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Effect of different hydroponic systems on growth and yield of celery (*Apium graveolens* L.)

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Abstract
A study was conducted in the rabi season of 2024-25 at the Instructional-cum-Research Farm, Horticulture Section, Rajarshee Chhatrapati Shahu Maharaj College of Agriculture, Kolhapur, to compare the growth and yield performance of celery under nine cultivation systems: Ebb & Flow, NFT (vertical, slanting, horizontal), Wick, Deep Water Culture, Drip & Drain, Coco slabs, and soil pot cultivation (control). Treatments were laid out in a Completely Randomized Design with three replications, and growth parameters (plant height, stalk length, number of stalks per plant and root length,) and yield (basal thickness, plant spread, yield per plant and yield per square meter) were measured. The Wick method (T_3) exhibited the highest values for plant height (52.21 cm), root length (37.40 cm), stalk length (24.59 cm), number of stalks per plant (8.60), basal thickness (1.81 cm), plant spread (58.00 cm), and yield per plant (75.04 g). Deep Water Culture (T_4) produced the maximum yield per square meter (2648.59 g/m2), followed by Ebb & Flow (1964.56 g/m2) and Wick (1810.83 g/m2). In contrast, soil pot cultivation (control) showed significantly lower performance in all growth and yield measures. These results demonstrate that hydroponic systems, especially Wick, Deep Water Culture and Ebb & Flow, can substantially improve celery growth and yield compared to conventional soil cultivation.

Keywords: Celery, hydroponic systems, wick method, deep water culture (DWC), nutrient film technique (NFT), soilless cultivation, ebb and flow system

Introduction
In recent years, hydroponic farming has emerged as a sustainable alternative to conventional agriculture, offering higher yields, lower water use, and precise regulation of growing conditions (Thapa, 2024; Sambo *et al*., 2019) [25, 21]. This soilless approach, first introduced by Gericke in the 1930s, enables plants to grow in nutrient-enriched water with or without inert substrates such as sand, gravel, or rock wool (Savvas, 2003; Maharana & Koul, 2011) [23, 12]. The system provides multiple benefits, including year-round production, efficient use of fertilisers, and up to ninety percent less water consumption compared to soil farming, making it especially valuable in regions with water scarcity or limited cultivable land (Gilmour *et al*., 2019; Chowdhury *et al*., 2020) [7, 3]. By supporting the growth of diverse crops, hydroponics also contributes to food security, increases the range of nutrients available to consumers, and promotes sustainable management of agricultural resources (Rajalakshmi, 2022; Sagwal *et al*., 2023) [17, 20].

Celery (*Apium graveolens* L.), a biennial member of the Apiaceae family, is cultivated globally for its aromatic seeds, essential oils, and edible stalks. It has three primary horticultural forms: dulce, rapaceum, and secalinum (Orton, 1984; Rubatzky & Yamaguchi, 1997) [14, 19]. Celery seeds contain 1.5 to 3 percent volatile oils, mainly consisting of limonene, selinene, and phthalides (Chevallier, 2001; Farrell, 1999) [1, 5]. The crop thrives in cool and humid climates, with germination best between 15-21 °C, and seed treatments with growth regulators such as $GA_{4/7}$ can enhance establishment (Thomas, 1990) [26]. Recently, hydroponic systems have been adopted for celery production, as they ensure uniform nutrient availability, accelerate vegetative growth, and enhance both quality and yield compared to traditional methods. With its shallow root structure, adaptability, and short growth duration, celery has strong potential for efficient production under controlled soilless systems (Resh, 2013; Malhotra, 2006) [18, 13].

Materials and Methods

Experimental site and conditions

The study was conducted during the rabi season of 2024-25 at the Hydroponics Demonstration Unit, Instructional cum Research Farm, Horticulture Section, Rajarshee Chhatrapati Shahu Maharaj College of Agriculture, Kolhapur, Maharashtra, India. The site is located at 16°41' N latitude, 74°16' E longitude, at an elevation of 546 m above mean sea level. The region lies in the sub-montane zone with an average annual rainfall of 1,057 mm, of which nearly 80% is received during the southwest monsoon (June-September). The experiment was carried out inside a polyhouse (16 m × 12 m) where temperature (26-28 °C) and relative humidity (60-70%) were maintained.

Experimental design and crop details

The experiment was laid out in a Completely Randomized Design (CRD) with nine treatments and three replications. The test crop was celery (*Apium graveolens* L.) cv. Tall Utah, known for its tall and crisp stalks, uniform growth, and adaptability under hydroponic conditions. Seeds were procured from Sangli and sown in pro-trays containing cocopeat on 20 September 2024. Seeds were lightly covered with the medium at a depth of 0.5-1.0 cm, and trays were covered with polythene until germination. Regular watering was done using a nozzle can. After 63 days, healthy seedlings were transplanted on 22 November 2024 into different hydroponic systems as per treatments, with cocopeat-filled pots serving as the control. A spacing of 30 × 30 cm was maintained. Each plot accommodated 30 plants, and five plants per replication were selected for recording observations on growth and yield.

Hydroponic systems and nutrient management

The treatments consisted of eight hydroponic systems: ebb and flow, wick system, deep water culture (DWC), drip and drain, vertical nutrient film technique (VNFT), horizontal nutrient film technique (HNFT), slanting nutrient film technique (SNFT), and coco slab culture, along with pot culture as control. Nutrient management was carried out using a standard A and B hydroponic nutrient solution. Solution A supplied macronutrients (N, P, K, Ca, Mg), while Solution B provided micronutrients (Fe, Mn, Zn, Cu, and others). The pH and electrical conductivity (EC) of the solution were monitored regularly and adjusted to maintain optimal growth conditions. In pot culture, cocopeat was used because of its high water retention and aeration capacity. Harvesting was performed at horticultural maturity by cutting plants at the base, leaving 2 to 3 cm of the stem intact.

Statistical analysis

The data collected on growth and yield attributes were subjected to analysis of variance (ANOVA) following the procedure for CRD. Treatment effects were tested at the 5% probability level, and the standard error of mean (SEm±) and critical difference (CD) values were calculated to compare treatment means.

Results and Discussion

Plant height

At harvest, celery height differed significantly among treatments. The wick system (T_3) produced the tallest plants (52.21 cm), followed by deep water culture (T_4) (50.62 cm) and ebb and flow (T_1) (46.90 cm), while pot cultivation (T_9) was lowest (32.54 cm). The consistently superior growth under wick and DWC confirms the advantage of hydroponic systems in maintaining continuous nutrient and moisture supply, leading to enhanced vertical growth compared with soil-based cultivation.

Root length

The longest roots were recorded in the wick system (37.40 cm), statistically similar to DWC (35.80 cm). Pot cultivation (34.27 cm) also supported longer roots compared with NFT horizontal (21.30 cm) and NFT vertical (22.47 cm). Longer roots in wick are attributed to capillary-driven nutrient delivery, while aeration in DWC facilitates active root elongation. These results align with Wang *et al*. (2023) [27] and Suryana *et al*. (2025), who reported significant variation in root development across hydroponic systems.

Stalk length

Stalk elongation was greatest in the wick system (24.59 cm), followed by DWC (22.48 cm), NFT slanting (22.30 cm), ebb and flow (22.20 cm), and drip and drain (21.11 cm). The shortest stalks occurred in pot culture (17.19 cm). The improved elongation under hydroponic systems reflects the steady nutrient environment, which stimulates internodal growth and biomass accumulation.

Number of stalks per plant

The maximum stalk number was observed in wick (8.60), nearly identical to ebb and flow (8.53) and NFT vertical (8.53), while coco slabs (7.97) were lowest. Pot cultivation maintained intermediate values (8.20). Enhanced tillering in hydroponic systems can be attributed to uniform nutrient and moisture availability, which supports multiple shoot initiation.

Basal thickness and plant spread

Basal plant thickness was greatest in wick (1.81 cm), followed by DWC (1.62 cm) and drip and drain (1.56 cm), whereas pot cultivation showed the least thickness (0.76 cm). Plant spread was widest in wick (58.00 cm), followed by DWC (49.67 cm), while NFT vertical (27.77 cm) and pot cultivation (28.33 cm) recorded the lowest spreads. Wider canopy in wick indicates a more stable root zone environment, which promotes lateral vegetative expansion.

Yield per plant

Fresh yield per plant was highest in wick (75.04 g), significantly superior to DWC (60.06 g) and ebb and flow (59.78 g). Pot cultivation produced the minimum (41.22 g). The passive but continuous nutrient supply in wick ensured optimal growth and biomass accumulation, demonstrating its suitability for leafy vegetables like celery.

Yield per square meter

In terms of productivity, DWC produced the maximum yield (2648.59 g/m²), outperforming ebb and flow (1964.56 g/m²) and wick (1810.83 g/m²). The higher efficiency of DWC is attributed to root submergence in oxygen-rich solution, which promotes nutrient uptake and rapid biomass accumulation. These results are in agreement with Gad *et al*.

(2023) [6], who reported higher yields in aerated hydroponic systems.

Table 1: Growth and yield parameters of celery at harvest grown under different hydroponic systems

Cultivation systems	Plant height (cm)	Root length (cm)	Stalk length (cm)	Number of stalks	Basal plant thickness (cm)	Plant spread (cm)	Yield per plant (g)	Yield per square meter (g/m²)
T_1-Ebb and Flow	46.90	30.28	22.20	8.53	1.35	38.00	44.59	1964.56
T_2-NFT (Vertical)	35.03	25.46	17.19	8.53	1.23	27.77	35.07	564.15
T_3-Wick method	52.21	37.40	24.59	8.60	1.81	58.00	75.04	1810.83
T_4-Deep water culture	50.62	35.80	22.48	8.47	1.62	49.67	60.06	2648.59
T_5-Drip and Drain method	37.28	28.75	21.11	8.40	1.56	36.50	37.37	429.31
T_6-NFT (Slanting)	41.71	27.12	22.30	8.47	1.22	28.50	35.15	1164.28
T_7-NFT (Horizontal)	40.89	21.30	18.61	8.00	1.31	39.30	41.83	674.84
T_8-Coco slabs	40.31	23.29	20.14	7.97	1.28	41.00	36.18	474.82
T_9-Pot cultivation (Control)	32.54	34.27	17.63	8.00	0.76	28.33	26.32	294.58
SE. m±	0.84	0.76	0.50	0.10	0.04	0.54	0.74	3.50
CD @ 5%	2.50	2.28	1.51	0.30	0.14	1.62	2.22	10.40
CV%	3.47	4.54	4.25	2.10	5.87	2.44	2.97	0.54

Conclusion

The study demonstrated that hydroponic systems, particularly the Wick method (T3), Deep Water Culture (T4), and Ebb and Flow (T1), significantly enhanced the growth and yield of celery compared to pot cultivation (T9). The Wick method consistently outperformed other systems in various growth parameters, including plant height, root length, stalk length, number of stalks per plant, basal plant thickness, and plant spread. Deep Water Culture achieved the highest yield per square meter, while the Wick method produced the highest yield per plant. These findings underscore the efficacy of hydroponic systems in promoting robust growth and higher yields in celery cultivation.

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