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Assessment of water use efficiency and fertilizer use efficiency of solar-powered aeroponic system

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Abstract
Global food consumption of the world's expanding population is predicted to increase significantly in the next decades. However, as the world's natural resource base (land, water, and air) is put under greater demand to raise food production, all of the main resources for modern agriculture are becoming less available. Increased food production can be achieved by expanding crop fields and improving cultivation. The hydroponic system is one of today's most advanced crop production methods. A hydroponic system's basic components include nutrient film technique (NFT), deep water culture (DWC), wick hydroponic, flood and drain system, drip hydroponic, and aeroponics. In this study, the solar-powered aeroponic system was compared to the conventional method of cultivating lettuce in terms of water and fertilizer efficiency. Lettuce crop production in aeroponic (5.0 kg m^{-2}) and traditional systems (1.5 kg m^{-2}). The water and fertilizer use efficiency of the aeroponic system and traditional approach have been determined to be 67.0 kg m^{-3} and 43.8%, respectively, and 6.1 kg m^{-3} and 25.3%.

Keywords: Hydroponic system, aeroponic system, Nutrient film technique, and solar-powered aeroponic system

Introduction
Expanding land and intensive farming may result in increased food production. Approximately 1.44 billion ha of the world's land is arable and under permanent agriculture. (FAO 1992, 1993) [6, 7]. Most of the land that could be brought under cropping has been utilized (Borlaug and Dowswell, 1993) [1]. On the other hand, intensive farming usually degrades the land and reduces its fertility and output. Many agricultural soils across the world lack one or more necessary elements for healthy and productive plant growth. Chemical fertilizers are one of the most expensive inputs used by farmers to increase crop yields, yet they do not attain nutrient usage efficiency due to high nutrient losses caused by leaching, run-off, gaseous emission, and soil fixation. These losses may contribute to the decline of soil and water quality, ultimately leading to overall environmental degradation. These are compelling arguments for increasing NUE. Despite high-yielding cultivars and an effective array of practices, farmers are unable to realize production potential when plants are not properly irrigated. Furthermore, India is already water-stressed and on its way to becoming water-scarce, and water has become a vital component in Indian agriculture. The eventual pressure for optimal utilization of highly restricted water resources consequently increases dramatically. It is very vital to use every drop of freshwater efficiently.

As a result, to achieve sustainability, water-smart technology must be developed. Water productivity can be increased by embracing the concept of multiple water usage, which goes beyond the traditional constraints of productive sectors. The multiple water use method can create additional economic benefits and reduce vulnerability by allowing for more diverse livelihood alternatives and boosting ecosystem sustainability. (Dhawan, 2017) [3]. To address the issues raised above, new farming methods have been investigated, one of which is aeroponic. Aeroponics means "growing in air." Aeroponics is a method in which the roots are suspended in the air and moistened with water at specific times. The benefit of this form of growing is that it uses less water than traditional soil farming.

Aeroponic farming allows farmers to produce some types of food crops faster and larger while using less water. Lettuce (*Lactuca sativa* L.) belongs to the Compositae family and is one of the world's most important vegetable crops. It is grown primarily in open fields as well as in greenhouse settings. It is well-known for its delicate, crunchy texture, slightly bitter flavour, and milky juice when fresh. It is the most popular of all salad vegetable harvests. (Squire *et al*., 1987) [16].

Lettuce is high in vitamin A and minerals such as calcium and iron. It also contains protein, carbohydrates, and vitamin C, and 100 g of edible portion of lettuce contains 93.4 g moisture, 2.1 g protein, 0.3 g fat, 1.2 g minerals, 0.5 g fibre, 2.5 g carbohydrates, 310 mg calcium, 80 mg phosphorus, 2.6 mg iron, 1650 I.U. vitamin A, 0.09 mg thiamine, 0.13 mg riboflavin, and approximately 10.0 mg vitamin C. (Gopalan and Balaraman, 1966). Solar energy is a renewable energy source that is readily available in any corner of the planet. Now, everyone is focusing on using sustainable energy sources. The fundamental issue in aeroponics is the constant supply of power. Solar energy can be stored as electrical energy in batteries made of PV cells to generate power. Solar energy is cost-effective, environmentally benign, and beneficial to farmers.

Materials and Methods

Location

The experiment was carried out in the Department of Soil and Water Engineering, College of Agricultural Engineering, University of Agricultural Sciences, Raichur in Karnataka. Raichur is located at latitude 16˚15′ N and longitude 77º 21 ′ E, with an elevation of 389 m above Mean Sea Level (MSL) with an average annual rainfall of roughly 650 mm. It is considered the North Eastern Dry Zone of Karnataka.

General description of solar-powered aeroponic system

The solar-powered aeroponic system used an aluminium rectangular frame of 2.0 m × 1.0 m × 0.6 m (L × W × H). The growing chamber was held at 0.4 m above ground and equipped with a longitudinal gradient. The growing chamber was covered with an acrylic sheet, while the inside was covered with a 300 µ black polythene sheet, with a drain exit at the edge to catch any excess spray. To accommodate the seedlings, the growth chamber was coated with a polystyrene sheet. Misters with 6.5 to 7.5 lph were placed in the bottom of the growth chamber to deliver the necessary water and nutrients to the seedlings that were placed on a polystyrene sheet. The fertilizer solution was stored in a rectangular loft tank and drained by gravity from the grow chamber. The design specification of the growth chamber is shown in Fig. 1.

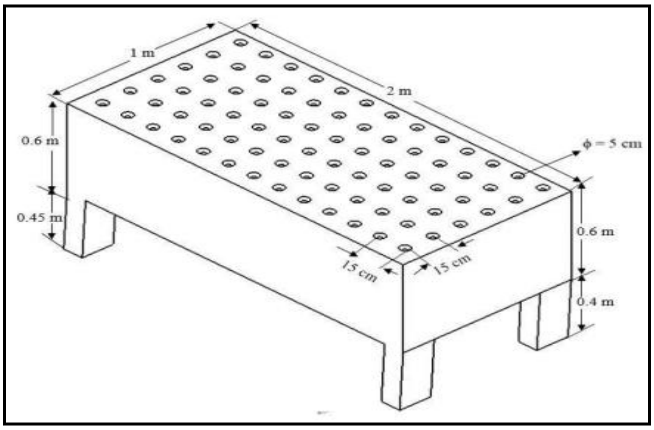

Fig 1: Design specification of growth chamber

Preparation of nutrient stock solution in aeroponic system

Two bottles were chosen: bottle A and bottle B. Bottle A contained calcium nitrate, potassium nitrate, manganese sulphate, EDTA iron, zinc sulphate, and copper sulphate, whereas bottle B had potassium nitrate, potassium dihydrogen phosphate, boric acid, and ammonium molybdate. (Hassan *et al*., 2018) [12]. The 6 ml of concentrated stock solution from each bottle was combined and diluted in 1 litre of normal water. The EC and pH were maintained before delivery to the crop.

Irrigation scheduling of aeroponic and conventional system

The irrigation duration and interval were 10 seconds on and 5 minutes off. Because of the misting interval, the temperature in the plant's root zone chamber is constantly monitored, which saves energy. Irrigation in the typical system is done on alternating days.

Crop water use in aeroponic system

The seasonal crop water use was calculated by using the water balance equation (Grewal *et al*., 2011) [11]

$$CWU = \frac{Q1-Q2}{A} \qquad (1)$$

Where,

CWU = Seasonal crop water use (m^3)

Q1 = The seasonal inflow volume to the aeroponic system (m^3)

Q2 = The seasonal outflow volume to the aeroponic system (m^3)

A = the floor area of the aeroponic system (m^2)

Assessment of crop water requirement in the conventional system

The crop water requirement was calculated by using the following equation …..(2)

$$ET_c = K_c \times ET_0 \qquad (2)$$

Where,

ET_c = Evapotranspiration of the crop, (mm day^{-1})

K_c = Crop coefficient, (Initial – 0.7, Developmental – 1.0, Middle – 1.0 and Late – 0.95)

ET_0= Reference evapotranspiration, (mm day^{-1})

ET_0 = Pan coefficient (0.7) × Pan Evaporation

Yield per m² (kg)

The yield was harvested from both aeroponic and conventional systems and then weighed and expressed in kg.

Water use efficiency

Water use efficiency (WUE) was calculated for the aeroponic system, which is the ratio of yield of the crop and total water applied

$$WUE\ (kg\ m^{-3}) = \frac{Y}{W.\ U} \qquad (3)$$

Where,

WUE = Water use Efficiency, (kg m^{-3})

Y = Crop yield, (kg)

W. U = Total amount of water used, (m^3)

Fertilizer use efficiency

Fertilizer usage efficiency (FUE) was estimated using Dobermann's (2007) [4] equation, which is the ratio of the nutrient content of the harvested portion of the crop and the amount of fertilizer applied in an aeroponic system.

$$FUE = \frac{UH}{F} \text{.......................}(4)$$

Where,
FUE = Fertilizer use efficiency, (%)
UH = Nutrient content of harvested portion of the crop, (g)
F = Amount of fertilizer applied, (g)

Estimation of nutrient content in crop

Total nitrogen (%)

The nitrogen was estimated by Micro Kjeldahl's method (Piper, 1966) [14].

Total phosphorus (%)

Phosphorus was estimated by vanadomolybdo phosphoric yellow colour method (Jackson, 1973) [13].

Total potassium (%)

Potassium concentration was determined by the flame photometric method (Jackson, 1973) [13].

Calcium and magnesium (%)

The calcium and magnesium concentrations were determined by complex-metric titration using a disodium solution of ethylene diamine tetra acetic acid (EDTA) method.

Total micronutrients (ppm)

The content of Iron (Fe) and Zinc (Zn) was estimated by using an Atomic Absorption Spectrophotometer (AAS) (Jackson, 1973) [13].

Results and Discussion

Water use efficiency in aeroponic and conventional systems

The water use efficiency (WUE) represents the yield obtained per unit volume of water used. The water consumption efficiency of lettuce crops as influenced by aeroponics and conventional systems is summarized in Table 1 and illustrated graphically in Figure 2. The results show that the aeroponic system was more efficient in terms of water use than the conventional approach. The highest water use efficiency of 67 kg m^{-3} was achieved in the aeroponic system, while the lowest was 6.13 kg m^{-3} in the conventional system.

Most water is lost through evaporation, seepage, and percolation, so plants never have the opportunity to use it in a typical system. In aeroponics, only transpiration was discovered to be dominating; there was no loss of water through infiltration, evaporation, seepage, or percolation, resulting in increased water use efficiency or productivity of the system. Aeroponics uses an extraordinary amount of water as little as compared to other plant growing methods and the system uses less water usage, maximum plant yield than other traditional methods or hydroponic systems, same trend results were reached by (Stoner and Schorr, 1983) [17]. Aeroponics systems utilize much less water than hydroponics, aquaponics, and traditional farming, resulting in increased water efficiency. Consumption was thereby limited to merely the amounts absorbed by the plants, allowing for significant water savings. For example, producing 1 kg of tomatoes with traditional land agriculture requires 200 to 400 litres of water, whereas hydroponics requires approximately 70 litres and aeroponics uses just about 20 litres. Because the aeroponic system is a continuous cycle in an enclosed space, and the reuse of nutritional solutions (Gopinath *et al*., 2017) [10]. The water use efficiency of aeroponic and conventional system is depicted graphically in Fig. 2.

The technology can conserve both water and electricity. Because aeroponics systems rely on nutrient solution recirculation, a small amount of water is required. It provides reduced water and energy inputs per unit growth area. Our analysis validates the results obtained by (Farran and Mingo-castel, 2006) [8] and (Ritter *et al*. 2001) [15].

Fertilizer use efficiency in aeroponic and conventional system

Fertilizer utilization efficiency (FUE) compares the nutrient content of the harvested section of the crop to the amount of fertilizer applied. Table 1 shows the fertilizer use efficiency for lettuce crops as influenced by aeroponics and conventional systems, and Fig 2 depicts this graphically. The results showed that the aeroponic system used fertilizer more efficiently than the conventional system. The highest fertilizer use efficiency of 43.83% was obtained in the aeroponic system, while the lowest was 25.38% in the traditional system. The nutrients were provided in a closed circuit, with the same nutrient solution being reused. Consumption is consequently limited to only the quantities absorbed by the plants, allowing for substantial enhancement of the fertilizer use efficiency. These results agreed with those obtained by Choi *et al*. (2016) [2]. After analyzing the data from the studies, it was discovered that the cultivation was carried out conveniently, as were the levels of macronutrients nitrogen, phosphorous, potassium, calcium, magnesium, and micronutrients iron and zinc. Table 2 summarizes the macro and micronutrient concentrations in lettuce from the trial. The macronutrient levels obtained for N, P, K, Ca, and Mg were found to be (%) 3.36, 1.28, 5.32, 0.6, and 0.4. Similarly, the micronutrients Fe and Zn were found to be (ppm) 26 and 5 under the aeroponic system. Under the conventional system, the macronutrient levels for N, P, K, Ca, and Mg were found to be (%) 3.8, 1.5, 5.65, 0.5, and 0.34. Similarly, micronutrients Fe and Zn were found to be (ppm) 532 and 32, respectively. These results are in accordance with Domingues *et al*. (2012) [5].

Table 1: Water use efficiency (WUE) and fertilizer use efficiency (FUE) in aeroponic and conventional system

Growing method	Yield (kg m^2)	Total depth of water applied (m^3)	Water use efficiency (kg m^{-3})	Fertilizer use efficiency (%)
Aeroponic system	5	0.3	66.7	43.8
Conventional system	1.5	0.49	6.1	25.3

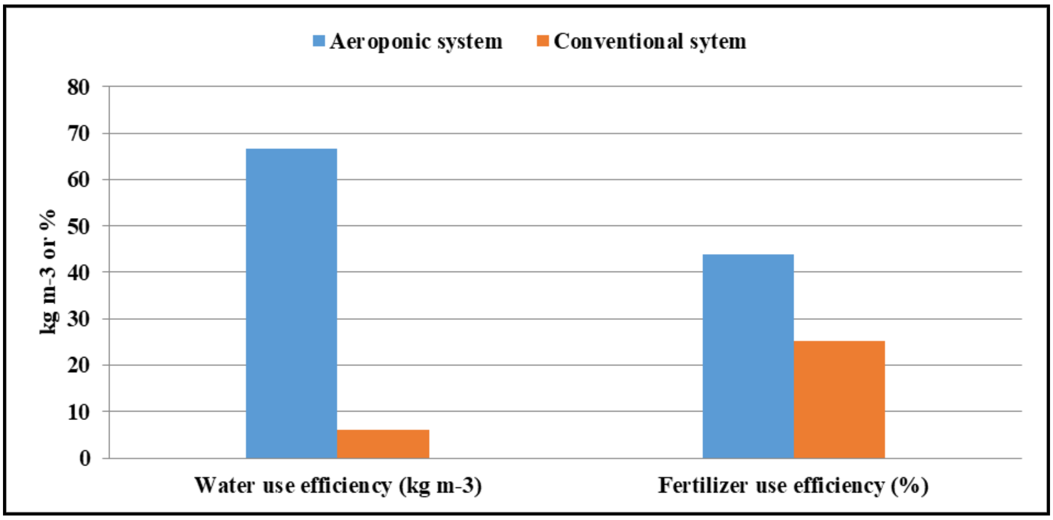

Fig 2: Water use efficiency and fertilizer use efficiency in aeroponic and conventional system

Table 2: Nutrient content in lettuce under aeroponic and conventional system

Sr. No.	Nutrients	Aeroponic system	Conventional system
1	N (%)	3.4	3.8
2	P (%)	1.3	1.5
3	K (%)	5.3	5.7
4	Ca (%)	0.6	0.6
5	Mg (%)	0.4	0.3
6	Fe (ppm)	26.0	532.0
7	Zn (ppm)	5.0	2.0

Conclusion

The lettuce crop performed exceptionally well in an aeroponics system, with the highest yield of 5 kg m^{-2} (50 t ha^{-1}). The conventional approach produced a lower yield of 1.5 kg m^{-2} (15 t ha^{-1}). The conventional system yield was lower.

The aeroponics system has the highest water use efficiency (67 kg m^{-3}). It was discovered that the aeroponics technology improved water use efficiency while requiring less water input. The conventional system has the lowest water use efficiency, measuring 6.13 kg m^{-3}. This was due to the lower yield attained in the conventional system. Similarly, the aeroponic system used fertilizer 1.73 times more efficiently than the conventional system.

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