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Modified Design for Drip Irrigation System to Improve the Productivity of Irrigation Water and Fertilizers Distribution

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Abstract : Due to limitation water resources in Egypt, the water use efficiency most be maximized to facing the population increase. Two field experiments were done during the two successive seasons 2014 and 2015, at El-Nubaria research station for National Research Centre, Egypt. The execution of modified design for drip irrigation system should be tested and evaluated in comparison with the other two designs to increase water and fertilizers use efficiency in the new reclaimed land. Three designs of drip irrigation systems will be tested in this study. The first establish design was the common design (control). The second one was with PRD technique (partial root drying; one emitter will irrigate half area of the root zone and emitters of other lateral will irrigate other half of root zone) where the two laterals were in the same direction. The last one was the modified design with PRD technique with oboist direction for the two laterals. Take into consideration the following parameters to determine the difference between the three designs (A) water emission uniformity, (B) soil moisture distribution, (C) application efficiency, (D) Water productivity of groundnut "$WP_{groundnut}$" and (E) yield of groundnut. Statistical analysis specified that the maximum values of water productivity and complete net return for farmers were discovered under the modified design (3). The result proved that, emotion uniformity will be increased from 74% : 75% : 99,6% throw out design (1) , design (2) and modified design (3), respectively as show in Fig. (3). Furthermore, the averages of emitter discharge along laterals L/h with modified design (3) were stable from start to end but with design (2) the averages were decrease Fig. (4). It means that, in the design (2) can be used but maximum lateral length of 25 m. The application efficiency (AE) was increased 91: 95: 99 % throw the three design respectively Fig. (8). The water productivity achieved high amount with modified design (3) compared with the others Fig. (9) and Table (6). The yield of groundnut was affected by different designs. It increased from 1.9: 2.1: 2.51 ton/fed. significantly throw the three designs.

Key words : *Modified design of drip irrigation, PRD technique, Water productivity of Groundnut.*

Introduction

In present years, the water scarcity will be increasing with fixed of water resources in Egypt. Growing competition for scarce water resources has led to applying modified techniques for maximizing water use efficiency and improving crop yields and quality, particularly in arid regions like Egypt[1]. Water scarcity is one of the major problems for crop production in Egypt, this is needs to reduce the consumption of water in irrigation by develop new technologies and methods that can be help full to utilize this precious input in an effective way[2]. It is necessary to apply alternative ways for maximization water use efficiency to rising quality and quantity of agriculture productivity, exception under arid and semiarid climate. The efficiency of water use is a very important economically notion for irrigation project directors. Quality of the agriculture productivity is the important criteria to evaluate irrigation systems efficiency. Generally, the drip irrigation system is usually strongly efficient as only on the root zone for every plant is wetted[3]. Throw out the additional irrigation, the productivity will be increasing. Predictions indicated that, the request for irrigation will be increasing a lot in coming years to moderate the results of climate change and more repeated and heavy dehydration, which become the major decreasing factor in crop productivity. (www.cropwat.agrif.bg.ac.rs). To covering the food requirement to face increasing population, more efforts had been done to develop crop agriculture area in marginal and new reclaimed land (sand soil) based on modification of techniques such as modified of irrigation methods[4]. (PRD) means that, the half of root area will be irrigated and let the other half area. The treating is then inverted; allowing the earlier good-watered part of the root zone to dry down while total irrigated earlier dry side. It could be concluded from this study the possibility of reducing irrigation water duty with drip irrigation system comparing to sprinkler irrigation system[5]. The recurrence of the turn is specified depended on soil type, climate data, genotype or anther factors. PRD irrigation should be turned steady from one side to other of the root zone to keep roots in dry soil grow and fully active and afford the growing of the root. The term of switching required could present significant and great in operating process of irrigation. By using PRD modified irrigation system, with opposite direction to achieve the pressure parlance in both lines must be measured the soil water depletion by specific device. (www.cropwat.agrif.bg.ac.rs).

Objective of this study was compare between the three designs of drip irrigation systems to maximize water and fertilizers use efficiency under sandy soil.

Materials and Methods

Description of Study Site

Location and climate of experimental site: Field experiments were conducted during two groundnut seasons at the experimental farm of National Research Center, El-Nubaria, Egypt (latitude 30^{o} 30$^{\backslash}$ 1.4$^{\backslash\backslash}$ N, and longitude 30^{o} 19$^{\backslash}$ 10.9$^{\backslash\backslash}$ E, and mean altitude 21 m above sea level). The experimental area has an arid climate with cool winters and hot dry summers prevailing in the experimental area. The data of maximum and minimum temperature, relative humidity, and wind speed were obtained from "Local Weather Station inside El-Nubaria Farm".

Irrigation system: Irrigation system components consisted of pumping system, control head and filtration unit. It consists of centrifugal pump with 45 m^3/h discharge and it was driven by electrical engine and screen filter and back flow prevention device, pressure regulator, pressure gauges, control valves and flow-meter. Main line was of PVC pipes with 110 mm in outside diameter (OD) to convey the water from the source to the main control points in the field. Sub-main lines were of PVC pipes with 75 mm (OD) was connected to the main line. Manifold lines: PE pipes was of 63 mm in (OD) were connected to the sub main line through control valve 2`` and discharge gauge. Emitters, built in laterals tubes of PE with 16 mm (OD) and 50 m in long (emitter discharge was 4 L/h at 1.0 bar operating pressure and 30 cm spacing between emitters.

Physical and chemical properties of soil and irrigation water: Some Properties of soil and irrigation water for experimental site are presented in (Tables 1, 2 and 3).

Table 1: Chemical and mechanical analyses of soil.

Depth	Chemical analysis				mechanical analysis			Texture
	OM (%)	pH (1:2.5)	EC (dSm^{-1})	$CaCO_3$ %	Course sand	Fine sand	Silt+ clay	
0-20	0.65	8.7	0.35	7.02	47.76	49.75	2.49	Sandy
20-40	0.40	8.8	0.32	2.34	56.72	39.56	3.72	
40-60	0.25	9.3	0.44	4.68	36.76	59.40	3.84	

OM= organic matter. pH= power of hydrogen EC= Electrical Conductivity

Table 2: Soil characteristics.

Depth	SP (%)	F.C (%)	W.P (%)	A.W (%)	Hydraulic conductivity(cm/hr)
0-20	21.0	10.1	4.7	5.4	22.5
20-40	19.0	13.5	5.6	7.9	19.0
40-60	22.0	12.5	4.6	7.9	21.0

S.P. = saturation point, F.C. = field capacity, W.P. = wilting point and A.W. = available water.

Table 3: Chemical characteristics of irrigation water.

pH	EC (dSm^{-1})	Cations and anions (meq/L)								SAR %
		Cations				Anions				
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}	
7.35	0.41	1	0.5	2.4	0.2	--	0.1	2.7	1.3	2.8

pH= power of hydrogen EC= Electrical Conductivity SAR= Sodium Adsorption Ratio

Crop Requirements

Irrigation requirements: Seasonal irrigation requirements for groundnut were estimated. The seasonal irrigation water applied was found to be 2120 m^3/fed./season for 2014 and 2100 m^3/fed./season for 2015 for drip irrigation system by following equation:

$$IRg = (ET_O \times Kc \times Kr) / Ei - R + LR \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where: IRg = Gross irrigation requirements, mm/day

ET_O = Reference evapotranspiration, mm/day (estimated by the meteorological data of local station in EL-NUBARYIA farm and according to Penman-Monteith equation)

Kc = Crop factor (FAO reference)

Kr = Ground cover reduction factor, Values of Kr suggested by different authors (FAO, 1984)

Ei = Irrigation efficiency = Ea x EU where Ea = (Vs/Va) x 100 where Vs = Average water stored in root zone; Va = Average water applied; EU = Coefficient reflecting the uniformity of application= (qm / qa) x100 where qm = the average flow rate of the emitters in the lowest quartile, (l/h); and qa = the average flow rate of all emitters under test, (l/h).

R = Water received by plant from sources other than irrigation, mm (for example rainfall)

LR = Amount of water required for the leaching of salts, mm = LRt x (IRn/Ei) where: LRt = leaching requirement ratio under drip irrigation = ECw /(2 x max ECe) where ECw = electrical conductivity of irrigation water (ds/m); max ECe = electrical conductivity of saturated soil extract that will reduce the crop yield to zero (dS/m); IRn (net irrigation requirement) = ETo x Kc x Kr

Fertilization program, weed and pest control: All irrigation treatments were done in separate blocks as well as, the amount of irrigation water was estimated and added according to the recommended doses and intervals for each treatment during the growing season. Seeds were sown on May 10th and 12th in the first and second seasons respectively. The seeds (Giza 6 c.v.) were coated just before sowing with the bacteria inoculants, using

Arabic gum (40 %) as adhesive agent and were sown in hills 10 cm apart. Phosphorus (calcium superphosphate, 15.5 % P_2O_5) at level 32 kg P_2O_5 fed.$^{-1}$ was added during the seed bed preparation and potassium (potassium sulfate (48.52 % K_2 O) was applied at the rate of 52 kg fed.$^{-1}$ before the first and third irrigations in two equal doses, while nitrogen fertilizer was added at level of 42 kg N fed.$^{-1}$ as ammonium sulfate, 20.6 % in four equal doses weekly starting from 15 days after sowing. The proceeding winter crop was faba bean and wheat in the first and the second season, respectively. Groundnut was manually harvested on September 14th and 16th in the first and second season, respectively.

Experimental Design: Experimental design was evaluation modified design for drip irrigation system with two traditional designs. Design (1) was drip irrigation system (control), design (2) was drip irrigation system with PRD technique (partial root drying; one emitter will irrigate one part of the root system and emitters of other lateral will irrigate other half of root system) with the same direction for main lines and laterals and Modified design (3) was drip irrigation system with PRD technique with opposite direction for main lines and laterals. The distance between laterals were 35 cm as Abdelraouf, 2013 recommended[6]. More details for all designs as shown in fig. (1)**.**

Evaluation Parameters

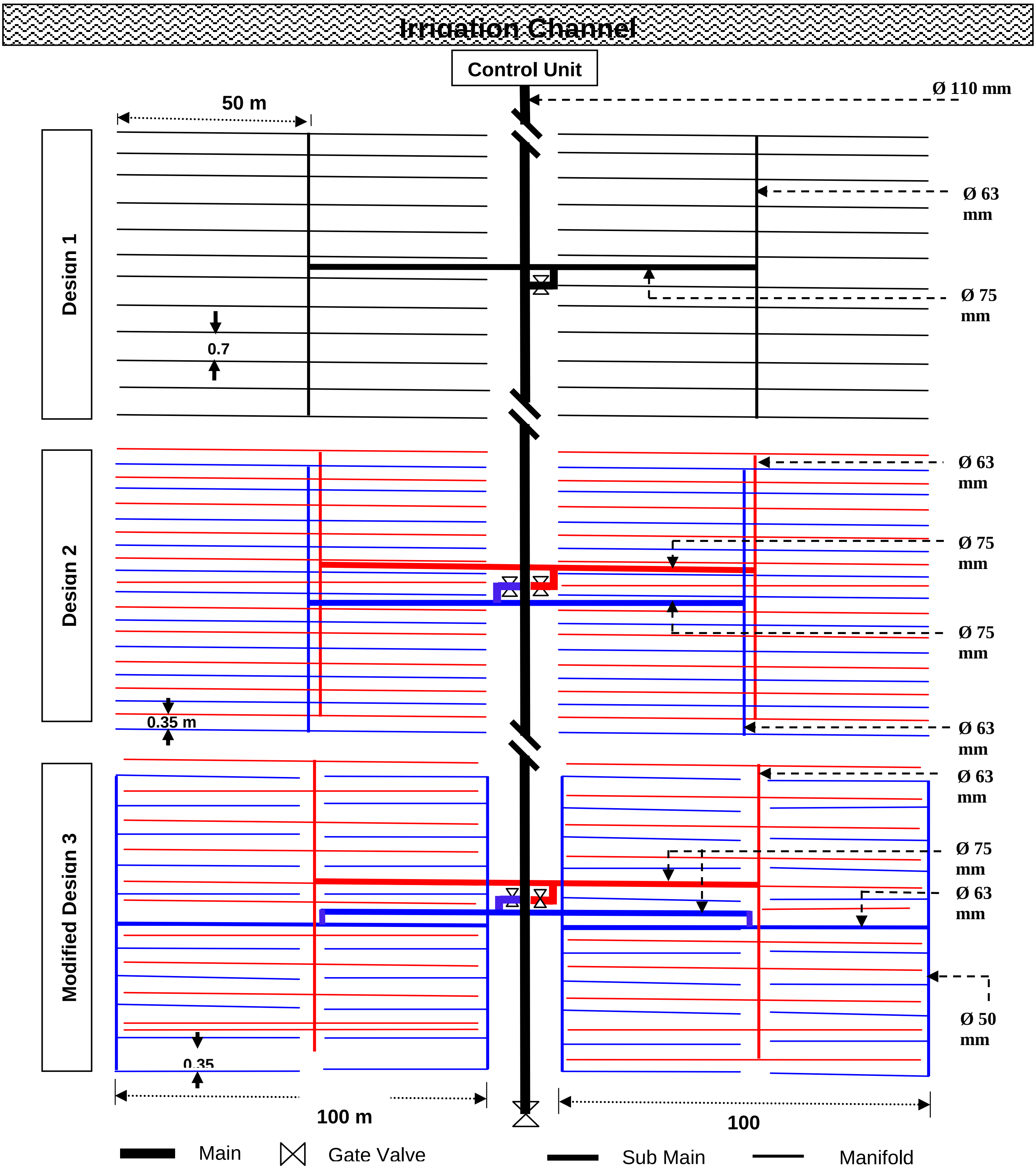
Emission uniformity: emission uniformity (EU) of water was estimated[7] along laterals drip irrigation system in every plot area under pressure range of 1.0 bar by using 20 collection cans and following Equation:

$$EU = (qm / qa)\ 100 \quad \ldots\ldots\ldots\ldots\ldots (2)$$

Where: EU = Emission uniformity, %; qm = the average flow rate of the emitters in the lowest quartile, (l/h); and qa = the average flow rate of all emitters under test, (l/h).

Soil moisture distribution: Soil moisture content was determined according to[8]. The soil samples were taken at maximum actual water requirements by profile probe a shown in fig. (2) before and 2 hours after irrigation and from different locations. In the case of 70 cm laterals space the sample locations were at 0, 10, 20, 30 and 35 cm on the X-axis (space between laterals). For each of these locations, soil samples were collected from different depths from soil surface, which were 0, 15, 30 and 45 cm on the Y-axis. By using "contouring program Surfer version 8", we obtained on contouring maps for different moisture levels with depths.

Fig. 2: Profile probe for measuring soil moisture content



Design (1) = Drip irrigation system (control)
Design (2) = Drip irrigation system with PRD technique with the same direction for manifolds and laterals
Modified Design (3) = Drip irrigation system with PRD technique with opposite direction for manifolds and

Fig. (1) Layout of drip irrigation systems under study

Application efficiency: Application efficiency relates to the actual storage of water in the root zone to meet the crop water needs in relation to the water applied to the field. According to[9] application efficiency "AE" was calculated using the following relation:

$$AE = V_s / V_a \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where: AE = Application efficiency, (%), V_s = Volume of stored water in root zone (cm.^{3}) where:

$$V_s = (\theta_1 - \theta_2) * d * \rho * A \ldots\ldots\ldots\ldots. (4)$$

V_a = Volume of applied water (cm^3), A = wetted surface area (cm.^{2}), d = Soil layer depth (cm), θ_1 = Soil moisture content after irrigation (%), θ_2 = Soil moisture content before irrigation (%), ρ = Relative bulk density of soil (dimensionless). Table (4) show estimation method of application efficiency in the field.

Table 4: Estimation method of application efficiency

Soil depth, cm	θ_1 %	θ_2 %	d, cm	P	A, cm^2	$V_s = (\theta_1 - \theta_2)*d*\rho*A$ cm^3	V_a, cm^3	$AE = V_s/V_a$ $AE = (V_{s1}+V_{s2}+V_{s3})/V_a$
0 -15						V_{s1}		
15 -30						V_{s2}		
30 -45						V_{s3}		

AE = Application efficiency, V_s =Volume of stored water in root zone, V_a =Volume of applied water, A = wetted surface area*, d =Soil layer depth, θ_1 =Soil moisture content after irrigation, θ_2 = Soil moisture content before irrigation, ρ = Relative bulk density of soil (dimensionless). V_{s1}= Volume of stored water in root zone from 0 – 15 cm , V_{s2}= Volume of stored water in root zone from 15 – 30 cm, V_{s3}= Volume of stored water in root zone from 30 –45cm*

Water productivity "WP $_{groundnut}$" was calculated according to[10] as follows:

$$WP_{groundnut} = (Ey/Ir) \times 100 \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where: $WP_{groundnut}$ is water productivity (kg $_{grain}$ / m^3 $_{water}$), Ey is the economical yield (kg grain /fed.); Ir is the amount of applied irrigation water (m^3 $_{water}$ /fed./season).

Yield of groundnut: At harvest, a random sample of 100 X 100 cm was taken from each plot to determine grain yields in the mentioned area and then converted to yield (ton/fed.).

Economical evaluation: Total income$^{-\text{ CM more than MC}}$ = Total income - (Costs of all required materials which more than the materials which used in the control treatment) where:

$$\text{Total income}^{-\text{ CM more than MC}} = TI - [(CL/2L_1) + (CP/2L_2) + (CV/2L_3)] \ldots\ldots\ldots\ldots\ldots (6)$$

CM more than MC: Costs of all required materials which more than the materials which used in the control treatment

TI: Total income = Total yield (ton/fed.)* price of ton

CL/2L1: Costs of laterals/ season, L.E./fed., Lifecycle, L1= 7 years

CP/2L2: Costs of pipes/season, L.E./fed. Lifecycle, L2= 10 years

CV/2L3: Cost of valve & elbows /season, L.E./fed., Lifecycle, L3= 25 years

Statistical Analysis

Combined analysis of data for two growing seasons was carried out according to[11] and the values of least significant differences (L.S.D. at 5 % level) were calculated to compare the means of different treatments.

Results and Discussion

Emission uniformity

By using drip irrigation system we expect high emission uniformity throughout full control of the whole system from the pump until the emission points (dripper). The emission uniformity plays a major role in irrigation process. It directly affects the soil and the plants.

Emission Uniformity of drip irrigation system can be calculated by dividing qm / qa%, where qm = the average flow rate of the emitters in the lowest quartile, qa = the average flow rate of all emitters under test Fig. 3, and table 5. Fig. 4 showed emission uniformity for the three designs. The highest value of emission uniformity (EU) will be achieved with modified design (3) in comparison with the other two designs. This is due to the fact that the two emission points built in the laterals are on opposite directions, so the decrease in one of them causes rise other. This ensures an equal distribution straight laterals, which results in high distribution symmetry and high EU under design (3).

The result proved that, emotion uniformity will be increased from 74%:99,6% throw out design (1) and modified design (3). Furthermore, the average of emitters discharge along laterals L/h with modified design (3) were stable from the beginning till the end while in design (1) and (2) the average of emitters discharge decreased in the same trend Fig. (4). In design (1) and (2) the lateral length should not exceed 25 m.

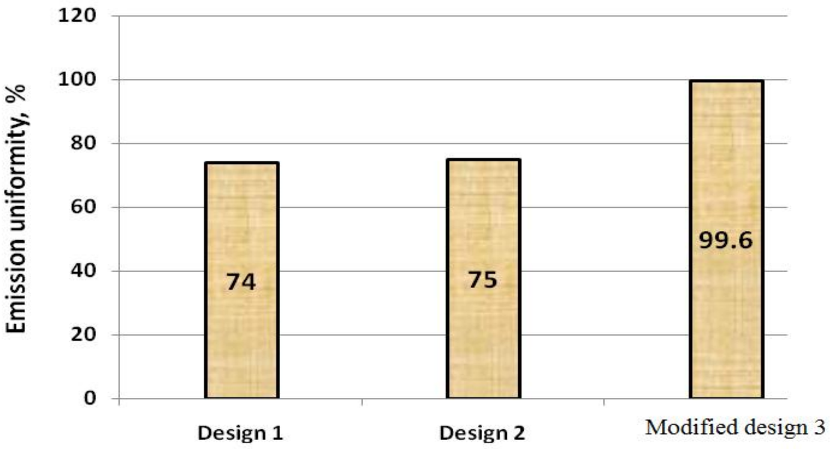


Fig. 3: The emission uniformity for the designs under study

Table 5: The Emission Uniformity under the designs under study

Can No.	Design 1 Dripline1	Design 2 Dripline1	Design 2 Dripline2	Design 2 Aver.	Modified Design 3 Dripline1	Modified Design 3 Dripline2	Modified Design 3 Aver.
1	5.0	5.2	5.3	5.25	5.1	2.5	3.8
2	4.8	4.8	4.9	4.85	4.8	2.5	3.65
3	4.6	4.6	4.7	4.65	4.6	2.6	3.6
4	4.5	4.5	4.6	4.55	4.6	3	3.8
5	4.3	4.3	4.3	4.30	4.2	3.1	3.65
6	4.2	4.2	4.3	4.25	4.2	3.1	3.65
7	4.1	4.1	4.2	4.15	4.1	3.1	3.6
8	3.9	3.9	3.9	3.90	3.9	3.4	3.65
9	3.8	3.8	3.8	3.80	3.8	3.5	3.65
10	3.7	3.8	3.7	3.75	3.8	3.7	3.75
11	3.7	3.8	3.7	3.75	3.7	3.8	3.75
12	3.5	3.5	3.4	3.45	3.5	3.8	3.65
13	3.4	3.4	3.4	3.40	3.2	3.9	3.55
14	3.1	3.1	3.1	3.10	3.1	4.1	3.6
15	3.0	3.1	3.0	3.05	3.1	4.2	3.65
16	3.0	3.0	3.0	3.00	3	4.3	3.65
17	2.8	3.0	2.8	2.90	3	4.5	3.75
18	2.7	2.7	2.7	2.75	2.7	4.6	3.65
19	2.7	2.5	2.7	2.60	2.5	4.8	3.65
20	2.6	2.4	2.5	2.54	2.5	5.1	3.8
Aver. qm	2.76			2.76			3.66
Aver. qa	3.71			3.70			3.67
EU,% = (qm/ qa)*100	74			75			99.6

Aver. qm: the average flow rate of the emitters in the lowest quartile, Aver. qa: the average flow rate of all emitters under test, EU: Emission uniformity %.

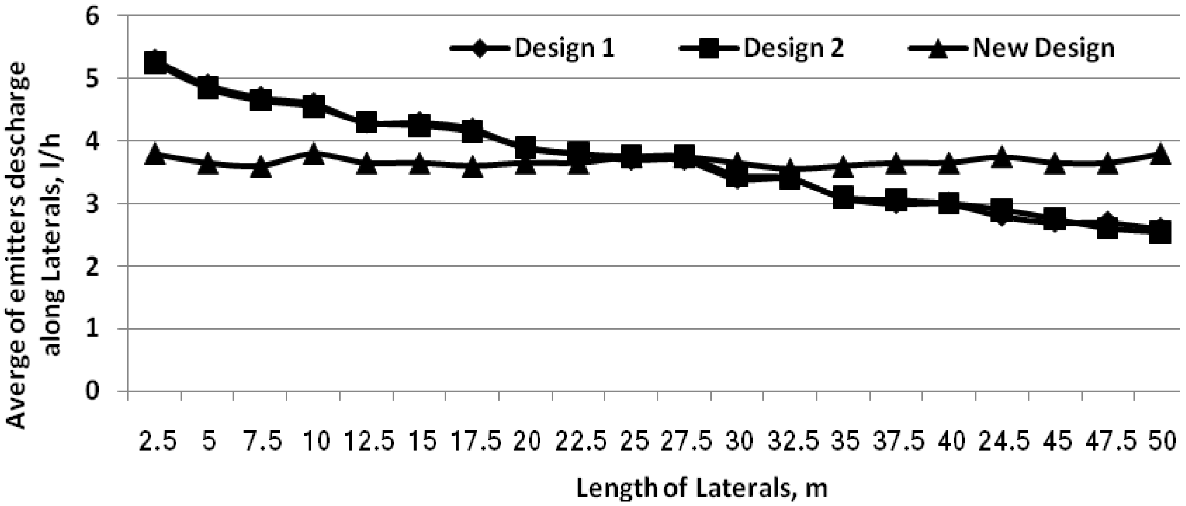


Fig. 4: The relationship between length of laterals and average of emitters discharge along laterals

Distribution uniformity of soil water moisture content

The moisture distribution and wetted soil volume (WSV) was in average 100 % from field capacity in root area Figs. (5,6 and 7).The WSV surrounded by approximately contour line 12 represents the field capacity. The modified design (3) showed better distribution uniformity of soil water moisture content compared to the other two designs. This may be due to the balance of pressure in the two opposite direction drip lines.

The highest value for $WSV_{\geq 100\%FC}$ occurred under modified design (3) in the root zone, decreasing the danger of drought stress into root area along laterals which will create a better media for plant grow.

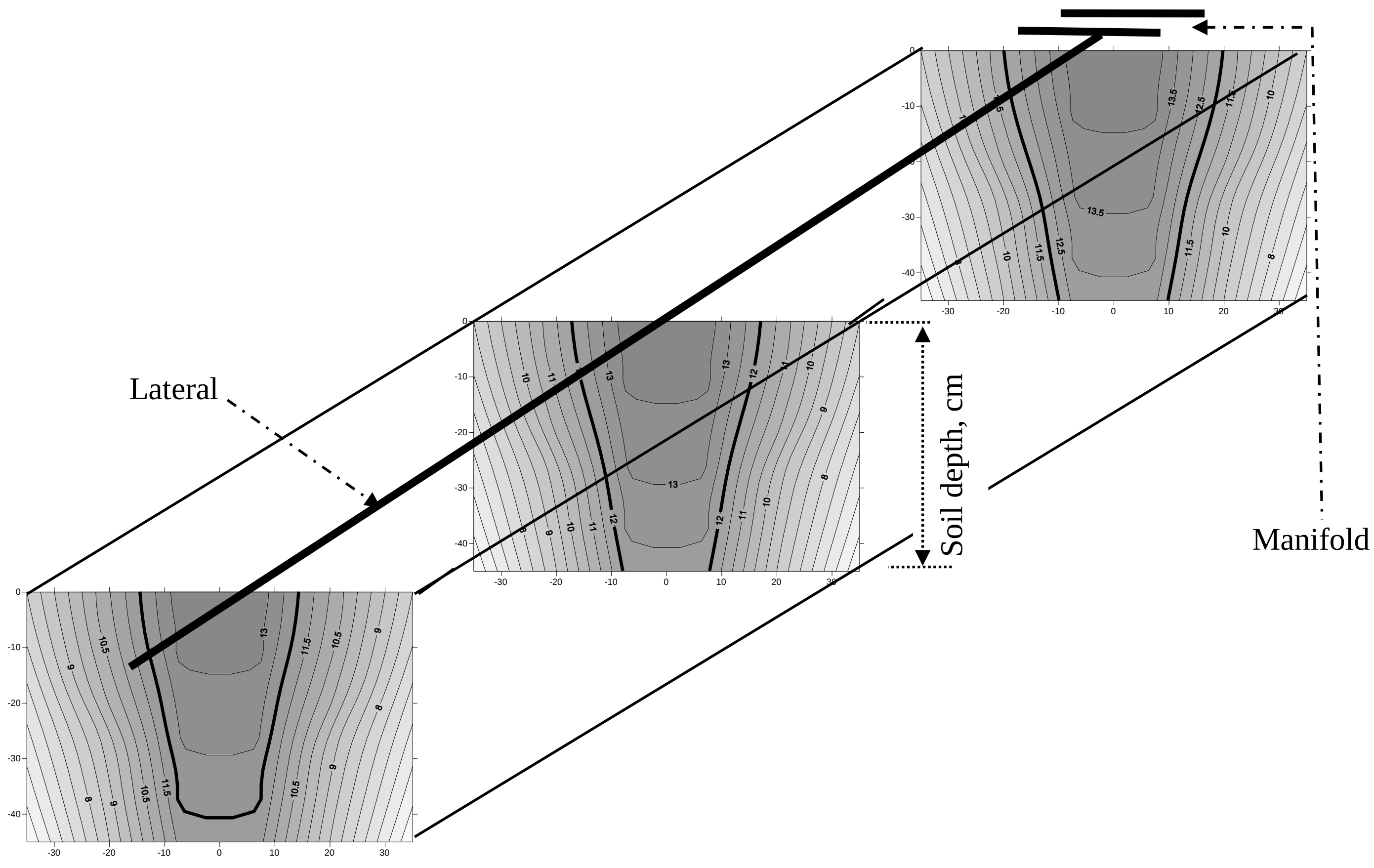


Fig. 5: Soil moisture **profile** along laterals in design (1). (Control)

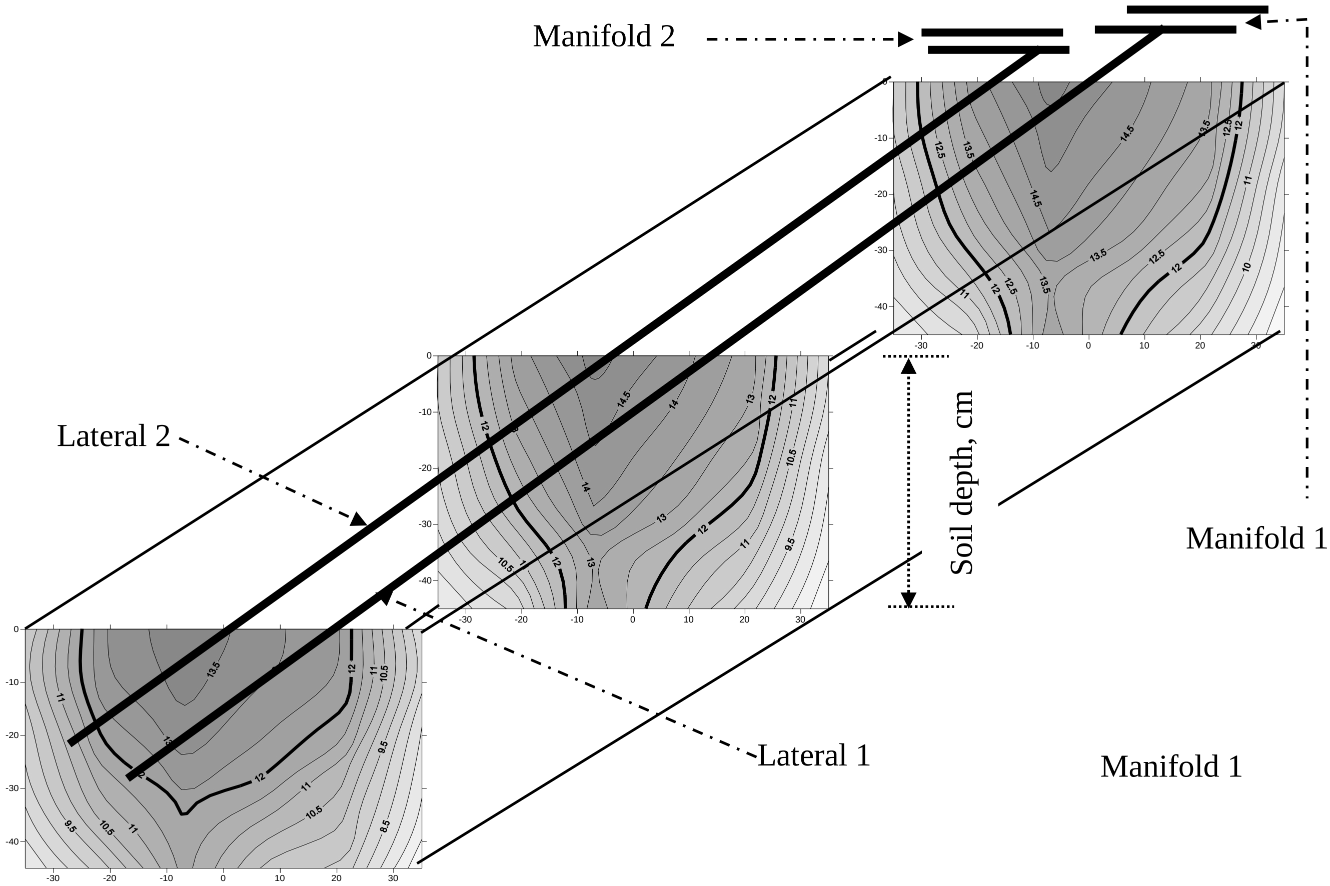


Fig. 6: Soil moisture profile along laterals in design (2) (PRD with same direction for mani-folds and laterals)

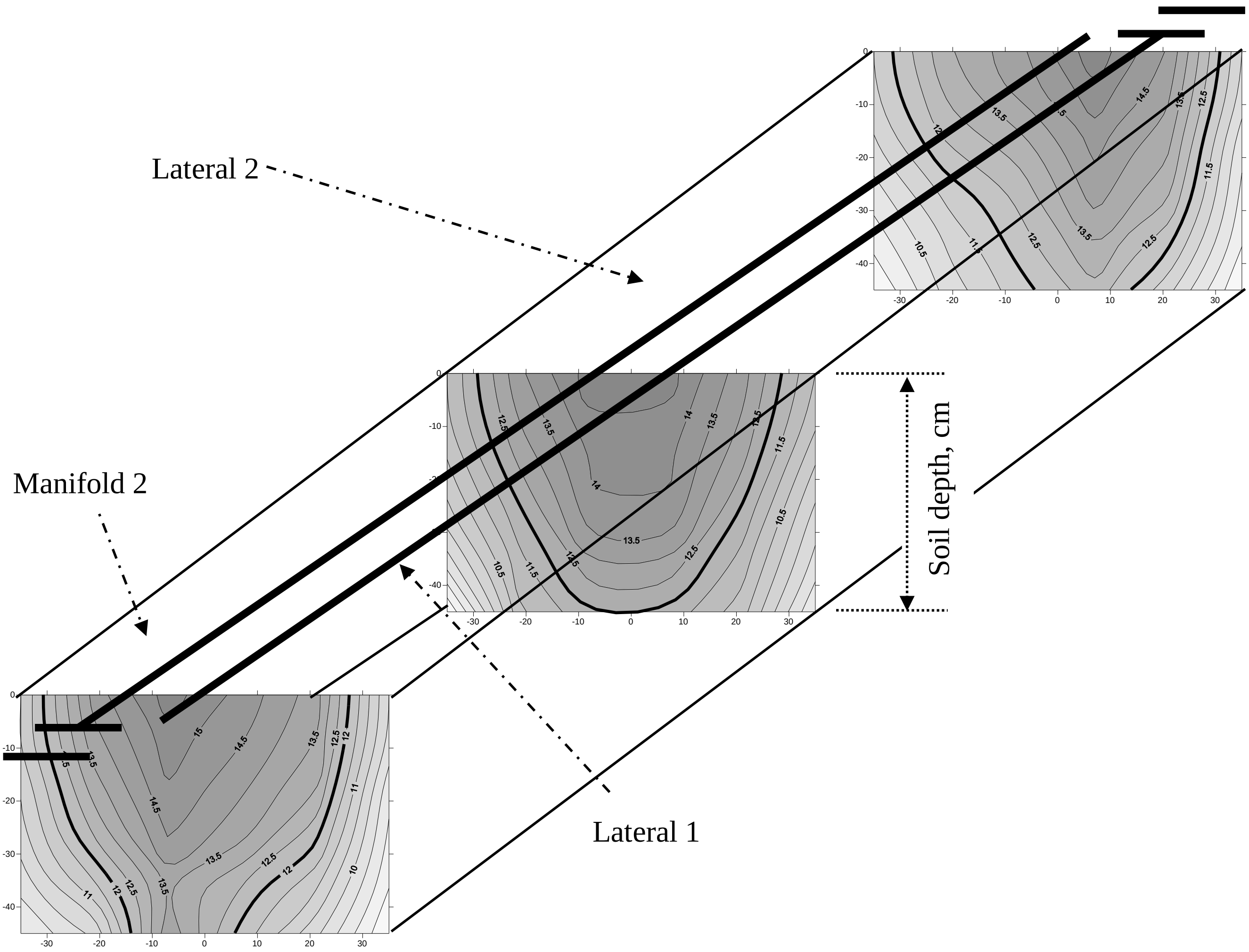


Fig. 7: Soil moisture profile along laterals in design (3) (PRD with same direction for mani-folds and laterals)

Application Efficiency

Application efficiency, (AE) = Volume of water in root area after 24 h / V of applied water. This means that the higher the value of $WSV_{\geq 100\%FC}$ in the root zone, the higher AE. Fig. (8). The highest application efficiency value occurred under modified design (3).This is caused by two reasons, 1- with increasing number of emission points most of irrigation water stored in effective root zone which increased $WSV_{\geq 100\%FC}$ root zone. 2- Equality in the applied water volume along laterals. The application efficiency was increased 91:95:99% through the three designs respectively Fig. (8).

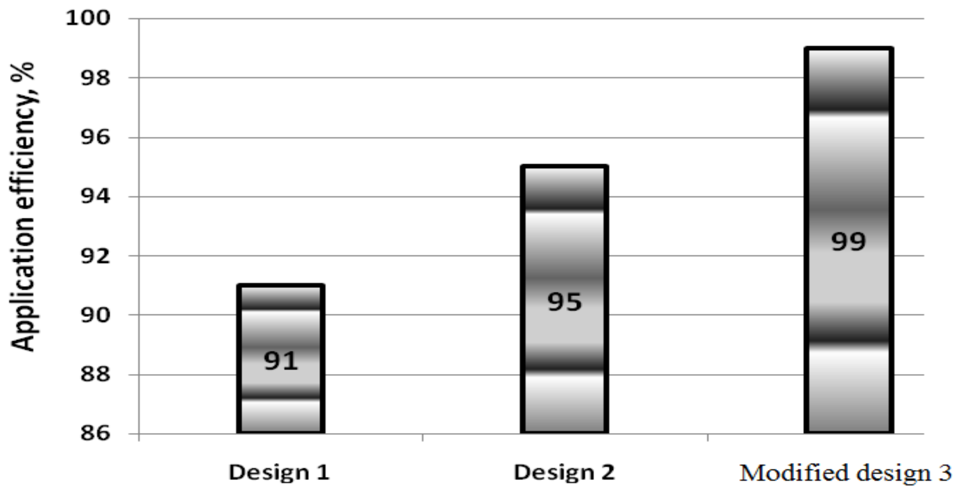


Fig. 8: Application efficiency for the designs under study

Water productivity

Water productivity (WP) was studied by dividing all yield/total applied irrigation water at the grow season of groundnut plant. The water productivity reached high amount with modified design (3) compared with the others Fig. (9). WP groundnut took the same trend productivity in design (1) and (2), the highest value of WP $_{groundnut}$ was at modified one.

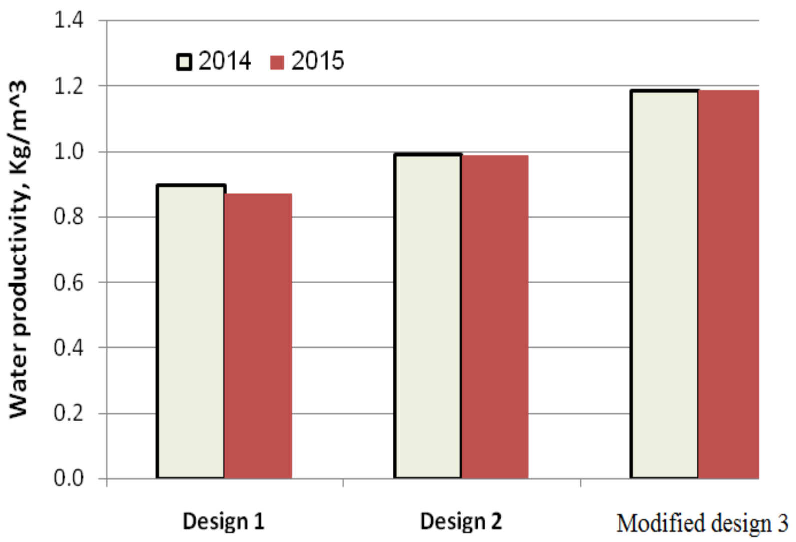


Fig. 9: Water productivity of groundnut for the designs in this study

Table 6: Effect of the designs under study on seed yield and water productivity of groundnut.

Designs	Seed yield (ton/fed.)		Water productivity of groundnut Kg $_{seed}$ / m^3 $_{water}$	
	2014	2015	2014	2015
Design (1)	1.90 c	1.83 c	0.90	0.87
Design (2)	2.10 b	2.07 b	0.99	0.99
Modified design (3)	2.51 a	2.49 a	1.18	1.19

Yield of groundnut

As positive effect from any development in irrigation systems increasd the productivity. Yield of groundnut was watched under three designs of drip irrigation systems. Fig. (10) and table (6) indicated that, seed yield of groundnut under the three designs. The yield of groundnut was affected by different designs. It increased from 1.9 : 2.1 : 2.51 t/fed. significantly throw the three designs, respectably Fig. (10) and Table (6). Highest value of yield was achieved with modified one (3) with significant deference's with compared with other designs and this probably due to equality the volume of irrigation water and fertilizers along drip lines hence, increasing the yield with the modified one compared with other planning's. These results were agreement with Abdelraouf, 2014 where test the modified design on the maize[12].

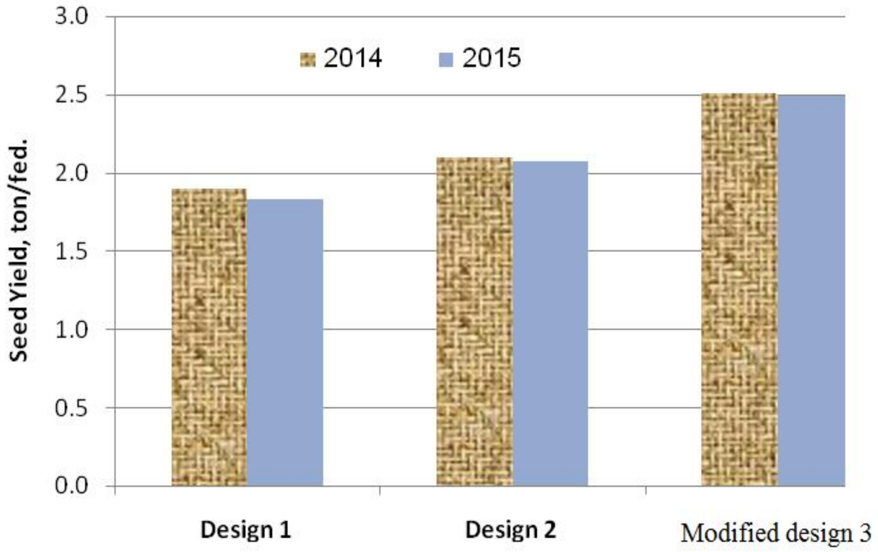


Fig. 10: Seed yield of groundnut for the designs under study

Conclusion

- The maximum values of water productivity and total income were detected under modified design (3) with PRD technique with opposite direction.
- In the future research, it will be more studies on the length lateral which more than 50 m especially with the modified design (3).

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