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Growth and Yield Performance of Celery (*Apium graveolens* L.) Under the Application of Liquid Organic Fertilizer from Tofu Residue in a Wick Hydroponic System

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Abstract
Celery (Apium graveolens L.) originates from Southern Europe and was first described by Carolus Linnaeus in Species Plantarum *(1753). In Indonesia, this plant is known as* seledri*. Celery is an annual herbaceous plant that grows in the form of grass or shrubs. It has an unbranched structure consisting of roots, stems, and leaf stalks. Hydroponic cultivation provides a controlled growth environment, which can optimize plant development. Liquid Organic Fertilizer (LOF) derived from tofu residue contains essential nutrients, namely N (1.2%), P (0.10%), and K (0.12%), which are crucial for plant growth. This study aimed to evaluate the effect of tofu residue-based LOF application and determine the optimum concentration for the growth and yield of celery cultivated using a wick hydroponic system. The research was conducted at BSIP (Agricultural Instrument Standardization Center), Bali. Randomized Completed Block Design (RCBD) was used with six treatment levels: (A1) 100* ml.L^{-1}*, (A2) 200* ml.L^{-1}*, (A3) 300* ml.L^{-1} *, (A4) 400* ml.L^{-1} *(A5) 500* ml.L^{-1}*, and (A6) 600* ml.L^{-13}*, with four replications, resulting in a total of 24 experimental units. Statistical analysis revealed that the application of tofu residue-based LOF had a highly significant effect on all observed parameters. The results showed that the 400* ml.L^{-1} *treatment produced the best outcomes, with a fresh plant weight of 14.18 g and an oven-dry weight of 1.78 g.*

Keywords:
Hydroponics, Tofu Residue, Celery, Organic Fertilizer

1. Introduction

Celery (*Apium graveolens*) is a leafy vegetable with numerous benefits, commonly used as a culinary spice and medicinal plant [1]. It is highly favored due to its distinctive aroma and is considered a commercially valuable crop that provides additional income. Celery is widely used in soups, as a raw vegetable (lalap), or finely chopped as a garnish for various dishes. Additionally, it has medicinal properties and is used to treat ailments such as rheumatism, gout, hypertension, and fever.

The high demand and various benefits of celery cultivation present significant business opportunities, particularly in increasing farmers' income and meeting the continuously growing market demand. However, the supply of fresh celery in Indonesia remains insufficient due to limited arable land. To address this issue, hydroponic cultivation is a viable alternative. Hydroponics is a soil-free cultivation system in which plants are grown using water as the primary growing medium [2]. Hydroponic cultivation, particularly using the wick system, is practical, requires minimal space, and has relatively low investment costs. One key advantage of the wick system is that it does not require electricity, while nutrient and water supply can be easily managed. The success of celery production in a wick hydroponic system is influenced by the type and quality of the wick material, which plays a crucial role in transporting water and nutrients from the reservoir to the growing medium.

Two critical factors in wick hydroponic cultivation are the choice of growing medium and nutrient solution, both of which must be optimized to ensure optimal plant growth [3]. The growing medium supports root development and provides essential nutrients. Additionally, the growing environment significantly influences the quality and yield of plants. Common hydroponic growing media include rockwool, cocopeat, and hydroton. Rockwool, derived from heated basalt rock, forms fine fibers that can retain water 14 times better than soil [4]. Another crucial factor determining hydroponic success is the nutrient solution. Plants require both macronutrients (N, P, K, Ca, S, and Mg) and micronutrients (Cu, Mn, Zn, Cl, Na, and Fe) in appropriate concentrations [5]. These elements must be provided in a well-balanced nutrient formula. Fertilizers are categorized into chemical and organic types. The commonly used AB mix fertilizer provides complete nutrients for hydroponic crops [6]. However, chemical fertilizers have drawbacks, including environmental concerns and potential chemical residues that may pose health risks.

Hydroponic technology is perceived as having high economic value due to maintenance costs and fertilizer prices. An alternative solution to facilitate hydroponic adoption, particularly for small-scale farmers, is utilizing low-cost nutrient sources such as tofu residue [7],[8],[9],[10],[11]. Various natural nutrient sources can be processed into liquid organic fertilizer (LOF), which contains essential nutrients required for plant growth. According to [25] and [26], fermented tofu residue contains 1.2% N, 0.10% P, and 0.12% K, which are vital for plant development. Nitrogen (N) stimulates overall plant growth, particularly roots, stems, and leaves, while phosphorus (P) is essential for energy transfer, and potassium (K) plays a key role in physiological processes and root development. Additionally, [12] reported that fermented tofu residue-based LOF contains 1.83% organic carbon (C) and a C/N ratio of 2.

Utilizing agricultural waste as organic fertilizer is an environmentally friendly approach to reducing pollution while enhancing microbial growth due to its high organic content [13].
The application of tofu residue-based LOF at a concentration of 400 ml.L^{-1}resulted in optimal growth and yield of celery. Similarly [10] found that applying 300 ml of tofu residue LOF significantly enhanced celery (*Apium graveolens L.*) growth, particularly in leaf number and plant height. This study aims to evaluate the effect of tofu residue-based liquid organic fertilizer on the growth and yield of celery cultivated using the wick hydroponic system and to determine the optimal concentration for achieving the best growth performance.

2. Material and Methods

This study was conducted at the Agricultural Instrument Standardization Center (BSIP) Bali, located on Jl. By Pass Ngurah Rai, Pesanggaran, South Denpasar, Bali. Geographically, the research site is positioned at coordinates -8° 42' 54", 115° 12' 42", with an altitude of 53.0 meters above sea level and an orientation of 300°. The research was carried out from January 5, 2024, to June 16, 2024.

The materials used in this study included celery seeds of the Arsemo variety, tofu residue-based liquid organic fertilizer (LOF), rockwool as the growing medium, and clean water. The hydroponic system was a simple wick system setup using recycled mineral water bottles.

Production of Liquid Organic Fertilizer (LOF) from Tofu Residue

The production of liquid organic fertilizer begins by mixing 10 kg of tofu residue with 15 liters of water, followed by the addition of 120 ml of EM4, 200 grams of granulated sugar, and 1 liter of coconut water. The mixture is then stirred thoroughly until it is well blended. Next, the container is sealed tightly to create anaerobic fermentation conditions, with a small hole made to channel the gas produced into a plastic bottle filled with water. After 28 days, the mixture is filtered to separate the solids from the liquid, allowing the remaining particles and tofu residue to settle, thus producing a cleaner liquid waste product.

The experiment was designed using a randomized complete block design (RCBD) with six treatments, each replicated four times, resulting in a total of 24 experimental units. The treatments applied were as follows:

- A1: 100 $ml.L^{-1}$ tofu residue LOF
- A2: 200 $ml.L^{-1}$ tofu residue LOF
- A3: 300 $ml.L^{-1}$ tofu residue LOF
- A4: 400 $ml.L^{-1}$ tofu residue LOF
- A5: 500 $ml.L^{-1}$ tofu residue LOF
- A6: 600 $ml.L^{-1}$ tofu residue LOF

Celery plant maintenance is carried out by regularly monitoring the nutrient solution, including checking the volume, pH, and nutrient concentration using a TDS meter before application. Nutrients are applied every three days or whenever there are signs of reduced concentration, lower solution volume, or symptoms of dryness in the plants. Additionally, replanting (gap filling) is performed to replace dead plants, and the plants are protected from pests and diseases (Plant Disturbing Organisms/PDO). Celery is harvested at 84 days after transplanting (DAT), by uprooting the entire plant along with its roots. Observations were conducted weekly after planting, with the measured parameters including plant height, number of leaves, number of tillers, root length, fresh plant weight, and oven-dry plant weight.

Data Analysis

All collected data were averaged and analysed using ANOVA. If significant or highly significant differences were observed, the analysis was followed by Duncan's Multiple Range Test (DMRT) at a 5% significance level [14].

3. Results and Discussion

The research findings indicate that the application of tofu residue-based liquid organic fertilizer (LOF) significantly affected all observed growth and yield parameters of celery (*Apium graveolens* L.). The highest plant height was observed at a concentration of 400 $ml.L^{-1}$, reaching an average of 24.80 cm. This result was significantly higher compared to other treatments (100 $ml.L^{-1}$, 200 $ml.L^{-13}$, 300 $ml.L^{-1}$, 500 $ml.L^{-1}$, and 600 $ml.L^{-1}$). This difference is attributed to the optimal nutrient absorption at this concentration, ensuring sufficient nutrient availability for celery growth.

In contrast, lower concentrations resulted in nutrient deficiency, while higher concentrations exceeded the plant's requirements.

Table 1.
Significant Parameters Observed

No	Observation Parameter	Notation
1	Plant Height (cm)	**
2	Number of Petioles (leaves)	**
3	Number of Tillers (clumps)	**
4	Root Length (cm)	**
5	Fresh Plant Weight (g)	**
6	Oven-Dry Plant Weight (g)	**

(**) : Highly significant effect (P<0.01)

Variations in nutrient concentration directly influenced plant height, as plant growth is driven by cell expansion and division, which require adequate essential nutrients for root absorption [15]. According to [16], a deficiency in essential nutrients disrupts plant metabolism, hindering root, stem, and leaf growth, which ultimately affects yield. [17] further explain that plants cannot achieve optimal yield without an adequate supply of essential nutrients. In hydroponic systems, nutrient availability plays a crucial role in plant growth, as it serves as the primary source of essential elements. An increase in plant height generally correlates with the number of leaves formed. Leaves are a critical component of plant growth, functioning as the primary site for photosynthesis, which generates energy for plant development. Nevertheless, increased fertilizer dosage does not necessarily translate into enhanced yield. A study by [18] demonstrated that while the application of higher potassium fertilizer levels positively influenced vegetative growth parameters in *Sesamum indicum* L., the optimal yield was obtained at a moderate dosage of 30 kg K_2O/ha. This finding indicates that excessive nutrient application may lead to diminishing returns.

Table 2.
Average Plant Height, Number of Leaves, Number of Tillers, Root Length, Fresh Weight, and Oven Dry Weight of Celery Plants on Hydroponic Media with the Application of Tofu Waste

Treatment	Plant Height (cm)	Number of Leaves (leaves)	Number of Tillers (clusters)	Root Length (cm)	Fresh Weight (g)	Oven Dry Weight (g)
A1	16,63 c	5,25 d	0,50 b	5,00 c	2,05 b	0,30 b
A2	21,33 b	13,75 abc	2,75 a	7,40 ab	11,35a	1,58 a
A3	22,35 ab	17,25 ab	2,75 a	7,95 ab	13,95 a	1,75 a
A4	24,80 a	18,00 a	3,00 a	8,15 a	14,18 a	1,78 a
A5	19,28 bc	12,25 bc	2,75 a	6,35 bc	8,63 b	1,13 a
A6	16,73 c	10,75 cd	2,75 a	5,23 c	8,20 b	0,98 ab
LSD 5%	3,32	5,70	1,41	2,04	6,77	0,82

Note: Average values followed by the same letter indicate no significant difference at the 5% LSD (Least Significant Different) test level.

The highest leaf count was recorded at a concentration of 400 $ml.L^{-1}$, with an average of 18.00 leaves, while the lowest was observed at 100 $ml.L^{-1}$, with only 5.25 leaves (Table 2). The limited nutrient availability at lower concentrations restricted celery growth and development. [19] states that nitrogen plays a key role in enzyme formation, which is essential for leaf development.

A nitrogen deficiency results in fewer leaves that appear yellowish rather than vibrant green. Increased leaf count and root length enhance nutrient uptake, leading to greater accumulation of photosynthates [20]. Statistical analysis of the number of tillers showed a significant effect. The highest number of tillers (3.00 per clump) was observed at a concentration of 400 $ml.L^{-1}$. Tiller formation is influenced by nutrient availability, particularly nitrogen (N) and phosphorus (P). Nitrogen enhances vegetative growth, including root, stem, and leaf development, by increasing the rate of photosynthesis. Meanwhile, phosphorus strengthens the root system, facilitating the development of productive tillers.

According to [19], roots are one of the most critical organs for plant growth, as root length is closely associated with drought resistance. In response to water scarcity, plants extend their roots to access deeper moisture reserves. The longest root growth was observed at a concentration of 400 $ml.L^{-1}$ with an average length of 8.15 cm. Root elongation is influenced by phosphorus content, which was measured at 283,000 ppm in tofu residue. [21] supports this finding, stating that sufficient phosphorus promotes extensive root development, enhancing nutrient absorption efficiency.

[22] explain that fresh plant weight is closely related to vegetative growth and is commonly used to assess plant biomass. The results show a trend of increasing fresh weight with higher concentrations of tofu residue LOF. The highest fresh weight was recorded at 400 $ml.L^{-1}$ averaging 14.18 g, while the lowest (2.05 g) was observed at 100 $ml.L^{-1}$ This outcome is due to the limited availability of essential nutrients in the growing medium, restricting optimal plant growth. The growing medium provides a foundation for plant development, with growth primarily determined by water and light availability. When photosynthesis proceeds efficiently, nutrient requirements are met, and environmental conditions are favorable, plant growth reaches its optimal potential, ultimately influencing plant height, weight, and yield.

Statistical analysis of oven-dry plant weight showed the highest value at 400 $ml.L^{-1}$, with an average of 1.78 g (Table 2). A higher dry weight indicates that plants experienced optimal growth and development conditions compared to other treatments. According to [5], nutrients and water absorbed by the roots are translocated throughout the plant, supporting metabolism and organ formation. The development of stems and leaves significantly impacts dry weight accumulation.

This research shows that applying tofu residue-based LOF at a concentration of 400 $ml.L^{-1}$ in a wick hydroponic system provides the highest growth and yield across all observed parameters in celery cultivation. This concentration facilitated more efficient nutrient absorption and enhanced photosynthate production, leading to an optimal fresh weight of 14.18 g and a dry weight of 1.78 g. These findings align with the study by [23], which reported that a 40% concentration of tofu residue resulted in the highest plant height (32.2 cm) in Chinese mustard (*Brassica juncea*) after 30 days of growth. [24] state that as nitrogen levels decrease, phosphorus availability is also affected. Reduced nitrogen levels limit microbial activity responsible for phosphorus mineralization, ultimately restricting plant growth. This deficiency leads to stunted growth, with initial symptoms including leaf curling, followed by yellowing at the leaf margins. Liebig's Law of the Minimum states that plant growth is limited by the scarcest nutrient, regardless of the abundance of other nutrients. A deficiency in one essential element prevents the effective absorption of others, leading to suboptimal plant growth.

4. Conclusion

The application of tofu waste liquid organic fertilizer significantly affects plant height, number of leaves, number of tillers, root length, fresh weight, and oven dry weight of celery plants. The optimum concentration for applying tofu waste liquid organic fertilizer is 400 $ml.L^{-1}$, which provides the best growth results with a fresh weight of 14.18 g and an oven-dry weight of 1.78 g. The application of tofu waste liquid organic fertilizer has the potential to improve the growth and yield of celery plants. To enhance the growth and yield of celery in hydroponic cultivation, it is recommended to use a concentration of 400 $ml.L^{-1}$.

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