OPTIMIZING IRRIGATION WATER BY DETECTING ACTIVE ROOT DEPTH USING NUCLEAR TECHNIQUE

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ABSTRACT

The experiment was carried out at the farm of soils and water research department, atomic energy authority. Inshas (latitude 30°24′ longitude 31°35′) altitude is 20 m above the sea level, during (2015/2016) growth season. The treatments of the water (T_1, T_2, T_3), were applied, which was (100%, 80% and 60%), respectively based an estimated amount of applied water to active root depth (ARD) which estimated according to the amount of water depleted from field capacity through ARD.

Actual evapotranspiration, yield, crop water use efficiency and active root depth were measured and estimated. The obtained results showed that the highest value of chickpea grain yield was 1218.09 kg/ha under T_2 treatment compared with 1170.37 kg/ha and 919.99 kg/ha for (T_1, T_3) respectively. Also the highest value of crop water use efficiency was btained by T_2 which was 0.28 kg/m^3 flowed by T_3 then T_1 which were 0.26 and 0.22 kg m^{-3} respectively. Difference between the T_1, T_2 and T_3 was found with grain yield and actual evapotranspiration between three treatments. Active root depth reached a maximum value was 71 cm, which approximates the actual value.

1. INTRODUCTION

Irrigation scheduling is the decision of farmers regarding the "when" the irrigation and how much water is required to be applied in each irrigation event. **(Fue and Sanga, 2015).**

Shock et al (2007) reported that irrigation scheduling involves determining the correct timing and depth of water necessary to maintain root zone moisture within the optimal range for crop growth. Irrigation uniformity is related to how evenly water is distributed over the field area. Active root depth is the depth of soil at which plant extracts most of its absorbed water. **El-Gendy et al (2000)** defined ARD as the soil depth, which separates the soil profile into two parts the upper one at which effect of evapotranspiration is dominant while, the second one represents the effect of gravity (deep percolation). Active root depth increase during the growing season as the crop develops. It begins at zero at planting and increases to its maximum depth with time, which occurs approximately at the midseason for most crop. This result can be estimated from the in situ measurements where hydraulic gradient equal zero (dH/dZ = 0) at (H, Z) function. So this depth is very important to identify the separate line in soil profile between the lower parts, at which water is lost by deep percolation and the upper parts at which water is lost through evaporation process and plant uptake.

The active root zone has the potential to return water to the atmosphere via evapotranspiration, and the depth of this zone affects the extent of the exchange between soil-moisture and water vapor **(Guswa, 2008).**

The aims of this study are, optimizing of irrigation water by drip irrigated chickpea for best irrigation management.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 The experimental site

A complete randomize field experiment was conducted at the farm of Nuclear Research Center, Atomic Energy Authority, Inshas, during (2015 /2016) growing season.

2.1.2. Physical and chemical properties.

- The following properties were measured and determined according to **Jacobs et al (1971).**
- Total porosity was calculating using the following equation

$$\phi = [1 - \rho b / \rho s] \; ....\; (1)$$

Where:

ϕ : Total porosity, cm^3.
ρb: soil bulk density, g /cm^3.
ρs : particle density , g/ cm^3 (assuming 2.65)
-Residual moisture content (θ_r) was determined as soil moisture content at dh/dZ $\approx$ zero at soil moisture retention curve (SMRC).
- Soil bulk density was determined according to **Blake and Hartge (1986)**.
- Pore size distribution was estimated according to **deLeenheer and de Boodt (1965)**

Table 1. Some physical properties of the investigated soil

Soil depth (cm)	Particle size distribution %			Texture Class	Bulk density g/cm^3	FC %	Total porosity cm^3	θ at 0.1 bar	θ at 15 bar
	Sand	Silt	Clay						
15	96.7	1.1	2.2	Sand	1.55	9.5	0.42	8.5	1.90
30	98.5	0.7	0.8	Sand	1.78	8.4	0.33	8.5	1.90
50	98.5	0.8	0.7	Sand	1.77	8.4	0.33	8.5	1.79
70	97.9	0.7	1.4	Sand	1.77	8.4	0.33	8.5	1.78
90	97.7	0.7	1.6	Sand	1.73	8.4	0.35	8.4	1.78

Table 2. Some chemical properties of investigated soil

Soil depth, (cm)	EC (dS/m)	*pH	Soluble cations (m eq/L)				Soluble anions (m eq/L)				SAR
			K$^+$	Mg^{++}	Ca^{++}	Na$^+$	CO$_3^{--}$	H CO$_3^-$	Cl$^-$	SO$_4^{--}$	
15	3.78	7.2	1.31	20.87	7	8.65	-	0.32	10	24.6	1.67
30	0.62	7.2	0.56	1.93	1.47	2.19	-	0.35	4.75	1.05	1.68
50	0.38	7.4	0.31	0.93	0.81	1.71	-	0.35	3.3	0.11	1.83
70	0.29	7.3	0.5	0.63	0.32	1.49	-	0.35	2.4	0.19	3.24
90	0.4	7.1	0.63	0.85	0.24	2.26	-	0.38	3.4	0.2	2.81

*pH (1: 2.5 Soil / Water suspension)

2.1.3. Irrigation system

Drip irrigation system was used to irrigate the chick pea plant. The system consists of:
- Control head, consist of sandy and screen media filters, pressure gauges and control valves
- Pipes Polyethylene (PE) tube 50 mm diameter for main and sub main lines, while the lateral tubes was 16mm diameter of PE built in drip line 4 L hr^{-1} /30 cm at an operating pressure of 1bar to serve crop rows.

2.1.4 Cultivated Crop

Chickpea seeds (*Cicer arietinum.*) Giza 531 variety was selected as the test plant, the amount of seeds required was 98.8 kg/ ha. The seeds planted at spacing of 30cm between plants and 50 cm between rows.

2.1.5. Fertilization

Chemical fertilizers were injected into irrigation water along the growing season according to plant stages growth needs through progressing stages according to Ministry of Agriculture.

All the experimental plots had the same characteristics and the same crop management's practices soil preparations, Fertilizers NPK were used at recommended rate…. etc.

2.2. Measurements and calculations

2.2.1. Active Root Depth (ARD)

ARD will be estimate by detecting hydraulic gradient within the soil profile to obtain the evapo-transpiration drip and drainage effects at (H/dZ = 0).

van Genuchten (1980) presented his model to represent soil moisture retention curve (SMRC) as the flowing equation

$$\theta_h = \theta_r + (\theta_s - \theta_r)[1+(\alpha h)^n]^{-m} \quad \text{…………………… (2)}$$

Tensiometric method was used to determined Soil matric suction according to (**kholood, 2004).**

Where:

  h: the soil matric potential, mbar
  h_b: the air entry suction, mbar
  θ_r: residual soil moisture, $cm^3 \, cm^{-3}$
  θ_s: saturation point, which equals total porosity m
   and n, constants for fitting soil moisture retention curve, and

Z: the soil depth, mbar
H: the hydraulic potential, m bar.
By rewriting this model to predict the soil matric suction (h, mbar) as the flowing equation

$$h = -(1/\alpha)[(Se)^{-1/m} -1]^{1/n} \quad \text{………………….. (3)}$$

Where:

$$Se = ((\theta-\theta_r)/(\theta_s-\theta_r))$$

Total hydraulic potential (H) in unsaturated state is the summation of both matric and gravitational potentials as the flowing equation

$$H = -h - Z \quad \text{………………………….………. (4)}$$

Where:

 h: the soil matric potential at Z soil depth, the negative sign before Z because the reference level was taken at the surface soil. The total hydraulic potential can be obtained at Z soil depth using substitution h from Eq.2 in Eq.3 as shown in Eq.4:

$$H = -h_b[((\theta-\theta_r)/(\theta_s-\theta_r))-1/m -1]^{1/n} - Z \quad \text{...……. (5)}$$

After obtaining values of the total hydraulic potential along the soil profile, it can be obtained on the relationship between H and Z shown in **Fig. (1)** to determined ARD
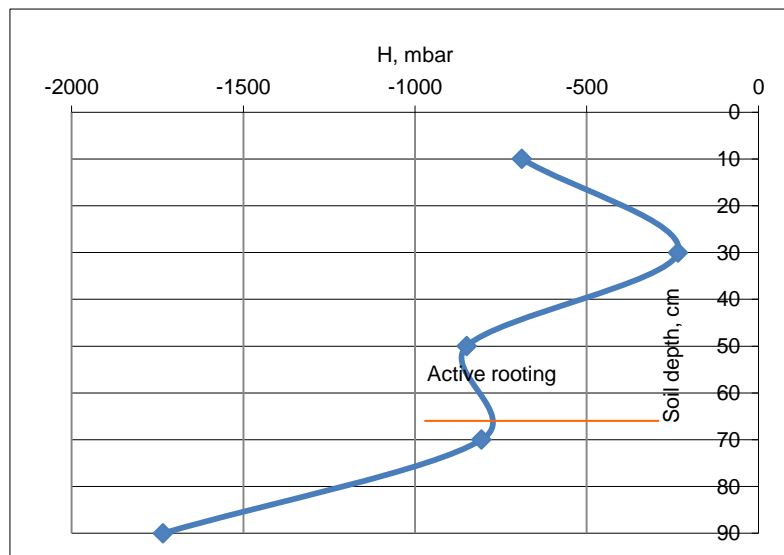

Fig. 1. Direction of soil water movement after and before irrigation for the experimental data

The values of water were estimated by the following equation:

$$WR= (\theta_{f.c} -\theta_{b.n.i})\times(D/100)\times A\times 1/E_i)\ldots\ldots\ldots\ldots(6)$$

Where:

WR : Irrigation water requirement, m^3
$\theta_{f.c}$: the soil water content at field capacity, %
$\theta_{b.n.i}$: the soil water content before irrigation, %
A: the experimental plot area, m^2, and
D: the soil depth, cm.

$1/E_i$: the inverse of irrigation system efficiency. **Israelsen and Hansen. (1962)**

2.2.2. Actual evapotranspiration (ET$_a$)

Actual evapotranspiration (ET_a) was estimated in situ by calculation soil moisture depletion in root zone by detection soil moisture content from 30cm up to 90cm *de* **Boodt et al (1967).**
Deep percolation was estimated by the difference between the applied water and ET_a.
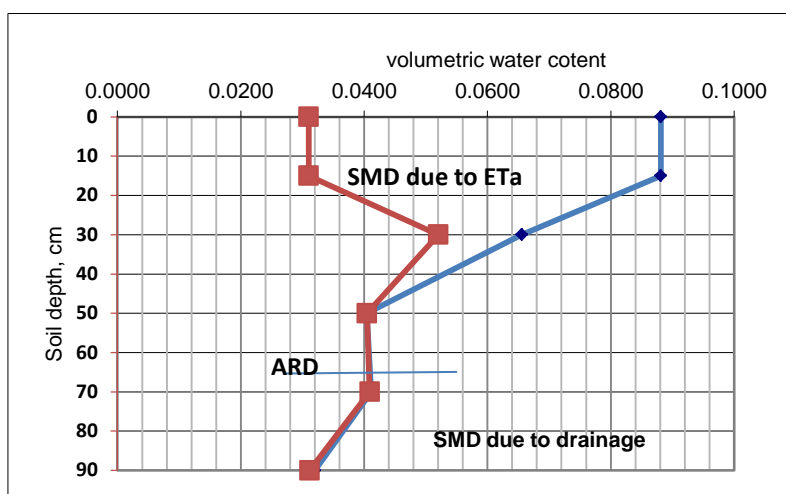

Fig. 2. Soil moisture distribution within the soil profile

The soil moisture depletion at certain was estimated by the following equation:

$$SMD= 0.5* (\theta_{ar}-\theta_b)+ (\theta_a -\theta_b)*Z \ldots\ldots\ldots\ldots\ldots.. (7)$$

Where:
SMD: Soil water depletion, mm
θ_a: the soil water content after irrigation.
θ_b: the soil water content before the next irrigation.
Z: soil depth, mm

2.2.3. Moisture measurement

Soil moisture content was measured gravimetrically in the upper layer (15cm) and by the neutron probe CPN, 50mCi. (503 DR hydro probe), Americium-241 Beryllium m source according to **IAEA (2008)** for deeper depths (30, 50, 70 and 90cm) were determined for soil under study. Soil moisture content was measured before irrigation and 2 hours after irrigation.

2.2.4. crop water use efficiency and Filed use efficiency

CWUE = Total grain yield (Kg/ha) / actual evapotranspiration (m^3 /ha) Kg/m^3 …………………. (8)

Field water use efficiency (FWUE) was calculated after **(Michael, 1978)**

FWUE = Y/WR …………………………………. (9)

Where:
  Y: Seed yield (kg/ha)
WR: The total amount of water applied in the field (m3/ha).

2.3. Experimental design

Completely randomized design with three treatment of water (T_1,T_2,T_3), were applied, which was (100%, 80% and 60%), respectively and with three replicated was used in this experiment. The experimental area was 296.4 m^2. shown in **Fig. (3).**
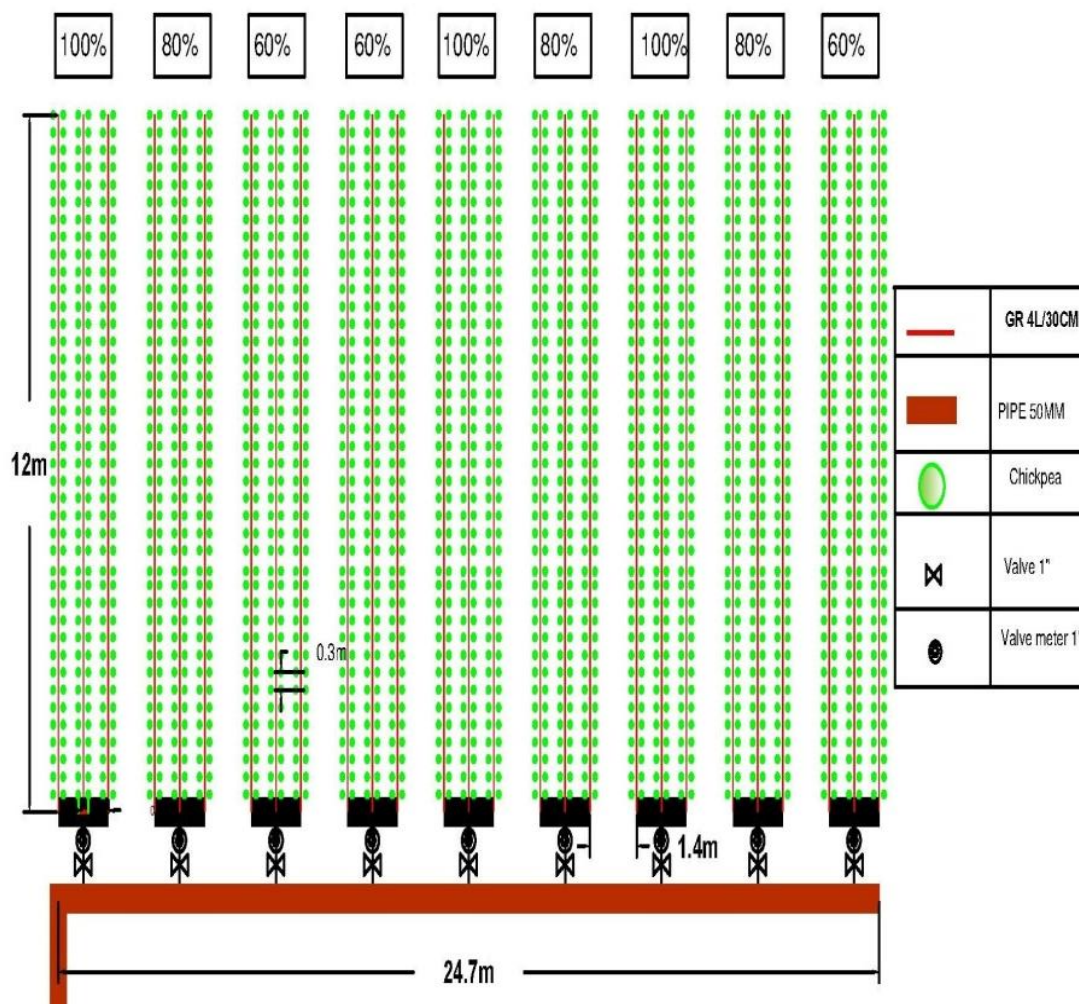
Fig. 3. Experimental Design

3. RESULT AND DISCUSSION

3.1. Calibration for neutron probe and active root depth

3.1.1. Neutron calibration curves

Fig. (4) and Table (3) illustrate the linear relationship between water content and count ration (CR) for Neutron probe at depth (30,50,70 and 90) cm soil depth. The result shown in **Table (3)** and this result agree with **Sallam and**

El-Gendy, (1999) which they founded that R average from 0.94 to 0.97 This means that the results are expressed and the relation between water content and count ration is positive.

3.1.2. Active root depth

Table (4) show Calibration of active root depth where founded that development stages showed the highest value was 68 cm compared actual root depth which recorded 60 cm even reached 71 cm at the end season compared with the actual root depth value of which recorded 75 cm.
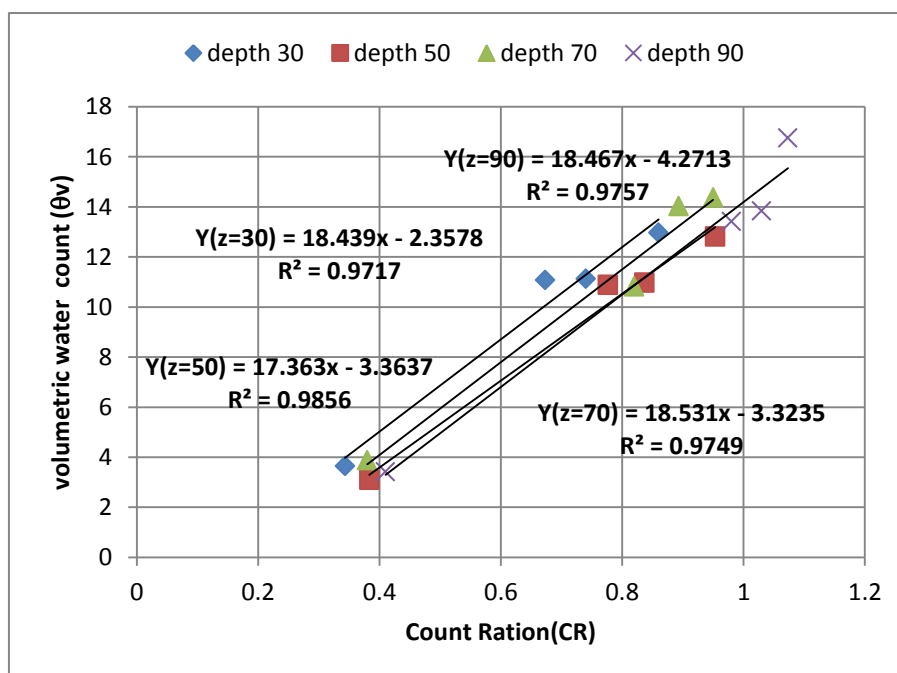
Fig. 4. Neutron calibration curves for four depth

Table 3. Regression equations of neutron calibration curves at different soil depths of the treatments under study

Depths	Regression equation	Coefficient of determination (R^2)
30	$\theta = 18.439$ C.R-2.3578	0.9717
50	$\theta = 17.363$ C.R -3.3637	0.9856
70	$\theta = 18.531$ C.R -3.3235	0.9749
90	$\theta = 18.467$ C.R -4.2713	0.9757

Table 4. Calibration lengths of chickpea for each stages

Stage	Active root depth (cm)	
	Measured	**actual**
Initial	12	15
Mid	68	60
End	71	75

3.2. Applied water by active root depth

The mean seasonal ET_a were 534.60, 435.42 and 347.32 mm, respectively for (T_1, T_2, T_3). The highest seasonal ET_a was recorded by treatment T_1, whereas the lowest seasonal ET_a recorded under T_3. The relation between actual evapotranspiration (ET_a) and climatic factors is important to evaluate the accurate treatment for estimating plant water requirements. Values of ET_a indicated that the total amount of water actually used by plant in increase with increasing the applied water.

Daily evapotranspiration from the date of planting to harvesting indicates that evapotranspiration started with lower values in initial stage, increased gradually in development and mid–season stages and decreased toward harvest due to physiological maturity of crop. There was a significant difference in total amount ET_a between the three irrigation treatments.

Don Scott (2000), added that the relation between the force of attraction of water by soil surfaces and water content is an inverse relationship; that's means the first layers of water is held with great forces of attraction, the magnitude of the forces of attraction for water decrease as the distance from the partial surface increase. Therefore, addition more amount of irrigation as in T_1 water give the opportunity to irrigation water to evaporate from soil surface more than T_2, also evaporation process from T_2 was more than T_3.

Table 5. Applied water (mm)

	Date	applied water		
	(2015-2016)	**T_1**	**T_2**	**T_3**
NOV.	*14-21	62.94	62.94	62.94
	22-30	18.16	14.53	10.90
Dec.	1—7	7.78	6.22	4.67
	8--15	7.22	5.78	4.33
	16-23	8.32	6.66	4.99
	24-31	13.99	11.19	8.39
Jan	1—7	4.97	3.98	2.98
	8--15	13.02	10.42	7.81
	16-22	26.96	23.56	13.79
	23-30	Rain fall = 3.3 mm		
Feb.	1—7	31.39	19.18	18.29
	8--15	82.48	59.13	46.24
	16-22	53.15	34.73	30.50
	23-30	53.70	35.40	30.28
Mar.	1—7	54.72	35.81	31.00
	8--15	45.50	28.83	26.43
	16-22	54.08	34.59	30.65
	23-30	49.49	35.34	28.99
Apr.	1—7	56.59	35.88	30.47
	8--15	51.19	34.05	29.85

*Agriculture day

3.3. Grain yield and crop water use efficiency (CWUE)

3.3.1. Grain Yield

Chick pea grain yield obtained under the three irrigation treatments is shown in **Fig. (4)**. It was 1170.37, 1218.09 and 919.99 kg ha^{-1} for T_1, T_2 and T_3, respectively shown in **Table (6)**. The grain yield

obtained with T_2 was recorded 3.96 % higher than T_1. In addition, with T_1 treatment resulted there was a significant reduction in crop yield.
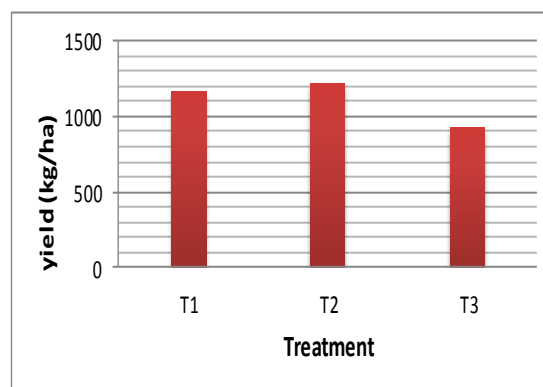

Fig. 4. Grain yield production for three treatments

3.3.2. Crop water use efficiency (CWUE)

Crop Water use efficiency (CWUE) was (0.22, 0.28 and 0.26 Kg/m^3) and filed Water use efficiency (FWUE) was (0.17, 0.24 and 0.22 kg/m^3) for three treatments (T_1, T_2 and T_3) respectively **(presented in Table 6)**. T_2 recorded highest values of CWUE and FWUE compared with treatment T_1 and T_3. The high values was obtained by improving both crop yield and water saving.

Table 6. Applied water (mm), grain yield (kg/ha), crop water use efficiency and filed water use efficiency (kg/m^3)

	T_1	**T_2**	**T_3**
Water applied (mm)	698.94	501.48	426.78
Grain yiled (kg/ha)	1170.37	1218.09	919.99
CWUE (Kg/m^3)	0.22	0.28	0.26
FWUE (Kg/m^3)	0.17	0.24	0.22

Conclusions

Three water treatments (100%, 80%, and 60%) of ARD were established. The results showed that 80% (T_2) treatment recorded the highest results in chickpea yield (1218.09 kg/ha), crop water use efficiency (0.28 kg/m^3) and water saving (27.83%) in comparison with (T_1), which gave the greatest value from Deep percolation (201.75mm) that cause to increase applied water and decrease both of yield and crop water use efficiency.

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