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Evaluation of the Coolnet Placement Distance to Direct Evaporative Cooling to Increase Potato Seed Production in Aeroponic Systems with Root Zone Cooling in the Lowlands

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ABSTRACT

Evaluation of the placement of the coolnet distance on direct evaporative cooling is needed in order to reduce the wilting percentage and improve seed production of potatoes. The aim of the study was to obtain the appropriate coolnet distance for the growth and development of aeroponic potato seedlings in evaporative cooling and root zone cooling applications in the tropical lowlands. The factors tested were: 1) Evaporative cooling (JEvap) distance: JEvap1 (25 cm from the top zone of the plant), JEvap2 (50 cm from the top zone), and Jevap3 (60 cm), and 2) Varieties (V): V1 (MZ), V2 (Granola K), V3 (Granola L). The design used was completely randomized design with 2 replications. Growth data and results were analyzed by the F test and continued with Duncan's Multiple Range Test (DMRT) at 5% level. The results showed that the direct evaporative cooling method and the coolnet spacing of 50-60 cm which were integrated with root zone cooling created an air temperature at the top of the plant 26-28 °C, reduced the percentage of burnt wilting, and increased the number of tubers by an average of 31.4 to 41.7 tubers/plant.

1. INTRODUCTION

Unoptimal conditions for potato plants in the lowlands can be improved through limited climate engineering in the root zone of potato plants, namely root zone cooling (Sumarni *et al*., 2013) and evaporative cooling so that potato plants in the lowlands produce tubers and can survive more than 60 days after planting (DAP) (Sumarni *et al*., 2019; 2020; 2021a; 2022). Several applications of root zone cooling have succeeded in supporting the growth and development of vegetable production in the summer well and in the roots and shoots there has been an increase in nutrient uptake (Al-Rawahy *et al*., 2018). Control by root zone cooling also accelerates the formation of flower buds on strawberry plants (Mizuno *et al*., 2022), improves broccoli growth (Díaz-Pérez, 2009), increases the productivity of lettuce plants (Jie & Kong, 1998), increases the rate of nutrient uptake and root growth on tomato plants (Kawasaki *et al*., 2013).

Cooling to reduce high air temperatures on the surface of potato plants in the tropical lowlands has been carried out through evaporative cooling methods, the application of nutrients, and the application of root zone cooling (Sumarni *et al*., 2021b; 2022). The air temperature that can be reduced from the application of direct evaporative cooling is up to 7 – 9.5 °C (depending on air conditions, water spray, and flow direction). The results of previous studies stated that direct evaporative cooling has lower energy consumption when the temperature drops to 26 °C, which is 389 kJ, while cooling using an air conditioner (AC) is 902 kJ (Yunianto, 2018). The use of a coolnet in direct evaporative cooling has been carried out and can reduce the air temperature in the greenhouse (Sumarni *et al*., 2021b). Coolnet delivers uniform micro -sized droplets (65 microns), thereby preventing crop damage.

Some research results that evaporative cooling has been shown to reduce heat stress around greenhouses and plant peak. The application of evaporative cooling in a greenhouse can reduce air temperature by 4 – 5 °C (Helmy *et al*., 2013). Therefore, the application of root zone cooling and evaporative cooling is important to improve the condition of the top of the plant when planting potato seedlings in the lowlands through an aeroponic system.

Potatoes can grow optimally in a specific environment, so the yield and quality are good. Environmental extremes, such as temperature or humidity that is too high or too low can cause decreased plant growth and tuber yield. High air temperature above the plant canopy (leaves) promotes vegetative growth and stimulates stem elongation (Tadesse *et al*., 2001). High air temperatures of more than 25-30 °C tend to increase stem length and branching but reduce leaf size and leaf area. An increase in air temperature of greater than 20 °C can hurt crop production in greenhouses for countries located in tropical and subtropical countries (Alves-Damasceno *et al*., 2017).

The results of previous research using the direct evaporative cooling method (cold water spray) and root zone cooling in the aeroponic system gave an average number of tubers of 9.4 plants and an average tuber weight of 6.3 grams of tuber-1 (Sumarni *et al*., 2021a). However, these results were still obtained in 45-50% of the plants burned on the leaves and stem aged 60 days after planting (DAP). From the results above, it is necessary to further study the evaluation of the distance between the coolnet installation for evaporative cooling to the top of the potato plant. This is to get the appropriate distance to reduce the percentage of wilting of the top of the plant and support the the increment within the number of tubers. The aim of this study was to obtain suitable spacing to support the growth and development of aeroponic potato seedlings in evaporative cooling and root zone cooling applications in the tropical lowlands.

2. MATERIALS AND METHODS

The research was conducted in September 2021-January 2022 in the greenhouse of the Faculty of Agriculture (7°24'28" S; 109°15'20" E), Jenderal Soedirman University, Purwokerto, Central Java at an altitude of ±115 m asl. Figure 1 shows the research layout in the greenhouse, while the details of the aeroponic root zone cooling and evaporative cooling systems are shown in Figure 2.

2.1. Design of Experimental

The root zone cooling application used in this study ws temperature of 10 °C (Sumarni *et al*., 2013; 2019; 2021ab). The factors tested in the evaluation of the placement of

evaporative cooling distances using the direct method were: 1) The distance of the evaporative cooling (JEvap) from the top zone, consisted of JEvap1 (25 cm), JEvap2 (50 cm), and Jevap3 (60 cm) (Sumarni *et al*., 2019), and 2) Varieties (V), consisted of: V1 (MZ), V2 (Granola K), and V3 (Granola L). The crop spacing used in this study was 15 cm x 15 cm. The potato seeds were cuttings obtained from potato seed growers at the potato center, Banjarnegara, Central Java.

Propagation of potato seeds from cuttings was done after the plantlets reach the age of 3-4 weeks. Cuttings can be cut after they have 5-7 leaves, have healthy roots, and have strong stems. Cuttings that are 2 weeks old can be transplanted into an aeroponic installation (Dianawati *et al*., 2013) and potato tubers for seeds are harvested at least 80 days after transplanting (DAT) so that the seeds have sufficient age.

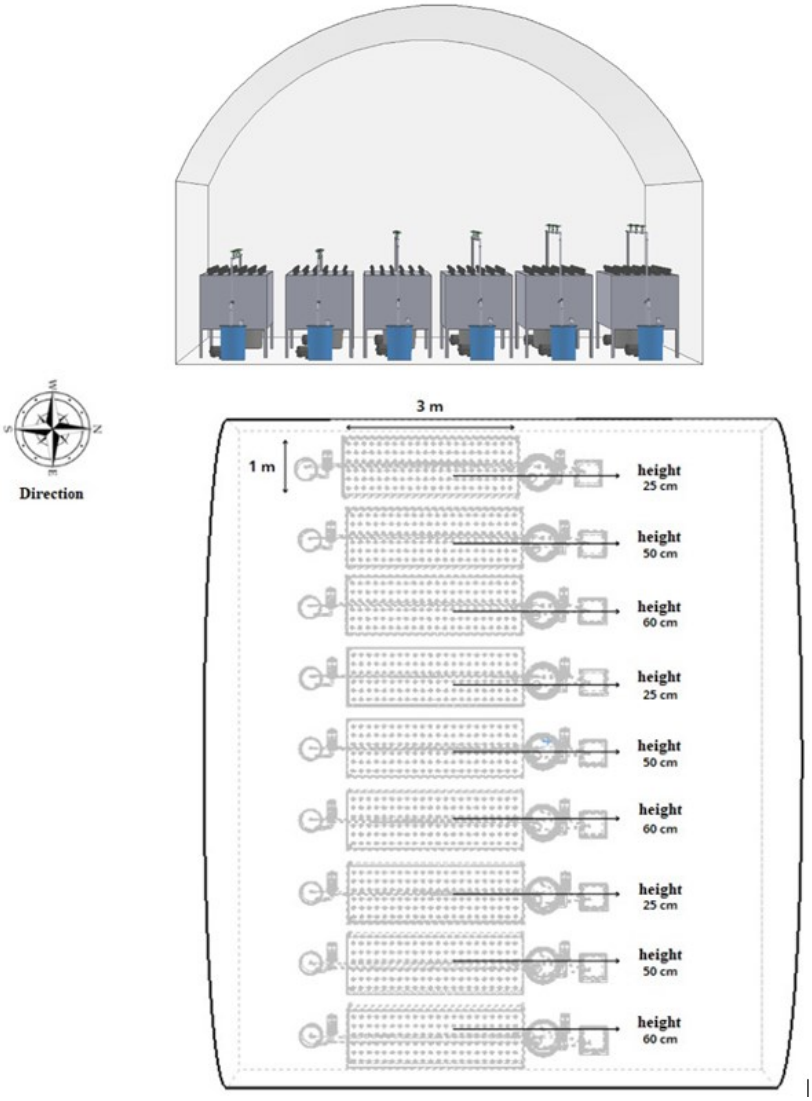

Figure 1. Layout of experiment in the greenhouse: front view (top), top view (bottom)

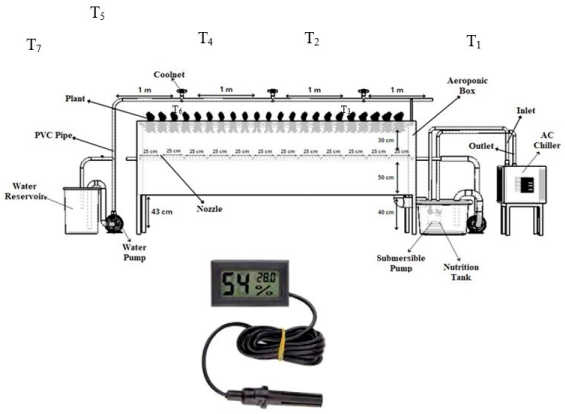

Figure 2. Detail of the aeroponic root zone of the evaporative cooling system (top) and temperature measuring instrument at each point (T = measurement point) (bottom)

The aeroponic system with root zone cooling works through the following stages: nutrients from the holding tank/bucket that have gone through the cooling system using chiller and are set up for appropriate temperatures around 10 °C (there is an automatic temperature setting button in the cooler according to the desired control temperature of ±1 °C). If the nutrient temperature in the nutrient tank rises to 11 °C, the fan on the cooling section will rotate and if it reaches 10 °C, the fan will stop turning on. The nutrients are then sprayed onto the roots (aeroponic) of the potato plants through nozzles with the help of pump (Sumarni *et al*., 2013).

Meanwhile the cooling in the top plant was performed using direct evaporative cooling system where water from the bucket was sprayed through the coolnett with the aid of a water pump. In addition, the greenhouse was equipped with some ACs to decrease temperature in the top of potato plant to decrease the burnt wilting occurrence of the plants.

Parameters of plant growth observed included plant height number of leaves and number of tubers. Growth parameters like length and number of leaves were measured every 7 DAT and the number of tubers was counted at 65 DAT. A tuber size of 0.5 g or more is an indicator of potato seed quality (Park *et al*., 2009). The experimental design used was a randomized block design with two replications. The nutrient composition used follows the formula of Otazu (2010) in Table 1. Data on growth observations and yields were analyzed by the F test and taken after by Duncan's Multiple Range Test (DMRT) at level α = 5%. Air temperature in the root area and the top of the plant was measured and observed to obtain microclimate information.

Table 1. Nutrient composition for potato seed production through aeroponic system (Otazu, 2010)

Nutrisi	Concentration
KNO_3	5.40 meL^{-1}
NH_4NO_3	4.4 meL^{-1}
Ca superphosphate	2.60 meL^{-1}
$MgSO_4$	1.00 mgL^{-1}
Fe (EDTA-Fe 6%)	8 mgL^{-1}
B (boric acid)	1 mgL^{-1}
Micro (Fertilon*)	12 mgL^{-1}

3. RESULTS AND DISCUSSION

3.1. Temperature and Relative Humidity

The average air temperature in the greenhouse reaches a maximum during the day at 13.00, which is 36.5 °C. These conditions are not optimal for the growth and development of potato plants in the lowlands. Potato plants can grow and develop optimally in the average daytime temperature range of 14 – 22 °C, higher temperatures can reduce yields significantly (Hancock *et al*., 2013; Muthoni & Kabira, 2015). However, this problem can be overcome by applying limited cooling in the root zone and this has been proven in a series of studies that have been conducted from 2013 to 2022 (Sumarni *et al*., 2013; 2019; 2021ab; 2022; Amaliah *et al*., 2018; Liu *et al*., 2022). In this research about the condition of the root zone by cooling the root zone be controlled at a temperature of 10.3 °C to 12.3 °C (Figure 3).

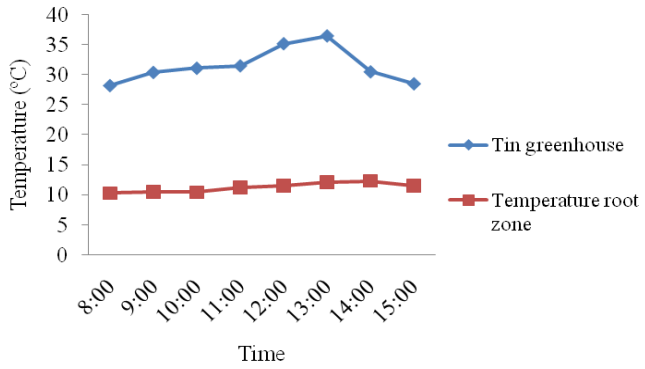

Figure 3. Air temperature in the greenhouse and the controlled temperature at the root zone

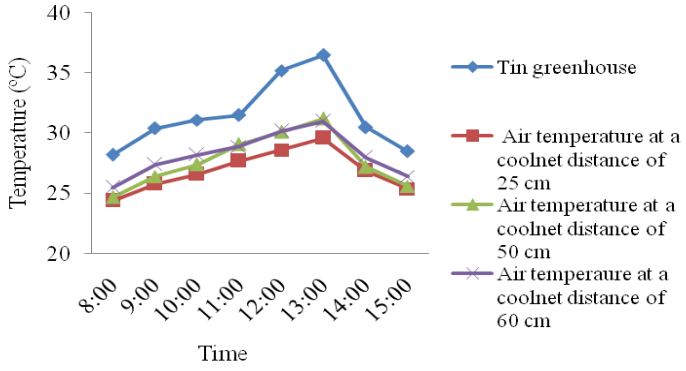

Figure 4. Air temperature in the greenhouse due to different coolnet distance

The results of the application of direct evaporative cooling on potato seed production in the lowlands of the tropics at several distances from the coolnet position provide a temperature drop of 3.3 – 4.6 °C. In direct evaporative cooling, the greenhouse cooling process is carried out by evaporating water in the air. During the evaporation process, the system absorbs heat from the incoming air which is in contact with water, some of the heat is absorbed by the water so that the air becomes colder. The results of this application show that the air temperature in the greenhouse drops from the top of the potato plant to a distance of about 30 cm in the vertical direction

inside the greenhouse (Figure 4). These results are supported by direct evaporative cooling testing in the vertical direction (Sitopu & Yunianto, 2015). The distance of the coolnet closer to the a lower leaf of the plant creates the area around the plant becomes more cold. Coolnet distance of 25 cm above the surface of the aeroponic box gives an average temperature of 26.9 °C around the plants, 50 cm coolnet distance gives an average temperature of 27.7 °C and 60 cm coolnet distance gives an average temperature of 28.2 °C. This is in accordance with the application of direct evaporative cooling (fan-pad) in previous studies which stated that the location closest to the placement of the evaporative cooling creates a lower temperature (about 5 °C) (Newir *et al*., 2017).

3.2. Plant Development and Improvement

3.2.1. Height and Number of Leaves on The Plant

The results of different coolnet spacing in the direct evaporative cooling application showed that there was an interaction between the coolnet spacing treatment and the tested potato varieties on plant height and number of leaves. The combination of the 60 cm coolnet distance and the Granola K variety produced the highest average plant height of 52.3 cm, while the lowest was resulted from the 25 cm coolnet distance combined with the MZ variety at plant age 49 DAT (Table 2). The highest average number of leaves (278.9 strands) was obtained from the combination of 50 cm coolnet distance and the Granola K variety which was not significantly different with those of the 60 cm coolnet distance with the granola K variety (271.4 strands) and the 60 cm coolnet distance with the MZ variety of 236 .8 strands.

Table 2. Interaction of coolnet distance in direct evaporative cooling on plant height and number of leaves

Treatment combination	Plant height (cm) (49 DAT)	Number of leaves (49 DAT)
$JEvap_1$-V1	34,9 d	151,7 bc
$JEvap_1$-V2	47,6 ab	188,8 b
$JEvap_1$-V3	40,3 cd	130,1 c
$JEvap_{2-}$-V1	46,2 abc	167,2 bc
$JEvap_2$-V2	48,5 ab	278,9 a
$JEvap_2$-V3	47,6 ab	190,8 b
$JEvap_3$-V1	49,0 ab	236,8 a
$JEvap_3$-V2	52,3 a	271,4 a
$JEvap_3$-V3	44,9 bc	176,1 bc

Note: Numbers followed by the same letter in the same column are not significantly different based on the DMRT at the level α = 5%; DAT = days after transplanting

The application of direct evaporative cooling can reduce the percentage of burnt wilting by up to 50% in the upper parts of the plant (leaves and stems) at 60 HST (Figure 5). This result is an increase from previous studies without the application of evaporative cooling where the upper part of the plant experienced more than 60% burnt wilting entering 60 HST (Sumarni *et al*., 2013).

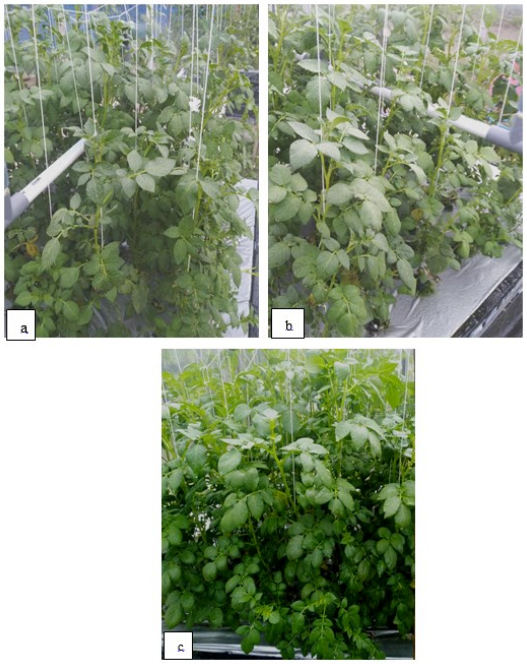

Figure 4. Appearance of potato plants in an aeroponic system in the tropical lowlands at 60 DAT at different coolnet distance : (a) 25 cm, (b) 50 cm, and (c) 60 cm

3.2.2. Number of Tubers

The application of direct evaporative cooling by paying attention to the placement of the coolnet distance gave different results on the number of tubers and there was an interaction between the coolnet distance and the varieties of potato tested. The treatment combination with the highest number of tubers was obtained by placing a coolnet at a distance of 50 cm and the Granola L variety with an average production of 41.7 tubers/plant. This means an increase of about 31% from previous studies in the lowlands without evaporative cooling applications (Sumarni *et al*., 2013). The treatment combination of coolnet distance of 60 cm and the MZ variety gave a production of 31.4 tubers/plant. While the lowest tuber production was obtained from the placement of a coolnet distance of 25 cm for the Granola K variety with an average tuber production of 1.7 tubers/plant (Table 3). The increase in the number of tubers produced in this study needs to be increased to achieve results such as in the highlands which can produce 70-100 tubers.

Table 3. Interaction of coolnet distance and potato varieties in direct evaporative cooling on potato tuber production

Treatment Combination	Number of tubers/plant
$JEvap_1$-V1	11,7 c
$JEvap_1$-V2	1,7 d
$JEvap_1$-V3	6,9 cd
$JEvap_2$-V1	27,3 b
$JEvap_2$-V2	11,8 c
$JEvap_2$-V3	41,7 a
$JEvap_3$-V1	31,4 b
$JEvap_3$-V2	3,9 cd
$JEvap_3$-V3	24,4 b

Note: Numbers followed by the same letter in the same column are not significantly different based on the DMRT at the level α = 5%.

The number of these tubers has increased compared to the results of previous studies (less than 20 tubers per plant) (Sumarni *et al*., 2021) which have not implemented coolnet spacing for direct evaporative cooling. In several studies, evaporative cooling can significantly increase yields in hydroponically cultivated lettuce (Chamroon & Aungkurabrut, 2019). So, direct evaporative cooling coolnet distance of 50-60 cm above the plant surface can provide good temperature control and increase tuber yield per plant. The coolnet distance supports a decrease in temperature around the potato crop canopy and in the vertical direction inside the greenhouse. The potato plant height reaches 80-100 cm and the coolnet reaches 40-60 cm. The shade created by the canopy from the height of the potato plants reduces the effects of solar radiation and solar radiation emissions in the greenhouse, thereby supporting the performance of the direct evaporative cooling provided. The effect of plant height by mixing air resulting from direct evaporative cooling prevents and reduces the transmission of accumulated heat from solar radiation, thereby lowering the air temperature in the greenhouse. These results are supported by previous research that the vertical distribution of air temperature has an important impact on plant height (Ahmed *et al*., 2019). The appearance of the highest and lowest number of tubers is presented in Figure 6.

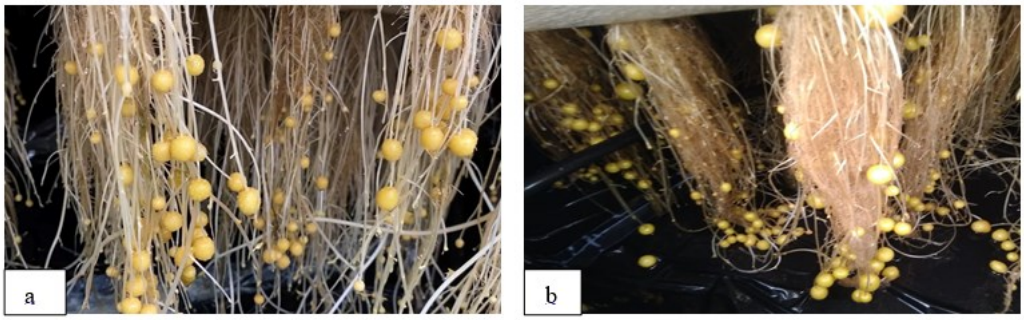

Figure 5. Appearance of the highest and the lowest tuber of potato production with coolnet distance treatment: (a) 60 cm, (b) 50 cm

4. CONCLUSIONS AND SUGGESTIONS

From the results of this study it was concluded that controlling the top of the plant using the direct evaporative cooling method and evaluating the coolnet placement distance of 50-60 cm and integrating it with root zone cooling control can improve the microclimate thereby reducing extreme temperatures on the top of the plant (around 26-28 °C), reduced the percentage of plants experiencing burnt wilting and increased the average number of tubers to 31.4 to 41.7 tubers/plant at a coolnet distance of 50 to 60 cm (10-31% increase from the previous yield) for potato variety of Granola L and MZ. In addition, it is necessary to further study the evaluation of the air temperature set point in evaporative cooling in order to maximize the production of aeroponic potato seeds in the tropical lowlands.

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