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Standardization of plant spacing and node pruning in basil under DWC aquaponics system

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Abstract
An investigation entitled Standardization of Plant Spacing and Node Pruning in Basil under the DWC technique of Aquaponics was conducted at the Landcraft Aquaponic Unit, Hatkangle. The experiment was laid out in a Factorial Completely Randomized Design (FCRD) with four different plant spacing treatments: S_1 (10 cm × 10 cm), S_2 (15 cm × 10 cm), S_3 (20 cm × 10 cm), and S_4 (20 cm × 20 cm), and four different node pruning treatments (cutting after node 2, node 3, node 4, and node 5), comprising 16 treatments, each replicated twice. Basil seedlings were transplanted with different spacing treatments, and observations were made on various growth parameters. Among the four spacing treatments, the wider spacing (20 cm × 20 cm) significantly improved growth parameters, including the number of leaves, plant height, plant yield and root length. Regarding the node pruning treatments, cutting after the 5^{th} node (C_4) resulted in taller plants. These results suggest that for maximum yield occurs with combination of wider spacing (20 cm × 20 cm) and cutting after the 5^{th} node is most beneficial for basil cultivation.

Keywords: Basil, spacing, cutting, node, growth and yield parameters

Introduction

Basil (*Ocimum basilicum* L.), commonly known as sweet basil, is a member of the mint family (Lamiaceae), within the subfamily Nepetoideae (Paton *et al*., 1999) [26]. The *Ocimum* genus includes approximately 200 species of herbs and shrubs and has a chromosome number of 2n = 48. Basil is well known for its culinary and medicinal properties, particularly in tropical and subtropical regions (Hakkim *et al*., 2008) [10]. It is an annual or sometimes short-lived perennial species cultivated primarily for its aromatic leaves. The plant exhibits an upright, bushy growth habit, typically reaching height of 30 to 100 cm under favourable conditions. Basil cultivation is now widespread in countries such as France, Italy, Bulgaria, Egypt, Hungary, Thailand, India, Haiti, and Guatemala. In India. It is short duration crop typically harvested within 75 to 90 days, making it ideal for intensive farming, aquaponic farming reduces the risk of soil-borne diseases, ensuring healthier crops. Aquaponics is rapidly emerging as sustainable and efficient food production system, capable of meeting human nutritional requirements. Among such crops basil has been identified as one of the most profitable for aquaponic cultivation and is currently one of the most widely grown herbs in aquaponic systems (Love *et al*., 2015) [15] valued for its rapid growth, compact habit, and high fresh market value when paired with various aquatic organisms. Unlike many crops, basil does not require pollination. Research indicates that basil yields are generally higher in aquaponic or other soilless systems compared to traditional soil-based farming (Roosta *et al*., 2014) [29]. Most studies focus on its impact on soil and hydroponics with limited research on aquaponic cultivation in tropical regions. Limited studies have addressed these aspects of spacing and proper multiple cuttings in aquaponic basil cultivation, especially, in tropical regions.

Materials and Methods

The experiment entitled Standardization of plant spacing and node pruning in basil under DWC Aquaponics system was conducted during the *kharif* season at the Land craft Agro

Aquaponics Unit, located in Hatkanangale, Kolhapur Dist, from August, 2024 to October, 2024. Treatments were laid in Factorial Completely Randomized Design (FCRD) with two replications under aquaponics conditions. The Gross plot size for each individual polystyrene sheet was 1.2 m x 0.6 m. The study evaluated two repetitions of 16 treatment combinations (Four spacing treatment x four node cutting treatment) were arranged in a raft as per the statistical design two factors *viz*., (S_1:10 cm x 10 cm, S_2:20 cm x 10 cm, S_3:20 cm x 15 cm S_4:20 cm x 20 cm) with 4 node cutting (C_1: After node 2, C_2: After node 3, C_3: After node 4, C_4: After node 5). The foliage of five observational plants per treatments was harvested and weighed using a Baidyanath Premnath weighing balance. Yellow and blue sticky traps were strategically placed 30-45 cm above crop height to capture sucking pests such as thrips, jassids, mites, and whiteflies.

Results and Discussions

Growth parameters

Number of leaves

At the first harvest number of leaves of basil plant was non-significantly affected by plant spacing and as well as its interaction. However, node pruning has significant effect on it. The highest number of leaves per plant (11.90) was observed at the closest spacing (10 × 10 cm, S_1), followed by 20 × 20 cm (11.75)) and the closer spacing (20 × 15 cm, S_3) resulted in the lowest leaf count (11.53). The number of leaves at the first harvest was significantly influenced by the first cutting treatment applied to the basil plant, with plants cut after the 5th node (C_4) resulted in an average of 12.10 leaves per plant, which was significantly larger than the other cutting treatment. It was followed by cut after the 4th node (C_3), while the fewest leaves (11.18) were recorded when pruning occurred after the 2nd node (C_1). The interaction between spacing and cutting treatment had a non-significantly impact at the time of the first harvest. Among all the combinations tested, the maximum number of leaves per plant (12.30) was noted in the treatment where basil was spaced at 20 x 20 cm and cut after the 5th node (S_4C_4). This treatment clearly outperformed all others. On the flip side, the lowest leaf count (11.00 leaves per plant) was recorded in the S_1C_1 treatment, where plant was grown at the closest spacing of 10 x 10 cm and cut after the 2nd node. The wider spacing helps to reduce competition for light and nutrients, though the optimal cutting allows the plant to retain more foliage and regenerate better after harvest. Similar results were reported by Moderalli *et al*. (2023) [19]. At the second harvest, similar trends were continued. The widest spacing (20 × 20 cm, S_4) again resulted in the highest number of leaves (44.98), while the closer spacing (10 × 10 cm, S_1) yielded the fewest (39.00). Barut *et al.* (2020) [5] demonstrated that wider plant spacing promotes better growth and development of basil plant, particularly in terms of leaf production. Plant spaced further apart had a highest number of leaves due to improved access to sunlight, which could penetrate the canopy more productively under less crowded conditions. This enhanced light availability, along with better air circulation, supported enhanced leaf proliferation, allowing each plant to fully develop and produce a greater number of leaves. Cutting after the 5th node (C_4) led to the highest average number of leaves (50.85). The combination of S_4C_4 produced the highest leaf count (53.20), significantly surpassing all other treatments. The lowest leaf count was recorded in S_1C_1 (31.40). These results confirm that wider spacing and higher cutting enhance leaf production in basil. Wider spacing, such as 20 × 15 cm and 20 × 20 cm, significantly increased the number of leaves per plant by providing ample space for each plant to grow, thus reducing competition for resources like light, water, and nutrients. This facilitated enhanced vegetative growth and enhanced leaf production (Singh *et al*., 2020) [30]. The similar results were reported by Lam *et al*. (2019) [14] in Watercress; Wiangasmut and Koolpluksee (2020) [31] in Pak choi and Green oak; Woldu *et al*. (2019) [32] and Belanke *et al*. (2022) [6] in Swiss chard; Maludin *et al*. (2020) [6] in Curly dwarf Pak choy; and Noboa *et al*. (2022) [18] in Kale. The result of study is in confirmation with Corrado *et al*. (2020) [7] in Basil.

Leaf length

The various spacing treatment didn't produce remarkable variation in leaf length at 2nd harvest. A maximum leaf length (6.20 cm) was found in a spacing treatment of 20 x 20 cm (S_4), closely followed by the treatment 20 x 15 cm (S_3), 20 x 10 cm (S_2) and a minimum leaf length in 10 x 10 cm (S1) treatment with numerical values of 6.13 cm, 6.05 cm, and 5.98 cm, respectively. Rakocy *et al*. (2006) [28] found that basil plant grown at wider spacings developed longer and more extensive root systems, improving their ability to absorb nutrients and water from the soil. These measurements are in line with earlier recorded by Pluato *et* in Lettuce. The assorted node cutting treatment of basil didn't produce any observable variation on leaf length at harvest. A maximum leaf length (6.21 cm) was reported in a cutting treatment C_1 (cut after node 2) which was closely followed by C_2 (cut after node 3) with a leaf length of 6.12 cm, C_3 with leaves 6.03 cm longer and a minimum leaf length of 6.01 cm recorded in first cut treatment of C_4 (after node 5 cutting). The interaction effects of spacing and pickings after manifold nodes also reported similar non-significantly variations with leaf length ranging from 5.85 cm in plant spaced at 10 x 10 cm and cut after node number four to maximum average leaf length of 6.26 cm produced in the treatment of plant spaced at 20 x 15 cm and given a first harvest cut after node number two.

Plant Height

At the first harvest, plant height was significantly influenced by spacing, node cutting and its interaction. The tallest plant height was recorded in (S_1 10 x 10 cm) *i.e* (25.84 cm) while the shortest (23.56 cm) were observed in S_4. Among cutting treatments, the tallest plants (32.71 cm) were found in C_4 (cut after the 5th node), and the shortest plants (14.73 cm) in C_1 (cut after the 2nd node). The tallest plants (36.95 cm) were observed in the S_4C_4 combination (20 × 20 cm spacing and cut after the 5th node), while the shortest plants (14.42 cm) were recorded in S_1C_1. It indicates that cutting after the 5th node, and using wider spacing leads to taller plants. The increased height at closer spacing aligns with the findings of Mushtaq *et al*. (2021) [21] Gunda *et al.* (2022) [9], who noted that higher planting densities intensify competition for light, forcing plants to elongate their stems to satisfy their photosynthetic demands. These result findings are also supported further by the observations of Hasan *et al*. (2017) [11], who reported that under dense planting conditions, basil plant exhibit increased stem elongation as a physiological response to reduced light availability. The plant adapts by elongating their stems to access better light conditions, thereby increasing plant height though potentially limiting horizontal expansion. Plant under closer spacing tend to grow vertically for lighter and air and hence plant were taller (*Mushtaq et al.*, 2021; Balyan *et al*., 1987) [21, 4]. These findings are in linear with earlier recorded by Maboko and Du ploy. (2009) [16] in Lettuce; Lam *et al*. (2019) [14] in Watercress; Dalve. In Dill. At the second harvest, both spacing and cutting treatments had a significant effect on plant height. The closest spacing (10 × 10 cm, S_1) resulted in the tallest plants (35.33 cm), followed by S_2 (33.11 cm) and S_3 (32.59 cm), while the shortest plants were observed in S_4 (31.78 cm). Cutting after the 4th node (C_3) produced the tallest plants (37.63 cm), followed by C_4 (37.18 cm), with C_1 resulting in the shortest plants (28.28 cm). The tallest plants (40.60 cm) were observed in S_4C_4, while the shortest plants (26.20 cm) were recorded in S_1C_1. These findings suggest that widest spacing and later node cutting contribute to taller growth. The similar trends were reported by (Hasan *et al*., 2017: Balyan *et al*., 1987) [11, 4], Malludin in Curly dwarf Pak choi; Wiangsmut and Koolpluksee (2020) [31] in Pak choi and Green oak; Noboa *et al*. (2022) [23] in Kale.

Root Length at Second Harvest (cm)

Plant spacing significantly affected root development at the harvest. The maximum root length (38.57 cm) was recorded in the widest spacing (S_4 20 cm × 20 cm), which was statistically superior over rest of three treatment which were followed by 20 × 15 cm spacing (S_3), where the root length was 36.83 cm and 20 cm × 10 cm spacing treatment (S_2), 36.06 cm. In contrast, the minimum root length (35.47 cm) was identified in the closely spaced 10 cm × 10 cm treatment (S_1). These observations indicate that wider spacing, promote more root length than closer spacing and significantly promotes better root development in basil plant. Patel *et al*. (2021) [25] found that basil plant grown at wider spacings developed a more extensive and vigorous root system, enhancing nutrient uptake and biomass accumulation. Similarly, Rakocy *et al*. (2006) [28] reported that wider spacing enabled basil plant to develop longer and more extensive roots, thereby improving their ability to absorb nutrients and water, The similar outcomes were also reported by Belanke (2022) [6] in Swiss chard. The effect of multiple nodes cutting treatment of on root development was non- significantly found at the time of harvesting. The root length of basil had non-significantly variation at the time of harvesting root length of Basil. However, the maximum root length (37.60) was witnessed in the cutting treatment C_4 (cut after node 5) which was comparable with C_3 (cut after node 4) with a root length of (36.96 cm), and C_2 with root length (36.81 cm). The statistically minimum root length (35.55) was recorded in C_1 (after node 2 cutting). The interaction effect between spacing and cutting treatment on the root length at second harvest was statistically non-significantly found at the time of the second harvest. The interaction between spacing and cutting was also not statistically significant. However longest root length at the second harvest (39.84) was recorded in the plant spaced at 20 × 20 cm and cut after the 4th node (S_4C_4). In contrast, the treatment S_1C_1, where plant was spaced at (10 × 10 cm) and cut after the 2nd node, recorded the minimum root length (34.32) per plant. Singh *et al*. (2020) [30] suggested that wider spacing allows basil plant to develop deeper and longer roots, improving nutrient absorption and overall plant health.

Yield parameters

Fresh Yield per Plant at the Time of First Harvest (g)

Plant spacing treatment exhibited statistically non-significantly effect on the fresh weight at the time of first harvest. The highest mean value 2.86 g was recorded in widest spacing *i.e.* S_4 (20 cm x 20cm), the minimum mean value 2.68 g was reported in narrowest spacing *i.e.* S_1 (10 x 10 cm). However, when measuring the length of the 2nd internode of the branch at the second harvest, wider spacing likely improved light and nutrients, which led to enhanced fresh weight as supported by (Hasan *et al.*, 2017) [11]. The similar findings were also reported by earlier findings of Raimondi *et al*. (2016) [27], Macmaster *et al*. (2014) [17] and Badakhshan *et al*. (2018) [3] in Basil; Woldu *et al*. (2019) [32] in Swiss chard. In contrast, cutting treatment had a significant effect on fresh yield. The highest fresh weight (3.09 g) was obtained in C_4 (cut after the 5th node), followed by C_3 (2.98 g), while the lowest (2.39 g) was recorded in C_1 (cut after the 2nd node). Similar findings were reported by Modarelli *et al*. (2023) [19], showing that delayed cutting improves leaf weight and area. The highest fresh yield at the first harvest was Mounika *et al.* (2021) [20] detected that late Kharif and Rabi-sown crops outperformed Kharif crops, with larger leaf weights and greater leaf area per plant. The similar outputs were also reported by earlier findings of Modarelli *et al*. (2023) [19]. The interaction effect between spacing and cutting treatment on fresh yield of basil was statistically non-significant at the first harvest. Among all treatment combinations studied, the maximum fresh yield 3.14 g was recorded in plant spaced at 20× 20 cm and cut after the 4th node (S_4C_4)

Fresh Yield per Plant at the Time of Second Harvest (g)

Plant spacing had a statistically significant effect at the second harvest. The highest fresh yield 8.19 g was measured in S_4 (20 × 20 cm), the widest spacing, marginally outperforming the other treatment. This was followed closely by S_3 (20 × 15 cm) with mean values of 7.03 g the lowest mean yield (6.67) was recorded in S_1 (10 × 10 cm). However, measuring the length of the 2nd internode of the branch at the second harvest, wider spacing allowed plant to receive more light and nutrients, which led to greater fresh weight (Hasan *et al*., 2017) [11].The observations are in confirmation with earlier findings of Raimondi *et al*. (2016) [27] in Basil; Nguyen *et al*. (2016) in Lettuce; Lam *et al* (2019) [14] in Watercress; Malludin *et al*. in Curly dwarf Pak choy; Wiangasmut and Koolpluskee (2020) [31] in Pak choi and Green oak. Cutting treatment applied to the basil plant. The maximum fresh weight per plant was recorded in the C_4 treatment, where the plant was cut after the 5th node. This treatment resulted in an average fresh weight of 11.02 g per plant, which was significantly superior to that of the other cutting treatment. It was followed by C_3 (cut after the 4th node) with 8.57 g. The lowest fresh yield (3.68 g) was detected in the C_1 treatment, where plant was cut after the 2nd node. In case of wider spacing plant receive enough light and nutrients which leads to attain maximum fresh weight of plant (Hasan *et al.*, 2017) [11]. The findings are in confirmation with earlier findings of Modarelli *et al*. (2023) [19] in basil. Variation at the time of the second harvest. Among all treatment combinations, the maximum fresh yield at the second harvest 12.71 g was recorded in the plant spaced at 20 × 20 cm and cut after the 4th node (S_4C_4), which was significantly outperforming all others. In contrast, the treatment S_1C_1, where plant was spaced at 10 × 10 cm and cut after the 2nd node, recorded the minimum fresh yield 3.36 g.

Fresh Yield per Sheet at the time of First Harvest (g)
Plant spacing exhibited statistically significantly effect on fresh yield per sheet at the first harvest. The maximum fresh yield per sheet 192.51 g was recorded in S_4 (20 × 20 cm), the wider spacing, surpassing all other treatment. This was followed by S_3 (20 × 15 cm) and S_2 (20 × 10 cm), with mean values of 100.58 g and 90.23 g, respectively. The lowest mean yield 51.39 g was recorded in S_1 (10 × 10 cm) the spacing treatment significantly affects the fresh yield per sheet. The similar findings were also reported by Woldu *et al*. (2019) [32] in Swiss chard: Dalve) in Dill: Hossain *et al*. (2022) [12] in Indian Spinach. The fresh yield at first harvest was significantly affected by the cutting treatment applied to basil. The highest yield was recorded in the C_4 treatment, where plant was pruned after the 5th node, with an average fresh weight of 121.09 g per plant. This was significantly elevated than the other cutting treatment. The C_3 treatment (cut after the 4th node) followed with 115.48 g. The lowest yield was assessed in the C_1 treatment (cut after the 2nd node), with 94.48 g. The interaction effect between spacing and cutting treatment of fresh yield per sheet was statistically significantly found at the time of the harvest. Among all the treatment combinations studied, the highest fresh yield per sheet at the 2nd harvest 215.64 g was recorded in the S4C4 treatment, where plant was spaced at 20 × 20 cm and cut after the 5th node. This combination was significantly superior among all treatment combinations. The lowest fresh yield (43.56 g per plant) was noted in the S1C1 treatment, which involved the closest spacing (10 × 10 cm) and cutting after the 2nd node. Pruning above the 2nd, 3rd, or 4th nodes significantly improved fresh weight, by promoting the growth of additional leaves and branches, enhancing overall biomass. (Abbas *et al*., 2020) [1]. Cutting at higher nodes enables plant to b allocate more resources to remaining stems and leaves.

Fresh Yield per Sheet at the time of second harvest (g)
Plant spacing treatment had a statistically significant effect on the fresh yield per sheet at the time of the second harvest. The highest fresh yield per sheet 480.55 g was monitored in S_4 (20 × 20 cm), the widest spacing, surpassing the other treatment. This was followed by S_3 (20 × 15 cm) with mean value of 243.99 g. The lowest mean yield 147.42 g was recorded in S_1 (10 × 10 cm) similarly, the spacing treatment significantly affects the fresh yield per sheet. The similar findings were reported by Woldu *et al*. (2019) [32] in Swiss chard: Dalve in Dill: Hossain *et al*. (2022) [12] in Indian Spinach. The fresh yield per sheet at the second harvest was significantly influenced by the cutting treatment applied to the basil plant. The C_4 treatment, where plant was pruned after the 5th node, recorded the highest fresh yield per plant, with an average weight of 420.89 g, which was significantly greater than that of the other treatment. The C_3 treatment (cut after the 4th node) followed with a fresh weight of 330.04 g, while C_2 (cut after the 3rd node) yielded 205.29 g. The lowest fresh yield 140.70 g was saw in the C_1 treatment. The interaction effect between spacing and cutting treatment of fresh yield per sheet was statistically significant. The highest fresh yield per sheet at the second harvest 735.70 g was recorded in the S_4C_4 treatment, where plant was spaced at 20 × 20 cm and cut after the 5th node. The lowest fresh yield (72.70 g per plant) was noted in the S_1C_1 treatment, which involved the closest spacing (10 × 10 cm) and cutting after the 2nd node. Cutting at higher nodes allows plant to better allocate resources, thereby promoting greater biomass accumulation (Kumar *et al*., 2019) [13].

Table 1: Effect of spacing and node cutting on number of leaves at first harvest in basil

	S_1 (10x10 cm)	**S_2 (20x10 cm)**	**S_3 (20x15 cm)**	**S_4 (20x20 cm)**	**Mean (C)**
C_1 (Cut after node 2)	11.00	11.10	11.30	11.30	11.18
C_2 (Cut after node 3)	11.40	11.30	11.50	11.60	11.45
C_3 (Cut after node 4)	11.50	11.70	11.60	11.80	11.65
C_4 (Cut after node 5)	11.90	12.00	12.20	12.30	12.10
Mean (S)	11.90	11.53	11.65	11.75	11.59
	SEm(±)	CD at 5%	CV (%)		
Spacing (S)	0.13	NS	3.06		
Cutting (C)	0.13	0.38			
Interaction (SxC)	0.25	NS			

Table 2: Effect of spacing and node cutting on number of leaves at second harvest in basil

	S_1 (10x10 cm)	**S_2 (20x10 cm)**	**S_3 (20x15 cm)**	**S_4 (20x20 cm)**	**Mean (C)**
C_1 (Cut after node 2)	31.40	33.70	35.70	35.60	34.10
C_2 (Cut after node 3)	36.30	37.80	38.10	39.00	37.80
C_3 (Cut after node 4)	42.40	48.50	51.00	52.10	48.50
C_4 (Cut after node 5)	45.90	52.10	52.20	53.20	50.85
Mean (S)	39.00	43.03	44.25	44.98	42.81
	SEm(±)	CD at 5%	CV (%)		
Spacing (S)	0.22	0.66	1.46		
Cutting (C)	0.22	0.66			
Interaction (SxC)	0.44	1.32			

Table 3: Effect of spacing and node cutting on plant height at first harvest in basil (cm)

	S_1 (10x10 cm)	S_2 (20x10 cm)	S_3 (20x15 cm)	S_4 (20x20 cm)	Mean (C)
C_1 (Cut after node 2)	15.17	14.72	14.59	14.42	14.73
C_2 (Cut after node 3)	25.01	22.41	23.36	23.79	23.64
C_3 (Cut after node 4)	26.21	25.72	25.17	27.18	26.07
C_4 (Cut after node 5)	36.95	33.20	31.84	28.86	32.71
Mean (S)	25.84	24.01	23.74	23.56	24.29
	SEm(±)	CD at 5%	CV (%)		
Spacing (S)	0.4	1.2	4.67		
Cutting (C)	0.4	1.2			
Interaction (SxC)	0.8	2.4			

Table 4: Effect of spacing and node cutting on plant height at second harvest in basil (cm)

	S_1 (10x10 cm)	S_2 (20x10 cm)	S_3 (20x15 cm)	S_4 (20x20 cm)	Mean (C)
C_1 (Cut after node 2)	30.70	28.70	27.90	26.20	28.38
C_2 (Cut after node 3)	31.50	29.20	29.00	28.80	29.63
C_3 (Cut after node 4)	38.50	37.95	37.45	36.60	37.63
C_4 (Cut after node 5)	40.60	36.60	36.00	35.50	37.18
Mean (S)	35.33	33.11	32.59	31.78	33.20
	SEm(±)	CD at 5%	CV (%)		
Spacing (S)	0.35	1.06	3.01		
Cutting (C)	0.35	1.06			
Interaction (SxC)	0.71	NS			

Table 5: Effect of spacing and node cutting on leaf length at harvest

	S_1 (10x10 cm)	S_2 (20x10 cm)	S_3 (20x15 cm)	S_4 (20x20 cm)	Mean (C)
C_1 (Cut after node 2)	6.09	6.23	6.26	6.25	6.21
C_2 (Cut after node 3)	6.02	6.12	6.17	6.17	6.12
C_3 (Cut after node 4)	5.89	5.91	6.11	6.21	6.03
C_4 (Cut after node 5)	5.91	5.95	5.98	6.18	6.01
Mean (S)	5.98	6.05	6.13	6.20	6.09
	SEm(±)	CD at 5%	CV (%)		
Spacing (S)	0.09	NS	3.98		
Cutting (C)	0.09	NS			
Interaction (SxC)	0.17	NS			

Table 6: Effect of spacing and node cutting on root length at secondary harvest

	S_1 (10x10 cm)	S_2 (20x10 cm)	S_3 (20x15 cm)	S_4 (20x20 cm)	Mean (C)
C_1 (Cut after node 2)	34.32	35.47	35.80	36.60	35.55
C_2 (Cut after node 3)	35.48	36.28	36.89	38.59	36.81
C_3 (Cut after node 4)	35.49	36.12	37.00	39.23	36.96
C_4 (Cut after node 5)	36.57	36.35	37.64	39.84	37.60
Mean (S)	35.47	36.06	36.83	38.57	36.73
	SEm(±)	CD at 5%	CV (%)		
Spacing (S)	0.62	1.86	4.77		
Cutting (C)	0.62	NS			
Interaction (SXC)	1.24	NS			

Table 7: Effect of spacing and node cutting on fresh weight of produce per plant at first harvest (g) in basil

	S_1 (10x10 cm)	S_2 (20x10 cm)	S_3 (20x15 cm)	S_4 (20x20 cm)	Mean (C)
C_1 (Cut after node 2)	2.40	2.38	2.38	2.42	2.39
C_2 (Cut after node 3)	2.52	2.71	2.73	2.77	2.68
C_3 (Cut after node 4)	2.81	2.97	3.05	3.09	2.98
C_4 (Cut after node 5)	3.00	3.13	3.12	3.14	3.09
Mean (S)	2.68	2.79	2.82	2.86	2.79
	SEm(±)	CD at 5%	CV (%)		
Spacing (S)	0.05	NS	4.69		
Cutting (C)	0.05	0.14			
Interaction (SxC)	0.09	NS			

Table 8: Effect of spacing and node cutting on fresh weight of produce per plant at second harvest (g) in basil

	S_1 (10x10 cm)	**S_2 (20x10 cm)**	**S_3 (20x15 cm)**	**S_4 (20x20 cm)**	**Mean (C)**
C_1 (Cut after node 2)	3.36	3.51	3.81	4.04	3.68
C_2 (Cut after node 3)	5.05	4.72	5.30	6.55	5.41
C_3 (Cut after node 4)	8.07	8.29	8.45	9.47	8.57
C_4 (Cut after node 5)	10.22	10.59	10.55	12.71	11.02
Mean (S)	6.67	6.78	7.03	8.19	7.17
	SEm(±)	CD at 5%	CV (%)		
Spacing (S)	0.12	0.35	4.58		
Cutting (C)	0.12	0.35			
Interacion (SxC)	0.23	0.70			

Table 9: Effect of spacing and node cutting on fresh yield per sheet at first harvest (g) in basil

	S_1 (10x10 cm)	**S_2 (20x10 cm)**	**S_3 (20x15 cm)**	**S_4 (20x20 cm)**	**Mean (C)**
C_1 (Cut after node 2)	43.56	76.29	85.50	172.58	**94.48**
C_2 (Cut after node 3)	49.86	87.36	97.56	181.44	**104.06**
C_3 (Cut after node 4)	55.62	97.60	106.74	201.96	**115.48**
C_4 (Cut after node 5)	56.52	99.68	112.50	215.64	**121.09**
Mean (S)	51.39	90.23	100.58	192.91	108.78
	SEm(±)	CD at 5%	CV (%)		
Spacing (S)	1.87	5.60	4.85		
Cutting (C)	1.87	5.60			
Interaction (SxC)	3.73	11.19			

Table 10: Effect of spacing and node cutting on fresh yield per sheet at second harvest (g) in basil

	S_1 (10x10 cm)	**S_2 (20x10 cm)**	**S_3 (20x15 cm)**	**S_4 (20x20 cm)**	**Mean (C)**
C_1 (Cut after node 2)	72.70	121.89	126.22	241.99	140.70
C_2 (Cut after node 3)	117.81	169.73	170.03	363.60	205.29
C_3 (Cut after node 4)	170.41	270.53	298.33	580.90	330.04
C_4 (Cut after node 5)	228.76	337.73	381.38	735.70	420.89
Mean (S)	147.42	224.97	243.99	480.55	274.23
	SEm(±)	CD at 5%	CV (%)		
Spacing (S)	4.25	12.74	4.38		
Cutting (C)	4.25	12.74			
Interaction (SxC)	8.50	25.47			

Table 11: Effect of spacing and node cutting on fresh yield per sheet at second harvest

	S_1 (10x10 cm)	**S_2 (20x10 cm)**	**S_3 (20x15 cm)**	**S_4 (20x20 cm)**	**Mean (C)**
C_1 (Cut after node 2)	72.70	121.89	126.22	241.99	140.70
C_2 (Cut after node 3)	117.81	169.73	170.03	363.60	205.29
C_3 (Cut after node 4)	170.41	270.53	298.33	580.90	330.04
C_4 (Cut after node 5)	228.76	337.73	381.38	735.70	420.89
Mean (S)	147.42	224.97	243.99	480.55	274.23
	SEm(±)	CD at 5%	CV (%)		
Spacing (S)	4.25	12.74	4.38		
Cutting (C)	4.25	12.74			
Interaction (SxC)	8.50	25.47			

Conclusion

Among the four spacing treatments, wider spacing (20 × 20 cm) significantly improved growth parameters, including the number of leaves, plant height, and root length. Among the four node pruning treatments, cutting after the 5th node (C_4) resulted in taller plants. For yield parameters, the fresh yield per plant at both the first and second harvest was higher under wider spacing combined with later node cutting treatments. The 20 × 20 cm spacing (S_4) also enhanced the fresh yield per shoot at both harvests, while the individual plant yield was highest under the wider spacing. Overall, the combination of 20 × 20 cm spacing and cutting after the 5th node (S_4C_4) produced the maximum fresh yield per plant.

Future line of work

1. Optimizing spacing and cutting combinations
2. Comparative study for yield and quality for aquaponics, polyhouse cultivation and open field conditions.
3. Economic feasibility and cost- benefit analysis studies for different combinations.
4. Integrate sensor-based monitoring to assess real-time plant responses to agronomic practices.
5. Analyze root development and morphology under varied pruning regimes in aquaponics

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