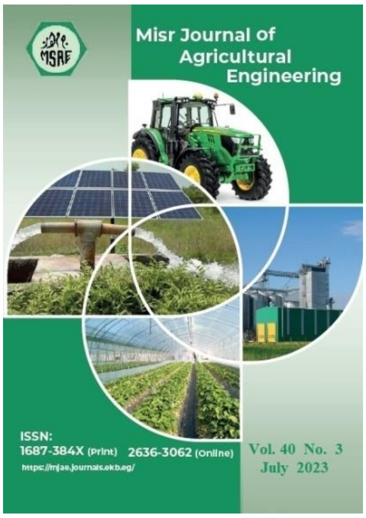
MISR JOURNAL OF AGRICULTURAL ENGINEERING
https://mjae.journals.ekb.eg/
ISSN-Print: 1687-384X
ISSN-Online: 2636-3062

Misr J. Ag. Eng., 40 (3): 161 – 172
DOI: 10.21608/mjae.2023.209600.1097

ASSESSMENT OF LOW HEAD IRRIGATION SYSTEMS AND SOIL MULCHING TO SAVE WATER FOR MAIZE CULTIVATION

Rashad, M. A.[1]; Zedan, A. M. I.[2&*]; Salman, M. S.[3] and Khedr, A. F. [4]

[1] Prof. of Irrig. and Drain. Eng., Ag. Eng. Dept., Fac. of Ag., Suez Canal U., Egypt.
[2] Prof. of Irrig. and Drain. Eng., Ag. Eng. Dept., Fac. of Ag., Zagazig U., Egypt.
[3] Researcher at the Plant Protection Institute, Agricultural Research Center (A.R.C.), Cairo, Egypt.
[4] Assoc. Prof. of Irrig. and Drain. Eng., Ag. Eng. Dept., Fac. of Ag., Suez Canal U., Egypt.
* E-mail: Mto252000@yahoo.com



Keywords:

Drip; Bubbler; Furrow; Maize; Soil covers.

ABSTRACT

Irrigation techniques are critical in reducing water consumption while maintaining or improving yield. A simple low-head bubbler with a high-water application uniformity (CU) of greater than or equal to 85 % was developed as an alternative to traditional furrow irrigation for producing intensive crops. For the evaluation of four bubbler designs with drip and furrow irrigation systems for maize production, a 20m lateral length was employed. The bubblers had two inside diameters (ID) of 8.8 and 13.6mm, each at a distance of 2 and 4m. The field application efficiency (Ea) of the different irrigation systems was estimated. For drip irrigation, it was (92.3%), while for furrow irrigation, it was only (63%). The two bubbler sizes, 8.8mm and 13.6mm, had better application efficiency at a short interval distance of 2m (80 and 82%), respectively. Then, compare the effects of different plastic mulch (M) and plastic mulch plus straw (M+S) soil covers to uncovered (Un) soil in terms of maize crop yield and water use efficiency (WUE). with (M), the WUE of grain and straw were for instance, under drip, bubbler 13.6mm at 2, bubbler 8.8mm at 2m, bubbler 13.6mm at 4m, furrow, and bubbler 8.8mm at 4m, in descending order, (0.92 and 0.98), (0.89 and 0.93), (0.79 and 0.91), (0.77 and 0.89), (0.72 and 0.87), and (0.70 and 0.85kg/m3, respectively. With the evaluated irrigation systems, the WUE values for (Un) and covered by (M+S) exhibit the same pattern as covered by M.

1. INTRODUCTION

Due to worldwide population growth and insufficient freshwater resources, several countries have reached the water poverty zone. The agricultural sector consumes about 70% of the world's freshwater, with Egypt's consumption reaching 85% (UNESCO 2001 and FAO, 2021), thus scientists have been pushed to develop effective methods for optimizing irrigation water use. Irrigated agriculture will have to produce two-thirds of the increase in food yields necessary by a growing population in the near future (Eduardo et al., 2009 and English et al., 2002).

The irrigation system's goal is to maximize agricultural production. In modern irrigation, irrigation method design is critical to improving irrigation application, efficiency, cost, and yield. Since modern irrigation systems, such as sprinklers and microirrigation, are expensive to install, operate, and maintain. Surface irrigation is the most inefficient of all irrigation methods, wasting up to 50% of the water used by 95% of the world's farmers. Local farmers employ traditional furrow irrigation as an improved surface irrigation system to cultivate intensive crops. It is an old irrigation system that is still in use today, especially in developing countries. However, surface irrigation is not suggested in sandy soils with high infiltration since it can result in unregulated water distribution .It also has a lot of water losses; thus, it can only be used in places where there is an unlimited supply of water (Merriam & Keller, 1978 and Cseko & Hayde, 2004).

Water application efficiency (Ea) is an indicator of how well an irrigation system can store water in the root zone of a crop. The parameter (Ea) is crucial for system selection, design, and irrigation operation (Solomon, 1983). Increased water efficiency from roughly 40% with traditional irrigation systems to over 85% with modern irrigation systems can result in higher yields and, as a result, more efficient water use. Microirrigation is a high-efficiency method of water and fertilizer delivery to crops. Microirrigation is the slow application of water at discrete places under operating pressure (Ngigi, 2008) .

Ibragimov et al. (2007) compared drip and furrow irrigation methods, finding that drip technologies conserved 18-42% of irrigation water and improved water usage efficiency by 35-103%. The necessity for better drip irrigation systems, according to Ainechee et al., (2009), is information regarding the moisture distribution pattern, shape, and amount of soil wetted by emitter. The wetting volume is influenced by several parameters, such emitter discharge rate, irrigation duration, water application, emitter spacing, and soil texture .

Maize (Zea mays) is an important part of human and animal nutrition, making it one of the world's most significant cereal crops. Maize is particularly sensitive to water scarcity due to its greater water requirement (Norwood, 2000). Irrigation systems have traditionally been significant in increasing agricultural yield by increasing irrigation water efficiency (Khan et al., 2015). Planting maize in the overlap of wetting pattern zones could be done with drip irrigation systems (Shan et al., 2011). With increasing watering frequency and rate under a drip irrigation system, maize yield production and water usage efficiency (WUE) increased (El-Hendawy and Schmidhalter, 2010) .

Soil moisture and evaporation have a significant impact on crop yield. Covering the soil surface is one way to reduce evaporation, conserve water, and enhance yield. (Khedr, 2018) investigated the impact of polyethylene sheets, rice straw, and maize straw soil covers on soil surface temperature and WUE with a drip irrigation system. With 8Mg ha^{-1} rice straw cover, the lowest soil surface temperature and maximum WUE of 1.54kg m^{-3} were recorded.

As an alternative to traditional furrow irrigation for cultivating intensive crops, Rashad et al. (2021) developed software to design a simple low head bubbler with a high-water application uniformity (CU) of greater than or equal to 85%. The goal of this research was to compare several of these low-head bubbler designs for maize cultivation against furrow and drip irrigation systems. Then investigate how different soil covers (plastic mulch and plastic mulch plus straw) influenced maize crop yield, water use efficiency (WUE), and soil moisture distribution.

2. MATERIALS AND METHODS

The study investigated how different water conservation practices interacted with different irrigation methods to produce a maize as an intensive crop. To evaluate the irrigation systems' efficiency and reliability, field experiments were conducted at the Agriculture Faculty's Research Farm in Ismailia, Egypt. The farm is located at an elevation of 13m above sea level and has a latitude of 30.58° north and a longitude of 32.23° east.

Irrigation Systems:

In this study, drip and furrow irrigation systems were compared to different low-head bubbler irrigation designs developed by Rashad et al. 2021, which had high water application uniformity for producing intensive crops.

Experimental Layout:

The experiment compares the effects of four low-head bubbler irrigation systems, a drip irrigation system, and a furrow irrigation system, which are all used in combination with soil covers, on water conservation and maize yield (Figure 1).Figure 2 shows a schematic diagram of the irrigation systems that were examined using the same area and 20-meter-long lateral pipes (or furrows).

Each low-head bubbler system is made up of a network of underground pipes, including a submain pipe with an ID of 61.8mm that transports water from the source to four lateral line pipes with an ID of 48.8mm. A soil furrow was created above each lateral pipe that was 0.5m high, 0.8m wide and spaced 0.7m apart. On top of the surface of the furrow, two 1.0m long bubbler tubes were installed. In the middle of the upper furrow, a riser tube with an ID of 13.6mm connected the tube openings with the lateral pipe below, each bubble tube's water discharge exits to one side of the furrow bottoms. As a result, each lateral pipe irrigates the bottoms of two soil furrows. To examine the effect of bubbler spacing and diameter on water application efficiency (Ea). There were four systems consisting of two bubblers with IDs of 8.8 or 13.6mm that were tested at two intervals of 2 and 4m. The four systems were evaluated at an effective pressure of 10.0kPa.

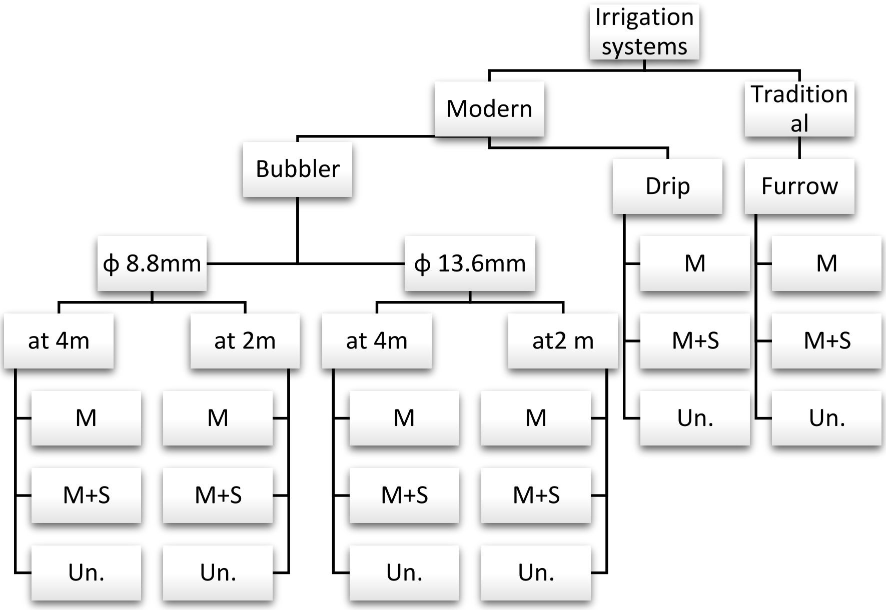


Figure (1): A flowchart shows the experiment design for irrigation systems and soil covering with mulch (M), mulch plus straw (M+S), and uncovered soil (Un.).

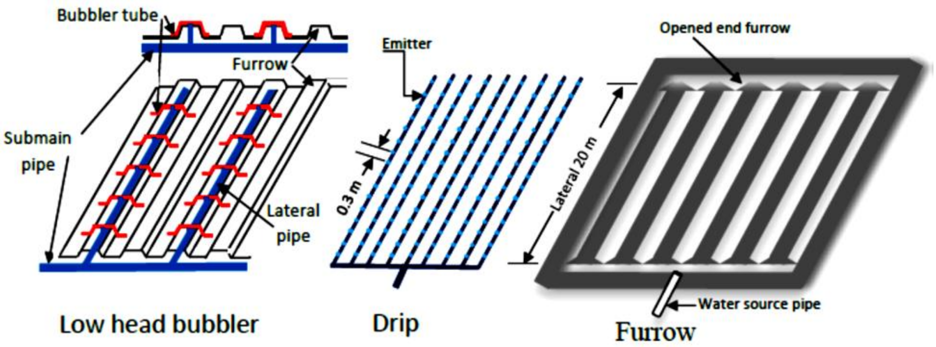


Figure (2): A schematic diagram of evaluated irrigation systems in the experiment.

A drip irrigation system was constructed using 13.6mm ID lateral pipes spaced 1.0m apart on flat terrain, together with local turbulent flow emitters mounted to the pipes at 0.3m-space. The system was evaluated at a low working pressure of 50kPa.

For this experiment, a constructed-furrow irrigation system was developed on 0.5% of the ground's surface. First, water delivery losses were decreased, and the system's operation was made simpler by transferring water through pipes from the source to the furrows and controlling it with valves. The next step is to create a channel around the furrows by digging the ends that don't contact the surrounding soil and an upper furrow level that is at ground level. As a result, it reduces surface runoff, increases soil water distribution efficiency, and conserves water as shown in Figure (2).

Water application efficiency:

The ratio of water received at the field inlet to that which is directly available to the crop is known as field application efficiency (Ea), and it indicates how effectively water is applied in the field. *Ea* is calculated using the following formula:

$$E_a = \frac{Depth\ of\ water\ stored\ in\ the\ rootzone\ (d_s)}{Depth\ of\ applied\ water\ (d_p)} \times 100 \qquad (1)$$

where:

E_a = Average water application efficiency, %

d_s = Depth of water stored in the rootzone, mm

d_p = Depth of applied water, mm

The irrigation technique and the degree of farmer discipline have the most impacts on field application efficiency (Ea). Table 1 provides some predictions of the average field application efficiency (Ea), but it should be noted that a lack of discipline could result in lower values (Brouwer et al., 1989).

Table (1): Indicative values of the field application efficiency (Ea)

Irrigation methods	Field application efficiency
Surface irrigation (border, furrow, basin)	60%
Sprinkler irrigation	75%
Drip irrigation	90%

The water application efficiency of each studied irrigation method was evaluated under similar weather, crop, soil, and water quantity conditions.

The Cultivated Crop:

The yield of maize *(Zea mays L.)* From the 15th of May until the 15th of September in the summer of 2020, a yellow variety of Three-Way Cross 352 *(T.W.C. 352)* was planted. The plant's grains were sown on the furrow sides at a rate of two per pot, 3-5cm deep, and 30cm apart.. The Egyptian Agriculture Ministry's cultivation and fertilization guidelines were followed. Biological resistance to pests was established and no chemical pesticides were used.

Irrigation water Requirements:

The full irrigation water requirements of the maize crop have been added. CROPWAT (8) was used to determine the maize crops' daily and full-season irrigation water requirements based on soil and climate using the Penman-Monteith equation. The crop evapotranspiration (ET_c, mm/day) was used to calculate maize irrigation requirements during the growing season. The irrigation frequency (F) in days is determined by the rate of water consumption by the plants and the irrigation depth applied by each cycle, as follows:

$$ET_c = ET_o . k_c \qquad (2)$$

$$F = \frac{d_n}{ET_c} \qquad (3)$$

where, ET_o is the reference evapotranspiration (mm/day), d_n is the net depth of each irrigation application (mm), and k_c is the crop coefficient.

The gross irrigation depth (d_g), in mm, accounts for water loss during irrigation and is calculated using the formula:

$$d_g = \frac{d_n}{E_a} \times 100 \qquad (4)$$

Soil moisture content :

To determine the amount of water available in the soil, field measurements of water content are required. The Moisture Meter Model (*HH2*) device (Figure 3) was used to determine the moisture content of the soil.

Figure (3): *Model HH2 of the moisture meter device.*

By calculating the water content of measured soil moisture, the HH2 was calibrated. After irrigation (for around 24hours), the soil moisture distribution pattern was measured. The soil moisture was recorded horizontally 40cm from the bubbler with a 10cm increment and vertically from the soil surface to a depth of 40cm with a 10cm increase. The 3-dimensional curves for the soil moisture distribution pattern were drawn using the computer software SURFER (Golden Software, 2000).

Soil Covering:

One of the field research objectives is to study how different types of soil surface covers affect soil moisture content and crop yield when compared to uncovered soil. The first treatment (Un) was an uncovered soil surface. In the second (M), a 0.12mm thick black plastic mulch covered the soil surface. Thirdly treatment (M + S), Dry rice straw was put to the area surrounding the plant stem at a ratio of 8Mg ha-1 at a diameter of 0.3m, and a 0.12mm thick black plastic mulch was placed over the exposed soil. The interaction between these treatments and the irrigation techniques proposed in the experiment was evaluated.

Experiment Soil:

Soil samples were collected and analyzed to determine some physical characteristics of the soil at root depths from 0 to 60cm. According to the analysis, the soil at this depth was considered as a homogeneous layer, as shown in Table (2).

Table (2): Some soil characteristics associated with irrigation of the experimental site.

Depth (cm)	Particle size distribution Sand (%) Coarse	Fine	Silt (%)	Clay (%)	Texture Class	ρ_s g/cm^3	Soil moisture content by weight *FC* (%)	*PWP* (%)	*TAW* (%)	*RAW* (%)
0 - 20	78.8	15.9	2.1	3.2	Sandy	1.65	8.8	1.79	7.34	4.55
20 - 40	79.0	16.1	1.9	3.0	Sandy	1.63	9.0	1.80	7.2	4.65
40 - 60	79.2	16.3	1.7	2.8	Sandy	1.63	9.1	1.90	7.2	4.65

ρ_s: Dry bulk density, *FC*: Field capacity (at -0.1atm), *PWP*: Permanent wilting point percentage (at -15.0bar), *TAW*: Total Available Water, *RAW*: Radial available water for maize [*RAW* = *AW*. *MAD* (0.65)] and *MAD*: maximum allowable depletion for corn.

Water Use Efficiency:

The yield weight of the crop was measured and expressed in kg/feddan using a digital balance with a precision of 0.001g. The water use efficiency (WUE) given in kg/m^3 for various irrigation systems was calculated using the following formula:

$$WUE\ (kg/m^3) = \frac{Totalcorn\ yield\ (kg/fed.)}{Total\ water\ applied\ \ (m^3/fed.)} \qquad (5)$$

3. RESULTS AND DISCUSSION

Irrigation System Efficiency:

The field application efficiency (Ea) for various irrigation systems was displayed in Table (3) and Figure (4). It was found that drip irrigation had the best field application efficiency (92.3%), whereas furrow irrigation had the lowest field application efficiency (63%). The application efficiency of bubbler irrigation systems (reaching 82%) was good compared to sprinkler irrigation (75%). The two bubbler sizes, 8.8mm and 13.6mm, had higher field application efficiency at short interval distances of 2m (80 and 82%) compared to long intervals of 4m (73 and 77%).

Amount of Applied Water (AW):

The applied water requirements for various irrigation systems are displayed in Table (3). There were 3381, 3782, 3900, 4052, 4274, and 4953m^3/fed of water in the drip, bubbler 13.6mm at 2m, bubbler 8.8mm at 2m, bubbler 13.6mm at 4m, bubbler 8.8mm at 4m, and furrow respectively. Due to the efficiency of water application, drip irrigation required the least amount of water whereas furrow irrigation required the most.

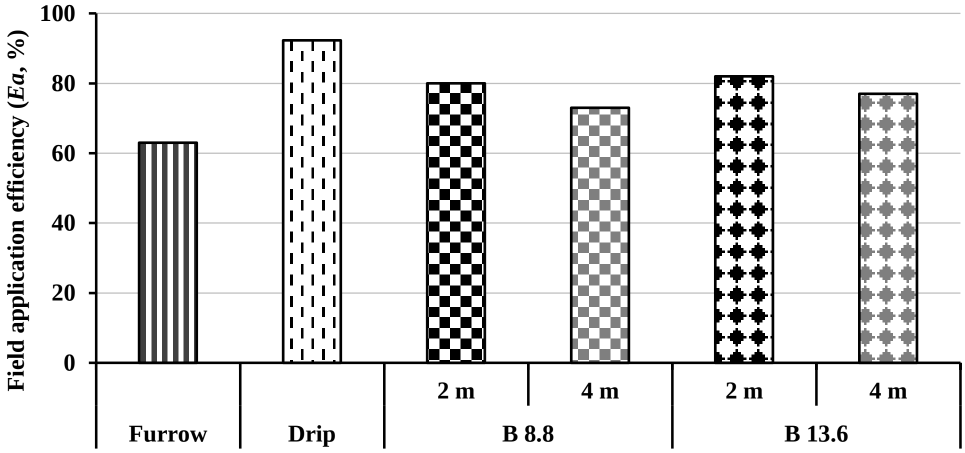
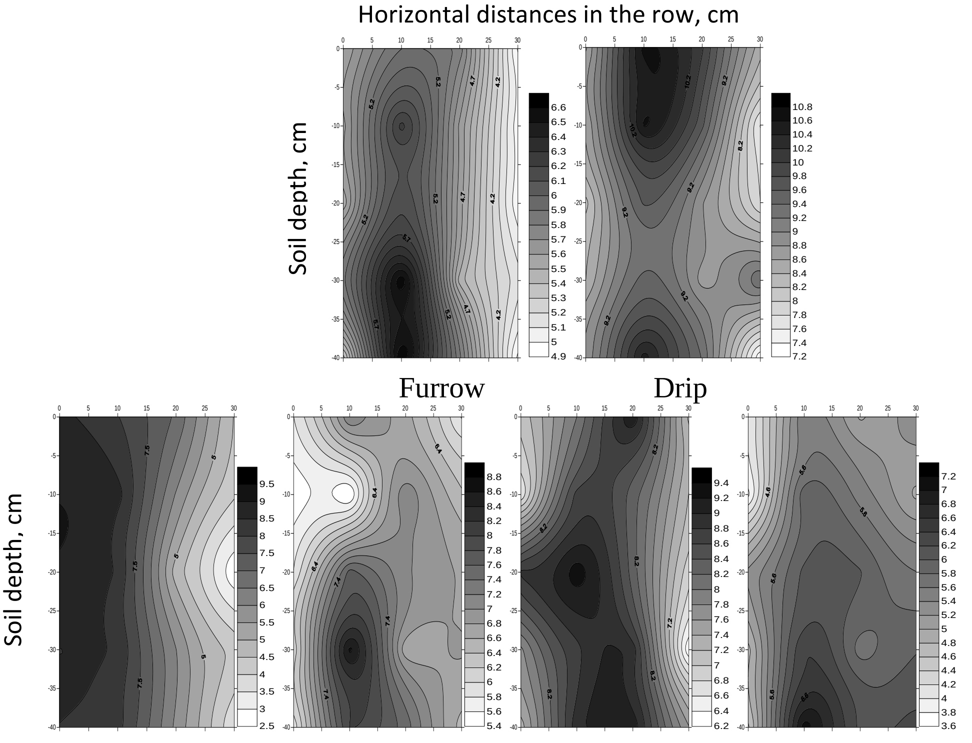


Figure (4): Field application Efficiency (Ea) of compared irrigation systems.

Soil Moisture:

The soil moisture distribution of the evaluated irrigation systems is compared in Figure 5. The average soil moisture ratio expanded for the following irrigation systems: drip, bubbler 13.6mm at 2m, bubbler 8.8mm at 2m, bubbler 13.6mm at 4m, bubbler 8.8mm at 4m, and furrow respectively, from (7.2 to 10.8), (2.5 to 9.5), (6.2 to 9.4), (5.4 to 8.8), (3.6 to 7.2) and (4.9 to 6.6%). The highest averages of soil moisture content were recorded with drip irrigation agreed with **Ainechee *et al*., (2009)**. The maximum soil moisture content of the drip irrigation system, 10.8%, was higher than the estimated soil field capacity. This is due to manure fertilizers was applied in all irrigation systems that were examined to prepare the soil for planting, and drip irrigation applies water more slowly than other irrigation methods.



Furrow Drip

Bubbler 8.8 mm at 2 m Bubbler 8.8 mm at 4 m Bubbler 13.6 mm at 2 m Bubbler 13.6 mm at 4 m

Figures (5): The average values for the soil moisture distribution pattern under furrow, drip, and bubblers irrigation.

In general, it can be concluded that the drip irrigation system was the best for retaining soil moisture content when using three different irrigation methods, followed by bubbler 13.6mm at 2m, bubbler 8.8mm at 2m, bubbler 13.6mm at 4m, bubbler 8.8mm at 4m, and then furrow irrigation system, respectively.

Impact of soil surface covering on yield:

The grain and straw yield of maize with mulch (M), mulch plus straw (M+S), and uncovered soil (Un.) are displayed in Table (3) and Figure (6). The results revealed that grain and straw yields with (M) were higher under various irrigation systems examined than with (M+S) and (Un.). This variation in yields was probably due to reducing evaporation from the soil surface, which was graded in descending order starting with the highest value with (M), then (M+S), and finally with (Un.). For instance, the grain and straw yields with (M) were respectively 3542 and 4310kg/fed for furrow; 3381 and 3500kg/fed for bubbler 13.6mm at 2m; 3106 and 3300kg/fed for drip; 3101 and 3400kg/fed for bubbler 13.6mm at 4m; 3101 and 3600kg/fed for bubbler 13.6mm at 4m; 3086 and 3550kg/fed for bubbler 8.8mm at 2m; finally, 2993 and 3250kg/fed for bubbler 8.8mm at 4m.

The covered soil surface with (M) under furrow irrigation produced the maximum grain and straw yield, whereas (Un.) under bubbler 8.8mm at 4m produced the lowest. Drip irrigation with (M) may perform better than other evaluated irrigation methods in enhancing the grain and straw yield of maize because of the physical properties of the soil and the availability of optimum moisture to the crop at various phases of growth.

Table (3): Field application efficiency (Ea) and water use efficiency (WUE) of maize with different irrigation systems and soil covers.

Irrigation System		*Treat.*	*(Ea)*	*AW* (m^3/*fed.*)	*Yield* (*kg/fed.*)		*WUE* (*kg/*m^3)	
					Grain	*Straw*	*Grain*	*straw*
Furrow		M	63	4953	3542	4310	0.72	0.87
		M+ S			3314	4247	0.67	0.86
		Un			3197	4009	0.65	0.81
Drip		M	92.3	3381	3106	3300	0.92	0.98
		M+ S			2990	3250	0.88	0.96
		Un			2785	3100	0.82	0.92
$B_{8.8}$	*2m*	M	80	3900	3086	3550	0.79	0.91
		M+ S			2864	3430	0.73	0.88
		Un			2644	3320	0.68	0.85
	4m	M	73	4274	2993	3650	0.70	0.85
		M+ S			2797	3490	0.65	0.82
		Un			2600	3460	0.61	0.81
$B_{13.6}$	*2m*	M	82	3782	3381	3500	0.89	0.93
		M+ S			3113	3400	0.82	0.90
		Un			2980	3300	0.79	0.87
	4m	M	77	4052	3101	3600	0.77	0.89
		M+ S			2897	3530	0.71	0.87
		Un			2811	3400	0.69	0.84

Efficiency of water use:

The water uses efficiency (WUE) of grain and straw maize yield for covered soil surface by (M), (M+S), and (Un.) is displayed in Table (3) and Figure (4). According to the results, WUE was ranked in descending order, starting with the highest value with (M), then (M+S), and finally with (Un.). WUE of grain and straw, for instance, with (M) were, respectively, (0.92 and 0.98), (0.89 and 0.93), (0.79 and 0.91), (0.77 and 0.89), (0.72 and 0.87), and (0.70 and 0.85kg/m^3, under drip, bubbler 13.6m at 2, bubbler 8.8mm at 2m, bubbler 13.6mm at 4m, furrow, and bubbler 8.8mm at 4m.

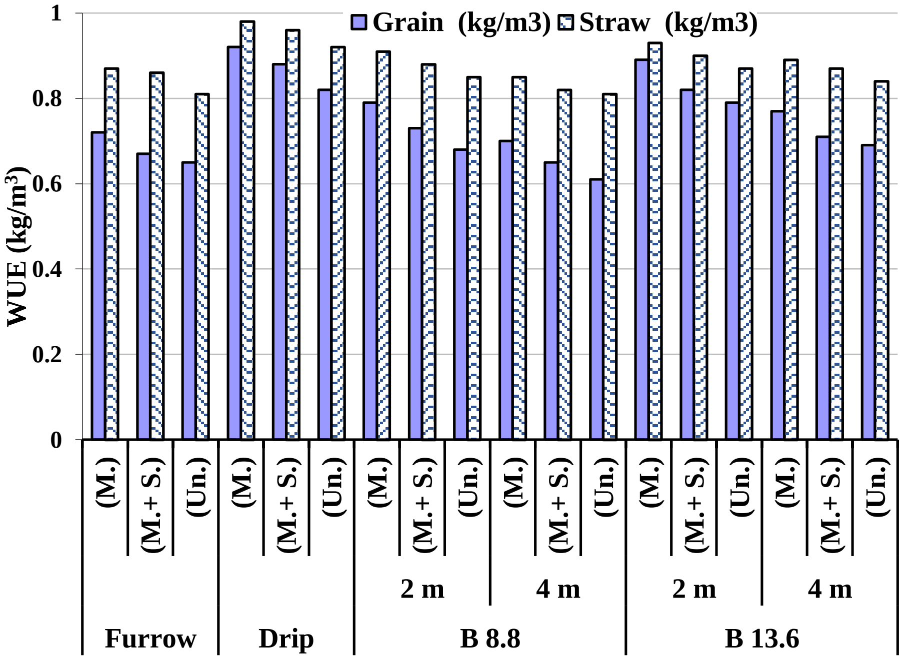


Figure (4): The water use efficiency (WUE) of the irrigation systems under investigation with various soil covers.

The findings demonstrate that the WUE of grain and straw yield followed the same data values trend of (M) When the soil surface was covered by (M+S) or uncovered (Un.). The better WUE values were obtained using (M) and may be arranged in the following decreasing order of irrigation systems: drip; bubbler 13.6mm at 2m; bubbler 8.8mm at 2m; bubbler 13.6mm at 4m; furrow; and bubbler 8.8mm at 4m.

When growing maize on sandy soil, it is advised to use drip irrigation first, followed by low-head bubbler irrigation, for a good WUE. Practically speaking, low-head bubbler irrigation is preferred since it is reliable and easy to use.

4. CONCLUSIONS

The goal of this research was to develop low-head bubbler irrigation systems as a water- and energy-saving alternative to conventional furrow irrigation. The study compared a few systems of this irrigation technology with furrow and drip irrigation methods to obtain a standard design. The low-head bubbler designs had bubblers (ID) of 8.8 and 13.6mm and were placed 2 to 4 meters apart on the soil's surface. The field application efficiency (Ea) of the different irrigation systems was estimated through field experiments. It was found that drip irrigation had the best field application efficiency (92.3%), whereas furrow irrigation had the lowest field application efficiency (63%). Bubbler systems, which attain 82% efficiency, are more effective than sprinkler systems, which only reach 75% (Table 1). Based on the irrigation application efficiency, the full amount of water required by the maize crop from each irrigation system was calculated. Drip hence had a lesser value, while furrow had a larger one. According to the results of Ea , the drip irrigation system was the most efficient, followed by bubblers 13.6mm at 2m, bubblers 8.8mm at 2m, bubblers 13.6mm at 4m, bubblers 8.8mm at 4m, and then the furrow irrigation system.

The impact of soil surface covering on the grain and straw yield of maize grown under mulch (M) and mulch plus straw (M+S) was evaluated by comparing it with uncovered soil (Un.). For producing maize grain and straw under all cover treatments, furrow irrigation may be preferable to alternative irrigation methods. The irrigation methods, on the other hand, had the following water usage efficiency (WUE) rankings in descending order: drip, bubbler 13.6mm at 2m, bubbler 8.8mm at 2m, bubbler 13.6mm at 4m, furrow, and bubbler 8.8mm at 4m. Generally, for all tested irrigation methods, A soil cover (M) was more effective in terms of yield and WUE than the cover (M+S), and both were preferable to the uncovered soil (Un). To achieve a good WUE during maize cultivation on sandy soils, the research found that drip irrigation comes in first, followed by low-head irrigation. Low-head bubble irrigation requires additional study. Future research may find that this technique is preferred since it is simple to use and maintain in practical applications.

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تقييم أنظمة الري منخفضة الضاغط وتغطية التربة من حيث حفظها للمياه في زراعة الذرة

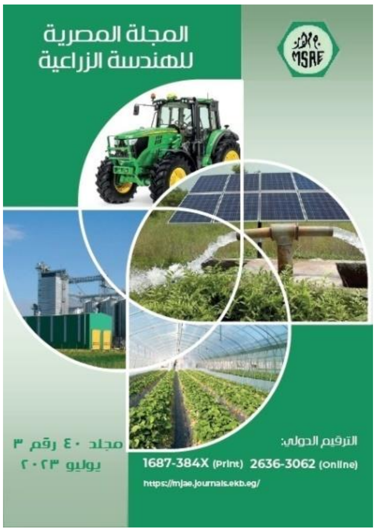
محمد أبوزيد رشاد[١]، عبد التواب متولي ابراهيم زيدان[٢] ، محمد سلمي سالمان[٣] و أحمد فتحي محمد خضر[٤]

[١] أستاذ هندسة الري والصرف - قسم الهندسة الزراعية - كلية الزراعة - جامعة قناة السويس - مصر.

[٢] أستاذ هندسة الري والصرف - قسم الهندسة الزراعية - كلية الزراعة - جامعة الزقازيق - مصر.

[٣] باحث بمعهد بحوث وقاية النباتات - مركز البحوث الزراعية - القاهرة - مصر.

[٤] أستاذ مساعد هندسة الري والصرف - قسم الهندسة الزراعية - كلية الزراعة - جامعة قناة السويس - مصر.



الكلمات المفتاحية:
التنقيط، الفوار؛ الخطوط؛ الذرة؛ أغطية التربة.

الملخص العربي

يهدف البحث الي تقييم أداء نظم ري فوار (الببلر) منخفض الضاغط لري المحاصيل الكثيفة الذرة في الأراضي الرملية ومقارنته بنظم الري الأخرى مثل الري بالتنقيط والخطوط التقليدية عند طوال ٢٠م، من حيث كفاءة حفظ المياه والمحتوي الرطوبي للتربة عند استخدام معاملات حفظ المياه بتغطية سطح التربة. وكانت هناك أربع أنظمة للري الفوار تصميمها كالتالي: الخطوط الجانبية للري الفوار مدفونة تحت سطح التربة بقطر ٤٨,٨مم مركب عليها أنابيب قائمة صاعدة بارتفاع ٠,٥م لتصل فوق سطح التربة ومركب على فوهتها وصلة على شكل حرف (T) وعلى مسافات بينية للفوارات ٢ أو ٤م، كل مسافة يركب عليها انبوبين للفوارات بأحد القطرين ٨,٨ أو ١٣,٦مم وبطول ١,٠م لتصب الماء داخل بطن الخط. تم تقدير كفاءة الإضافة الحقلية (Ea) لأنظمة الري المختلفة. وبلغت كفاءة الري بالتنقيط (٩٢,٣٪)، أما الري بالخطوط التقليدي بلغت (٦٣٪). وسجلت الفوارات بقطر ٨,٨مم و١٣,٦مم، كفاءة أفضل (٨٠ و٨٢٪) عند تركيبها على مسافات قصيرة (٢م). وكان ترتيب نظم الري من حيث كميات المياه كالتالي: الري بالتنقيط، الفوارات ٨,٨مم عند ٢م، الفوارات ١٣,٦مم عند ٢م، الفوارات ٨,٨مم عند ٤م، الفوارات ٨,٨مم عند ٤م، والخطوط التقليدية على التوالي. تمت مقارنة تأثير بالتغطية بأغطية بلاستيكية (M) بالإضافة للتغطية حول ساق النباتات بقش الأرز المجفف مع تغطية أجزاء سطح التربة المكشوفة بأغطية بلاستيكية (M + S) بالتربة المكشوفة (Un) من حيث محصول الذرة وكفاءة استخدام المياه (WUE). وكان تأثير الأغطية: الأغطية البلاستيكية تليها القش مع الأغطية البلاستيكية واخيراً التربة بدون تغطية.