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Effect of temperature gradient generated by fan-pad cooling system on yield of cabbage grown using fertigation technique under side netted rain shelter

(Kesan kecerunan suhu sistem kipas dan pad penyejuk terhadap hasil kubis yang ditanam menggunakan teknik fertigasi di bawah struktur pelindung hujan)

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Keywords: temperature gradient, fan-pad cooling system, cabbage, yield, fertigation

Abstract

A field experiment was carried out to determine the effect of temperature gradient generated by fan-pad cooling system on yield of KY Cross cabbage grown using fertigation technique under 30 m long x 10 m wide x 4.5 m high rain shelter with side netting. The fan-pad cooling system provides evaporative cooling inside the shelter and lowers the air temperature significantly below ambient. The temperature in the structure was 3–5 °C lower than the outside temperature. With 70% efficiency, the system was able to reduce from 42 °C of the outside air to 33.6 °C when exiting the cooling pad. However, the temperature in the shelter increased as the air moved from cooling pad towards the exhaust fans producing a temperature gradient across the length of the shelter (up to 4.5 °C). The temperature gradient caused a negative correlation between the cooling pad distance and the canopy diameter as well as yield of cabbage. The average canopy diameter (77.34 cm) and cabbage head weight (2.62 kg) after 75 days were significantly higher towards the cooling pad. The further the distance between the plants and the cooling pad, the smaller the canopy diameter (48.85 cm) and cabbage head weight (0.65 kg). Grade 1 cabbage heads were produced from the first 12.35 m from the cooling pad (average weight 2.5 kg). At 15.35–21.35 m, the cabbage heads fall into grade 2 with an average weight of 1.33 kg, while grade 3 cabbage heads were produced between 24.35–27.35 m from the cooling pad.

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Introduction

Crop cultivation in lowlands is subjected to unpredictable weather changes, low yields and quality. This is normally due to hot and wet weather, damages by insects and diseases and bad agricultural management. However, for upscaling purposes, crops have been cultivated in lowlands (Fadelah et al. 1990). Usually, a rain shelter is built to maintain an environment that could result in profitable production of high value commercial crops. Temperate vegetables can be successfully cultivated in the lowlands when grown under rain shelters (Illias and Vimala 2005). For optimum plant growth under hot conditions, rain shelters require cooling systems. Evaporative cooling system can be used to produce lower temperatures under rain shelters. The most commonly used evaporative cooling system is the fan and pad system. In this system, water is applied to the pad material as air is being drawn through the pads by fans located on the opposite side of the rain shelter. Evaporative cooling produces changes in humidity and temperature of the air exiting the pads.

Using the specified cooling system would result in cooler air exiting the pad and an increase in humidity inside the rain shelter. The air will be at its lowest temperature immediately after passing through the pads. As the air moves across the rain shelter to the fans, the air picks up heat from solar radiation, plants, and soil, and the temperature of the air gradually increases. The increase in temperature produces a temperature gradient across the length of the rain shelter, with the pad side being the coolest and the fan side the warmest. The effect of temperature gradient generated by fan-pad cooling system on the yield of KY Cross cabbage was studied using fertigation technique under rain shelter with insect proof side netting. The experiment was conducted at MARDI Station in Kluang, Johor.

Materials and methods

Plant materials and growth medium

KY Cross cabbage was selected and used in the study. Under normal condition, KY cabbage can be harvested at about 70–75 days after transplanting. The 30-day-old seedlings of KY Cross cabbage were obtained from MARDI Cameron Highlands. The seedling trays were immediately transferred into the rain shelter. Each seedling, about 8–10 cm tall with three pairs of leaves, were transplanted into a 3-litre black polyethylene bag (30 cm height x 20 cm diameter) filled with 1.2 kg coco peat. A total of 552 polyethylene bags were placed on both sides of the six tertiary irrigation pipes and individually irrigated with nutrient solution via a 4 mm micro tube equipped with an arrow dripper. The volume of fertilizer solution was approximately 1.5 litres per plant per day.

Rain shelter structure

The side netted rain shelter 30 m long x 10 m wide x 4.5 m high which has straight sides and tunnel roofing shape (*Plate 1*) was used in the study. The frames were made of galvanized Southern Pipe steel, transparent polyethylene film (180 µm thick) roofing and polyethylene insect-screen (24 mesh) side cladding. Entrance into the rain shelter is made possible through a double door to reduce the chance entry of insect pests.

Fan-pad cooling system

The rain shelter was equipped with four 100 kW fans (Termotecnica Pericoli SRL, Italy) and 15.35 m^2 cooling pad (*Table 1*). The fans were erected at one end of the structure while the pad was located at the opposite end (*Plate 2*). The principle of evaporative cooling was applied by running a water stream over the pad and consequent withdrawal of air through it by exhaust fans on the opposite end. Both fans and pad were automatically operated via sensors when the temperature inside the shelter was above 30 °C. The fan-pad cooling system caused two changes in the environmental

Plate 1. Rain shelter used in the study showing the fans at one end of the structure

Plate 2. The fan-pad cooling system used in the experiment

Table 1. Fan-pad cooling system parameters

Parameter	Value
Motor power	110 kW
Rotation	anti clockwise
Nominal air displacement	44,500 mc/h
Propeller diameter	1.27 m
Propeller revolution	440 rpm
Noise level at 7 m	65 Db
Cooling pad area	15.35 m^2
Cooling pad position	0.55 m from the floor
Cooling pad water pump	1 Hp
Cooling pad water tank	900 litres
Evaporative cooling system efficiency	70%
Cooling pad substance	Fine wire muslin

conditions in the rain shelter, namely, the air becomes cooler and its humidity increased. Parameters such as length of the structure, distance of the cooling pad from the plant and height of the cooling pad were recorded. The storage water tank used as cooling medium for the shelter was buried underground.

Irrigation system set up

The irrigation system consisted of a 2,600-litre tank, 1.5 HP water pump, water filter, pressure meter and six tertiary irrigation pipes (each 28 m long) connected at both ends to the secondary pipe (trapped/ looped system). The apparatus used in the experiment is illustrated in *Figure 1*. On each of the six tertiary irrigation pipes, 92 drippers were located in 2 rows on both sides of the irrigation pipe. The distance between each tertiary pipe was 0.153 m and between each dripper point was 0.3 m. A pressure valve was placed after the pump to control the amount of flow of the fertilizer solution into each individual polyethylene bag. A small stop cork was also attached to each tertiary line to regulate the flow of fertilizer through the line.

Plant growth measurements

Ten points from each tertiary line were selected and marked with numbers. Each point in the line corresponds to a certain distance from the cooling pad that provides cool air (1, 5, 10, 15, 20, 25, 30, 35, 40, 45 corresponds to 0.95, 3.35, 6.35, 9.35, 12.35, 15.35, 18.35, 21.35, 24.35, 27.35 m from the cooling pad respectively). The total number of the points was 60. All measurements on plant performances were done on the points.

The cabbage growth was monitored by measuring the canopy diameter at two week intervals starting two weeks after transplanting. The KY Cross cabbage head weights were measured immediately after harvest to prevent desiccation and water loss.

Most cabbages are susceptible to common soft rot disease. As a preventive

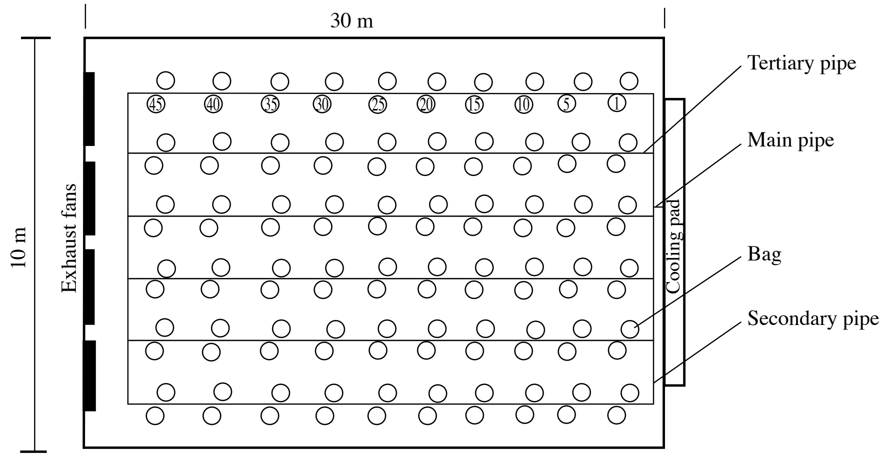

Figure 1. The arrangement of polyethylene bags and the position of the cooling pad and exhaust fans

measure, the growing medium used (coco peat) was treated with Previcur N before transplanting. Any chance of entry for the common pests (*Plutella* and *Hellula*) through torn nets, unclosed door and carried in by workers through their clothing or field equipments were closely observed. Spraying was only carried out during the first 2 weeks after transplanting to ensure there was no carry-over pest infestation through imported seedlings.

Temperature measurements

Two types of temperature measurements were taken to determine the effectiveness of the fan-pad cooling system, i.e. the dry and wet bulb temperatures inside and outside the rain shelter. The dry and wet bulb temperatures were measured to calculate the potential cooling performance of the evaporative cooling system. The dry bulb temperature was at its peak in the afternoon because solar radiation and outside temperatures were highest. This was also the time when the difference between dry and wet bulb temperatures was greatest and with maximum potential for cooling. The parameters were measured continuously for one month. The dry bulb temperature was the air temperature and it was measured by exposing the thermometer to the air stream near each point in the irrigation line. The wet bulb temperature was the lowest temperature that can be reached by the evaporation of water. It was also an indication of the amount of moisture in the air. The wet bulb temperature was measured using wet bulb psycho meters that was exposed to the same air stream that measured the dry bulb temperature. Both temperature measurements were taken from 0700 h to 1700 h, at one hour intervals. In addition, hand-held electronic temperature and humidity sensors were also used for verification of the measurements.

Nutrient concentrations and irrigation frequencies

The fertilizer formula was based on the leafy vegetables hydroponic formulation (Mahamud et al. 2007). All of the fertilizer compounds were water soluble. The macro and micro components were prepared separately as A and B stock solutions at 100 times dilution. Stock solution A contains calcium nitrate and iron, while stock solution B contains all the other compounds. All the compounds were added one by one to ensure that they dissolved completely in the water. Stock A solution was prepared by adding calcium nitrate into a 12-litre pail containing tap water and stirred until completely dissolved. The solution was then poured into a 100-litre container. Similarly, the iron powder was dissolved in tap water and then added into the container. Clean water was added to make up the volume to 100 litres. A similar procedure was applied in the preparation of stock B solution.

Stock A and B solutions were then mixed in a 2,600-litre tank in a 1:1 ratio until the needed electrical-conductivity (EC) reading was achieved. The EC of the fertilizer solution during 1–32 days after transplanting (DAT) was 1.8 µS/m and during 33–70 DAT, the EC was 2.5 µS/m. An identical amount of fertilizer solution was applied to all polybags. Pressure-compensated micro tubes and drippers supplying 35 ml/min (2.1 litres/ha) were used. The frequency of drip irrigation depended very much on the stage of growth of the vegetable. The irrigation scheduling was automatically run by digital timers was at 0800 h, 1200 h and 1600 h during 1–32 DAT and at 0800 h, 900 h, 1000 h, 1200 h, 1400 h and 1600 h during 33–70 DAT. The duration of irrigation was 3 min. The daily irrigation volumes per plant were 750 ml during 1–32 DAT and 1,500 ml during 33–70 DAT, with excess irrigation at least equal to the evapotranspiration.

Statistical analysis

Data obtained were statistically analysed using analysis of variance procedures to test the significant effects of all the variables investigated using SAS version 9.1. Means were separated using the Duncan Multiple Range Test as the test of significance at $p \leq 0.05$.

Results and discussion

Temperature gradient

The temperature inside the structure varied from 3 °C to 5 °C lower than the outside temperature (*Figure 2*). Experimental studies conducted by Jain and Tiwari (2002) in 24 m^2 greenhouses with a fan-pad cooling system of 3 x 1.15 m^2 in the west wall and two fans in the east wall, showed that the greenhouse air temperature was 4–5 °C lower as compared to the outside conditions.

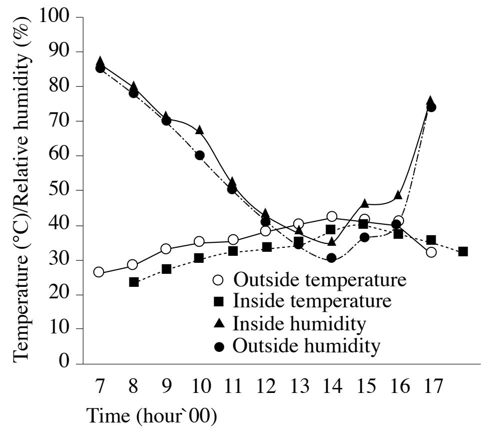

Figure 2. Temperature and relative humidity inside and outside the rain shelter from 7 am to 5 pm

Compared to the basic netted structure, the temperature inside the shelter was usually higher than outside because it depended on natural ventilation to cool the inside ambient temperature. The relative humidity (RH) in the structure at 0700 h and 1300 h was about 87% and 35% respectively, compared to 85% and 30% in the open (*Figure 2*). Netted structure without any cooling system had temperatures 0.5 °C to 2.8 °C higher than the open temperature (Leong, Amatjuri and et al. 1994), while the RH was slightly lower compared to the open (Leong, Yeoh and et al. 1994).

The wet and dry bulbs temperatures at each point rose significantly in the afternoon and dropped in the late evening (*Figures 3a* and *3b*). The best time to calculate the maximum potential cooling performance of the evaporative cooling system was in the afternoon. This was when the wet and dry bulbs of temperatures were at the peak because solar radiation and outside temperature was highest (Bucklin et al. 2005). The outside air temperatures between 1200 h and 1400 h were extremely high and the RH was greatly reduced. The air temperature inside the shelter was significantly lower and the RH was higher than the outside condition. The highest dry and wet bulb temperatures recorded in the

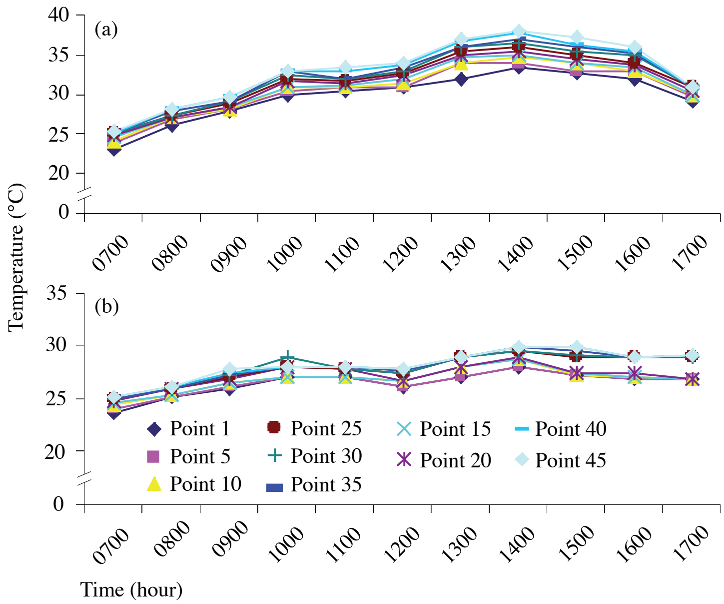

Figure 3. The dry (a) and wet (b) bulb temperatures from 0700 h to 1700 h in the middle irrigation line

shelter at 1400 h were 40 °C and 29.8 °C respectively, lower than the outside dry (42 °C) and wet bulb (30 °C) temperatures. Experimental data showed that the cooling system was able to keep the shelter air temperature at lower levels. The efficiency of the evaporative cooling system was 70% according to Rezuwan et al. (2008). With this efficiency, the temperature of air exiting the cooling pad can be calculated using the following equation proposed by Bucklin et al. (2005):

$$\text{Tcool} = \text{Tout} - (\%\ \text{efficiency})\ (\text{Tout} - \text{Twb})$$

Where: Tcool = temperature of air exiting cooling pad;
Tout = temperature of the outside air;
Twb = wet bulb temperature of the outside air

The difference between the dry and wet bulb temperatures is referred to as the wet bulb depression. If the efficiency of the system used was 70% (Rezuwan et al. 2008), at 42 °C outside air temperature and wet bulb temperature at 30 °C, the air entering the shelter was calculated to be 33.6 °C. With an outdoor RH 30% and temperature of 42 °C, this fan-pad cooling system was able to reduce the temperature to 33.6 °C.

The 15.35 m^2 cooling pad through which the air enters the shelter created non uniform temperature distributions across the structure due to the significant length of the shelter (30 m). As the air travels across the rain shelter, from the cooling pad to the exhaust fans, a rise in temperature resulted from the energy (solar radiation) that entered the shelter. Large temperature gradients (up to 4.5 °C) were observed from pads to fans. The temperature at point number 1, 0.95 m from the pad, was the lowest (23 °C), but the temperature increased as the distance from the pad increased. At point 45, 27.35 m from the cooling pad, the temperature was 25.7 °C (*Figure 4*). At 1400 h, at point 45, the temperature observed was 38 °C and significantly higher than at point 1 (33.5 °C) (*Figure 4*). The increase in temperature across the shelter was not easy to predict because it was affected by many variables such as the percentage of floor areas covered by plants, arrangement of the plants, physical obstructions to the

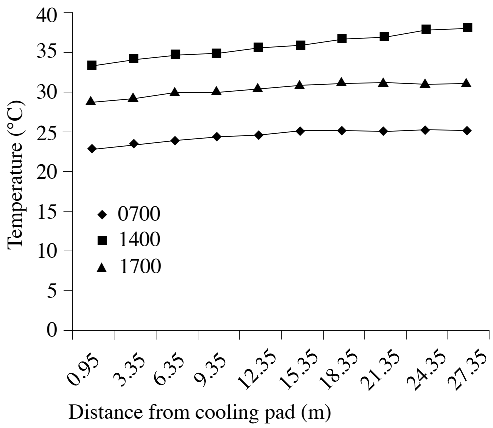

Figure 4. Temperature gradient measured in the middle of irrigation line. The temperature gradient at 0700 h, 1400 h and 1700 h

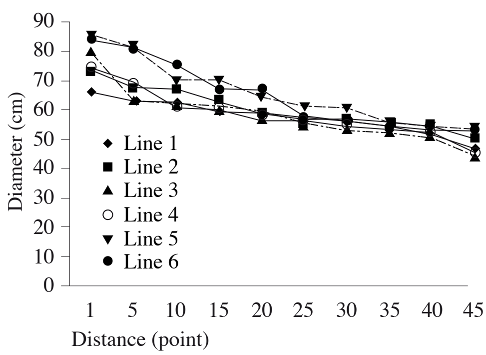

Figure 5. Effect of cooling pad distance on canopy diameter of cabbage after eight weeks growth

movement of air across the shelter and the types of floor used (bare soil, concrete or covered with geo-textile). The air was at its lowest temperature after passing through the cooling pads. As the air moved across the shelter towards the fans by suction force, the temperature of the air gradually increased producing a temperature gradient across the length of the shelter, with the pad side being the coolest and the fan side the warmest.

Effect on growth and canopy diameter

Cabbage cultivar KY Cross can be successfully grown with proper crop management practices. The maturity period of the KY Cross in the study was 75 days after transplanting. It was exactly similar to the maturity period of the KY Cross cabbage grown in the highlands. Canopy diameter contributes positively to yields through increased leaf area for photosynthesis. Larger surface area can support higher photosynthesis activity (Vimala et al. 2006).

The canopy diameter was significantly affected by the cooling pad distance. The further the distance of the plants from the cooling pad, the smaller the canopy diameter (*Figure 5*). Cabbage planted at points 1 and 5 were 0.95 m and 3.35 m respectively from the cooling pad. All plants within this distance which received the coolest air have the largest canopy diameter. The largest canopy diameter was 0.95 m obtained from plants at point 5 located 3.35 m from the cooling pad. As the air moved across the shelter towards the exhaust fans, it gradually picked up solar heat resulting in higher temperature when exiting out from the fans. In the process, a temperature gradient was created resulting in uneven temperature within the shelter and the warmest temperature was created near the fan side. As expected, the further the cabbage was planted from the cooling pad, the smaller was the canopy developed. Thus, cabbage planted at point 45 which was 27.35 m from the cooling pad gave the smallest canopy diameter at 0.49 m. The development of the cabbage canopy was significantly affected by the temperature gradient.

Effect on yield and cabbage head weight

Using fertigation system, the growth of cabbage was more uniform and the yield was higher than conventional planting (Illias and Ramli 1994). However, in the current experiment the distributions of cabbage yield were not uniform between each point. Cabbage head weights were similar at points 1, 5, 10, 15 and 20 with the distance ranging from 0.95 m to 12.35 m from the cooling pad (*Table 2*). Lower head weights were observed when cabbage were planted between 15.35 m and 18.35 m, but the lowest head weights were observed between 24.35 m and 27.35 m from the cooling

Table 2. Mean of cabbage head weights after 8 weeks growth period

Point	Distance from cooling pad (m)	Head weight mean (kg)	Standard deviation	CV
1	0.95	2.62a	0.40	15.27%
5	3.35	2.60a	0.39	15.00%
10	6.35	2.53a	0.48	18.97%
15	9.35	2.35a	0.36	15.32%
20	12.35	2.03a	0.71	35.00%
25	15.35	1.53b	0.33	21.60%
30	18.35	1.28b	0.33	25.78%
35	21.35	1.03c	0.23	22.33%
40	24.35	0.95c	0.48	50.53%
45	27.35	0.65c	0.22	33.85%

Means of cabbage head weights having the same letter in the column are not significantly different at $p \leq 0.05$ using DMRT

pads. As expected, a very low weight was obtained from the plants near the exhaust fan. As the distance from the cooling pad increased and nearer to the exhaust fans, the higher the temperature was and the lower the weight of the cabbage head (*Table 2*). The highest head weight recorded was 3.3 kg, which was on point 1 at irrigation line number 5.

The cabbage heads were evaluated based on FAMA grading specification. All wrapper leaves were green in colour and head shape free from deformation and damage before harvest. Cabbage between points 1 and 20 have heavy and dense heads, while those harvested at points 25 to 45 have light and hollow heads. The cabbage head formation was also affected by the cooling pad distance and temperature gradient. Cabbage harvested at 12.35 m from the cooling pad was graded as grade 1 (222 heads, average weight 2.5 kg). Those harvested at location between 15.35 m and 21.35 m fell into grade 2 (234 heads, average weight 1.33 kg). As expected grade 3 cabbages were produced at 24.35 m to 27.35 m from the cooling pad.

Conclusion

There was a negative correlation between the cooling pad distance and the canopy diameter as well as the yield of cabbage cultivar KY Cross. The cabbage canopy diameter and head weights grown under rain shelter were affected by two factors, i.e. the plant distance from the cooling pad and the temperature gradient that existed along the irrigation line from the cooling pad towards the exhaust fan. The cabbage growth performance decreased as the distance from the cooling pad increased. The temperature gradient caused the cabbage yield to differ at each point. The lowest temperature was recorded near the cooling pad and the temperature increased as the air flowed towards the fan. The pad cooling system at 70% efficiency was able to reduce the air temperature entering the shelter from 42 ºC to 33.6 ºC. However, due to the significant length of the shelter (30 m), large temperature gradients (up to 4.5 °C) were observed from pads to fans. To obtain high cabbage yield, the maximum length of side netted rain shelter should not be more than 12.35 m.

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Abstrak

Eksperimen di lapangan telah dijalankan bagi menentukan kesan kecerunan suhu sistem kipas dan pad penyejuk terhadap hasil kubis KY yang ditanam menggunakan teknik fertigasi di bawah struktur pelindung hujan (SPH) berjaring kalis serangga 30 m panjang x 10 m lebar dan 4.5 m tinggi. Sistem ini memberi penyejukan secara sejatan dan berupaya menurunkan suhu udara di dalam SPH ke bawah suhu ambien. Suhu di dalam SPH didapati berbeza 3–5 °C lebih rendah berbanding dengan suhu luar. Dengan kecekapan 70%, sistem ini berupaya menurunkan suhu luar daripada 42 °C kepada 33.6 °C apabila keluar dari pad penyejuk. Walau bagaimanapun suhu di dalam SPH meningkat selari dengan pergerakan udara dari pad penyejuk ke kipas ekzos (sehingga 4.5 °C) dengan menghasilkan kecerunan suhu di sepanjang SPH. Kecerunan suhu ini menyebabkan pertalian negatif antara jarak pad penyejuk dengan garis pusat kanopi dan hasil kubis. Purata garis pusat kanopi (77.34 cm) dan berat hasil kubis (2.62 kg) selepas 75 hari adalah lebih tinggi daripada pokok berhampiran pad penyejuk. Semakin jauh jarak pokok kubis dengan pad penyejuk, semakin kecil garis pusat kanopi (48.85 cm) dan berat hasil kubis (0.65 kg). Hasil kubis gred 1 diperoleh pada jarak 12.35 m dari pad penyejuk (purata berat 2.5 kg). Pada jarak antara 15.35–21.35 m, hasil kubis jatuh kepada gred 2 (purata berat 1.33 kg), sementara kubis gred 3 pula diperoleh pada jarak antara 24.35–27.35 m dari pad penyejuk.

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