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EVALUATION OF FURROW IRRIGATION METHOD USING THE POWER ADVANCE APPROACH OF THE VOLUME BALANCE MODEL

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ABSTRACT

The study was conducted to evaluate the furrow irrigation method using the power advance approach of the volume balance model. Specifically, it aimed to develop a computer model that will compute furrow application efficiency, deep percolation ratio and tailwater ratio. Also, a simulation of the performance of furrow irrigation method was done using the computer program.

Three CLSU experimental areas were used in the evaluation of furrow irrigation method in three soil types. This included the establishment of infiltration depth function,wherein four infiltration depth functions were established in each soil type. The net depth of water to be applied was also determined.

In calibrating the model, iteration was used to get the correct slope of the power advance equation. Iteration procedure was likewise used to determine the correct value of the water subsurface factor, σ_z. The values of r and σ_z were aided in the prediction of the advance distance, L, along the furrow. A comparison between the predicted and observed advance distance was done.

The developed computer model was used to evaluate the furrow application efficiency at different furrow inflow discharges. Results showed that the computed application efficiencies were 34.5%, 59.4% and 34.4% for clay, clay loam and sandy clay loam soils, respectively, when the recommended inflow discharge (Q) was used. When the inflow discharge was decreased by half (0.5Q), the resulting application efficiencies were 28.0%, 84.5% and 45% for clay, clay loam and sandy clay loam soils, respectively. Increasing the inflow discharge by 50 percent (1.5Q) resulted in an application efficiency of 33.8%, 62.4% and 31.8% for clay, clay loam and sandy clay loam soils, respectively. In addition, doubling the inflow discharge (2Q) resulted in an application efficiency of 25.8%, 69.8% and 66.6% for clay, clay loam and sandy clay loam soils, respectively. Furthermore, using 0.5Q of inflow discharge, clay loam and sandy clay loam soils recorded the highest tailwater ratio of 88.6% and 86.5%, respectively. However, when the inflow discharge was increased to 1.5Q, clay exhibited the highest tailwater ratio of 74.0%.

The developed computed model can be recoomended for use in evaluating the performance of furrow irrigation method, particularly on how the application efficiency can be increased and, conversely, how the tailwater ratio and deep percolation ratio can be decreased. It can also be used to determine the appropriate furrow length and furrow discharge.

Keywords: power advance, volume balance, furrow irrigation

INTRODUCTION

The volume of applied water above the field always exceeds the volume of water that infiltrates; thus, runoff normally occurs. Surface irrigation methods are characterized by low application efficiency (El-Adl, 2010). Furrow irrigation is one of the cheap and probably low-technique methods of surface irrigation. This runoff may be determined either by actual measurement or by using the water balance analysis.

The volume balance model (VBM) is commonly used in surface irrigation design, evaluation and management because the sophisticated models require extensive programming and high computer cost due to the long execution time (Alazba, 1999). There is, therefore, a growing concern for efficient use of water to be delivered. Irrigation water efficiency addresses as the irrigation system performance, the uniformity of water application and the response of crop to irrigation.

Irrigation systems should be designed efficiently to uniformly apply irrigation water without causing excessive water loss, erosion, or water quality impairment (Cinense, 2010). However, in the Philippine, the sizes (length and width) of many fields that are irrigated by any surface irrigation method are determined by using the ingenuity and experience of Filipino farmers who have been practicing farming for a very long time. Some farmers, however, might have to determine the right size of their field by trial and error. In a bid to deliver the right amount of water and increase its application efficiency, an evaluation procedure for furrow irrigated field must be offered in a timely manner.

The general objective of the study was to evaluate the performance of furrow irrigation method using the power advance approach of the VBM. The specific objectives of the study were to develop a computer program that will determine the furrow application efficiency, deep percolation ratio and tail water ratio using the VBM and simulate the furrow irrigation method using the computer program.

The furrow irrigation method was evaluated in the study using the power advance approach of the VBM. Emphasis was given on the right amount of water (inflow in terms of both depth and discharge) that will enter the field, the size of field (particularly its length), infiltration capacity of soil in a particular field, the right amount of water that should be delivered in the root zone, the irrigation application time and the application efficiency after the furrow irrigation method. Furthermore, the study was also limits on the comparison of the observed advance distance and the predicted advance distance in a particular advance time. Validation of the model was not done due to time limitation.

MATERIALS AND METHODS

Conceptual Framework

It is recognizable that there is declining water supply for agriculture and the way the Filipino farmers determine the size of their field for irrigation, which is based on their experience or the so called trial-and-error method and the poor application efficiency if the most common method of irrigation they use, the furrow irrigation.

To address the identified issues and concerns, the furrow irrigation was designed using power advance approach of the VBM. Also, a computer program was developed in aid of evaluating furrow irrigation method. The output of the study included the determination of furrow efficiency, deep percolation ratio, tailwater ratio, the recommended furrow length that will increase furrow application efficiency and the developed computer program that will serve as decision-support tool in determining size of the field for irrigation.

Materials and Equipment

Furrow irrigation method, in three soil types in CLSU, was established and evaluated. The following materials and equipment were used: furrow profilometer, ring infiltrometer, stop watch, soil oven and trapezoidal of rectangular weir.

Description of Study Sites

The experimental sites were located at experimental areas of WRMC Experimental Station, Research Office and Small Ruminant Center with soil types of clay, clay loam and sandy clay loam, respectively. The WRMC experimental station has a bulk density of 1.63 g/cc, water holding capacity of 45.41 mm, field capacity of 28.24 mm and permanent wilting point of 10.19 mm (Mactal, 1998). The Research office experimental site has a bulk

density of 1.43 g/cc, water holding capacity of 57.17, field capacity of 35.15 mm and permanent wilting point of 16.77 mm. The SRC has a bulk density of 1.58 g/cc, water holding capacity of 46.97 mm, field capacity of 15.06 mm and permanent wilting point of 10.51 mm. The discharge (Q), used in the 3 study sites for measured by parshall flume was 0.158 m³/min for clay soil, 0.089 for clay loam, and 0.290 m³/min for sandy clay loam.

Field Experiment

Determination of Infiltration Depth Function

Soil infiltration depth equation was determined before the first irrigation water application. Three-ring infiltrometers were set up in each furrow, one each at the head, middle and end of the furrow. Water was poured slowly in the inner cylinder of the infiltrometer up to about one inch from its top. The downward movement of water at a pre-determined time interval was observed and recorded. There were three observations depths at a given time intervals since three ring infiltrometers were installed. Hence, the average cumulative depth at a given time interval was taken as the representative depth at that time interval. The data on cumulative times and average cumulative depth data were then regressed and the resulting equation gave the infiltration depth equation. Plotting the cumulative times versus cumulative depths in a normal scale will show that the cumulative infiltration depth increases in a non-linear manner. Hence, a non-linear regression analysis was used to determine the following infiltration depth equation:

$$z = kt^a \qquad (1)$$

where: z = infiltration depth
k = infiltration time
t = intercept of infiltration
a = slope of infiltration

Determination of Net Depth of Water

The net depth of water to be applied was com-puted by the following equation:

$$d_n = (FC - CSM)A_s D_s \qquad …(2)$$

where:
d_n = net depth of water to be applied
FC = field capacity of the soil
CSM = current soil moisture before irrigation
A_s = Apparent specific gravity of the soil

D_s = soil depth (50 cm for corn)

Determination of Furrow Cross-section

The furrow cross-sectional area was determined during the furrow irrigation. The profilometer was used in measuring the furrow cross-section. It is composed of removable stake with 5 cm distances. Three profilometer were set up in a furrow, one each at the head, middle and end of furrow. There were ten depths measured for a profilometer. The distance between each stake created an area in a profilometer. The data on depth of the each stake and the area between two stakes were regressed, and the resulting equation was area of the furrow. A non-linear regression analysis was used to determine the following furrow cross section:

$$A_0 = A_1 y^{A_2} \qquad …(3)$$

where: A_0 = furrow cross-sectional area
A_1 = average depth of water
y = depth of water in each stake
A_2 = area between two stakes

Model Calibration

The model was calibrated in order to simulate correctly the circumstances above and below the soil surface during irrigation water application. The model calibration included the field determination of the following parameters (aside from the establishment of infiltration depth function): furrow length, L; inflow discharge, Q_0; outflow, Q_e; inflow depth, y_0; furrow spacing; average furrow cross-sectional area, A_0,,and advance time over the total furrow length.

The VBM using the power advance approach was calibrated and used in simulating field conditions during irrigation. This model is:

$$Q_0 t_L = \sigma_y A_0 L + \sigma_z k t^a w L + c t_L/(r + 1) \qquad …(4)$$

where:
Q_0 = inflow
t_L = advance time at the end of the furrow

σ_y = surface shape factor

L = Length of the furrow
σ_z = sub-surface shape factor
w = width of the furrow
r = slope of the power advance equation

The furrow irrigation efficiency was evaluated using the power advance approach of the VBM. The volume of infiltration, V_z was computed as

$$V_z = \sigma_z k t^a w L + c t_L w L / (r + 1) \quad \text{...(5)}$$

Using the value of r, an initial value of σ_z from equation (4) was computed. Iterative solution was done in order to find the values of r and σ_z. Substituting the values of Q_0, k, c, a, w, A_0, σ_z, r in equation (4) after simplica-tion became,

$$L = (Q_0 t_L) / (\sigma_y A_0 + \sigma_z k t^a w + \frac{c t_L w L}{r+1}) \quad \text{...(6)}$$

The volume of water stored in the soil was computed using

$$V_d = L w d_n \quad \text{...(7)}$$

The infiltration time needed to store the water was computed using net depth equation and $z = k t^a$, that is substituting d = z in equation $k t^a$. Substituting t in equation (30) and solving L gave a furrow length with stored depth. This gave a distance for the completely irrigated area, and the volume of water to be stored in this furrow is

$$V_x = d_n X_d w \quad \text{...(8)}$$

The other length $(L - X_d)$ of the furrow was under irrigated, and the volume of water stored in this furrow distance was computed.

$$V_{(L - X_d)} = \sigma_z k t^a w (L - X_d) + \frac{c t_{L - X_d} w (L - X_d)}{r+1} \quad \text{...(9)}$$

The total volume of water stored was computed using

$$V_T = (V_x + V_{(L - X_d)}) \quad \text{...(10)}$$

Determination of Furrow Application Efficiency

The application efficiency in the complete and over irrigation cases is:

$$E_a(CI) = E_a(OI) = \frac{DL}{V_z} x 100 \quad \text{...(11)}$$

The application efficiency in the under irrigation

$$E_a(UI) = \frac{D X_d}{V_z} x 100 \quad \text{...(12)}$$

Determination of Deep Percolation Ratio

The deep percolation ratio for the complete and over-irrigation cases is:

$$DPR(CI) = DPR(OI) = \beta i(P) z_0' w \ell + z_0'' w \ell \{1 - [r/(r+1)P]\} - D \cdot L) / V_z \quad \text{...(13)}$$

Where

$$\beta i(P) = p^r \left(1 - \frac{ra}{r+1} p\right) + \left(\frac{ra(a-1)}{2(r+1)} p^2\right) \quad \text{...(14)}$$

$z_0' = kta$

$z_0'' = ct$

where: c = constant rate of infiltration

The deep percolation ratio for the under-irrigation case is

$$DPR(UI) = \frac{V_z(\mu) - D X_d}{V_z} x 100 \quad \text{...(15)}$$

where:

$$(\mu) = t_D / t_L \quad \text{...(16)}$$

Determination of Tailwater Ratio

The tailwater ratio, TWR, was computed as for complete and an over-irrigation case is:

$$TWR(CI) = TWR(OI) = \frac{V_z - V_z(P)}{V_z} x 100 \quad \text{...(17)}$$

For the under irrigation case, the TWR was com-puted as:

$$TWR(UI) = \frac{V_z - V_z(\mu)}{V_z} x 100 \quad \text{...(18)}$$

Computer Program Development

The evaluation of the furrow irrigation method, using the power advance approach of the VBM, was done using the Microsoft Excel. The Visual Basic 2008 was used to Development the computer program.

Inputs for the Computer Program Development

The following were the inputs required by the computer program: location, soil type, field capacity, current soil moisture, apparent specific gravity, soil depth, average depth of water, wetted width, inflow, outflow, profilometer depth of stake, area between stake of profilometer, cumulative time of infiltration, cumulative depth of infiltration, advance time, and observed advance distance.

Model Output

The output of the program was the application efficiency, deep percolation ratio and tailwater ratio.

Computer Model Simulation

The computed application efficiency was compared to the recommended efficiency for furrow irrigation. If the computed application efficiency by the model was lower than the recommended value, then adjustments were with done either the water application time or the furrow length. Also, the comparison between the observe advance distance and predicted advance distance were shown in the model. This portion of the model was referred to as the simulation process.

RESULTS AND DISCUSSION

The field experiment of the study was condu-cted to evaluate the furrow irrigation method in three soil types in Central Luzon State University. The field experiment included the establishment of infiltration function, determination of net depth of water to be applied, calibration of the model and evaluation of furrow irrigation application efficiency.

The established infiltration functions for three soil types at four different discharge values are as follows:

$$z_1 = 000671t^{025\ 330} + 00472t \quad \ldots(19)$$
$$z_2 = 000671t^{025\ 330} + 00469t \quad \ldots(20)$$
$$z_3 = 000671t^{025\ 330} + 00402t \quad \ldots(21)$$
$$z_4 = 000671t^{025\ 330} + 00400t \quad \ldots(22)$$
$$z_5 = 000997t^{059\ 770} + 00346t \quad \ldots(23)$$
$$z_6 = 000997t^{059\ 770} + 00296t \quad \ldots(24)$$
$$z_7 = 000997t^{059\ 770} + 00160t \quad \ldots(25)$$
$$z_8 = 000997t^{059\ 770} + 00090t \quad \ldots(26)$$
$$z_9 = 001259t^{046\ 950} + 00744t \quad \ldots(27)$$
$$z_{10} = 0012\ 59t^{04\ 6950} + 0070\ 9t \quad \ldots(28)$$
$$z_{11} = 0012\ 59t^{04\ 6950} + 0065\ 3t \quad \ldots(29)$$
$$z_{12} = 0012\ 59t^{04\ 6950} + 0060\ 5t \quad \ldots(30)$$

Equations 19 -22 are for clay soil at 2Q, 1.5Q, Q and 0.5Q discharges, respectively. Note that only the constant rate of infiltration changes because it is affected by the increase and decrease in furrow inflow discharges. The same observations are exhibited by Equations 23-26 for clay loam soil as well as by Equations 27 – 30 for sandy clay loam soil.

Initial Net Depth of Water in the Soil

Table 1. Net depth of water of the three soil types, D_s

SOIL TYPE	NET DEPTH, mm
Clay	11.60
Clay loam	19.40
Sandy clay loam	19.75

Model Calibration

The model was calibrated in order to simulate correctly what was going on above and below the soil surface during irrigation water application. The model calibration includes the field determination of the following parameters (aside from the establishment of infiltration depth function)

TheVBM using the power advance approach which is described by Equation 24 is the model that was calibrated. That is, values of Q_0, σ_y, k, a, w, A_0, σ_z, r were specified in Equation 24 to end with Equations 31 – 42 as the calibrated VBM.

$$L_{2Q\ of\ clay} = \frac{0198t}{(00277 + 000179t^{02533} + 000170t)} \quad \ldots(31)$$

$$L_{15Q\ of\ clay} = \frac{0189t}{(00320 + 000183t^{02533} + 000169t)} \quad \ldots(32)$$

$$L_{Q\ of\ clay} = \frac{0158t}{(00277 + 00243t^{02533} + 000221t)} \quad \ldots(33)$$

$$L_{05Q\ of\ clay} = \frac{0156t}{(00101 + 000140t^{02533} + 000148t)} \quad \ldots(34)$$

$$L_{2Q\ of\ clay\ loam} = \frac{0153t}{(00372 + 000121\ 0t^{05977} + 000081\ 65t)} \quad \ldots(35)$$

$$L_{15Q\ of\ clay\ loam} = \frac{0123t}{(00456 + 000058\ 1t^{05977} + 000075t)} \quad \ldots(36)$$

$$L_{Q\ of\ clay\ loam} = \frac{0089t}{(00351 + 000072\ 9t^{05977} + 000198t)} \quad \ldots(37)$$

$$L_{05Q\ of\ clay\ loam} = \frac{0057t}{(00422 + 000006\ 1t^{05977} + 000001\ 93t)} \quad \ldots(38)$$

$$L_{2Q\ of\ sandy\ clay\ loam} = \frac{03864t}{(00335 + 00003t^{04\ 695} + 00027t)} \quad \ldots(39)$$

$$L_{15Q\ of\ sa\ ndy\ clay\ loam} = \frac{0345t}{(01314 + 00510t^{04\ 695} + 000303t)} \quad \ldots(40)$$

$$L_{Q \text{ of sandy clay loam}} = \frac{0290t}{(00233+00021t^{046\,95}+000203t)} \quad \ldots(41)$$

$$L_{Q \text{ of sandy clay loam}} = \frac{0240t}{(0044+000276t^{046\,95}+000218t)} \quad \ldots(42)$$

Where L is any advance distance between 0 and L of the furrow, and t_x is any distance between 0 and advance time, t_L. (Note that Equation 31 to Equation 42 could also be used to compute a furrow distance beyond its actual length, L. That is, the distance beyond the actual length, L is called the imaginary length of the field.) Equations 31 to Equation 42 were then used to compute the simulated advance distance, X, at any given time, t_x. Figure 1 to Figure 12 show the comparison of the actual to the computed distance by the model.
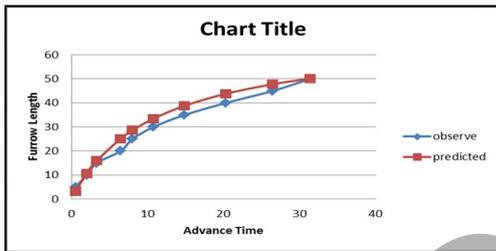
Fig.1. Comparison of observed vs. predicted distance of water along furrow at given advance time (0<t<35 min) using Equation 31
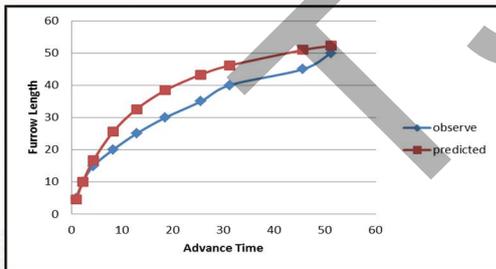
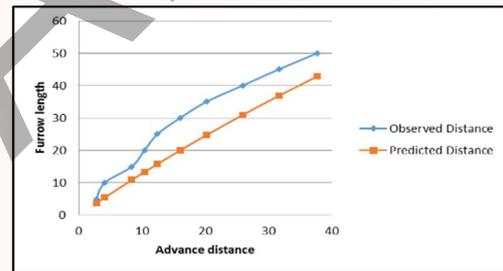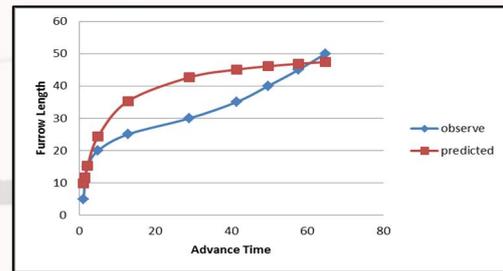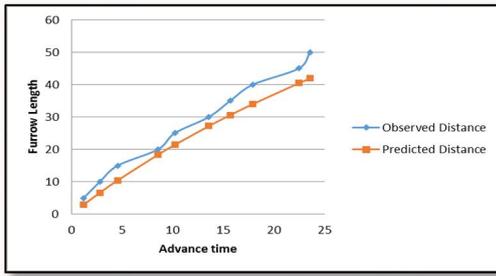Fig.2. Comparison of observed vs. predicted distance of water along furrow at a given advance time (0<t<60 min) using Equation 32
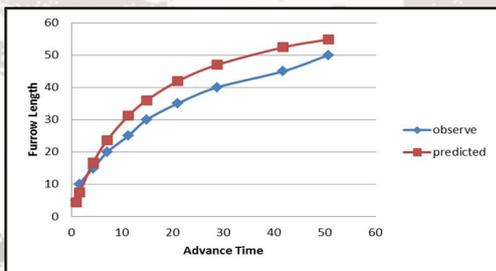
Fig.3. Comparison of observed vs. predicted distance of water along furrow at a given advance time (0<t<50 min) using Equation 33
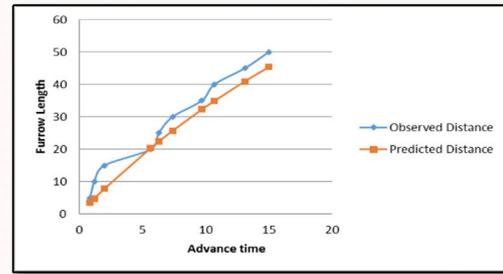
Fig.4. Comparison of observed vs. predicted distance of water along furrow at a given advance time (0<t< 70 min) using Equation 34
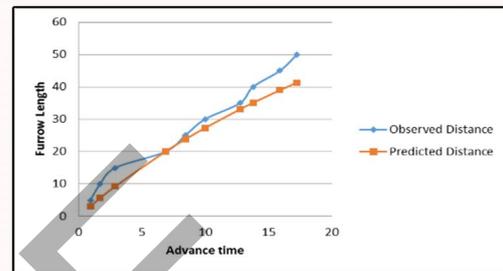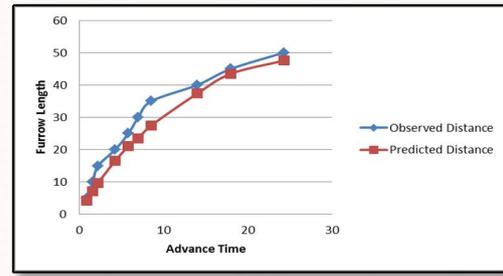

Fig.5 Comparison of observed vs. predicted distance of water along furrow at a given advance time (0<t<15 min) using Equation 35

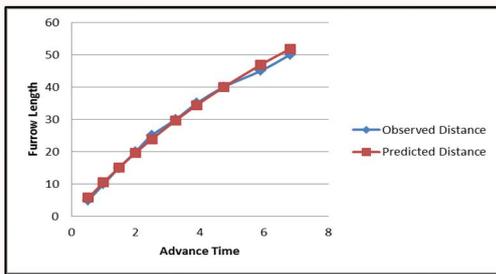Fig.6. Comparison of observed vs. predicted distance of water along furrow at given advance time (0<t<25 min) using Equation 36

Fig.7. Comparison of observed vs. predicted distance of water along furrow at a given advance time (0<t<25 min) using Equation 37

Fig.8. Comparison of observed vs. predicted distance of water along furrow at given advance time (0<t<40 min) using Equation 38

Fig.9. Comparison of observed vs. predicted distance of water along furrow at a given advance time (0<t<10 min) using Equation 39
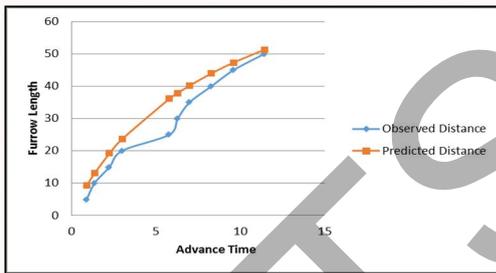

Fig.10. Comparison of observed vs. predicted distance of water along furrow at a given advance time (0<t<15 min) using Equation 40

Fig.11. Comparison of observed vs. predicted distance of water along furrow at a given advance time (0<t<20 min) using Equation 41

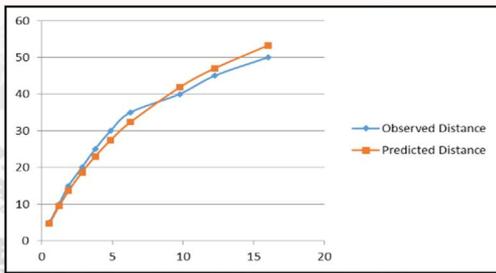
Fig.12. Comparison of observed vs. predicted distance of water along furrow at a given advance time (0<t<30 min) using Equation 42

Table 1. Furrow application efficiency for different soil type in CLSU

SOIL TYPE	FURROW APPLICATION EFFICIENCY (%)			
	2Q	1.5Q	Q	0.5Q
Clay	25.83	33.83	34.47	27.98
Clay loam	69.80	62.43	59.35	84.51
Sandy clay loam	66.64	31.76	34.44	45.02

Table 2. Deep percolation ratio in three different soil type in CLSU

SOIL TYPE	DEEP PERCOLATION RATIO (%)			
	2Q	1.5Q	Q	0.5Q
Clay	18.50	12.84	12.40	13.65
Clay loam	11.70	10.83	10.24	9.40
Sandy clay loam	19.51	10.13	17.47	11.01

Table 3. Tailwater ratio for different soil type in CLSU

SOIL TYPE	TAILWATER RATIO (%)			
	2Q	1.5Q	Q	0.5Q
Clay	55.67	53.32	53.12	58.37
Clay loam	39.46	42.59	46.09	22.79
Sandy clay loam	15.85	58.10	48.09	43.96
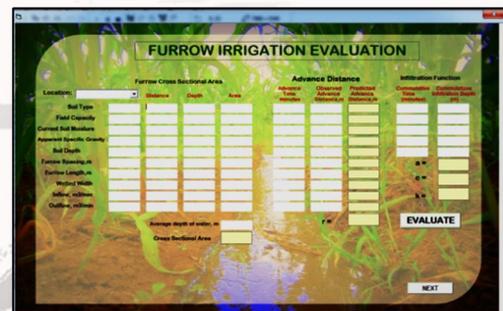
Fig.13. The main menu of the program
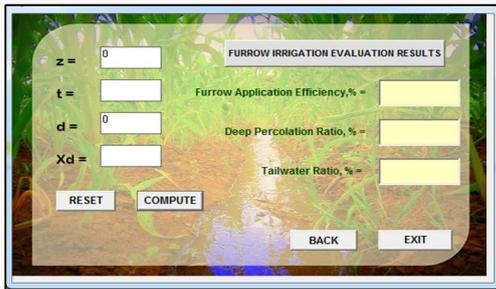
Fig.14. The Furrow Results window

CONCLUSIONS

Based from the results of the study, the following conclusions were drawn:

1. Evaluation of the furrow irrigation method using the power advance approach of the VBM for three different soil types in CLSU and four different inflow discharges showed that the furrow application efficiency, deep percolation ratio and tailwater ratio varied for the different soil types. A higher volume of water application in the field does not necessarily mean that it will produce higher application efficiency.

2. The model calibration was done through iteration. Results showed that the disparity between the predicted advance distance and the observed advance distance had a range of 1 to 9 meters.

3. The developed computer program allowed the evaluation the furrow irrigation method, obtaining computed values for furrow application efficiency, deep percola-tion ratio and tailwater ratio. The simplicity and ease of usage of the computer program offer a support system for the evaluation of furrow irrigation method.

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