Effect of fish effluent on cabbage yield under organic mulching conditions

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Abstract: Egypt is suffering of limited water resources and facing some challenges, which result in water shortage for covering agricultural requirements. The objectives of this study were to use the effluent from fish farming for irrigation; to use organic mulching for cabbage crop to reduce nitrogen fertilizer addition; to enhance micro-environment; and to examine the water use index performance of irrigation systems. Tested treatments were irrigation water, irrigation system (drip and sprinkler) and soil mulching. The mulching material was 4.5 cm thick. Analysis of total ammonia nitrogen (TAN), nitrate and nitrite were performed twice weekly. The results indicated that the organic mulching treatments retained more heat than without mulching. Moreover, the water use index for drip irrigation with fish effluent was 0.0458 and 0.0507 m^3 kg^{-1} with and without mulching, respectively. The water use index for drip irrigation with mulching was 0.0458 and 0.1852 m^3 kg^{-1} for fish effluent and canal water, respectively. Fish effluent water increase crop productivity and raise yield from a unit volume of water.

Keywords: fish; effluent; mulching; cabbage; irrigation

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1 Introduction

Egypt is suffering of limited water resources and facing some challenges, which result in shortage of water to cover the industrial, human and agricultural requirements. The major source of surface renewable fresh water is Nile River, which gave an annual quota of 55.5 billion m^3, set by the "Nile water agreement" singed in 1959 with Nile countries (Zaghloul, 2013). Agriculture sector needs nearly 85% from the water resources in Egypt, which represents a great facing challenge due to the limitation of water resources. In addition, a rapidly growing population is a great problem facing the Egyptian policymakers to ensure food security (Ministry of Agriculture and Land Reclamation (MALR), 2009).

To solve the fixed budget of the Nile water, several policies for increasing the useable supply of water or improving the efficiency of its use have been identified. These policies do not only consist in improving management of irrigation systems, but also recycling the drainage water of fish farming.

The wastewater produced from aquaculture farming has rich with organic matter for agriculture use and can reduce the total costs of fertilizers, which demanded to push the growth of plant. Furthermore, the reuse water of fish farming can improve soil quality and consequently increase crops productivity (Ebong and Ebong, 2006). Vegetables

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represent a corner stone in the Egyptian agricultural since they include many vitamins and essential minerals for human healthy. MALR (2009) stated that vegetables consumed annually 6.5 million m^3 of water per year. Many researchers used the wastewater from fish farms for the vegetable crops irrigation aiming to provide water throughout non-renewable sources of water and reduce the costs of crop's fertilizers. Khater et al. (2015) evaluated the content of nutrients in water fish farming as a source for growing tomato plants. They found that the water use efficiency increased from 5.54 to 7.16 kg m^{-3} with increasing drip emitter flow rate from 4 to 6 l h^{-1}. Also, their results showed that using the effluent fish could save fertilizers which equivalents 0.13 Egyptian pound per kilogram fruits. Abdelraouf (2015) stated that using wastewater of fish farms in the irrigation can save at least 40% from mineral fertilizers and 100% from irrigation water under sprinkler irrigation system.

Cabbage (*Brassica Oleracea L. var. Capitata*) is one of the most important leafy and popular traditional vegetables in Egypt. In addition, is an excellent source of calcium, potassium, and vitamin C. It is also an important source of antioxidants since it is rich in certain substances with high antioxidants capacity such as carotenoids and polyphenols (Leja et al., 2007). Also, the cabbage nutritional quality is highly influenced by fertilization, particularly nitrogen (N). Recycled water from fish farming will contain high or low dissolved nitrogen levels depending on fish density. Fish excrete waste nitrogen, in form of ammonia, directly into the water through their gills. Therefore, the aquaculture outlet water can cover the fertilizer requirements of nitrogen for cabbage crop.

Ramadan and Omar (2017) reported that cabbage is cultivated over the year in Egypt, being the cultivated area in 2015 18872 ha, producing 555396 ton with an average yield of 29.3905 ton ha^{-1}.

Mulching is an effective way to change the micro-environment to increase crop yield. Based on the materials used, the cover can be divided into three main types: organic cover (crops, leaves, geotextiles, etc.), inorganic cover (plastic film, degradable film, etc.) and mixed mulching (plastic, straw, grass, gravel, etc.) (Kader et al., 2017). Li et al. (2018) found that inorganic covering and organic covering increased potato yield in average by 24.3% and 16.0%, respectively.

Cohen et al. (2018) compared the additive life cycles of traditional, large-scale lettuce and tilapia production with combined aquaponic agriculture and evaluated these methods based on their material efficiency and their associated environmental impacts. Analysis of the mean and interval characteristics indicates that the effects of eutrophication, water usage and geographical footprint on aquatic plants were significantly reduced using the productivity of the communal ecosystem, which has reduced traditional agriculture.

The impact of cover on soil moisture depends on rainfall and climate factors. By adjusting the surface evaporation rate, the cover affects the soil moisture conditions advantageous. In the summer, the cover protects soil moisture by reducing the evaporation rate. The cover enhances the ability to maintain soil moisture and soil structure and prevents the weed growth (Mutetwa and Mtaita, 2014).

The amount of soil moisture made by various mulching materials varies with soil type and climatic conditions. Normally, the cover process holds high soil moisture compared to bare soils (Chakraborty et al., 2008; Zhao et al., 2014). The change in soil moisture in the upper surface layer (0-10 cm) is highly dynamic due to the flow of water vapor through the soil-atmospheric interface (Bittelli et al., 2008). However, coverage can reduce soil moisture and soil temperature fluctuations (Abouziena and Radwan, 2015).

Crop microorganisms in soil cover change the soil temperature and affect the growth of plants and the yield (Zhang et al., 2009). Generally, the effect of cover on the state of soil temperature varies with the capacity of the cover material to reflect and transmit solar energy (Lamont, 2005). Coverage reduces the temperature of the summer soil and increases in the winter. The cover changes the soil temperature and affects the thermal state of the soil (Arora et al., 2011; Pramanik et al., 2015). Paper coverage reduces soil temperature and ensures minimum soil temperature compared to black plastic coverings or bare soil (Kader, 2016). Organic coverage reduces topical thermal management by maintaining solar radiation (Komariah et al., 2008). Mulching reduce the maximum temperature of the soil but increase the minimum temperature of the soil, significantly reduce the temperature of the soil (Begum et al., 2001). Zhang et al. (2009) recorded a 4°C decrease in soil temperature in the hot period and a 2°C increase in soil temperature in the cold period at 10 cm soil depth. The soil moisture and temperature affected by the coverage will affect soil microbiology. The type and color of the cover material also controls the soil's microbial properties (Moreno and Moreno, 2008). Organic mulches add nutrients to the soil when decomposed by microbes, help in carbon sequestration (Ning and Hu, 1990) and work as fertilizers after use.

The present study used fish effluent from aquaculture depending on bio- engineering indicators under organic mulching conditions. Therefore, the objectives of this study were using the fish effluent from fish farms and organic mulching for cabbage crop to reduce industrial nitrogen fertilizer addition and enhancing micro-environment, and to maximize the economic profit

2 Materials and methods

2.1 Experimental site location and some soil characteristics

To fulfill the study objective, at June 2017, a field experiment using 0.053 ha (35 m × 15 m) was carried out at the agricultural research farm, Faculty of Agriculture, Kafrelsheikh University, Kafr Elsheikh Governorate, Egypt. The experimental site is located at 31°05'46"N latitude and 30°57'15"E longitude with an altitude of 6 m above sea level. Table 1 presents the experimental site soil mechanical analysis, soil texture class and some soil characteristics.

Table 1 Experimental site mechanical analysis, soil texture class and some soil characteristics (El-Serafy and El-Ghamry, 2006)

Soil depth, m	Particle size distribution			Soil characteristics			
	Sand, %	Silt, %	Clay, %	Soil texture	Field capacity, (Wt/wt) %	Permanent wilting point, (Wt/wt) %	Bulk density, g cm^{-3}
0-0.15	10.42	31.25	58.33	Clay	44.80	21.36	1.10
0.15-0.30	13.00	32.00	55.00	Clay	41.45	21.40	1.22
0.30-0.45	12.00	29.00	59.00	Clay	39.00	21.00	1.28
0.45-0.60	12.00	28.00	60.00	Clay	37.40	20.85	1.31

2.2 Agricultural practices

2.2.1 Seed bed preparation

The soil was prepared using a chisel plough in two perpendicular directions at 0.20 m depth. Then, the secondary tillage was carried out using a tandem disc harrow. The soil was leveled using a mounted hydraulic land leveler of 1.26 m^3 capacity (0.60 m×3.00 m× 0.70 m). The furrows were formed at 0.75 m spacing using two ridging bodies.

The furrows were mulched using rice straw layer of 0.045 m thickness. Table 2 indicates some rice straw characteristics.

2.2.2 Transplanting

The selected cabbage seedlings Baladi variety of 23 days old were transplanted manually at 0.30 m spacing apart at the same furrow.

Table 2 Some rice straw characteristics (El-Serafy and El-Ghamry, 2006).

Moisture content, % (d. b.)	Ash, %	Organic matter, %	Organic carbon, %	Total N, %	C/N ratio
9.00	17.79	75.21	43.46	0.482	90.16

2.2.3 Irrigation

The following irrigation systems were used:

1. Drip irrigation system of in-line GR pressure non compensating long path flow emitter, 4 l h^{-1} discharge at 100 kPa operating pressure and 3.5% manufacturing coefficient of variation (CV).

2. Rotator micro sprinkler system of 360° rotary sprinkler, spray diameter 3 m and spray flow 100 L h^{-1} at

250 kPa.

CROPWAT 8 software that depends on Penman-Monteith equation (Allen et al., 1998) was used to calculate the cabbage crop potential-evapotranspiration according to data recorded in the climate station at Rice Research and Training Center, Sakha City, Kafr El-Sheikh Governorate, which is affiliated to Agriculture Research Center, Ministry of Agriculture and Land Reclamation, Egypt. As shown in Figure 1, the total amount of applied irrigation water was 5385 and 4933 m^3 ha^{-1} for drip and sprinkler irrigation systems, respectively.

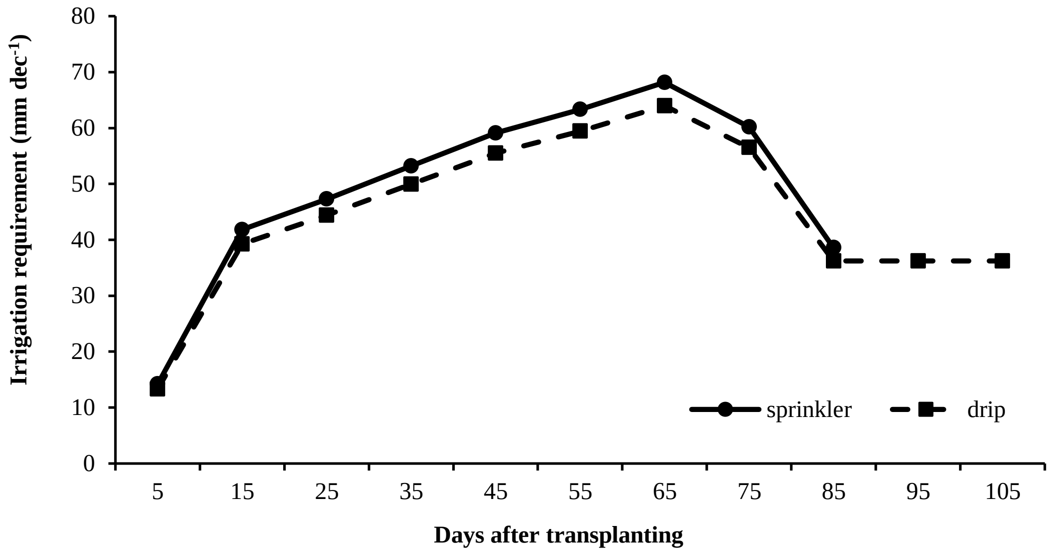


Figure 1 Amount of applied irrigation water during 2017 summer cabbage growing season.

Two types of the irrigation water were used as follows:

1. Experimental site canal water.
2. Fish farm drainage water (effluent).

The fish effluent was obtained from a fish farm which is located at a double polyethylene greenhouse with an east to west orientation. This farm had three fish ponds, being. two of them circular (2 m diameter) and the third one rectangular (4 m× 2 m). A pipe of 0.05 m inlet diameter was installed at the bottom of each fish pond to drain the water to the collecting pond. The collecting pond connected with each one of drip and sprinkler irrigation systems through a pipe of 0.05 m inlet diameter.

The ponds were stocked with 600 Nile tilapia (*Oreochromis niloticus*) (50 g/fish) at a stocking density of 42 fish m^{-3}. The fish were fed a 33% protein floating feed at 3%-5% body weight per day. Dissolved oxygen and temperature of fish culturing water were recorded twice daily. Characteristics of irrigation water was conducted in Food technology Departments, Faculty of Agriculture, Kafr El-Sheikh University as shown in Table 3.

Table 3 Canal and fish effluent irrigation water characteristics.

Irrigation water	pH, 1:2.5 (susp.)	EC, mg L^{-1}	TDS, mg L^{-1}	NH3, mg L^{-1}	NO_2, mg L^{-1}	NO_3, mg L^{-1}	BOD, mg L^{-1}	TSS, mg L^{-1}	DO, mg L^{-1}
Canal water	7.25	730	188	0.012	0.022	0.69	2.6	95	3.0
Fish effluent	7.43	810	420	0.182	0.214	1.69	6.9	166	4.7

Note: TDS is total dissolved solids, BOD is biological oxygen demand, TSS is total suspended solids and DO is dissolved oxygen.

2.2.4 Fertilization

The mineral nitrogen fertilizer in the form of ammonium sulphate (20.60% N) with a rate of 266 kg N ha^{-1} was applied in three equal doses which were injected through the canal irrigation water with nitrogen concentration of 43.73 mg L^{-1} that is equal the corresponding concentration of the fish effluent. The fish effluent nitrogen conversion ratio (NRC) was calculated according to Brown et al. (2014) as follows:

$$NCR,\% = \frac{nitrogen\ in\ feed,\%\times\ feed\ amount,kg}{fish\ biomass\ produced,kg} \quad (1)$$

2.2.5 Treatments and statistic design

During the study the following treatments were tested:

1. Irrigation water: it included the levels of canal water and farm fish effluent.

2. Irrigation system: it included the levels of drip and sprinkler irrigation systems.

3. Soil mulching: it included the levels of mulching using rice straw and bereaved of mulching.

The experiment was established and designed statistically as split-split plots with three replications. The main plots involved irrigation water treatment levels. The sub plots included irrigation system treatment levels. The sub-sub plots were located for soil mulching treatment levels.

2.2.6 Measurements

Soil temperature:

A digital soil thermometer (±0.1°C accuracy) was used to measure the temperature at the soil surface under mulching material that surrounded the vegetative cabbage plants, and at 0.05 m soil depth and 0;10 m depth from the soil surface.

Microbial total count:

According to Allen (1959), the microbial total count was determined using soil extract agar for bacteria, Martin's medium for fungi and Jensen's medium for counting soil actinomycetes.

Cabbage crop yield:

At harvest, across each experimental unit, an area of 1 m^2 was taken randomly to determine cabbage crop yield.

Fish yield:

Once the cabbage growing season ended, the final fish yield was determined.

Water use index:

As cited by Boyd (2005) and Boyd et al. (2007), water use index was estimated as follows:

$$\text{Water use index} = \frac{\text{total water used in production}}{\text{yield}}\ (m^3 kg^{-1}) \quad (2)$$

Return of irrigation water:

The return of irrigation water was computed as:

$$\text{Return of irrigation water} = \frac{\text{yield price}}{\text{total water used in production}}\ (\$\ m^{-3}) \quad (3)$$

2.2.7 Statistical Analysis:

MATLAB statistical analysis software (Mathworks, USA) was used for carrying out the analysis of variance (ANOVA) and the leas significance difference (LSD) tests at 95% confidence level for obtained data.

3 Results and discussion

3.1 Effect of mulching on soil temperature

Figure 2 shows that the mulching material surface temperature that surrounds the vegetative cabbage plants ranged between 35 ℃ and 20 ℃ throughout the day. The soil surface temperature under the mulching ranged between 30 ℃ and 20 ℃ and 31 ℃ and 21 ℃ using drip and sprinkler irrigation systems, respectively**.** At 5 cm depth from the soil surface, the soil temperature ranged between 28.3 ℃ and 27.2 ℃ and 32 ℃ and 26 ℃ using the drip and sprinkler irrigation systems, respectively. At 10 cm depth from the soil surface, the soil temperature ranged between 27.6 and 26.5 ℃ and 32 ℃ and 26 ℃ using the drip and sprinkler irrigation systems, respectively. Statistical analysis shows that there were significant differences (p<0.05) between the treatments of mulching on their effect on the soil temperature for all treatments.

In general, soil mulching has a clear effect on temperature at different irrigation systems. There were significant differences (p<0.05) between the surface soil temperature due to the changes of the irrigation systems. The effect of mulching on temperature with the drip irrigation system was significantly (p<0.05) greater than the sprinkler irrigation system. This was due to the addition of irrigation water was under the rice straw mulching. The temperature fluctuation (Figure 3) in the drip irrigation system was lower than the sprinkler irrigation system. This resulted in relative stability of soil temperature around the roots of the cabbage plant under drip irrigation, which is reflected in cabbage plants growth.

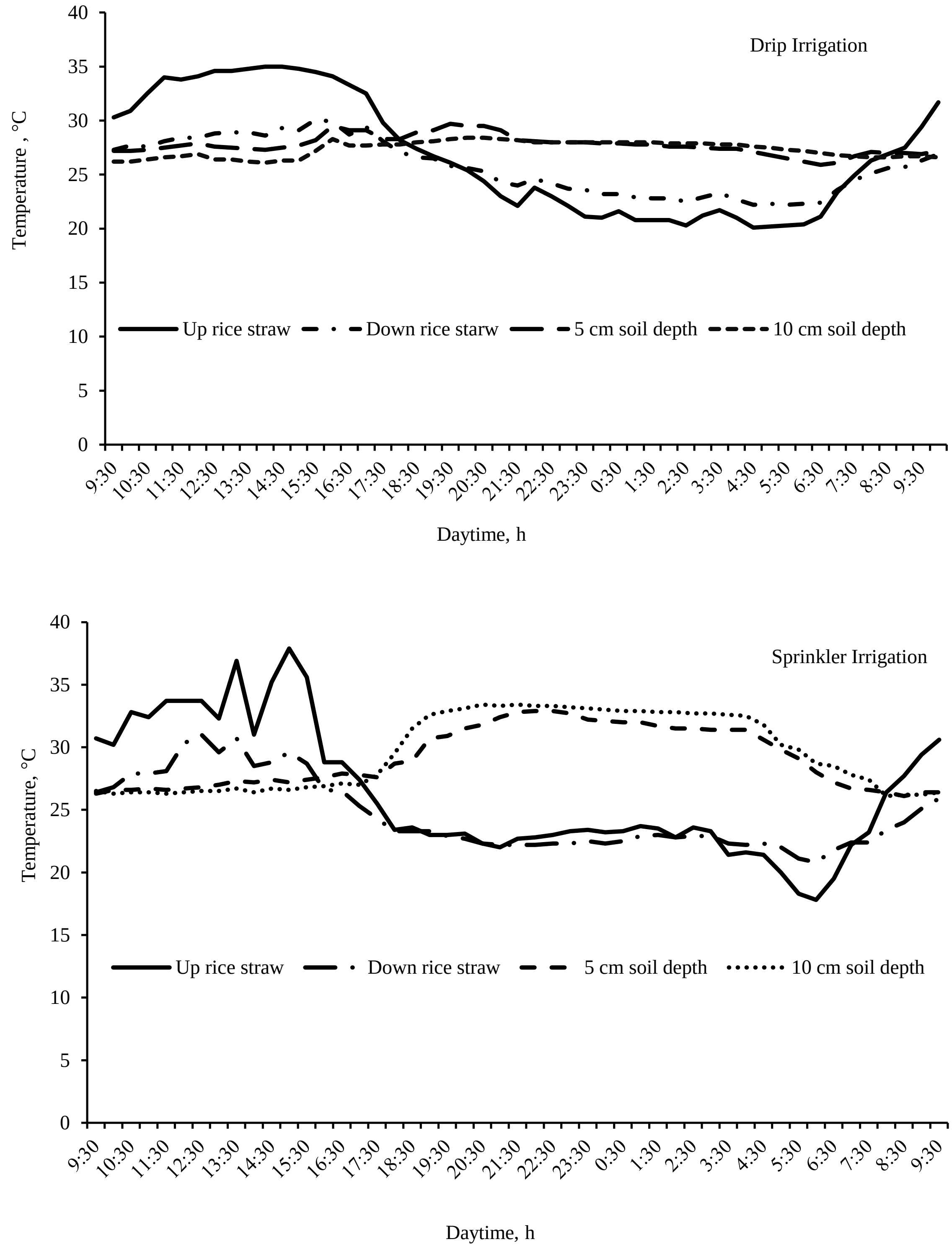
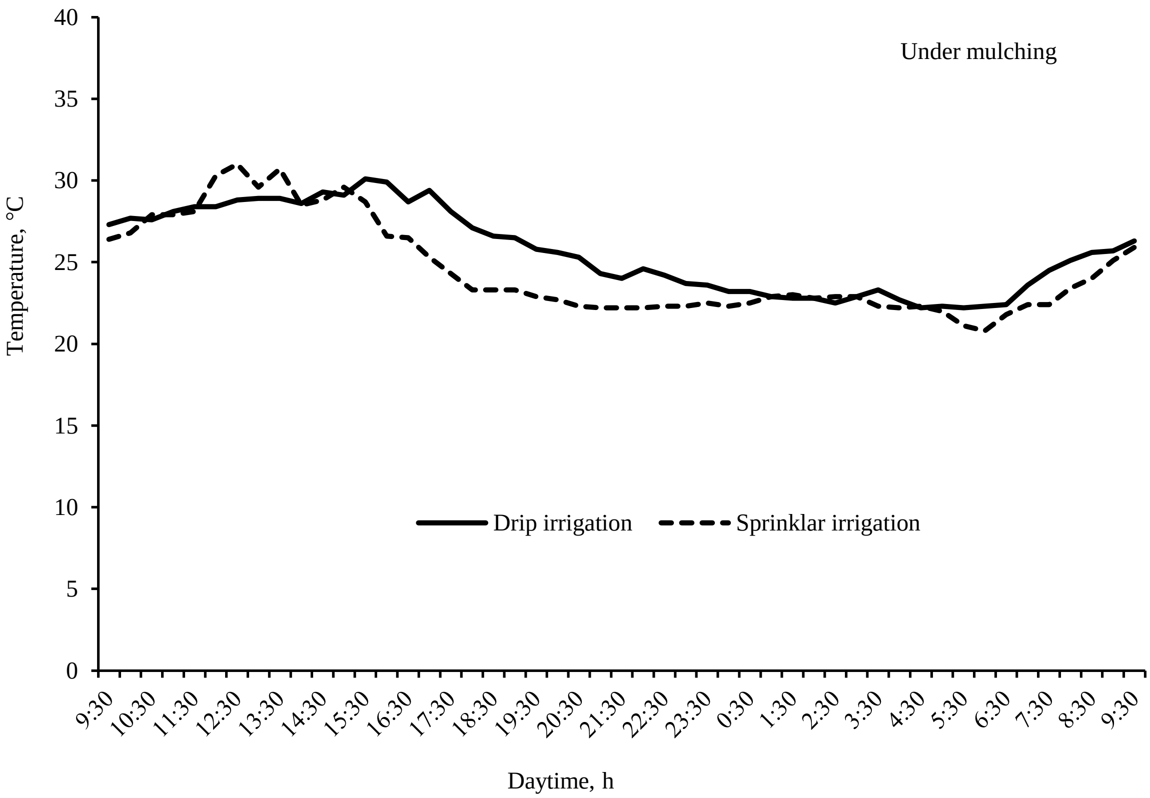
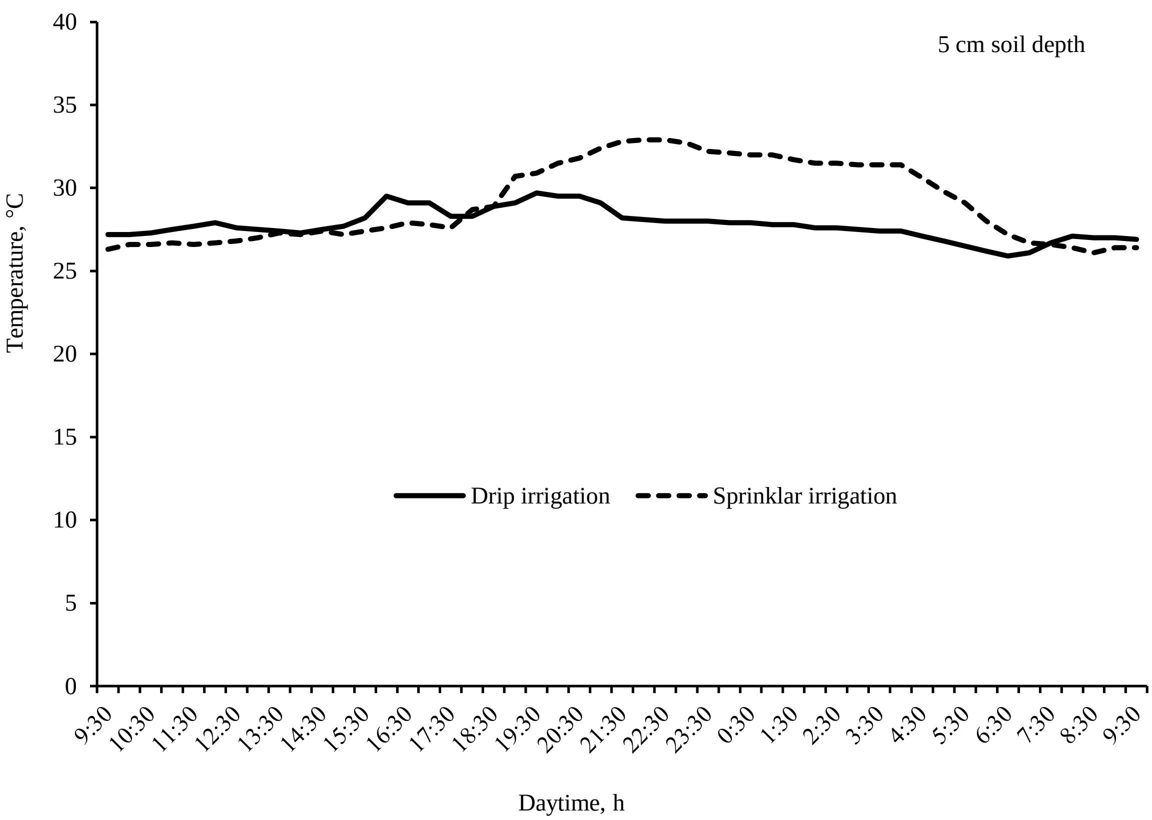


Figure 2 Average temperature of mulching material surface, soil depth of 5 cm and soil depth of 10 cm using drip and sprinkler irrigation systems


Under mulching
Temperature, °C
Drip irrigation
Sprinklar irrigation
Daytime, h


5 cm soil depth
Temperature, °C
Drip irrigation
Sprinklar irrigation
Daytime, h

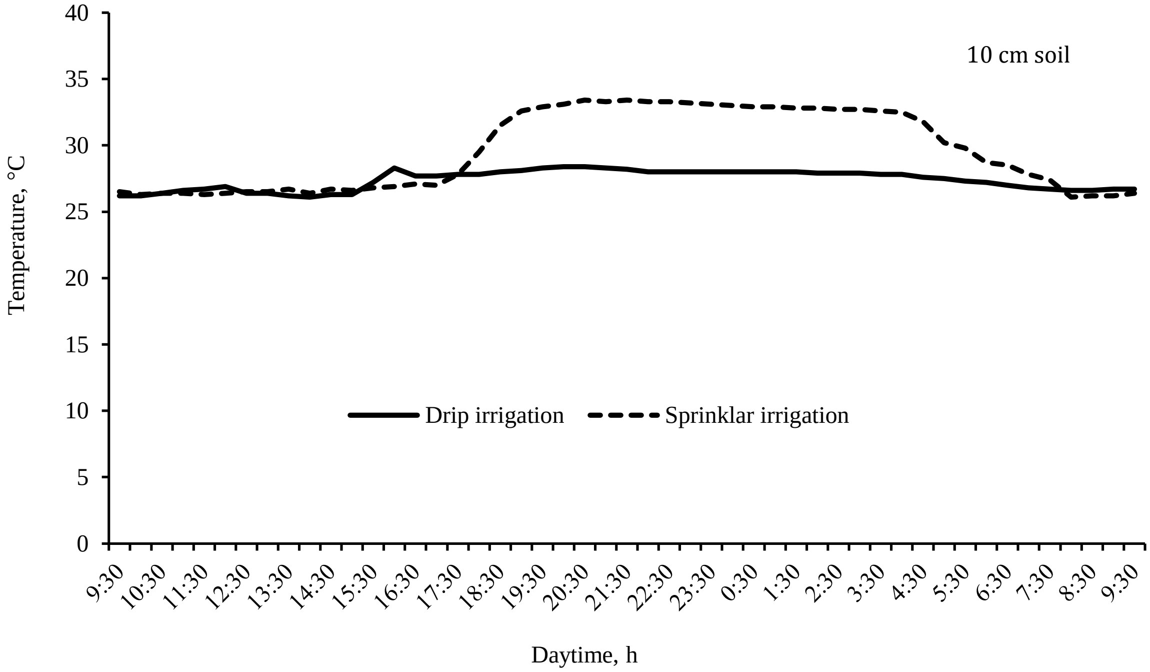


Figure 3 Average temperature fluctuation using drip and sprinkler irrigation systems

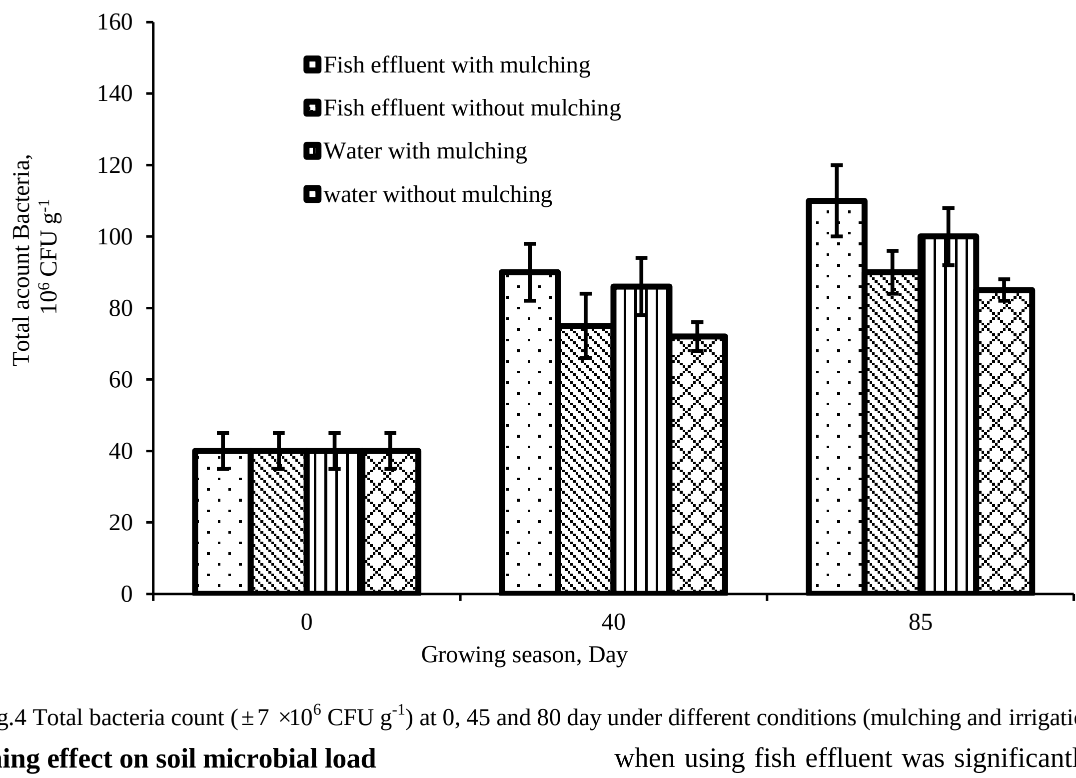


Fig.4 Total bacteria count (± 7 ×10^6 CFU g^{-1}) at 0, 45 and 80 day under different conditions (mulching and irrigation systems).

3.2 Mulching effect on soil microbial load

The microbial load of the soil under the mulching conditions was significantly greater (p<0.05) than under non-mulching conditions due to increased temperature under the mulching conditions. In addition, microbial load when using fish effluent was significantly greater (p<0.05) than microbial load when using water from the canal. Increased microbial activity leads to increased soil fertility. Under mulching conditions, microbial load at the beginning of the growing season was 40×10^6 CFU g^{-1} and at the end of the growing season were 110 $\times10^6$ CFU g^{-1} and 100 $\times10^6$ CFU g^{-1} for fish effluent and irrigation water, respectively. Under non mulching conditions, microbial load at the beginning of the growing season was 40×10^6 CFU g^{-1}, while at the end of the growing season were 90 $\times10^6$ CFU g^{-1} and 85 $\times10^6$ CFU g^{-1} for fish effluent and canal water, respectively (Figure 4).

There were significant differences ($p<0.05$) between soil microbial load due to changes of mulching treatments and different types of irrigation water. Under irrigation with fish effluent, there were no significant differences ($p>0.05$) on soil microbial load using different irrigation systems with mulching condition.

3.3 Cabbage and fish yield

Cabbage yield was generally significantly higher ($p<0.05$) in the mulching system at different irrigation systems. Cabbage yields with mulching and fish effluent water were 72.4 and 123.8 ton ha^{-1} for drip and sprinkler irrigation systems, respectively, while without mulching and fish effluent water were 61 and 80.7 ton ha^{-1} for drip and sprinkler irrigation systems, respectively. Overall, cabbage yield was significantly higher ($p<0.05$) with sprinkler irrigation system at different mulching conditions as shown in Table 4. On the other hand, the initial weight of the fish was 50 g $fish^{-1}$ and the final weight was 210 g $fish^{-1}$, therefore the weight gain was about 160 g $fish^{-1}$, subsequently, the fish productivity was 8.4 kg m^{-3} (Table 4).

Table 4 Effect of mulching and irrigation system type on cabbage and fish yield.

	Fish effluent water				Irrigation water			
	With mulching		Without mulching		With mulching		Without mulching	
	Drip irrigation	Sprinkler irrigation	Drip irrigation	Sprinkler irrigation	Drip irrigation	Sprinkler irrigation	Drip irrigation	Sprinkler irrigation
Crop properties								
Average weight (kg/cabbage)	3.05	5.9	2.5	4.2	1.3	4.28	1.79	3.18
Commercial weight (kg/cabbage)	1.9	3.25	1.5	2.12	0.76	2.01	1.11	1.66
Perimeter (cm)	60	87	70	75	45	77.77	53	66
Height (cm)	20	17	18	23	17	21.67	19	20.33
Crop yield								
Total productivity (ton ha^{-1})	116.2	224.8	95.2	160	49.5	182.9	68.1	121.2
Commercial productivity (ton ha^{-1})	72.4	123.8	61.0	80.7	29.0	76.7	42.4	63.3
Fish productivity								
Initial weight (g)	50	50	50	50	--	--	--	--
Final weight (g)	210	210	210	210	--	--	--	--
Weight gain (g)	160	160	160	160	--	--	--	--
Fish yield (kg m^{-3})	8.4	8.4	8.4	8.4	--	--	--	--
Water used								
Planting (m^3 ha^{-1})	476.2	476.2	476.2	476.2	476.2	476.2	476.2	476.2
Irrigation (m^3 ha^{-1})	4909.5	4457.1	4909.5	4457.1	4909.5	4457.1	4909.5	4457.1
Total water (m^3 ha^{-1})	5385.7	4933.3	5385.7	4933.3	5385.7	4933.3	5385.7	4933.3
Benefit of water								
Cabbage crop (kg m^{-3})	13.44	25.10	11.32	16.36	5.40	15.54	7.87	9.94
Fish (kg m^{-3})	8.4	8.4	8.4	8.4	--	--	--	--
Water use efficiency (kg m^{-3})	21.84	33.50	19.72	24.76	5.40	15.54	7.87	9.94
Return of irrigation water ($ m^{-3})*	10.91	12.22	10.68	11.24	0.60	1.74	0.88	1.11

Note: * Average price of cabbage (2 EGP kg^{-1}), fish (20 EGP kg^{-1}). EGP = 0.056 US Dollar

3.4 Total water amount and water use efficiency

The grown cabbage plants under drip irrigation system required significantly higher ($p<0.05$) amount of water than under sprinkler irrigation. The reason is that the growth period of the crop was longer using the drip irrigation system than with sprinkler irrigation. Total amount of water was 5385.7 and 4933.3 m^3 ha^{-1} for drip irrigation and sprinkler irrigation systems, respectively. In general, water use efficiency of water with sprinkler irrigation system was significantly higher ($p<0.05$) than with drip irrigation under the different tested conditions. In addition to differences in water use efficiency related to irrigation system, mulching and the interaction between irrigation system and mulching were also significant (p<0.05). There were significant differences (p<0.05) between the water use efficiency due to changes of different types of irrigation water.

Water productivity with mulching and fish effluent water were 13.44 and 25.10 kg m^{-3} for drip and sprinkler irrigation systems, respectively. On the other hand, water productivity without mulching and fish effluent water were 11.32 and 16.36 kg m^{-3} for drip and sprinkler irrigation systems, respectively. Water use index when using fish effluent water was significantly less (p<0.05) than water use index when using irrigation water under different conditions. Water use index with mulching and fish effluent water were 0.0458 and 0.0298 m^3 kg^{-1} for drip and sprinkler irrigation systems, respectively. While, water use index without mulching and fish effluent water were 0.0507 and 0.0404 m^3 kg^{-1} for drip and sprinkler irrigation systems respectively. Overall, the return from the unit volume of water when using sprinkler irrigation was significantly higher (p<0.05) than drip irrigation under different conditions (Table 4).

4 Conclusion

Mulching material surface temperature that surrounds the vegetative cabbage plants ranged between 35 ℃ and 20 ℃ throughout the day. To increase crop productivity and raise yield from unit volume of water, fish effluent water should be used for irrigation. Sprinkler irrigation system and mulching using rice straw should be applied since they allowed reaching higher cabbage yields.

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