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ENHANCING GROWTH, YIELD AND ECONOMIC VIABILITY OF LEMONGRASS (*CYMBOPOGON FLEXUOSUS* CV. KRISHNA) THROUGH SEAWEED EXTRACT

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ABSTRACT

Lemongrass (*Cymbopogon flexuosus* cv. Krishna) is a valuable aromatic perennial crop known for its citral-rich essential oil, widely used in perfumery, medicine, cosmetics, and aromatherapy. A field experiment was conducted at the Horticultural Research Station, Mondouri, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, to evaluate the impact of seaweed extract application on lemongrass growth, yield and economics across three harvesting seasons under New Alluvial Zone (NAZ) conditions. The study used a Randomized Block Design (RBD) with seven treatments involving different doses of seaweed extract applied as root dips or foliar sprays, combined with recommended fertilizer doses (NPK 120:60:60 kg/ha), with three replications. The region experienced typical seasonal variations with moderate temperature, humidity, and rainfall conducive to lemongrass growth. Results showed that foliar spray of 2 ml seaweed extract twice (T_6) significantly improved plant height, tiller and leaf number, leaf size, essential oil percentage, fresh and dry herbage yield, and oil yield per hectare compared to other treatments. Treatment T_6 also recorded the highest benefit-cost ratio (BCR) over the three harvesting seasons, indicating enhanced profitability. These findings suggest that foliar application of seaweed extracts under NAZ meteorological conditions is an effective practice for optimizing lemongrass productivity and economic returns.
Keywords: Seaweed extract, foliar spray, root dipping, lemongrass, oil yield, benefit-cost ratio, agricultural productivity.

Introduction

Lemongrass *Cymbopogon flexuosus* (*family:poaceae*) is an important industrial perennial tropical plant renowned for its high citral content, which imparts its distinctive lemon fragrance. In perfumery, it is used to create fresh, citrusy scents. In the medical and pharmaceutical fields, lemongrass is valued for its antibacterial, antifungal, and anti-inflammatory properties, contributing to the formulation of various treatments. Its essential oil is a popular ingredient in cosmetics, enhancing products with its fragrance and therapeutic benefits. Besides its industrial value, lemongrass oil is well-regarded for its medicinal properties, which include analgesic, anti-inflammatory, antipyretic, diuretic, antimicrobial, antioxidant, and sedative effects (Onawunmi *et al*., 1984; Negrelle and Gomes, 2007; Horne *et al*., 2001; Dorman *et al*., 2000; Chao and Young, 2000). In cooking, lemongrass adds a unique flavour to dishes, particularly in Asian cuisines. Additionally, lemongrass is utilized as an insect repellent and in aromatherapy for its calming effects. Its versatility and the economic value of its essential oil make lemongrass a significant crop across these diverse sectors, driving its importance in global agriculture and industry.

Lemongrass has a long history of use in traditional medicine, where it is believed to offer a range of health benefits. The essential oils extracted from lemongrass contain compounds such as citral, geraniol and neral which contribute to its therapeutic effects. Moreover, lemongrass can contribute to soil health and erosion control. Its dense root system helps stabilize the soil and prevent erosion, making it a useful plant in agroforestry and conservation projects. The plant's fast growth and high yield also make it an attractive option for farmers looking to diversify their crops and improve soil quality.

Seaweed extracts are valued for their rich content of growth regulators, nutrients, and bioactive compounds that can significantly enhance plant development and productivity. The extract enhances plant growth by promoting root and shoot development, increasing chlorophyll content, and improving stress tolerance. Additionally, it contributes to higher crop yields and better-quality produce. These benefits are attributed to the extract's rich composition of growth hormones, nutrients, and bioactive compounds.

The role of agricultural bio stimulants in food production worldwide is expanding, especially those made from seaweed extracts (SWE). Bio stimulants made from seaweeds have properties that improve plant growth, yield and quality and increase tolerance to abiotic and biotic stresses, as well as improving nutrient use (Arioli *et al.,* 2015; Shukla *et al*., 2019). field studies have demonstrated that SWE applied at relatively low rates as foliar sprays or soil fertigation increase yield among diverse crops such as wine grapes, sugarcane, strawberries and vegetables (Khan *et al*., 2009; Arioli *et al*., 2015; Shukla *et al.,* 2019). Seaweeds have been proven as a source of antioxidants, plant growth hormones, osmoprotectants, mineral nutrients and many other organic compounds including novel bioactive molecules (Akila and Jeyadoss 2010; Ramarajan *et al*., 2013; Ismail and El-Shafay 2015). Very less information is available on the performance of Seaweed extracts on lemongrass. keeping the following information in view the present experiment has been studied.

Materials and Methods

The study was conducted at the Horticultural Research Station, Mondouri, Bidhan Chandra Krishi Viswavidyalaya, located in Nadia, West Bengal from August, 2022 to July, 2023. This research station is situated at a latitude of 23° North and a longitude of 89° East, with an elevation of 9.75 meters above sea level. The soil where the experiment was conducted was of Gangetic alluvial sandy clay-loam in texture, with pH of 4.82 pH meter, (Jackson, 1996), EC (mS/cm) of 0.39, organic carbon % of 1.15 (Walkey and Black method, 1967), available N of 282.81 kg/ha Modified Kjeldhal's (Jackson, 1973), available P_2O_5 of 62.81.80 kg/ha Modified Olsen (Jackson, 1973) and available k_2O of 340.8 kg/ha Flame photometer (Jackson, 1973) well drained with good water-holding. The field was prepared by ploughing it thoroughly to achieve a fine tilth, followed by removing debris and levelling the surface. The area was then divided into 21 plots, each measuring 1.8 x 1.8 meters i.e. 3.24 meters square as with 90 cm wide channels separating them. Well-rooted slips were separated from mother clumps, with one slip planted per pit in the main field, spaced 60 cm apart and well irrigated immediately. The liquid seaweed extract was applied in different concentrations as root dip before planting followed by spray after planting. For root dipping, fresh lemongrass slips were harvested and the roots were exposed to sun light for drying for 5-6 hours for ease of root dipping. For sprying plants were directly planted followed by spraying at two intervals i.e., 45 days after planting and 60 days after planting throughout the crop growth period of 120 days as harvest. After ratoon only spray was given for root dipped plants i.e., after 60 days of ratooing while twice spray for rest of the treatments. The treatments include T_1 (0.5 ml root dip + 1 spray), T_2(1 ml root dip + 1 spray), T_3(2 ml root dip + 1 spray), T_4 (0.5 ml - 2 sprays), T_5 (1 ml -2 sprays), T_6 (2 ml - 2 sprays) and T_7 (control water spray). Fertilizers were applied in the form of urea (46% nitrogen), Single Super Phosphate (16% phosphorus) and Muriate of Potash (60% potassium). Fertilization involved applying one sixth split of the nitrogen, along with full doses of phosphorus, potassium, and 10 tonnes farmyard manure (FYM). The remaining nitrogen was applied after harvest and 35 days after the initial dressing or ratooning. Subsequent irrigations were provided every 10-15 days interval as needed.

Metrological data of the experimental location:

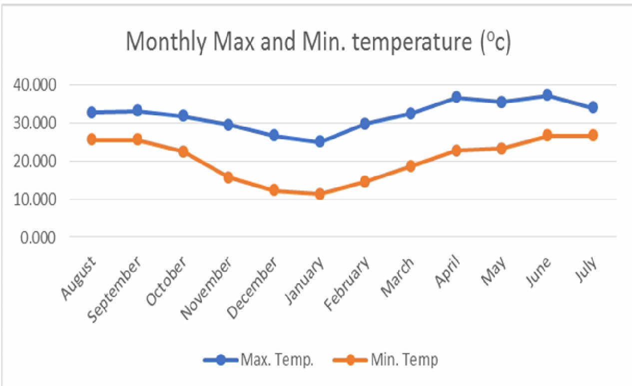

Fig. (1a) : Monthly average Maximum and Minimum temperature (°c)

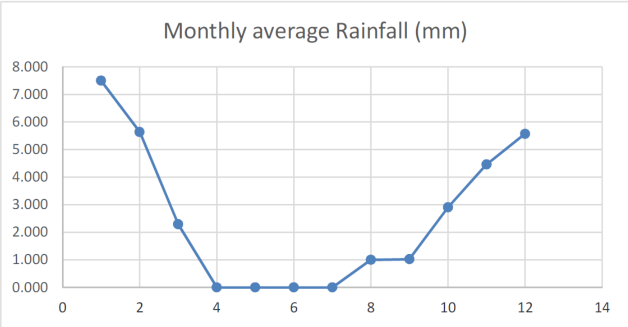

Fig. (1b) : Monthly average rainfall (mm)

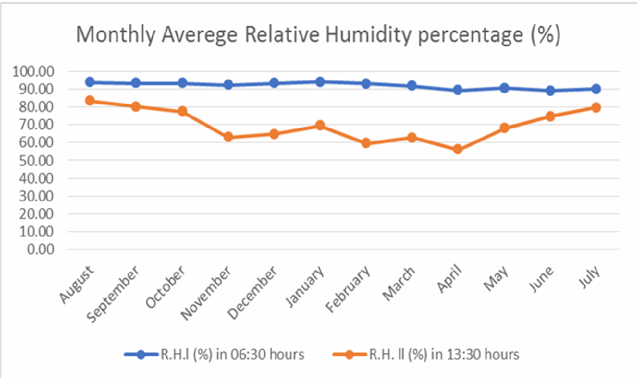

Fig. (1c) : Monthly average Relative humidity (%)

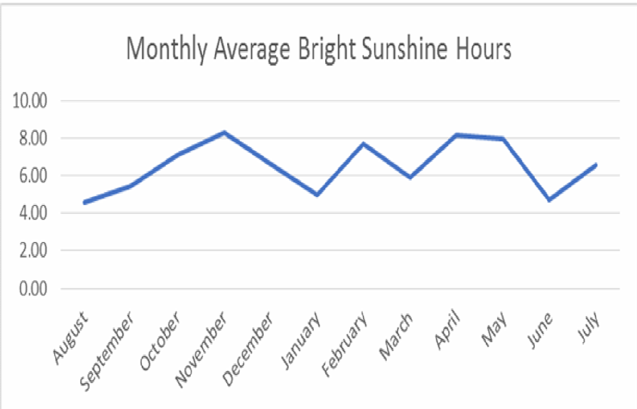

Fig. (1d) : Monthly average Brighty Sunshine hours:

Source: Department of Agro-Meteorology and Physics, B.C.K.V, Mohanpur, Nadia, West Bengal.

Observations recorded

Parameters such plant height (cm), number of tiller/clumps, no. of leaves per clump/clump, leaf length (cm), leaf breadth (cm), fresh herbage yield per plot, dry herbage yield per plot and oil percentage were considered. Harvesting was performed using a sickle cutting the tillers at 10-15 cm above the ground level from tagged plants after 120 days after planting and allowed to ratooning for accessing the experiment for next two seasons. The experimental data were analyzed using the Randomized Block Design (RBD) as per the method outlined by Gomez and Gomez (1984). Treatment effects were tested using Fisher and Snedecor's F-test at a 5% probability level. The least significant difference (LSD) values were calculated using the tabulated values provided by Fisher and Yates (1974) to determine significant differences among treatment means. Additionally, correlation analysis among yield attributes and weather parameters was performed using Python. This enabled the construction of a correlation matrix and heatmap for enhanced interpretation of inter-variable relationships.

Determination of essential oil percentage

As Prins *et al.*, 2016 suggests maximum oil content observed at 117 to 125 days after planting. Considering the above findings, fresh leaves and immature stems of lemongrass were harvested at 120 days after planting and ratooning. The samples were cut into 3-5 cm pieces and distilled using a Clevenger apparatus. The essential oil was collected in a burette after boiling with distilled water at 98°C for 2.5 – 3 hours, and the volume was recorded. The essential oil was recorded as per fresh herbage yield per hectare with 80% of area occupied by lemongrass.

$$\text{Essential oil \% (v/v)} = \frac{\text{Volume of oil extracted (ml)}}{\text{Fresh weight of the sample (gm)}} \times 100$$

Economics of lemongrass cultivation

The total cost of production (COP) and gross returns (GR) were calculated to assess the economic viability of lemongrass cultivation. Inputs included Urea (46% N) at Rs. 8.5/kg, SSP (16% P_2O_5) at Rs. 15/kg, MOP (60% K_2O) at Rs. 22/kg, Liquid Seaweed Extract at Rs. 1000 per litre, planting material at Rs. 2/slip, labour at Rs. 328 for an 8-hour day, and oil selling price at Rs. 1800/litre. For working the Gross Return (GR) selling price of essential oil as Rs.2500/litre was considered while Net Return (NR) was calculated as cost of production (COP) – Gross Return (GR). For Cost benefit ratio, Net Return (NR) was divided by Gross Return (GR) as (NR/GR).

Fig. (2a) : drying of lemongrass slips for root dipping with seaweed extract. (2.b)- Root dipping with seaweed extract. (2.c)- Spraying of seaweed extract. (2.d) -Lemongrass experiment field. (2.e).-harvesting of lemongras. (2.f). – Distillation of lemongrass. (2.g)- Lemongrass essential oil and hydrosol

Results and Discussion

Table 1 : Effect of liquid seaweed extract on phenological traits of lemongrass during the year 2022.

Treatments	Plant height			No. of tillers			No. of leaves			Leaf length				Leaf breadth	
	Harvest 1 (November)	Harvest 2 (March)	Harvest 3 (July)	Harvest 1 (November)	Harvest 2 (March)	Harvest 3 (July)	Harvest 1 (November)	Harvest 2 (March)	Harvest 3 (July)	Harvest 1 (Nov-ember)	Harvest 2 (March)	Harvest 3 (July)	Harvest 1 (November)	Harvest 2 (March)	Harvest 3 (July)
T_1	148.82	155.79	167.43	54.407	61.86	67.70	272.03	309.29	338.53	128.52	137.64	150.41	2.24	2.35	2.34
T_2	151.50	158.63	168.10	59.604	64.679	70.84	298.02	323.39	354.2	128.63	137.66	150.48	2.25	2.36	2.36
T_3	153.08	162.17	168.30	61.457	66.087	75.41	307.28	330.43	377.05	129.66	138.59	151.26	2.25	2.36	2.36
T_4	154.23	162.63	167.97	61.513	69.962	78.54	307.56	349.81	392.71	131.22	142.10	153.91	2.28	2.36	2.41
T_5	156.20	167.63	171.40	64.317	74.836	81.88	321.58	374.18	409.43	131.83	144.56	156.52	2.28	2.38	2.43
T_6	158.75	170.33	175.93	66.563	76.02	83.84	332.81	380.10	419.20	133.03	144.97	156.72	2.30	2.38	2.44
Control	144.35	150.73	158.80	50.87	56.797	58.933	254.35	283.98	294.66	126.78	133.67	143.04	2.21	2.33	2.33
SEm +	0.245	1.057	1.912	0.534	0.375	1.565	2.666	1.873	7.826	1.814	1.353	1.339	0.021	0.016	0.03
CD (5%)	0.765	3.293	5.957	1.663	1.168	4.876	8.307	5.836	24.381	NS	4.216	4.171	NS	NS	NS

Phenological traits:

Based on the data recorded across three harvests (November, March, and July), the application of liquid seaweed extract had a significant positive influence on the phenological traits of lemongrass (*Cymbopogon flexuosus* cv. Krishna). Among the treatments, T_6 (2 ml seaweed extract spray) consistently outperformed all others, recording the highest values for plant height, number of tillers, number of leaves, and leaf length across all harvests. Plant height under T_6 increased progressively from 158.75 cm in November to 175.93 cm in July, significantly surpassing the control (144.35 cm to 158.80 cm) and other treatments. T_5 (1.5 ml spray) was statistically at par with T_6 in March (170.33 cm vs. 167.63 cm) and July (175.93 cm vs. 171.40 cm) respectively. Similarly, the number of tillers in T_6 increased from 66.563 to 83.84 over the three harvests, with significantly higher values than the control, and T_5 being at par in the first two harvests. The number of leaves also peaked in T_6 as (332.81 to 419.20). For leaf length, T_6 recorded the maximum values (133.03 to 156.72 cm); the difference was non-significant in November but statistically significant in March and July. In contrast, leaf breadth did not vary significantly across treatments during any harvest, although T_6 recorded the highest numerical values (2.30 cm to 2.44 cm).

The observed enhancement in growth attributes under T_6 can be attributed to the bioactive compounds present in seaweed extract, such as auxins, cytokinins, and micronutrients, which are known to improve nutrient uptake and stimulate plant growth. These results are in agreement with the findings of Khan *et al.* (2009) and Craigie (2011), who reported enhanced plant elongation due to phytohormones in seaweed. Increased tiller formation and leaf production under seaweed application have also been documented by Jannin *et al.* (2014) and Muraoka *et al.* (2004), indicating hormonal stimulation and improved nutrient assimilation. Moreover, the enhancement in photosynthetic area and vegetative growth under T_6 aligns with observations by Taboada *et al.* (2016) and Yakhin *et al.* (2017), who highlighted the ability of seaweed extracts to promote foliar development. Although leaf breadth did not respond significantly, the overall morphological improvement is consistent with reports by Sivasankar *et al.* (2011) and Shrivastava *et al.* (2020), who linked seaweed application with better plant architecture.

Table 2: Effect of liquid seaweed extract on fresh herbage yield, dry yield, oil percentage and oil yield of lemongrass:

Treatments	Fresh Herbage yield (Tonnes/ha)			Dry Herbage Yield (Tonnes/ha)			Oil %			Oil Yield (Liters/Ha)		
	Harvest 1 (November)	Harvest 2 (March)	Harvest 3 (July)	Harvest 1 (November)	Harvest 2 (March)	Harvest 3 (July)	Harvest 1 (November)	Harvest 2 (March)	Harvest 3 (July)	Harvest 1 (November)	Harvest 2 (March)	Harvest 3 (July)
T_1	9.65	10.82	12.75	3.44	3.01	4.50	0.72	0.73	0.50	69.13	78.68	63.14
T_2	9.86	11.24	13.30	3.75	3.16	4.64	0.72	0.73	0.50	71.32	82.15	65.83
T_3	11.38	11.43	13.37	4.24	3.21	4.68	0.73	0.73	0.50	83.05	83.60	67.05
T_4	11.74	11.98	13.58	4.26	3.25	4.77	0.73	0.73	0.50	85.72	87.73	67.76
T_5	12.23	12.92	13.91	4.38	3.35	4.83	0.74	0.76	0.51	90.56	97.87	71.44
T_6	13.12	13.18	15.02	4.41	3.37	4.93	0.75	0.78	0.52	98.07	103.08	78.59
Control	8.73	8.41	11.05	2.96	2.71	4.22	0.70	0.64	0.48	61.07	53.12	53.12
S.Em (+)	0.396	0.28	0.525	0.048	0.056	0.089	0.006	0.012	0.005	3.005	1.841	2.656
CD (5%)	1.232	0.872	1.636	0.151	0.175	0.278	0.02	0.038	0.015	9.362	5.734	8.274

Projected Yield and Oil percentage:

The application of liquid seaweed extract significantly improved the yield attributes of lemongrass (*Cymbopogon flexuosus* cv. Krishna) across all three harvests. Treatment T_6 (2 ml seaweed extract spray) recorded the highest fresh herbage yields 13.12 t/ha in November, 13.18 t/ha in March, and 15.02 t/ha in July which were significantly superior to the control and all other treatments. The dry herbage yield also followed a similar trend, with T_6 producing 4.41, 3.37, and 4.93 t/ha over the three seasons substantially higher than the T_7 (control). These results affirm that seaweed extract enhances biomass accumulation and vegetative mass, corroborating earlier findings by Khan *et al.* (2009), Sivasankar *et al.* (2011), and Hossain *et al.* (2017). In terms of essential oil content, T_6 exhibited the highest oil percentage across all harvests (0.75%, 0.78%, and 0.52%), closely followed by T_5. Although the third harvest recorded a lower oil percentage, seasonal influence on oil biosynthesis is documented. The oil yield was also maximized under T_6, with 98.07, 103.08, and 78.59 litres/ha recorded across the three harvests substantially higher than the T_7 control. These improvements may be attributed to the presence of growth-promoting substances such as cytokinins, auxins, and micronutrients in the seaweed extract, which enhance both primary and secondary metabolism. The findings are supported by prior reports from Muraoka *et al.* (2004), Siddiqui *et al.* (2016), Shrivastava *et al.* (2020), and Taboada *et al.* (2016), who highlighted the stimulatory effects of seaweed-based bio-stimulants on essential oil crops.

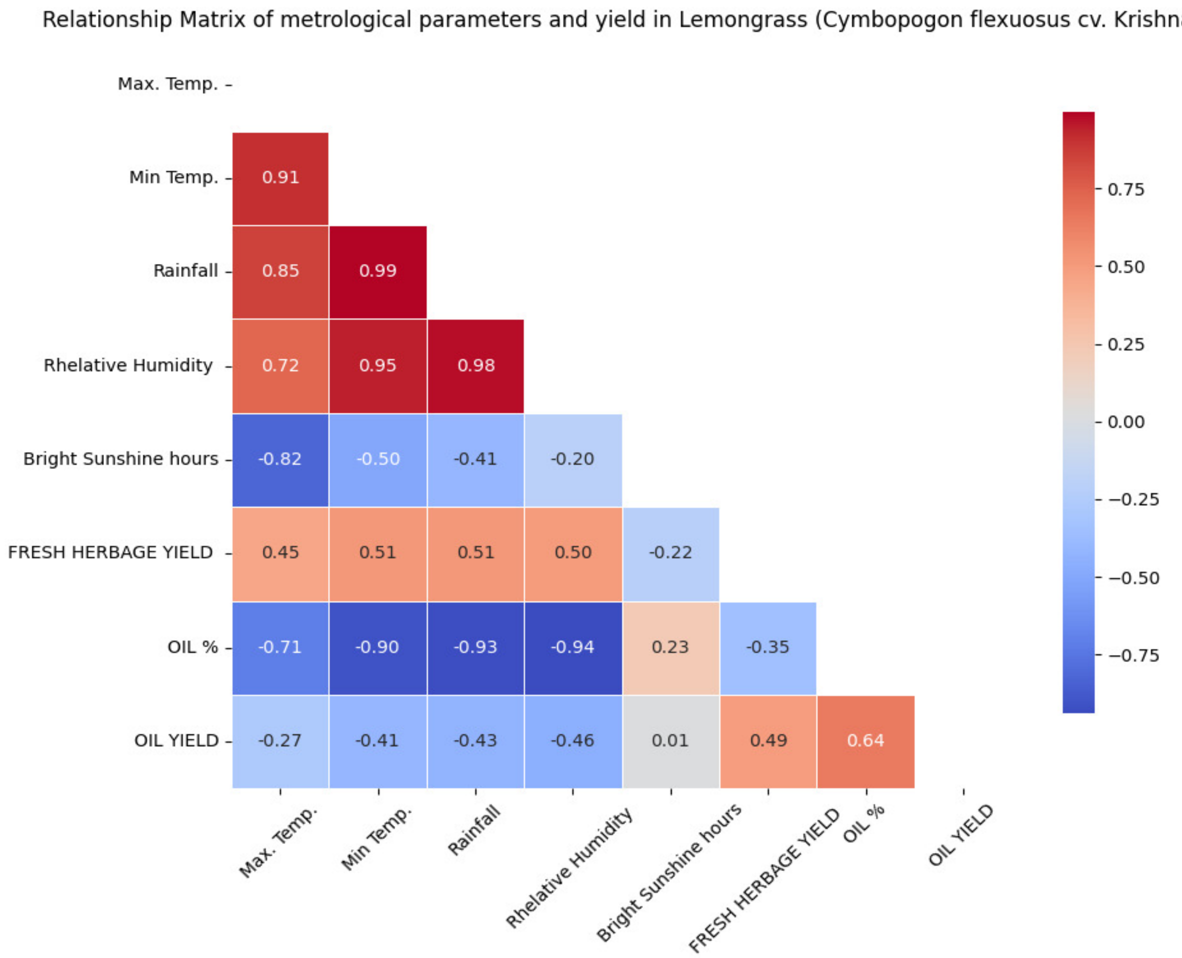

Fig. 3: Correlation Analysis Between Lemongrass Yield and Meteorological Variables:

The correlation analysis highlights the intricate relationship between environmental factors and the productivity of lemongrass (*Cymbopogon flexuosus* cv. Krishna). It reveals that conditions favoring vegetative growth, such as higher temperatures, rainfall, and humidity, do not necessarily support essential oil accumulation. While these factors promote lush biomass development, they often lead to a dilution of oil content or interfere with the physiological processes involved in oil biosynthesis. On the other hand, drier conditions with adequate sunshine, although less conducive to fresh herbage production, appear to favor oil quality by enhancing secondary metabolite formation. This indicates a trade-off between biomass and oil concentration, suggesting that optimal lemongrass cultivation requires a balance between moisture availability and light intensity. Agronomic strategies should therefore focus not only on maximizing growth but also on enhancing oil synthesis under prevailing environmental conditions.

The application of seaweed extracts has been widely recognized for its potential to significantly boost plant growth and productivity. Among the various methods of application, foliar spraying twice has emerged as the most effective compared to root dipping/one spray. This method allows for direct nutrient absorption through the foliage, ensuring quicker and more efficient uptake. Several researchers have emphasized the advantages of foliar application. For instance, Khan and Choi (2017) reported that foliar feeding considerably enhances plant growth and nutrient assimilation when compared to soil or root-based treatments. Sivasankar and Ramesh (2011) also observed improved growth and yield with foliar application due to its superior nutrient delivery efficiency. Supporting this, Zodape and Sankhla (2013) found that foliar-applied seaweed extract significantly promotes plant development and yield, outperforming other modes of application. Similarly, Khan and Bano (2010) demonstrated that foliar treatment enhances both growth and yield of wheat more effectively than root application. This efficiency can be attributed to the faster and more direct mode of nutrient entry into the plant system via foliar pathways, resulting in rapid physiological responses and enhanced plant vigor. Mali and Sontakke (2021) further confirmed that foliar application leads to better outcomes in growth and yield than soil treatments. Moreover, foliar feeding serves as a faster means of delivery, potentially due to active uptake through stomata rather than the cuticle, as noted by Shah *et al.* (2013) and Nedumaran and Arulbalachandran (2015), with further physiological insights provided by Fernandez and Brown (2013).

Table (3a) : Effect of seaweed on Benefit cost of lemongrass: First season:

Season 1	Oil yield	Gross return	Cost of Production	Net Return	Benefit:Cost
T1	69.13	124439.40	82439.20	42000.20	0.51
T2	71.32	128370.60	82939.20	45431.40	0.55
T3	83.05	149495.40	83439.20	66056.20	0.79
T4	85.72	154290.60	82439.20	71851.40	0.87
T5	90.56	163002.60	82939.20	80063.40	0.97
T6	98.07	176520.60	83439.20	93081.40	1.12
T7	61.07	109931.40	81439.20	28492.20	0.35

Table (3b): Effect of seaweed on Benefit cost of lemongrass: Second season:

Season 2	Oil yield	Gross return	Cost of Production	Net Return	Benefit:Cost
T1	78.68	141624.00	46117.20	95506.80	2.07
T2	82.15	147870.00	46617.20	101252.80	2.17
T3	83.60	150480.00	47117.20	103362.80	2.19
T4	87.73	157908.60	46117.20	111791.40	2.42
T5	97.87	176160.60	46617.20	129543.40	2.78
T6	103.08	185549.40	47117.20	138432.20	2.94
T7	53.12	95610.60	45117.20	50493.40	1.12

Table (3c) : Effect of seaweed on Benefit cost of lemongrass: Third season:

Season 3	Oil yield	Gross return	Cost of Production	Net Return	Benefit:Cost
T1	63.143	113657.4	46117.2	67540.20	1.46
T2	65.83	118494	46617.2	71876.80	1.54
T3	67.05	120690	47117.2	73572.80	1.56
T4	67.76	121968	46117.2	75850.80	1.64
T5	71.443	128597.4	46617.2	81980.20	1.76
T6	78.593	141467.4	47117.2	94350.20	2.00
T7	53.123	95621.4	45117.2	50504.20	1.12

Conclusion

Briey, the experimental evidence strongly concludes the use of foliar spray as a more effective method for applying seaweed extracts compared to root dipping. Foliar applications facilitate better nutrient uptake, promote healthier plant growth, and result in higher yields and improved quality of crops. This method is advantageous for its efficiency in delivering essential nutrients directly to the plant's foliage, leading to more immediate and beneficial effects. The application of seaweed treatments, particularly at higher concentrations, significantly enhances fresh herbage yield, dry yield, oil percentage, and oil yield in lemongrass. Treatment 6 with 2 ml seaweed as foliar spray was the most effective treatment, leading to the highest values in all parameters. These results align with the extensive body of research confirming the beneficial effects of seaweed extracts on crop growth and essential oil production for improving crop growth and productivity (Hernández-Hernández & Gómez, 2020; Yakhin *et al*., 2017). The evidence supports the use of seaweed-based treatments as a valuable tool for enhancing lemongrass cultivation and essential oil production. It is also evident that different harvesting time of a year influenced morphological traits such as plant height, number of tillers, number of leaves, leaf length, leaf breadth as well as yield attributes such as fresh herbage yield, dry herbage yield, oil percentage and oil yield under New Alluvial Zone of West Bengal.

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