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Effect of Diurnal Temperature Alternations on Plant Growth and Mineral Composition in Cucumber, Melon and Watermelon

Phommy Inthichack, Yasuyo Nishimura and Yasufumi Fukumoto
Faculty of Agriculture, Kochi University, Monobe, Nankoku, 783-8502, Kochi, Japan

Abstract: This study investigated plant growth and mineral composition in three cucurbit crops of cucumber, melon and watermelon grown under four constant day and night temperatures (DIF) of 25/15, 22.5/17.5, 17.5/22.5 and 15/25°C. As expected, the growth and development of the three cucurbits were strongly temperature dependent. Plant height and relative chlorophyll content of the three crops decreased linearly along with decreases in day temperature. Leaf and stem dry weight decreased significantly under negative DIFs and the lowest value was in DIF plot 15/25°C. However, the negative DIF of 15/25°C resulted in increased content of all mineral nutrients (N, P, K, Ca, Mg, Mn and Cu) in both the leaf and stem of the three cucurbit crops. The data suggest that a negative DIF as low as 15/25°C may be beneficial to greenhouse-grown cucurbit crop producers, by controlling vegetative growth that facilitates crop management, with no negative effect on or enhancement of the uptake rates of mineral nutrients which are required to determine yield and fruit quality at the production stage. Effective utilization of diurnal temperature alternations is one strategy that can be used to reduce energy consumption in greenhouses.

Key words: Chlorophyll content, cucurbit, DIF, growth and development, mineral composition

INTRODUCTION

Global temperatures are rising and the severity and frequency of above-optimal temperature episodes will increase in the coming decades (Bell *et al*., 2000). Temperature strongly affects the vegetative and reproductive processes in plants, because the biochemical reactions, fundamental for normal cell function in plants, are disrupted by high temperatures (Abdalla and Verkerk, 1968). As a result, significant losses in productivity occur due to reduced fruit set and lower quality fruit (Sato *et al*., 2002; Stevens and Rudich, 1978). High temperature conditions reduce the range and production of many crops and are often prevalent during the growing season in the tropics. As a result of climate changes, crops are subjected to increased temperature stress in that region. Previous studies reported that many aspects of temperature affect plant growth (Erwin and Heins, 1990; Ito *et al*., 1997a; Markovskaya *et al*., 1996; Moe and Heins, 1990; Niu *et al*., 2001; Shimizu, 2007) where average daily temperature (over a 24-h period) plays an important role in rapid growth and development. Plant height is particularly affected by the difference between day and night temperatures (Erwin *et al*., 1989; Berghage and Heins, 1991; Ito *et al*., 1995; Koyano *et al*., 2005; Shimizu and Heins, 2000; Shimizu and Hisamatsu, 2009; Shimizu *et al*., 2008). The difference in day and night temperature (DIF) influences several morphological characteristics of plants including internode length, plant height, leaf orientation, shoot orientation, chlorophyll content, lateral branching and petiole and flower stalk elongation (Myster and Moe, 1995). However, the effects are specific to plant species, age, nutrition and plant organ. At the same time, fluctuations in temperature regimes affect nutrient uptake of plants indirectly by influencing transpiration and stomata functioning. The effect of diurnal temperature control on nutrient uptake could lead to a disruption of the nutrient balance, necessary for better growth and high quality crop yield (Fukumoto *et al*., 2007; Inthichack *et al*., 2010, 2013). In some plants, the influence could be either minor or dramatic. Most previous research on the influence of DIF was on interrupting treatments in which plants grown under ambient day and night temperatures were subjected to positive and negative DIF for a short period (Ito *et al*., 1997b). Erwin *et al*. (1989) and Niu *et al*. (2001) discovered that plant height was much more strongly dependent on the difference between day and night temperatures than simply on the absolute value of either temperature level.

In the modern world of horticultural production, temperature control, such as in a greenhouse as well as in a growth chamber, is a tool which can improve agricultural

Corresponding Author: Yasuyo Nishimura, Faculty of Agriculture, Kochi University, Monobe, Nankoku, 783-8502, Kochi, Japan
Tel: +81-88-864-5129 Fax: +81-88-864-5129

product quality through provision of optimum culture conditions for specific crops (Houter and Nederhoff, 2006), especially for vegetable crops. In an insulated room, temperature as well as humidity can be maintained at a suitable level. The difference between day and night temperatures during propagation influences morphology and dry matter distribution in crop transplants. Lower temperatures during the day rather than at night retards plant elongation and improves the growth of transplants and results in higher yield in three brassica crops (Bakken and Flones, 1995).

Cucumber, melon and watermelon, the major crops among *cucurbitaceous* plants, are commercially cultivated in frost-free areas that have a long and warm growing season. Plants are widely spaced because of the long-trailing vines, so management of trailing vines in greenhouse production of these crops is essential during the production period. The studies conducted by Grimstad (1993) and Grimstad and Frimanslund (1993) showed that the stem and internode length of cucumber strongly respond to negative DIF which can be used as a method of managing plant height in the greenhouse as an important quality consideration for transplant producers. However, information on the effect of DIF is still limited, particularly the effect on mineral composition in different plant parts of each crop species at different stages of growth and development.

The objective of this study was to determine vegetative growth and development as well as mineral nutrient accumulation in three cucurbit species in response to four different day and night temperature (DIF) conditions that were set continuously for the whole experimental period. One particular objective was to determine the lowest negative DIF beneficial to crop mangement without limiting the uptake rates of mineral nutrients that are required for fruit yield and fruit quality at the fruit production stage.

MATRRIALS AND METHODS

Material under test: The experiment was carried out inside phytotrons at the experimental site of the Faculty of Agriculture, Kochi University, Kochi, Japan. On May 9th, 2007, seeds of cucumber (*Cucumis sativus* cv. ‘Sharp I’), melon (*Cucumis melo* cv. ‘Shalon’) and watermelon (*Citrullus lanatus* cv. ‘Wasenisshou’) were sown in black seedling trays (L 47.3×W 32.5×D 7.2 cm) filled with bark compost and irrigated with tap water. Approximately 18 days after sowing, on May 26th, all germinated seedlings were transplanted into black polyethylene pots of 7.5 cm diameter with a slow-release fertilizer of Crotonylidene Diurea (CDU) NPK 25 kg per 10a and Mg and Ca 120 kg per 10a. On May 31st, the potted seedlings were transplanted into 1/2000a Wagner pots filled with a mixture of mountain soil and bark compost at a ratio of 1:1 and placed inside a phytotron with day and night temperatures set at 22.5/17.5°C for 7 days for the uniform growth of all plants. On June 7th, five plants of each test crop were randomly established inside four phytotrons and temperature treatments were started. At this stage (1 days of temperature treatment), the cucumber, melon and watermelon plants had 2 true leaves, 1.5 true leaves and 1 true leaf, respectively. Each phytotron was 2 m in height and 2 m in width and covered with clear glass that allowed plants to be exposed to full natural sunlight.

The experiment was laid out in a randomized block design without replication, using 4 treatments of different day and night temperature (DIF) alternations. Plastic rope was used to connect one support to another for trailing of lateral stems. The plants were spaced 30 cm apart. Temperature treatments of different day and night temperatures with a daily mean temperature set at 20°C were assigned to four separate phytotrons: 15/25, 17.5/22.5, 22.5/17.5 and 25/15°C. The temperature treatments were maintained for 12 h during the day starting at 6:30 a.m. and 12 h at night starting at 6:30 p.m. All the potted crops were trained using a trellis system with nylon rope connected to tensile wire above the plant to the base of the stem of each plant to let the plant grow vertically. All potted plants received a slow-release fertilizer (CDU) NPK 25 kg per 10a and Mg and Ca 120 kg per 10a and were manually irrigated with tap water three times a day during the whole experimental period.

Measurment and analysis: On June 18th, at 11 days of temperature treatment, chlorophyll count (SPAD value) of leaf (an average of three values of the 4th leaf) was measured by a chlorophyll meter (SPAD-502, Konica Minolta Sensing, Inc. Japan) and stem length as well as lateral shoot number and fresh weight of all five plants of the three tested crops were recorded. On July 3rd, at 26 days of temperature treatment, all plants of each tested crop from each temperature treatment were cut and measured for stem length, fresh weight, leaf fresh weight, dry weight and Chlorophyll count (an average of three values of the 5th leaf). The stem and leaf were then separately dried for one week for dry weight measurement and for mineral composition analysis. After the dry weights were recorded, individually dried leaves and stems were ground in preparation for mineral composition analysis (N, P, K, Ca, Mg, Cu and Mn). Regarding N(nitrate nitrogen), colorimetry in Alkali reduction/diazo pigments method was measured by a Soil Plant General

Analyzer SFP (SFP-3, Fujihira Industry Co., Ltd., Japan). The tissue samples were burned and the ash was dissolved in 50% hydrochloric acid and heated. The dissolved samples were filtrated and made up to 100 mL with pure water. The dissolved samples were analyzed for Ca, Cu, K, Mg and Mn using a Polarized Zeeman Atomic Absorption Spectrophotometer (Z-2310, Hitachi Co., Ltd., Japan) Regarding P, colorimetry in vanadate-molybdate method was measured by using a Spectrophotometer (U-2810, Hitachi High-Technologies Corporation, Japan).

Statistical analysis: All results was performed using one-way Analysis of Variance (ANOVA) with a general linear model procedure and means were separated and compared using Tukey's test at $p \leq 0.05$ on each of the significant variables measured. The SPSS (Statistical Package for the Social Sciences) program was used for all statistical analysis.

RESULTS

Effect of DIF on vegetative growth and development: The effect of different day and night temperature treatments on growth and development of the three tested crops is shown from 11 days of temperature treatment (Fig. 1 and Table 1). At this time point, the plant height of cucumber was significantly influenced by all the DIF treatments, with the tallest plant observed under the 22.5/17.5°C condition (Fig. 1). There was no significant change in plant height in melon and watermelon due to the temperature treatments. Significant differences in relative chlorophyll content, indirectely measured as SPAD value, were observed in the 4th leaf from the top in all the tested crops (Table 1). The SPAD values significantly increased under the positive DIFs of 25/15 and 22.5/17.5°C and decreased significantly under the negative DIFs of 17.5/22.5 and 15/25°C. Neither lateral shoot number nor fresh weight of any of the crops were affected by DIF treatments (Table 1). At 26 days of temperature treatment, the higher positive DIF of 25/15°C resulted in a significant increase in plant height in all the crops (Fig. 1). In addition, plants grown under the positive DIFs of 25/15 and 22.5/17.5°C were significantly taller than under the negative DIFs of 17.5/22.5 and 15/25°C. A similar result was also found for the SPAD value in the 5th leaf from the top for all the crops. The SPAD value for melon and watermelon was highest under the positive DIF of 25/15, followed by the 22.5/17.5, 17.5/22.5 and 15/25°C treatments. The SPAD value for cucumber was also highest under the positive DIF of 25/15°C, but was followed by 17.5/22.5, 22.5/17.5 and 15/25°C in decreasing order (Table 2). Significant differences in the average leaf number per plant were observed only for cucumber, with the highest leaf numbers promoted under 25/15 and 15/25°C. Leaf number was lowest under 17.5/22.5°C for all the cucurbits. As for dry matter of different plant organs at 26 days of temperature treatment (Table 2), a significant difference in leaf dry weight was observed only in melon, but in all three crops for stem dry weight. The leaf dry weight of melon increased significantly under the highest positive DIF of 25/15°C and decreased significantly under the negative DIF of 17.5/22.5°C. Stem dry weight was significantly greater under 25/15°C for cucumber, but under 22.5/17.5°C for melon and watermelon.

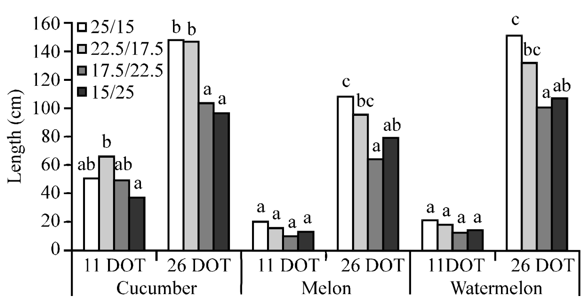

Fig. 1: Effect of DIF on stem length at 11 and 26 days of temperature treatmentand. Means of each bar followed by the same letter are not significantly different at $p \leq 0.05$ by Tukey test

Effect of DIF on nutrient accumulation in different plant organs: Mineral accumulation in the leaf and stem due to the effect of different day and night temperature treatments for the three crops was also investigated (Table 3-5). The results contrasted with the results for vegetative growth, as the highest accumulation of all

Table 1: Effect of DIF on leaf SPAD and lateral shoots at 11 days of temperature treatment

Temperature treatment Day/night (°C)	SPAD of 4th leaf from top	Lateral shoot FW (g)	Lateral shoot No.
Cucumber			
25.0/15.0	39.7^{a}	3.9^{a}	2^{a}
22.5/17.5	39.9^{a}	9.9^{a}	4^{a}
17.5/22.5	33.4^{b}	8.9^{a}	3^{a}
15.0/25.0	29.8^{b}	11.4^{a}	3^{a}
Melon			
25.0/15.0	36.5^{a}	11.5^{a}	3^{a}
22.5/17.5	33.0^{ab}	7.1^{a}	3^{a}
17.5/22.5	29.2^{bc}	3.4^{a}	2^{a}
15.0/25.0	25.7^{c}	8.6^{a}	2^{a}
Watermelon			
25.0/15.0	45.9^{a}	2.0^{a}	3^{a}
22.5/17.5	45.2^{a}	1.0^{a}	2^{a}
17.5/22.5	39.5^{b}	0.6^{a}	2^{a}
15.0/25.0	33.5^{c}	2.2^{a}	2^{a}

[z]Means in each column followed by the same letter are not significantly different at $p \leq 0.05$ by Tukey test

Table 2: Effect of DIF on leaf SPAD, leaf No., leaf DW and stem DW at 26 days of temperature treatment

Temperature treatment Day/night (°C)	SPAD of 5th leaf from top	Leaf No.	Leaf DW (g)	Stem DW (g)
Cucumber				
25.0/15.0	30.7^{a}	20.8^{a}	15.1^{a}	8.1^{ab}
22.5/17.5	23.8^{bc}	17.6^{b}	14.5^{a}	8.4^{a}
17.5/22.5	27.7^{ab}	17.2^{b}	13.2^{a}	6.4^{ab}
15.0/25.0	23.3^{c}	21.0^{a}	14.0^{a}	5.6^{b}
Melon				
25.0/15.0	45.5^{a}	18.2^{a}	18.4^{a}	7.9^{a}
22.5/17.5	35.7^{a}	17.4^{a}	13.6^{ab}	5.8^{ab}
17.5/22.5	29.2^{b}	15.8^{a}	10.7^{b}	3.2^{b}
15.0/25.0	27.1^{b}	17.2^{a}	12.9^{ab}	4.5^{b}
Watermelon				
25.0/15.0	55.3^{a}	18.8a	12.0^{a}	6.9^{a}
22.5/17.5	41.1^{a}	17.8^{ab}	11.5^{a}	6.1^{ab}
17.5/22.5	30.3^{b}	15.6^{b}	08.1^{a}	4.2^{b}
15.0/25.0	28.8^{b}	17.6^{ab}	09.2^{a}	4.1^{b}

^{z}Means in each column followed by the same letter are not significantly different at $p \leq 0.05$ by Tukey test

Table 3: Effect of DIF on mineral composition in leaf and stem of cucumber 'sharp I'

Temperature treatment Day/night (°C)	N^{z} (ppm)^{y}	P (%)	K (%)	Ca (%)	Mg (%)	Mn (ppm)	Cu (ppm)
Leaf							
25.0/15.0	06.7^{bx}	1.5^{b}	3.3^{ab}	4.4^{a}	1.8^{a}	50.4^{a}	205.2^{a}
22.5/17.5	27.1^{ab}	1.7^{ab}	3.5^{a}	4.5^{a}	1.4^{a}	52.4^{a}	111.2^{a}
17.5/22.5	70.9^{a}	1.8^{ab}	3.1^{c}	4.6^{a}	1.8^{a}	57.1^{a}	110.4^{a}
15.0/25.0	77.6^{a}	2.0^{a}	3.3^{ab}	4.7^{a}	2.0^{a}	59.1^{a}	118.9^{a}
Stem							
25.0/15.0		1.3^{c}	5.0^{a}	0.9^{a}	0.7^{a}	15.1^{a}	96.6^{a}
22.5/17.5		1.4^{ab}	4.7^{ab}	1.0^{a}	0.8^{a}	18.1^{a}	127.5^{a}
17.5/22.5		1.5^{a}	4.5^{c}	0.8^{a}	0.7^{a}	19.1^{a}	118.0^{a}
15.0/25.0		1.5^{a}	5.0^{a}	1.0^{a}	0.7^{a}	18.9^{a}	108.2^{a}

^{z}Nitrate nitrogen, ^{y}Per dry wt, ^{x}Means in each column followed by the same letter are not significantly different at $p \leq 0.05$ by Tukey test

Table 4: Effect of DIF on mineral composition in leaf and stem of melon 'Shalon'

Temperature treatment Day/night (°C)	N^{z} (ppm)^{y}	P (%)	K (%)	Ca (%)	Mg (%)	Mn (ppm)	Cu (ppm)
Leaf							
25.0/15.0	7.7b^{x}	0.4^{c}	2.6^{b}	5.1^{b}	1.3^{a}	47.4^{c}	52.6^{c}
22.5/17.5	9.6^{b}	0.5^{b}	2.8^{ab}	5.4^{ab}	1.3a	55.2^{b}	66.2^{b}
17.5/22.5	28.1^{a}	0.6^{a}	3.0^{a}	5.8^{ab}	1.5^{a}	61.1^{ab}	87.0^{a}
15.0/25.0	28.9^{a}	0.5^{b}	2.8^{ab}	6.0^{a}	1.4^{a}	61.7^{a}	77.5^{ab}
Stem							
25.0/15.0		0.7^{c}	4.7^{b}	0.9^{a}	0.6^{b}	14.5 ^{b}	63.1^{a}
22.5/17.5		0.9^{ab}	4.8^{ab}	1.0^{a}	0.7^{ab}	17.0^{ab}	69.5^{a}
17.5/22.5		1.0^{a}	5.0^{a}	1.0^{a}	0.8^{a}	18.8^{a}	83.3^{a}
15.0/25.0		08.^{bc}	5.0^{a}	1.0^{a}	0.6^{b}	18.9^{a}	79.7^{a}

^{z}Nitrate nitrogen, ^{y}Per dry wt, ^{x}Means in each column followed by the same letter are not significantly different at $p \leq 0.05$ by Tukey test

nutrients accumulated in the leaf and stem was promoted under a negative DIF. For cucumber, significant differences between treatments were found for N, P and K in both the leaf and stem (Table 3). The lowest negative DIF of 15/25°C significantly promoted N accumulation in the leaf and P accumulation in the leaf and stem, followed by 17.5/22.5, 22.5/17.5 and 25/15°C in decreasing

Table 5: Effect of DIF on mineral composition in leaf and stem of watermelon 'Wasenisshou'

Temperature treatment Day/night (°C)	N^{z} (ppm)^{y}	P (%)	K (%)	Ca (%)	Mg (%)	Mn (ppm)	Cu (ppm)
Leaf							
25.0/15.0	12.5^{cx}	0.5^{b}	2.7^{b}	2.9^{ab}	0.6^{b}	28.8^{b}	76.0^{b}
22.5/17.5	19.8^{bc}	0.5^{b}	2.8^{b}	2.6^{b}	0.6b	31.3^{ab}	88.0^{b}
17.5/22.5	31.3^{ab}	0.6^{a}	2.9^{ab}	2.8^{b}	0.7^{ab}	33.1^{ab}	133.4^{a}
15.0/25.0	37.3^{a}	0.6^{a}	3.2^{a}	3.4^{a}	0.8^{a}	35.7^{a}	99.0^{b}
Stem							
25.0/15.0		0.4^{b}	3.9^{c}	0.6^{ab}	0.3^{bc}	11.3^{a}	56.3^{b}
22.5/17.5		0.5a	4.4^{b}	0.5^{b}	0.3^{c}	12.0^{a}	63.4^{ab}
17.5/22.5		0.6^{a}	4.6^{ab}	0.5^{b}	0.3^{b}	12.7^{a}	72.6^{a}
15.0/25.0		0.5^{a}	4.7^{a}	0.7^{a}	0.4^{a}	12.2^{a}	60.4^{b}

^{z}Nitrate nitrogen, ^{y}Per dry wt, ^{x}Means in each column followed by the same letter are not significantly different at $p \leq 0.05$ by Tukey test

order. For K accumulation, however, the highest accumulation was under 22.5/17.5°C for the leaf and under both 25/15 and 15/25°C for the stem. For melon, significant differences between treatments were found for P, K and Mn in both the leaf and stem, Ca and Cu in the leaf and Mg in the stem (Table 4). For watermelon, significant differences between treatments were found for P, K, Ca, Mg and Cu in both the leaf and stem, but for Mn only in the the leaf (Table 5).

Overall, all three crops showed a similar pattern of mineral nutrient accumulation in both the leaf and stem and were significantly higher under the two negative DIFs of 17.5/22.5 and 15/25°C than the two positive DIFs.

DISCUSSION

This sudy focused on the response of plants grown under four constant DIFs and the results showed that the four constant DIFs greatly influenced the vegetative growth of the three cucurbit crops. All plants of the three tested crops grew to maturity and as expected, the positive DIF of 25/15°C promoted taller plants as well as higher leaf chlorophyll content in all the tested crops. This finding is in agreement with the previous findings of Ito *et al.* (1997a) that higher day temperatures enhance the elongation of different plant parts in all plant species and that plant height in particular is affected by the difference between day and night temperatures (Erwin *et al.*, 1989; Bakker and van Uffelen, 1988; Berghage and Heins, 1991; Ito *et al.*, 1995; Koyano *et al.*, 2005; Shimizu and Heins, 2000; Shimizu and Hisamatsu, 2009; Shimizu *et al.*, 2008). Doggett (1967) emphasized that an increase in internode length, as well as the small increase in height, stem thickness and leaf area, could add up to a large increase in photosynthetic area. In this experiment, leaf SPAD decreased significantly as a result of a decline in day temperature, supporting the findings of Tutty *et al.* (1992, 1994) that plants respond directly to a change in DIF manipulated in the greenhouse. Maintaining or pulsing DIF for lower day and higher night temperatures for short periods could retard stem elongation, as confirmed by Moe *et al.* (1991), who found that the long-day plant grown under a negative DIF of 15/21°C was significantly shorter than for a positive DIF of 21/15°C. The negative DIFs, particularly 15/25°C in this experiment, suppressed the accumulation of dry matter of plant organs for the three crops. On the other hand, higher day temperatures with a positive DIF tended to promote dry weight accumulation in almost all plant organs. The non-significant difference in dry leaf weight of cucumber and watermelon under the four DIF treatments can probably be explained on the basis that the two plants were not under any degree of temperature stress (Berke *et al.*, 2003). Although cucumber leaf numbers were significantly higher under 25/15 and 15/25°C, the non-significant difference in dry weight suggested that 22.5/17.5 and 17.5/22.5°C increased cell elongation and increased leaf area of this crop, supporting the suggestion by Erwin *et al.* (1994) that the effect of DIF on internode length was due to increased cell elongation.

Although low negative DIF suppressed the growth and development of the three cucurbitaceous plants, as reflected in lower SPAD and stem length as well as leaf dry weight and stem dry weight, the effect however is positive, considering the increased mineral nutrient accumulation in the leaf and stem. The balance of nutrient accumulation in plant parts at this growth stage indicates insufficiency or sufficiency leading to better fertilizer management for better crop yield. Non-significant differences were observed for Ca, Mg, Mn and Cu in the leaf and stem of cucumber, but only for Ca in the stem, Mg in the leaf and Cu in the stem of melon and only for Mn in the stem of watermelon, suggesting that nutrient accumulation in cucumber is not sensitive to DIF treatments. For N, the analysis was done only for leaf and of the four DIF treatments, only plants grown under a negative DIF demonstrated higher N concentration. K is an essential mineral element for photosynthesis and has an important function in plant growth and development (Maschmann *et al.*, 2008). An increase in K uptake and availability in plants resulted in an increase in net photosynthetic rate and an increase in crop yield (Ding *et al.*, 2006). Wyn Jones and Lunt (1967) reported that Ca is needed for selective transport of ions like K across membranes. Ca deficiency is often considered the major cause of physiological disorders such as blossom end rot in fruit (Collier and Huntington, 1983). In this study, in contrast to the higher K concentration in the stem, Ca concentration was higher in the leaf of the three cucurbits suggesting that a sufficient level of Ca is distributed during fruit production and contributes to higher quality fruit of the three cucurbits.

In conclusion, plant growth and development of the three cucurbit crops during the fast growing stage are affected by DIF treatments. The use of negative DIF as low as 15/25°C during the propagation and fast growing stage resulted in shorter plants, lower chlorophyll content and lower dry matter, but it is not regarded as an adverse effect. Instead, it enhanced the accumulation of important nutrients in plant parts which is essential for plant production and final fruit yield. The use of negative DIF can be considered the most effective practice to shorten plant height as part of crop management. Effective utilization of diurnal temperature alternations is one strategy that can be used to reduce energy consumption in greenhouses. Since this experimental study was conducted only during the vegetative growth stage, further experiments are necessary to clarify the effect of DIFs on the final fruit yield of these three crops.

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