RESEARCH ARTICLE

Influence of super absorbent polymer (ZEBA) on growth, yield of cabbage (*Brassica oleracea*), and soil water retention under temperature and water stress condition

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Submitted: November 10, 2020; Revised: December 26, 2020; Accepted: December 30, 2020
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ABSTRACT

Agricultural crop productivity is decreasing due to various unprecedented climatic variations like water and temperature stresses. Therefore, it is imperative to find sustainable agricultural productivity without underestimating the losses due to the vagaries of climatic changes. Application of super absorbent polymers (SAPs) is one of the modern techniques that can be used to mitigate the water stress in plants induced by temperature stress. ZEBA is an organic type of SAPs. This study investigated the interaction effects of irrigation, temperature, and application of ZEBA on the growth and yield of cabbage (Brassica oleracea) and soil moisture, N, P, and K of soil at the Open University, Sri Lanka. An experiment was carried out in a factorial layout based on a completely random design with three replications. The factors were two-level of ZEBA (with and without application of ZEBA), three irrigation intervals (3, 5 and 8 d), and two temperature conditions (32-33 °C and 35-36 °C). Analysis of variance (ANOVA) for measuring parameters was run by the SAS programme package (SAS studio 3.8), and a three-factor model was used to determine the effect of temperature, irrigation interval, ZEBA, and their interaction effects on measure parameters at the 0.05 significance level. Results of the statistical analysis showed that ZEBA, irrigation levels, temperature, and their interactions had a significant ($P<0.05$) effect on measured growth, yield, and soil parameters. Results proved that application of ZEBA with three days and five days irrigation intervals significantly ($P<0.05$) increased the plant height, width of canopy, fresh weight of leaves, fresh weight of heads, the relative water content of leaves, soil moisture, N, P, and K either at the ambient temperature or increased temperature conditions. While considering the water stress that can be occurred due to global warming, the irrigation interval could be extended up to 5 d without a yield reduction, using ZEBA to conserve water in cabbage cultivation.

Keywords: *Cabbage, super absorbent polymers, temperature stress, water stress*

INTRODUCTION

Sri Lanka is a developing country, and agriculture is one of the most prominent ways for income generation, while over 25% of Sri Lankans are employed in this sector (Dharmarathna *et al.,* 2019). Among agricultural crops, vegetables belong to cash crops, and farmers are more inclined to cultivate them. However, vegetable crops are more sensitive to extreme and variations in climatic conditions like temperature and water stress (Sayyari and Ghanbari, 2012). Recent global estimates predict that, by 2080, climate change will reduce world agricultural production capacity as much as 16% of average production and when considering Sri Lanka, reported that the reduction is projected to be more severe, with production losses of up to 20% (Cline, 2007).

According to many findings in Sri Lanka based on Hadley Centre of Climate Change Prediction developed HadCM3 (UK) general circulation model has revealed that the temperature will increase by 2 °C in 2050 (De Silva *et al.,* 2007; Gunawardana and De Silva, 2014). The trends for mean surface temperatures show a trend of 2.6 °C/100 y on average in annual average maximum temperature and 1.7 °C/100 y for annual average minimum temperature in Sri Lanka (Zubair *et al.,* 2005). High temperature could limit plant growth, leaf development, and photosynthesis (Rodríguez *et al.,* 2015).

Water stress is another of the utmost imperative stress situations, causing severe impacts on crop growth and crop development, thus affecting its productivity. Sri Lanka is well endowed with water resources, but with an increase in population and the emerging problem of water quality degradation, the water resources available for drinking, agricultural and commercial uses is likely to reduce in the future (Nisansala *et al.,* 2019). Most of the Dry Zone districts will face severe seasonal or year-round water scarcity by 2025 with the present level of irrigation efficiency (Samad *et al.,* 2017). Therefore, it is crucial to improve the water use efficiency of plants with an improved water use efficiency technologies to use a limited amount of available water effectively.

There is a need to develop innovative techniques to effectively use water in agriculture to meet the growing demands for food. The use of soil conditioners like super absorbent polymers (SAPs) has a great potential to conserve existing water in soil due to its ability to absorb and retain large amounts of water against gravitational forces and release it on demand meet plant water requirements. SAPs can be categorized as inorganic and organic.

ZEBA is an organic type of SAPs and produced using corn starch as the main ingredient. ZEBA is water-retaining, cross-linked hydrophilic, a biodegradable polymer which can absorb and retain water at least 400 times its original weight and make at least 95% its stored water available for plant absorption (Johnson and Veltkamp, 1985). Also, SAPs can act as a reservoir holding on to nutrients from fertilizer, preventing them from leaching from the root zone (Liang *et al.,* 2007; Rudzinski *et al.,* 2002).

Cabbage (*Brassica oleracea*), belonging to the family Brassicaceae is one of the important vegetable crops in many parts of Sri Lanka. Cabbage is more sensitive to temperature and water stress conditions. Application of SAPs recorded higher yield of cabbage both on per plant and on area basis, while lower yield was noticed in control (Ananda, 2009).

Keeping these aspects in view and considering their importance in increasing growth and yield in cabbage, the present investigation on "Effect of Super Absorbent Polymer (ZEBA) on growth, yield of cabbage (*Brassica oleracea)* and water retention of the soil under temperature and water stress condition" was carried out. Further, the interaction effect of ZEBA (organic based SAPs), temperature, and irrigation on physiological parameters, productivity potential in cabbage, soil nutrient, and soil moisture retention were tested in the study.

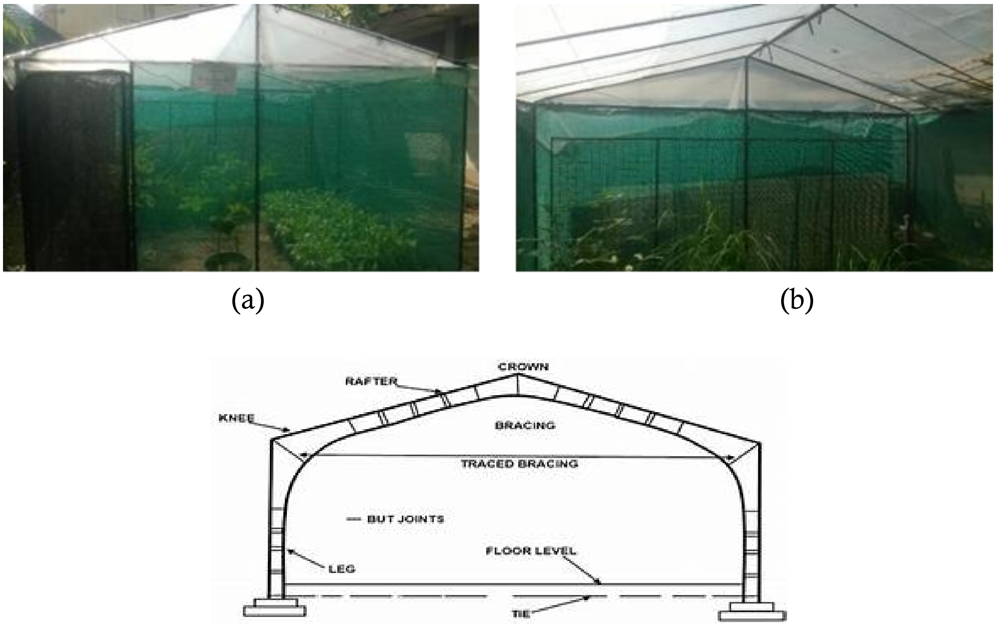
MATERIALS AND METHODS

The study was conducted at the Open University of Sri Lanka, Nawala, Nugegoda, from September 2018 to October 2020, and the experiments were replicated thrice. The cabbage cultivar Exotic-F1 was used in this study. Three weeks old healthy and uniform cabbage seedlings were obtained from the nursery and transplanted in pots filled with reddish-brown earth soil.

Treatments details

This study was carried out as a factorial experiment in a completely random design. Plant house was used to maintain plants at ambient temperature (32-33 °C), and this temperature range was selected based on the data of the Meteorological Department of Sri Lanka. According to that maximum ambient temperature around Colombo is around 32 °C during the years of 2015-2018. The temperature of the plant house was measured three times per day throughout the day time to check the temperature fluctuations during the period of study, and the measured average temperature during the study period was around 32 °C (Figure 1).

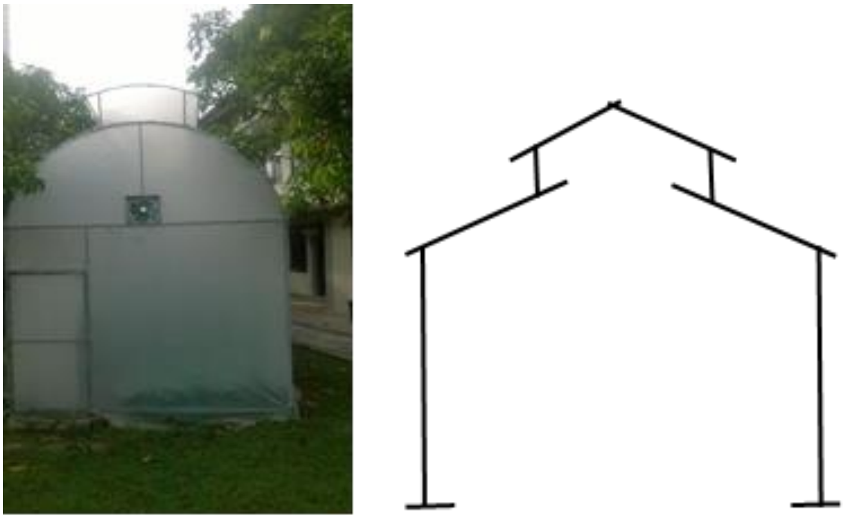
The polytunnel was used to maintain plants at increased temperatures (35–36 °C) (Figure 2). Automated temperature controlling unit, thermostats, and ventilation fans were installed in polytunnel (Figure 3), and the temperature was set for 36 °C as maximum temperature. These temperatures were selected based on Intergovernmental Panel on Climate Change results on global climate (IPCC, 2007) and the HadCM3 (UK) predictions of Sri Lankan air temperature in 2050 for the A2 scenario of IPCC (De Silva *et al.,* 2007; De Silva, 2006). When the temperature inside the polytunnel increases above the maximum set temperature of 36 °C, the ventilation fans start to operate automatically until the temperature is reduced to the maximum set temperature in the thermostats. Semi-circular elongated in shape with open space at the top of the poly tunnel facilitated the natural circulation of air.



(a) (b)

(c)

Figure 1: Plant house used to keep plants at ambient temperature condition (32–33 °C), (a) Front view of the plant house, (b) Inside of the plant house, (c) Rigid frame structure of the plant house.



(a) (b)

Figure 2: Polytunnel used to keep plants at increased temperature condition and its open vent roof structure which facilitated the natural air circulation. (a) Front view of the polytunnel, (b) Top-vent roof structure of the polytunnel.

(a) (b)

Figure 3: Temperature control unit inside the polytunnel which was installed to keep plants at increased temperature (36 °C). (a) Thermostat meter, (b)Ventilation fan.

The variation of the temperature inside the polytunnel and the plant house over 24 h was observed as shown below (Figure 4). The temperature at the plant house was lower than the maximum temperature set for that particular polytunnel, and during the day, it varied to represent the diurnal variation. However, the temperature maintained inside the polytunnels was always higher than the ambient temperature at the plant house; therefore, temperature stress was forced on the plants during day time while there was photosynthetic activity.

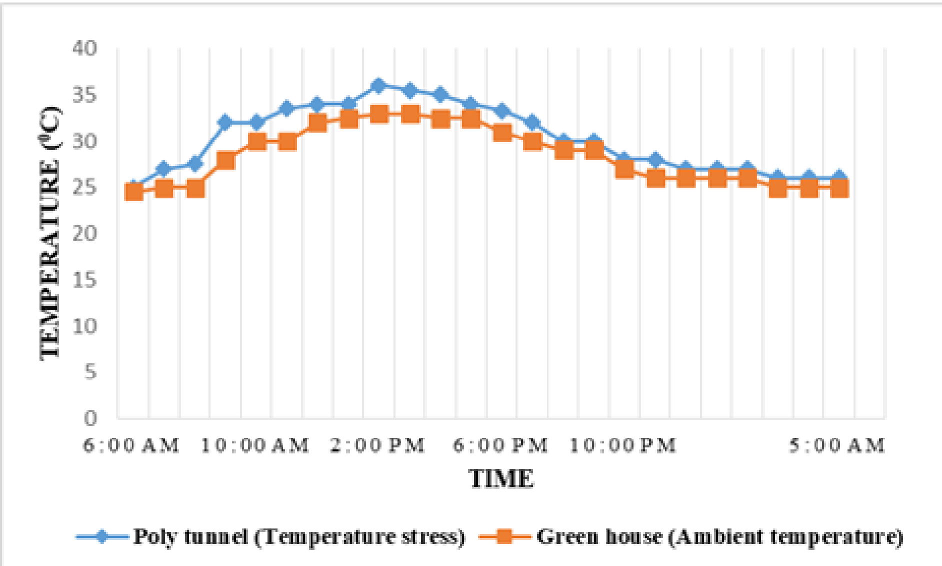


Figure 4: Average Temperature variations inside the polytunnel and plant house within a day

Relative humidity and light intensity were measured daily inside the polytunnel and plant house to keep the environment uniform. But, there were no significant (*P*>0.05) differences in RH and light intensity observed inside the two structures. These results were comparable with prior findings, which were obtained using these same structures at the Open University of Sri Lanka (Gunawardena and De Silva, 2014).

The second factor considered in this study was irrigation interval with three levels as 3, 5 and 8 d. Generally, the watering of cabbage was done once in three days, according to the recommendation of the Department of Agriculture, Sri Lanka.

Therefore, extended irrigation intervals up to 5 and 8 d were produced water stress conditions to the plant due to lack of water in soil media. The third factor was application of ZEBA with two levels as without and with 2 g of ZEBA per pot. The details of all the treatments were furnished below (Table 1).

Table 1: Different treatments used to identify the interaction effect of ZEBA, temperature, and irrigation interval on growth and yield of cabbage and soil water retention and nutrient.

Factor 1	Factor 2	Factor 3	Treatments
Temperature (T)	ZEBA (Z)	Irrigation interval (I)	
Increased temperature (35-36 °C) – T1	Without ZEBA- (Z1)	3 d – (I1)	T1Z1I1
		5 d – (I2)	T1Z1I2
		8 d – (I3)	T1Z1I3
	With ZEBA – (Z2)	3 d – (I1)	T1Z2I1
		5 d – (I2)	T1Z2I2
		8 d – (I3)	T1Z2I3
Ambient Temperature (32-33 °C) – T2	Without ZEBA– (Z1)	3 d – (I1)	T2Z1I1
		5 d – (I2)	T2Z1I2
		8 d – (I3)	T2Z1I3
	With ZEBA – (Z2)	3 d – (I1)	T2Z2I1
		5 d – (I2)	T2Z2I2
		8 d – (I3)	T2Z2I3

Water management

After transplanting, plants were watered daily for seven (07) days to field capacity measured by pressure plate until plants were well established. Additional eighteen pots were placed inside the plant house and polytunnel (three different pots for each treatment) without adding ZEBA and plants to determine the weight losses in soil media due to evaporation. They were watered following the watering intervals with three replicates. Before watering the additional eighteen pots at the poly tunnel and plant house were weighted and confirmed the constant weight in all pots. According to the weight losses amount of water required for each pot was calculated as follows.

$$\text{Weight losses from evaporation} = [W2 - W1]\ g$$

W1 g - Total weight of dried soil in the pot and empty weight of the pot
W2 g - Total weight of dried soil in the pot, empty weight of the pot, and added water to reach to the field capacity).
(W2 - W1) g - Amount of water added to each pot during watering.

Fertilization and other management practices were done according to recommendations of the Department of Agriculture, Sri Lanka.

Data analysis

All the measured data (Table 2) were subjected to Analysis of Variance (ANOVA) using SAS programme package (SAS studio 3.8), and a three-factor model was used to determine the effect of temperature (T), irrigation interval (I) and ZEBA (Z) and their interaction effects (T*I*Z, T*I, T*Z, Z*I) on plant height (cm), the width of the canopy (cm), fresh weight of leaves (g), the relative water content of leaves (%), fresh weight of heads (g) and selected soil properties of soil moisture (%), soil nitrate (%), water-soluble phosphorous (ppm) and available potassium (ppm) and significant at the 0.05 probability level.

RESULTS AND DISCUSSION

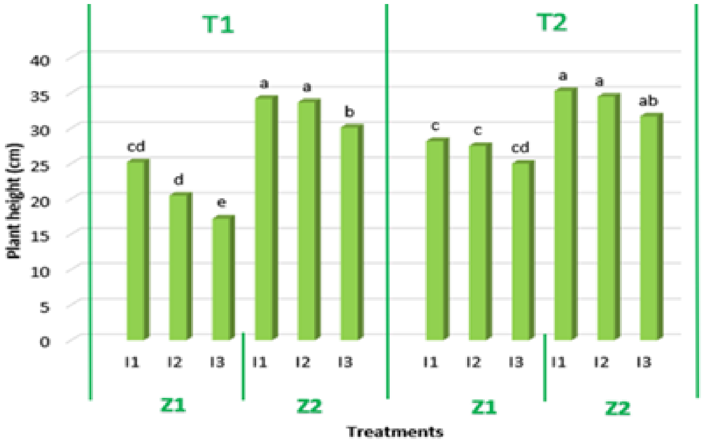
Growth parameters

Plant height and the width of the canopy

The data on plant height presented in Figure 5 indicated significant ($P<0.05$) differences among treatments. Treatment of ambient temperature with ZEBA and three days irrigation interval (T2Z2I1) was resulted in the highest plant height and width of the canopy (35.3, 30.2 cm, respectively) (Figure 5, 6). However, it was not significantly ($P>0.05$) different from the treatment of ambient temperature, with ZEBA, 5 d irrigation interval (T2Z2I2 – 34.5 cm, 30 cm) and treatments of increased temperature, with ZEBA, three days irrigation interval (T1Z2I1 – 34.2 cm, 28.2 cm) and increased temperature, with ZEBA, 5 d irrigation interval (T1Z2I2 – 33.7 cm, 27.5 cm).

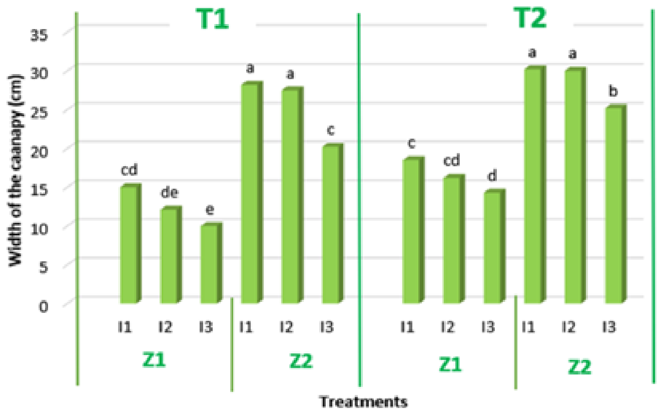
Table 2: Methods used to measure selected growth and yield parameters of cabbage and soil moisture, soil N, P, and K.

	CABBAGE Growth and Yield Parameters
Plant height (cm)	The height of the plants for each replicate recorded in centimetre by measuring the height from ground level to the terminal growing point of the shoot, then mean height worked out for each treatment.
Width of the Canopy (cm)	Width of the canopy of the plants for each replicate measured in centimetre by measuring the width of top of the canopy
Relative water content (%)	The relative water content was estimated based on the method of Barrs and Weatherly (1960). The RWC (%) was calculated by using the following formula; $\text{RwC (\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \text{X } 100$
Fresh weight of head (g per plant)	Cabbage heads were harvested when they are firm, compact and attained physiological maturity. The fresh weight of heads was recorded and the average weight of head was calculated for each treatment.
Dry weight of head (g per plant)	Harvested cabbage heads were chopped into small pieces to enable drying and were over dried at 80 °C to a constant weight. The oven dry weight of head was used work out dry weight of head per plant.
	Soil parameters
Soil nitrate (%)	measured using transnitration of salicylic acid method (Paul *et al.,* 1990)
Water soluble P (ppm)	Soil phosphorus measured calorimetrically using ammonium molybdate procedure by spectrophotometer according to Chapman and Pratt (1961) and Jackson (1973)
Soil available K (ppm)	K content measured using Ammonium acetate extraction method (Helmke and Sparks, 1996)
Soil moisture (%)	Soil moisture measured gravimetric method (Jalota *et al.,* 1998) before irrigation



T1 – Increased temperature, **T2** – Ambient temperature
I1 – 3 d, **I2** – 5 d, **I3** – days
Z1 – Without ZEBA, **Z2** – With ZEBA

Figure 5: Effect of different treatments on plant height (cm) of cabbage (*Brassica oleracea)* at harvest. Values followed by the same letter are not significantly different at p =0.05 level.



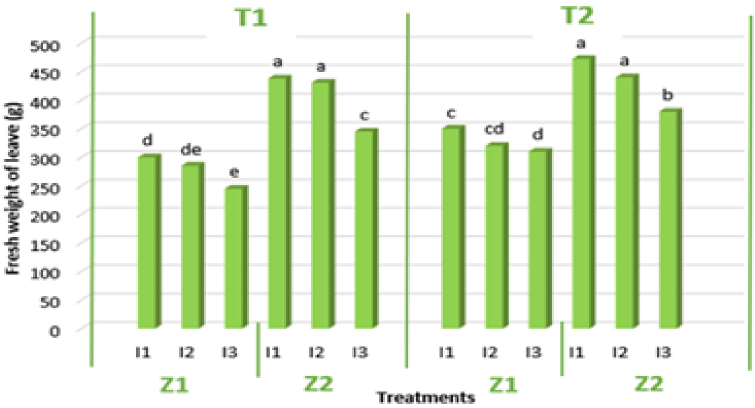
T1 – Increased temperature, **T2** – Ambient temperature
I1 – 3 d, **I2** – 5 d, **I3** – d
Z1 – Without ZEBA, **Z2** – With ZEBA

Figure 6: Effect of different treatments on the width of the canopy (cm) of cabbage (*Brassica oleracea).* Values followed by the same letter are not significantly different at *P* =0.05 level.

Significantly ($P<0.05$) the lowest plat height and width of the canopy were recorded to treat increased temperature, without ZEBA, 8 d irrigation interval (T1Z1I3) due to temperature stress condition and lack of water in soil media imposed by extended irrigation interval. Increased temperature and extended irrigation interval have resulted in leaf senescence and temporary wilting of cabbage plants. Gunawardena and De Silva (2014) reported that the interaction effect of both temperature and water stresses severely and negatively affects the plant growth and width of canopy. The same results were observed in this study.

Fresh weight of leaves

Application of ZEBA significantly ($P<0.05$) influenced the fresh weight of the leaves of cabbage (Figure 7).



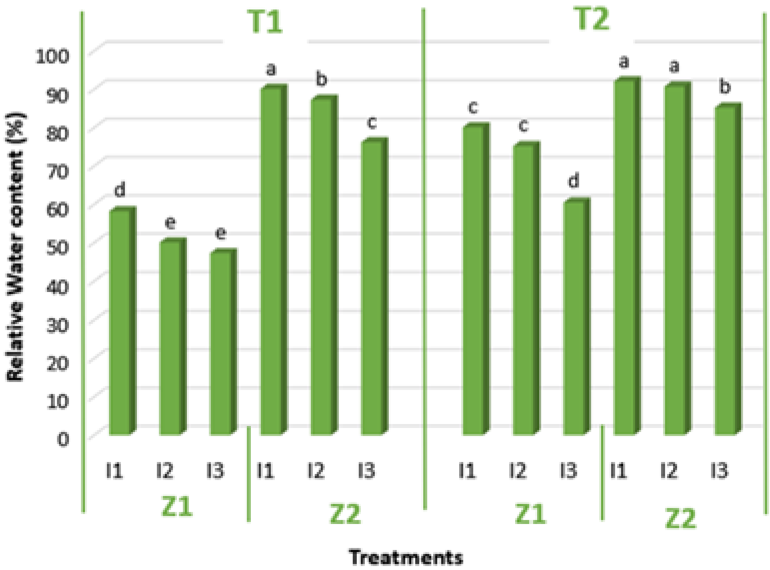
T1 – Increased temperature, **T2** – Ambient temperature
I1 – 3 d, **I2** – 5 d, **I3** – d
Z1 – Without ZEBA, **Z2** – With ZEBA

Figure 7: Effect of different treatments on fresh weight of leave (g) of cabbage (*Brassica oleracea)*. Values followed by the same letter are not significantly different at p =0.05 level.

The maximum fresh weight of leaves was recorded in the treatment of ambient temperature with ZEBA, 3 d irrigation interval (T2Z2I1 – 472 g). However, it was not significantly ($P>0.05$) different from the treatments of 3 d irrigation interval and 5 d irrigation interval with ZEBA at increased temperature conditions. Significantly ($P>0.05$) lower fresh weight of leaves was recorded in the treatments of 5 and 8 d irrigation interval, without ZEBA, at increased temperature conditions (T1Z1I2, T1Z1I3). It might be due to the fact that the increased temperature associated with longer irrigation intervals and absence of ZEBA. These results conform to the reports of Rodriguez *et al.* (2015); Islam *et al.* (2011). They reported that under increased temperature (higher than, 34 °C), there was a reduction in the weight of cabbage leaves that could be associated with general impairment of the photosynthetic activity. Further, they stated that the positive effect of SAPs in reducing the adverse effects of water stress conditions due to increased irrigation interval was reported in corn.

Relative water content (RWC) of cabbage leaves

One of the indices showed the status of water of plant is RWC. In this study, by increasing irrigation interval, RWC of the leaf was reduced (Figure 8), and it is in line with the results of Khadem *et al.* (2010).



T1 – Increased temperature, **T2** – Ambient temperature
I1 – 3 d, **I2** – 5 d, **I3** – d
Z1 – Without ZEBA, **Z2** – With ZEBA

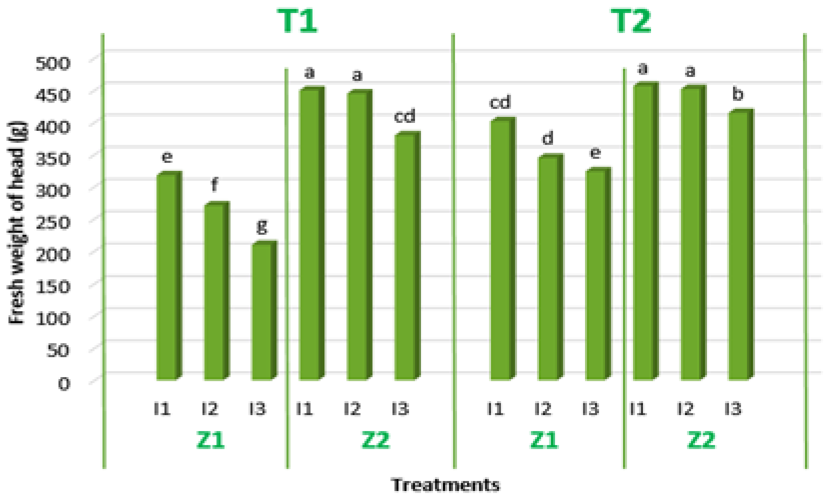
Figure 8: Effect of different treatments on the relative water content of leaves (%) of cabbage (*Brassica oleracea)*. Values followed by the same letter are not significantly different at p =0.05 level.

The reduction of RWC of the leaf has a direct relation with water reduction in soil (Nautiyal *et al.,* 2002). Using SAPs as ZEBA with storage of considerable water can keep humidity in the soil, and the amount of water is increased in the plant. The results of this study supported the above items as applying 2 g of ZEBA increased the RWC of leaves either at the increased temperature and longer irrigation interval, and that is in line with the results of Khadem *et al.* (2010) in corn and Nazerli *et al.* (2010) in sunflower plant. Treatment of ambient temperature with ZEBA, 3 d irrigation interval (T2Z2I1) has shown the highest percentage of RWC (92.1%) while treatment of increased temperature, without ZEBA and 8 d irrigation interval (T1Z1I3) has shown the lowest RWC (47.3%).

Yield parameters

Fresh weight and dry weight of heads

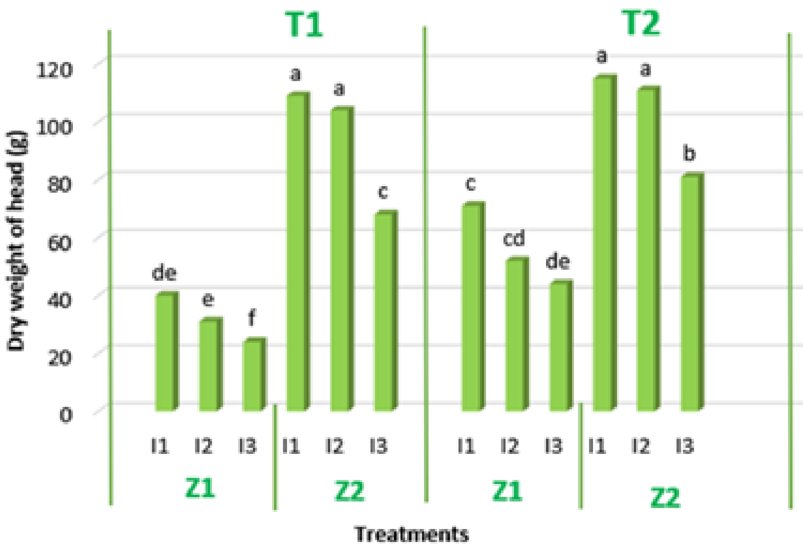
Treatment of increased temperature, without ZEBA, 8 d irrigation interval (T1Z1I3) was shown the significantly (*P*<0.05) lowest fresh and dry weight of the head. In contrast, treatment of ambient temperature, with ZEBA, 3 d irrigation interval was reported the highest weight of the head (Figure 9 and 10).



T1 – Increased temperature, **T2** – Ambient temperature
I1 – 3 d, **I2** – 5 d, **I3** – d
Z1 – Without ZEBA, **Z2** – With ZEBA

Figure 9: Effect of different treatments on fresh weight of heads (g per plant) of cabbage (*Brassica oleracea).* Values followed by the same letter are not significantly different at *P*=0.05 level.

Therefore, increased temperature and longer irrigation interval resulted in low marketable yield as well as total yield. The study indicated that the yield determining components such as fresh and dry weight of head were significantly (*P*<0.05) increased with the presence of ZEBA in the soil (Figure 10, 11). An improvement in yield contributing characters might be due to an increase in plant growth parameters due to the application of ZEBA. The positive effects of SAPs in increasing yield in tomato (El-Hadi and Camelia, 2004), sunflower (Nazarli *et al.,* 2010), and soybean (Yazdani *et al.,* 2007) have been reported and were in consistent with the findings of the present study.



T1 – Increased temperature, **T2** – Ambient temperature
I1 – 3 d, **I2** – 5 d, **I3** – d
Z1 – Without ZEBA, **Z2** – With ZEBA

Figure 10: Effect of different treatments on the dry weight of heads (g per plant) of cabbage (*Brassica oleracea).* Values followed by the same letter are not significantly different at *P*=0.05 level

Figure 11: Effect of different treatments on the yield of cabbage (*Brassica oleracea).*

Soil parameters

Soil moisture

According to the data on soil moisture presented in Table 3, treatment of ambient temperature, with ZEBA, 3 d irrigation interval (T2Z2I1) has shown the highest moisture content (58.2%). It was not significantly ($P>0.05$) different from the treatment of ambient temperature, with ZEBA, 5 d irrigation interval (T2Z2I2) and treatments of increased temperature, with ZEBA irrigated to 3 and 5 d irrigation interval (T1Z2I1, T1Z2I2). The lowest soil moisture content was recorded in the treatment of increased temperature, without ZEBA, 8 d irrigation interval (T1Z1I3 – 20.12%). It might be due to the higher transpiration and evaporation losses under increased temperature and longer irrigation intervals. The application of SAPs increased water retention significantly and reduced irrigation frequency (Flannery and Busscher, 1982). According to the findings of this study, most of the growth and yield parameters are directly proportional to the soil moisture content, and it has confirmed by Rossato *et al.* (2017) in their reports. They reported that the average crop yield is directly associated with practices that increase soil moisture at a depth of the root system in order to reduce the effects caused by longer irrigation intervals.

Soil N, P and K

According to the data on soil N, P, and K presented in Table 3, treatment of ambient temperature, with ZEBA, 3 d irrigation interval (T2Z2I1) has shown the highest amount of soil nitrate, water-soluble phosphorous, and available potassium (0.33%, 100.9 ppm and 615.7 ppm, respectively) while treatment of increased temperature, without ZEBA, 8 d irrigation interval has shown the lowest value on N, P and K (0.15%, 25.6 ppm, and 183.3 ppm, respectively). The lowest amounts of N, P and K in the soil media might be due to lower solubility of ions because of lower soil moisture in the media incorporated by longer irrigation interval and increased temperature. Treatments applied with ZEBA resulted in a higher amount of N, P and K due to superabsorbent polymers' ability to increase fertilizer-retaining capacity and it has confirmed by Abrisham *et al.* (2018) in their reports.

Table 3: Effect of different treatments on soil moisture, soil nitrate, water-soluble phosphorous and soil available potassium. Values followed by the same letter are not significantly different at *P* =0.05 level.

Treatment	Soil moisture (%)	Soil nitrate (%)	Water soluble P (ppm)	Soil available K (ppm)
T1Z1I1	31.15[e]	0.19[f]	27.2[j]	274.2[g]
T1Z1I2	25.42[f]	0.17[f]	26.4[k]	225.7[j]
T1Z1I3	20.12[fg]	0.15[g]	25.6[l]	183.3[l]
T1Z2I1	55[a]	0.32[a]	72.5[d]	513.10[b]
T1Z2I2	51.2[a]	0.28[b]	60.8[e]	316.5[f]
T1Z2I3	43.1[c]	0.23[d]	56.9[f]	265.7[h]
T2Z1I1	44.52[c]	0.30[b]	38.5[g]	344[e]
T2Z1I2	37.54[d]	0.25[c]	36.8[h]	257.4[i]
T2Z1I3	34.11[de]	0.22[e]	35.8[i]	204.1[k]
T2Z2I1	58.21[a]	0.33[a]	100.9[a]	615.7[a]
T2Z2I2	55.12[a]	0.32[a]	85[b]	443.20[c]
T2Z2I3	49.5[b]	0.27[c]	74.3[c]	368.2[d]
T*Z*I*	P<0.05	P<0.05	P<0.05	P<0.05

T1 = Increased temperature T2 = Ambient temperature
Z1 = Without Zeba Z2 = With Zeba
I1 = 3 d irrigation interval I2 = 5 d irrigation interval
I3 = 8 d irrigation interval

CONCLUSIONS

Cabbage growth was restricted under longer irrigation intervals and increased temperature conditions. The ability of ZEBA to conserve soil water positively influenced on increasing cabbage growth, yield and, soil moisture, N, P, and K. For almost every property of soil and plant, treatments with ZEBA showed better effects than treatments without ZEBA because of the application of ZEBA moderated the negative effect of longer irrigation intervals and increased temperature on plant growth and productivity. Treatment of ambient temperature, with ZEBA, 3 d irrigation interval has recorded the highest growth and yield of cabbage, as well as the highest amount of soil moisture and soil N, P, K. Water conserving agricultural techniques are very vital to conserve limited resource of available water under increased temperature condition due to global warming. Therefore, the application of ZEBA with a 5 d irrigation interval can be implemented either at the ambient temperature or increased temperature without a significant yield reduction.

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