions that should be observed in fertigation management **(Boswell 1990 and Montag 1997):**

1- High solubility of the fertilizer materials is essential factor in choosing chemical sources in fertigation.

2- Proper mixture of materials (when more than one chemical is used) so as to avoid reactions that lead to precipitates. This is done in particularly cases where stock solutions of mixed sources are prepared for injection into the drip or sprinkler systems.

3-Mixing compatibility of fertilizer materials should be observed. When the need arises to mix more than fertilizer material to prepare a stock solution (to be used for fertigation) formation of precipitates may take place. In such case, the use of the stock solution would be of limited benefit since this would lead to clogging of drippers and orifices. Special attention should be paid in order to avoid mixing in one tank materials which lead to forming precipitates in the tank. Solutions of such materials should be prepared separate in different tanks. Table (2-3)

Materials which are compatible for mixing may be mixed together with little risk of precipitate formation. As a rule, all fertilizers containing no calcium may be mixed together (e.g MAP +U+AN, KS + KC).

Table (2-3) Compatibility of fertilizer material for mixing in preparation for stock solutions utilized in fertigation (Boswell 1990 and Montag 1997).

Fertilizer material	Compatibility							
	U	AN	AS	CN	MAP	MKP	KS	KC
Urea (U)	X\\\	C	C	C	C	C	C	C
Ammonium nitrate (AN)	C	X	C	C	C	C	C	C
Ammonium sulphate (AS)	C	C	X	L	C	C	C	C
Calcium nitrate (CN)	C	C	L	X\\\	X	X	C	C
Mono-ammonium	C	C	C	X	X	C	C	C
Mono-potassium phosphate	C	C	C	X	C	X	C	C
Potassium sulphate (KS)	C	C	C	L	C	C	X\\\	C
Potassium chloride (KC)	C	C	C	L	C	C	C	X\\\
C = compatible	L=Little compatibility				X = non-compatible			

Nutritive acids such as phosphoric and nitric acids could be mixed with most fertilizers with little risk of precipitates, particularly and they cause a reduction in alkalinity and a raise in acidity of the solution. Location of fertilizer mixing point should be upstream of the irrigation system's filters. This would insure eliminating impurities and suspended materials resulting from the fertilizer liquid **(Boswell, 1990).**

2.11. Positive features of fertigation

There are a number of special features with positive effect from the agriculture viewpoint. Some of these features are related to the technique itself and some are associated with the irrigation system through which it is applied. This is particularly apparent with lands which are recently reclaimed**. Rolston *et al.* (1979)** stated the recognised advantages of fertigation through drip-irrigation as follows: improved efficiency, labor saving, energy saving, flexibility of timing nutrient application crop demand regardless of growth stage, or accessibility of fertilizing machinery.

2.11.1. Uniform and easy application of fertilizers.

Nutrients are applied soluble with water and move within the rhizosphere to plant roots. This is particularly important in newly reclaimed sandy soils, where little colloids retain soluble ions of plant nutrients. In this respect, horizontal as well as vertical movement of water containing fertilizers could be controlled when irrigation systems such as drip and sprinkler are used in order to confine fertilizer application to the wetted zone. If the system is well designed, high degree of uniformity could be attained **(Gascho, 1991).**

2.11.2. Possibility of application regardless of some adverse factors:

Fertigation is not be hindered by factors such as plant height, or adverse weather conditions **(Dasberg *et al.*, 1988).**

2.11.3. Possibility of applying chemicals other than fertilizers in the fertigation solution.

For example pesticides and some soil improving chemicals could be added, which would save the expense of two or more applications **(Koode, 1989 and Aboukhaled, 1991).**

2.11.4. Low operational hazards:

Fertigation can be accomplished with no fertilizer dusts or dangerous gases in the immediate vicinity of the fields, **(Koo, 1984)**, thus lowering operational hazards.

2.11.5. Soil conservation:

Since fertigation requires no need for the use of equipment treading over soil surface (such as equipment spreading fertilizers), it's would reduce soil compaction as well as possible damage to growing plants.

2.11.6. Decreasing the adverse effect of salinity:

Drip irrigation through which irrigation is practiced enables the soil moisture tension to be kept low, thus, concentration of salts in the soil water can be held low **(Bar-Yosef, 1977 and Bresler, 1977).**

2.11.7. Easier control of pests and weeds:

Because of the foliage and great portion of soil surface are not wetted, with drip irrigation allows more efficient and economic control of pests and weeds **(Vermeiren and Jobling, 1984).**

2.12. Nigative features of fertigation

There are some features to fertigation which may be viewed negative. Most of them are associated with features inherent in the irrigation system through which fertigation is practiced (e.g. drip and sprinkler systems). The most important of such features are as followings **(Vermeiren and Jobling, 1984, Randall *et al* 1985):**

2.12.1. High capital expenditure:

Fertigation is a rather high-cost technique which requires a high initial capital expenditure which covers its equipment and devices.

2.12.2. High incidents of clogging:

The drippers and orifices in the irrigation pipe network may exhibit more frequent incidents of clogging. Mixing fertilizer chemicals, may lead to precipitates. Also, since plant nutrients are involved, enhanced micro-organism growth such as algae and bacterial slimes may occur. Under such condition incidents of clogging may occur because of salt precipitates and lumps of microorganism growth.

2.12.3. High incidents of salinity build-up:

Salinity build-up is an inherent property of systems such as the drip irrigation where increased salinity accumulates in the periphery of the water front zone of the wetted soil volume. With the use of dissolved chemical salts in the drip irrigation water (through fertigation), such increased build up of salinity would be enhanced

2.12.4. High need for technical and operational handling:

Using fertigation requires accurate and enlightened decisions since errors in system calibration mixing procedure and mixing rates, and timing may result in crop damage and economic losses.

2.13. Fertigation operations on different crops and soils

Investigations were carried out to compare fertigation with conventional methods of fertilizer application and nitrogen fertigation received the greatest attention**. Bester *et al.* (1977)** used fertigation on orange orchards in South Africa and reported increased N content in fertigated trees in comparison with trees given solid fertilizers. **Phene and Beale (1976) and Phene *et al*. (1979)** reported greater fertilizer use efficiency with fertigation in comparison with solid fertilizer application.

Malik *et al.* (1995) conducted a field experiment on a loamy sand soil in India to study the uniformity of using fertigation with urea through drip irrigation of pea *(Pisum staivum)* and obtained greater efficiency of water as well as fertilizer use in comparison with solid urea application under surface irrigation. **Mohammad *et al.,* (1999)** conducted field experiments in a clay soil in the Jordan valley to evaluate potato response to fertigation using $(NH_4)_2S0_4$ as N source through drip irrigation in comparison with solid fertilizer under surface irrigation. They used N concentration of up to 150 nig

N liter^{-1}. Labeled N^{15} was used to evaluate N recovery and utilization efficiency. They found that N derived from fertilizer was the same regardless of the method of application and yield as well as fertilizer utilization was also rather similar in the two methods.

Faria *et al.* (2000) used fertigation through drip irrigation to tomatoes in Brazil and found that plant growth and fruit yields were greater with fertigation than with the solid fertilizer application.

Papadopoulos (1987) fertigated tomatoes through drip irrigation using concentrations ranging from 90 to 270 mg N/L in the ultimate water of fertigation and obtained increases in soil solution EC, particularly in treatments receiving the high rate of N.

Ibrahim (1992) compared fertigation on tomato using drip or furrow irrigation as well as application of fertilizer in bands under either system. Fertilizers were ammonium nitrate, calcium orthophsphate, and potassium sulphate. The soil was a reclaimed sand dune (a sandy soil), and the crop was tomatoes *(Lycopersicon esculentuni).* Irrigation water was of 2.1 dS m^{-1}. Yields were highest with fertigation through drip irrigation, 50 Mg (Mg = megagram = 106 g)/ha. Fertigation through furrow irrigation gave 43 Mg/ha; banding under drip gave 40

Mg/ha compared with 38 Mg/ha given by banding with furrow irrigation.

Fiskell and Locascio (1983) fertigated tomatoes using urea and ammonium nitrate through drip irrigation and concluded that most of N requirement for the crop could be given by fertigation.

Awad *et al.* (2000) conducted a study on a newly reclaimed sand soil under wheat *(Triticwn aestivum L.)* at El-Bostan desert area, west of Delta Nile, Egypt. They applied N and K fertilizers (urea and K_2SO_4) by fertigation through sprinkler irrigation or by broad casting the solid fertilizers under sprinkler irrigation. Yields were greater by fertigation. In the Libyan desert reclamation projects of center pivot sprinkler irrigation on a coarse sand soils produced up to 7.0 Mg wheat grains/ha using soil application of N, P, and K fertigation with micronutrients **(FDC 1979)**

Buban *et al.* (2002) compared two fertigation regimes on young apple orchards: an interchange NH_4: NO_3 versus a constant one during the season. They found that trunk increment arid shoot mass were increased by the first fertigation regime in some cultivars.

Keng (1978) conducted greenhouse studies on sweet green pepper comparing fertigation with banded and broadcast P and found that fertigation resulted in higher yield than the other used methods. **Keng *et al.* (1979)** reported that fertigation gave 15.8 % more paper yield than the broadcast method.

Alam *et al.* (2000) reported that applying P by fertigation resulted in increased fertilizer use efficiency compared with the pre-sowing broadcast method; and that owing giving half of the P by fertigation produced a grain yield and P-uptake equivalent to that obtained by the full P rate applied through soil application.

2.14. Important aspects on successful Fertigation

Modern irrigation systems, including a fertigation unit, represent a substantial investment for farmer. Therefore, the potential use of the fertigation technology is directly related to the extent to which the farmers are financially awarded by using this technology. The level of increase in production, improvement of quality of product, efficient use of inputs and saving in energy and labour are the main factors which are directly related to the acceptance of the fertigation Increased yield obtained with fertigation might be mainly attributed to the modern irrigation systems.

(Papadopoulos, 1988b and Ibrahim, 1992) reported values for cost of tomato production under drip or furrow irrigation systems using fertigation or banding. Results showed that the lowest cost (in terms of Egyptian pounds "£E" per megagram "Mg" of fruit yield) was 17 £E/Mg given by fertigation with furrow irrigation; the highest was 29£E using banding under drip irrigation. Other values were 20 £E/Mg for banding under furrow and 22 £E/Mg for fertigation under drip. The conclusion was that using fertigation whether under drip or furrow lowered the cost of fruit production per unit weight of produce. Beside the increase in yield with fertigation (by providing carefully balanced nutrient solutions to suit particular growth stages of the crop), the quality of fruit production may improve. Also, fertigation may be an effective way for increasing yield of good quality potatoes. The concentration of $N0_3$-N, in potatoes should not exceed the acceptable level demanded level demanded by law in Europe **(Papadopoulos, 1988b). Nilay *et al.* (2000)** added soluble Fe through fertigation of rice plant and obtained increased Fe content in rice grain.

In this respect, of particular importance is the substantial increase in water use efficiency. **Chopade *et al* (1998)** estimates a range between 30 to 80 % more efficiency due fertigation. In case of using excess irrigation, fertigation may lead to substantial loss of fertilizers particularly of nitrogen, lost by leaching and possible pollution of underground water particularly in sandy soils. However, **Ibrahim (1992)** reported values of water use efficiency (WUE) in terms of liter of water per kilogram of fruits (L/kg) as follows: 4.8 L/kg for fertigation through drip, 3.8 L/kg for banding under drip; 2.8 L/kg for fertigation under furrow, 2.5 L/kg for banding under furrow irrigation. Such results indicate that fertigation was associated with low water use efficiency as compared with solid fertilizer application **(Randall *et al.*, 1985).** Fertigation on some newly reclaimed sandy soils yielded as much as 200 Mg (megagram)/ha of cucumber in regions where yields range between 50 to 80 Mg/ha **(Papadopoulos, 1988b, 1989, 1990 a and 1990b).**

2.14.1. Proper operation:

The irrigation system must work properly, since any failure and/or losses of water cause losses of fertilizer the design and function of the irrigation system must be proper as to ensure uniform water distribution.

2.14.2. Equipment maintenance:

Availability, maintenance and cost of equipment may not be a Float constraints in most countries since reliable and inexpensive equipment, is available.

2.14.3. Cost and availability of fertilizers:

The potential for fertigation expansion on a large scale, depends on the availability of suitable water soluble fertilizers at a reasonable price.

2.14.4. Enlightened water -requirement background:

Sound fertigation is also based on enlightened on background on crop water requirement, since irrigation and fertilization are becoming one unique agricultural practice.

2.14.5. Soil fertility:

The inherited fertility of the soil and the probable residual fertilizers, are important parameters for maximizing fertigation efficiency. In this respect, fertigation should be modified and adjusted according to soil fertility.

2.14.6. Enlightened choice of crops and skill availability

Modern irrigation systems are a substantial investment for the farmer and' their maintenance requires considerable attention. Thus, the crops chosen for cultivation need to be intensively grown so as to assure an acceptable financial return. Fertigation is a relatively new technique which requires more knowledge and skills to operate and maintain with therefore training of workers is indispensable for its success.

2.15. Calculations for fertigation:

Papadopoulos (1996) said that, the concentrated stock solution which it will be in the reservoir of the fertigator can be calculated with the following equation

$$\textbf{Dilution Factor} = \frac{\textbf{Flow rate of the irrigation system}}{\textbf{Flow rate of the fertigatior}}$$

$$C = \frac{F.DF.N.100}{a} \quad \textbf{Eq. 40}$$

Where:

C = Weight of the fertilizer in g in the stock solution

F = Desired concentration of a nutrient in the irrigation water (g / m^3)

N = Volume of the reservoir for the stock solution (m^3)

a = % of a pure nutrient in the fertilizer

DF = Dilution Factor

$$Q_{pump} / Q_{inj} \quad \textbf{Eq. 41}$$

$$F = F_r / W_R \quad \textbf{Eq. 42}$$

Where:

Q_{pump} = Flow rate of the irrigation system, m^3 / hr.

Q_{inj} = Flow rate of the fertigatior, m^3 / hr.

F_r = fertilizer required, g / f.

W_R = water requirement, m^3 / f.

According to **Montag, (1999)** the mass of soil root zone can be calculated from the following relation:

$$S_{Weight} = 4200\ Z_{rm}\ \gamma_b /\ 100$$ **Eq.43**

Where:

S_{weight} mass of soil root zone, ton.

γb= soil denisity, ton / $m^3 Z_{rm}$ = root depth, cm.

Also, we can determind the available nuitrent in soil root zone from the following relation:

$$n_{av} = (S_{n\ Content} - n_{Cv})\ S_{Weight}\ /\ 1000$$ **Eq.44**

Where:

n_{av} = the avialble nuitrent in soil root zone, kg.

$S_{n\ content}$ = soil content from nuitrent, kg.

n_{cv} = the critical value of nuitrent in soil

The available soil content from nutrient can be determind from the following equation

$$n_{actsoil} = n_{av}\ Pw$$ **Eq. 45**

Where:

$N_{actsoil}$ = soil content from nuitrent in wetting area, kg.

P_w = percente of wetting area.

The actual amont of required fertilizers can be calculated from the following equation:

$$n_{addAct} = \frac{n_{actsoil}\,100}{N_{Ad\ Eff}}$$ **Eq.46**

Where:

N_{addAct} = the actual amont of required fertilizers, kg.

$N_{Ad\ Eff}$ = the adsorption efficiency, %.

2.16. Expert Systems:

2.16.1. Definitions

Waterman (1986) defined the Expert System (ES) as a computer program designed to emulate logic and reasoning process that expert would use to solve a problem in his field of expertise, by using artificial intelligence technology. It performs many functions as an expert does, such as posing relevant questions explaining its reasoning process.

Robinson and Frank (1987) clarified that one of the newer methods using computer for solving practical problems in agricultures is through the use of expert system. The name comes from the idea that the computer system is programmed to simulate an expert in communication with a client who has a problem to be solved.

Parsaye and Chignell (1988) defined an ES as a sophisticated program that relies on a body of the knowledge to perform a somewhat difficult task usually performed by a human expert. The principal power of ES is derived from the knowledge, the system embodies rather than from search algorithms and specific reasoning methods.

Kourtz (1990) defined an ES as a sophisticated computer program that is in some ways mimics the problem solving process used by an expert. The system contains both the body of the specific knowledge and the rules of thumb for solving problems.

Toister *et al.* (1992) defined the expert system (ES) as a computer program designed to emulate logic and reasoning processes that expert would use to solve the problem in his field of interest, by using artificial intelligence technology. Artificial Intelligence is a new science that deals with the representation, automatic acquisition and use of knowledge. The goal of artificial intelligence is to make computers more useful for reasoning, planning, acting and communicating with humans.

Dunkin (1994) stated that the computer program that designed to modulate the problem solving ability of a human expert is called expert system. This system has to have two principle modules: 1) a knowledge-base that contains highly specialized knowledge in the field of a problem as provided by the domain expert. It includes problem facts, rules, concepts and relationships; and 2) an inference engine that is the knowledge processor that is modeled after the expert's reasoning. The engine works with available information on a given problem coupled with the knowledge stored in the knowledge base to draw conclusions or recommendations.

Rafea (1998) reported that an expert system (ES) is a computer program designed to simulate the problem solving behavior of an expert in a narrow domain or discipline.

2.15.2. Advantages of expert systems

Expert systems are computer programs that enable a computer to mimic an expert in helping peoples to diagnosis problems; select among alternatives and plan and manage operational systems. On the other hands, conventional computer programs are algorithmic in nature and will not entail subjective information. Table (2-4) summarizes the differences between expert systems and other conventional computer programs.

Nebandahl (1988) reported some features and advantages of expert system programs which can be listed as follows:

1- Use rules, heuristics and other techniques to represent knowledge in a symbolic manner.

2-Has the ability to effectively integrate procedural; judgmental or preferential and uncertain information.

3- Interacts with human in ways that are suitable to understand.

4- Contains a knowledge-base or specific decision domain that is in a large measure distinct from the inference mechanisms.

5-Contains an inference engine or inferential reasoning capability that is in a large measure distinct from the knowledge base.

Hassan and Sharaf (1997) speculated that the advantages of an expert system over other conventional programming techniques lie on their ability to integrate subjective; objective and uncertain information. Also, they added that a good ES program can make decision or give advice equivalent to those of human expert in a specific area of expertise.

Rafea (1998) and Waterman (1986) stated that expert systems are sophisticated computer programs that manipulate knowledge to solve the problems efficiently and effectively in narrow problem areas. However, these programs have some advantages over human expertise as: it is permanent; consistent; easy to transfer, documented and cheaper.

Meanwhile**, Awady (2010), Kabany (2003) and Dent and Jones (1989)** reported some advantages of ES programs that may be summarized as follows:

Table (2-4): Expert systems versus conventional computer programs

Expert systems	**Conventional programs**
Involves heuristics	Involves algorithmic processing
Represents and use knowledge	Represents and use data
Effectivly manipulate large knowledge bases	Effectivly manipulate large databases
Run-time explanations desirable and achievable	Run-time (mid-run) explanations may not be possible
Can function with incomplete set of information	Require complete set of data
Experienced-based information, assumptions; other rules-of- thumb can be easily represented	Practical experience may not be entailed in the solutions
Provides conclusions from the stored information	Does not provide conclusions from the results

1-Minimizing or avoiding errors in complex tasks;
2-Protecting the perishable knowledge of experts and make it available and where required;
3-Systematically considering all possible alternatives;
4-Displaying unbiased judgment;
5-Immediately available for use unlike human experts; and
6-Less expensive to consult than human experts.

2.15.3. Classes of an expert systems

A detailed review on the earlier expert systems in agricultural systems and its classes have been seen in **Davis and Clark (1989); Jones (1989); Lambert and Wood (1989) and Peart *et aL* (1986).** They stated that ES techniques has been the emerging area in the last two decades and is being applied to agricultural systems and natural resource management. These systems fall on one of the following classes of problems: interpretation; consultation; diagnosis; monitoring; planning; design and management.

On the other hands, **Murase (2000); Mohan and Arumugan (1995) and McKinion and Lemmon (1985)** stated that ES applications' in general' may be fall under three classes namely: expert systems proper; intelligent front-ends and hybrid systems.

* **An expert system proper** is a purely rule-based system relying on a sizable knowledge base. It is based on a quantitive' causal understanding of how things work. Such a system is more suitable under situations wherein not much quantitive data are used. It is essentially conceptual and heuristic rule-

based system.

* **An intelligent front-ends** is a user friendly interface to a software package that enables the user tointer act with the computer using the user terminologies. It minimizes or avoids misuse of complex models by less experienced users. This class of ES is applied under situations wherein a range of procedures or methods exists.

* **A hybrid system** "it is also referred as model-based expert system by **Jones (1989)**" represents the integration of algorithmic techniques with EX concepts. The basic idea of this expert system is to incorporate the data knowledge and heuristics that are relevant to a given area into a software system.

In addition to these classes, expert systems are used as supporting systems and are henceforth referred to as supporting expert systems. This kind of expert systems is primarily linked with a large databases and also geographical information systems. It may be noted that a geographical information systems integrates spatially referenced data in a problem solving environment.

2.15.4. Building an expert system

Whittaker *et al.* (1987); Waterman (1986) and Hays-Roth *et al*, (1983) presented five development stages of the expert systems. These stages include: identification of the problem, conceptualization; formalization; implementation and verifying and validation. This methodology represents an attempt by experienced knowledge engineers to characterize the complex process that takes place during the development process, also, these stages are highly interrelated and interdependent.

They also added that building an ES involves recycling through the development process stages. This iterative process continues until the system consistently and correctly produce appropriate solutions. Moreover, these stages represent an organized method of discussing the key concepts and components involved in the development process.

Rafea (1998); Popov *et al.* (1996); Hassan (1995); Schalkoff (1990); Nebandahl (1988) and Jones (1985) reported some basic concepts that have to be taken into consideration while building an expert system program. These concepts namely: goals; knowledge-base components; inference engine; production rule functions and user interface. A goal is one of many possible conclusions or end results from a line of reasoning. A **knowledge-base** includes both domain facts and heuristics. This component part is usually developed with assistance from at least one human domain expert. Facts of the domain constitutes a body of information widely shared and generally publicly available within the domain. Heuristics include rule-of-thumbs; judgements and sometimes experience based guesses that typically characterize a human expert level decision making. **An Inference engine** contains the general problem solving approaches. It decides which heuristics are applied to the problem, accesses the appropriate rules in the knowledge-base, executes the rules and determines when an acceptable solution has been found. It uses the production-rule-function and other information in the knowledge-base, as well as, a user supplied data. **A production-rule-function** is a conditional-conclusion pair that represents reasoning logic. Typically these rules are in the form of **IF** (condition) **THEN** (conclusion). The production-rule-function is the part of knowledge-base to provide computer branching (or searching) for

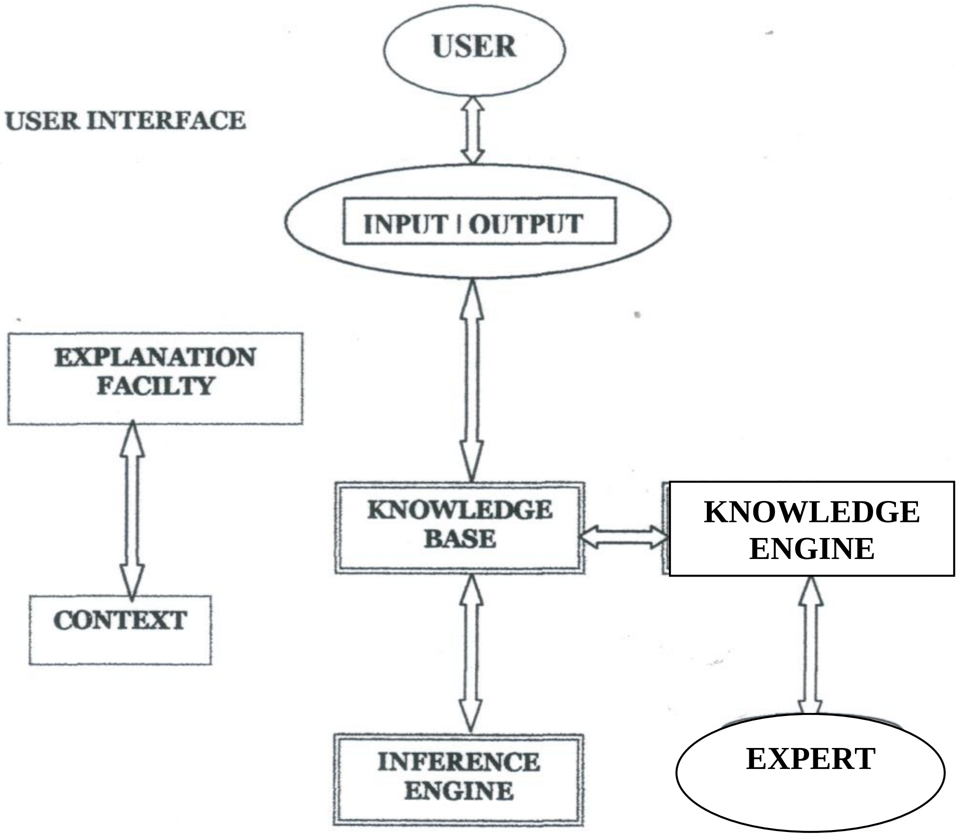


Fig. 2.1: Components of an expert system.

2.15.5. Verifications and Validations of Expert Systems

Syn (1982) stated that validation determines if the ES model in hand is on accurate representation of the real-world system under study.

Ostergrad (1992) stated that if expert systems are not tested against real problems in the field, then they can not be truly calibrated. It should be noted that the performance of ES is primarily related to how effectively the knowledge is acquired and incorporated. Any inadequacy in the collection and representation of knowledge will drastically affect the system performance and its reliability. This problem can be avoided by involving more domain experts and evaluating the ES to make necessary modifications. He also added that for the validation process of the expert system, the dominate method is using test cases previously solved by the expert and/or new cases.

Rafea and Shaalan (1996) reported that validation is the process of evaluating software at the end the software development process to ensure compliance with software requirements. Typically validation is more complex than verification. The validation process aims at making sure that the expert system is valid from the point of view of the domain expert. Meanwhile, verification is the demonstration of the consistency, completeness and correctness of the software. It should be done at the end of each phase of the life cycle. So, it is also the process of determining weather or not the products of a given phase of the software development cycle fulfill the requirements established during the previous phase.

2.15.6. Applications of ES in on-farm irrigation

Expert system concepts can be used as an integration of model results, expert knowledge and data for many applications in agriculture. The successful agricultural applications of ES are those which integrate these methods with mathematical modeling, simulation and optimizing data base management and other system analysis tools for problem-oriented research.

In general, however, ES may obtain data from real time sensors, from historical data base and from simulation models. The REACtOR expert system was designed to receive data directly from nuclear reactor plant instrumentations well as the plant operator to diagnose and treat accidents.

In the domain of irrigation, there have applications of expert systems such as: irrigation scheduling, irrigation systems evaluation, selection of pumps, selection and design of sprinkler irrigation systems, irrigation systems operation and fault diagnosis.

Kline *et al.* (1986) developed expert system, FINDS, On-farm irrigation management. FINDS combine the analytical strength of linear programming and simulation models with a knowledge-based expert system. FINDS automatically utilizes the coupled LP and simulation models where appropriate and interprets the relevant output to recommend the optimal machinery management practices. Optimal irrigation recommendations are based on the farm returns that are obtained and the level of risk that is acceptable to user. FINDS can also provide detailed explanations of the reasoning behind its machinery selection.

Bennett *et al.* (1988) said that expert systems have been used to aid farmers in their land management tasks such as machine selection and evaluation of irrigation system alternatives.

Witney (1988) mentioned that optimum On-farm irrigation management is achieved when the overall profitability of the farm business is maximized. This economic goal is not necessarily equivalent to minimizing irrigation costs for a number of reasons. Different enterprises demand different tractor-power combinations, and optimum utilization may require area adjustments which are unacceptable for reasons of crop rotation.

Clark *et al.* (1989) built and validate an expert system called IRRIGATOR for irrigation scheduling based on the available soil water and the rain fall probability.

Kourtz (1990) stated that the field of Artificial Intelligence (AI)can be broken into many sub-fields. One of the most immediate interest to irrigation management is Expert System. Expert System is often needed to implement Linear Programming and Simulation models and for an accurate interpretation of the model outputs. Scarcity of these experts makes it difficult to utilize Linear Programming and simulation techniques for farm irrigation systems. Expert system technology offers a possible solution for making linear programming and simulation models more accessible to decision makers, but the difficulties are the cost associated of building it and more time consuming to build it. Small expert systems can be developed on common microcomputers using existing low-cost commercial expert shells. Shells are general expert systems empty of knowledge.

Hawkins and Burt (1990) developed an expert systems called AGWATER for irrigation systems management based on the combinations of soil properties, plant water requirements, irrigation system design and irrigation scheduling.

Meanwhile**, Srinivasan *et al* (1991)** development an ES called ESIM for making decisions on water management of any irrigation project, based on the statistical analysis of flow rates. They suggested a new index called probabilistic scheduling index for a particular type of scheduling it was derived by dividing fixed *arranged*\\ demand. Outputs were found to be reasonable, demonstrated and could be assist in improving water management decision for irrigation projects.

Didan (1991) developed an expert system with a set of external programs to accomplish the drip irrigation system design. In addition, to simulate the human expert, a new drip irrigation design evaluation factor has been introduced (Design Success Indicator, **DSI**) in order to estimate the system response on field developing on the confidence of data being used.

Wilmes *et al.* (1994) developed a decision support system package for selection of center pivoting system depend on soil types, water and energy uses.

Hassan (1995) developed a decision support system for planning, selection, design, evaluation and management of different sprinkler irrigation systems. It depended on physical resources as: farm features (field size and sharp, topography, obstructions, soil type and texture), crop properties (crop type, height and root depth), labors (availability and quality), climatic conditions and costs.

Mohan and Arumugan (1995) developed an intelligent from end expert system called ETES to select an appropriate ET estimation method under certain situations. It was based on the location, data available of soils and climatic conditions.

Awady and Ahmed (1996) developed an algorithmic computer program for prediction of farm trickle irrigation layouts. The optimum plan is terms of various affeding variables are input to the computer by the user as choice of numerical ranges.

Thomson (1996) developed a computer-based decision support system to facilitate soil moisture sensor use and to provide interpretation for the farm manager to ensure efficient irrigation scheduling. The system detects the bottom of the root zone by relative drying responses indicated by sensors placed at several depths. In this way, the system could adjust water amounts according to an expanding root system.

Hassan and Sharaf (1997) developed a computer based decision support system **(DSS)** for evaluating micro-irrigating (localized) systems. They stated that conventional information sources regarding evaluation keys and its calculations were considered in developing the expert system. Input data included crop, soil, irrigation, dripper type and discharge rate, mean while, outputs recommended some remedial action to improve the system performance.

Yitayew *et al.* (1999) developed a microcomputer program called BUBBLER for low head gravity bubbler irrigation system and analysis. It works DOS environment, takes minimal data inputs as elevation of the water resource, crop and row spacing, field and the elevation of the four corners of the field. Outputs include the mainline, sub-main, lateral size, delivery hose size, delivery hose elevations and cost estimations.

Ismail *et al.* (2001) built-a program in V-BASIC called micro-CAD for helping in a trickle irrigation system design. Functions in planning the network layout, hydraulic design and calculations of system costs. The model, supported by some data bases like the common emitters data, crop properties, land zone climatic and physical properties data base.

Awady *et al.* (2002) reported some criteria concerning the selection processes of irrigation system in certain situations depending on farm resources (soil, water, crop, labors, energy and costs). Also, they added that the validation cases proved the integrity of the ES constructed that gave the best practice in judging extreme cases and anticipated variants in between.

Kady (2003) developed an ES for selecting and managing the appropriate sprinkler irrigation systems under the newly reclaimed areas of Egypt. Also, this program can help in the calculation of crop water requirements under certain extreme conditions.

Kabany (2003) reported that the applications of ES in agriculture were developed that broke new ground agriculture software and gave agriculture high tech help for greater profitability. Also, he added that ES applications should be sold to and used by farmers or may be used by the experts themselves including consultants and advisory specialists. A significant number will be used by other specialists in research, extension and agribusiness.

Arafa *et al* (2004) built an expert system called LIS-ES for application priorities of localized irrigation systems under diverse conditions of the newly reclaimed lands in the northwestern regions of Egypt. They speculated that surface drip irrigation system has the majority for application under different soils and crop patterns. Meanwhile, bubbler and low-head-gravity-flow bubbler irrigation systems have the advantages for application under orchard crops, whenever, irrigation water is low in quality and soils are affected by both salinity and high levels of calcium carbonate fractions.

EI-Bagoury *et aL* (2004) developed an expert system named ISS-ES for irrigation water scheduling for maize crop under drought conditions of Egypt. They stated that statistical analysis can be used efficiently for validation process of expert system programs. Also, they added that there is no significant effect between ISS-ES outputs and hand calculations which had been done by irrigation specialists for calculating the crop-water requirements all over the growing stages of maize crop.

MATERIALS AND METHODS

3. MATRIALS AND METHODS

To establish an expert system able to assist decision makers in the proper management of fertigation systems, the following steps were carried out:

1. Building the expert system
2. Conducting field and laboratory experiments
3. Validation of the built expert system.

The following materials were used to design the fertigation expert system program:

Microsoft visual C#.net 2005

Microsoft Access 2003

Pc. Pentium 4.

3.1 Building the Expert system (ES)

The following steps were conducted to build the expert system.

3.1.1 Identification of the problem

The problem of this study was to define and exactly determine the most important parameters affecting irrigation and fertilization management, such as soil, crop and water relationships, irrigation system performance, fertilizer application methods and fertilizer material properties. By identifying the parameters, collecting the related information were started.

3.1.2 Conceptualization

This process involves the information analysis and identifying the decision making process and activities related to the application priorities of fertigation under different farm systems.

3.1.2.1. Required Concepts

Soil properties

The following properties were investigated under this study: texture of the soil, soil type, soil bulk density, soil salinity, field capacity, welting point, pH of soil, the percentage of calcium carbonate in soil, cation exchange capacity, soil content of available nitrogen, soil content of available phosphorus, soil content of available potassium, the critical nitrogen in soil, the critical phosphor in soil, the critical potassium content in soil and soil type test as shown in Tables (7.1, 7-2 and 7-5) in the Appendix.

Water properties

The following properties were investigated under this study: water salinity, pH of water, content of nitrogen, phosphor, potassium, calcium and magnesium contents in irrigation water as shown Tables (7.2 and 7-6) in the Appendix.

Climate conditions

The following climate parameters were collected and analyzed: average temperature, average relative humidity, actual sunshine hours, maximum sunshine hours, extra radiation, maximum relative humidity, mean wind speed, day wind speed, night wind speed, average temperature for next month, average relative humidity for next month, actual sunshine hours for next month, maximum sunshine hours for next month and extra radiation (Climate data of Qalubiya Governorate, average values for the period extending from 1997 until 2006, CLAC, 2007) Tables (7-4 and 7-7) in the Appendix.

Crop properties

The following crop characteristics were investigated : the length of the initiation stage in days, the length of the vegetative stage in days, the length of the middle stage in days, the length of the harvest stage in days, plant age, Kc in initial stage, Kc in development stage, Kc in middle stage, Kc in late stage, the height of plant, distance between plants, moisture content in plant, water depletion, the maximum root depth, the nitrogen , phosphorus and potassium requirement for the crop type table in Appendix (7-8).

Farm conditions

Farm location parameters (latitude, altitude and longitude), farm area, farm type and type of irrigation system were collected and recorded as data base, Table (7-9) in the Appendix.

Fertilizer properties

Fertilizer type, fertilizer density, the percentage of nitrogen, phosphor i and potassium contents in each fertilizer were recorded as data base, Table (7-10) in the Appendix.

Manure properties

The quantities of nitrogen , phosphorus and potassium in manure , as well as the weight and the volume of manure that may be required for certain crop were obtained and recorded in the data base, Table (7-11) in the Appendix.

Irrigation system

The type of irrigation system, injection device, discharge of pump, the efficiency of irrigation system, the wetted area, the fertilizer injection rate, the volume of fertilizer tank, the efficiency of nitrogen , phosphorus, and potassium Absorption and advance time of water flow were investigated and analyzed table in Appendix (7-12).

Crop tolerance for salinity expressed as EC:

The EC of soil in which the crop yield 100% (no yield reduction), the soil EC in which the crop yield decreases by 10 %, the soil EC in which the crop yield decreases by 25 %, the soil EC in which the yield of plant decreases by 50 %, the maximum soil EC that plant can’t servive after it, the EC of irrigation water in which the crop yield decreases were recorded

Fertilizer selection

The proposed expert system was able to choose the right fertilizerس according to the factors tested in this study. It was able to determine nitrogen, phosphorus and potassium fertilizer Table (7-14) in the Appendix

3.1.3 Formulation

Formulation involves characterizing the variables; the key factors and qualifiers for fertigation technique under diverse farm situation and conditions. Therefore, this procedure involves the representation of the variables; key factors and qualifiers into the production rules that make it usable within the development environment of the construction of the expert system rule-based program. Easiest and best ways to represent knowledge and data analysis is the development of knowledge and data as rules.

3.1.3.1 Required rules

In the following sub-sections, the list of rules that are required for using the generic irrigation model will be detailed. For each rule, a description as well as the required output will be described. Though, in some cases an input might also be outlined, the expert system designer is free not to use that particular input, or to use other inputs as long as the specified output results from the relation.

Rules between soil texture and soil test type:

These rules are used to determine the value of critical P content which may be 14, 23, 26, 30, 35, 42, 58 or 90 **mg . kg^{-1} (Victoria, 2010)**. Table (3-1) shows the rules used under this study in terms of soil texture and soil type to obtain the value of critical phosphorus content.

Table (3-1): Rules among soil texture, soil test type and critical phosphorus content (in mg . kg^{-1}).

Relation	Condition	Action
R1	If soil texture = sandy and soil test type = Colwell P (mg/kg)	Critical P = 23
R2	If soil texture = sandy loam and soil test type = Colwell P (mg/kg)	Critical P = 26
R3	If soil texture = silty loam and soil test type = Colwell P (mg/kg)	Critical P = 30
R4	If soil texture = silty clay loam and soil test type = Colwell P (mg/kg)	Critical P = 35
R5	If soil texture = clay loam and soil test type = Colwell P (mg/kg)	Critical P = 42
R6	If soil texture = clay and soil test type = Colwell P (mg/kg)	Critical P = 58
R7	If soil texture = volcanic clays & Peat and soil test type = Colwell P (mg/kg)	Critical P = 90
R8	If soil test type = Olsen P (mg/kg)	Critical P = 14

Relation between soil texture and critical potassium (Victoria, 2010):

This relation is used to determine the value of critical K content which can be 120, 130 or 150.

Table (3-2): Relation between soil texture and critical potassium content in (mg . kg^{-1})

Relation	Condition	Action
R1	If soil texture = Sandy	Critical K = 120
R2	If soil texture = Sandy loam	Critical K = 120
R3	If soil texture = Silty loam	Critical K = 130
R4	If soil texture = Silty clay loam	Critical K = 130
R5	If soil texture = Clay loam	Critical K = 150
R6	If soil texture = Clay	Critical K = 150
R7	If soil texture = Volcanic clays & Peat	Critical K = 150

Relation between soil texture and soil type (El-Beltagy, *et. al.*, 2004)

This relation is used to determine the value of soil type which can be fine, coarse or medium.

Table (3-3): Relation between soil texture and soil type.

Relation	Condition	Action
R1	If soil texture = (clay , clay loam , silty clay or silty clay loam)	soil type = fine
R2	If soil texture = (sandy clay , silt loam or silty loam)	soil type = medium
R3	If soil texture = (sandy clay loam , sandy loam , sand or loamy sand)	soil type = coarse

Relation between type of irrigation system and irrigation efficiency

This relation is used to determine the value of irrigation efficiency which can be 90, 70 or 65.

Table (3-4): Relation between type of irrigation system and irrigation efficiency (Moon and Van der Gulik, 1996).

Relation	Condition	Action
R1	If Irrigation system = Drip irrigation	Irrigation efficiency = 90
R2	If Irrigation system = Sprinkler irrigation	Irrigation efficiency = 70
R3	If Irrigation system = Surface irrigation	Irrigation efficiency = 65

Relation between type of irrigation system and wetting area

This relation is used to determine the value of welting area which can be 0.35 or 1.

Table (3-5): Relation between type of irrigation system and the wetting area.

Relation	Condition	Action
R1	If Irrigation System = Drip irrigation	wetting area =0.35
R2	If Irrigation System = Sprinkler irrigation	wetting area =1
R3	If Irrigation System = Surface irrigation	wetting area =1

Relation among type of irrigation system, soil type and nitrogen Absorption efficiency (FAO/RNEA, 1992)

This relation is used to determine the value of Absorption efficiency of nitrogen which can be 85, 80, 75, 70, 65, 60, 50 or 40.

Table (3-6): Relation among type of irrigation system, soil type and nitrogen Absorption efficiency (expressed as %)

Relation	Condition	Action
R1	If Irrigation system = Drip irrigation and soil type = fine	85
R2	If Irrigation system = Drip irrigation and soil type = medium	80
R3	If Irrigation system = Drip irrigation and soil type = coarse	75
R4	If Irrigation system = Sprinkler irrigation and soil type = fine	70
R5	If Irrigation System = Sprinkler irrigation and soil type = medium	65
R6	If Irrigation system = Sprinkler irrigation and soil type = coarse	60
R7	If Irrigation system = Surface irrigation and soil type = fine	60
R8	If Irrigation system = Surface irrigation and soil type = medium	50
R9	If Irrigation system = Surface irrigation and soil type = coarse	40

Relation among type of irrigation system, soil type and phosphorus Absorption efficiency (FAO/RNEA, 1992)

This relation is used to determine the value of Absorption efficiency of phosphorus which can be 35, 30, 25, 20, 15 or 10.

Table (3-7): Relation among type of irrigation system, soil type and phosphorus absorption efficiency

Relation	Condition	Action
R1	If Irrigation system = Drip irrigation and soil type = fine	35
R2	If Irrigation system = Drip irrigation and soil type = medium	30
R3	If Irrigation system = Drip irrigation and soil type = coarse	25
R4	If Irrigation system = Sprinkler Irrigation and soil type = fine	25
R5	If Irrigation system = Sprinkler irrigation and soil type = medium	20
R6	If Irrigation system = Sprinkler irrigation and soil type = coarse	15
R7	If Irrigation system = Surface irrigation and soil type = fine	20
R8	If Irrigation system = Surface irrigation and soil type = medium	15
R9	If Irrigation system = Surface irrigation and soil type = coarse	10

Relation among type of irrigation system, soil type and potassium Absorption efficiency (FAO/RNEA, 1992)

This relation is used to determine the value of Absorption efficiency of potassium which can be 90, 85, 80, 75, 70, 67.5 or 60.

Table (3-8): Relation among type of irrigation system, soil type and potassium Absorption efficiency

Relation	Condition	Action
R1	If (irrigation system = Drip irrigation and soil type = fine)	90
R2	If (irrigation system = Drip irrigation and soil type = medium)	85
R3	If (irrigation system = Drip irrigation and soil type = coarse)	80
R4	If (irrigation system = Sprinkler irrigation and soil type = fine)	80
R5	If (irrigation system = Sprinkler irrigation and soil type = medium)	75
R6	If (irrigation system = Sprinkler irrigation and soil type = coarse)	70
R7	If (irrigation system = Surface irrigation and soil type = fine)	75
R8	If (irrigation system = Surface irrigation and soil type = medium)	67.5
R9	If (irrigation system = Surface irrigation and soil type = coarse)	60

Relation between farm type and used equation of evapotranspiration (El- Beltagy, *et. al., 2004)*

This relation is used to select the equation of ET_O which can be Penman-montith or Hargrives.

Table (3-9): Relation between farm type and used equation of evapotranspiration

Relation	Condition	Action
R1	If (farm type = open_field)	Et_o = Eto_Benman-Montith
R2	If (farm type = low_tunnel)	Et_o = Eto_Benman-Montith
R3	If (farm type = high_tunnel)	Et_o = Eto_Hargraves

Relation between calcium carbonate content and reduction factor (Al-Shorbagi, 2004)

This relation is used to determine the value of reduction factor of fertilizer which can be 0.9 or 1.

Table (3-10): Relation between calcium carbonate content and reduction factor (RF)

Relation	Condition	Action
R1	If (calcium carbonate >=10 %)	RF = 0.9
R2	If (calcium carbonate <10 %)	RF = 1

Relation between plantation stage and crop factor (According to Allen et al. (1996), Neale (1996) and ASCE (1996))

This relation is used to determine the value of Kc which can be Kc-Inti, Kc_Dev, Kc_midAdj or Kc_endAdj.

Table (3-11): Relation between plantation stage and crop factor (Kc)

Relation	Condition	Action
R1	If (stage name = initial_stage)	Kc = Kc-Inti
R2	If (stage name = develop_stage)	Kc = Kc_Dev
R3	If (stage name = mid_stage)	$Kc = Kc\_Mid_{(table)} + [(0.04 \times (u_2 - 2) - 0.004 \times (RH_{min} - 45))] \times (h_p / 3)^{0.3}$
R4	If (stage name = end_stage)	$Kc = Kc\_End_{(table)} + [(0.04 \times (u_2 - 2) - 0.004 \times (RH_{min} - 45))] \times (h_p / 3)^{0.3}$

Relation among electrical conductivity for soil “ECe”, electrical conductivity for irrigation water “ECiw”, crop tolerance electrical conductivity and yield predicted factor

This relation is used to determine the value of yield predicted factor which can be 1, 0.9, 0.75, 0.5 or 0.25.

Table (3-12): Relation among electrical conductivity for soil “ECe”, electrical conductivity for irrigation water “ECiw”, crop tolerance electrical conductivity and plantation Predicted factor

Relation	Condition	Action
R1	If ((EC + ECiw) <= (ECw100 + ECe100))	1
R2	If (EC + ECiw > (ECw100 + ECe100) and EC + ECiw <= (ECw90 + ECe90))	0.9
R3	If (EC + ECiw > (ECw90 + ECe90) and EC + ECiw <= (ECw75 + ECe75))	0.75
R4	If (EC + ECiw > (ECw75 + ECe75) and EC + ECiw <= (ECw50 + ECe50))	0.5
R5	If (EC + ECiw > (ECw50 + ECe50) and EC + ECiw <= (ECw0 + ECe0))	0.25

Relation between previous crop and nitrogen added for crop

This relation is used to determine the amount of nitrogen that should be added for crop

Table (3-13): Relation between previous crop and crop content from nitrogen

Relation	Condition	Action
R1	If (previous crop= vegetable)	Nitrogen added = (F add)* × plantation optimum yield × Yield predicted factor × 0.85
R2	If (previous crop= grouses)	Nitrogen added = (F add)× plantation optimum yield × Yield predicted factor × 1.15
R3	If (previous crop= other)	Nitrogen added = (F add) × plantation optimum yield × Yield predicted factor × 1

* see model of fertilizer requirement

Relation between irrigation system and leaching requirement (Pereira, et. al., 1999)

This relation is used to determine the value of leaching requirement.

Table (3-14): Relation between irrigation system and leaching requirement

Relation	Condition	Action
R1	If (irrigation system = Drip irrigation)	$LR = (ECiw / (2 \times ECe0)) \times 0.9$
R2	If (irrigation system = other)	$LR=(ECiw / ((5 \times 1.5\times ECiw) - ECiw)) \times 0.9$

Relation between water consumptive use and depletion (Ismail, 2002)

This relation is used to determine the value of corrected depletion needed to add for plant.

Table (3-15): Relation between water consumptive use and depletion

Relation	Condition	Action
R1	If (ETc <= 3)	Deplation_Kc = Deplation × 1.3
R2	If (ETc >= 8)	Deplation_Kc = Deplation × 0.7
R3	Else	Deplation_Kc = Deplation × 1

Relation among planting season, growth stage, fertilizer type and fertilizer add factor (Kn)

This relation is used to determine the value of filtilizer add factor depletion needed to add for plant.

Added factor (Kn) is determind value for regration of fertilizer application from the average of fertilizers required.

Table (3-16) Relation among planting season, growth stage, fertilizer type and fertilizer added factor (Kn)

This relation is used to determine the value of fertilizer add factor for plant (Kn).

Relations	Condition	Action
R1	If (season = summer , stage = initial and fertilizer = nitrogen)	0.945
R2	If (season = summer , stage = mid and fertilizer = nitrogen)	1.23
R3	If (season = summer , stage = late and fertilizer = nitrogen)	0.825
R4	If (season = summer , stage = initial and fertilizer = phosphorus)	1.2
R5	If (season = summer , stage = mid and fertilizer = phosphorus)	1
R6	If (season = summer , stage = late and fertilizer = phosphorus)	0.8
R7	If (season = summer , stage = initial and fertilizer = potash)	0.82
R8	If (season = summer , stage = mid and fertilizer = potash)	0.95
R9	If (season = summer , stage = late and fertilizer = potash)	1.23
R10	If (season = winter , stage = initial and fertilizer = nitrogen)	0.7
R11	If (season = winter , stage = mid and fertilizer = nitrogen)	1.37
R12	If (season = winter , stage = late and fertilizer = nitrogen)	0.93

R13	If (season = winter , stage = initial and fertilizer = phosphorus)	1.2
R14	If (season = winter , stage = mid and fertilizer = phosphorus)	1
R15	If (season = winter , stage = late and fertilizer = phosphorus)	0.8
R16	If (season = summer , stage = initial and fertilizer = potash)	0.8
R17	If (season = summer , stage = mid and fertilizer = potash)	1
R18	If (season = summer , stage = late and fertilizer = potash)	1.2
R19	If (season = autumn , stage = intial and fertilizer = nitrogen)	0.99
R20	If (season = autumn , stage = mid and fertilizer = nitrogen)	1.23
R21	If (season = autumn , stage = late and fertilizer = nitrogen)	0.78
R22	If (season = summer , stage = initial and fertilizer = phosphorus)	1.2
R23	If (season = summer , stage = mid and fertilizer = phosphorus)	1
R24	If (season = summer , stage = late and fertilizer = phosphorus)	0.8
R25	If (season = summer , stage = initial and fertilizer = potash)	0.81
R26	If (season = summer , stage = mid and fertilizer = potash)	1.03
R27	If (season = summer , stage = late and fertilizer = potash)	1.22

3.1.3.2 Inference Knowledge

The design of inference knowledge for expert system technique consists of two main parts namely: inference structure and inference specification. (**Rafea, 1998**).

As shown in Fig. 3.1 the inference structure includes five inference steps. These were to:

1- Connect to the database
2- determine the evapotranspiration

3- determine water consumptive use
4- determine water requirement
5- determine concentration of fertilizer in irrigation water

3.1.4. Implementation

A computer program was designed to represent and analyze fertigation data by using Visual C#.net language. The flow chart of this program is shown in Fig. 3.2.

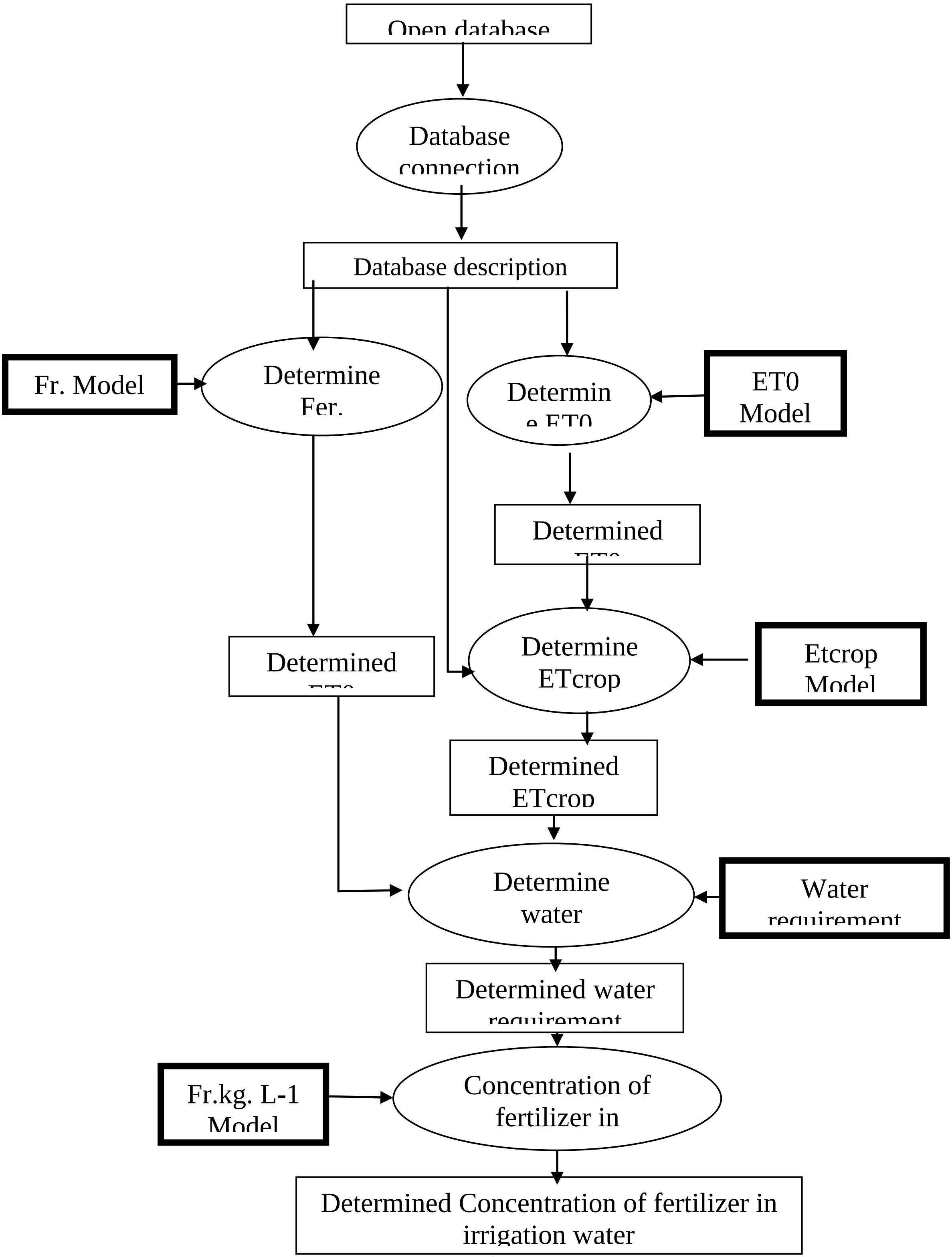


Fig. 3.1: Inference structure.

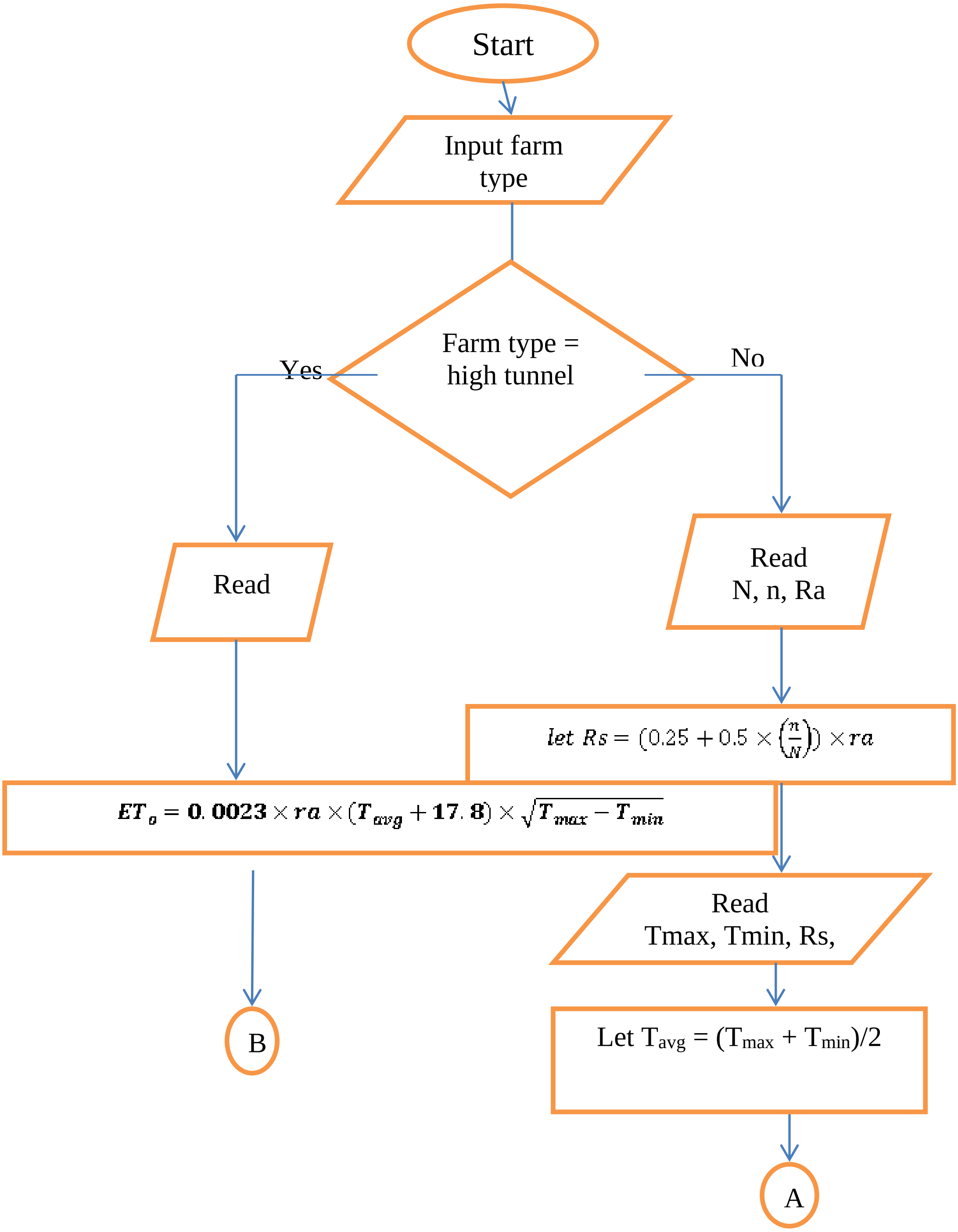


Fig. 3.2: Flow chart for OA-fertigation program.

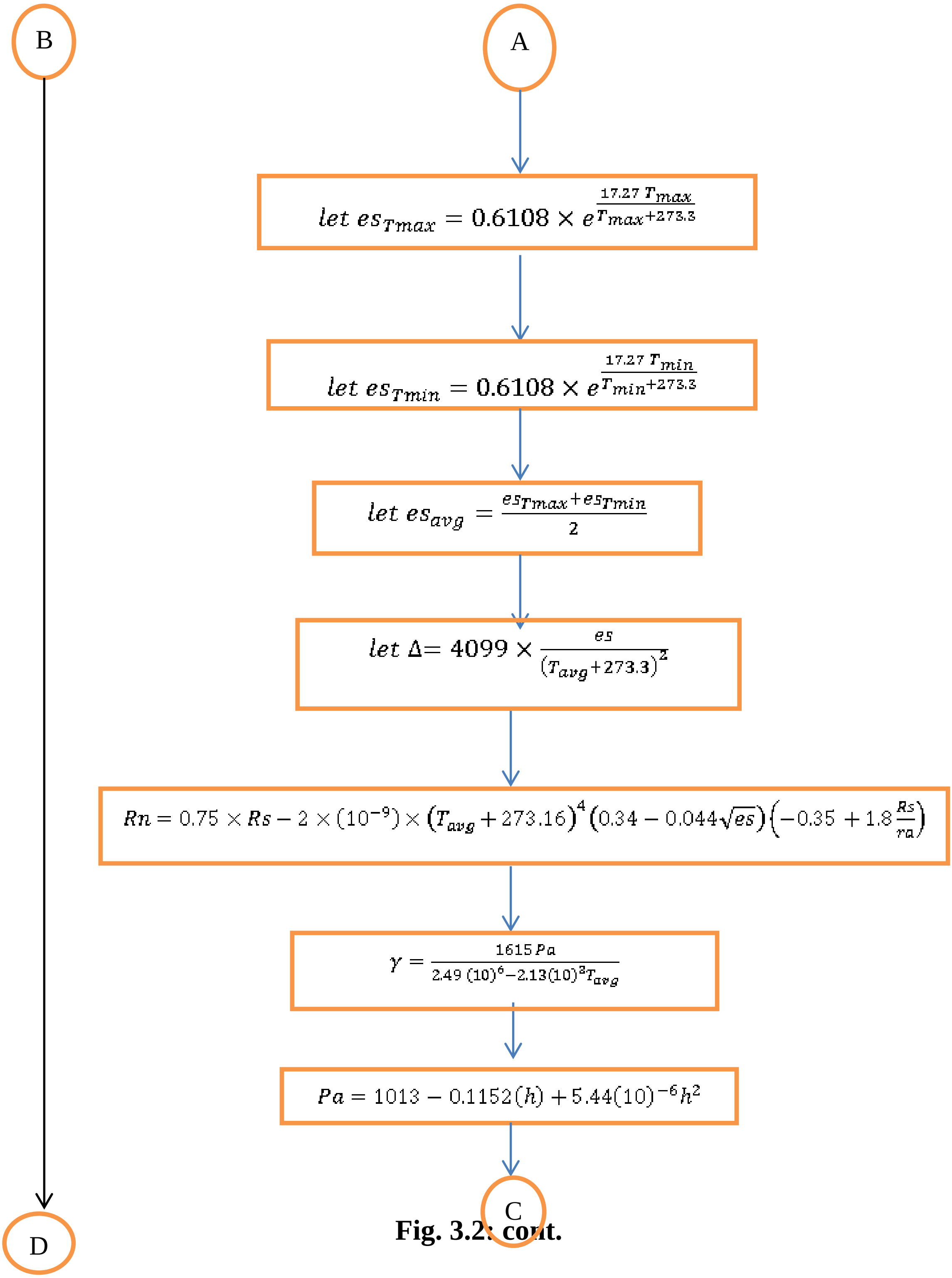

B
A
let $es_{Tmax} = 0.6108 \times e^{\frac{17.27\,T_{max}}{T_{max}+273.3}}$
let $es_{Tmin} = 0.6108 \times e^{\frac{17.27\,T_{min}}{T_{min}+273.3}}$
let $es_{avg} = \frac{es_{Tmax}+es_{Tmin}}{2}$
let $\Delta = 4099 \times \frac{es}{(T_{avg}+273.3)^2}$
$Rn = 0.75 \times Rs - 2 \times (10^{-9}) \times (T_{avg}+273.16)^4 (0.34 - 0.044\sqrt{es})\left(-0.35 + 1.8\frac{Rs}{ra}\right)$
$\gamma = \frac{1615\,Pa}{2.49\,(10)^6 - 2.13(10)^3 T_{avg}}$
$Pa = 1013 - 0.1152(h) + 5.44(10)^{-6}h^2$
C
D

Fig. 3.2: cont.

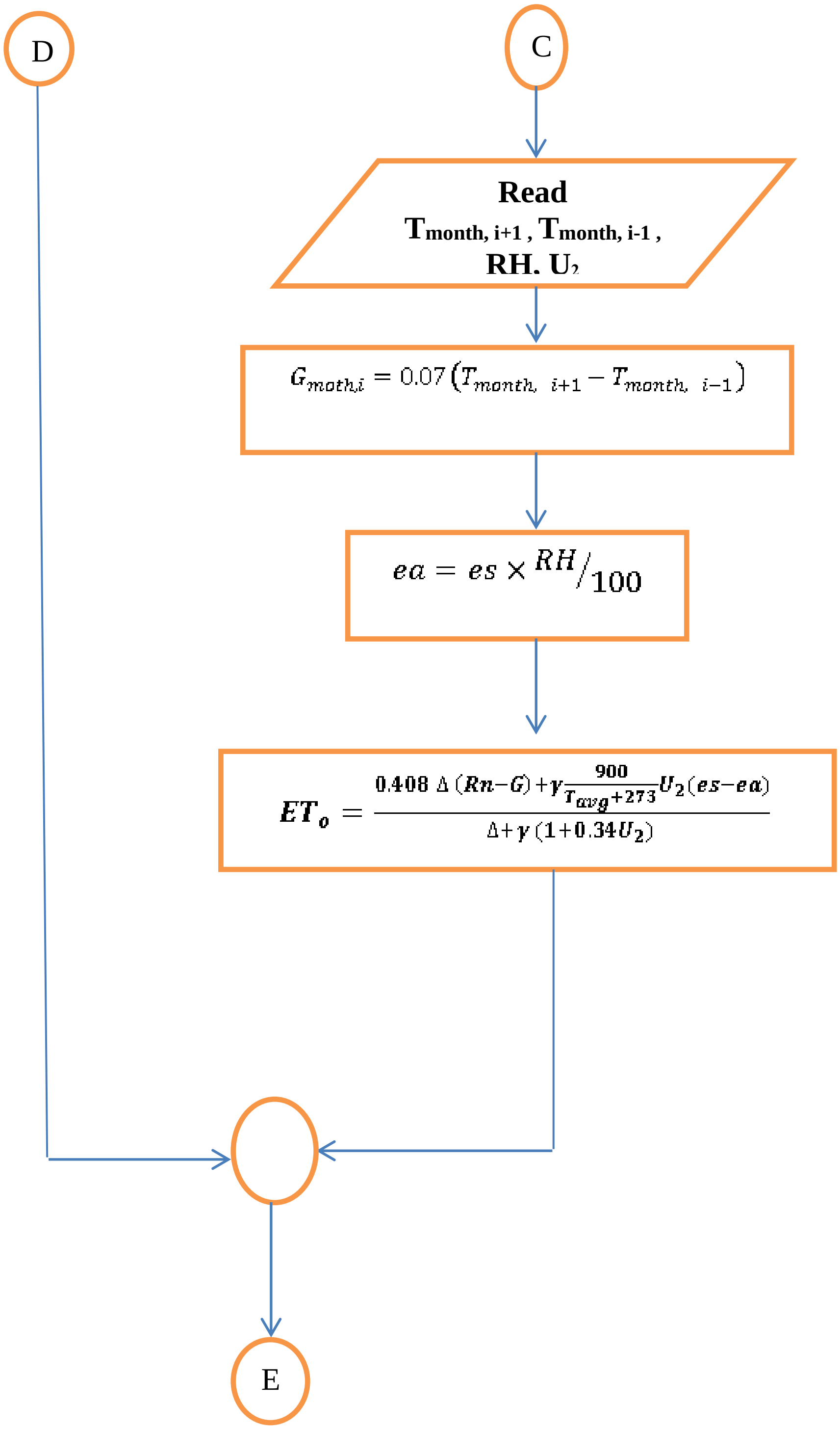

D
C
Read
$T_{month,\ i+1}$, $T_{month,\ i-1}$,
RH. U_2
$G_{moth,i} = 0.07\left(T_{month,\ i+1} - T_{month,\ i-1}\right)$
$ea = es \times {RH}/{100}$
$ET_o = \frac{0.408\,\Delta\,(Rn-G)+\gamma\frac{900}{T_{avg}+273}U_2(es-ea)}{\Delta+\gamma\,(1+0.34U_2)}$
E

Fig. 3.2: cont.

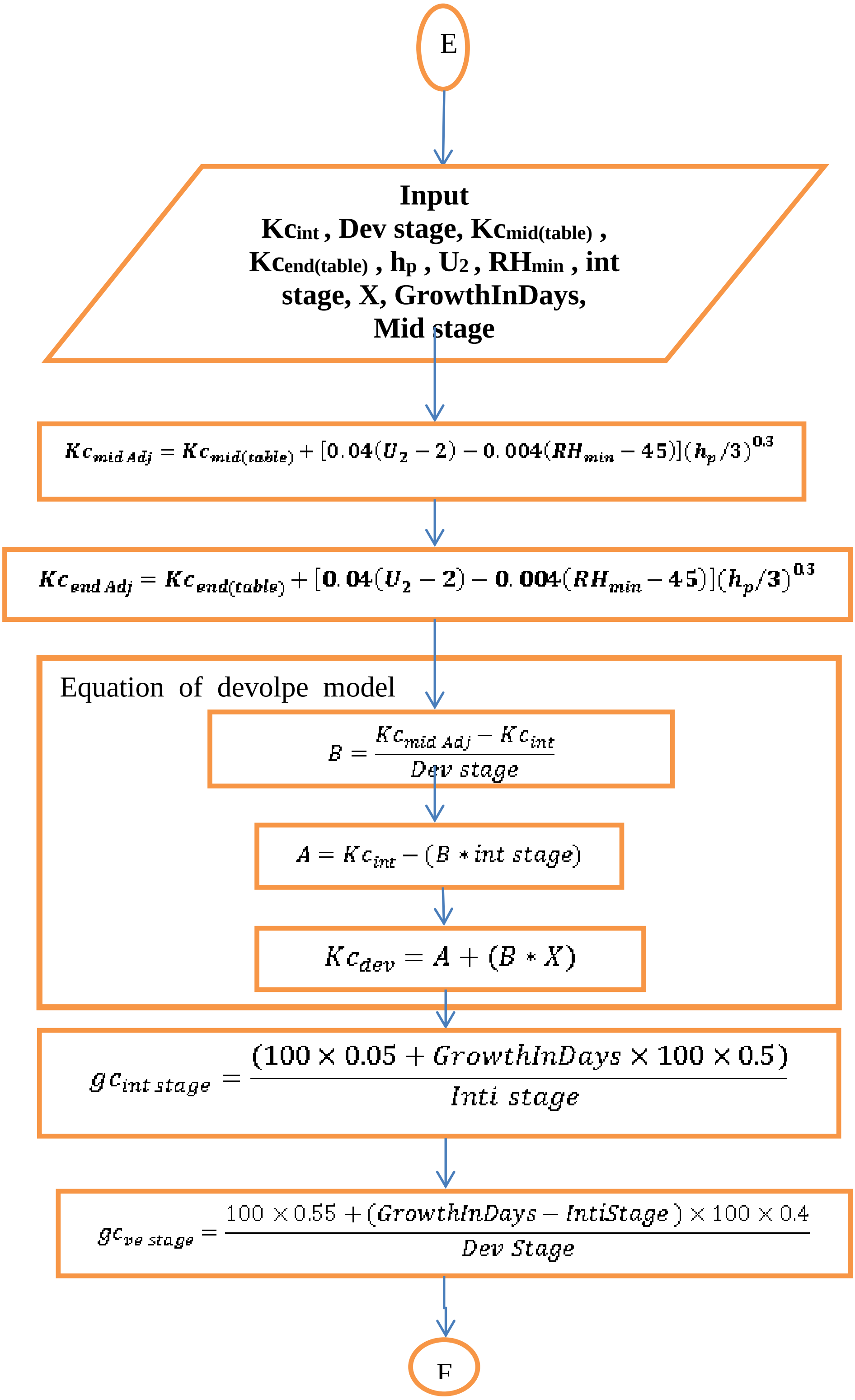

E
Input
Kc_{int}, Dev stage, $Kc_{mid(table)}$, $Kc_{end(table)}$, h_p, U_2, RH_{min}, int stage, X, GrowthInDays, Mid stage
$Kc_{mid\,Adj} = Kc_{mid(table)} + [0.04(U_2 - 2) - 0.004(RH_{min} - 45)](h_p/3)^{0.3}$
$Kc_{end\,Adj} = Kc_{end(table)} + [0.04(U_2 - 2) - 0.004(RH_{min} - 45)](h_p/3)^{0.3}$
Equation of devolpe model
$B = \frac{Kc_{mid\,Adj} - Kc_{int}}{Dev\ stage}$
$A = Kc_{int} - (B * int\ stage)$
$Kc_{dev} = A + (B * X)$
$gc_{int\,stage} = \frac{(100 \times 0.05 + GrowthInDays \times 100 \times 0.5)}{Inti\ stage}$
$gc_{ve\,stage} = \frac{100 \times 0.55 + (GrowthInDays - IntiStage) \times 100 \times 0.4}{Dev\ Stage}$
F

Fig. 3.2: cont.

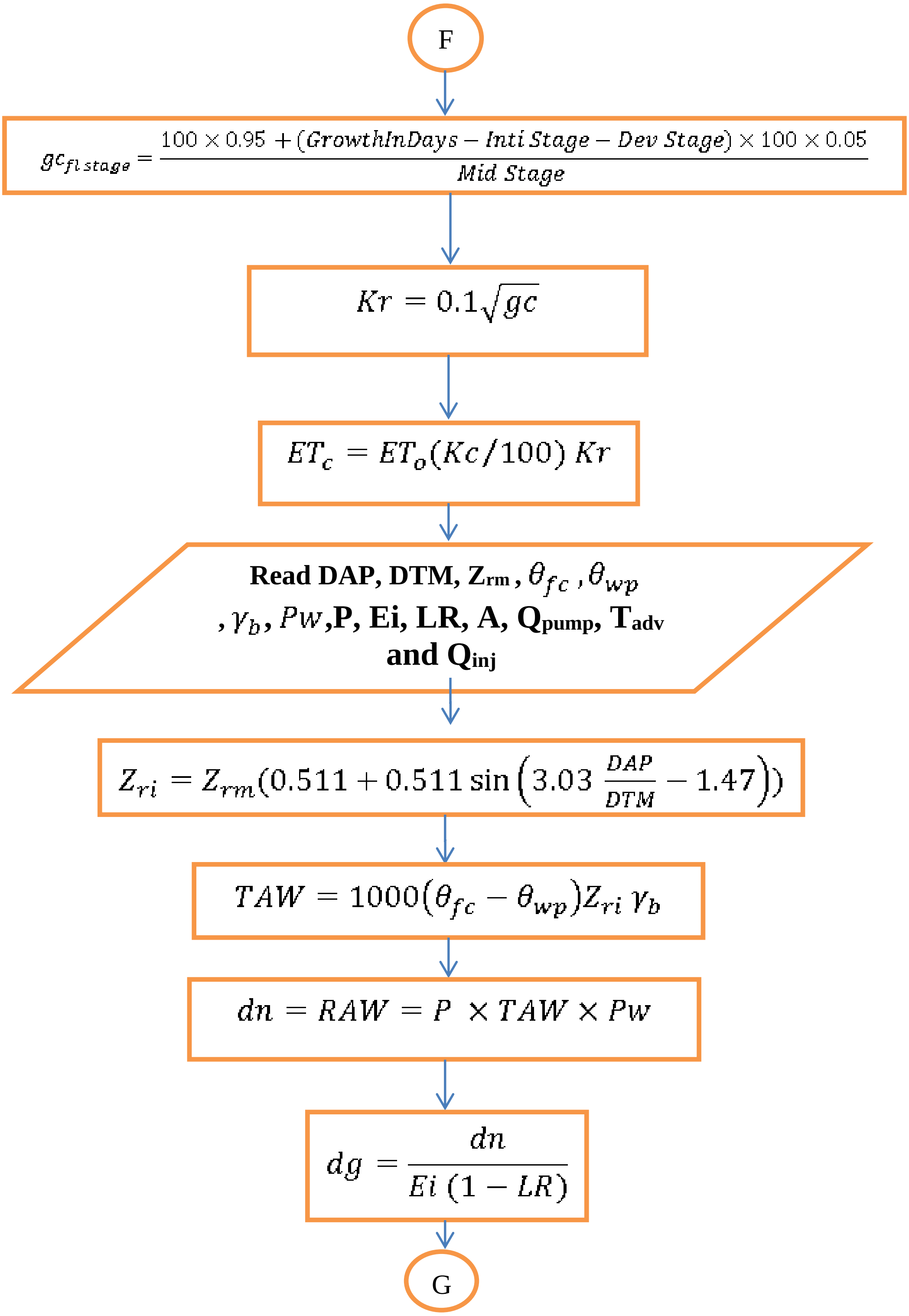

F
$gc_{fl\,stage} = \frac{100 \times 0.95 + (GrowthInDays - Inti\,Stage - Dev\,Stage) \times 100 \times 0.05}{Mid\,Stage}$
$Kr = 0.1\sqrt{gc}$
$ET_c = ET_o(Kc/100)\,Kr$
Read DAP, DTM, Z_{rm}, θ_{fc}, θ_{wp}, γ_b, Pw, P, Ei, LR, A, Q_{pump}, T_{adv} and Q_{inj}
$Z_{ri} = Z_{rm}\left(0.511 + 0.511 \sin\left(3.03\,\frac{DAP}{DTM} - 1.47\right)\right)$
$TAW = 1000(\theta_{fc} - \theta_{wp}) Z_{ri}\,\gamma_b$
$dn = RAW = P \times TAW \times Pw$
$dg = \frac{dn}{Ei\,(1 - LR)}$
G

Fig. 3.2: cont.

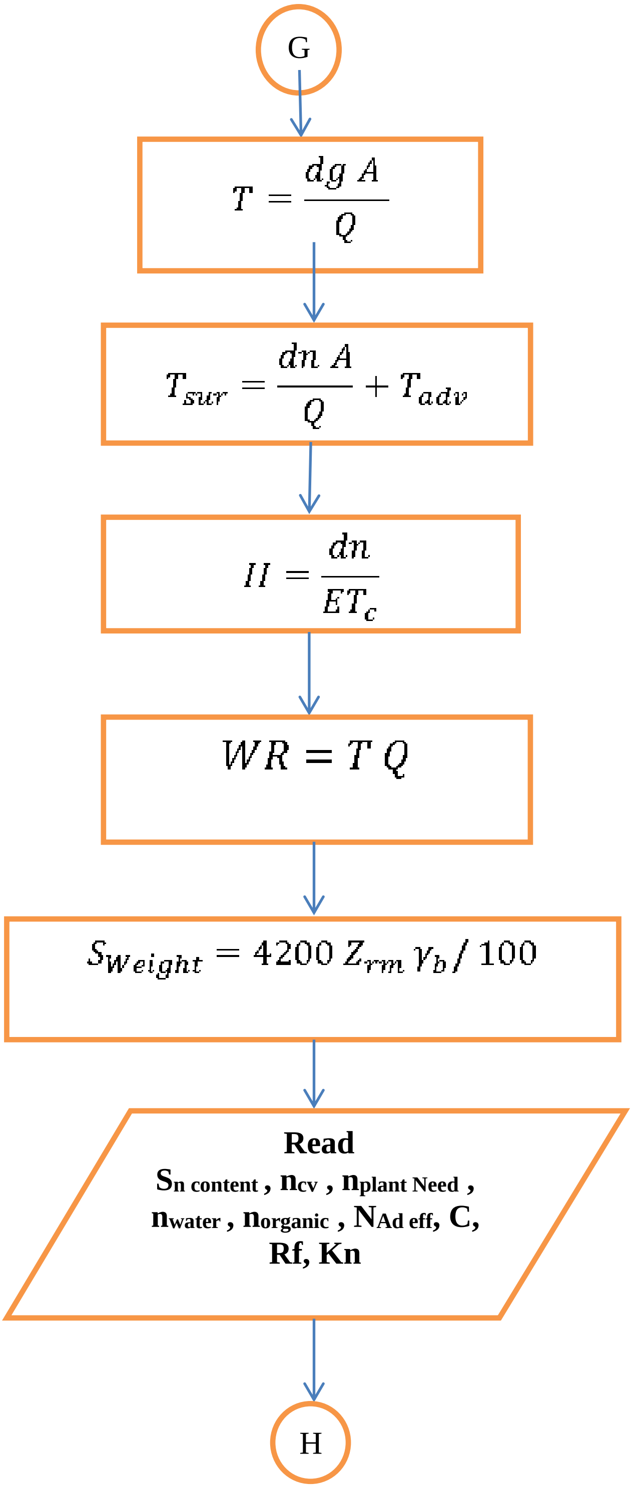
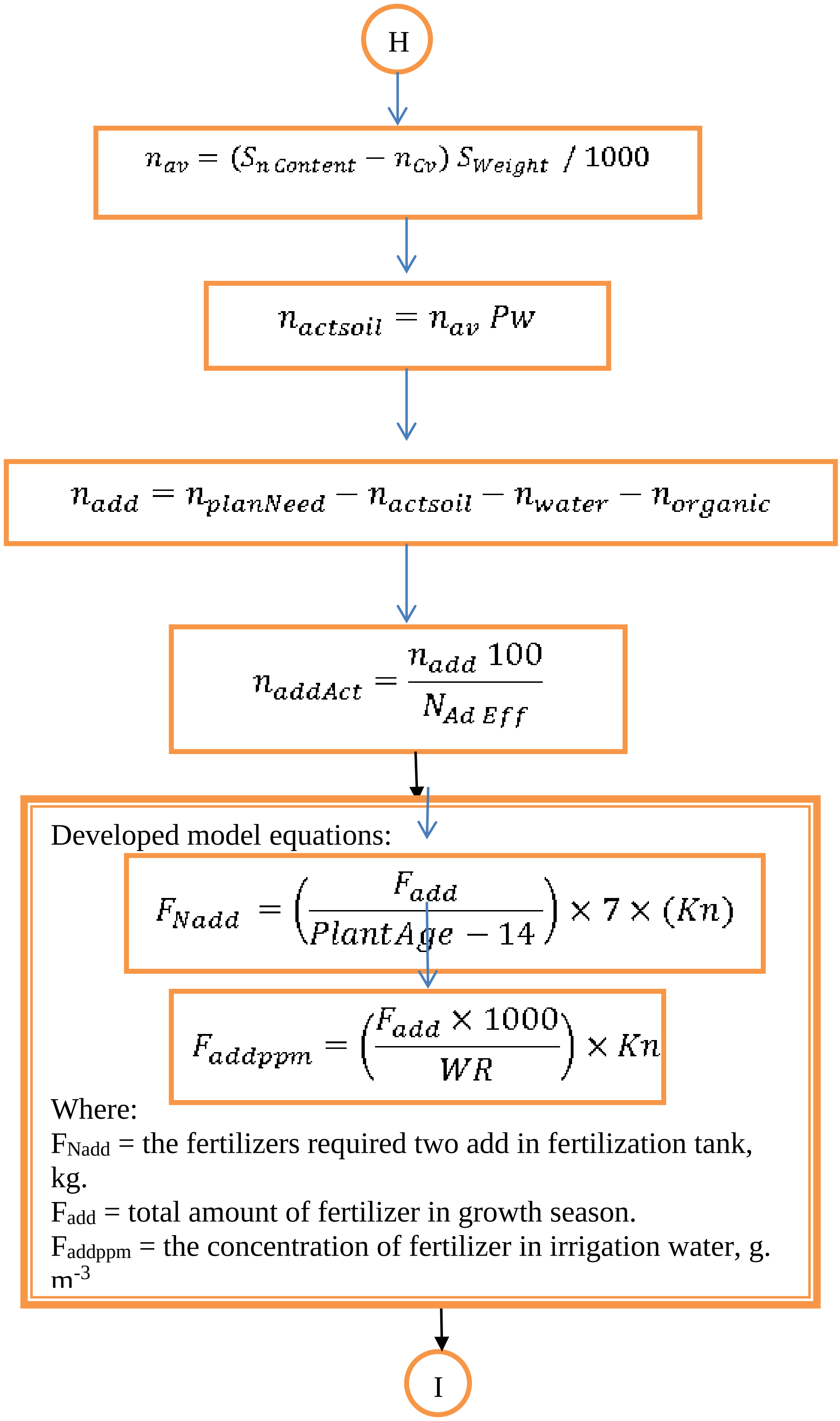

G
$T = \frac{dg\ A}{Q}$
$T_{sur} = \frac{dn\ A}{Q} + T_{adv}$
$II = \frac{dn}{ET_c}$
$WR = T\ Q$
$S_{Weight} = 4200\ Z_{rm}\ \gamma_b / 100$
Read
$S_{n\ content}$, n_{cv}, $n_{plant\ Need}$,
n_{water}, $n_{organic}$, $N_{Ad\ eff}$, C,
Rf, Kn
H

Fig. 3.2: cont.



$$n_{av} = (S_{n\,Content} - n_{Cv})\, S_{Weight} \;/\; 1000$$

$$n_{actsoil} = n_{av}\, PW$$

$$n_{add} = n_{planNeed} - n_{actsoil} - n_{water} - n_{organic}$$

$$n_{addAct} = \frac{n_{add}\, 100}{N_{Ad\,Eff}}$$

Developed model equations:

$$F_{Nadd} = \left(\frac{F_{add}}{PlantAge - 14}\right) \times 7 \times (Kn)$$

$$F_{addppm} = \left(\frac{F_{add} \times 1000}{WR}\right) \times Kn$$

Where:

F_{Nadd} = the fertilizers required two add in fertilization tank, kg.

F_{add} = total amount of fertilizer in growth season.

F_{addppm} = the concentration of fertilizer in irrigation water, g. m^{-3}

Fig. 3.2: cont.

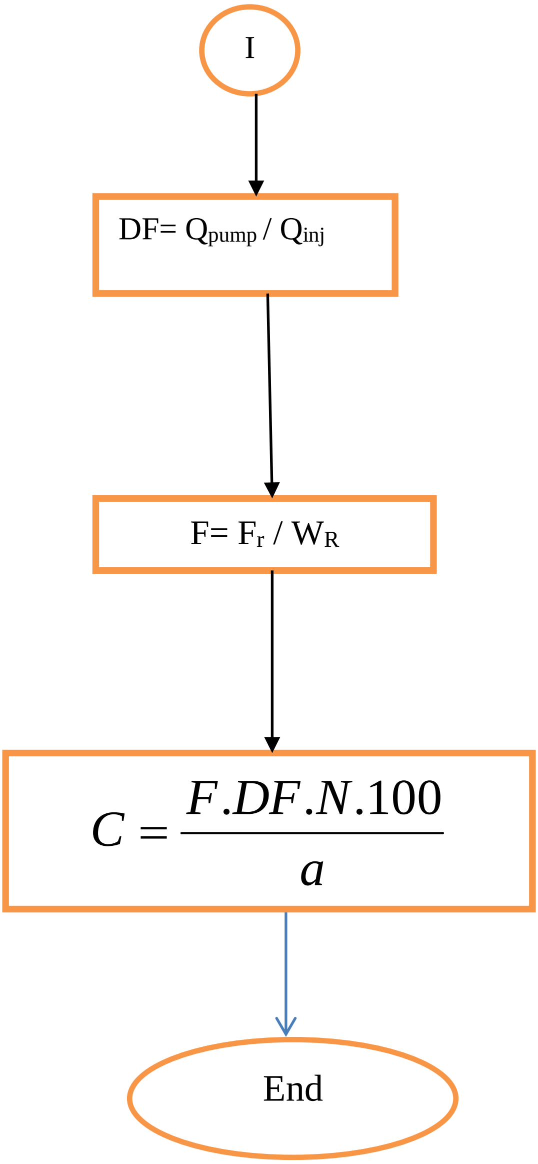


Fig. 3.2: cont.

3.2. The field experiments

The filed experiments were carried out to verify the validity of the expert system to predict the output results which may be obtained from the program and also to measure the degree of confidence of using expert system program.

Two field experiments were conducted at the farm of the Faculty of Agriculture, Moshtohor, Benha University, during winter season 2009 and summer season 2010. Cucumber (*Cucumis sativus*) was planted during the winter 2009 and bean (*Phaseolus vulgaris L.*) was planted during summer 2010. The soil of the two experimental fields was loamy clay in texture with pH value of 7.6. Soil physical and chemical analyses were carried out for the experimental field. Data of these analyses are shown in Tables (7-1 and 7-2) in Appendix. The two crops were chosen because bean is sensitive to irrigation water and cucumber was chosen because its infection by drowny mild is enfuluonced by the fertigation management.It has a good response for fertilizer and water applied.

Two experiments were carried out under this study. The first experiment was conducted to study the effect of nutrient calculated by OA-Fertigation on infection by *downy mildew* in cucumber. The second experiment was conducted to study the effect of the fertigation management systems on water use efficiency and nutrient use efficiency for bean crop.

The experimental area was divided into eighteen plots. Three irrigation systems and two management systems with three replicates were investigated. Each plot had number of rows of 100 cm row spacing and 25 m length.

The agricultural practices pertain each crop in terms of seedbed preparation, planting, cultivation and all other operations were conducted for the two experiments.

The recommended fertilizer requirements added to the soil for cucumber were (80 kg N / fed.), (55 kg P_2O_5 / fed.) and (120 kg K_2O / fed.) **(Papadopoulos, 1996)**

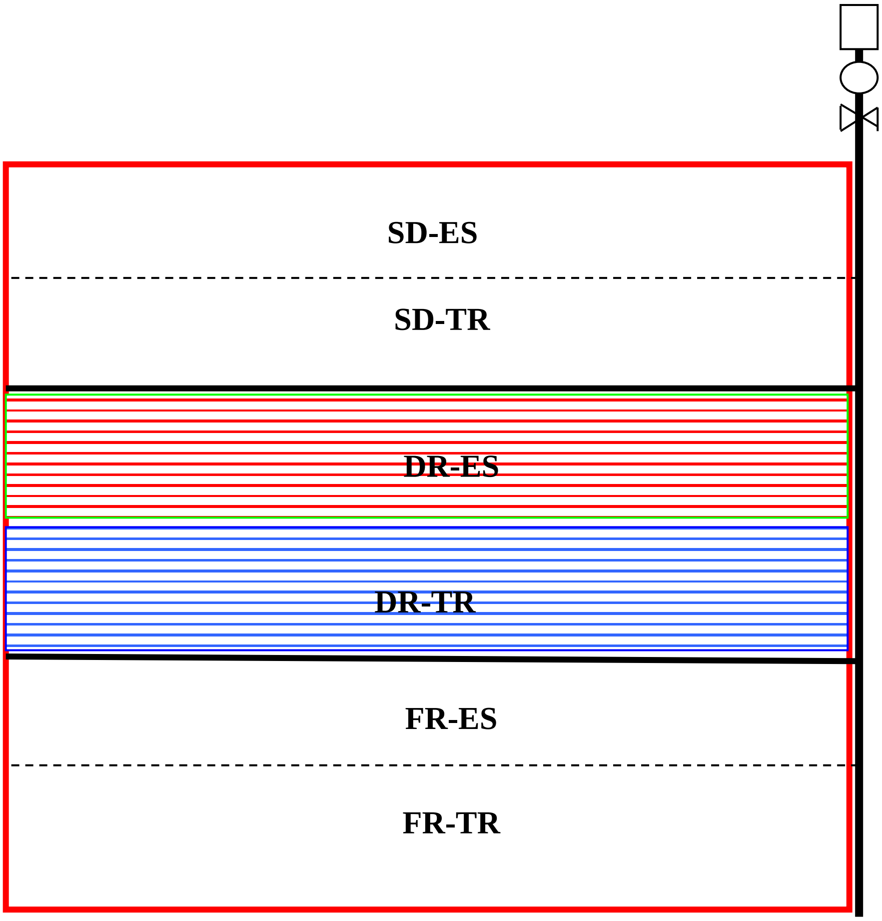


Fig. 3.3: Layout of the experimental plots.

SD = Sub drip irrigation

ES = Expert system (OA-Fertigation program)

DR=Drip irrigation

TR = Traditional method

The recommended fertilizer requirements added to the soil for bean crop were 40 kg N / fed. , 48 kg P_2O_5 / fed. and 48 kg K_2O / fed (**El-Shimi, 2004**).

Analyses and measurements

Soil Analyses:

Random soil samples were taken before planting for physical and chemical analyses as described by ***Chapman and Pratt (1961) and Jackson (1965).***

Water measurements

Irrigation water sample was taken for physical and chemical analyses.

Crop measurements for bean

1. **biological properties**

The biological properties for bean crop were plant height, root mass, root depth, plant mass, chlorophyll, stem mass and number of leaves. Twelve random samples were taken from each plot and the averages of measurements were determined, for the upove mentioned properties.

2. **Chemical properties**

The chemical properties for bean crop were (Organic carbon) O.C%, (Organic matter) O.M %, Ash %, (Total nitrogen) T.N% and C/N ratio. Three samples were taken from each plot to determine the chemical properties in laboratory.

3. Chlorophyll concentration

30 samples were selected for each plot to measure chlorophyll concentration at the first and of the development stages.

4. Dry seed yield

The dry seed yield was calculated for each plot and the average was recorded.

5. The mass of 100 seeds

The mass of 100 seeds was determined by taking three samples from each plots and the average was recorded.

6. Water use efficiency

It was calculated from the equation:

WUE = Yield (kg) / Water requirement (m^3)

7. Nutrient use efficiency

It was calculatied according to the equation:

NUE = Yield (kg) / nutrient used by (kg)

Crop measurements for cucumber

1. number of infected leaves

Nine random samples were selected from each plot for measuring number of infected leaves.

2. Chlorophyll concentration

30 samples were selected from each plot to measure chlorophyll concentration at the start and end of development stage.

3. Yield of 7 cuts and number of infected fruits

Also, the yield of 7 cuts was measured for each plot and also the number of infected fruits was recorded.

4. Water and nutrient use efficiencies

The same definitions were used as for the bean experiment.

RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

4.1 Expert system “OA-Fertigation program”

A software program was designed for fertigation management depending on the expert system “ES” technique. The program was given a name of “OA-Fertigation”. The main menu of this program consists of three menu bars (Fig. 4.1). These were the start menu, databases and identification of the program.

4.1. 1 The Start menu

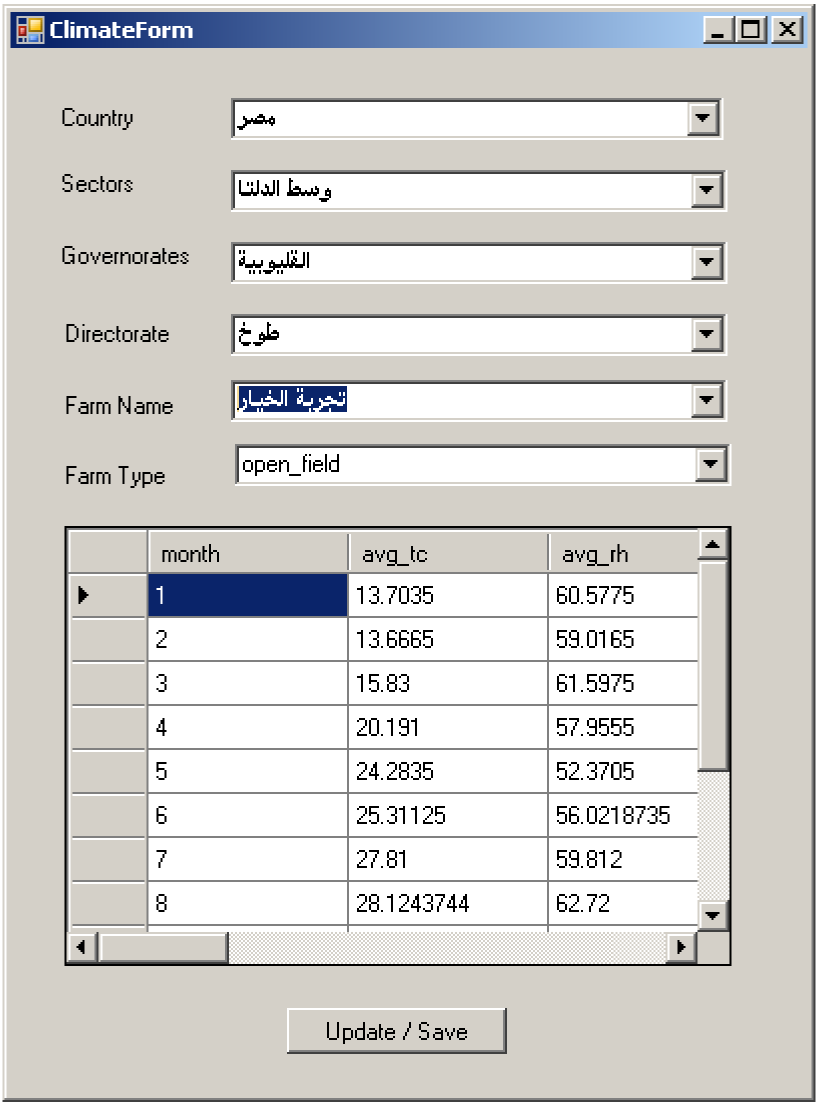
This menu consisted of three commands. The first command is used to open the data base of the program. The second command is used for running the program. The third command is used to select the fertilizers. The second menu bar consists of several commands opening data bases (climate database, soil, water, farm, fertilizer, manure database, crop and irrigation system databases). Moreover, the third menu bar includes information about the program.

Fig. 4.1: The program user interface.

4.1.2. Databases

4.1.2.1 Climate database

User can update and delete data from climate database easily by selecting the data of the farm.



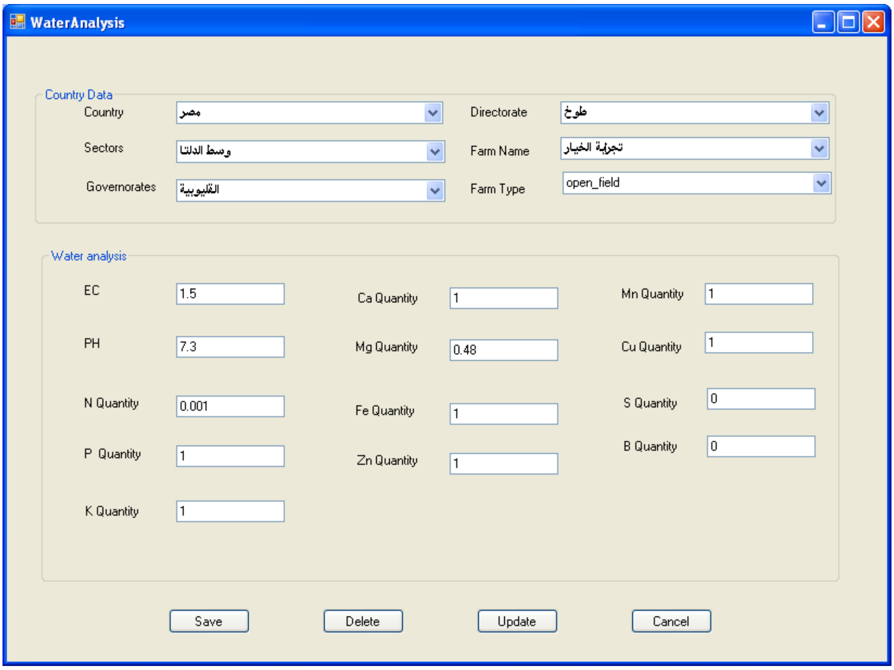
Country	مصر
Sectors	وسط الدلتا
Governorates	القليوبية
Directorate	طوخ
Farm Name	تجربة الخيار
Farm Type	open_field

month	avg_tc	avg_rh
1	13.7035	60.5775
2	13.6665	59.0165
3	15.83	61.5975
4	20.191	57.9555
5	24.2835	52.3705
6	25.31125	56.0218735
7	27.81	59.812
8	28.1243744	62.72

Fig. 4.2: Climate database.

4.1.2.2. Water database

Water database provides the program engine tool by data of water analysis as shown in Fig. 4.3. User can update the database.



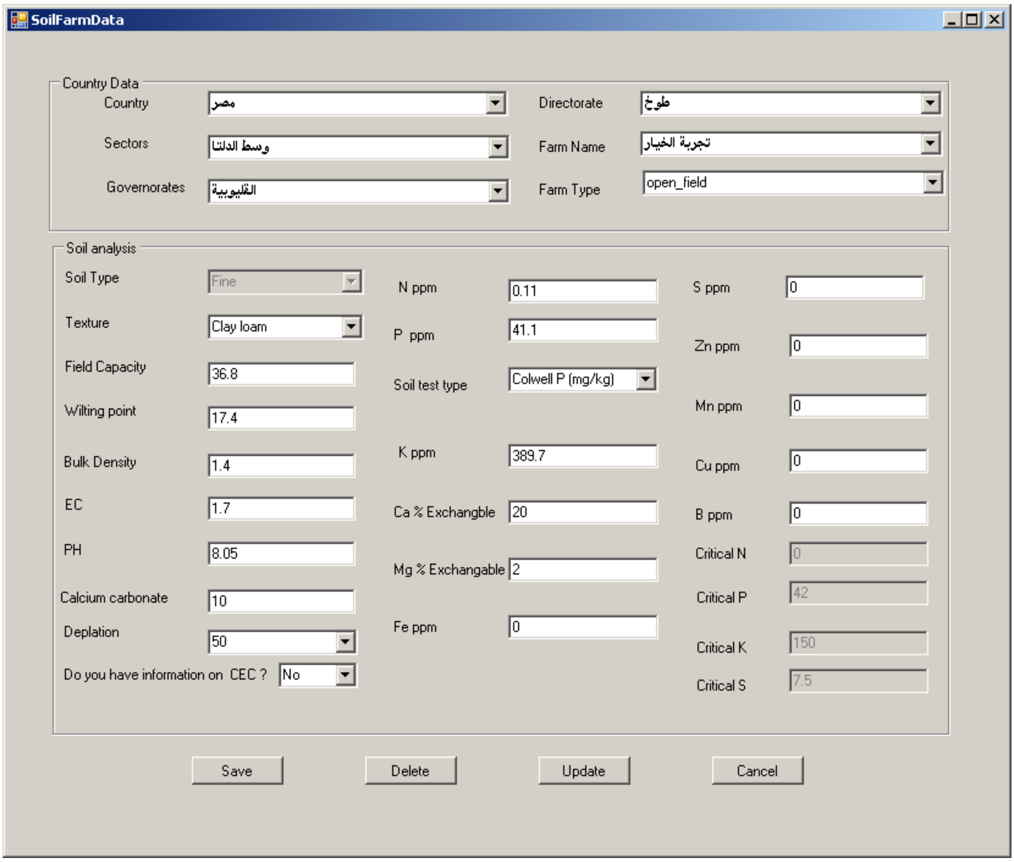
Country مصر
Sectors وسط الدلتا
Governorates القليوبية
Directorate طوخ
Farm Name تجربة الخيار
Farm Type open_field

EC 1.5
PH 7.3
N Quantity 0.001
P Quantity 1
K Quantity 1
Ca Quantity 1
Mg Quantity 0.48
Fe Quantity 1
Zn Quantity 1
Mn Quantity 1
Cu Quantity 1
S Quantity 0
B Quantity 0

Fig. 4.3: Water database.

4.1.2.3. Soil database

To run the program, you must input the soil analyses as shown in Fig. 4.4.



Country Data

Country: مصر

Sectors: وسط الدلتا

Governorates: القليوبية

Directorate: طوخ

Farm Name: تجربة الخيار

Farm Type: open_field

Soil analysis

Soil Type: Fine

Texture: Clay loam

Field Capacity: 36.8

Wilting point: 17.4

Bulk Density: 1.4

EC: 1.7

PH: 8.05

Calcium carbonate: 10

Deplation: 50

Do you have information on CEC ? No

N ppm: 0.11

P ppm: 41.1

Soil test type: Colwell P (mg/kg)

K ppm: 389.7

Ca % Exchangble: 20

Mg % Exchangable: 2

Fe ppm: 0

S ppm: 0

Zn ppm: 0

Mn ppm: 0

Cu ppm: 0

B ppm: 0

Critical N: 0

Critical P: 42

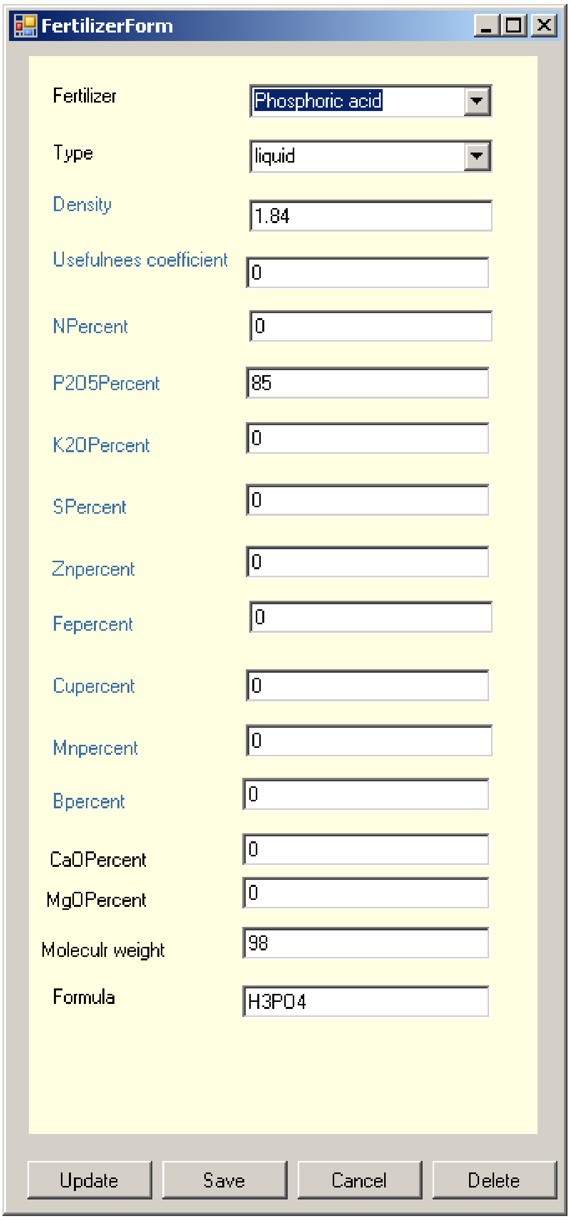
Critical K: 150

Critical S: 7.5

Fig. 4.4: Soil database.

4.1.2.4. Fertilizer database

Fertilizer database provides the program engine tool by data of fertilizers and their properties as shown in Fig. 4.5.



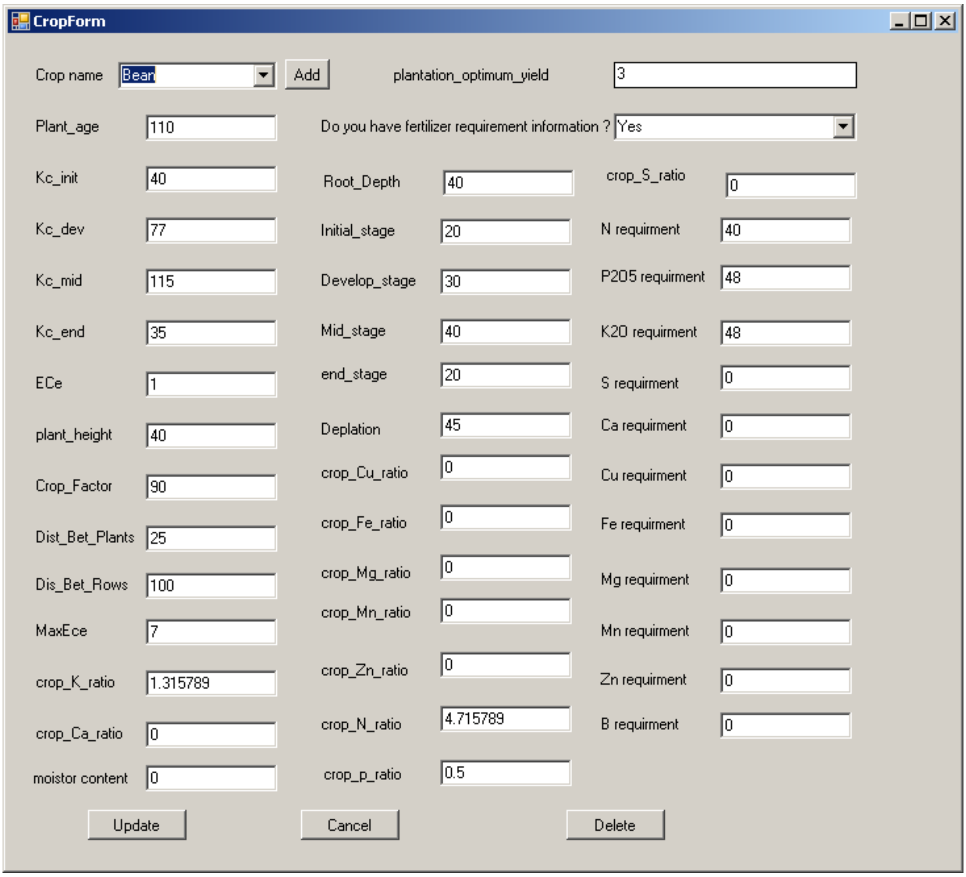
FertilizerForm

Fertilizer	Phosphoric acid
Type	liquid
Density	1.84
Usefulnees coefficient	0
NPercent	0
P205Percent	85
K20Percent	0
SPercent	0
Znpercent	0
Fepercent	0
Cupercent	0
Mnpercent	0
Bpercent	0
CaOPercent	0
MgOPercent	0
Moleculr weight	98
Formula	H3PO4

Fig. 4.5: Fertilizer database.

4.1.2.5. Crop database

Crop database provides the program engine tool by data of crop concept as shown in Fig. 4.6.

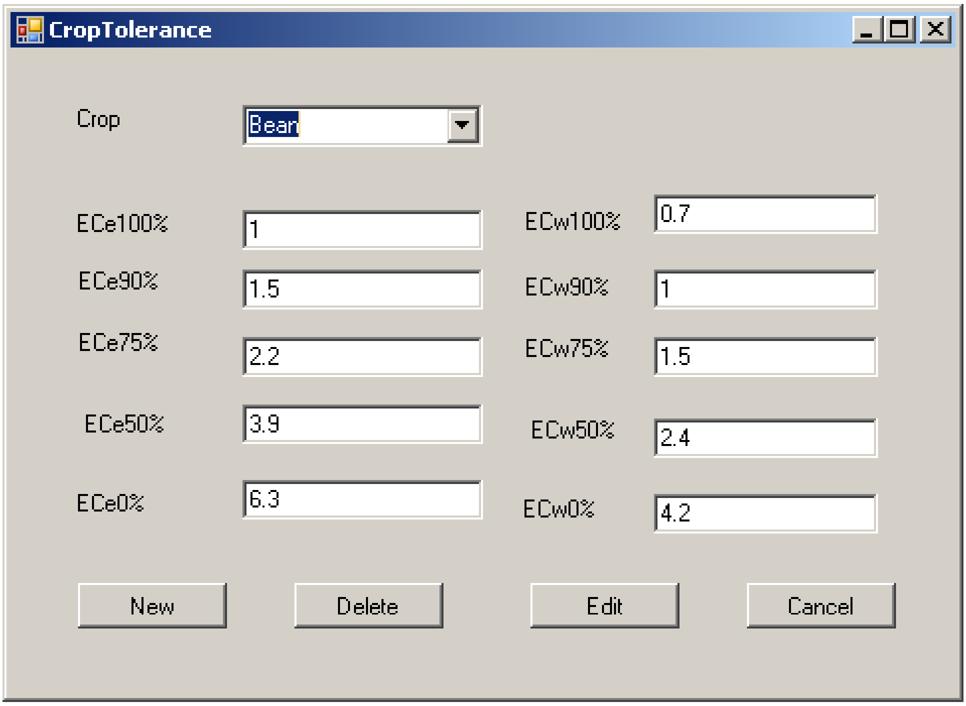


Crop name	Bean	plantation_optimum_yield	3		
Plant_age	110	Do you have fertilizer requirement information ?	Yes		
Kc_init	40	Root_Depth	40	crop_S_ratio	0
Kc_dev	77	Initial_stage	20	N requirment	40
Kc_mid	115	Develop_stage	30	P205 requirment	48
Kc_end	35	Mid_stage	40	K20 requirment	48
ECe	1	end_stage	20	S requirment	0
plant_height	40	Deplation	45	Ca requirment	0
Crop_Factor	90	crop_Cu_ratio	0	Cu requirment	0
Dist_Bet_Plants	25	crop_Fe_ratio	0	Fe requirment	0
Dis_Bet_Rows	100	crop_Mg_ratio	0	Mg requirment	0
MaxEce	7	crop_Mn_ratio	0	Mn requirment	0
crop_K_ratio	1.315789	crop_Zn_ratio	0	Zn requirment	0
crop_Ca_ratio	0	crop_N_ratio	4.715789	B requirment	0
moistor content	0	crop_p_ratio	0.5		

Fig. 4.6: Crop database.

4.1.2.6. Crop salt-tolerance database

Crop salt-tolerance database provides the program engine tool by data of crop tolerance as shown in Fig. 4.7.



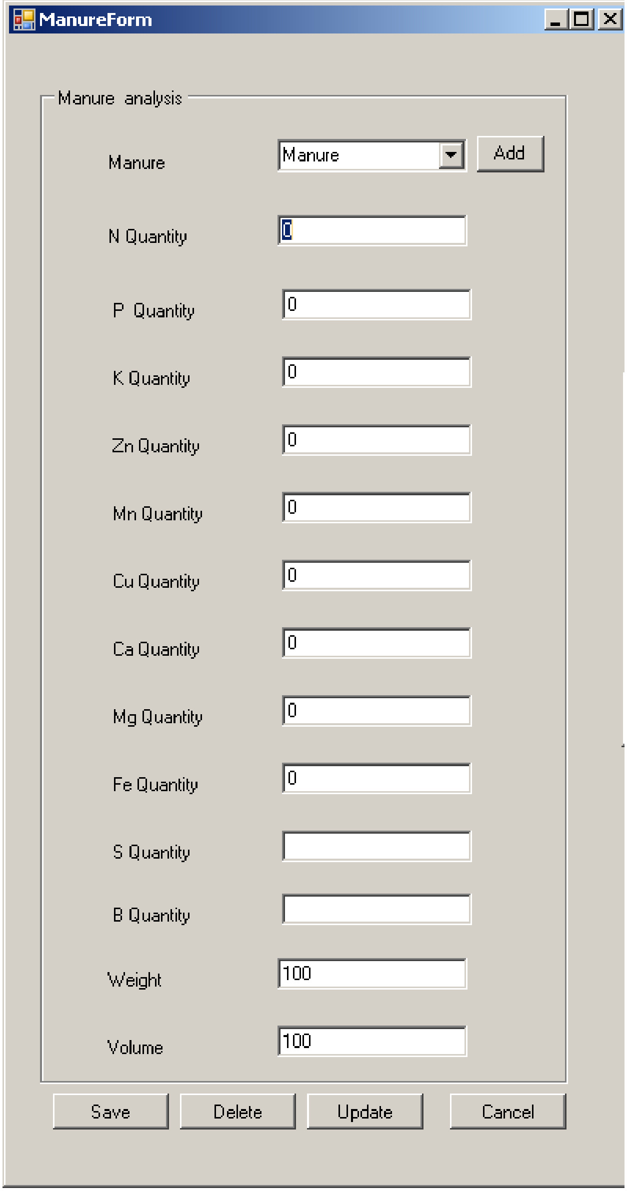
Crop: Bean

ECe100%	1	ECw100%	0.7
ECe90%	1.5	ECw90%	1
ECe75%	2.2	ECw75%	1.5
ECe50%	3.9	ECw50%	2.4
ECe0%	6.3	ECw0%	4.2

Fig. 4.7: Crop tolerance database.

4.1.2.7. Manure database

Manure database provides the program engine tool by data of manure witch users can use before planting.

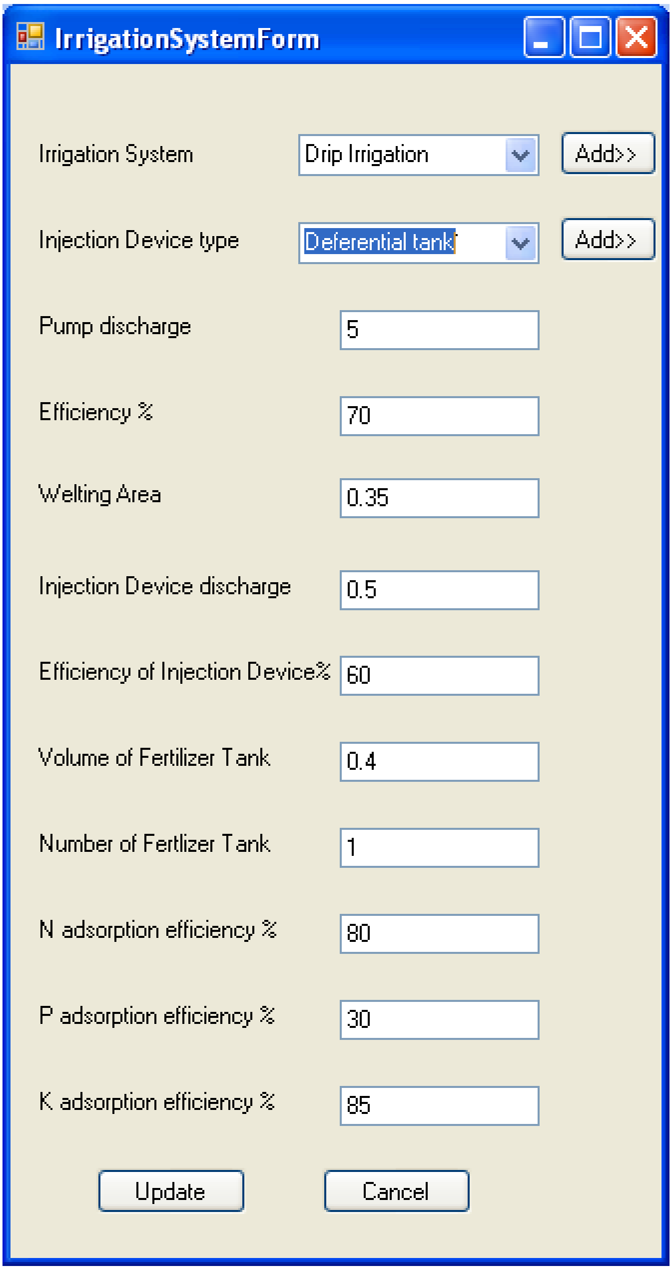


Manure: Manure
N Quantity: 0
P Quantity: 0
K Quantity: 0
Zn Quantity: 0
Mn Quantity: 0
Cu Quantity: 0
Ca Quantity: 0
Mg Quantity: 0
Fe Quantity: 0
S Quantity:
B Quantity:
Weight: 100
Volume: 100

Fig. 4.8: Manure database.

4.1.2.8. Irrigation system database

Irrigation system database provides the program engine tool by the data of irrigation system

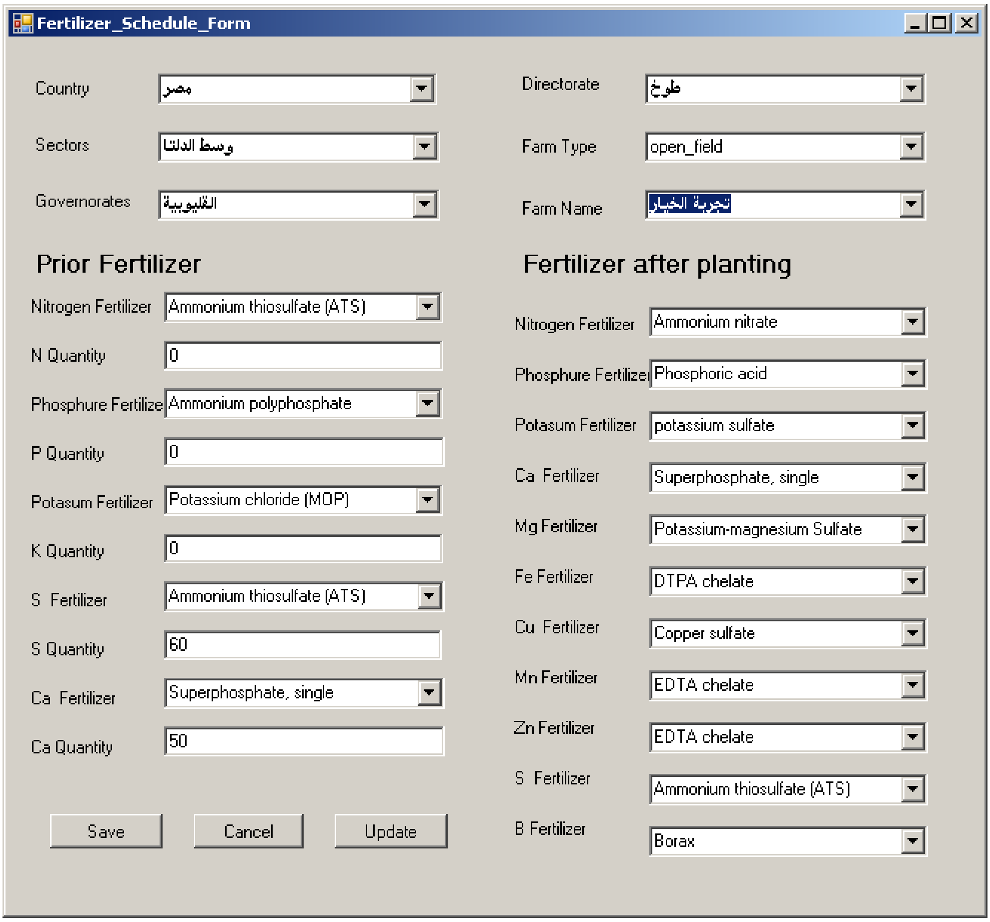


Irrigation System: Drip Irrigation
Injection Device type: Deferential tank
Pump discharge: 5
Efficiency %: 70
Welting Area: 0.35
Injection Device discharge: 0.5
Efficiency of Injection Device%: 60
Volume of Fertilizer Tank: 0.4
Number of Fertlizer Tank: 1
N adsorption efficiency %: 80
P adsorption efficiency %: 30
K adsorption efficiency %: 85

Fig. 4.9: Irrigation system database.

4.1.2.9. Fertilizer schedule

User must select the fertilizer after he has run the program as shown in Fig. 4.10.



Fertilizer_Schedule_Form

Country: مصر

Sectors: وسط الدلتا

Governorates: القليوبية

Directorate: طوخ

Farm Type: open_field

Farm Name: تجربة الخيار

Prior Fertilizer

Nitrogen Fertilizer: Ammonium thiosulfate (ATS)

N Quantity: 0

Phosphure Fertilize: Ammonium polyphosphate

P Quantity: 0

Potasum Fertilizer: Potassium chloride (MOP)

K Quantity: 0

S Fertilizer: Ammonium thiosulfate (ATS)

S Quantity: 60

Ca Fertilizer: Superphosphate, single

Ca Quantity: 50

Fertilizer after planting

Nitrogen Fertilizer: Ammonium nitrate

Phosphure Fertilizer: Phosphoric acid

Potasum Fertilizer: potassium sulfate

Ca Fertilizer: Superphosphate, single

Mg Fertilizer: Potassium-magnesium Sulfate

Fe Fertilizer: DTPA chelate

Cu Fertilizer: Copper sulfate

Mn Fertilizer: EDTA chelate

Zn Fertilizer: EDTA chelate

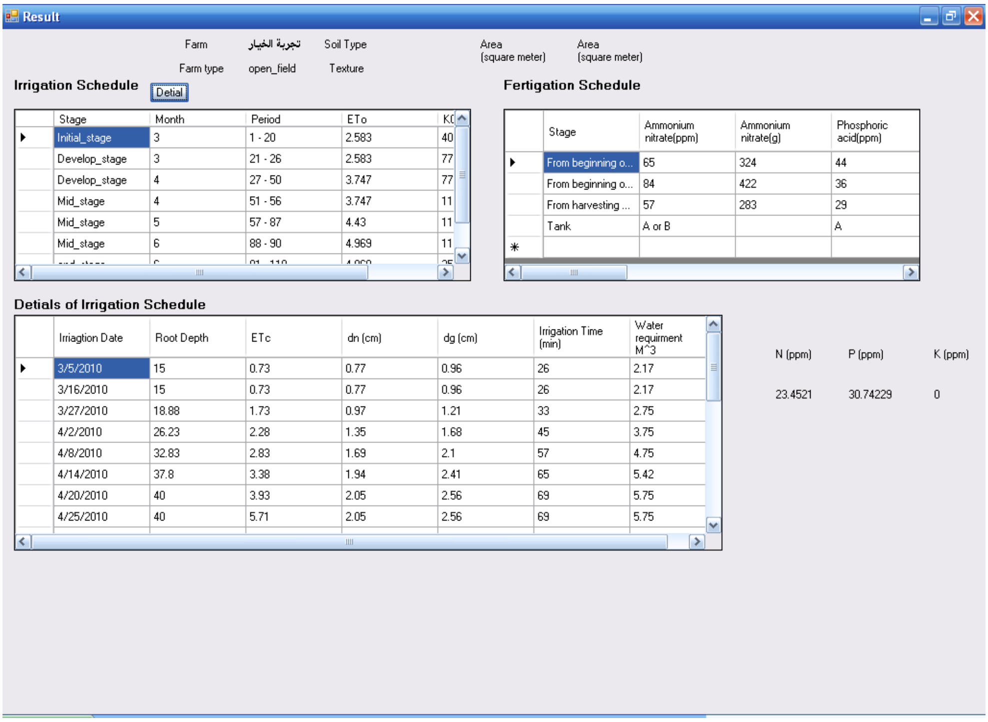
S Fertilizer: Ammonium thiosulfate (ATS)

B Fertilizer: Borax

Fig. 4.10: Fertilizer schedule.

4.2 The outputs of “OA-Fertigation” program and CROPWAT program

Output data include tables for: irrigation scheduling, fertigation scheduling and irrigation dates, as shown in Fig. 4.11.



Farm تجربة الخيار

Farm type open_field

Soil Type Texture

Area (square meter)

Area (square meter)

Irrigation Schedule

Stage	Month	Period	ETo	K
Initial_stage	3	1 - 20	2.583	40
Develop_stage	3	21 - 26	2.583	77
Develop_stage	4	27 - 50	3.747	77
Mid_stage	4	51 - 56	3.747	11
Mid_stage	5	57 - 87	4.43	11
Mid_stage	6	88 - 90	4.969	11

Fertigation Schedule

Stage	Ammonium nitrate(ppm)	Ammonium nitrate(g)	Phosphoric acid(ppm)
From beginning o...	65	324	44
From beginning o...	84	422	36
From harvesting ...	57	283	29
Tank	A or B		A

Detials of Irrigation Schedule

Irriagtion Date	Root Depth	ETc	dn (cm)	dg (cm)	Irrigation Time (min)	Water requirment M^3
3/5/2010	15	0.73	0.77	0.96	26	2.17
3/16/2010	15	0.73	0.77	0.96	26	2.17
3/27/2010	18.88	1.73	0.97	1.21	33	2.75
4/2/2010	26.23	2.28	1.35	1.68	45	3.75
4/8/2010	32.83	2.83	1.69	2.1	57	4.75
4/14/2010	37.8	3.38	1.94	2.41	65	5.42
4/20/2010	40	3.93	2.05	2.56	69	5.75
4/25/2010	40	5.71	2.05	2.56	69	5.75

N (ppm)	P (ppm)	K (ppm)
23.4521	30.74229	0

Fig. 4.11: Output form “OA-Fertigation” program.

4.2.1 Evapotranspiration methods

Four methods were used to determine the evapotranspiration during a year under Qalubiya governorate conditions. The first and second methods were estimated using "OA-Fertigation" program. However, the third method depended on CROPWAT program while the fourth method depended on CLAC. The OA-Fertigation program was used to estimate the evapotranspiration (Et_o) using two equations. The first equation was (Penman-Monteith equation), which can be used under open field and low tunnel. The second equation (Hargreaves Equation) which can be used under high tunnel.

Table (4-1) and Figure 4.12 show the effect of a month of a year on evapotranspiration using the mentioned four methods in Qalubiya governorate. It shows that the evapotranspiration increased graually from January until July. beyond which, the evapotranspiration decreased. The highest values of evapotranspiration were obtained in June and July months. On the other hand, the lowest values of evapotranspiration were given at January and December months. These results can be attributed to the following reasons:

1 Increasing the average temperature from January to July by 54% and on the other hand, decreasing the average temperature from July to December by 43.76% (Table 7-4) in the Appendix.

2 Increasing the radiation from January to July by 52.94% and on the other hand, decreasing the average radiation from July to December by 52.94% (Table 7-4) in the Appendix.

3 The increase in the mean daily actual sunshine hours from January to July by 16.7% and on the other hand, decrease the mean of daily actual sunshine hours from July to December by 9.1% (Table 7-4) in the Appendix.

4 The increase in the mean daily max. sunshine hours from January to July by 12.5% and on the other hand, decrease in the mean of daily max. sunshine hours from July to December by 12.5% (Table 7-4) in the Appendix.

Results of comparison among the four methods of determining the evapotranspiration showed that there were no differences among OA-Fertigation program depending on Hargreaves Equation (HG), CROPWAT method and CLAC (Central laboratory of agricultural climate) method. However, the lowest values of evapotranspiration (Et_o) were obtained by OA-Fertigation program depending on FAO-Penman-Monteith equation (PM) during a year. In July, the evapotranspiration by OA-Fertigation program depending FAO-Penman-Monteith (PM) decreased by 21.6%, 24.7% and 19.8% for HG, CROPWAT and CLAC, respectively. These results may be because to the usage of the OA-Fertigation program depending FAO-Penman-Monteith for several factors did not used by the other methods. These factors were mean daily maximum sunshine hours, mean daily actual sunshine hours and mean relative humidity (Table 7-4) in the Appendix.

Regression analyses were carried out to evaluate the results of evapotranspiration under the various used methods. These analyses showed that, the agreement between the OA-Fertigation program depending on Penman-Monteith equation (PM) and Hargrives equation (HG) was 96.29% (Figure 4.13). This means that the results of OA-Fertigation program depending on FAO-Penman-Monteith equation (PM) can be used instead of experimental fields to determine the evapotranspiration with 96.29%accuracy compared with of the experimental filed different methods .Like wise, the agreement between the OA-Fertigation program depending on Penman-Monteith equation (PM) and Hargrives was 96.29% (Figure 4.14) *i.e*. the results of OA-Fertigation program depending on Penman-Monteith equation (PM) can be used instead of the experimental fields to determine the evapotranspiration with 0.975 accuracy compared with different methods. Also, the agreement between the OA-Fertigation program depending on FAO-Penman-Monteith equation (PM) and CLAC method was 91.3% (Figure 4.15). Which means that the results of OA-Fertigation program depending on FAO-Penman-Monteith equation (PM) can be used instead of the experimental fields to determine the evapotranspiration with 0.913 accuracy.

Table (4-1): Evapotranspiration during a year using four methods of determining

Month	Et_o PM	Et_o HG**	Et_o CROPWAT***	CLAC****
1	1.537	1.86	1.91	1.5
2	1.764	2.71	2.33	2.1
3	2.583	3.74	3.25	3.38
4	3.747	5.01	4.85	3.2
5	4.43	6.05	6.52	4.6
6	4.969	6.33	6.78	6.7
7	4.97	6.34	6.6	6.2
8	4.646	5.98	6.21	5.9
9	4.112	4.91	5.1	4.9
10	3.375	3.89	4.1	3.7
11	2.642	2.88	2.81	3.2
12	1.604	1.90	1.96	1.2

*Evapotranspiration calculated by OA-Fertigation program for open field and low tunnel.

** Evapotranspiration calculated by OA-Fertigation for high tunnel.

*** Evapotranspiration calculated by “CROPWAT program”.

**** Evapotranspiration measured by Center Laboratory of Agricultural Climate (CLAC).

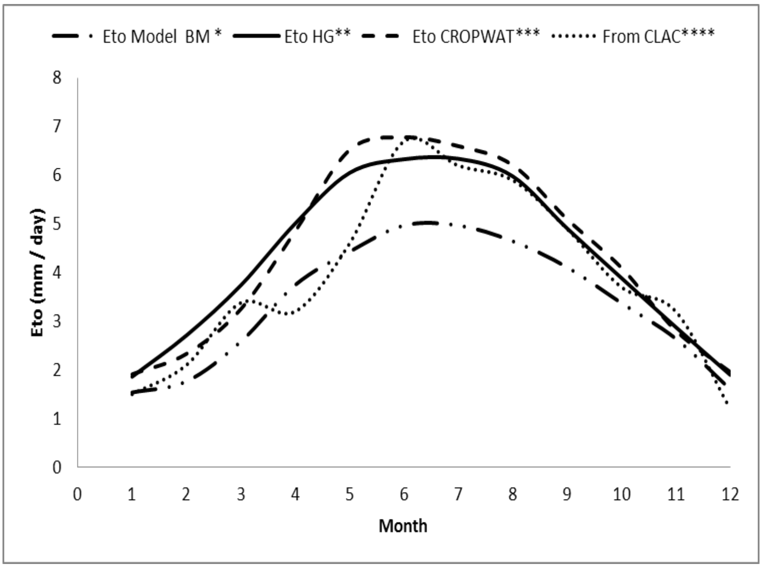


Fig. 4.12: Monthly evapotranspiration determine by using deferant using methods in quliobia gevarnorat

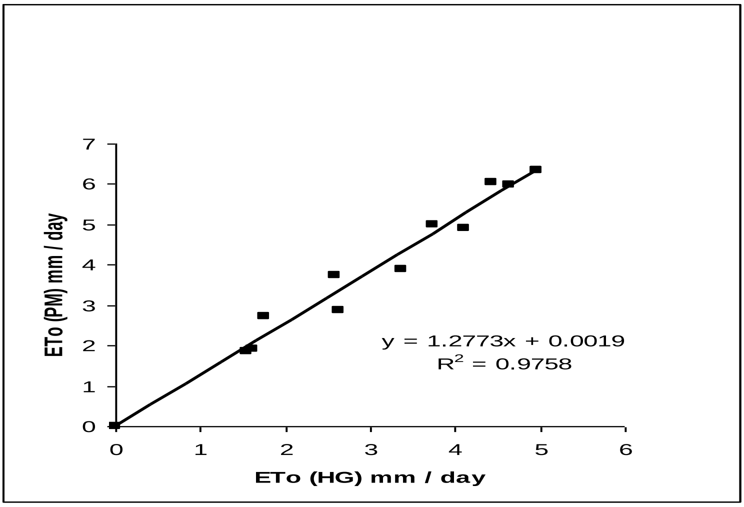


Fig. 4.13: Regression for determining Evapotranspiration depending on FAO-Penman-montith (PM) and Hargrives (HG) Program.

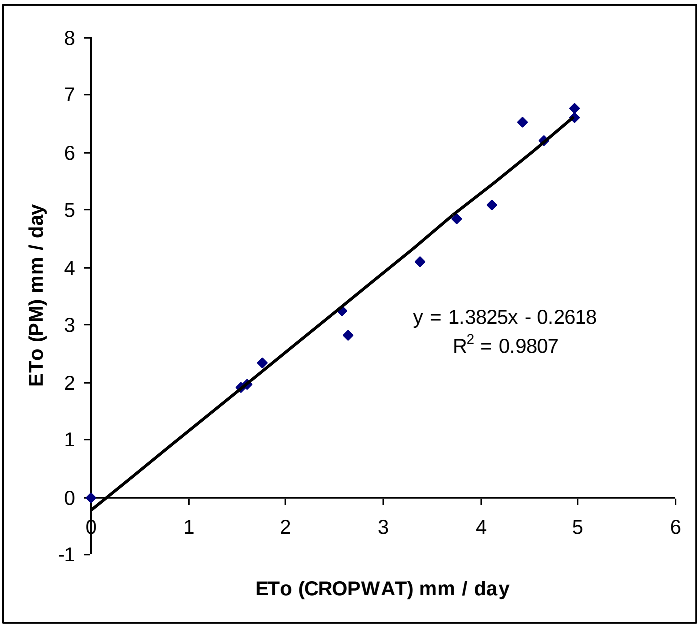


Fig. 4.14: Regression for determining Evapotranspiration depending on PM and CROPWAT Program.

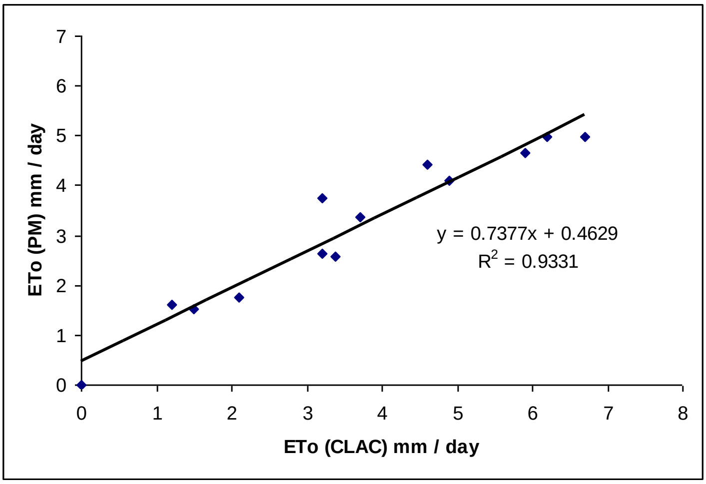


Fig. 4.15: Regression for determining Evapotranspiration depending on PM and CLAC method.

4.2.2Water requirement

4.2.2.1 Water requirement for bean crop

Table (4-2) and Figure (4.16) show the effect of plant stage on water requirement for bean using the two predicting methods CROPWAT and OA-Fertigation under three irrigation systems, which were sub drip irrigation, drip irrigation and furrow irrigation systems. The water requirement increased from the intial plant stage until the mid stage were it achieved highest value thereafter the water requirement decreased. The highest values of water requirement were obtained at mid growth stage. On the other hand, the lowest values of water requirement were given at the initial growth stage. These results can be attributed to the following reasons:

1- The increasing root depth from the initial growth stage to the mid growth stage (Tables 7-29, 7-29b, 7-30a and 7-30b) in the Appendix.

2- The increasing in water consumptive use from the initial growth stage to the mid growth stage and on the other hand, the decrease in water consumption from the mid growth stage to late growth stage (see tables 7-29a, 7-29b, 7-30a and 7-30b) in the Appendix.

Results of comparison between the two methods of determination of the water requirement showed that there were no differences between drip and subdrip irrigation systems under OA-Fertigation program and between drip and subdrip irrigation systems under CROPWAT program. However, the lower values of water requirement were obtained by OA-Fertigation program during a year under three irrigation systems. In the mid growth stage, the water requirement determined by OA-Fertigation program decreased by 46 %, 46% and 53.3 % as compared with corresponding ones recorded by CROPWAT under drip, subdrip and furrow irrigation systems respectively. These results may be becaause the OA-Fertigation program used several factors not used by other methods. These factors were root depth model, crop factor model and calculating evapotranspiration depending on FAO-Penman-Montith method.

Regression analyses were carried out to evaluate the results of water requirement under various methods. They show the agreement between the OA-Fertigation program and CROPWAT was 98.77% under drip irrigation and sub drip irrigation systems (Figure 4.17). This means that the results of

OA-Fertigation program can be used instead of field experiments to determine the water requirement with 0.9877 accuracy, of other methods. Also, it shows that the agreement between the OA-Fertigation program and CROPWAT program was 97.32% under furrow irrigation (Figure 4.18). This means that the results of OA-Fertigation program can be used instead of field experiments to determine the water requirement with 0.9732 accuracy other methods.

Table (4-2): Effect of plant growth stage on water requirement under three irrigation systems using two predicting methods.

Water calculation method	Water requirement (m^3 / f)					
	Irrigation system	Initial	Develop	Mid	Late	Total
ES	(SD and DR)	132.3	367.2	1073.3	429.3	2002.2
	FR	294.6	1161	1342.3	894.9	3692.8
CW	(SD and DR)	267.1	958.9	1994.2	570.4	3790.5
	FR	400.26	1439.34	2992.08	855.96	5687.64

ES = OA-Fertigation program

CW = CROPWAT program

SD= Sub drip irrigation system

DR=Drip irrigation system

FR= Furrow irrigation system

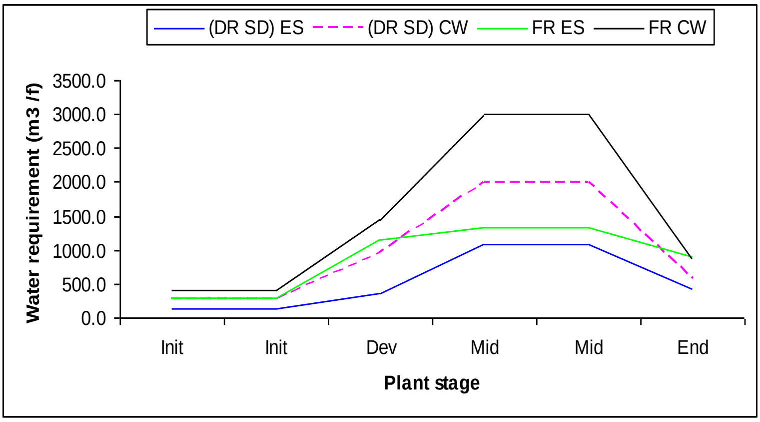


Fig. 4.16: Effect of bean growth stage on water requirement under three irrigation systems using two predicting methods.

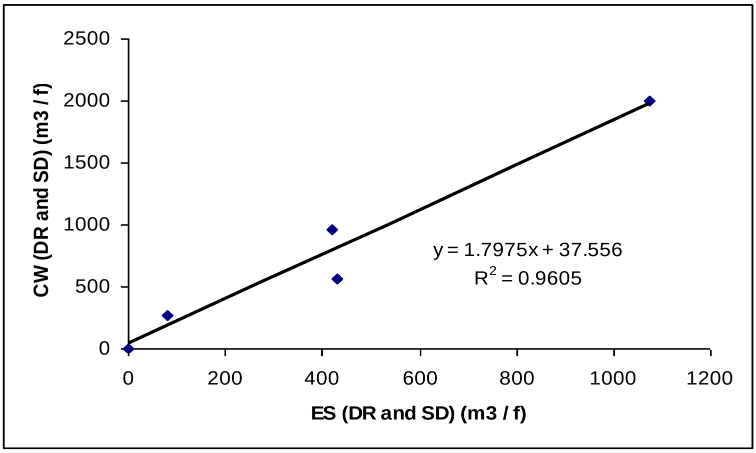


Fig. 4.17: Regression for determination water requirement depending on OA-Fertigation and CROPWAT program under drip and subdrip irrigation systems.

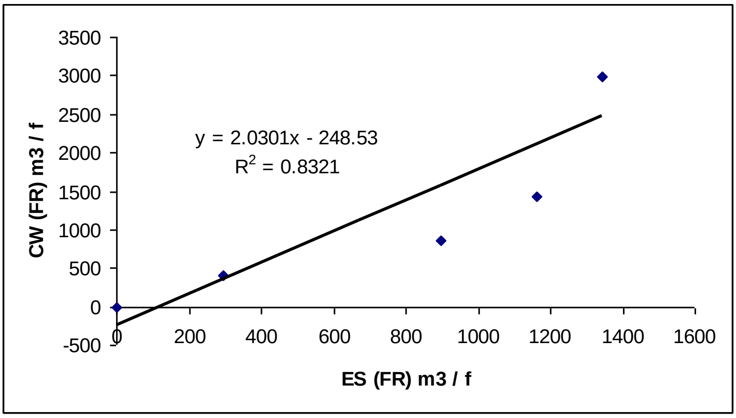


Fig. 4.18: Regression for the determination water requirement depending on OA-Fertigation and CROPWAT program under furrow irrigation systems.

4.2.2.2 Water requirement for cucumber crop

Table (4-3) and Figure (4.19) show the effect of plant growth stage on the water requirement for cucumber using the two predicting methods CROPWAT and OA-Fertigation under three irrigation systems, which were subdrip, drip and furrow irrigation systems. The water requirement increased as the plant growth stage increased until the mid growth stage. However, as the plant stage increased from the mid growth stage to the late growth stage, the water requirement decreased. The greatest values of water requirement were obtained at the mid growth stage. On the other hand, the lowest values of water requirement were given at initial stage. These results can be attributed to the following reasons:

1- The gradual increase in root depth from the initial growth stage to mid stage (Tables 7-31a, 7-31b, 7-32a and 7-32b) in the Appendix.

2- The Increase in the water consumptive use from the initial growth stage to the mid growth stage and on the other hand, the decrease in water consumptive use from mid stage to late growth stage (see Tables 7-31a, 7-31b, 7-32a and 7-32b) in the Appendix.

Results of comparison between the two methods used for determining the water requirement showed that there were no obvious differences between drip and subdrip irrigation systems under OA-Fertigation program and drip and subdrip irrigation systems under CROPWAT program method. However, the lowest values of the water requirement were recorded by the OA-Fertigation program during the period of study under three irrigation systems. In mid stage, the water requirement determined by OA-Fertigation program decreased by 61.76 %, 61.76 and 67.4% as compared to the corresponding determind ones by the CROPWAT under drip, subdrip and furrow irrigation systems respectively. These results may be because the OA-Fertigation program used several factors not used by other methods. These factors were root depth, crop factor and calculating evapotranspiration by FAO-Penman-Montith.

The regression analyses carried out to evaluate the results of water requirement under the studied various methods, show agreement between the OA-Fertigation program and CROPWAT was (r = 0.9862) under drip and subdrip irrigation systems (Figure 4.20). This means that the results of OA-Fertigation program can be used instead of field experiments to determine the water requirement with accuracy 98.62 %. Also, an agreement was found between the OA-Fertigation program and CROPWAT was (r = 0.9518) under furrow irrigation (Figure 4.21). This means that the results of OA-Fertigation program can be used instead of field experiments to determine the water requirement with accuracy 95.18 %.

Table (4-3): Effects of plant growth stage on water requirement for cucumber under three irrigation systems by using the two predicting methods.

Water calculation method	Water requirement (m^3 / f)					
	Irrigation system	Initial	Develop	Mid	Late	Total
ES	(SD and DR)	217.47	343.84	516.69	258.35	1336.35
	FR	589.12	756	896	504.56	2059.68
CW	(SD and DR)	619.92	748.44	831.6	348.18	2548.14
	FR	929.04	1123.5	1247.4	522.48	3822.42

See footnot of Table (4-

2)

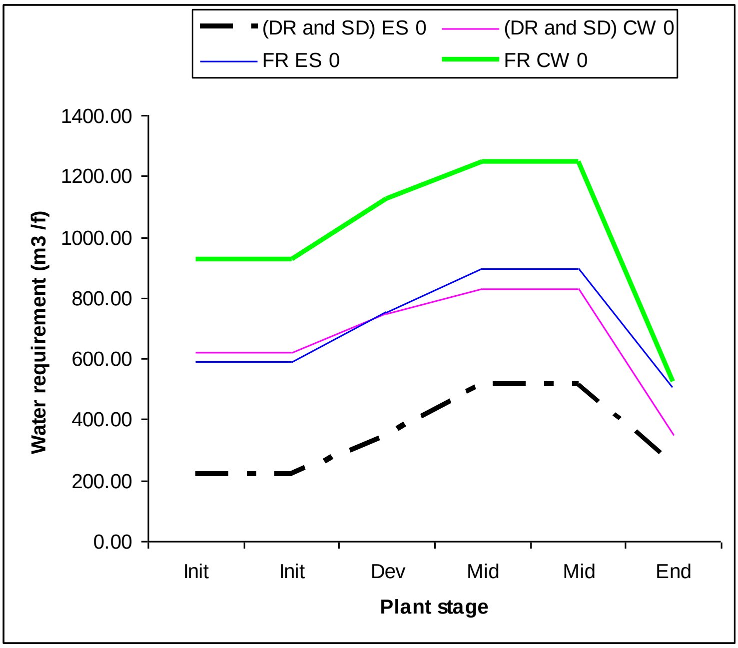


Fig. 4.19: Effect of the plant growth stage on water requirement of cucumber under three irrigation systems by using two predicting methods.

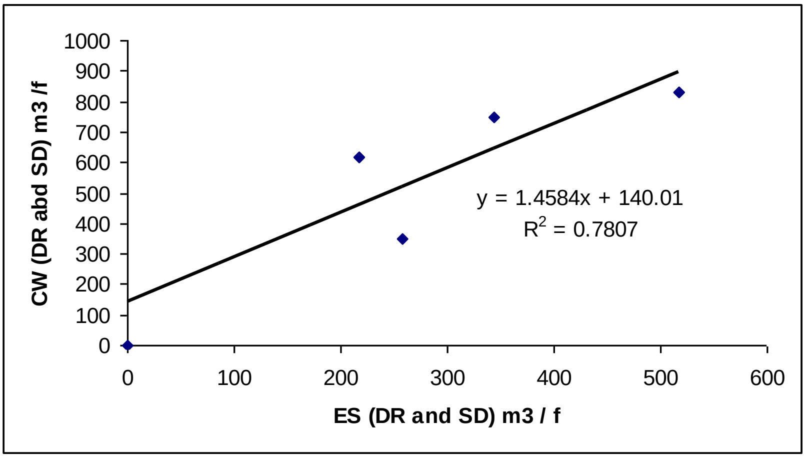


Fig. 4.20: Regression for determining water

requirement depending on OA-Fertigation and CROPWAT program under drip and subdrip irrigation systems.

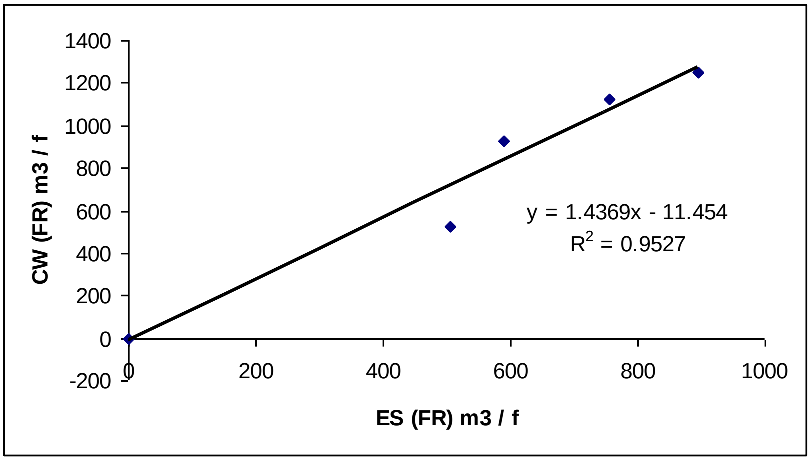


Fig. 4.21: Regression for determining water requirements for cucumber crop measured by CROPWAT (CW) and OA-Fertigation under drip, subdrip and furrow irrigation systems.

4.2.3 Crop yield

4.2.3.1 Seed dry yield for bean crop

Table (4-4) and Figure (4.22) show the effect of the used two fertigation management methods (OA-Fertigation method (ES) and the traditional method (TR)) and the three irrigation systems (subdrip, drip irrigation and furrow irrigation systems) on bean crop yield. Highest values for yield were obtained by using ES (under furrow irrigation, subdrip and drip irrigation systems) than the corresponding values of yield obtained for TR method (under drip, subdrip and furrow irrigation systems). These results can be attributed to the following reasons:

1- Root depth, root weight, number of leaves, plant height and stem weight measured under ES method were higher than TR method (Tables 7-16, 7-17,7-18,7-20 and 7-21) in the Appendix.
2- Percentage of chlorophyll under ES method was higher than TR method (Table 7-19) in the Appendix.
3- Total nitrogen in leaves under ES was higher than its content under TR method (Table 7-22) in the Appendix.

4.2.3. 2 Yield of cucumber (kg / f)

Table (4-5) and Figure (4.24) show the effect of the used two fertigation management methods (OA-Fertigation method (ES) and the traditional method (TR)) and the three used irrigation systems (subdrip, drip and furrow irrigation systems) on cucumber crop yield. The values of yield obtained by using ES under drip, subdrip and furrow irrigation systems were higher than the corresponding values of yield obtained by using the TR method.

These results can be attributed to the following reasons:

1- Numbers of infected leaves and infected fruits under ES method wereless than those under TR method; tables (7-25 and 7-26) in the Appendix.
2- Percentage of chlorophyll under ES method was higher than those under the TR method; table (7-27 and 7-28) in the Appendix.

4.2.4 Water Use Efficiency (WUE) and Nutrient Use Efficiency (NUE)

Table (4-4) and Figures (4.22 and 4.23) show the effect of the used two fertigation management methods (OA-Fertigation method (ES) and Traditional method (TR)) and the three irrigation systems (subdrip ., drip . and furrow irrigation systems) on WUE for bean. Highest values of WUE were obtained by using ES under furrow irrigation system, sub drip irrigation system and drip irrigation system than the corresponding values of WUE given by using TR method

Highest values of NUE were obtained by using ES under furrow irrigation system, and TR under furrow irrigation system. On the other hand, the lowest values of NUE were given by using TR method under drip system and subdrip irrigation systems. Middle values were obtained by using ES method under subsdrip and drip irrigation systems.

These results can be attributed to the following reasons:

1- The yield achived by using ES was more than that achieved done to TR method (Table 4-4).

2- Amounts of the fertilizers added to crop by using ES were less than the added by using TR method (Tables ; 7-33 , 7-34 and 7-35) in the Appendix.

3- Potassium was not added to soil because soil content form potassium was (available potassium 389.7 mg. kg^{-1}) was more than that required (Table 7-2) in the Appendix.

4- Water requirements by using ES was less than those under the TR method (Table 4-3)

Table (4-4): Yield, WUE and NUE for bean crop.

Fertigation method	Irrigation system	Yield (kg / f)	WUE (kg. m^{-3})	NUE (kg. kg^{-1})
ES	**SD**	2564	0.91	13.4
	DR	1827.4	0.66	9.7
	FR	2864	1.02	21.1
TR	**SD**	1194.3	0.32	8.8
	DR	1109.3	0.29	8.2
	FR	1314.9	0.45	18.9

See foot note of Table (4-1)

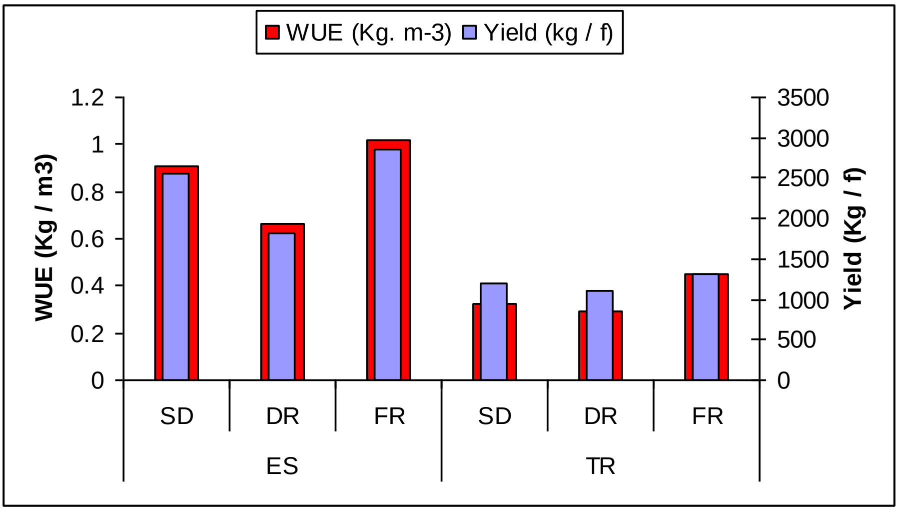


Fig. 4.22: Yield and WUE for bean crop.

Table (4-5) and Figures (4.24 and 4.25) show the effect of the two fertigation management methods (OA-Fertigation method (ES) and Traditional method (TR)) and three irrigation systems (subdrip, drip and furrow irrigation systems) on WUE for cucumber crop. The highest values of WUE were obtained by using ES with subdrip and drip irrigation systems. On the other hand, the lowest value of WUE was given by using TR method under furrow irrigation system. Middle values were obtained by using TR method under subdrip and drip irrigation systems and ES method under furrow irrigation system. The highest values of NUE were obtained by using ES under drip irrigation system and sub drip irrigation system. On the other hand, the lowest value of NUE was given by using TR method under furrow irrigation system. Middle values were obtained by using ES method under furrow irrigation system and TR method under subdrip and drip irrigation systems. These results can be attributed to the following reasons:

1- The yield obtained due to using ES system was more than the achieved due to TR method (Table 4-5).

2- Fertilizer requirements by using ES was less than the corresponding ones used under the TR method

Tables (7-36, 7-37 and 7-38) in the Appendix.

3- Water requirements by using ES were less than those by usingTR method; Table (4-3).

4- Potassium was not added to soil because soil content form potassium was (available potassium 389.7 mg.kg^{-1}) more than the required fertilizers; Table (7-2) in the Appendix.

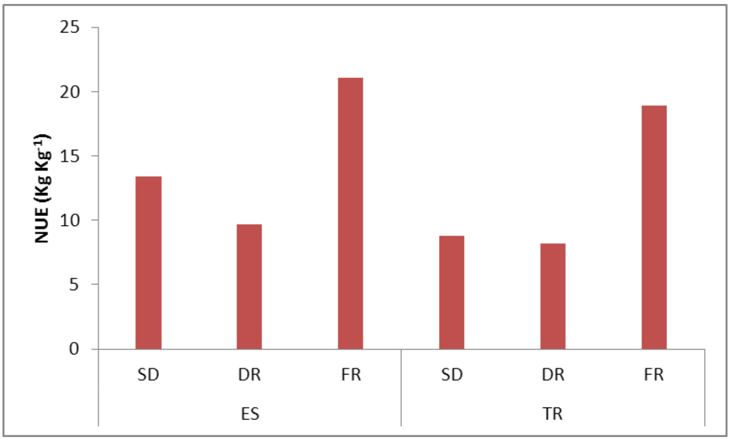


Fig. 4.23: NUE for bean crop.

Table (4-5): Yield, WUE and NUE for cucumber.

Fertigation method	Irrigation system	Yield (kg / f)	WUE (kg. m^{-3})	NUE (kg. Kg^{-1})
ES	SD	1806	1.35	7.08
	DR	1459.9	1.57	8.2
	FR	2091.6	0.64	5.2
TR	SD	1638	0.57	5.73
	DR	1327	0.64	6.42
	FR	966	0.25	3.79

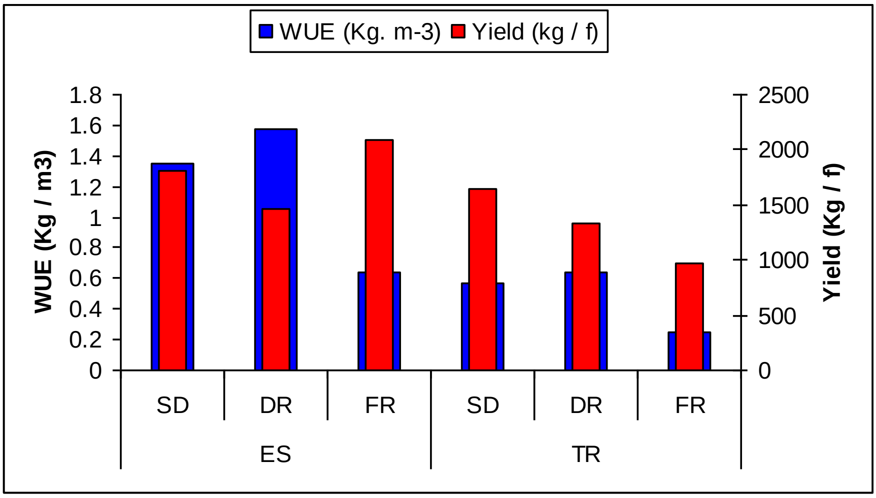


Fig. 4.24: Yield and WUE for cucumber.

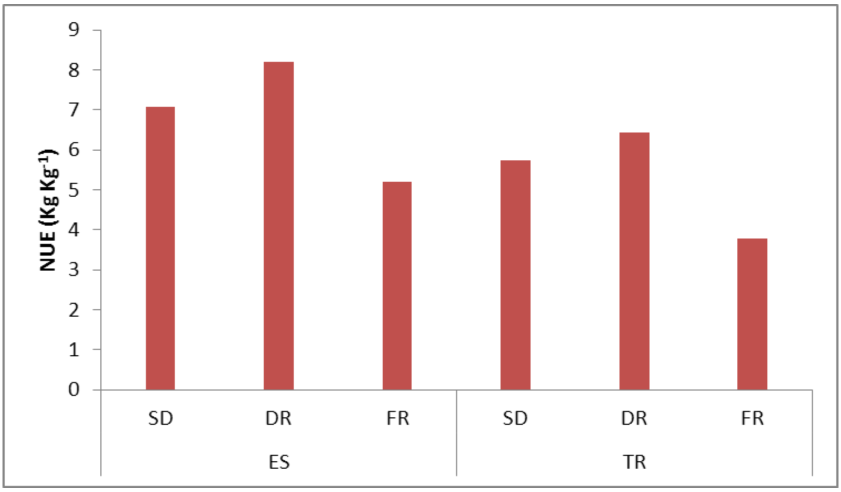


Fig. 4.25: NUE for cucumber.

SUMMARY AND CONCLUSION

5. SUMMARY AND CONCLUSION

The objective of this study was to design a fertigation program using the expert system (ES).To achieve the objective of this study, the following steps were required:

i. Identification of the problem
ii. Analysis of the information
iii. Characterizing the variables of the key factors and qualifiers.

The study involved also a comparison between the ES program outputs and the corresponding ones recommended by the Ministry of Agriculture. To establish such a comparative study, a field experiment was executed on bean plant after dividing the filed of study into two sections. In the first, the experimental work was carried out using the ES fertigation management, while in the second section, the well known “CROPWAT Program”, was used for the scheduling of the irrigation together with the traditional methods of fertigation outlined by the Ministry of Agriculture, Egypt.

Higher values for bean crop yield were obtained by using ES (under furrow irrigation, sub drip and drip irrigation systems) than the corresponding values of yield obtained for TR method (under drip, sub drip and furrow irrigation systems).

> The values of cucumber yield obtained by using ES under drip, sub drip and furrow irrigation systems were higher than the corresponding values of yield obtained by using the TR method.

The results of comparison assured the superiority of the ES over the other traditional one, where higher values of water use efficiency “WUE” and nutrient use efficiency “NUE” were achieved by the former than the latter.

The aforementioned results impose the importance of applying an expert system program for management of fertilization and irrigation of vegetable crops such as the ones used in this investigation. Such a program besides of its ability to save water used for irrigation which in turn, reflected on higher values of water use efficiency as compared with the traditional fertilization and irrigation managements.

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APPENDIX

7. APPENDIX

7-1 The mechanical and chemical analyses of the soil

Table (7-1): Soil physical properties of the experimental filed:

Particle size distribution (%)				Organic matter %	Texture
Coarse sand	Sand	Silt	Clay		
2	24.71	36.0	35.4	1.89	Clay loam

Table (7-2): Soil Chemical properties of the experimental filed.

Soil property	Unit	Results
Electrical conductivity (1:5)	dS/m	0.5
pH (1:5)		8.5
Total nitrogen	%	0.11
AV. K	ppm	389.7
AV.P	ppm	41.1

7-2 The Chemical properties of the irrigation water

Table (7-3): Chemical properties of the irrigation water.

Water property	Unit	Results
Electrical conductivity (EC)	dS/m	1.5
pH		7.3
Total nitrogen	%	0.001
Na	mg l^{-1}	219
Cl	mg l^{-1}	418
mg	mg l^{-1}	0.48
No3	mg l^{-1}	0.16

7-3 Climate data of Qalubiya Governorate, average values for the period extending form 1997 until 2006

Table (7-4): Climate data of Qalubiya Governorate, average values for the period extending from 1997 until 2006, CLAC, 2007.

Month	Extra radiation	Mean relative humidity	Mean daily actual sun-shine hours	Mean daily max. Sunshine hours	Max. temp.	Min. temp.	Average temp.
1	8	60.58	12	8	19.7	8.9	12.35
2	9	59.02	12	8	20	8.5	13.1
3	13	61.60	12	9	22.8	10	15.25
4	15	57.96	12	8	28.3	13.6	18.85
5	16	52.37	10	8	33	17.1	23.05
6	17	56.02	10	9	32.9	19.7	25.6
7	17	59.81	10	9	35	22	26.85
8	16	62.72	10	9	35.2	22.2	26.85
9	14	57.17	10	7	32.6	20.2	24.9
10	12	56.24	10	7	30.4	18.5	22.75
11	10	55.01	11	8	25.7	14	19.35
12	8	58.70	11	8	21.2	11.1	15.1

7-4 Concept of expert system

7-4-1 Concept of soil

Table (7-5): The soil properties used under this study

Soil property	Description	Source of Value	Type	Legal values
Texture	Texture of the soil	DB*	String	Sandy, Sandy loam, Silty loam, Silty clay loam, Clay loam, Clay and Volcanic clay & Peat
Type	Denotes the classification of the soil texture	Relation	String	fine, medium and corase
Sbd	Soil bulk density	DB	Single	Number-range (0, 1000)
Ec	Soil salinity	DB	Single	Number-range (0, 6)
FC	Field capacity	DB	Single	Number-range (0, 100)
WP	Welting point	DB	Single	Number-range (0, 100)
pH	pH of soil	DB	Single	Number-range (0, 14)
Calcium carbonate	the percentage of calcium carbonate in soil	DB	Single	more than 10 % or less than 10 %
CEC	Cation exchange capacity	DB	single	Number-range (0, 100)

N mg kg^{-1}	Soil content of available nitrogen	DB	single	Number-range (0, 1000)
P mg kg^{-1}	Soil content of available phosphor	DB	single	Number-range (0, 1000)
K mg kg^{-1}	Soil content of available potassium	DB	single	Number-range (0, 1000)
Critical N	The critical nitrogen in soil	DB	single	0
Critical P	The critical phosphor in soil	DB	single	14, 23, 26, 30, 35, 42, 58 and 90
Critical K	The critical potassium in soil	DB	single	120, 130 and 150
Critical S	The critical sulphur in soil	DB	single	7.5
Soil test type	Soil test type	DB	single	Olsen P (mg/kg) or Colwell P (mg/kg)

DB: Database

7-4-2 Concept of water

Table (7-6): The water properties of concern in the expert system

Water property	Description	Source of Value	Type	Legal values
Ec	Water salinity	DB	Single	Number-range (0, 6)
pH	pH of water	DB	Single	Number-range (0, 14)
N Quantity	Water content of nitrogen	DB	Single	Number-range (0, 1000)
P Quantity	Water content of phosphor	DB	Single	Number-range (0, 1000)
K Quantity	Water content of potassium	DB	Single	Number-range (0, 1000)
Ca Quantity	Water content of calcium	DB	Single	Number-range (0, 1000)
Mg Quantity	Water content of magnesium	DB	Single	Number-range (0, 1000)

7-4-3 Concept of climate

Table (7-7): The climate properties of concern in the expert system

Climate property	Description	Source of Value	Type	Legal values
avg_tc	Average temperature	DB	Single	Number-range (0, 40)
avg_rh	Average relative humidity	DB	Single	Number-range (0,100)
ash	Actual sun shine hours	DB	Single	Number-range (5, 17)
msh	Maximum sun shine hours	DB	Single	Number-range (5, 17)
ra	Extraterrestrial	DB	Single	Number-range (3, 17)
max_rh	Maximum relative humidity	DB	Single	Number-range (0,100)
mws	Mean wind speed	DB	Single	Number-range (0,100)
dws	Day wind speed	DB	Single	Number-range (0,100)
nws	Night wind speed	DB	Single	Number-range (0,100)
avg_tc_next_month	Average temperature for next month	DB	Single	Number-range (0, 40)

avg_rh_next_month	Average relative humidity for next month	DB	Single	Number-range (0,100)
ash_next_month	Actual sun shine hours for next month	DB	Single	Number-range (5, 17)
msh_next_month	maximum suns shine hours for next month	DB	Single	Number-range (5, 17)
ra_next_month	Extraterrestrial for next month	DB	Single	Number-range (3, 17)

7-4-4 Concept of plant

Table (7-8): The plant properties concern in the expert system

Plant Property	Description	Source of Value	Type	Legal values
init_stage	The length of the initiation stage in days	DB	Single	Number-range (0, 1000)
ve_stage	The length of the vegetative stage in days	DB	Integer	Number-range (0, 1000)
middle_stage	The length of the middle stage in days	DB	Integer	Number-range (0, 1000)
end_stage	The length of the harvest stage in days	DB	Integer	Number-range (0, 1000)
Plant age	Plant age	DB	Integer	Number-range (0, 1000)
Kc_inti	Kc in initial stage	DB	Integer	Number-range (0, 1000)
Kc_dev	Kc in develop stage	DB	Integer	Number-range (0, 1000)
Kc_mid	Kc in middle stage	DB	Integer	Number-range (0, 1000)
Kc_end	Kc in late stage	DB	Integer	Number-range (0, 1000)
plant hight	The height of plant	DB	single	Number-range (0, 1000)
dis_Bet_plants	Distance between plants	DB	single	Number-range (0, 1000)
moisture_content	Content of moisture in plant	DB	single	Number-range (0, 100)

Depletion	Water depletion	DB	single	Number-range (0, 100)
Zri	The maximum root depth	DB	single	Number-range (0, 1000)
N_requirement	The requirement of nitrogen	DB	single	Number-range (0, 1000)
P2O5_requirement	The requirement of phosphorus	DB	single	Number-range (0, 1000)
K2O_requirement	The requirement of potassium	DB	single	Number-range (0, 1000)

7-4-5 Concept of farm

Table (7-9): Farm properties of concern in the expert system

Properties	Description	Source of Value	Type	Legal values
latitude	Farm latitude	DB	Single	Number-range (0, 1000)
altitude	Farm altitude	DB	Single	Number-range (0, 1000)
longitude	Farm longitude	DB	Single	Number-range (0, 1000)
area	Farm area	DB	Single	Number-range (0, 1000000)
Farm type	Farm type	DB	Single	Open_field, low_tunnel, and high_tunnel
Irr_Method	irrigation method	DB	Single	Surface irrigation, drip irrigation and sprinkler irrigation

7-4-6 Concept of fertilizer

Table (7-10): Fertilizer properties of concern in the expert system

Properties	Description	Source of Value	Type	Legal values
Type	Fertilizer type	DB	String	solid, gas and liquid
Density	Fertilizer density	user	Single	Number-range (0, 100)
Usefulness_Cof.	Fertilizer Usefulness coefficient	user	Single	Number-range (0, 100)
N_Percient	the percentage of nitrogen in fertilizer	DB	Single	Number-range (0, 100)
P2O5_Percent	the percentage of phosphor in fertilizer	DB	Single	Number-range (0, 100)
K2O_Percent	the percentage of potassium in fertilizer	DB	Single	Number-range (0, 100)
S_Percent	the percentage of nitrogen in sulphor	DB	Single	Number-range (0, 100)
Zn_Percent	the percentage of zinc in fertilizer	DB	Single	Number-range (0, 100)
Fe_Percent	the percentage of iron in fertilizer	DB	Single	Number-range (0, 100)
Cu_Percent	the percentage of copper in fertilizer	DB	Single	Number-range (0, 100)
Mn_Percent	the percentage of manganese in fertilizer	DB	Single	Number-range (0, 100)

B_Percent	the percentage of boron in fertilizer	DB	Single	Number-range (0, 100)
CaO_Percent	the percentage of calcium in fertilizer	DB	Single	Number-range (0, 100)
MgO_Percent	the percentage of Magnesium in fertilizer	DB	Single	Number-range (0, 100)

7-4-7 Concept of manure

Table (7-11): Manure properties of concern in the expert system

Properties	Description	Source of Value	Type	Legal values
N_Quantity	the quantity of nitrogen in manure	DB	Single	Number-range (0, 100)
P_Quantity	the quantity of phosphorus in manure	DB	Single	Number-range (0, 100)
K_Quantity	the quantity of potassium in manure	DB	Single	Number-range (0, 100)
Zn_Quantity	the quantity of zinc in manure	DB	Single	Number-range (0, 100)
Mn_Quantity	the quantity of manganese in manure	DB	Single	Number-range (0, 100)
Cu_Quantity	the quantity of copper in manure	DB	Single	Number-range (0, 100)
Ca_Quantity	the quantity of calcium in manure	DB	Single	Number-range (0, 100)
Mg_Quantity	the quantity of magnesium in manure	DB	Single	Number-range (0, 100)
Fe_Quantity	the quantity of iron in manure	DB	Single	Number-range (0, 100)
S_Quantity	the quantity of sulphor in manure	DB	Single	Number-range (0, 100)
B_Quantity	the quantity of boron in manure	DB	Single	Number-range (0, 100)
weight	the weight of manure	DB	Single	Number-range (0, 1000)
volume	the volume of manure	DB	Single	Number-range (0, 1000)

7-4-8 Concept of irrigation system

Table (7-12): The irrigation system properties of concern in the expert system

Property	Description	Source of Value	Type	Legal values
Irrigation system	type of irrigation system	DB	Float	Surface irrigation, drip Irrigation and sprinkler irrigation
Injection device type	type of injection device	DB	Float	Injection pump, deferential tank and venturi
Pump discharge	discharge of pump	DB	single	Number-range (0, 1000)
Efficiency %	the efficiency of irrigation system	DB	single	Number-range (0, 100)
Welting area	the welting of irrigated area	DB	single	Number-range (0, 1)
injection device discharge	the discharge of injection device	DB	single	Number-range (0, 100)
Efficiency of injection device	the efficiency of injection device	DB	single	Number-range (0, 100)
volume of fertilizer tank	the volume of fertilizer tank	DB	single	Number-range (0, 10)
N_ adsorption%	the efficiency of adsorption of nitrogen	DB	single	Number-range (0, 100)

P_ adsorption%	the efficiency of adsorption of phosphorus	DB	single	Number-range (0, 100)
K_ adsorption%	the efficiency of adsorption of potassium	DB	single	Number-range (0, 100)
Advance time	advance time of water flow	DB	single	Number-range (0, 100)

7-4-9 Concept of crop Tolerance

Table (7-13): The Crop tolerance concern in the expert system

Property	Description	Source of Value	Type	Legal values
ECe100%	the soil EC in which the yield of plant doesn’t decrease potential yield is 100%	DB	single	Number-range (0, 10)
ECe90%	the percentage of soil EC in which the yield of plant decreases by 10 % potential yield is 90%	DB	single	Number-range (0, 10)
ECe75 %	the percentage of soil EC in which the yield of plant decreases by 25 % potential yield is 75%	DB	single	Number-range (0, 13)
ECe50%	the percentage of soil EC in which the yield of plant decreases by 50 % potential yield is 50%	DB	single	Number-range (0, 18)
ECe0%	the maximum soil EC that plant can’t live after it potential yield is zero%	DB	single	Number-range (0, 50)
ECw100%	the percentage of irrigation water EC in which the yield of plant doesn’t decreases	DB	single	Number-range (0, 6)

ECw90%	the percentage of irrigation water EC in which the yield of plant decreases by 10 %	DB	single	Number-range (0, 7)
ECw75%	the percentage of irrigation water EC in which the yield of plant decreases by 25 %	DB	single	Number-range (0, 9)
ECw50%	the percentage of irrigation water EC in which the yield of plant decreases by 50 %	DB	single	Number-range (0, 12)
ECw0%	the maximum irrigation water EC that plant can't live after it potential yield is zero%	DB	single	Number-range (0, 50)

7-4-10 Concept of fertilizer selection

Table (7-14): The fertilizer selection concern in the expert system

Property	Description	Source of Value	Type	Legal values
Nitrogen fertilizer	selection of nitrogen fertilizer	DB	Float	Ammonium thiosulfate (ATS), urea, ammonium nitrate, ammonium sulfate, aqua ammonia, potassium nitrate , nitric acid, 19-19-19 and 46-12-6.
Phosphorus fertilizer	selection of phosphorus fertilizer	DB	Float	Ammonium polyphosphate, diammonium phosphate (DAP), monoammonium phosphate (MAP), superphosphate single, 12-12-12, 14-14-14, 12-12-17-2, rock phosphate, partly acidulated rock phosphate, finely powdered, superphosphate triple , starter 8-20-5-5, starter 9-18-9, ammonium phosphates , phosphoric acid, 19-19-19 and 46-12-6.

Potassium fertilizer	selection of potassium fertilizer	DB	Float	Potassium chloride (MOP), potassium-magnesium sulfate, potassium nitrate, 12-12-12, 14-14-14, 16-0-31, 12-12-17-2, kainite, langbeinite, potassium sulfate, starter 8-20-5-5, starter 9-18-9 , potassium chloride,19-19-19 and 46-12-6 .
Ca fertilizer	selection of calcium fertilizer	DB	Float	Superphosphate single, calcium chloride, calcium sulfate (Gypsum), dolomite, rock phosphate, partly acidulated, superphosphate triple, calcium carbonate (Lime)
Mg fertilizer	selection of magnesium fertilizer	DB	Float	Potassium-magnesium sulfate, dolomite, kieserite, magnesium sulfate (Epsom salt), manganese sulfate, NTA chelate, zinc chelate, langbeinite and magnesium oxide (Magnesia)
Fe fertilizer	selection of iron fertilizer	DB	Float	DTPA chelate, EDDHA chelate, EDTA chelate, Ferrous sulfate, HEEDTA chelate and NTA chelate
Cu fertilizer	selection of copper fertilizer	DB	Float	Copper sulfate, EDTA chelate and HEEDTA chelate
Mn fertilizer	selection of manganese fertilizer	DB	Float	EDTA chelate, HEEDTA chelate and manganese sulfate
Zn fertilizer	selection of zinc	DB	Float	EDTA chelate, HEEDTA chelate, NTA chelate, zinc chelate,

	fertilizer			zinc chloride, zinc oxide, zinc sulfate, 15% nulex Liq. Zn and 20% nulex Liq. Zn
S fertilizer	selection of sulfate fertilizer	DB	Float	Ammonium thiosulfate (ATS), superphosphate single, potassium-magnesium sulfate, calcium sulfate (Gypsum), ammonium_sulfate, kieserite, magnesium sulfate (Epsom salt), sulfur, sulfuric acid, 12-12-17-2, superphosphate triple, Langbeinite, Potassium sulfate, Starter 8-20-5-5 and Ammonium sulfate
B fertilizer	selection of boron fertilizer	DB	Float	Borax and Boron 15%

7-5 Bean biological properties

7-5-1 Plant height

Table (7-15): Bean plant height

Irrigation systems	Fertigation system	Plant Height (cm)				
		R1	R2	R3	R4	Mean
SD	ES	32.5	33.5	34	35	33.75
		35.5	30	32.5	19	29.25
		35	35	37.5	34.5	35.5
	TR	29.5	31.5	31	33	31.25
		38.5	35.5	26	34	33.5
		31.5	36	33.5	21	30.5
DR	ES	27	30	29	34	30
		31	27	32.5	33	30.88
		32	29	32	31	31
	TR	30	30	28	27	28.75
		30	23	27	26	26.5
		25.5	28.5	32	23	27.25
FR	ES	34.5	32	40.5	38	36.25
		40	34.5	39.5	40	38.5
		32	40	33.5	42	36.88
	TR	31.5	30	36	39.5	34.25
		27	38	34.5	31.5	32.75
		37	32.5	35	36	35.13

7-5-2 Root depth

Table (7-16): Bean root depth

Irrigation systems	Fertigation system	Root Depth (cm)				
		R1	**R2**	**R3**	**R4**	**Mean**
SD	**ES**	23.5	25	30	19	24.38
		27.5	21.5	21	25.5	23.88
		18	26.5	22.5	27	23.5
	TR	21.5	19	14.5	21.5	19.13
		26	22	19.5	12	19.88
		27	28	29.5	28	28.13
DR	**ES**	20	20.5	28	15.5	21
		21	18	18	17	18.5
		20.5	18	22.5	19	20
	TR	15	23	12.5	16	16.63
		17	15	20	23	18.75
		21.5	16.5	22	22	20.5
FR	**ES**	13	17	22.5	22	18.63
		15	19	21.5	15	17.63
		13	13	18	15	14.75
	TR	17	15	20	20.5	18.13
		17	14.5	13	14	14.63
		12.5	14.5	17	15	14.75

7-5-3 Plant weight

Table (7-17): Bean plant weight

Irrigation systems	Fertigation system	Plant weight (g)				
		R1	R2	R3	R4	Mean
SD	ES	31.03	24.88	34.74	27.54	29.5475
		28.98	29.14	27.76	5.03	22.7275
		56.1	38.605	39.825	34.22	42.1875
	TR	28.655	34.67	37.83	26.34	31.87375
		42.51	26.55	18.82	29.71	29.3975
		22.275	46.015	29.72	19.28	29.3225
DR	ES	23.36	16.825	32.96	24.085	24.3075
		29.35	15.88	18.835	28.38	23.11125
		23.545	29.52	38.81	27.75	29.90625
	TR	33.77	27.92	24.585	16.6	25.71875
		18.955	11.37	17.435	24.82	18.145
		22.135	21.49	22.89	25.15	22.91625
FR	ES	38.08	48.41	75.45	78.49	60.1075
		73.795	40.67	36.48	51.94	50.72125
		24.4	95.18	45.93	119.4	71.2275
	TR	22.35	37.63	52.05	50.885	40.72875
		77.8	49.46	25.76	14.19	41.8025
		25.74	30.215	19.115	30	26.2675

7-5-4 Root weight

Table (7-18): Bean root weight

Irrigation systems	**Fertigation system**	**Root Weight (g)**				
		R1	**R2**	**R3**	**R4**	**Mean**
SD	**ES**	1.615	0.99	1.855	1.395	1.5
		1.62	1.24	1.45	0.75	1.3
		2.84	2.21	2.365	2.04	2.4
	TR	1.1	1.385	1.86	1.85	1.5
		1.685	1.105	1.29	1.32	1.4
		0.68	2.085	1.765	1.13	1.4
DR	**ES**	0.82	0.96	1.59	1.23	1.2
		1.61	1.02	0.965	1.45	1.3
		1.4	1.73	1.81	1.095	1.5
	TR	1.16	1.72	0.9	0.905	1.2
		0.99	0.57	0.91	1.2	0.9
		1.37	0.96	1.345	1.1	1.2
FR	**ES**	1.525	1.84	2.27	2.62	2.1
		1.945	1.38	1.15	1.34	1.5
		0.925	2.81	1.59	2.83	2.0
	TR	1.03	1.33	2.19	1.41	1.5
		2.38	1.6	0.75	0.675	1.4
		0.905	1.35	1.01	1	1.1

7-5-5 Percentage of chlorophyll

Table (7-19): Percentage of chlorophyll in bean leaves

Irrigation systems	Fertigation system	Percentage of chlorophyll				
		R1	**R2**	**R3**	**R4**	**Mean**
SD	**ES**	42.6	48.85	56.3	46.4	48.5
		53	49	36.1	48.4	46.6
		46.8	48.2	48.2	48.6	48.0
	TR	41.45	45.15	48.9	50.85	46.6
		49.8	44.9	49.85	42.3	46.7
		43.8	44.85	46.8	48.55	46.0
DR	**ES**	45.8	49	43.1	42.3	45.1
		47.1	45.8	43.85	53.1	47.5
		44.75	44.7	42.65	46.75	44.7
	TR	39.3	39.5	46.2	38.25	40.8
		38.15	43.1	44.8	33	39.8
		43.25	46.15	44.55	37	42.7
FR	**ES**	35.45	42.5	37.3	52.05	41.8
		48.7	40.8	36.7	45.9	43.0
		38..5	39.3	41.4	42.2	41.0
	TR	35.4	44.5	42.6	40	40.6
		41.55	44.7	35.3	40.1	40.4
		42.85	41	38	45.9	41.9

7-5-6 Stem weight

Table (7-20): weight of stem for Bean crop

Irrigation systems	Fertigation system	Stem weight (g)				
		R1	R2	R3	R4	Mean
SD	**ES**	9.5	13.4	13	12.8	12.2
		20.6	15	4.8	11.3	12.9
		9.2	20.7	15.6	5.8	12.8
	TR	9.4	6.7	12.8	9.4	9.6
		11.7	8.2	10.2	9	9.8
		13.8	11.2	13.3	12.4	12.7
DR	**ES**	5.7	5.3	10	7.5	7.1
		8.2	4	5.1	8	6.4
		6.2	5.2	10.4	7.2	7.3
	TR	8.6	7.8	7.2	4.7	7.1
		5.8	3	6.1	7	5.4
		7.5	6.4	7.1	5.8	6.7
FR	**ES**	9.8	16.3	26.5	23.8	19.1
		38	19.5	8.4	22.9	22.2
		7.6	25	16.5	47.3	24.1
	TR	5.6	10.3	24.7	17.6	14.6
		24	21	20	5.3	17.5
		8	8.8	5.5	6	7.1

7-5-7 Number of leaves

Table (7-21): Number of Leaves for bean crop

Irrigation systems	Fertigation system	Number of Levees, ( )				
		R1	**R2**	**R3**	**R4**	**Mean**
SD	**ES**	13	17	12	12	14
		15	12	9	14	12
		10	18	15	8	12
	TR	12	9	10	10	10
		12	15	11	5	11
		21	12	12	13	14
DR	**ES**	14	8	10	10	10
		10	10	11	11	11
		10	11	17	12	12
	TR	10	11	9	10	10
		9	9	8	14	10
		11	12	9	12	11
FR	**ES**	12	14	22	21	17
		21	13	14	19	17
		8	20		33	20
	TR	8	13	18	18	14
		20	18	10	9	14
		8	9	9	10	9

7- 6 Chemical properties for bean crop

Table (7-22): Beans crop analysis

Irrigation systems	Fertigation system	O.C %	O.M %	Ash %	T.N %	C/N Ratio
Sub Drip Irrigation	**ES**	45.8	79	21	5.38	8.5
	TR	47	81	19	5.4	8.8
Drip Irrigation	**ES**	47.1	81.3	18.8	5.21	9
	TR	47.3	81.5	18.5	4.76	9.9
Furrow Irrigation	**ES**	49	84	16	5.6	8.7
	TR	47.7	82.2	17.8	5.04	9.5

7-7 Mass of 100 seeds for bean crop

Table (7-23): Mass of 100 seeds for bean crop

Fertigation method	Irrigation system	Mean
ES	**SD**	37
	DR	39
	FR	43
TR	**SD**	33
	DR	38
	FR	42

7-8 Yield of cucumber

Table (7-24): Yield of cucumber (kg / f)

Irrigation systems	Fertigation system	Yield (kg / f)							
		N1[*]	**N2**	**N3**	**N4**	**N5**	**N6**	**N7**	**Total**
Sub Drip Irrigation	ES	151.2	159.6	117.6	252	235.2	571.2	319.2	1806
	TR	134.4	115.92	100.8	201.6	184.8	436.8	285.6	1459.92
Drip Irrigation	ES	58.8	92.4	109.2	218.4	336	672	604.8	2091.6
	TR	50.4	50.4	92.4	201.6	252	504	487.2	1638
Furrow Irrigation	ES	84	84	100.8	50.4	84	336	588	1327
	TR	58.8	67.2	84	33.6	50.4	252	420	966

***Notes:** N1, N2, N3, N4, N5, N6 and N7 are the number of cuts.

7-9 Number of infected leaves

Table (7-25): Number of infected leaves

Number of infected leaves					
Irrigation systems	**Fertigation system**	**R1**	**R2**	**R3**	**Mean**
Sub Drip Irrigation	**ES**	14	5	4	7.7
		27	12	9	16
		24	9	10	14.3
	TR	17	7	5	9.7
		30	15	11	18.7
		27	13	9	16.3
Drip Irrigation	**ES**	14	9	5	9.3
		9	15	8	10.7
		16	12	8	12
	TR	16	11	7	11.3
		10	17	9	12
		17	12	13	14
Furrow Irrigation	**ES**	15	15	7	12.3
		12	10	8	10
		14	18	9	13.7
	TR	18	17	9	14.7
		15	13	9	12.3
		16	20	11	15.7

7-10 Number of total fruits and number of infected fruits

Table (7-26): Number of total fruits and number of infected fruits

Irrigation systems	Fertigation system	Infected fruits / plot	Total / plot	% of infect fruits
Sub Drip Irrigation	**SD-ES**	91	245	37
	SD-TR	101	211	48
Drip Irrigation	**D-ES**	106	229	46
	D-TR	109	210	52
Furrow Irrigation	**F-ES**	102	165	62
	F-TR	91	144	63

7-11 Percentage of chlorophyll

7-11-1 Percentage of chlorophyll at first of develop stage

Table (7-27): Percentage of Chlorophyll in leaves at first of develop stage

Percentage of Chlorophyll in leaves at first of develop stage												
Irrigation systems	**Fertigation system**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**Mean**
Sub Drip Irrigation	**ES**	32.6	37.4	32.4	41.2	20.7	36.3	39.9	36.5	45.4	35	35.7
		39.3	42.6	40.2	43.9	46	37.6	42.9	48.3	42.3	46.4	43
		31.6	40.2	29.5	34.6	40	28.5	30.9	32.9	31.5	30.2	33
	TR	27.8	28.7	42.7	49.8	30	35	29	30.1	25	29	32.7
		37	41.6	43.5	40.3	40.9	35.8	46.4	36.7	36.8	33.1	39.2
		16.4	35.4	31.3	35.8	26.7	41.2	18.3	38.3	32.8	25.5	30.2
Drip Irrigation	**ES**	44.8	52.1	37.8	51.9	50.5	55.8	43.6	55.1	48.4	52	49.2
		44.7	42.9	46.3	42.4	49.9	49.3	48.6	40.8	42.8	46.9	45.5
		36.9	33.1	35	38.4	37	10.7	44	36	45.1	37.9	35.4
	TR	42.7	49.2	50.8	32.5	37.9	45.1	37.5	39.3	49.2	35	41.9
		38.4	44.8	38.6	35.8	43.6	55.2	44.7	49.8	40.4	40.2	43.2

Cont. Table (7-27)

		41.8	32.1	24.6	37.9	27.8	29.3	23	23.2	35.4	29	30.4
Furrow Irrigation	**ES**	45.2	47	46.2	46.4	25.8	36.4	50.7	34.8	26.1	30	38.9
		41.6	40	46.8	30.1	35.3	43.8	39.9	40	45.3	39	40.2
		30.8	21.7	33.8	25.2	22.6	23.9	33.8	31.6	25.6	22.9	27.2
	TR	30.5	47.9	34	37.6	37	28	25.3	47.2	26.7	31	34.5
		33.1	38.3	30.8	29.9	23	34.7	18.5	36.7	41.9	17.3	30.4
		26.7	24.6	32.8	13.1	24.2	15.3	27.2	32.1	35.4	24.3	25.6

7-11-2 Percentage of chlorophyll at end of develop stage

Table (7-28): Percentage of Chlorophyll in leaves at the end of development stage

Percentage of chlorophyll in leaves at the end of develop stage												
Irrigation systems	**Fertigation system**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**Mean**
Sub Drip Irrigation	**ES**	31.4	38.4	37.2	36.6	39.8	40.5	14.9	31	38.8	37	34.56
		40.1	25.6	33.6	34	14	19.8	39.2	21.2	23.5	28	28
		37	33	40.1	32.8	30.6	22.8	30.9	23.5	34.7	29	31
	TR	21.4	27.4	28.2	30.3	30.8	33.4	34.5	34.6	34.8	41.4	32
		29.4	23.3	27.7	28.7	27.7	28.6	15.4	9.9	33.6	25.0	25
		23.7	29.6	32.8	26.4	32.3	33.4	37.6	32.3	30.8	25.9	30
Drip Irrigation	**ES**	26.9	36.4	43.2	40	32.6	27.8	36.1	29.3	43.6	31	34.7
		33.5	42.3	34.4	36.6	29.2	29.9	35.3	35.1	32.6	18.8	32.8
		26.7	34.2	24.3	34.5	27.4	21.7	31.8	35.3	27.4	34.0	29.7

	TR	33.9	31.7	36.8	32.3	36.1	32.8	37.4	34.3	31.2	34.6	34.1
		39.5	24.4	30.7	31.2	34.8	33.3	37.9	25	26.3	36.9	32
		30.4	30.3	29.1	21.9	28	30.5	39.2	12.4	23.6	27	27.2
Furrow Irrigation	**ES**	34.2	21.2	36.7	33.9	29.4	33.3	28	31.1	26.7	38.1	31.3
		37	26.6	31.6	31.7	31.8	34.8	37.6	34.5	32	30.1	32.8
		25.2	27.8	22.5	21.8	36.3	34.4	32.2	31	29.3	26	28.7
	TR	29.3	38	35.1	24.2	39.1	32.7	13.2	29.1	21.1	31.8	29
		38.2	27.1	13.2	22.7	21.9	29.8	33.9	24.9	25.0	23	26
		26.3	35.3	29.5	31.1	17.2	31.2	27.9	17.5	23.8	29.3	27

7-12 Water requirements for bean crop

7-12-1 Water requirement for bean under drip and sub-drip irrigation systems from the "CROPWAT program"

Table (7-29a): Water requirement for bean under drip and sub-drip irrigation systems from the "CROPWAT program"

Date	**Day**	**Stage**	**Depl**	**dn[**]**	**dg[***]**	**T**	**II[*]**
			%	**mm**	**mm**	**(min)**	**days**
5-Mar	1	Init	57	16.8	18.7	50	
12-Mar	8	Init	51	18.3	20.4	55	7
20-Mar	16	Init	50	22	24.5	66	8
28-Mar	24	Dev	54	27.5	30.6	83	8
4-Apr	31	Dev	57	32.8	36.4	98	7
10-Apr	37	Dev	53	33.7	37.4	101	6
14-Apr	41	Dev	48	32.6	36.2	98	4
19-Apr	46	Dev	56	40.7	45.2	122	5
23-Apr	50	Dev	50	38.3	42.5	115	4
27-Apr	54	Mid	51	38.9	43.2	117	4
1-May	58	Mid	52	39.6	44	119	4
5-May	62	Mid	55	41.9	46.5	126	4
9-May	66	Mid	55	41.9	46.5	126	4
13-May	70	Mid	58	43.8	48.6	131	4
17-May	74	Mid	58	44.4	49.3	133	4
21-May	78	Mid	59	44.5	49.5	134	4
25-May	82	Mid	59	45	50	135	4
29-May	86	Mid	59	45	50	135	4
2-Jun	90	Mid	56	42.5	47.2	127	4
6-Jun	94	End	53	39.9	44.3	120	4
10-Jun	98	End	53	39.9	44.3	120	4
17-Jun	105	End	56	42.5	47.2	127	7
22-Jun	End	End	29				
Total		**3790.5 m^3 / f**			**902.5**		

- ***** Irrigation intervals, ****** Net depth of irrigation water requirement. , ******Growth depth of irrigation water requirement.

7-12-2 Water requirement for bean under furrow irrigation system from CROPWAT program

Table (7-29b): Water requirement for bean under furrow irrigation system from CROPWAT program

Date	**Day**	**Stage**	**Depl**	**dn**	**dg**	**Tn**	**Tco**	**II**
			%	**mm**	**mm**	**min**		
5-Mar	1	Init	57	16.8	28	8.4	15	
12-Mar	8	Init	51	18.3	30.6	9.18	16	7
20-Mar	16	Init	50	22	36.7	11.01	18	8
28-Mar	24	Dev	54	27.5	45.9	13.77	21	8
4-Apr	31	Dev	57	32.8	54.7	16.41	23	7
10-Apr	37	Dev	53	33.7	56.2	16.86	24	6
14-Apr	41	Dev	48	32.6	54.3	16.29	23	4
19-Apr	46	Dev	56	40.7	67.8	20.34	27	5
23-Apr	50	Dev	50	38.3	63.8	19.14	26	4
27-Apr	54	Mid	51	38.9	64.8	19.44	26	4
1-May	58	Mid	52	39.6	66.1	19.83	27	4
5-May	62	Mid	55	41.9	69.8	20.94	28	4
9-May	66	Mid	55	41.9	69.8	20.94	28	4
13-May	70	Mid	58	43.8	72.9	21.87	29	4
17-May	74	Mid	58	44.4	74	22.2	29	4
21-May	78	Mid	59	44.5	74.2	22.26	29	4
25-May	82	Mid	59	45	75	22.5	30	4
29-May	86	Mid	59	45	75	22.5	30	4
2-Jun	90	Mid	56	42.5	70.8	21.24	28	4
6-Jun	94	End	53	39.9	66.5	19.95	27	4
10-Jun	98	End	53	39.9	66.5	19.95	27	4
17-Jun	105	End	56	42.5	70.8	21.24	28	7
22-Jun	End	End	29					
Total	**5687.64 m^3 / f**				**1354.2 mm**			

See footnotes of Table (24-a)

7-12-3 Water requirement for bean under drip and sub drip irrigation systems as outputs of OA-Fertigation program

Table (7-30-a): Water requirement for bean under drip and sub drip irrigation systems as outputs of OA-Fertigation program

Irrigation date	Root depth (cm)	Etc (mm / day)	dn (mm)	dg (mm)	Irrigation time (min)	Water applied (m^3 / f)	II*
3/5/2010	15	0.73	7.7	9.6	26	40.5	-
3/16/2010	15	0.73	7.7	9.6	26	40.5	11
3/27/2010	18.88	1.73	9.7	12.1	33	51.3	11
4/2/2010	26.23	2.28	13.5	16.8	45	70.0	6
4/8/2010	32.83	2.83	16.9	21	57	88.7	6
4/14/2010	37.8	3.38	19.4	24.1	65	101.2	6
4/20/2010	40	3.93	20.5	25.6	69	107.3	6
4/25/2010	40	5.71	20.5	25.6	69	107.3	5
4/29/2010	40	5.71	20.5	25.6	69	107.3	4
5/3/2010	40	5.71	20.5	25.6	69	107.3	4
5/7/2010	40	5.71	20.5	25.6	69	107.3	4
5/11/2010	40	5.71	20.5	25.6	69	107.3	4
5/15/2010	40	5.71	20.5	25.6	69	107.3	4
5/19/2010	40	5.71	20.5	25.6	69	107.3	4
5/23/2010	40	5.71	20.5	25.6	69	107.3	4
5/27/2010	40	5.71	20.5	25.6	69	107.3	4
5/31/2010	40	5.71	20.5	25.6	69	107.3	4
6/4/2010	40	5.32	20.5	25.6	69	107.3	4
6/8/2010	40	4.52	20.5	25.6	69	107.3	4
6/13/2010	40	3.53	20.5	25.6	69	107.3	5
6/19/2010	40	2.34	20.5	25.6	69	107.3	-
Total						**2002.2**	

- * Irrigation intervals, days.

7-12-4 Water requirement for bean under furrow irrigation systems as outputs of the "OA-Fertigation" program

Table (7-30-b): Water requirement for bean under furrow irrigation systems as outputs of the "OA-Fertigation" program.

Irrigation date	**Root depth (mm)**	**Etc (mm / day)**	**dn (mm)**	**dg (mm)**	**Irrigation time (min)**	**Water applied (m^3 / f)**	**II**
3/5/2010	150	1.03	22	42.6	14	196.56	-
3/26/2010	176.5	1.69	25.9	50.1	15	210	21
4/10/2010	347	3.09	50.9	98.5	22	307.44	15
4/26/2010	400	5.71	58.7	113.5	25	349.44	16
5/6/2010	400	5.71	58.7	113.5	25	349.44	10
5/16/2010	400	5.71	58.7	113.5	25	349.44	10
5/26/2010	400	5.71	58.7	113.5	25	349.44	10
6/5/2010	400	5.12	58.7	113.5	25	349.44	10
6/16/2010	400	2.93	58.7	113.5	25	349.44	-
Total						**2810.64**	

7-13 Water requirements for cucumber

7-13-1 Water requirement for cucumber under drip and sub drip irrigation system from CROPWAT program

Table (7-31a): Water requirement for cucumber under drip and sub drip irrigation system from CROPWAT program

Date	Day	Stage	Depl	dn	dg	T	II
			%	mm	mm	min	
1-Sep	1	Init	65	19.1	21.2	57	-
5-Sep	5	Init	60	19.4	21.6	58	4
9-Sep	9	Init	54	19.4	21.6	58	4
14-Sep	14	Init	60	23.7	26.3	71	5
19-Sep	19	Init	54	23.5	26.2	71	5
25-Sep	25	Init	57	27.6	30.7	83	6
1-Oct	31	Dev	53	27.9	31.1	84	6
7-Oct	37	Dev	52	30.1	33.5	90	6
13-Oct	43	Dev	50	31.4	34.8	94	6
19-Oct	49	Dev	48	32.6	36.2	98	6
26-Oct	56	Dev	53	38.4	42.6	115	7
2-Nov	63	Mid	47	35.8	39.8	107	7
10-Nov	71	Mid	48	36.5	40.5	109	8
19-Nov	80	Mid	45	34.3	38.1	103	9
29-Nov	90	Mid	48	36.5	40.6	110	10
9-Dec	100	Mid	46	35.1	39	105	10
20-Dec	111	End	48	36.3	40.3	109	11
2-Jan	124	End	50	38.3	42.6	115	13
8-Jan	End	End	17				
Total	**2548.14 m^3 / f**				**606.7**		

7-13-2 Water requirement for cucumber under furrow irrigation system from CROPWAT program

Table (7-31b): Water requirement for cucumber under furrow irrigation system from CROPWAT program

Date	Day	Stage	Depl	dn	dg	Flow	Tn	Tco	II
			%	mm	mm	l/s/ha		min	days
1-Sep	1	Init	65	19.1	31.8	3.68	10	17	
5-Sep	5	Init	60	19.4	32.3	0.94	10	17	4
9-Sep	9	Init	54	19.4	32.3	0.94	10	17	4
14-Sep	14	Init	60	23.7	39.5	0.91	12	19	5
19-Sep	19	Init	54	23.5	39.2	0.91	12	19	5
25-Sep	25	Init	57	27.6	46.1	0.89	14	21	6
1-Oct	31	Dev	53	27.9	46.6	0.9	14	21	6
7-Oct	37	Dev	52	30.1	50.2	0.97	15	22	6
13-Oct	43	Dev	50	31.4	52.3	1.01	16	23	6
19-Oct	49	Dev	48	32.6	54.4	1.05	16	23	6
26-Oct	56	Dev	53	38.4	64	1.06	19	26	7
2-Nov	63	Mid	47	35.8	59.6	0.99	18	25	7
10-Nov	71	Mid	48	36.5	60.8	0.88	18	25	8
19-Nov	80	Mid	45	34.3	57.2	0.74	17	24	9
29-Nov	90	Mid	48	36.5	60.9	0.7	18	25	10
9-Dec	100	Mid	46	35.1	58.5	0.68	18	25	10
20-Dec	111	End	48	36.3	60.5	0.64	18	25	11
2-Jan	124	End	50	38.3	63.9	0.57	19	26	13
8-Jan	End	End	17						
Total	**3822.42 m^3 / f**				**910.1**				

7-13-3 Water requirement for cucumber under drip and sub drip irrigation systems as outputs of "OA-Fertigation" program

Table (7-32a): Water requirement for cucumber under drip and sub drip irrigation systems as outputs of "OA-Fertigation" program

Irrigation date	Root depth (mm)	Etc (mm / day)	dn (mm)	dg (mm)	Irrigation time (min)	Water requirement (m^3 / f)	II
9/1/2009	150	1.75	8.6	10.2	28	43.5	-
9/6/2009	150	1.75	8.6	10.2	28	43.5	5
9/11/2009	150	1.75	8.6	10.2	28	43.5	5
9/16/2009	150	1.75	8.6	10.2	28	43.5	5
9/21/2009	150	1.75	8.6	10.2	28	43.5	5
9/26/2009	194	2.01	11.1	13.2	36	56.0	5
10/2/2009	263.4	2.24	15	17.9	48	74.7	6
10/9/2009	340.1	2.5	19.4	23.1	62	96.5	7
10/17/2009	410.6	2.8	23.4	27.9	75	116.7	8
10/25/2009	450	3.1	25.7	30.6	83	129.2	8
11/2/2009	450	1.6	25.7	30.6	83	129.2	8
11/18/2009	450	1.6	25.7	30.6	83	129.2	16
12/4/2009	450	1.6	25.7	30.6	83	129.2	16
12/20/2009	450	1.52	25.7	30.6	83	129.2	16
1/6/2010	450	1.19	25.7	30.6	83	129.2	-
Total						**1336.35**	

7-13-4 Water requirement for cucumber under furrow irrigation systems as outputs of the "OA-Fertigation" program

Table (7-32b): Water requirement for cucumber under furrow irrigation systems as outputs of the "OA-Fertigation" program

Irrigation date	Root depth (mm)	Etc (mm / day)	dn (mm)	dg (mm)	Irrigation time (min)	Water requirement (m^3 / f)	II
9/1/2009	150	2.47	24.4	47.3	14	196.56	-
9/11/2009	150	2.47	24.4	47.3	14	196.56	10
9/21/2009	150	2.47	24.4	47.3	14	196.56	10
10/1/2009	251.9	2.26	41	79.4	19	265.44	10
10/19/2009	424	2.95	69.1	133.7	28	391.44	18
11/11/2009	450	1.6	73.3	141.9	29	406.56	23
12/27/2009	450	1.38	73.3	141.9	29	406.56	46
Total						**2059.68**	

7-14 Fertilizer requirements for bean crop

7-14-1 Fertilizer requirements for bean under drip and sub drip irrigation system as outputs of OA-Fertigation program and the traditional method

Table (7-33): Fertilizer requirements for bean under drip and sub drip irrigation system as outputs of OA-Fertigation program and the traditional method.

Stage	**Ammonium nitrate ($g.m^{-3}$)**		**Phosphoric acid($g.m^{-3}$)**		**Potassium sulfate ($g.m^{-3}$)**	
	ES	**TR**	**ES**	**TR**	**ES**	**TR**
S1	65	161	44	120	0	200
S2	85	250	36	100	0	230
S3	57	170	29	80	0	300
Tank	**A or B**		**A**		**A or B**	

- S1= From beginning of seedling emergence up to beginning of flowering
- S2= From beginning of flowering up to beginning of harvesting
- S3= From beginning of harvesting up to one week before end of harvesting
- TR=Traditional method (CROPWAT program was used for the scheduling of the irrigation together with the traditional methods of fertigation as outlined by the Ministry of Agriculture, Egypt).
- ES=OA-Fertigation program.
- A = the first tank.
- B= the second tank.

7-14-2 Fertilizer requirements for bean under drip and sub drip irrigation as outputs of OA-Fertigation program

Table (7-34): Fertilizer requirements for bean under drip and sub drip irrigation as outputs of OA-Fertigation program

Stage	**Ammonium Nitrate (kg / week / f)**		**Phosphoric acid (liter / week / f)**		**Potassium sulfate (kg / week / f)**	
	ES	**TR**	**ES**	**TR**	**ES**	**TR**
S1	8.31	38.83	3.45	15.74	0	48.23
S2	12.39	60.31	2.89	13.10	0	55.48
S3	9.52	41.01	2.31	10.49	0	72.37
Tank	**A or B**		**A**		**A or B**	

7-14-3 Fertilizer requirements for bean under furrow irrigation as outputs of OA-Fertigation program

Table (7-35): Fertilizer requirements for bean under furrow irrigation as outputs of OA-Fertigation program

Stage	**Ammonium Nitrate (kg / week / f)**		**Phosphoric acid (liter / week / f)**		**Potassium sulfate (kg / week / f)**	
	ES	**TR**	**ES**	**TR**	**ES**	**TR**
S1	12.10	58.28	6.38	23.61	0	72.39
S2	18.14	90.48	5.38	19.67	0	83.25
S3	13.94	61.53	4.20	15.74	0	108.58
Tank	**A or B**		**A**		**A or B**	

7-15 Fertilizer requirements for cucumber

7-15-1 Fertilizer requirements for cucumber under drip and sub drip irrigation system as outputs of OA-Fertigation program and the traditional method

Table (7-36): Fertilizer requirements for cucumber under drip and sub drip irrigation system as outputs of OA-Fertigation program and the traditional method.

Stage	**Ammonium nitrate ($g . m^{-3}$)**		**Phosphoric acid ($g . m^{-3}$)**		**Potassium sulfate ($g . m^{-3}$)**	
	ES	**TR**	**ES**	**TR**	**ES**	**TR**
S1	130	313	68	150	0	320
S2	255	350	57	120	0	375
S3	173	250	45	100	0	600
Tank	**A or B**		**A**		**A or B**	

7-15-2 Fertilizer requirements for cucumber under drip and sub drip irrigation as outputs of OA-Fertigation program

Table (7-37): Fertilizer requirements for cucumber under drip and sub drip irrigation as outputs of OA-Fertigation program

Stage	**Ammonium Nitrate (kg / week / f)**		**Phosphoric acid (liter / week / f)**		**Potassium sulfate (kg / week / f)**	
	ES	**TR**	**ES**	**TR**	**ES**	**TR**
S1	11.67	42.95	3.30	11.18	0	43.90
S2	22.85	48.03	2.76	8.94	0	51.45
S3	15.51	34.31	2.20	7.45	0	82.32
Tank	**A or B**		**A**		**A or B**	

7-15-3 Fertilizer requirements for cucumber under furrow irrigation as outputs of OA-Fertigation program

Table (7-38): Fertilizer requirements for cucumber under furrow irrigation as outputs of OA-Fertigation program

Stage	**Ammonium Nitrate (kg / week / f)**		**Phosphoric acid (liter / week / f)**		**Potassium sulfate (kg / week / f)**	
	ES	**TR**	**ES**	**TR**	**ES**	**TR**
S1	16.3	43	5.9	11.3	0	43.8
S2	31.9	48	5.0	8.9	0	51.4
S3	21.7	34	4.0	7.4	0	82.3
Tank	**A or B**		**A**		**A or B**	

ARABIC SUMMARY

8- الملخص العربي

إدارة تقنيات الري التسميدي إعتمادا علي النظم الخبيرة

الري التسميدي (الرسمدة) هي إضافة الماء والسماد متزامنين في شبكة الري ، ويوجد للرسمدة مزايا عديدة.

الهدف الرئيس من البحث هو تصميم نظام خبير يمد المزارعين بالقرارات الصائبة في مجال إدارة الري والتسميد (الرسمدة)

وهناك بعض الأهداف الفرعية التي سوف تتحقق من تحقيق الهدف الرئيس وهي كتالي:

1- تحسين كفاءة إستخدام الماء والسماد.

2- تحديد أنسب مصدر سمادي، المعدل المناسب من إضافة الأسمدة , المعدل المناسب من الإحتياجات المائية، زمن الري المناسب و التركيز المناسب لإضافة السماد.

المواد والطرق:

لتحقيق الأهداف السابقة تم إجراء الخطوات التالية:

أ- بناء النظام:

a. المواد المستخدمة في بناء النظام:

i. جهاز كمبيوتر بنتيوم 4

ii. ميكروسوفت فيجول سي شارب دوت نت 2005

iii. ميكروسوفت أكسس 2003 (Access 2003)

b. الطرق المتبعة لبناء النظام:

i. تعريف المشكلة:

المشكلة التي يدرسها هذا البحث هي إيجاد برنامج خبير تستخدم في حل المشاكل المتعلقة بإدارة الرسمدة.

عمل برنامج كمبيوتر يستطيع أن يحلل ويمثل البيانات وذلك إعتمادا علي لغة البرمجة فيجول سي شارب دوت نت. تم عمل مقارنة بين مخرجات البرنامج المعتمد علي آراء الخبراء في مجال الرسمدة ، وذلك من خلال مقانة مخرجات البرنامج مع طرق مختلفة لحساب البخر نت و برنامج CROPWAT المتخصص في جدولة الري ، ونشرة وزارة الزراعة الإرشادية الخاصة بالرسمدة .

تم إجراء تطبيق حقلي للبرنامج في إدارة الري والتسميد لمحصولين الفاصوليا والخيار في مزرعة كلية الزراعة بمشتهر مقارنة بالإدارة التقليدية تحت ثلاث نظم ري وهي الري السطحي في خطوط والري بالتنقيط السطحي والري بالتنقيط تحت السطحي والمعدلات السمادية الموصى بها من وزارة الزراعة.

ب- مدخلات النظام:

بيانات التربة - بيانات المناخ - بيانات الماء - بيانات الأسمدة - بيانات المحصول- بيانات نظام الري - بيانات تحمل المحصول للملوحة - بيانات المزرعة

ت- القياسات :

تم تقسيم التجربة إلي ست قطاعات ، القطعة الأولي والثانية بها نظام الري بالتنقيط تحت السطحي ، القطعة الثالثة والرابعة بها نظام الري بالتنقيط ، والقطعة الخامسة والسادسة بها نظام الري السطحي في خطوط. أبعاد القطعة 25 × 9 متر ، تم تطبيق النظام الخبير علي القطع الأولي، الثالثة والرابعة ، والقطع الآخرى تم تطبيق الطريقة التقليدية في باقي القطع.

a. الخواص البيلوجية للمحصول:

كل قطعة تجريبية تتكون من 9 خطوط ، تم أخذ 12 عينة نباتية من كل قطعة تجريبية بطريقة عشوائية، وذلك لقياس طول النبات، وعمق الجذر ، وزن النبات، عدد الأوراق، نسبة الكلوروفيل، وزن الساق.

b. الخواص الكميائية للمحصول:

بعد إجراء الإختبارات البيلوجية علي النبات تم إجراء تجفيف لأوراق كل قطعة علي حدة تجفيف هوائي، وبعد التجفيف تم عمل تحليل للأوراق لتقدير المادة العضوية، الكربون العضوي ، ونسبة العناصر المعدنية، والتركيز الكلي للنيتروجين، ونسبة الكربون إلي النيتروجين.

أوضحت أهم النتائج ما يلي :

1- تفوق النظام الخبير في سرعة وسهولة إستخدامعه عن الطريقة التقليدية.

2- أوضحت دراسة الخواص البيولوجية والكيميائية تفوق النظام الخبير عن الطريقة التقليدية.

3- زيادة إنتاج المحصول الفاصوليا (53.4 % ، 39.3 % ، 54.1 %) والخيار(9.3 %، 9.1 % ، 53.8 %) تحت النظام الخبير عنه للطريقة التقليدية تحت نظم الري الثلاثة (الري بالتنقيط تحت السطحي، الري بالتنقيط ، الري السطحي في خطوط) علي الترتيب.

4- زيادة وزن 100حبة لمحصول الفاصوليا تحت النظام الخبير عنه للطريقة التقليدية تحت نظم الري الثلاثة (الري بالتنقيط تحت السطحي، الري بالتنقيط ، الري السطحي في خطوط) (10.8 % ، 2.6 % ، 2.3 %) علي الترتيب.

5- زيادة كفاءة إستخدام المياه لمحصول الفاصوليا تحت النظام الخبير عنه للطريقة التقليدية تحت نظم الري الثلاثة (الري بالتنقيط تحت السطحي، الري بالتنقيط ، الري السطحي في خطوط) (64.8 % ، 56.1 %، 55.9 %) علي الترتيب، كما زادة كفاءة إستخدام المياه لمحصول الخيار تحت النظام الخبير عنه للطريقة التقليدية تحت نظم الري الثلاثة (الري بالتنقيط تحت السطحي، الري بالتنقيط ، الري السطحي في خطوط) (57.8 % ، 59.2 %، 60.9 %) علي الترتيب

6- زيادة كفاءة إستخدام السماد لمحصول الفاصوليا تحت النظام الخبير عنه للطريقة التقليدية تحت نظم الري الثلاثة (الري بالتنقيط تحت السطحي، الري بالتنقيط ، الري السطحي في خطوط) (34.3 % ، 15.5 %، 10.4 %) علي الترتيب، كما زادة كفاءة إستخدام السماد لمحصول الخيار تحت النظام الخبير عنه للطريقة التقليدية تحت نظم الري الثلاثة (الري بالتنقيط تحت السطحي، الري بالتنقيط ، الري السطحي في خطوط) (19.1 % ، 21.7 %، 27.1 %) علي الترتيب.

إدارة تقنيات الري التسميدي إعتمادا علي النظم الخبيرة

رسالة مقدمة من

أبوسريع أحمد حسن فرج

بكالوريوس ميكنة زراعية – كلية الزراعة - جامعة الزقازيق – فرع بنها 2003
ماجيستير هندسة زراعية – كلية الزراعة – جامعة بنها - 2007

لإستيفاء الدراسات المقررة للحصول علي درجة الدكتوراة
في فلسفة العلوم الزراعية تخصص هندسة زراعية

قسم الهندسة الزراعية

كلية الزراعة بمشتهر
جامعة بنها
2012

إدارة تقنيات الري التسميدي إعتمادا علي النظم الخبيرة

رسالة مقدمة من

أبوسريع أحمد حسن فرج

بكالوريوس ميكنة زراعية – كلية الزراعة - جامعة الزقازيق – فرع بنها 2003
ماجيستير هندسة زراعية – كلية الزراعة – جامعة بنها - 2007

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أ.د / محمد يوسف الأنصارى ....

أستاذ الهندسة الزراعية - كلية الزراعة بمشتهر – جامعة بنها

د / منتصر عبدالله عواد ....

أستاذ الهندسه الزراعية المساعد - كلية الزراعة بمشتهر – جامعة بنها

د / محمد تهامي عفيفي ....

مدرس الهندسة الزراعية - كلية الزراعة بمشتهر – جامعة بنها

أ.د / محمود عبد الواحد رافع ....

رئيس بحوث بالمعمل المركزي للنظم الزراعية الخبيرة - الجيزة - مصر

صفحة الموافقة علي الرسالة

إدارة تقنيات الري التسميدي إعتمادا علي النظم الخبيرة

رسالة مقدمة من

أبوسريع أحمد حسن فرج

بكالوريوس ميكنة زراعية – كلية الزراعة - جامعة الزقازيق – فرع بنها 2003

ماجيستير هندسة زراعية – كلية الزراعة – جامعة بنها – 2007

للحصول علي

درجة الدكتوراه في العلوم الزراعية (هندسة زراعية)
وقد تمت مناقشة الرسالة والموافقة عليها

اللجنـــة :

أ.د / محمد نبيل محمد عبد العظيم العوضي ....

أستاذ الهندسة الزراعية الغير متفرغ - كلية الزراعة – جامعة عين شمس

أ.د / حسن حمزة عباس ....

أستاذ الأراضي - كلية الزراعة - جامعة بنها

أ.د / محمود عبد الواحد رافع ....

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أ.د / محمد يوسف الأنصاري ....

أستاذ الهندسة الزراعية المتفرغ - كلية الزراعة - جامعة بنها

د / منتصر عبد الله عواد ....

أستاذ مساعد الهندسة الزراعية - كلية الزراعة - جامعة بنها

تاريخ الموافقة / / 2012