***Original Research Article***

**Effect of variable seeding density and cell spacing on dill (*Anethum graveolens* L.) growth, yield and biochemical parameters** **under deep water culture (DWC)**

**ABSTRACT**

The present investigation entitled “Effect of variable seeding density and cell spacing on dill (*Anethum graveolens* L.) growth, yield and biochemical parameters under DWC (Deep Water Culture)” was carried out at Landcraft Aquaponics Unit, Hatkanangale, Tal. Hatkanangale, Dist. Kolhapur, (MS) India during December, 2021 to February, 2022. An experiment was comprised of factors; cell spacing and seed density, laid into Factorial Completely Randomized Design (FCRD) with two replications. The factors a cell spacing and seeding density had significant effects on growth, yield and yield contributing characters of dill under DWC. For yield and yield contributing characters, treatment S1D5 recorded significantly superior weight of leaves (51.95 g/cell), weight of stems (14.32 g/cell), weight of roots (10.99 g/cell), fresh yield of dill (65.99 g/cell) and yield of leaves (106.96 kg/100 sqm.). The treatments did not differ significantly for biochemical parameters (chlorophyll content, micronutrient content, ash and moisture percentage). There was no any significant difference reported among the treatments for sensory parameters (colour, texture and aroma). Hence, on the basis of growth, yield, biochemical and sensory parameters, it is concluded that the treatment S1D5 i.e. 18 cell-sheet (spacing- 14 cm 14 cm) with seed density 20 seeds per cup was found the best treatment for higher yield in Dill cultivation under Deep Water Culture Technique of aquaponics.

***Keywords:*** *cell spacing; dill; DWC; growth; seeding density*.

1. **INTRODUCTION**

Dill belongs to the family Umbelliferae (Apiaceae) which comes under the genera Anethum, in which there are two species under cultivation, namely: the European Dill, *A*. *graveolens* L. and another closely related Indian Dill, *A*. *Sowa* Roxb (Farooqi and Sreeramu, 2004). Dill is believed to have originated in the Eastern Mediterranean (Passam, 2021). In the Southern Mediterranean region, as early as 3000 A.C., dill was popular for its medicinal properties. The Norse parents used it to ease the stomach pains of crying babies and to lull them to sleep. Hence, the name Dill has come from the Old Norse word, dilla, meaning “to soothe”.

In Egypt, it was discovered in the tomb of Amenhotep II (reigned 1427-1401 BC), while in Ancient Greece, dill-scented oil was burnt in homes and used to flavour the wine. Hippocrates (c.460—c.370 se) prepared a mouthwash from its seeds in wine and leaves were placed over the eyes to induce sleep. Roman gladiators ate dill with their meals and applied its oil to invigorate themselves and bring good fortune.

In India and South-East Asia, dill has been cultivated since ancient times (Le Strange, 1977). Dill is recommended mostly against gastritis, insomnia and tension of arteries. It has been the king of herbs in Sweden. Nowadays, dill is increasingly grown as herb and to produce oil for the food and pharmaceutical industries.

Dill grows best in full sun. However, hot weather can be a determining factor in causing the plant to flower early, which hampers the leaf production. Dill (*Anethum graveolens* L.) is considered a cool season crop. It grows well in temperatures ranging from 42.8-79° F (6-26° C). High winds can cause great damage to dill crop because the hollow stems break and bend easily. Staking may help to minimize the damage. Hail and low moisture can also have a detrimental effect on this herb (Small, 2006).

Soil based agriculture is now facing various challenges such as urbanization, natural disaster, climate change, indiscriminate use of chemicals and pesticides which is depleting the land fertility (Sharma *et al*., 2018). Therefore, growers are trying to adopt new techniques of cultivation. New advanced method for improving cultivation of different vegetable crops is soil-less cultivation. It is a method of growing vegetables without the using soil as a rooting medium. The roots are supplied with the inorganic nutrients through irrigation water. The technique is known as hydroponics, aeroponics and aquaponics. Aquaponics is the technique in which, aquatic animals such as snails, fish, crayfish and prawns, etc., are grown in water tanks along with vegetables grown in hydroponics in a symbiotic environment (Waiba *et al*., 2020) and it has been gaining more attention (Rakocy *et al*., 2006) to serves as a bio-integrated model for sustainable vegetable production (Diver, 2006).

Interlinking of aqua cultural and hydroponic procedures increases popularity of this technique (Goddek *et al*., 2015). It can also ensure food security where normal vegetable cultivation cannot be followed like in urban areas (Maharana and Koul, 2011). Decreasing fertile land, soil degradation, lack of freshwater supplies for the crop, and soil nutrient depletion add an extra challenge for soil-based vegetable farming (Bindraban *et al*., 2012) and (Klinger and Naylor, 2012). To mitigate such challenges, aquaponic systems can be the good solutions (Singh and Singh, 2012) and in recent years the leading countries are Israel, India, China and Africa.

In deep water culture, roots of plants are suspended in nutrient rich water and air is provided directly to the roots by an air stone. Hydroponics bucket system is classical example of this system. Plants are placed in net pots and roots are suspended in nutrient solution where they grow quickly in a large mass (Sharma *et al*., 2018). Similarly, there is no risk of plant damage in the event of a power cut off and even stop of the air pump because plants are floating in contact with the nutrient solution. The most common vegetables grown in DWC are Lettuce, Chinese Cabbage, Curly Kale, Spinach, etc.

In India, still there is lack of research work in respect to soil less vegetable cultivation. On the other hand, there is growing demand for off-season and year-round production due to higher price realization in urban area. Thus, looking towards scope of increasing demand and to test its performance under DWC technique the current study was undertaken.

1. **MATERIALS AND METHODS**

The present investigation entitled “Effect of variable seeding density and cell spacing on dill (*Anethum graveolens* L.) growth, yield and biochemical parameters under DWC (Deep Water Culture)” was carried out at Landcraft Aquaponics Unit, Hatkanangale, Tal. Hatkanangale, Dist. Kolhapur, (MS) India under the supervision of Department of Horticulture, RCSM College of Agriculture, Kolhapur (MS) India.

* 1. **DWC hydroponics assembly**

The experiment was carried out in the hydroponics unit set accommodating over an area of 0.5 ha enclosed with 32 permanent beds built with RCC for setting up DWC hydroponics assembly in a partially controlled greenhouse (fig 1). The bed dimension was 29.0 m length 2.0 m width 0.45 m height, internally lined with black polyethylene sheet. A 12.0 HP motor blower is installed inside the bed water for the purpose of air circulation. It maintains airflow of 8 to 10 ppm into water. Each of the bed occupies 96 floating rafts made of Styrofoam sheet, meant for growing crops. These rafts are made up of food grade polystyrene (Styrofoam) sheets, which are 1.2 m long, 0.6 m wide and 0.5 m thick. Each bed is fertilized weekly with powdered ferrous sulphate weighing 100 grams. It is the source of iron (Fe) and sulphur (S) for plant nutrition. Temperature of water is kept regularly at 20 to 22°C, being optimum for nutrient uptake and water absorption. Water is re-cycled and re-used within the circulation system between hydroponics and aquaculture system.

* 1. **Instrumentation and experimental procedures**

Sowing was accomplished on 27 December 2021. Considering the requirement for two replications, 21 plug trays of 60 cells each were used for sowing as per treatments. Seeds were sowing in plug trays with cocopeat as principal medium. A required number of dill seeds as per treatment was sown at 1-1.5 cm depth in moistened cocopeat of each cell incorporated with plastic cups and finally, the trays were stacked and covered by using a black polyethylene sheet for rapid germination. Fully grown healthy seedlings were shifted on the 24th day to aquaponics unit (i.e. on 20 January, 2022). According to treatment combinations (table 1) of three cell spacing and five seed densities, cups were shifted to cell sheets (18, 36 and 72) and transferred over water surface.



**Fig. 1 Experimental view of DWC cultivation of dill**

**Table 1. Treatment combinations**

|  |  |  |
| --- | --- | --- |
| **Treatments** | **Combinations** | **Interactions** |
| T1 | S1D1 | (14 cm 14 cm) 04 seeds/cup |
| T2 | S1D2 | (14 cm 14 cm) 08 seeds/cup |
| T3 | S1D3 | (14 cm 14 cm) 12 seeds/cup |
| T4 | S1D4 | (14 cm 14 cm) 16 seeds/cup |
| T5 | S1D5 | (14 cm 14 cm) 20 seeds/cup |
| T6 | S2D1 | (10 cm 10 cm) 04 seeds/cup |
| T7 | S2D2 | (10 cm 10 cm) 08 seeds/cup |
| T8 | S2D3 | (10 cm 10 cm) 12 seeds/cup |
| T9 | S2D4 | (10 cm 10 cm) 16 seeds/cup |
| T10 | S2D5 | (10 cm 10 cm) 20 seeds/cup |
| T11 | S3D1 | (5 cm 5 cm) 04 seeds/cup |
| T12 | S3D2 | (5 cm 5 cm) 08 seeds/cup |
| T13 | S3D3 | (5 cm 5 cm)12 seeds/cup |
| T14 | S3D4 | (5 cm 5 cm) 16 seeds/cup |
| T15 | S3D5 | (5 cm 5 cm) 20 seeds/cup |

**2.3 Analysis of growth contributing characters**

Sampling was carried out for growth analysis. Five plants were randomly selected from each treatment from both replications. All growth parameters were studied from days of transplanting to the days of final harvest. The data on various parameters was recorded according to standard procedures during the period of experimentation.

**2.4 Analysis of chlorophyll content (mg/100g)**

The total chlorophyll content in the leaves of dill was estimated as per the standard procedure given by Ranganna (2005) in terms of mg per 100 g. The known sample of dill was macerated in Mortar and Pestle by using 85% acetone. The absorbance was measured at 644 and 662 nm using instrument Spectrophotometer.

**2.5 Analysis of micronutrient content (Fe, Zn, Mn and Cu) (mg/100g)**

Micronutrient contents from oven dried plant sample were determined by Atomic Absorption Spectrophotometry (AAS). The sample digestion was carried out as per the standard procedure given by Perkin-Elmer (1976). 0.5 gram of finely powdered dill plant sample was taken in a 250 ml conical flask and 10 ml of mixture of concentrated nitric acid and perchloric acid in the ratio 9:4 was added, mixed and digested on hotplate at the temperature of 200°C for about 2-3 hours. Samples were then allowed to cool and volumes were made up to 100 ml using distilled water. Later, the diluted samples were filtered through Whatman Filter Paper No. 42. This filtrate was used at different wavelengths to estimate iron (248.3 nm), zinc (213.9 nm), manganese (279.5 nm) and copper (324.8 nm) with the help of atomic absorption spectrophotometer.

**2.6 Analysis of *moisture content (%)***

The per cent moisture was calculated by drying known weight of sample into hot air oven at about 60°C for 24 hours up to a constant known weight (AOAC, 2010).

Moisture (%): Initial weight (g) – Final weight (g) 100

Initial weight (g)

**2.7 Analysis of ash content (%)**

Ash content was determined by using the standard procedure given by Ranganna (2005).

**2.8 Statistical analysis**

The data generated through the present investigation were analyzed rigorously to evaluate the effect of cell spacing and seeding density on dill. The analysis of variance was performed as per the methods given by Panse and Sukhatme (1985). The significance level was set at p < 0.05.

1. **RESULTS AND DISCUSSION**

**3.1 Analysis of growth parameters of dill**

Results presented in table 2 depicted that plant height (22.98 to 29.87 cm) and stem girth (6.65 to 9.07 mm) varied non-significant for interaction effect at harvest. The root characters such as root length, number of primary roots and number of secondary roots varied significantly for interaction effect at harvest. More root length was observed in the T10 (S2D5) (25.80 cm) and rest of the treatments except T1 (S1D1), T6 (S2D2), T8 (S2D3), T12 (S3D2) and T13 (S3D3) were at par with it. For number of primary roots T10 (S2D5) recorded more values of 19.10 and it was at par with the T5 (S1D5) and T15 (S3D5). The numbers of secondary roots were significantly superior in T15 (S3D5). All these growth parameters were influenced significantly at individual level by seeding density.

**Table no 2. Growth parameters of dill at harvest as influenced by cell spacing and seeding density**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treatments** | **Plant height (cm)** | **Stem girth (mm)** | **Root length (cm)** | **Number of primary roots** | **Number of secondary roots** |
| S1 | 26.49 | 7.45 | 21.02 | 11.20 | 24.12 |
| S2 | 26.42 | 7.70 | 18.71 | 11.16 | 30.82 |
| S3 | 27.71 | 8.07 | 20.36 | 11.22 | 31.52 |
| S.E.(m)± | 0.58 | 0.18 | 1.04 | 0.12 | 0.34 |
| C.D. @ 5% | NS | NS | NS | NS | 1.5 |
| D1 | 24.50 | 7.21 | 16.36 | 3.50 | 10.30 |
| D2 | 26.54 | 7.70 | 19.94 | 7.23 | 18.90 |
| D3 | 26.32 | 7.22 | 17.98 | 11.00 | 27.80 |
| D4 | 28.43 | 8.80 | 21.62 | 15.27 | 38.77 |
| D5 | 28.58 | 8.50 | 24.24 | 18.97 | 48.33 |
| S.E.(m)± | 0.75 | 0.23 | 1.35 | 0.16 | 0.44 |
| C.D. @ 5% | 2.29 | 0.71 | 4.08 | 0.50 | 1.35 |
| T1 (S1D1) | 25.80 | 6.65 | 16.53 | 3.40 | 8.40 |
| T2 (S1D2) | 25.22 | 7.94 | 22.21 | 7.10 | 15.50 |
| T3 (S1D3) | 24.97 | 6.69 | 20.75 | 11.40 | 24.10 |
| T4 (S1D4) | 29.22 | 8.26 | 21.89 | 15.30 | 30.40 |
| T5 (S1D5) | 27.95 | 7.70 | 23.70 | 18.80 | 42.20 |
| T6 (S2D1) | 22.98 | 7.33 | 12.87 | 3.50 | 11.00 |
| T7 (S2D2) | 26.98 | 7.79 | 19.04 | 7.40 | 18.90 |
| T8 (S2D3) | 26.75 | 6.93 | 16.44 | 10.70 | 29.50 |
| T9 (S2D4) | 27.48 | 7.38 | 19.40 | 15.10 | 44.90 |
| T10 (S2D5) | 27.93 | 9.07 | 25.80 | 19.10 | 49.80 |
| T11 (S3D1) | 25.43 | 7.64 | 19.68 | 3.60 | 11.50 |
| T12 (S3D2) | 27.42 | 7.36 | 18.57 | 7.20 | 22.30 |
| T13 (S3D3) | 27.23 | 8.04 | 16.75 | 10.90 | 29.80 |
| T14 (S3D4) | 28.58 | 8.60 | 23.57 | 15.40 | 41.00 |
| T15 (S3D5) | 29.87 | 8.73 | 23.23 | 19.00 | 53.00 |
| S.E.(m)± | 1.31 | 0.40 | 2.34 | 0.28 | 0.77 |
| C.D. @ 5% | NS | NS | 7.02 | 0.84 | 2.34 |

**3.2 Analysis of yield parameters of dill**

As shown in the table 3, the treatment combinations significantly affected the weight of leaves per cell, weight of stems per cell, weight of roots per cell, fresh yield of dill per cell, yield of leaves per sheet and yield of leaves per 100 sqm. Weight of leaves ranged between 3.46 g to 51.95 g with mean of 15.81 g. For interaction effects treatment combination T5 (S1D5)*i.e.* cell spacing of 14 cm x 14 cm with seeding density of 20 seeds per cup recorded highest weight of leaves produced per cell (51.95 g) and it was significantly superior to rest of the treatment combinations. Similar trend was observed for the weight of stems per cell which ranged from (1.27 g to 14.32 g), weight of roots per cell (1.34 g to 10.99 g) and for fresh yield of dill per cell (4.73 g to 65.99 g).

**Table no 3. Yield parameters of dill as influenced by cell spacing and seeding density**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **Weight of leaves per cell (g)** | **Weight of stems per cell (g)** | **Weight of roots per cell (g)** | **Fresh yield of dill per cell (g)** | **Yield of leaves per sheet (kg)** | **Yield of leaves per sheet of 100 sq. m. (kg)** |
| S1 | 23.57 | 6.38 | 5.34 | 29.90 | 0.42 | 91.44 |
| S2 | 14.39 | 4.36 | 3.15 | 18.75 | 0.52 | 63.00 |
| S3 | 9.47 | 2.58 | 2.03 | 12.5 | 0.68 | 75.29 |
| S.E.(m)± | 1.70 | 0.20 | 0.25 | 1.80 | 0.06 | 2.28 |
| C.D. @ 5% | 5.14 | 0.63 | 0.76 | 5.44 | 0.20 | 6.88 |
| D1 | 4.89 | 2.03 | 1.76 | 6.92 | 0.21 | 62.49 |
| D2 | 13.28 | 3.94 | 3.11 | 17.21 | 0.53 | 83.09 |
| D3 | 13.39 | 3.43 | 2.99 | 16.83 | 0.52 | 76.34 |
| D4 | 20.22 | 5.09 | 4.35 | 25.31 | 0.63 | 70.92 |
| D5 | 27.27 | 7.72 | 5.31 | 34.90 | 0.82 | 90.03 |
| S.E.(m)± | 2.19 | 0.27 | 0.32 | 2.33 | 0.8 | 2.94 |
| C.D. @ 5% | 6.63 | 0.81 | 0.99 | 7.03 | 0.27 | 8.88 |
| T1 (S1D1) | 5.41 | 2.36 | 1.77 | 7.77 | 0.10 | 70.81 |
| T2 (S1D2) | 10.20 | 3.21 | 3.07 | 13.41 | 0.18 | 89.60 |
| T3 (S1D3) | 14.09 | 3.80 | 3.32 | 17.89 | 0.25 | 91.45 |
| T4 (S1D4) | 36.21 | 8.23 | 7.56 | 44.44 | 0.65 | 98.37 |
| T5 (S1D5) | 51.95 | 14.32 | 10.99 | 65.99 | 0.94 | 106.96 |
| T6 (S2D1) | 3.46 | 1.27 | 1.34 | 4.73 | 0.12 | 58.55 |
| T7 (S2D2) | 20.37 | 6.21 | 4.74 | 26.58 | 0.73 | 84.14 |
| T8 (S2D3) | 15.93 | 4.60 | 3.19 | 20.52 | 0.57 | 49.75 |
| T9 (S2D4) | 14.79 | 4.23 | 3.73 | 19.02 | 0.53 | 46.35 |
| T10 (S2D5) | 17.42 | 5.51 | 2.75 | 22.93 | 0.63 | 76.23 |
| T11 (S3D1) | 5.81 | 2.47 | 2.19 | 8.27 | 0.42 | 58.13 |
| T12 (S3D2) | 9.27 | 2.39 | 1.53 | 11.66 | 0.67 | 75.53 |
| T13 (S3D3) | 10.17 | 1.91 | 2.45 | 12.07 | 0.73 | 87.83 |
| T14 (S3D4) | 9.67 | 2.81 | 1.76 | 12.48 | 0.70 | 68.03 |
| T15 (S3D5) | 12.46 | 3.33 | 2.21 | 15.79 | 0.90 | 86.92 |
| S.E.(m)± | 3.81 | 0.46 | 0.56 | 4.03 | 0.15 | 5.10 |
| C.D. @ 5% | 11.49 | 1.41 | 1.71 | 12.17 | 0.45 | 15.38 |

Yield of leaves per sheet of dill was more in treatment T5 (S1D5) (0.94 kg) and it was at par with the T4 (S1D4), T7 (S2D2), T8 (S2D3), T9 (S2D4), T10 (S2D5), T12 (S3D2), T13 (S3D3), T14 (S3D4) and T15 (S3D5). While the yield of leaves per 100 sqm was more in T5 (S1D5) (106.96 kg) and it was at par with the T4 (S1D4) (98.37 kg). Rest of the treatments recorded significantly lower yield of leaves per 100 sqm than T5 (S1D5)*i.e.* cell spacing of 14 cm x 14 cm with seeding density of 20 seeds per cup.

**3.3 Analysis of biochemical parameters of dill**

At a glance on table 4 it is very clear that there was no significant difference among the biochemical characters such as Chlorophyll (46.75 to 84.60 mg/100g), Iron (59.00 to 389.00 mg/100g), Zinc (3.00 to 5.00 mg/100g), Manganese (7.00 to 12.00 mg/100g) and Copper (37.00 to 81.50 mg/100g) of the dill grown under the varying seeding density and cell spacing.

**Table no 4. Biochemical parameters of dill as influenced by cell spacing and seeding density**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treatments** | **Chlorophyll (mg/100g)** | **Iron (mg/100g)** | **Zinc (mg/100g)** | **Manganese (mg/100g)** | **Copper (mg/100g)** |
| S1 | 68.83 | 108.60 | 3.60 | 9.80 | 51.80 |
| S2 | 61.40 | 222.20 | 4.40 | 9.20 | 57.50 |
| S3 | 72.19 | 259.80 | 4.20 | 7.80 | 63.20 |
| S.E.(m)± | 6.86 | 46.51 | 0.47 | 0.67 | 6.45 |
| C.D. @ 5% | NS | NS | NS | NS | NS |
| D1 | 67.12 | 271.33 | 4.67 | 8.67 | 49.00 |
| D2 | 69.75 | 157.67 | 4.00 | 9.33 | 59.50 |
| D3 | 68.27 | 206.00 | 4.00 | 9.00 | 66.00 |
| D4 | 57.52 | 183.67 | 4.33 | 9.33 | 48.00 |
| D5 | 74.72 | 165.67 | 3.33 | 8.33 | 65.00 |
| S.E.(m)± | 8.86 | 60.5 | 0.61 | 0.86 | 8.32 |
| C.D. @ 5% | NS | NS | NS | NS | NS |
| T1 (S1D1) | 84.60 | 146.00 | 4.00 | 8.00 | 41.00 |
| T2 (S1D2) | 54.75 | 59.00 | 3.00 | 10.00 | 45.00 |
| T3 (S1D3) | 76.10 | 144.00 | 3.00 | 9.00 | 62.00 |
| T4 (S1D4) | 46.75 | 134.00 | 5.00 | 12.00 | 59.00 |
| T5 (S1D5) | 81.95 | 60.00 | 3.00 | 10.00 | 52.00 |
| T6 (S2D1) | 63.55 | 279.00 | 5.00 | 10.00 | 37.00 |
| T7 (S2D2) | 78.55 | 283.00 | 4.00 | 10.00 | 81.50 |
| T8 (S2D3) | 52.85 | 230.00 | 5.00 | 10.00 | 58.00 |
| T9 (S2D4) | 48.80 | 152.00 | 4.00 | 8.00 | 47.00 |
| T10 (S2D5) | 63.25 | 167.00 | 4.00 | 8.00 | 64.00 |
| T11 (S3D1) | 53.20 | 389.00 | 5.00 | 8.00 | 69.00 |
| T12 (S3D2) | 75.95 | 131.00 | 5.00 | 8.00 | 52.00 |
| T13 (S3D3) | 75.85 | 244.00 | 4.00 | 8.00 | 78.00 |
| T14 (S3D4) | 77.00 | 265.00 | 4.00 | 8.00 | 38.00 |
| T15 (S3D5) | 78.95 | 270.00 | 3.00 | 7.00 | 79.00 |
| S.E.(m)± | 15.34 | 104.01 | 1.06 | 1.50 | 14.42 |
| C.D. @ 5% | NS | NS | NS | NS | NS |

The data presented in fig. 2, proved that there was no significant difference observed in case of moisture content in dill plants. Moisture percentage varied between 88.02 to 89.92 percent. Similarly, results as laid-out in fig. 3 indicated that there was no significant response observed in case of ash content. Ash percentage from dill leaf samples ranged between 6.00 to 9.00 percent.

**Fig. 2: Moisture content (%) of dill as influenced by cell spacing and seeding density**

**Fig 3: Ash content (%) of dill as influenced by cell spacing and seeding density**

**3.4 Discussion**

Deep Water Culture (DWC) is one of the most effective and economical hydroponics methods for growing large production of leafy greens on a floating raft made of stretchy plastic that keeps the rootstocks in a good solution. (Hamz *et al*. 2022). Deepwater aquaculture was developed as the most economical and simplest soilless culture method by Jensen and Collins (1985) in Arizona and Massantini (1976) in Italy. In India, cultivation of vegetables on floating bamboo rafts at Dal Lake is a classical example of DWC. The augmentation of yield in DWC technique grown plants is most likely due to more uniform water and better nutrients supply as reported by Abou-Hadid *et al*. (1989). This could be a effect of good supply of nutrients in available through nutrient solution which increases the uptake of nitrogen which in turn encourage the vegetative growth (Lester *et al*. 2006). Also Graves (1983) added that the highly response of the crop grown in DWC is most likely related to better nutrition of the plants and the continuous supply of aerated water and attributed to reduction of tissue water deficits (Newton and Sahraoui, 1996). In the current experiment the significant difference among the treatment combinations for vegetative parameters was mainly attributed to the competition among the plants for space, light and the nutrients. Plant height is one of the important characters contributing towards yield in leafy vegetables. At 35 days after transplanting when the harvesting was done the seeding density had significant effect highlighting the importance of standardizing the seeding density in dill cultivation under DWC technique of aquaponics. Similar plant height was observed in dill when grown in NFT system by Udagawa (1995). Parallel results of augmentation of growth were also reported by Riblta (2020) in Indian palak grown in commercial scale in or by nutrient film technique and Maboko and Du Plooy (2013) basil grown in gravel film technique of hydroponics. Root length of dill increased with increase in the seeding density. This may be due to competition among the plants for nutrient uptake. Also roots were suspended in water over complete growth period after transplanting. This might have led to such a profuse growth of roots. As the dill crop was grown in DWC technique of aquaponics, it was intended for fresh consumption; the weight of leaves per cell is significant parameter deciding the overall yield levels. In this study whole crop was harvested on 35th day after transplanting as the crop had attended horticultural maturity at the same time. The performance of dill regarding days required for harvest was in line with the results of experiments reported by Kling *et al*. (2020). Similar results for days for harvest were noticed by Kulkarni *et al.* (2018) in spinach and coriander when grown in hydroponics.

Non-significance in amount of chlorophyll recorded might be due to uniform availability of sunlight which diffused in the growing atmosphere under polyhouse structure. It helped in avoiding the shadowing of upper leaves on lower ones. The chlorophyll content in dill leaves is in line with the results obtained by El-Nakhel *et al*. (2021). Though there was no any significant difference among the treatments, the iron content was reported considerably higher than the results obtained in the dill grown by conventional methods (USDA-ARS. 2018). This might be due to enrichment of DWC system with powdered ferrous sulphate at weekly interval. Higher iron content was reported by Himabindhu (2020) in water spinach, Malabar spinach and tuberless colocasia when crops were grown in commercial scale aquaponics. Also, Salem (2019) reported similar increase in micronutrients in lettuce under DWC. Average moisture content of dill was more than conventionally grown dill as plants were grown in deep water culture environment, (USDA-ARS. 2018).

Dill has been grown using various hydroponic techniques for variety of purposes eg. Micro-greens (El-Nakhel, 2021), essential oils (Udagawa, 1995) and leafy vegetables in current study. Deep water culture and other hydroponic techniques are opening up new avenues for crop cultivation. This also facilitates to cater the diversified needs and make leaf vegetables available throughout year. But, standardizing all the crop specific aspects of cultivation will eventually decide the success.

1. **CONCLUSION**

In current study, effect of variable cell spacing and seeding density on dill was studied. Our results shown that cell spacing and seeding density had profound effect on plant height, root length, number of roots and fresh yield of dill under DWC. The treatment combination T5 (S1D5)*i.e.* cell spacing of 14 cm x 14 cm with seeding density of 20 seeds per cup recorded highest yield levels. This study provides useful information for the scientific cultivation of dill under deep water culture. Further research should explore into year round cultivation of dill as the crop cycle is very short or use it as alternatives to add in the protective cultivation crop calendar.

**Disclaimer (ARTIFICIAL INTELLIGENCE)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

**REFERENCES**

Abou-Hadid AF, Zayed AM, El-Behairy UA, El-Beltagy AS (1989) A comparison between nutrient film technique (NFT) and soil for tomato production under protected cultivation in Egypt. Egyptina Journal of Horticulture 16(2): 111-118.

A. O. A. C. (2010) International Official Methods of Analysis, 18thEdn., Association of Official Analytical Chemists, Washington DC, USA.

Bindraban PS, Van Der Velde M, Ye L, Van Den Berg M, Materechera S, Kiba DI (2012) Assessing the impact of soil degradation on food production. Current Opinion in Environmental Sustainability 78-488. https://doi.org/[10.1016/j.cosust.2012.09.015](http://dx.doi.org/10.1016/j.cosust.2012.09.015)

Diver S, (2006) Aquaponics- Integration of Hydroponics with Aquaculture. Amy Smith, Production. A Publication of AITRA- national sustainable agriculture information service. [www.attra.ncat.org](http://www.attra.ncat.org).

El-Nakhel C, Ciriello M, Formisano L, Pannico A, Giordano M, Gentile BR, Fusco GM, Kyriacou MC, Carillo P, Rouphael Y (2021) Protein Hydrolysate Combined with Hydroponics Divergently Modifies Growth and Shuffles Pigments and Free Amino Acids of Carrot and Dill Microgreens. Horticulturae 7: 279. <https://doi.org/10.3390/horticulturae7090279>

Farooqi AA, Sreeramu BS (2004) Cultivation of Medicinal and Aromatic Crops. pp. 419.

Goddek S, Delaide B, Manakasingh U, Ragnarsdottir KV, Jijakil MH, Thorarinsdottir R (2015). Challenges of sustainable and commercial aquaponics. Sustainability**7**(4): 4199-4224. <https://doi.org/10.3390/su7044199>

Graves, CJ. (1983) The nutrient film technique. Horticultural Reviews 5:1-44 https://doi.org/[10.1002/9781118060728.ch1](http://dx.doi.org/10.1002/9781118060728.ch1)

Hamza A, Abdelraouf RE, Helmy YI, El-Sawy SMM (2022) Using deep water culture as one of the important hydroponic systems for saving water, mineral fertilizers and improving the productivity of lettuce crop. International Journal of Health Sciences 6(S9), 2311–2331. https://doi.org/[10.53730/ijhs.v6nS9.12932](http://dx.doi.org/10.53730/ijhs.v6nS9.12932)

Himabindhu B, Divakar S, Pillali SP, Joseph B, Krishnaja U (2020) Quality evaluation of Tuberless colocasia (*Colocasia esculenta*) leaves cultivated through aquaponics. Journal of Pharmacognosy and Phytochemistry 9(5): 1710-1715.

Jensen MH, Collins WL (1985) Hydroponic vegetable production. Horticultural Reviews 7: 483-558. https://doi.org/[10.1002/9781118060735.ch10](http://dx.doi.org/10.1002/9781118060735.ch10)

Kling A,Vladimir P, Vladimir K, Yuri K (2020) Modern Practices for the Cultivation of Leaf Vegetables in Hydroponics. Advances in Social Science, Education and Humanities Research 393: 280-285.

Klinger D, Naylor RL (2012) Searching for Solutions in aquaculture: Charting a sustainable course. The Annual Review of Environment and Resources Pp. 247-276.

Kulkarni S, Abraham PS, Mohanty N, Kadam NN, Thakur M (2018) Sustainable raft based hydroponic system for growing spinach and coriander. In: Pawar PM, Ronge BP, Balasubramaniam R, Seshabhattar S, editors. Techno-societal 2016. Cham: Springer International Publishing; p. 117-25.

Le Strange R (1977) A history of herbal plants. New York, New York: Arco Publishing Company.

Lester GE, Jifon JL, Makus DJ (2006) Supplemental foliar potassium applications with or without a surfactant ca enhance netted muskmelon quality. Horticultural Science 41(3): 741-744. https://doi.org/[10.21273/HORTSCI.41.3.741](http://dx.doi.org/10.21273/HORTSCI.41.3.741)

Maboko MM, Du Plooy CP (2013) High-plant density planting of basil (*Ocimum basilicum*) during summer/fall growth season improves yield in a closed hydroponic system. Acta Agriculturae Scandinavica,Section B-Soil & Plant Science 63(8): 748-752. <https://doi.org/10.180/09064710.2013.861921>

Maharana L, Koul DN (2011) The emergence of Hydroponics. Yojana (June). pp. 39-40.

Massantini F (1976). Floating hydroponics; A new method of soilless culture, 4th Intl Congr. On Soilless Culture, Las Palmas, 25 Oct. To 1 Nov. pp 91-98.

Newton P, Sahraoui R (1996) The influence of air temperature on truss weight of tomatoes. Acta Horticulturae, 507, 43–49.

Panse VG, Sukhatme PV (1985) Statistical methods for Agricultural workers, Fourth edition of Indian Council of Agricultural Research, New Delhi.

Perkin E (1976) Perkin Elmer Manual: Analysis of tissues-determination of zinc. In: Analytical methods for atomic absorption spectrophotometry. Connecticut, USA. *p*.:260.

Passam HC (2021) Dill, Carrots and Related Apiaceae Crops, 2nd Edition (eds E. Geoffriau and P.W. Simon) CABI, UK pp 296.

Rakocy J, Masser M, Losordo T (2006) Recirculating aquaculture tank production systems: aquaponics- integrating fish and plant culture. Southern Regional Aquaculture Centre*.* SRAC Publication No. 454: United States Department of Agriculture, USA*.*

Ranganna S (2005) Hand book of analysis and quality control for fruit and vegetable products. New Delhi: Tata McGrow-Hill Publishing Co. Ltd., 12th reprint, 2nd edition. 1-1112.

Riblta R (2020) Comparative studies on cultivation of Indian Palak in hydroponics and other growing media. MSc Thesis, Horticulture and Forestry in Univ. in Nauni, India.

Salem L (2019) Assessing Deep-Water Culture and Sand-Bed Aquaponics Systems for Lettuce (*Lactuca sativa*) Yield and Water Consumption. MSc Thesis, American Univ. in Cairo.

Sharma N, Acharya S, Kumar K, Singh N, Chaurasia O P (2018) Hydroponics as an advanced technique for vegetable production: An overview. Journal of Soil and Water Conservation 17(4): 364-371. <https://doi.org/10.5958/2455-7145.2018.00056.5>

Singh S, Singh BS (2012) Hydroponics- A technique for cultivation of vegetables and medicinal plants. In. Proceedings of 4th Global conference on - Horticulture for Food, Nutrition and Livelihood Options*.,* Bhubaneshwar, Odisha, India. pp-220.

Small E (2006) Culinary herbs (2nd edition). Ottawa, Canada: NRC Research Press.

Udagawa Y (1995) Some responses of dill (*Anethumgr aveolens*) and thyme (*Thymus vulgaris*), grown in hydroponic, to the concentration of nutrient solution. Acta Horticulturae 396: 203-210. <https://doi.org/10.17660/ActaHortic.1995.396.24>

USDA-ARS. 2018. <https://fdc.nal.usda.gov/fdc-app.html#/food details/172233/>nutrients.

Waiba KM, Sharma P, Sharma A, Chadha S, Kaur M (2020) Soil-less vegetable cultivation: A review. Journal of Pharmacognosy and Phytochemistry 9(5): 631-636.