Effects of Irrigation Interval and Method on Growth, Photosynthesis, Yield, and Water Use Efficiency of Maize in the Nile Delta of Egypt

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Abstract A study to elucidate the possibility of water-saving irrigation methods for maize (Zea mays L.) by reducing frequency and wetting area was conducted in 2013 and 2014 on Vertisols of the Nile Delta. The water-saving methods tested were prolonging the interval by about 1 week and strip method with wide planting bed which results in reducing number of irrigation ditches by 50%. The water-saving ratio was higher with strip method (26 - 31%) than prolonging the interval (8 - 19%). The growth, photosynthetic rate, and grain yield of maize plants were investigated under 4 treatments, i.e. the combination of interval (about 2 weeks or 3 weeks) and method (furrow or strip). Although the treatments had different effects in 2 years, our results can suggest that prolonging the interval by about 1 week from the conventional interval has a risk of yield reduction in the field with soil clay contents equal to or less than 50%, while, strip method has possibility to sustain the grain yield of maize and to improve water use efficiency, calculated as the grain yield divided by the total amount of irrigation water, as much as 71% when irrigation interval was practiced as conventional. Under the prolonged irrigation interval, maize with strip method showed low photosynthetic rates caused by water deficit. Thus, the strip irrigation method with the conventional interval is recommended for saving limited water resources without yield reduction of maize in the Egyptian Nile Delta.

Key words: Photosynthetic rate, Prolonged irrigation interval, Soil water potential, Strip irrigation method, Vertisols, Water-saving ratio

Introduction

Water is the fundamental factor for agriculture in Egypt as the country has arid desert climate with annual average precipitation of less than 100 mm (El-Nahrawy, 2011). Crop production in Egypt is entirely dependent on irrigation by the water from the River Nile, and spend approximately 81% of the water use in the country (Noaman, 2017). The present cultivated area is about 3.5% of the total area of the country (Zaghloul, 2013) around and within the Nile Delta. The agriculture land is 100% irrigated.

In Egypt Maize (Zea mays L.) is one of the most important summer crop, and utilized for human consumption, for animal feed, and as industrial materials for starch and oil production. Annual population growing rate is high and now 1.8% (Worldometers, 2019), and the population was increased by almost three times since 50 years ago. This causes the high demand of food production and decreases water resources which can be used per capita. Although maize is widely cultivated within the Nile Delta, the production has not been sufficient to fulfill the demand, and about 51% of the consumption is imported (data of 2017 from FAO, 2020).

Due to the limited water resources, increase of water needs, and high demand of maize, proper water management with more efficiency needs to be achieved. To enhance the effective water saving on-farm management, there are two possible approaches, i.e. reducing the irrigation frequency and limiting the wetting zone. Former approach can be practiced by prolonging the irrigation interval from the conventional practice, where maize is commonly irrigated every 12-15 days (ARC, 2012) on the heavy clayey Vertisols in the Nile Delta. The latter approach can be practiced by drip irrigation method or reducing the number of irrigation ditches.

Several studies are reported for the aim of water-saving crop production. El-Hendawy et al. (2008) tried to develop drip irrigation system for maize production, and found that the system has advantage only on sandy soils with deep percolation. Practicing drip irrigation is costly
for most of local farmers, especially with cereal cultivation like maize. The drip irrigation is mainly practiced for fruit production in the sandy soil and for horticulture under the facility in Egypt. Abo-El-Kheir and Mekki (2007) showed that maize grain yield decreased by 28% and 36% when irrigation events were omitted during silking and grain filling stages, respectively. Ibrahim and Hala (2007) also investigated that prolonging irrigation intervals from 10 to 18 days reduced the maize grain yield in Egypt. However, Kubota et al. (2016) reported no yield reduction in spite of the prolonged irrigation interval on the heavy clayey Vertisols with high ground level.

One of the methods to reduce the number of irrigation ditches per area in order to limit the wetting zone is strip irrigation method with growing maize on wide planting bed (Maruyama et al., 2017). This strip method was first proposed by Atta and Ibrahim (2005) for rice cultivation and then for maize cultivation (Atta, 2007). This approach of strip method decreased irrigation water use by 35% for rice and 53% for maize as maximum, and even increased maize grain yield. In the study of Atta and Ibrahim (2005) and Atta (2007), plants were grown within the furrow, however, maize were planted on the planting bed in the present study as same as reported by Maruyama et al. (2017).

In water-saving approach in crop production, to find the threshold is the key for deciding whether we can recommend the method to farmers or not. Even if water-saving ratio is high no farmers would accept the method when crop productivity decreases. If water-deficit is not too severe to cause major physiological damage, plants try to adapt physiologically and morphologically to minimize water use. Some studies concluded that root development was improved under reduced irrigation (Nicoullaud et al., 1994; Sharp and Davis, 1985; Kang et al., 2000). If the water reduction is exceeded, plants try to adapt by delaying dehydration through reduction of stomatal conductance, lower the photosynthetic rate and then crop productivity (Yu et al., 1997; Shinoto et al., 2018).

Water use efficiency (WUE), the ratio of the target crop production to the amount of irrigated water, is also the practical means to evaluate water-saving irrigation method for sustainable farming. Several studies showed that WUE was improved under reduced irrigation (Asseng et al., 1998; Mansouri-Far et al., 2010; Kubota et al., 2016).

This study was a part of a research project conducted in Egyptian Nile Delta, and several different studies were carried out. For crop production aspects with different irrigation approach, Sugita et al. (2017), and El-Kilani and Sugita (2017) clarified the water requirements, using ET as an indicator, of several crops under various irrigation methods, and Maruyama et al. (2017) studied the performances, such as plant growth and yield, of several crops under various irrigation methods. Kubota et al. (2016) studied about irrigation intervals for maize production, including effects on its photosynthetic rate, in different location in the Nile Delta from the present study. In our present study the objective was to analyze the response of maize plants, such as photosynthetic rate, plant growth, grain yield, and WUE, under two water-saving approaches which were prolonging irrigation interval and strip irrigation method with wide planting bed. The primary target was to find out the effective water-saving irrigation method without yield reduction of maize for farmers in Egyptian Nile Delta.

Materials and Methods

Experimental site

The field experiment was conducted from June to September in 2013 and 2014 in the experimental field of Water Management Research Institute (WMRI) located in Zankalon Village of Sharqia Governorate (Fig. 1). The experimental field was located at 30°34'50.04"N and 31°25'59.94"E. The soil is classified into Vertisols by Soil Taxonomy. It had clay contents between 47 and 48%, and bulk density of about 1.6 g cm^{-3} until 80 cm deep as investigated (Table 1). The climate of the area belongs to arid climate characterized by very dry hot summer, and the field did not receive any rain during the experiment in both years (Table 2). Temperature was consistent during the maize growing period in both years, and the medium temperature stayed between 26 and 28°C.

Crop management and irrigation methods

The experimental plots were prepared according to the treatments. The experimental treatments had two factors using split plot design with three replications.

The main factor was irrigation intervals, i.e. conventional and prolonged interval. The conventional interval plots were irrigated with about 2-week interval as recommended for maize cultivation by Agriculture Research Center (ARC) (2012), and the prolonged interval plots were irrigated at about 3-week interval since after the 3rd irrigation (July 25) in 2013, and after 2nd irrigation (June 25) in 2014. The irrigation schedule had to be adjusted by a few days in some cases due to the
The availability of water in the main canal.

The sub factor was irrigation methods with conventional furrow with 70 cm between rows, and strip irrigation with 140 cm between the centers of wide beds (110 cm wide) with 2 rows of planting each (Fig. 2). As a result of strip irrigation method, the number of the irrigation ditches (or furrows) per area was reduced to a half of the conventional furrow irrigation method. The distance between plants on row was 25 cm, and the plant density was 57140 plants ha$^{-1}$ in all the plots. In all cases the height of planting bed was 15 cm. The plot size was 17.5 m wide and 20 m long for 1st and 2nd replication plots, and 20.5 m wide and 20 m long in 3rd replication plots. The plot size slightly differed due to the original experimental field design of the institute. A branch waterway was at the middle of the plot which was parallel to the long side (Fig. 3).

Maize (*Zea mays* L., ‘Three Ways Cross 324’) was sown in the field on June 16 in 2013 and June 8 in 2014. Two seeds were sown in each hill, and thinned to one plant after seedling emergence. Water was irrigated according to the practice of regional farmers. The irrigation water was supplied through a weir and the waterway at the middle of each plot, and stopped when the water front reached the end of the furrow. The time of irrigation was recorded to calculate the quantities of applied water using an equation $Q = c L h^{1.5}$, where $Q$ is water discharge (in m$^3$ min$^{-1}$), $c$ is correction coefficient.

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Table 1. Soil characteristics of the experimental field in Zankalon village.

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>Bulk density (g cm$^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>14</td>
<td>39</td>
<td>47</td>
<td>1.57</td>
</tr>
<tr>
<td>20-40</td>
<td>15</td>
<td>37</td>
<td>48</td>
<td>1.60</td>
</tr>
<tr>
<td>40-60</td>
<td>15</td>
<td>37</td>
<td>48</td>
<td>1.60</td>
</tr>
<tr>
<td>60-80</td>
<td>14</td>
<td>39</td>
<td>47</td>
<td>1.55</td>
</tr>
</tbody>
</table>

Table 2. Meteorological data in the experimental field during the maize growth.

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Temperature (%)</th>
<th>E pan (mm day$^{-1}$)</th>
<th>Relative humidity (%)</th>
<th>Wind speed (m s$^{-1}$)</th>
<th>Precipitation (mm)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Medium</td>
<td>11.0</td>
<td>41.7</td>
</tr>
<tr>
<td>2013</td>
<td>June</td>
<td>20.4</td>
<td>35.0</td>
<td>27.7</td>
<td>21.0</td>
<td>33.3</td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>19.9</td>
<td>35.8</td>
<td>27.8</td>
<td>6.7</td>
<td>47.8</td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>18.1</td>
<td>33.8</td>
<td>26.0</td>
<td>5.7</td>
<td>46.0</td>
</tr>
<tr>
<td>2014</td>
<td>June</td>
<td>20.0</td>
<td>33.5</td>
<td>26.8</td>
<td>9.8</td>
<td>48.0</td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>21.6</td>
<td>33.6</td>
<td>27.6</td>
<td>7.8</td>
<td>54.6</td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>20.9</td>
<td>35.8</td>
<td>28.4</td>
<td>6.7</td>
<td>59.3</td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>18.4</td>
<td>34.3</td>
<td>26.4</td>
<td>6.1</td>
<td>55.8</td>
</tr>
</tbody>
</table>

Source: Meteorological Station, Zankalon Experimental Field, WMRI.
(0.3), L is the length of the weir (1.5 m) and h is the head in the weir (in m) (El-Khateeb et al., 2009).

Table 3 shows the treatments, treatment symbols, irrigation frequency, irrigated water amount and water saving ratio, comparing with the irrigation treatment of conventional interval and conventional furrow method (CF) as a standard treatment. In CF plots 5353 m$^3$ ha$^{-1}$ and 5514 m$^3$ ha$^{-1}$ of water were applied in 2013 and 2014, respectively. Under the conventional irrigation interval, the strip irrigation method (CS) saved 26 - 31%. While, prolonging the interval with conventional furrow irrigation (PF) and the combination of both water-saving treatments (PS) could save 8 - 19% and 28 - 37%, respectively.

Fertilizer was applied by a method practiced by the regional farmers. All plots received 274 kg N, 55 kg P$_2$O$_5$ and 57 kg K$_2$O ha$^{-1}$ in total. Urea, superphosphate and potassium sulfate were used to apply these nutrient rates. Superphosphate was applied during land preparation, and 1/5 of the urea and all the potassium sulfate were applied with the 1st irrigation after seeding. The remaining amount of urea was applied at 1 month after sowing and at the beginning of the tasseling stage (2/5 of urea each time).

Maize were harvested on Sep 22 (98 days after sowing; DAS) in 2013 and Sep 16 (100 DAS) in 2014.

**Monitoring soil water status**

Soil water potential in each plot was measured at 10 cm, 20 cm and 40 cm depth from the soil surface between June and September in the maize growing seasons in 2013, using tensiometers (DIK-8343, 8333, 833, Daiki Rika Kogyo Co. Ltd.). In each plot, a set of tensiometers for measuring at 10, 20, 40 cm depth was installed at around the center of the half the plot which was divided by waterway (Fig. 3), and the mean values over the 3 replicated plots are presented. The soil water

Table 3. Irrigation amount and water saving ratio of each irrigation treatment.

<table>
<thead>
<tr>
<th>Year</th>
<th>Irrigation interval</th>
<th>Irrigation method</th>
<th>Treatment symbol</th>
<th>Total irrigation times</th>
<th>Total irrigation amount (m$^3$ ha$^{-1}$)</th>
<th>Water saving ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>Conventional</td>
<td>Furrow irrigation</td>
<td>CF</td>
<td>6</td>
<td>5353</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strip irrigation (Wide-bed furrow)</td>
<td>CS</td>
<td>6</td>
<td>3978</td>
<td>25.7</td>
</tr>
<tr>
<td></td>
<td>Prolonged</td>
<td>Furrow irrigation</td>
<td>PF</td>
<td>5</td>
<td>4936</td>
<td>7.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strip irrigation (Wide-bed furrow)</td>
<td>PS</td>
<td>5</td>
<td>3866</td>
<td>27.8</td>
</tr>
<tr>
<td>2014</td>
<td>Conventional</td>
<td>Furrow irrigation</td>
<td>CF</td>
<td>6</td>
<td>5514</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strip irrigation (Wide-bed furrow)</td>
<td>CS</td>
<td>6</td>
<td>3829</td>
<td>30.6</td>
</tr>
<tr>
<td></td>
<td>Prolonged</td>
<td>Furrow irrigation</td>
<td>PF</td>
<td>5</td>
<td>4492</td>
<td>18.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strip irrigation (Wide-bed furrow)</td>
<td>PS</td>
<td>5</td>
<td>3488</td>
<td>36.7</td>
</tr>
</tbody>
</table>

* : Water saving ratio was calculated using CF treatment as a control.
tension was recorded twice a week.

Maize plant growth

Maize plants were sampled at the beginning of their reproductive phases to investigate the effects of irrigation intervals and irrigation methods on plant growth during the season. Those were Aug 24 (69 DAS) which was early grain filing stage in 2013, and Aug 9 (62 DAS) which was early ear setting stage in 2014. Three plants were sampled from each plot, and the plant height, number of leaves and SPAD values were recorded. They were moderately-growing plants selected at around the center on the diagonal line of half part of the plot which was divided by waterway (Fig. 3). The plants were separated to leaf, stem and ear, and dried in oven at 70°C for 72 h to obtain the dry weight of each part. Water use efficiency at this stage (WUEER) was calculated as the above-ground dry weight divided by the amount of irrigated water from sowing day to the investigated day.

Measurement of photosynthetic rate

In 2014 photosynthetic rate of maize leaves were measured using a portable photosynthesis system (LI-6400 EX, LI-COR Inc.) at the beginning of reproductive growth. This was conducted 1 and 2 days after the sampling of maize plants for growth investigation. The photosynthetic rates were measured as (1) diurnal changes within a day using the natural sun light, and (2) response to different photosynthetic photon flux density (PPFD) values, i.e. light response curve of photosynthesis. For all the measurements, the 3rd leaf from the flag leaf was selected in the 3 plants in each plot which were close to the plants for plant growth investigation. The air flow rate sent to the chamber was 500 μmol s⁻¹. The ambient CO₂ concentration sent to the chamber was 372 ± 24.6 μmol mol⁻¹ (Aug 10) and 378 ± 26.6 μmol mol⁻¹ (Aug 11) for recording diurnal changes, and 371 ± 7.6 μmol mol⁻¹ for light response curve (Aug 12). The temperature in the chamber was controlled at 30°C. The procedures of these 2 measurements are given below.

(1) To investigate the diurnal changes of the photosynthetic rate, measurements were carried out every 1.5 h between 7:30 and 18:00. The measurements were conducted on Aug 10 for conventional interval plots (CF and CS), and Aug 11 for prolonged interval plots (PF and PS). The plastic filmed chamber containing the maize leaf was held perpendicular to the sunlight to measure the actual photosynthetic rate under natural light. Photosynthetic rates were recorded 8 times with an interval of 10 sec for each leaf by AutoLog, and the mean value was presented. The diurnal changes of photosynthetic photon flux density (PPFD) which the leaves received were also recorded. The vapor pressure deficit in the chamber was not controlled, and it was 1.70 ± 0.55 kPa on Aug 10 and 1.66 ± 0.86 kPa on Aug 11. On the day of measuring the soil samples were taken from 0 · 20 cm depth, and dried at 105°C for 48 h in the oven to obtain soil moisture content.

(2) Response of photosynthetic rate to PPFD was measured at between 9:00 and 12:20 using LED chamber with artificial light on Aug 12. The PPFD applied were between 0 and 2000 μm⁻² s⁻¹. The measurement was carried out with the following order of PPFD: 2000, 1500, 1200, 1000, 800, 600, 400, 200 100, 50 and then 0 μm⁻² s⁻¹, by AutoLog of the portable photosynthesis system (once at each PPFD).

Grain yield and the final WUE

At harvest time, 3 plants were randomly selected from 3 spots in each plot, i.e. 9 plants from each plot, on Sep 22 in 2013 and Sep 16 in 2014. These 3 spots were selected on the diagonal line of half part of the plot which was divided by waterway. After maize plants were cut at the soil level, the plants were separated into each part, and the ears were first dried under the sun. The grains were separated from the ears, and then dried in the oven at 70°C for 72 h together with other parts of plant samples to obtain their dry weight. The data of grain yield was obtained by adjusting the weight to 15% moisture content. The WUE_GY was calculated as the grain yield divided by the total amount of irrigation water (from sowing to the harvest). The WUE_DW was calculated as the final above-ground dry weight divided by the total amount of irrigation water (from sowing to the harvest).

The effects of the treatments in all data sets were analyzed by using Statistix ver. 9 (Analytical Software. Co. Ltd.).

Results

Change in soil water potential

Figure 3 shows the change of soil water potential measured from June 23 to Sep 23 in 2013. From the end of August soil up to 40 cm depth tended to get drier than the earlier time. At the middle of September, the soil became drier again especially in the plots of CS and PS, and the moisture states at 10 cm depth reached the lento-capillary point (-50 kPa). Just after the irrigation
on July 25, tensiometer readings could not be taken for some uncontrollable reason.

**Plant growth at the beginning of reproductive phase**

Table 4 shows, in both years, there were no significant effect of irrigation treatments except on \( \text{WUE}_{\text{ER}} \). Effects of irrigation treatments on \( \text{WUE} \) until this stage (\( \text{WUE}_{\text{ER}} \)) were consistent regardless of the years, and the strip irrigation method had higher \( \text{WUE}_{\text{ER}} \) than conventional furrow irrigation under both irrigation intervals. The plant height, leaf number, SPAD value and above-ground dry weight did not show any single treatment effect. They had some interaction effects such as with SPAD in 2013, and with plant height and stem dry weight in 2014 where strip method showed tendency to have positive effect under conventional interval but not under the prolonged interval.

**Photosynthetic activities of maize leaves**

**Diurnal changes**

The diurnal changes of photosynthetic rate of
maize leaves at early reproductive phase were measured in 2014, and the soil moisture contents (by weight) of 0–20 cm depth on the day of measurement were recorded (foot note of Fig. 5). The soil in CF and CS were drier than PF and PS, and there were little difference between PF and PS. This is because CF and CS plots, and PF and PS plots were irrigated 14 days and 5 days before the measurement, respectively.

Figures 5a and 5b show that PPFD reached about 1500 μmol m⁻² s⁻¹ at midday on both days. Although there were no significant differences in photosynthetic rates among the treatments, there were some tendencies. Under the conventional irrigation interval (Fig. 5c), there were little differences between strip irrigation plots (CS) and furrow irrigation plots (CF), while, under the prolonged irrigation interval (Fig. 5d), maize leaves in the strip irrigation plots (PS) tended to decrease the photosynthetic rates after midday but those in the furrow irrigation plots (PF) did not reduce the rate until in the late afternoon. These tendencies of PF and PS were not corresponding to the soil moisture contents of that day.

Light response curve of photosynthesis

Interaction effects of irrigation methods were significant in the response of photosynthetic rate of maize leaves to the PPFD of the artificial light at 600, 1000, 1200 and 1500 μmol m⁻² s⁻¹ (Fig. 6). There were effects of irrigation interval on photosynthetic rate with PPFD equal to and higher than 200 μmol m⁻² s⁻¹, except with PPFD of 1500 μmol m⁻² s⁻¹. The positive tendency of strip irrigation method was shown in photosynthesis under the conventional irrigation interval but not under the prolonged interval. Under the PPFD of 2000 μmol m⁻² s⁻¹ the highest rate was 47.3 μmol CO₂ m⁻² s⁻¹ with CS, and the lowest was 29.3 μmol CO₂ m⁻² s⁻¹ with PS treatment.

Grain yield, dry matter production and WUE

Although the growing environment was the same in 2013 and 2014 (Table 2), the grain yield differs among years (Table 5).

In 2013 with all parameters (above-ground dry weight, grain yield, grain number, 100-grain weight, and WUEs) except CGR, values were higher with conventional interval, and PS. Prolonged interval and furrow irrigation, PS. Prolonged interval and strip irrigation.


<table>
<thead>
<tr>
<th>Year (growth stage)</th>
<th>Irrigation treatment</th>
<th>Plant height (cm)</th>
<th>Leaf No.</th>
<th>SPAD</th>
<th>Above-ground dry wt (t ha⁻¹)</th>
<th>Water irrigated (m³ ha⁻¹)</th>
<th>WUEER⁺ (kg m⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013 (69 DAS: early grain-filling stage)</td>
<td>CF</td>
<td>260.3</td>
<td>14.3</td>
<td>50.2</td>
<td>2.2</td>
<td>4.9</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>CS</td>
<td>283.9</td>
<td>12.7</td>
<td>52.2</td>
<td>2.3</td>
<td>5.1</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>266.3</td>
<td>13.0</td>
<td>54.2</td>
<td>2.1</td>
<td>4.8</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>PS</td>
<td>274.8</td>
<td>13.1</td>
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<td>2.4</td>
<td>4.6</td>
<td>2.0</td>
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<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
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<td>n.s.</td>
</tr>
<tr>
<td>2014 (62 DAS: ear-setting stage)</td>
<td>CF</td>
<td>200.3</td>
<td>14.2</td>
<td>42.6</td>
<td>2.3</td>
<td>3.7</td>
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<tr>
<td></td>
<td>CS</td>
<td>226.7</td>
<td>14.7</td>
<td>45.0</td>
<td>2.3</td>
<td>5.0</td>
<td>7.3</td>
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<td></td>
<td>PF</td>
<td>236.0</td>
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<td></td>
<td>PS</td>
<td>223.7</td>
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<td>45.3</td>
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</tr>
<tr>
<td>Interval × Method</td>
<td>**</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
</tbody>
</table>


**: "n.s." indicates there was no significant difference at p<0.05.

**: "*" and "**" indicate that the difference was significant with p<0.05 and p<0.01, respectively.

**: The plants in 2014 had not formed ears yet.

**: WUEER: Water use efficiency at early reproductive growth stage.
interval (Table 5). Under both irrigation intervals the strip irrigation method made dry matter production lower than the furrow irrigation method. There were no significant effects of the irrigation method on grain yield. The WUE_DW and WUE_GY were significantly higher with strip method than with furrow method under both irrigation intervals. The interaction effects of two treatments were not significant in 2014.

**Discussion**

**Irrigated water amount and soil water status**

The amount of water was controlled by frequency...
and the number of the irrigation ditches per area. Prolonging the irrigation interval by about 1 week saved 8 - 19%, and the strip irrigation with fewer irrigation ditches saved 26 - 31% (Table 3). This clearly shows that the strip method is more effective in saving water than reducing the frequency of irrigation events. Although the number of irrigation ditches was reduced by 50% with strip method, the water applied was not reduced by 50% because the water seepage horizontally to the wide planting bed.

The water amount saved by prolonging the irrigation interval were similar to the study with the same treatment but in the different experimental field (Kubota et al., 2016). In referred study the field experiment was conducted in the different location of different Governorate in the Nile Delta, and showed that the water was saved by 8 - 11% by prolonging the interval by 1 week although the soil characteristics were different with the higher clay contents (60 - 70%) than the presently studied field (47 - 48%, Table 1). These results also follows the measurement of evapotranspiration in maize fields by Sugita et al. (2017) in the Nile Delta region. In their study, comparing with the standard furrow irrigation method in maize field, strip irrigation method lowered evapotranspiration rate more than prolonged interval irrigation. Those irrigation treatments affected soil water potential mainly the surface soil (0-10 cm) (Fig. 4). After the end of August soil was drier than lento-capillary point in strip irrigation method plots, especially in under prolonged interval (PS). This means the soil water was not enough in PS for maize plant, which can cause water-deficit condition.

**Dry matter production and grain yield**

We obtained different results in 2013 and 2014 in final above-ground dry weight and grain productions. The grain yield range of maize also differed. The final dry weight of maize plants were greater in 2014 than those in 2013 (Table 5) although at the beginning of the reproductive phase there were no difference among years when investigation timing is considered (Table 4). The greater dry matter production in 2014 is corresponding to the higher CGR during reproductive phase in 2014 than those in 2013 except CS treatment (Table 5). The CGR of all treatments in 2014 and that of CS treatment in 2013 were quite high and ranged between 30 and 40 g m⁻² day⁻¹. An example of high CGR values was also reported in the study of Shinoto et al. (2017) with maize grown in an upland field converted from rice paddy field. The CGR were between 21

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Table 5. Above-ground dry weight of maize plants at harvesting time, grain yield and water use efficiency (WUE). (harvested on Sep 22 in 2013, and Sep 16 in 2014)

<table>
<thead>
<tr>
<th>Year</th>
<th>Irrigation treatment</th>
<th>Above-ground</th>
<th>Grain</th>
<th>Irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Above-ground dry wt (t ha⁻¹)</td>
<td>CGR during 2 investigations (g m⁻² day⁻¹)</td>
<td>Grain yield (t ha⁻¹)</td>
</tr>
<tr>
<td>2013</td>
<td>CF</td>
<td>12.9</td>
<td>15.1</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>CS</td>
<td>17.8</td>
<td>31.0</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>11.4</td>
<td>12.4</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>PS</td>
<td>9.6</td>
<td>2.3</td>
<td>3.3</td>
</tr>
</tbody>
</table>

**Interval**

n.s. * **

**Method**

* n.s. n.s. n.s. **

**Interval × Method**

* n.s. n.s. n.s. **

| 2014 | CF                  | 21.3         | 40.3  | 9.6        | 2985       | 32.2          | 5514              | 3.86            | 1.74           |
|      | CS                  | 18.8         | 30.2  | 8.5        | 2739       | 31.0          | 3829              | 4.91            | 2.21           |
|      | PF                  | 20.9         | 36.8  | 8.8        | 2835       | 31.0          | 4492              | 4.65            | 1.96           |
|      | PS                  | 18.1         | 30.2  | 8.1        | 2597       | 31.3          | 3488              | 5.20            | 2.33           |

**Interval**

n.s. n.s. n.s. n.s. n.s. n.s.

**Method**

* n.s. n.s. n.s. **

**Interval × Method**

n.s. n.s. n.s. n.s. n.s. n.s.

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* CF: Conventional interval and furrow irrigation, CS: Conventional interval and strip irrigation, PF: Prolonged interval and furrow irrigation, PS: Prolonged interval and strip irrigation.

* CGR: Crop growth rate.

* "*" and "**" indicate that the difference was significant with \( p < 0.05 \) and \( p < 0.01 \), respectively.

* n.s." indicates there was no significant difference at \( p <0.05 \).

* WUE DW: Water use efficiency based on dry weight of above-ground dry weight.

* WUE GY: Water use efficiency based on the grain yield.

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and 40 g m⁻² day⁻¹, in referred study. The dry matter production and grain yield of PS in 2013 were very low, which was possibly caused by water deficit indicated by the tensiometer readings (Fig. 4). We cannot clearly explain the reason of these differences among 2 years since climate condition and irrigated water amount were almost identical (Table 2, Table 5). Only the difference was the sowing date.

Although the soil moisture data in PS was not lower than that in PF plot, the photosynthetic rate of maize leaves in PS plots declined when PPFD raised in midday and showed that they were under water deficit stress (Fig. 4).

The photosynthetic rates were measured only once during the maize growth in 2014. The light response curves of photosynthesis showed the tendency of CS>CF>PF>PS. These results, though limited, suggest that the differences in dry matter production among treatment (Table 5) relate to the water deficit condition during their growth.

Effects of irrigation treatments were not consistent with investigated parameters and years. However, one can conclude that strip irrigation method has no negative effect on maize grain yield, while, prolonging the interval may have a risk to reduce the maize yield (Table 5).

About strip irrigation method, the result of 2013 showed a tendency agreed with the study of Atta (2007), conducted in the same experimental field, that the wide-planting-bed strip irrigation increases maize grain yield by 8.5% (6.3 to 6.8 t ha⁻¹) under the conventional irrigation interval, although the difference was not statistically significant in our study. One of the possibilities why the strip method can increase the maize productivity is improved aeration in the soil. Kubota et al. (2016) observed unexpected stagnation in photosynthetic rate for about 6 days after irrigation event with maize plants grown in the field within the Nile Delta, and suggested this is possibly caused by waterlogging in the clayey soil. These results suggest that strip irrigation method can be an effective method particularly in the clayey soil.

Our results indicate prolonging the interval by about 1 week has a risk of reducing the dry matter production and grain yield of maize. This result is controversy to the study of Kubota et al. (2016) which was conducted in the different location within the Nile Delta. According to the referred study, prolonging the interval by about 1 week did not affect the maize grain yield. The soil clay contents of the present study were between 47 and 48% (Table 1), while, those of referred study were between 60 and 70% at 0 - 80 cm depth (Kubota et al. 2016). The available water of volumetric water content, which is generally defined as the difference between soil moisture content at field capacity and wilting point, was determined as 0.15 cm³ cm⁻³ with the surface soil from the present study field (Kubota et al., 2017), while, it was 0.20 cm³ cm⁻³ with the surface soil of the field from the referred study (Kubota et al., 2016). The level of ground water also differed among 2 studies. The level was lower in the field of present study (1.34 ± 0.26 m in 2013 and 1.60 ± 0.20 m in 2014), than that in the field for the referred study (0.65 - 0.71 m) (calculated from data provided by M. Sugita). These comparison confirmed that when we try to save water by prolonging irrigation interval, we need to collect information of soil clay contents, water holding capacity and ground water levels of the target field.

Water Use Efficiency (WUE)

At the beginning of reproductive phase of maize plants, strip method increased WUEₓₒ in both years (Table 4). On the investigation at harvest, strip method had positive effects on WUEₓₒ and WUEᵧ in both years. However, in 2013, strip irrigation could improve WUEs only under the conventional interval. With PS treatment, dry matter production and grain yield were very low and could not contribute to improve both WUEs. In 2013, under the conventional interval, the effect of strip method was clear. It improved WUEᵧ by 71%, and could be estimated that CS treatment saved about 192 L of water to produce 1 kg of maize grain compared to CF treatment. In 2014, strip method improved WUEs under both irrigation intervals. Maruyama et al. (2017) also reported that the strip irrigation method for maize cultivation in Egypt improved WUE, grain yield/ET, by 18% compared with furrow irrigation method. The ET measured during the maize growing season under furrow and strip irrigation method were 356 and 258 mm, respectively.

Prolonging interval did not improve WUEₓₒ and WUEᵧ in 2013 but decreased. There was no effects of interval treatments on WUEs in 2014. This again agrees with the study of Maruyama et al. (2017) that prolonged irrigation interval from 14 to 21 days reduced ET by 3%, and lowered maize grain yield by 16%, which led to no improvement in WUE.

Conclusion

The strip irrigation method with wide planting bed was more effective in saving water (26 - 31%) than prolonging the irrigation interval by about 1 week (8 -
19%). Although the treatments had different effects in 2 years, our results suggest that prolonging the interval by about 1 week from the conventional interval has a risk of yield reduction in the field with soil clay contents equal to or less than 50% and rather low ground water level of 1.3 – 1.6 m. While, the strip irrigation method has possibility to sustain the grain yield of maize and to improve WUE$_{cv}$ as much as 71% when irrigation interval is practiced as conventional. Under the prolonged irrigation interval, maize plants with the strip method showed low photosynthetic rates due to water deficit. Thus, the strip irrigation method with the conventional interval, which is not technically and financially difficult to be practiced by farmers in the region, is recommended for both maize production and saving limited water resources in the Nile Delta.

Acknowledgments

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