Technical Paper

IRRIGATION EFFICIENCY AND UNIFORMITY OF AEROPONICS SYSTEM A CASE STUDY IN PARUNG HYDROPONICS FARM

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ABSTRACT

The evaluation of the irrigation efficiency and coefficient of uniformity (CU) of the existing aeroponics system has been conducted for one growing season of petsai (Brassica pekinensis L) in Parung - Bogor, Indonesia. The evaluation covers the CU of the spray discharge, pH, temperature and electrical conductivity (EC) of the nutrient solution. It was concluded that the CU of spray discharge, pH and temperature of the nutrient solution were relatively high, but the CU of EC of the nutrient solution was relatively low. Conveyance efficiency and water-use efficiency were about 84.38% and 40.09%, respectively. The average crop water requirement was about 1,457 cc/crop/season or equal to 16,870 cc per Kg of petsai produced.

Keywords: *Aeroponics, coefficient of uniformity, irrigation efficiency*

Diterima: 02 Januari 2007; Disetujui: 19 Pebruari 2007

BACKGROUND

The aeroponics system is one of the hydroponics cultures that exploit the land optimally and increase yields as well as the quality of crops. Basically, the aeroponics system is a cultivation technique in which the nutrition solution is provided by spraying (Sutiyoso, 2003). Various plants that generally could be cultivated by aeroponics are vegetables; among others is *petsai (Brassica pekinensis* L). Beside that, with good management, using the aeroponics system in crop production could ensure the quality and quantity of yields and continuity as well.

The principle of aeroponics is that the plant needn't be embedded in the media of land or water, but should hang in the air. The nutrients for the plant are supplied from the bottom and wet the roots through the spraying of the nutrient solution regularly utilizing high pressure pumps. One of the advantages of the aeroponics system is that the oxygenation of nutrients fogs the root (Sutiyoso, 2003). The nutrients hold oxygen from the air until the level of dissolved oxygen is increased. So, respiration on the root can produce much energy.

The coefficient of uniformity, irrigation efficiency and crops water requirements, constitutes the parameters that should

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be considered in evaluating the technical performance of the aeroponics system. Research on the technical performance of the aeroponics system is needed in order to determine the effectiveness and efficiency of water and nutrient solution use.

The objective of this research was to evaluate the technical performance of the aeroponics system, which includes the parameter of uniformity of the nutrient solution, irrigation efficiency, and irrigation water requirements.

METHODS

Irrigation efficiency is a concept used extensively in system design and management. It can be divided into two components, uniformity of application and losses. If uniformity is poor or losses are high, efficiency will be low (Keller and Bleisner, 1990). A useful term/formula for placing a numerical value on the uniformity of application for agricultural irrigation systems is the Coefficient of Uniformity (CU) developed by Christiansen (1942):

$$CU = 100\left[1 - \Sigma\left\{\frac{|Xi - X|}{nX}\right\}\right]\% \quad (1)$$

where, *CU* coefficient of uniformity (%), *n* number of observations, *X* mean depth of observations (mm), *Xi* individual depth of catch observation from uniformity test (mm), |*Xi* – *X*| absolute deviation of the individual observation from the mean (mm)

Uniformity evaluation in this research includes CU of nutrient solution as well as CU of yields. The CU of nutrient solution includes CU of sprayer discharge, pH and electrical conductivity of nutrient solution. Four sampling beds were utilized

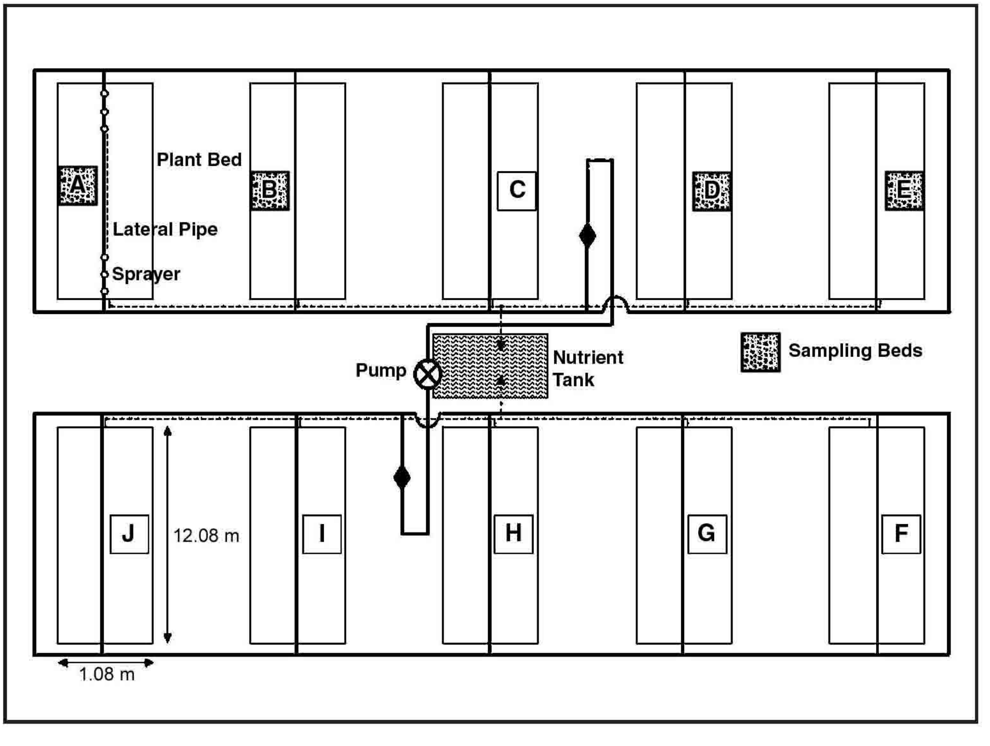

Figure 1. Aeroponics System Network

Table 1. Coefficient of Uniformity (CU) of Nutrient Solution

Parameters	CU of nutrient solution (%)		
	Subunit 1	Subunit 2	Average
Sprayer discharge	93.36	93.16	93.26
Electrical Conductivity (EC)	49.50	50.57	50.04
pH	93.97	93.90	93.93
Temperature	94.90	94.63	94.76

for measurements of sprayer discharge, pH, temperature and electrical conductivity of nutrient solution, and yields, as presented in Figure 1. The irrigation component in the aeroponics system consists of pumps, a nutrient tank, pipelines, and sprayers. Sprayer discharge was about 50 l/h at 1.5-2 bar operating pressure. Lateral length was 12m with 19-21 units of sprayers per lateral.

Irrigation efficiency was calculated by the following formula (Schwab *et al.*, 1981):

1. Water conveyance efficiency,
2. Water-use efficiency,

where, *Wd* water delivered by a distribution system, *Wi*, water introduced into the distribution system, *Wu* water beneficially used.

RESULTS AND DISCUSSION

Coefficient of Uniformity

According to Keller and Bleisner (1990), there are four types of emitter; i.e. the drip system, sub surface system, bubbler system, and sprayer system. The aeroponics system uses the sprayer type as an emitter. The recommended uniformity value for the spray system is 85 % to 95 %. However, the optimum uniformity is determined by the economics of the crop and applied water values, crop response to water and deficits, and drainage economics. The results of the uniformity measurements are summarized in Table 1.

The CU of sprayer discharge was relatively high; i.e. about 91%-97%. This indicates that the number of sprayers per lateral and the length and diameter of the lateral pipes met the hydraulics criteria. The high value of CU also indicates that the nutrient solution flow along the laterals was relatively uniform in providing water, nutrients, and air for the crops.

During irrigation, the values of the electrical conductivity (EC) of the nutrient solution varied from 0.5 to 2.1 mmhos, with an average of 1.2 mmhos. The uniformity of EC of the nutrient solution was relatively low in each growing stage; i.e. varied at 24%-88%. It also was apparent that the electric ions did not move properly from the nutrient solution to the plant root. If the plant root absorbs fewer nutrients than needed, then the plant productivity will be decreased and less uniform. The low CU of EC of the nutrient solution happened due to the difference in the value of EC for each measurement as a consequence of the continuous filling of water into the nutrient tank. The chart for the EC uniformity is shown in Figure 2. Prastowo *et al.* (2004) stated that the CU of EC of the nutrient solution in the NFT system was about 89.5%.

The pH of the nutrient solution varied at 4.8 – 6.3 with an average pH of 5.6. Uniformity of the pH was relatively high, i.e. about 93%. The value of pH uniformity indicates that the nutrient solution tended to be absorbed easily by the plant root. **Figure 3** shows that the relationship between the EC and pH of the nutrient solution in plant beds was an exponential equation ($y = -0.3344x3 + 1.4148x2 - 2.481x + 6.8612$ with $R^2 = 0.98$, n=37). This equation indicates that there was a significant relationship between the electrical conductivity (EC) and the acidity (pH) of the nutrient solution.

The uniformity of temperature of the nutrient solution, both in the nutrient tank as well as in the plant beds had the same relatively; i.e. varied at 93 % to 97 %. The value only indicates the uniformity of the nutrient dissolve capability. The high level of uniformity of the nutrient solution temperature does not indicate high dissolve capability. However, the dissolve capability of the nutrient solution is influenced by the temperature. The nutrient solution has an ideal temperature to dissolve at. If the temperature increases above the ideal point, then the dissolve capability decreases proportionally.

Crop Yields

One of the purposes of plant cultivation using the aeroponics system is achieving high levels of quantity and high quality of agricultural products. The plant productivity can be measured by parameters of crop weight and its uniformity. Plant productivity is influenced by nutrient solution uniformity, electrical conductivity of the nutrient solution, cultivation methods, and other micro-environmental factors. The results of measurement show that the crop yields along the plant bed (lateral) varied from 51.54 g/crop to 54.92 g/crop with an average yield of 54.73 g/crop. The CU of yields was relatively low; i.e. about

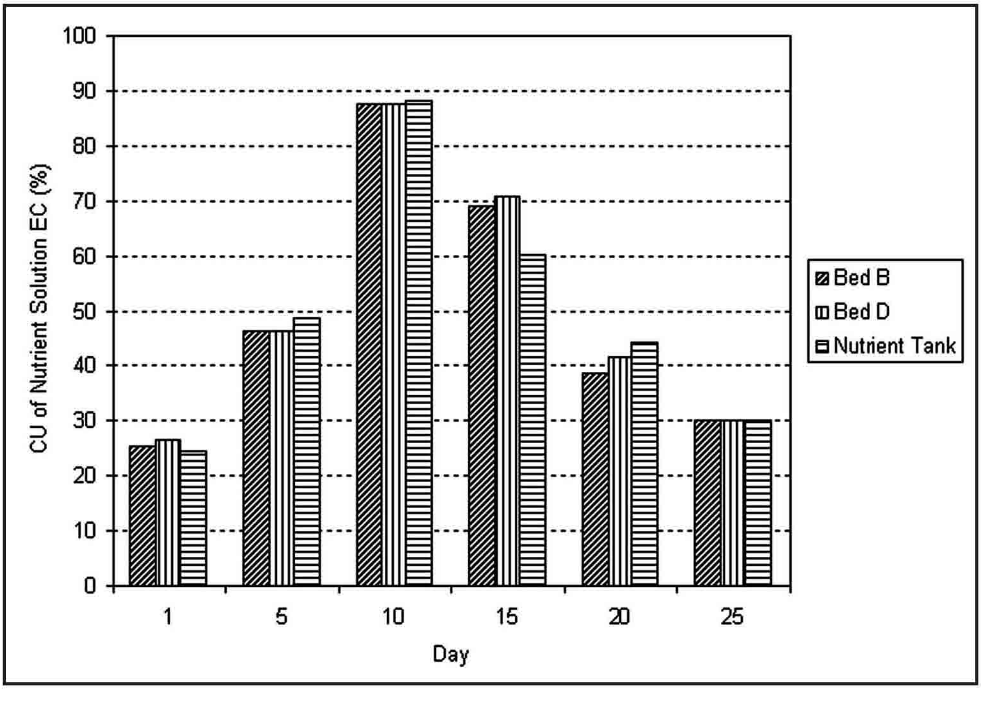

Figure 2. CU of Nutrient Solution EC during the Growing Stage

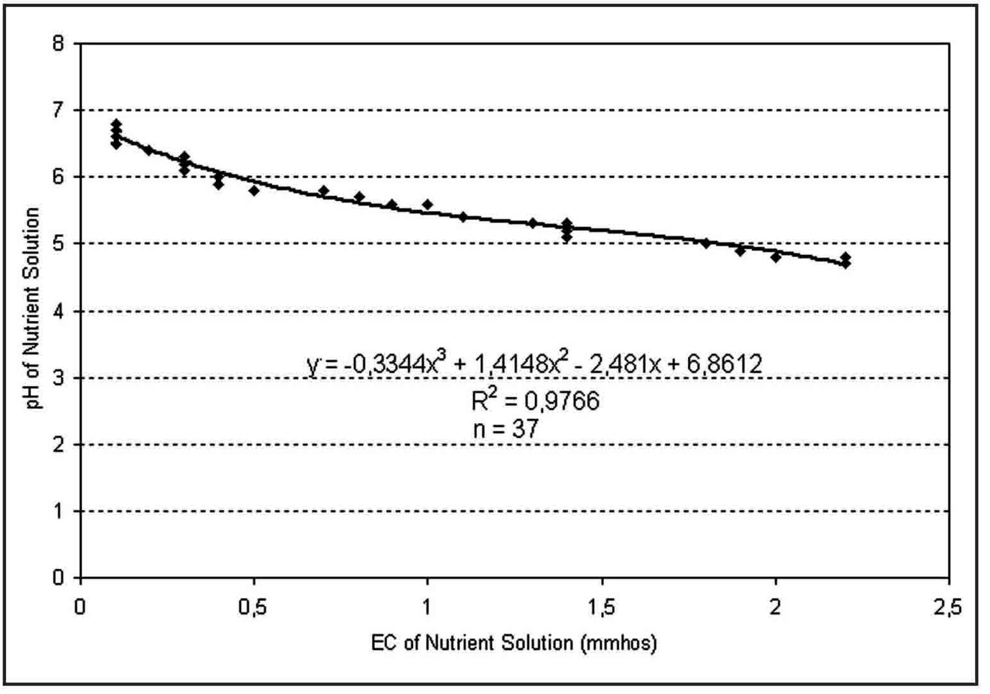

Figure 3. Relationship between EC and pH of Nutrient Solution at Plant Beds

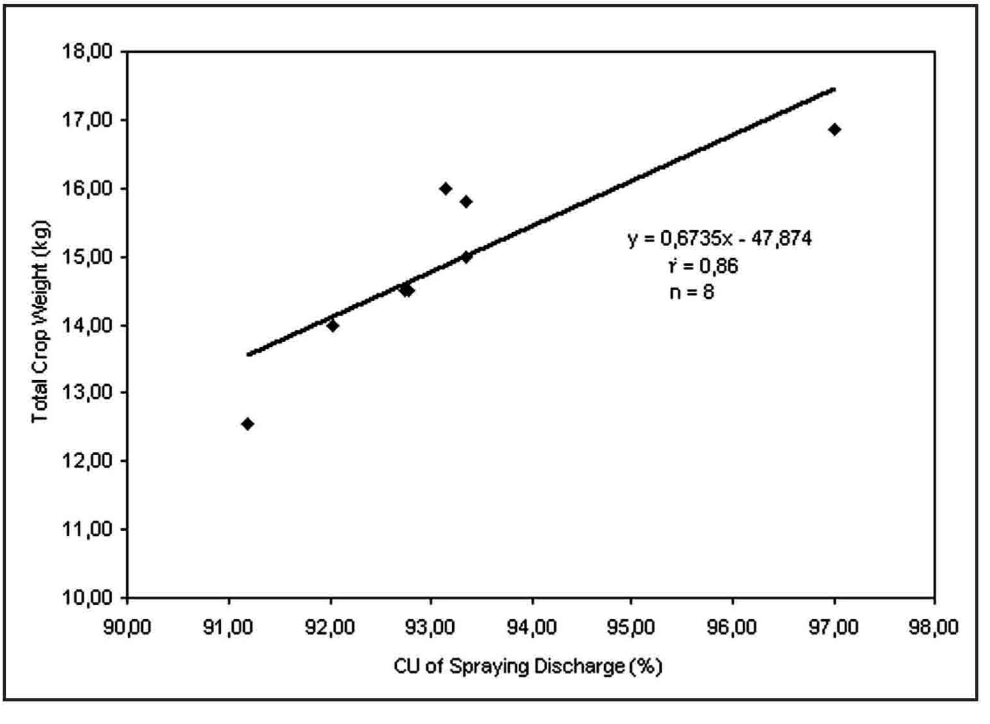

Figure 4. Relationship between Total Crop Weight and CU of Spraying Discharge

60.34%. Permatasari (2001) stated that the yield of *petsai* with the hydroponics-*para* system was about 61.24 grams/crop, while Prastowo *et al*, (2004) stated that with the NFT (nutrient film technique) system, the average yields of petsai was 45.44 g/crop.

The relationship between crop yields and the CU of spraying discharge was a linear equation ($y = 0.6735x - 47.874$ with $r = 0.86$, $n = 8$) as shown in **Figure 4.** The chart shows that the total crop weight has a tendency to increase proportionally to the uniformity of the spreading of the nutrient solution.

Irrigation Efficiency and Crop Water Requirements

The definition of water conveyance efficiency can obviously be applied along any range of a distribution system. The water application efficiency may be calculated for an individual furrow or border, for the entire field, or for the entire farm or project. The concept of beneficial use differs from that of water stored in the root zone in that leaching water would be considered beneficially used although it moved through the soil moisture reservoir. Sometimes water-use efficiency is based on the dry plant weight produced by a unit volume of water (Schwab *et al*., 1981).

The results of measurement gave rise to the conclusion that the conveyance efficiency and water-use efficiency of the existing aeroponics system were about 84.38% and 40.09%, respectively, and the irrigation efficiency of the system was about 33.80%. The main factor in the water losses was leakage in the plant bed due to some holes in the bed cover. The lower value of water use efficiency shows that the amount of irrigation water was not used effectively for plant growth. According to Keller and Bleisner (1990), the best value for irrigation water conveyance efficiency varies at 90 % - 100 %.

Water requirements for each crop are calculated on the basis of meeting the evapotranspiration rate (ET_{crop}) of a disease-free crop growing in large fields under optimal soil conditions, including sufficient water and fertility, and achieving full production potential under a given growing environment. This depends mainly on climate, growing season, crop development, and agricultural and irrigation practices (Raes, D. 1989).

The average reference crop evapotranspiration was 4.0-5.3 mm/day, calculated by the radiation method. The actual crop water requirement was calculated based on the measurement of the lateral inlet discharge and the outlet discharge. The actual crop water requirement was about 480 cc/crop/day or 16,800 cc/crop/season, or equal to 16,930 cc per Kg of *petsai* produced. As a comparative, the water requirement of *petsai* with the NFT system was about 32,064 cc per Kg of *petsai* produced (Prastowo *et al*, 2004). The actual crop water requirements were less than that calculated crop water requirements. The actual values rose during initial growth (1^{st} day until 10^{th} day) and then decreased at the end of growth (15^{th} day until 25^{th} day). The fluctuation of crop water requirements was caused by the uniformity of nutrient absorption by the plant roots in each growing period.

CONCLUSIONS

The CU and irrigation efficiency of the existing aeroponics system have been evaluated. The CU of spraying discharge, the pH and the temperature of the nutrient solution were relatively high, but the CU of the EC of the nutrient solution was relatively low. The irrigation efficiency of the aeroponics system was relatively low; i.e. about 33.80 %, and the crop water requirement was 16,870 cc/Kg-crops of *petsai*.

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