BIO Web of Conferences **202**, 01004 (2025) https://doi.org/10.1051/bioconf/202520201004
ICB3 2025

Micronanobubble-aerated Drip Irrigation Enhanced The Morphophysiological Characteristics of Shallot Growth Nourished with Fermented Organic Waste

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Abstract. Long-term intensive agriculture affects soil fertility by compacting the soil and reducing soil organic matter. The growth of shallots as an essential food component on degraded land requires technical intervention to address the issue of low fertility. Increased soil aeration is required to increase oxygen levels. Micro-nanobubble technology paired with subsurface drip irrigation is projected to promote soil oxygen, microbial activity, and nutrient uptake.The objective of the study was to evaluate vegetative growth and pigmentation of shallot cv. Tajuk, affected by fermented-goat manures and aerated micro-nanobubble drip irrigation. Shallot tubers were germinated under hydroculture in hydroton-enriched nanobubble nutrition. Uniform seedlings were selected and planted on the growth medium fertilized by organic fertilizer at the ratio of 1-5 over chemical fertilizer. Tillerings were regularly checked during vegetative growth and pigments were observed prior generative period. Remarkable growth of shallot tillers number (8-10.5) and pigments of total chlorophyll (7.6-8.2 μg/mL) and carotenoid (0.6-0.9 μg/mL) treated by organic-chemical over conventional fertilizer were observed. Aerated drip irrigation enhanced vegetative growth and pigmentation of shallot. The study confirmed positive effect of organic waste circulation enriched aerobic microbial, and aerated rhizosphere on plant growth improvement and indeed improved physiological characters of plants grown organically

1 Introduction

Long-term intensive agriculture affects soil fertility by compacting the soil and reducing soil organic matter. The growth of shallots as an essential food component on degraded land requires technical intervention to address the issue of low fertility. Increased soil aeration is required to increase oxygen levels. Soil organic matter is essential for maintaining soil chemical, physical, and biological fertility. Organic matter has various functions, including boosting soil cation exchange capacity, improving water infiltration and water holding capacity, and functioning as a slow-release reservoir of nutrients (particularly N, P, and S) [1]. Decomposition of organic waste is important because it recycles nutrients into valuable, nutrient-rich compost. Organic matter decomposition is a complex process requiring the combined action of multiple organisms that produce and release a variety of extracellular enzymes that aid in the depolymerization and mineralization of complex organic compounds into smaller molecules that can then be assimilated [2]. Soil microorganisms including bacteria, fungi, and archaea are pivotal in driving essential soil functions such as nutrient cycling, organic matter decomposition, and disease suppression[3]. Mutualistic microbe-plant connections have been well-documented on plant growth promotion (PGP) and improved protection against biotic and abiotic challenges and long-term sustainable food supply[4].

Aerobic fermentation occurs in the presence of oxygen and has been used to break down compounds to make them available for plant uptake [5]. However, in large-scale aerobic fermentation processes, sufficient oxygen supply is often a challenge [6]. Transporting water enriched in air or oxygen in the form of micro-nano bubbles (MNBs) to crop root zones effectively improved aeration conditions and soil oxygen contents[7]. Nanobubbles (NB) that have high stability oxygenation in liquids[8]could increase aerobic fermentation.

Oxygen content enhancement activates the biomass and aerobes and facultative anaerobes activity, while those of the obligate anaerobes were inhibited[9]. Aerated irrigation have also significantly regulate soil nitrogen (N) dynamics, biochemical characteristics, which are crucial for enhancing N absorption and utilization efficiency, strengthen soil nitrification processesand reduce nitrogen loses[10].

However, there was a lack of information on shallot growth under organic supplementation and oxygenation MNB drip irrigation. The effects of aerobic MNB-fermented (FW) and non-fermented goat manure (NFW) on the medium of shallot development and tuberization were assessed in the presence of biofertilizer and oxygenation drip irrigation.

2 Material and methods

2.1 Growth condition and plant materials

The research was conducted at the screen-house and open field of Experiment Station of the Filant Corp, located in the district of Kota Batu, East Java Indonesia (7°54'38.1"S 112°32'12.1"E). The study area is characterized by a tropical climate, with average minimum and maximum temperatures ranging from 22 to 32 °C during June to July 2025.Shallot tubers are germinated in germination trays with cocopeat as the growing medium, fertilized by 1000 S/cm liquid fertilizer based on Hoagland's formulation.A 10 cm seedlings with 2-3 leaves, were prepared and transferred to the treatment medium.

2.2 Bio-fertilizer generation

The aerobic fermentation of goat manures was accelerated using commercial biofertilizer that contains *Azotobacter* sp. ($2x10^8$), *Azospirillum* sp. ($1.05 \text{ x}10^8$), *Bacillus* sp. ($1.8 \text{ x}10^8$), *Pseudomonas* sp. ($2.4 \text{ x}10^8$), *Rhizobium* sp. ($8{,}5 \text{ x}10^8$), and *Trichoderma* sp. (1.76 x 108). Using liquid medium containing 15 mg/L dissolved oxygen-NB produced by an oxygen concentrator and NB generator, dried goat manures were immersed (1:5). An equivalent volume of liquid was added after five days, and microbubbles formed at a rate of two vvm air flow. solid and well combined.

2.3 Planting and micro-nanobubble drip irrigation

Healthy shallot seedlings were chosen from the tubers that germinated and planted on adverse-soil fertilized by 1-7% of solid phase fermented goat manures (FW) compared with dried goat manures (NFW) supplemented by bio-fertilizer commercial (B) and liquid phase of fermented goat manures (F). Aeration with oxygenation MNB were carried-out by an atomizer aerator that was powered by a constantly hi-blow air pump at a rate of 2 vvm. When the dissolved oxygen level reached 8–10 mg/L, the plant was given liquid fertilizer and/or raw water via a drip system. In addition to oxygenation drip irrigation, synthetic fertilizers based on the Hoagland formulation were applied to the culture after being dissolved in liquid.

2.4 Experimental Setup, Data Collection, and Statistical Analysis

The experiments followed a completely randomized design with five replications. The data of morphology; tillering (TILL), total chlorophyll (chl-tot), and carotenoids (car) were identified analyzed by a one-way ANOVA. The mean values were compared using the Tukey test at a 5% error probability. The data was also subjected to principal component analysis (PCA) using XLStat 2021 software.

3 Result and Discussion

Applying non-fermented and aerobically fermented goat manure alongside bio-fertilizer improves soil chemical properties, including pH, carbon-to-nitrogen ratio (C/N), and cation exchange capacity (CEC). Furthermore, incorporating Oxygenation MNB drip irrigation enhances these benefits and improves overall soil physical and chemical characteristics when used with organic fertilizers.

Data in **Table 1**. show the effect of bio-fertilization on the photosynthetic pigments. The formation of the shallot stem occurs within 40 days of cultivation. The application of dry goat manure (NFW) and aerobically fermented (FW), showed a significant effect on shoot formation and subsequently tuberization. NFW treatments enriched commercial bio-fertilizer with aeration MNB drip irrigation increased shoot formation by 10.3-17.2% compared to the adverse-soil control (T-Control). The maximum number of tillers were obtained from 3% organic fertilizer (P2), while the 5% (P3) and 7% (P4) NFW produced 8 tillers/plant. Similar treatments on sandy soil showed that 3% organic fertilizer ((P6) produced 9.25 tillers/plant, which was 19.4% higher than the control (P-Control). NFW enriched commercial bio-fertilizer and aeration MNB drip irrigation promoted 6.9% more tiller on shallot under sandy soil. Application of NFW and bio-fertilizer produced by aerobic fermentation using MNB increased tillering by 13.8-27.6% compared to the control. The maximum number of tillers reached 9.25 tillers/plant was obtained from the 3% organic fertilizer treatment (P10), while the 5% treatment (P12) produced 8.25 tillers/plant. While on sandy soil, 3% organic fertilizer (P14) resulted in the formation of 9.75 tillers/plant, which was 25.8% higher than the control. The lowest yield was obtained from the 5% (P15) and 7% (P16) treatments, that reached 8.75 tillers/plant. NFW enriched new bio-fertilizer derived aerobic MNB fermented goat manures and aeration MNB drip irrigation promoted 5% more tiller on shallot under sandy soil. Interestingly, FW administered enriched bio-fertilizer derived aerobic fermentation using MNB increased tillering by 27-31% compared to the adverse-soil control (T-Control). The maximum number of tillers reached 9.5 tillers/plant was obtained from the 3%, 5%, and 7%

of organic fertilizer treatment (P18-P20). While other treatment (P17) produced 9.25 tillers/plant. Shallots planted on sandy soil produce more tillers than in degraded soil. The treatment 7% organic fertilizers (P24) produced 10.5 tillers/plant, which was 35.5% higher than the control and the most tillers number in this study. However, lower concentration of organic fertilizer (5%) produced 10 tillers/plant. The treatment of FW enriched bio-fertilizer derived aerobic MNB fermented goat manures and aeration MNB drip irrigation on shallots planted on sandy soils promoted 26% more tiller compared to the control. This study showed that shallot, which require better aeration of growth medium, performed a better tillering in well-drained soils such as sandy soil. The application of organic materials NFW and FW enriched with bio-fertilizer improved tillering formation and their growth, as indicated by the number of tiller number per cluster of plant.

Shallot pigment formation is influenced by the application of organic fertilizer. The application of dried goat manure (NFW)and FW enriched bio-fertilizer and aeration MNB drip irrigation showed a significant effect on pigmentation, chlorophyll, and carotenoids. Treatment with NFW and commercial bio-fertilizer using drip irrigation with aeration increased chlorophyll formation by 13.7-20.7% compared to the sub-optimal soil control. Interestingly, the treatment negatively affected carotenoid formation. The Shallots treated with organic fertilizer at 1-7% NFW and aeration, produced lower carotenoid concentration than the control. The shallots planted on sandy soil produce better pigmentation than those planted on adverse soils. The percentage of chlorophyll and carotenoid formation was higher by 16.3-19.1% and 7-39%, respectively. Treatment of P7, with 5% organic fertilizer, produced 7.97 ug/mL chlorophyll and 0.75 ug/mL carotenoid, while P6 (3%) produced 0.8 ug/mL carotenoid and 7.79 ug/mL chlorophyll.Combined growth medium of NFW - commercial bio-fertilizer - aeration MNB drip irrigation in the soil facilitated better chlorophyll pigment formation (0.7%) but lower carotenoid content (-11.4%).

Table 1. Pigmentation of Shallots var Tajuk grown in adverse soil with different concentration of non-fermented (NFW) and fermented (FW) organic goat manures at ratio of 1-7% over Hoagland modified liquid fertilizer enriched oxygenation micro-nano (MNB) at 8-10 mg/L dissolved oxygen.

Code	Treatment	TLL	Chl-T	Car
CP	P-Control	7.750 ab	6.694 a	0.577 a
CT	T-Control	7.250 a	6.718 ab	0.664 a
P1	T-1%-NFW-MNB-B	8.250 abcd	7.640 abc	0.618 a
P2	T-3%-NFW-MNB-B	8.500 abcd	8.111 bc	0.631 a
P3	T-5%-NFW-MNB-B	8.000 abc	8.015 abc	0.649 a
P4	T-7%-NFW-MNB-B	8.000 abc	7.875 abc	0.650 a
P5	P-1%-NFW-MNB-B	8.750 abcde	7.783 abc	0.666 a
P6	P-3%-NFW-MNB-B	9.250 bcde	7.787 abc	0.804 a
P7	P-5%-NFW-MNB-B	8.500 abcd	7.971 abc	0.746 a
P8	P-7%-NFW-MNB-B	8.500 abcd	7.892 abc	0.622 a
P9	T-1%-NFW-MNB-F	8.500 abcd	7.614 abc	0.808 a
P10	T-3%-NFW-MNB-F	9.250 bcde	8.156 c	0.773 a
P11	T-5%-NFW-MNB-F	8.750 abcde	7.745 abc	0.701 a
P12	T-7%-NFW-MNB-F	8.250 abcd	8.094 bc	0.691 a
P13	P-1%-NFW-MNB-F	9.250 bcde	7.722 abc	0.632 a
P14	P-3%-NFW-MNB-F	9.750 cde	7.935 abc	0.637 a
P15	P-5%-NFW-MNB-F	8.750 abcde	7.781 abc	0.711 a
P16	P-7%-NFW-MNB-F	8.750 abcde	7.754 abc	0.620 a

P17	T-1%-FW-MNB-F	9.250 bcde	7.605 abc	0.748 a
P18	T-3%-FW-MNB-F	9.500 bcde	7.803 abc	0.800 a
P19	T-5%-FW-MNB-F	9.500 bcde	8.133 c	0.826 a
P20	T-7%-FW-MNB-F	9.500 bcde	7.778 abc	0.822 a
P21	P-1%-FW-MNB-F	8.500 abcd	7.615 abc	0.737 a
P22	P-3%-FW-MNB-F	9.750 cde	7.734 abc	0.810 a
P23	P-5%-FW-MNB-F	10.000 de	7.914 abc	0.913 a
P24	P-7%-FW-MNB-F	10.500 e	8.179 c	0.796 a

The combination of NFW with bio-fertilizer derived aerobic fermentation with drip irrigation aeration in the adverse soil, increased chlorophyll formation of shallots by 13.3-21.4% over the control. Treatment P10 (3%) on shallots produced 8.16 ug/mL of chlorophyll and 0.77 ug/mL of carotenoids, the highest chlorophyll concentration among the treatments. Meanwhile, on the sandy soil, the treatment improved chlorophyll content of shallots by 15.5-18.5%, and carotenoid by 7.5-23.3%, higher compared to the control. Treatment P14 (3%) on shallots reached the maximum chlorophyll concentration (7.94 ug/mL) but not carotenoid (0.64 ug/mL). While P15 (5% organic fertilizer) produced the maximum carotenoid concentration, reaching 0.71 ug/mL, but lower chlorophyll content (7.78 ug/mL) than P14. The shallots in adverse soil medium treated by aeration MNB in drip irrigation and FW and biofertilizer-derived fermentation improved higher chlorophyll and carotenoid formation in the range of 13.2 to 21.1% and 12.6 to 24.3%, respectively, compared to the control. Interestingly, application of NFW and biofertilizer-derived fermentation in soil medium produced higher chlorophyll and carotenoid content, 1.3% and 12.5%, compared to sandy soil. The highest chlorophyll concentration was obtained from treatment P19 (5%) at 8.13 ug/mL and 0.82 ug/mL carotenoids. In the similar treatments on sandy soil, chlorophyll concentration increased by 13.8-18.2% and carotenoid by 27.8-58.3%. P24 (7% FW) produced 8.18 ug/mL chlorophyll and 0.8 ug/mL carotenoids, while P23 (5%) produced the highest carotenoid level at 0.91 ug/mL and 7.91 ug/mL chlorophyll. A solid phase of aerobic fermented goat manures and its liquid phase performed better in the soil medium, that were 0.4% and 1.9% better in pigmentation compared to sandy soil (**Table 1**).

The application of organic fertilizer increases the color variation of onion stems. At high concentrations of organic matter, the stem color is red, predominantly followed by yellowish-pink and minor green. In the control and some low concentrations of organic matter (CT, CP, P1, P5, P9, P13, and P21), the stems tend to be green (**Fig. 1**).

Fig. 1. Stem color of of Shallots var Tajuk grown in adverse soil with different concentration of non-fermented (NFW) and fermented (FW) organic goat manures at ratio of 1-7% over Hoagland modified liquid fertilizer enriched oxygenation micro-nano (MNB) at 8-10 mg/L dissolved oxygen.

The application of organic matter and biofertilizers increases chlorophyll content in shallot [11]. Bio-fertilizers application also supports the conditions of root growth, increase the growth of the above-ground parts and finally improve the biological functions of the plant [12]. Microorganisms and the plant host form a mutually beneficial relationship where the host provides nutrients for the growth of microorganisms and microorganisms offer a better stress adaptation for the host by producing important hormones[13].

Micro-nanobubbles (MNBs) with higher oxygen concentration can enhance dissolved oxygen in growth media, which is then used in drip irrigation to promote plant growth and improve crop yield and quality. MNBs effectively increase the dissolved oxygen (DO) in the root zone, supporting aerobic microbial activity, improving root respiration, and enhancing overall nutrient absorption by plants. MNB increased dissolved oxygen and enhanced nutrient availability for plant growth and development [14]. MNB oxygenation irrigation application has been demonstrated to enhance the structure of the soil microbial community, stimulate soil respiration, and augment the abundance of soil microorganisms, thereby improving soil fertility and nutrient uptake[15].

Organic fertilizers can improve plant pH and increase biomass, though the effect on pH is variable: some organic fertilizers can increase soil pH, while others may decrease it, depending on the specific material. Overall, organic fertilizers enhance soil health and fertility, which supports plant growth, leading to increased biomass production. They also provide slow-release nutrients and improve soil structure, fostering a healthier environment for plants to thrive. Fertilizers increase the pH of tuber biomass by changing the soil pH, with nitrate-based fertilizers increasing it and ammonium or urea-based fertilizers decreasing it. This change in soil pH affects nutrient availability for plants and influences overall plant health, which in turn impacts tuber composition and yield.

In addition, the application of organic fertilizer not only improves the soil nutrients and microbial quantity, but also enhances the water retention ability, activates the activity of soil enzymes, and promotes the decomposition and release of organic matter, as indicated by the result.

4 Conclusion

Tillerings were regularly checked during vegetative growth and pigments were observed prior generative period. Remarkable growth of shallot tillers number (8-10.5) and pigments of total chlorophyll (7.60-8.23μg/mL) and carotenoid (0.62-0.88μg/mL) treated by organic-chemical over conventional fertilizer were observed. Aerated drip irrigation enhanced vegetative growth and pigmentation by 15% and 19.9% over non-aerated drip irrigation. The study confirmed positive effect of organic waste circulation enriched aerobic microbial, and aerated rhizosphere on plant growth improvement and indeed improved physiological characters of plants grown organically.

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