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IMPROVING CROP PRODUCTION AND WATER PRODUCTIVITY USING A NEW FIELD DRIP IRRIGATION DESIGN

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Abstract

Coping with the limited water resources in Egypt is a big challenge and there is a need to find new and innovative techniques for saving irrigation water. Although drip irrigation is the most efficient system for preserving irrigation water, the water distribution uniformity of the standard drippers requires great attention as it varies over drip line length. Two experiments were conducted during the growing seasons of 2015/2016 and 2016/2017, in the north of Egypt to assess the performance of a newly developed design of drip irrigation system compared with two conventional irrigation system designs. The aim is to save water and fertilizers in sandy soil, using potato crop as a sensitive crop to water stress. The tested drip irrigation systems were: Design1: traditional drip irrigation system (control), Design2: drip irrigation system with the same direction for manifolds lines and laterals and Design 3, the new design: drip irrigation system with opposite direction for manifolds lines and laterals. The following parameters were considered to assess the performance of the different irrigation system designs: (1) the average emitter discharge along laterals for the three designs, (2) water emission uniformity, (3) application efficiency of irrigation water (4) tuber yield of potato (5) water productivity of potato "WP potato" and (6) nitrogen productivity of potato "NP potato". The results of the study revealed that the maximum values of yield, WP potato and FP potato were obtained under the new design. This was due to the high uniformity in distribution of irrigation water and fertilizers along drip lines.

Key words: Innovative drip irrigation design, application efficiency, water productivity, potato crop.

Introduction

The limited water resources in Egypt led to a severe water scarcity, which is increasing as the population increases. Growing competition for the scarce water resources between different sectors means that innovative ways of saving water are extremely important. In agriculture, there is a need to modify irrigation techniques in order to maximize water use efficiency and improve crop yield and quality (Abdelraouf and El Habbasha, 2014, El-Metwally, et al., 2015 and Marwa, et al., 2017). Optimization of irrigation water consumption through the development of new technologies and approaches to use water in an effective way (Abdelraouf et al., 2013 a, b) is necessary. In addition to this, climate predictions indicate that the irrigation demand will increase in the coming years (www.cropwat.agrif.bg.ac.rs). In arid regions with large population growth and with limitation of fresh water, there is significant stress on the agricultural sector for reducing the water consumption and access to fresh water for the urban and industrial sectors (Abdelraouf and Abuarab 2012). A serious challenge faces the agricultural sector for producing more food with minimum water volume, which can be achieved by increasing water productivity of crops (Abdelraouf et al., 2013 c) and (Eid and Negm 2019). To meet the increasing demand for high population growth, increasing the crop production is an important national goal (Bakry et al., 2012). Water productivity is extremely important because limitation of water resources in addition, limited precipitation (Hozayn et al., 2013 and Habbasha et al., 2014). Application of micro-irrigation irrigation systems which are highly efficient is an important concept that should be implemented in Egypt for saving more irrigation water (El-Habbasha et al., 2014).

To sufficiently increase food production for the increasing population, more efforts have also to be made to develop agriculture in marginal soil and newly reclaimed, mainly sandy, soil and using water saving irrigation techniques (Girgis, 2006). Meanwhile, also the economic aspects of efficient use of water for food production have to be considered.

Drip irrigation is considered one of the most efficient ways to deliver water to the plant as only the root zone of the plant is wetted, which means losses of irrigation water are minimal (Grabow et al., 2004). However, there are some points in the drip irrigation design that could be further improved. For example, the discharge from standard drippers at the beginning of the line can be 25% higher than the discharge at the end of the line. This means a decrease in the efficiency of water distribution towards the end of the line, which, in case of fertigation, will also result in unequal / non-uniform distribution of fertilizers.

Although recently, a new design of drippers “pressure compensating” has been developed, the cost is higher than the standard drippers. Given, the cost of a standard drip system is already a burden to farmers with smallholdings in developing countries, the “pressure compensating” could be an additional cost beyond their affordability. Perhaps, there is a room to adjust the cheaper standard system to mimic the "pressure compensating" drip system at no or minimum extra costs to farmers in developing countries.

The aim of this study is to compare three drip irrigation designs: Design1, is the traditional drip irrigation system (control), Design2, has the same flow direction for manifolds lines and laterals, Design3, is a new design, with opposite direction for manifolds lines and laterals to maximize water and fertilizer use efficiency. The drip irrigation designs will be tested for potato crop on sandy soil under the arid conditions in Egypt.

Material and Method

Chemicals and fungal strains

Lemongrass essential oil (LGO) was obtained from the fresh herb of *Cymbopogon citratus* using steam distillation process. An industrial scale distillation unit located at the Horticultural Research Institute, Medicinal and Aromatic Plant Research Section, Kanater, Egypt, was used for that purpose. The sample of LGO was kept at - 4°C during storage till used within 1 week.

Description of study site and irrigation system: Field experiments were conducted during two potato cultivation seasons at the experimental farm of National Research Centre, El-Nubaria, Al Buhayrah governorate in northern Egypt (Fig.1). The farm has a latitude of 30o 30'1.4''\ N, longitude 30o9' 10.9'' E and with 21mmean altitude above sea level. The experimental area has a semi-arid climate with mild winters and hot dry summers. The data of maximum and minimum temperature, relative humidity, and wind speed were obtained from the local weather station at El-Nubaria Farm.

Irrigation system components: pumping system, control pressure head and filtration unit:

The irrigation system consisted of a centrifugal pump with 45 m3/h discharge rate, a screen filter and a backflow prevention device, a pressure regulator, pressure gauges, control valves and a flow meter. The main line, a polyvinyl chloride (PVC) pipe with 110mm outer diameter (OD), conveyed the water from the source to the main control points in the field. Sub-main lines, connected to the main line, were PVC pipes with 75mm OD. Manifold lines, polyethylene (PE) pipes of 63 mm OD, were connected to the sub-main line and control valves and discharge gauges. The emitters were built in lateral PE tubes,50 m long and 16 mm OD. Emitter discharge was 4 l/h at 1.0 bar operating pressure, spacing between the emitters was 30cm.

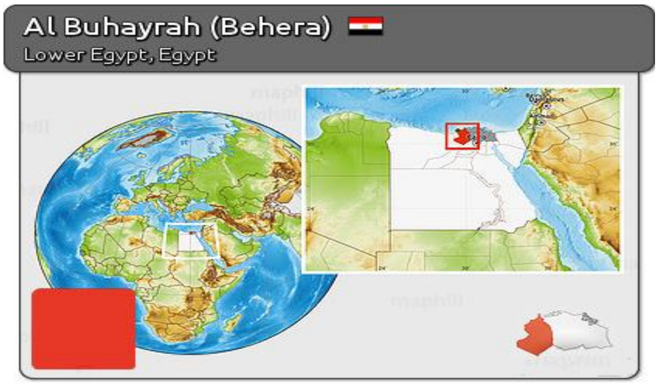

Figure 1: Location of study site in Al Buhayrah governorate in Egypt

Physical and chemical properties of soil and irrigation water: The soil texture is sandy (87.4% sand, 7.9% silt, and 4.7% clay), pH is 7.8, salinity expressed as electric conductivity, EC is1.68dS/m and organic matter content in the upper 30cm of the soils 0.44%. Available soil N, P, and K contents were 17.1, 4.4, and 26.0 mg/kg soil, respectively, and extractable-Fe, Mn and Zn were 2.98, 1.74, 0.66 mg/kg soil, respectively. The chemical characteristics of irrigation water are shown in table 1.

Table 1 : Chemical characteristics of the 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^{--}	
7.13	0.44	1.42	0.65	2.61	0.31	--	0.1	1.72	1.45	2.8

EC= Electrical Conductivity SAR= Sodium Adsorption Ratio

Table 2: Irrigation and fertilizing schedule of the three designs

Item	Design1	Design2	New Design
Seasonal irrigation water applied,m^3/ha	5714 for 2015/20165952 for 2016/2017	5714 for 2015/20165952 for 2016/2017	5714 for 2015/20165952 for 2016/2017
Irrigation frequency, day	1	1	1
Irrigation time, h	T	(T/2)+(T/2)	(T/2)+(T/2)
Seasonal nitrogen applied, kg/ha	216	108+108	108+108
Fertigation frequency during the fertilization period, day	1	1	1

T: Irrigation time at every irrigation, which varies throughout the crop growth season

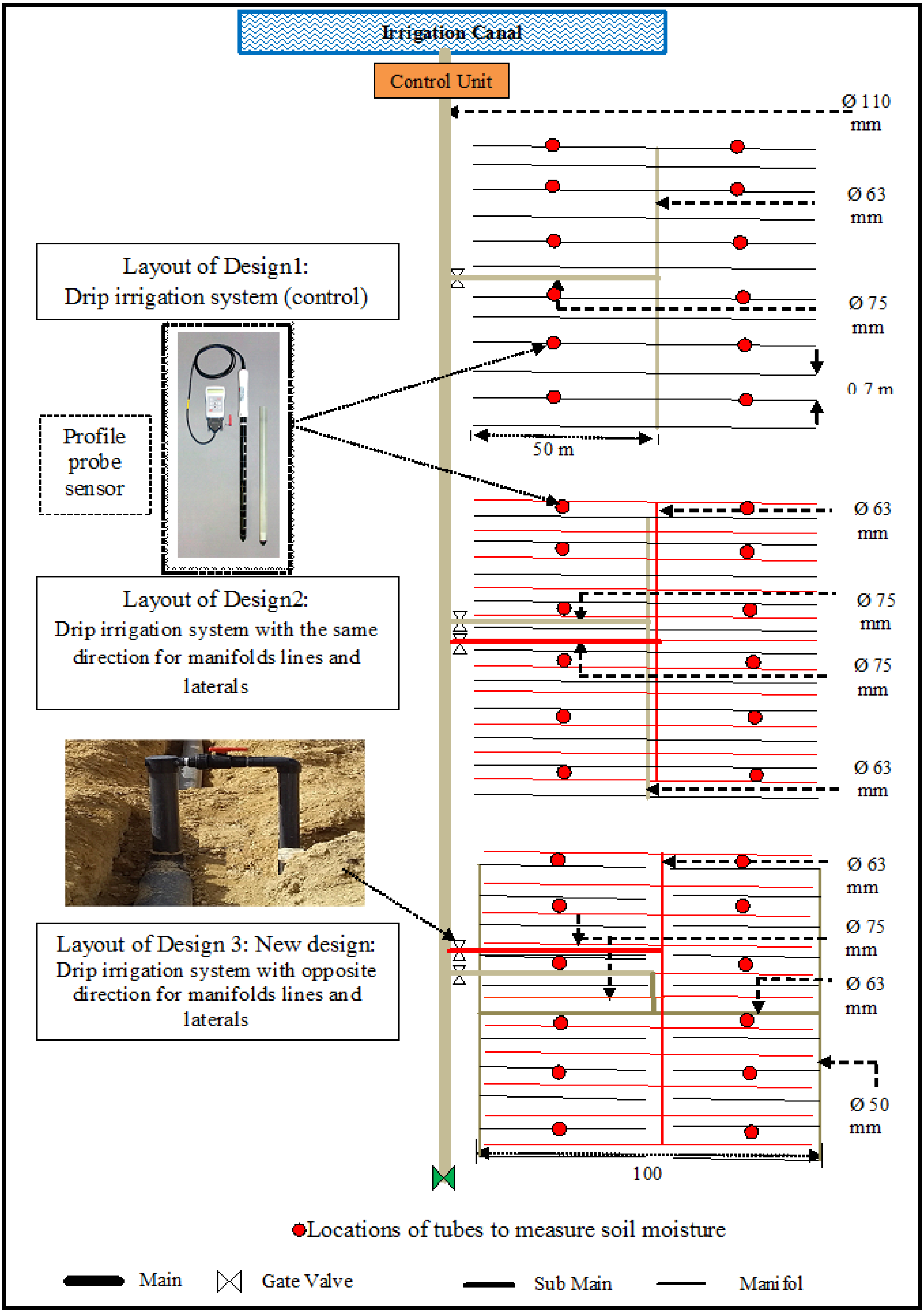

Figure 2: Layout of irrigation system designs.

Crop water requirements: Seasonal irrigation requirements for potato crop were calculated from 15/12/2015 to 15/4/2016 and from 15/12/2016 to 15/4/2017. The seasonal irrigation water applied, obtained from Equation 1, was 5714 m3/ha/season for 2015/2016 and 5952 m3/ha/season for 2016/2017.

IRg = [ETO x Kc x Kr] / Ei - R + LR ……….(1)

Where IRg = gross irrigation requirements, mm/day, ETO = reference evapotranspiration, mm/day (estimated from the Central Laboratory for Climate - Agricultural Research Center Egyptian Ministry of Agricultureat El-Nubaryia farm and according to Penman-Monteith equation), Kc = crop factor (Allen et al., 1998), Kr = ground cover reduction factor, Ei = irrigation efficiency, %, R = water received by the plant from sources other than irrigation, for example rainfall, mm, LR = amount of water required for the leaching of salts, mm.

Experimental Design: The following experimental drip irrigation designs were evaluated: Design1: the standard drip irrigation design (control), Design2: drip irrigation system with the same direction for manifolds lines and laterals and Design 3: the new drip irrigation design with opposite direction for manifold lines and laterals. The distance between laterals was 35cm, based on previous study (Abdelraouf et al..2013b). More details for all designs are shown in figure 2.

Irrigation and fertilizing scheduling of the three designs: The irrigation and fertilizing schedule for the three designs is given in table 2.

Emitter outflow: The pressure head discharge relationships for emitters were expressed by Equation 2 (Wu and Gitlin, 1977)

Q = Kd HX…………….. (2)

Where: Q = discharge rate of drippers (l h-1), Kd = discharge coefficient, H= pressure head, m and X= dripper flow exponent. The emitter discharge exponent (x) is a measure of the slope of the Q (y-axis) versus H (x-axis) curve. The lower the value of x, the less the flow will be affected by pressure variations. For fully compensating emitters x = 0, which means that the flow is not affected at all by pressure variations. Fully turbulent emitters, like the orifice, have an x value of 0.5 and vortex type emitters have an x of about 0.4. For tortuous-path emitters, x is between 0.5 and 0.7, while for long-path emitters x is between 0.7 and 0.8.In order to determine Kd and x, the values of q and Hwould have to be determined at two different pressures and discharges along a lateral line. The discharge exponent would then be calculated using Equation 3.

X= Log [q1/q2] / Log [H1/H2]…………….(3)

Kd is calculated by rearranging Equation 2 and introducing the value of x:

Kd = Q/Hx………………..(4)

Water emission uniformity: Water emission uniformity (EU) was estimated along laterals of the drip irrigation system in every plot area under pressure range of 1.0 bar by using 20 collection cans, using Equation5 (Marriam and Keller, 1978):

EU = (qm / qa) × 100 ……….(5)

Where EU is the water emission uniformity, %; qm is the average flow rate of the emitters in the lowest quartile, (l/h); and qa is the average flow rate of all tested emitters under test (l/h).

Application efficiency of irrigation water: Water application efficiency (AEIW) is the actual storage of water in the root zone to meet the crop water requirement relative to the water applied to the field. The AEIW was calculated using Equation 6:

AEIW = Ds/ Da……………….(6)

Where AEIW is the application efficiency of irrigation water,%, Ds is the depth of stored water

in the root zone, cm where:

Ds = (θ1 – θ2) * d * ρ…………………(7)

Da is the depth of applied water (mm), d is the soil layer depth (mm), θ1 is the average of soil moisture content in the root zone after irrigation (g/g), θ2 is the average of soil moisture content in the root zone before irrigation (g/g), ρ = bulk density of soil (g/cm3) as shown as in Figure 3.

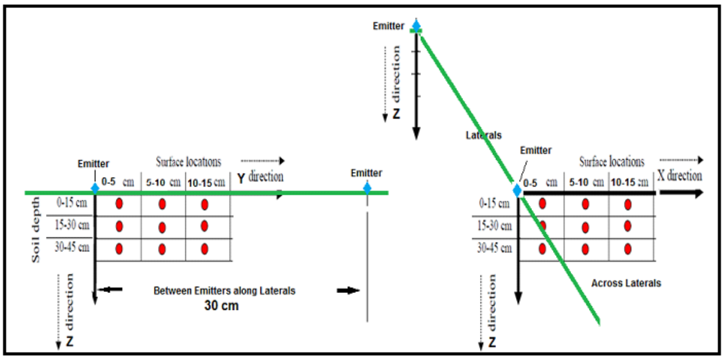

Figure 3: Estimating the application efficiency of irrigation water in the field

Potato yield: A random area of 100 x 100 cm was harvested from each plot. The tuber yield was expressed in kg/m2.

Water productivity of potato: "WP potato": The water productivity of potato was calculated according to James (1988) as follows:

WPpotato = Ey/Ir…………………..(8)

Where WPpotato is water productivity (kgpotato m-3water), Ey is the economical yield (kgpotato/ha); Ir is the amount of applied irrigation water (m3water/ha/season).

Nitrogen productivity of potato: "NP potato": Nitrogen productivity was calculated according to Barber (1976) by equation 9:

NPpotato (kgpotato/kg-N) = Ey/Nr ……………………(9)

Ey: Yield of potato (kgpotato/ha) and Nr = amount of nitrogen applied (kg-N/ha).

Economic evaluation: The economic evaluation will consider the costs of the excess raw materials for the irrigation network for design 2 and for the new design and compare them to the cost of the irrigation network with the traditional design. The productivity, in kg potato/hectare, between Design 2 and the new design will be compared with that of the traditional design. Equation 10 will then be used to calculate whether a difference in productivity in favor of the new design will cover the difference in the increased costs of the new design.

NIICP, (LE/ha) =TIICY,(LE/ha) -TCIPR, (LE/ha) ……. (10)

NIICP: Net income, LE/ha, TIICY: Total income, LE/ha and TCIPR: Total costs, LE: Egyptian Pound.

Statistical Analysis: Combined analysis of data for the two studied growing seasons was carried out according to Snedecor and Cochran (1982) and the values of least significant differences (L.S.D. at 5 % level) were calculated to compare the means of the different treatments.

Results and Discussion

Average of emitters discharge along laterals for the three designs

The variation in emitter's discharge along laterals was measured for the three designs. Maximum variation was under Design 1 and Design 2. The traditional drip irrigation system, Design 1, is known to show variation and dissimilarity in emitter discharge along the laterals, due to variation in pressure head loss along the laterals. Equally, the variation observed under Design 2 is caused by pressure head losses along the laterals from the beginning to the end of the lines. Minimum variation in emitter's discharge occurred under the new design. This may be due to the opposite direction of water movement within the laterals where the entry of water to the laterals is done in reverse to the other designs, by doing so, the reduction in the emitter discharge of one emitter along the laterals is balanced by an increase in the discharge along the other lateral. The greatest uniformity of water emission could be achieved with the new design compared with the other two designs. This could be because the two emission points in the laterals are created in opposite directions, so the pressure drop in one of them causes a rise in the other. The average emitter discharge along laterals with the new design was stable from the beginning to the end while in the Design 1 and Design 2 the average emitter discharge decreased as shown in figures 4, 5, 6 and table 3.

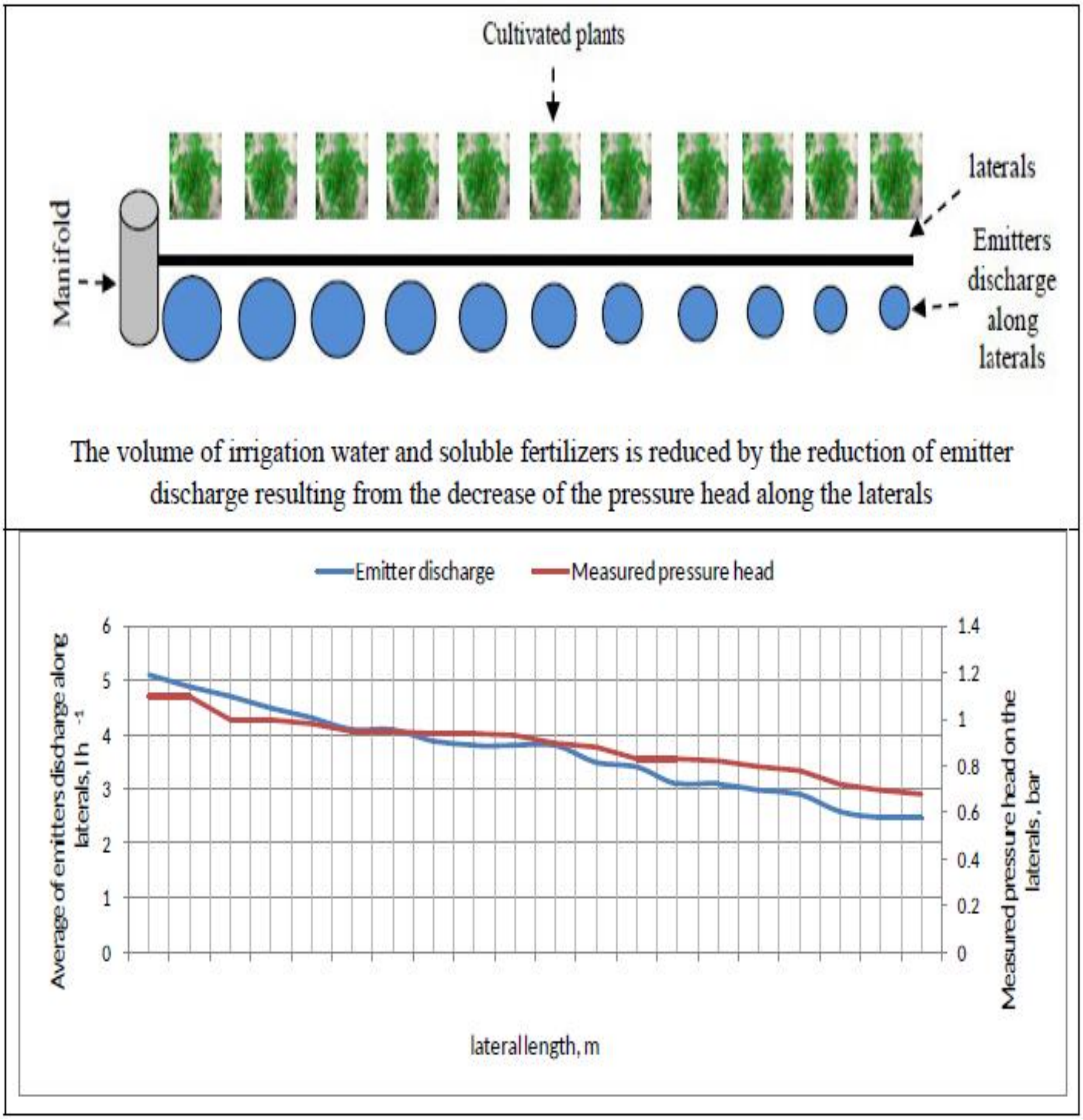

Figure 4: Particle size distribution of empty surfactant micelles (a), LGO microemulsion (b) and citral microemulsion (c)

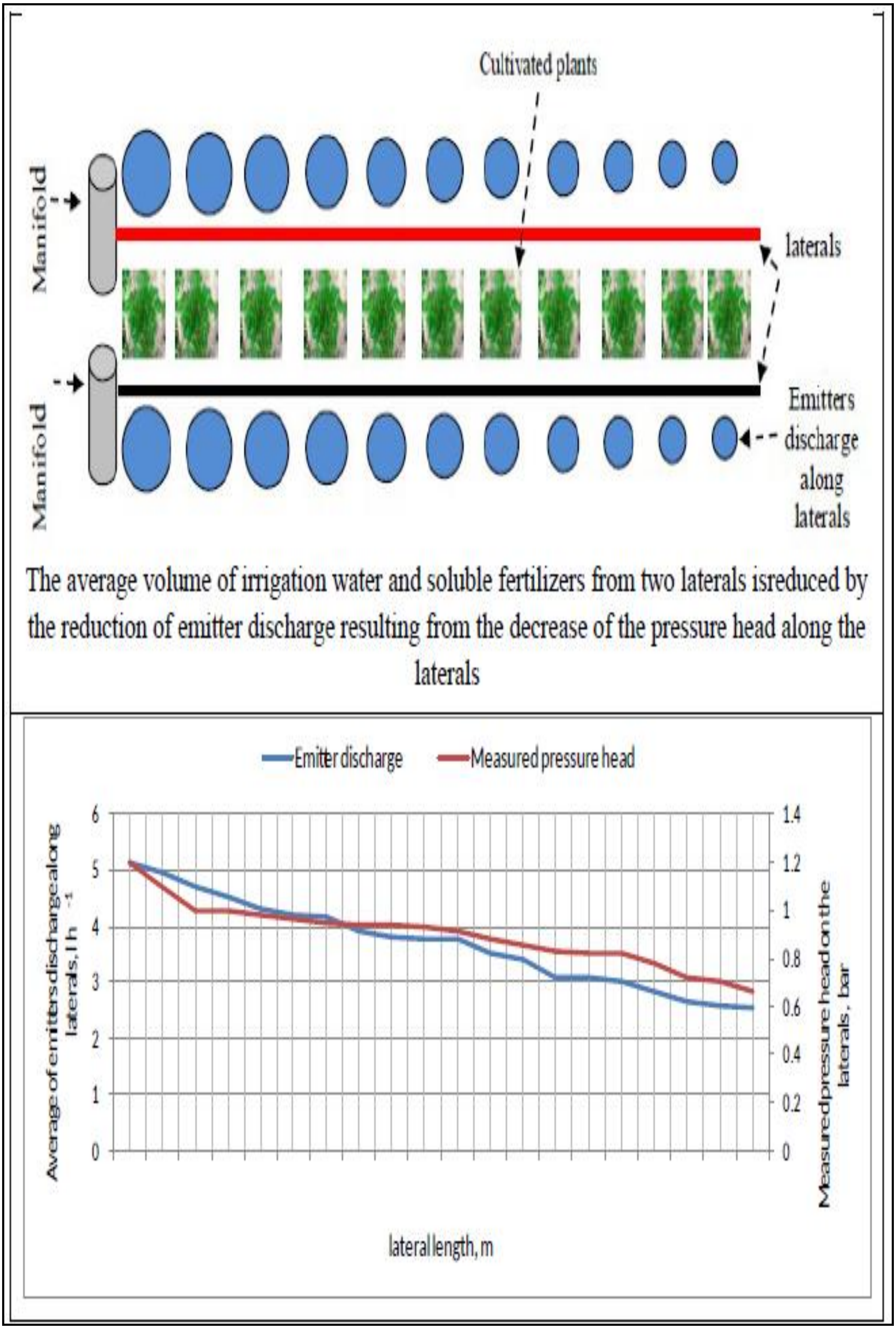

Figure 5: Decreasing average emitter discharge and pressure head along laterals for Design 2 (Drip irrigation system with the same direction for manifolds lines and laterals)

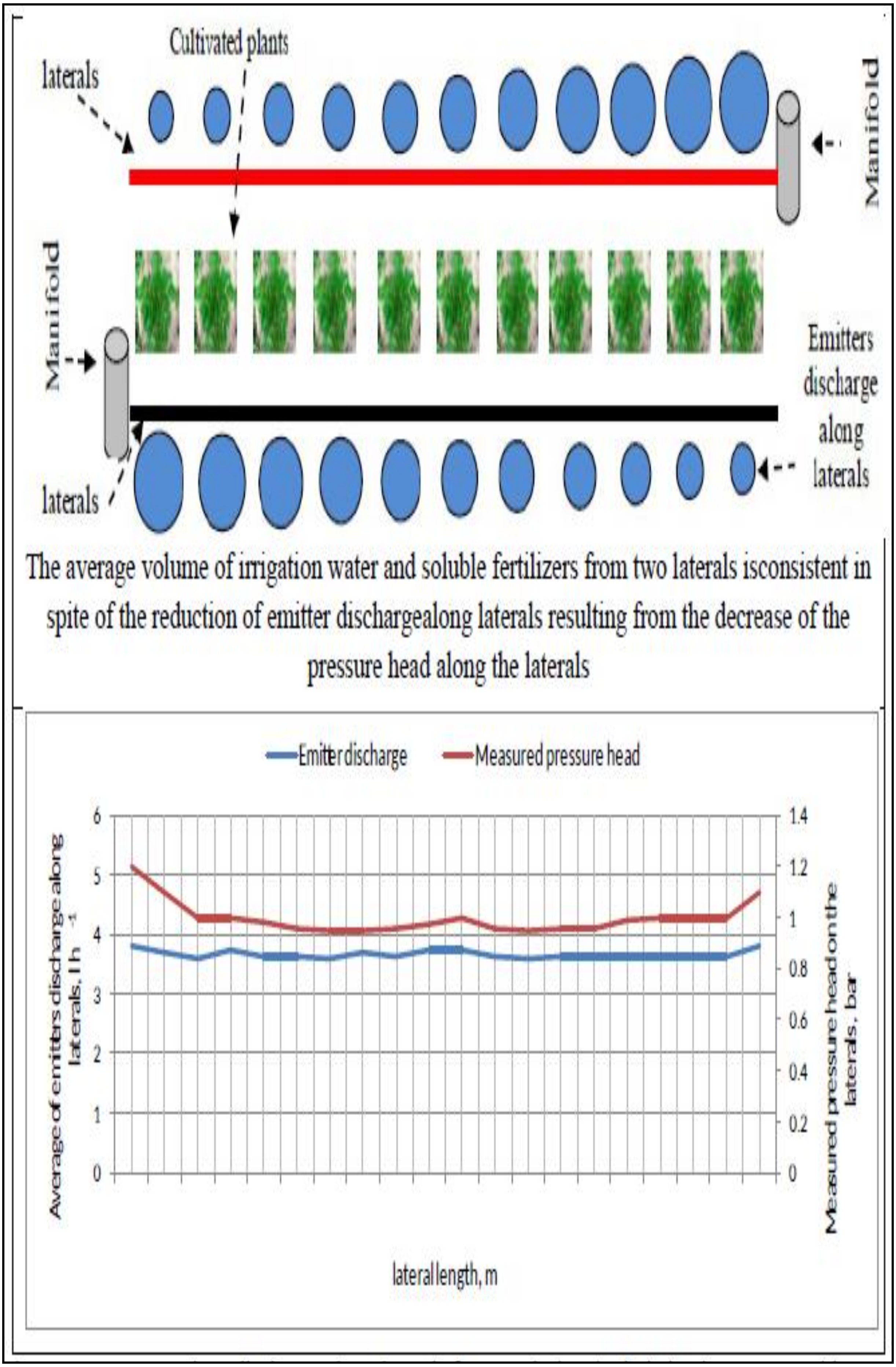

Figure 6: Average emitter discharge along laterals for new design (Drip irrigation system with opposite direction for manifolds lines and laterals)

Water emission uniformity

By using a standard drip irrigation system, one would expect high water emission uniformity throughout the whole system from the pump until the water emission points (dripper). The water emission uniformity of a drip irrigation system can be calculated by dividing qm/qa, %, where qm is the average flow rate of the emitters in the lowest quartile (greyed squares in table 3) and qa is the average flow rate of all emitters under test (Table 3). Water emission uniformity for the three designs is shown in Fig. 7. The highest value of water emission uniformity (EU) was achieved with new design in comparison with the other two designs. This is mainly due to fact that the two emission points built in the laterals are in opposite directions, so the decrease in one of them causes an increase in the other. This ensures an equal distribution in the straight laterals, which results in a high distribution symmetry and high EU in the new design. The results showed that water emission uniformity was increased from 73%, for Design 1, to 99.6% for the new design. Furthermore, the average of emitter discharge along laterals l/h with the new design was stable from the beginning till the end while in Designs 1 and2, the average of emitter discharge decreased with time.

Application Efficiency of irrigation water

The application efficiency of irrigation water, AEIW mean, is the depth of stored water in root zone after 24h to the depth of applied water. The highest value of AEIW occurred under the new design compared with the other two designs (Design 1 and Design 2), this is due to water uniformity distribution. The AEIW was increased from 92 to 98%, as shown in figure 8 and table 4.

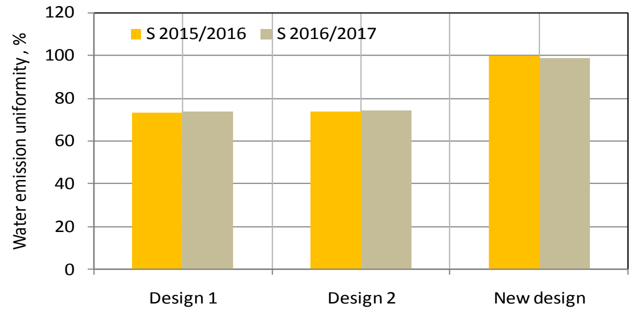

Figure7: Seasonal water emission uniformity for the three irrigation designs.

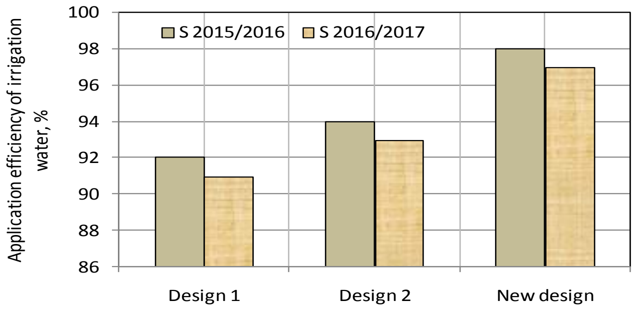

Figure8: Application efficiency of irrigation water for the three irrigation designs

Table 3 : Seasonal flow rate and water emission uniformity under the three designs.

Growing seasons	Can No.	Design 1	Design 2			New design		
		Dripline1	Dripline1	Dripline2	Aver.	Dripline1	Dripline2	Aver.
2015/2016	1	5.1	5.1	5.15	5.13	5	2.6	3.8
	2	4.9	4.9	5.00	4.95	4.9	2.5	3.7
	3	4.7	4.7	4.70	4.70	4.6	2.6	3.6
	4	4.5	4.5	4.55	4.53	4.6	2.9	3.75
	5	4.3	4.3	4.30	4.30	4.2	3.1	3.65
	6	4.1	4.1	4.30	4.20	4.2	3.1	3.65
	7	4.1	4.1	4.20	4.15	4.1	3.1	3.6
	8	3.9	3.9	3.90	3.90	4	3.4	3.7
	9	3.8	3.8	3.80	3.80	3.8	3.5	3.65
	10	3.8	3.8	3.70	3.75	3.8	3.7	3.75
	11	3.8	3.8	3.70	3.75	3.7	3.8	3.75
	12	3.5	3.5	3.50	3.50	3.5	3.8	3.65
	13	3.4	3.4	3.40	3.40	3.3	3.9	3.6
	14	3.1	3.1	3.10	3.10	3.15	4.1	3.625
	15	3.1	3.1	3.05	3.08	3.1	4.2	3.65
	16	3	3	3.00	3.00	3	4.3	3.65
	17	2.9	2.9	2.80	2.85	2.8	4.5	3.65
	18	2.6	2.6	2.70	2.65	2.7	4.6	3.65
	19	2.5	2.5	2.70	2.60	2.5	4.77	3.635
	20	2.5	2.5	2.60	2.55	2.5	5.1	3.8
	Aver. Qm	2.70			2.73			3.66
	Aver. Qa	3.68			3.69			3.67
	EU,%	73			74			99.6
2016/ 2017	Aver. Qm	2.62			2.70			3.61
	Aver. Qa	3.55			3.64			3.65
	EU,%	73.80			74.18			98.9

Aver. qm: the average flow rate of the emitters in the lowest quartile (greyed cells), Aver. qa: the average flow rate of all emitters under test, EU: Water Emission Uniformity, %.

Table 4: Application efficiency of irrigation water at peak of irrigation requirement for potato

Designs	Soil depth, cm	θ_1 %	θ_2 %	d, mm	ρ, g.mm^{-3}	$D_s = (\theta_1 - \theta_2)*d*\rho$ mm	$D_s = \sum D_{s1} + D_{s2} + D_{s3}$ Mm	D_a, mm	$AE_{IW} = [D_s/D_a]*100$	Seasons
Design1	0 -15	12.7	8	75	0.14	D_{s1} 4.94				2015/2016
	15 -30	11.5	7	75	0.15	D_{s2} 5.06				
	30 -45	10.6	6	75	0.16	D_{s3} 5.52	15.52	17	92	
Design 2	0 -15	14.5	9	75	0.14	D_{s1} 5.78				
	15 -30	13.2	9	75	0.15	D_{s2} 4.73				
	30 -45	12.5	8	75	0.16	D_{s3} 5.40	15.9	17	94	
New design	0 -15	14.5	10	75	0.14	D_{s1} 4.73				
	15 -30	14.1	9	75	0.15	D_{s2} 5.74				
	30 -45	13.2	8	75	0.16	D_{s3} 6.24	16.70	17	98	
Design1	0 -15	12.6	8	75	0.14	D_{s1} 4.83				2016/2017
	15 -30	12	7	75	0.15	D_{s2} 5.63				
	30 -45	11	6	75	0.16	D_{s3} 6.00	16.46	18	91	
Design 2	0 -15	13.7	8	75	0.14	D_{s1} 5.99				
	15 -30	13.1	8	75	0.15	D_{s2} 5.74				
	30 -45	11.2	7	75	0.16	D_{s3} 5.04	16.76	18	94	
New design	0 -15	14.1	9	75	0.14	D_{s1} 5.36				
	15 -30	13.2	8	75	0.15	D_{s2} 5.85				
	30 -45	12.2	7	75	0.16	D_{s3} 6.24	17.45	18	97	

AE_{IW} = Application efficiency of irrigation water, D_s =Depth of stored water in root zone, D_a =Depth of applied water, d =Soil layer depth, θ_1 =Average of soil moisture content after irrigation, θ_2 = Average of soil moisture content before irrigation, ρ = Relative bulk density of soil (dimensionless).D_{s1}=Depth of stored water in root zone from 0 – 15 cm ,D_{s2}= Depth of stored water in root zone from 15 – 30 cm, D_{s3}=Depth of stored water in root zone from 30 –45cm

Yield of potato

The new developed irrigation systems had a positive effect and increased the productivity of potato plants. Data in figure9 and Table 5 show that the yield of potato was markedly affected by the drip irrigation design. Potato yield was 24.24, 27.12 and 37.44 ton ha-1 under Design 1, Design 2 and the new design, respectively, for season 2015/2016 and 24.00, 24.96 and 34.42 ton ha-1 under Design 1, Design 2 and the new design, respectively, for season 2016/2017. The new design achieved an increase of 54 and 44 % compared to the traditional design for seasons 2014/2015 and 2015/2016, respectively.

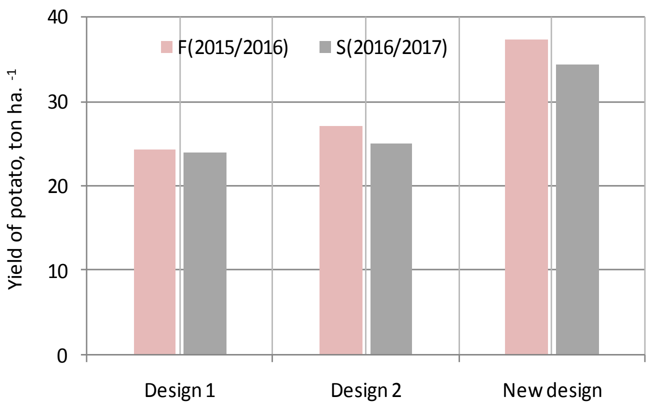

Figure 9: Yield of potato for the three designs during first season (2015/2016) and second season (2016/2017)

Water productivity of potato

Water productivity is an indicator of how much yield was obtained from a unit of water used (Abdelraouf, et al., 2012).Water productivity (WP) was studied by dividing the total achieved yield by the total applied irrigation water over the growing season. As shown in figure 10 and table 4, the water productivity reached a higher value with the new design, compared with the other irrigation designs.

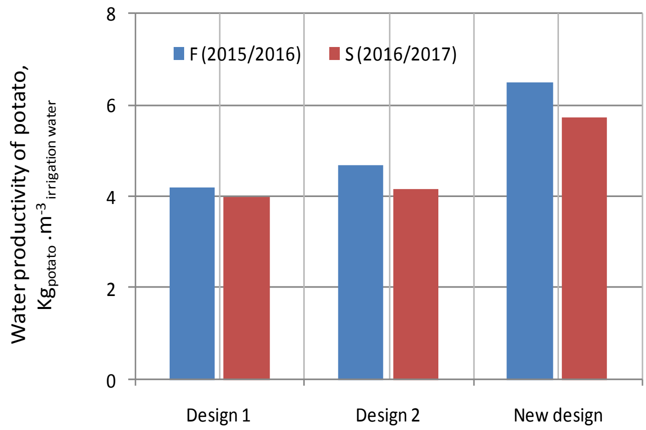

Figure10: Water productivity of potato for the designs during first season (2015/2016) and second season (2016/2017)

The potato yield achieved with the new irrigation design was significantly higher than the yield obtained with the other designs; this could possibly be attributed to the better distribution of irrigation water and fertilizers along drip lines in the new irrigation design compared with the other designs. These results are in agreement with those of Ghoname et al. (2012) and Abdelraouf and El Habbasha (2014).

Table 5. Effect of the irrigation design on potato yield and water productivity of potato.

Designs	Yield of potato (ton/ha)		Water productivity of potato kg $_{potato}$ / m^3$_{water}$	
	2015/2016	2016/2017	2015/2016	2016/2017
Design 1	24.24 c	24.00 c	4.21	4.00
Design 2	27.12 b	24.96 b	4.71	4.16
New design	37.44 a	34.42 a	6.50	5.74

a,b and c Indicate that there are significant differences between the means

Nitrogen productivity of potato "NPpotato" (kgpotato/kg-N)

Fertilizer use efficiency "FUE" is an indicator of the efficient use of fertilizer in crop production. Nitrogen productivity of potato "NP_{potato}" was calculated by dividing the total yield by the total amount of nitrogen fertilizer. The yield of potato was determined and the total amount of added N- fertilizer was 216 kg ha^{-1}, hence values of NP_{potato} for each irrigation design were calculated as shown in table 5.The data shown in table 6 and figure 11 reveal that the maximum values of NP_{potato} were 173.33 and 159.33 kg $_{potato}$/kg$_{-N}$ for 2015/2016 and 2016/2017, respectively,were obtained under the new design; while, the minimum values 112.22 and 111.11 kg $_{potato}$/kg$_{-N}$ for 2015/2016 and 2016/2017, respectively, were obtained under Design 1. Such results could be due to the positive effect of new design in increasing the volume of wetted soil in the root zone and the homogenous distribution for water and nitrogen fertilizer in the rhizosphere of potato plants hence enhancing fertilizer uptake by the roots.

Economic evaluation

The economic part was only to assess the cost/benefit of the irrigation designs. This takes into account the costs of the excess raw materials for the irrigation network with design2 and the new design and compares it to the irrigation network with the traditional design. The analysis considered two potato harvests per year. The results showed more net return with the new design from the first year in comparison with design2.Thenet income due to the increased crop yield/productivity after one year for the new design was 24000 L.E. (2015/2016) and 52100 L.E. (2016/2017)while it was -10620 L.E.(2015/2016) and 4800 L.E. (2016/2017) for design2.

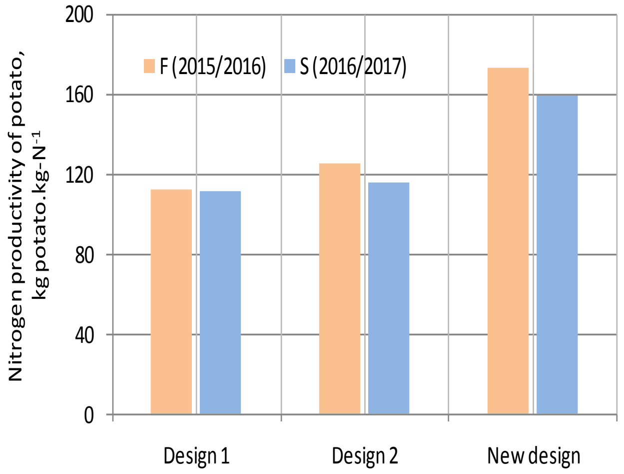

Figure 11: Nitrogen productivity of potato for the three irrigation designs during first season (2015/2016) and second season (2016/2017)

In spite of the slight increase in costs of the new system, it achieved a larger net profit and showed a significant difference during the first year and after planting potatoes twice a year. Table (7) indicates the best economic design was the new design.

Table 6 : Effect of the designs on nitrogen productivity of potato.

Designs	Applied nitrogen (kg $_{-N}$/ha)	Yield of potato (kg$_{potato}$/ha)		Nitrogen productivity of potato(kg$_{potato}$/kg$_{-N}$)	
		2015/2016	2016/2017	2015/2016	2016/2017
Design 1 (control)	216	24240	24000	112.22	111.11
Design 2	216	27120	24960	125.56	115.56
New design	216	37440	34420	173.33	159.33

Table 7: Economic evaluation of the new design and the traditional design (design 1).

Items	Quantity		Unit price, L.E.	Design 2		New Design	
	Design2	New Design		2015/2016	2016/2017	2015/2016	2016/2017
PVC pipe 75Ø, m	100	100	30	3000	0	3000	0
PVC pipe 63Ø, m	100	200	25	2500	0	5000	0
PVC pipe 50Ø, m	0	200	20	0	0	4000	0
Laterals, m	14200	14200	1	14200	0	14200	0
Valves	2 (75mm)	2 (75mm)	50	100	0	100	0
T	4(110/75 mm) 4(75/63 mm)	2(110/75 mm) 2(75/63 mm) 2(63/50 mm)	40 30 20	160 120	0 0	80 60 40	0 0 0
End of a line	4(63mm)	8(50mm)	15	60	0	120	0
Installation				2000	0	2200	0

Continue Table 7				
Total irrigation network raw material costs in excess of design 1	22140	0	28800	0
Potato overproduction under design 1, kg	2880	960	13200	10420
Price per kilo of potatoes at the farmer, L.E.	2	2.5	2	2.5
Total price of potato overproduction under design 1	5760	2400	26400	26050
Total revenue in excess of design 1 (The first period of the year), L.E./ha (Calculated and measured)	-16380	2400	-2400	26050
Total revenue in excess of design 1 (The second period of the year), L.E./ha (Predicted)	5760	2400	26400	26050
Total revenue in excess of design 1 per year), L.E./ha	-10620	4800	24000	52100

Conclusion

The large variation of emitter's discharge observed under Design1 and Design 2 could be attributed to the higher pressure head loss along laterals from the beginning to the end of laterals. Minimum variation occurred under the new design. This may be due to the opposite direction of water movement within the laterals where the entry of water to the laterals is carried out in reverse to the other designs, by doing so, the reduction in the emitter's discharge of one along the laterals is balanced by an increase in the discharge of another one along the other lateral. The greatest uniformity of water emission was achieved with the new design compared with the other two designs. This could be because the two emission points in the laterals are created in opposite directions, so the pressure drop in one of them causes a rise in the other. The average emitter's discharge along laterals with the new design was stable from the beginning to the end in comparison to Design1 and Design2.

Yield of potato was affected by the irrigation system design. In comparison to the traditional design, the new design achieved a yield increase of 54 and 44 % for season 2015/2016 and 2016/2017, respectively. Potato yield was significantly higher with the new design compared with the other two designs and this probably could be due to the better distribution of irrigation water and fertilizer along drip lines.

The water productivity WPpotato was higher with the new design compared with the others irrigation designs. Nitrogen productivity of potato, NPpotato, was higher with the new design. This result might be due to the positive effect of the new design on increasing the volume of wetted soil in the root zone, hence increasing water and nutrient availability to the crop.

In spite of the slight increase of the costs with the new system, it achieved a large net profit compared with the other designs.

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