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Re-inventing crop nutrition: Integrated impact of nano-fertilizers, organics and recommended dose of fertilizers on growth and physiology of red Amaranthus

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Abstract

Red amaranthus (*Amaranthus tricolor* L.) is a nutritionally important leafy vegetable requiring efficient nutrient management for sustainable productivity. An experiment was conducted at APHC Farm, Kalavai, Tamil Nadu, to evaluate the effects of inorganic and nano-fertilizers on growth, yield, and attributes of Red amaranthus cv. Arka Arunima. The experiment was arranged in a randomized block design with seven treatments replicated thrice. Treatments comprised 100% recommended dose of fertilizers (RDF), 100% farmyard manure (FYM), 100% vermicompost, 100% nano-fertilizer, and combinations of 50% RDF with 50% FYM, vermicompost, or nano-fertilizer. Growth, yield attributes and chlorophyll content index (CCI) were assessed, and data were analysed using ANOVA. The combined application of 50% RDF and 50% nano-fertilizer (T₇) produced the greatest plant height, stem circumference, shoot length, number of leaves, leaf length, leaf width, fresh weight, dry weight, yield, and CCI. T₇ recorded 13.15 leaves per plant, 73.50 g fresh weight, 19.11 g dry weight, 6.25 kg yield per plot, and a CCI of 33.03. However, maximum root length (8.05 cm) occurred with 50% RDF plus 50% FYM. These findings demonstrate that integrating RDF with nano-fertilizer improves nutrient-use efficiency and productivity while reducing dependence on fertilizers.

Keywords: Red amaranthus, fertilizers, inorganic, organic, nano-fertilizers

1. Introduction

Vegetables play a vital role in human nutrition by supplying essential vitamins, minerals, dietary fibre, and bioactive compounds necessary for maintaining health. India is the second-largest producer of vegetables in the world after China, and leafy vegetables constitute an important component of daily dietary requirements. Among leafy vegetables, red amaranthus (*Amaranthus tricolor* L.) is widely cultivated and consumed due to its high nutritional value. The crop is rich in proteins, carotenoids, iron, vitamin C, folic acid, and vitamin K, making it an important source of micronutrients, particularly in developing countries. Besides its nutritional significance, red amaranthus possesses medicinal properties such as antioxidant, anti-inflammatory, anticancer, and cholesterol-lowering activities, which enhance its importance in human diets.

The global population, estimated at over 9.1 billion people, continues to increase, intensifying the demand for food and nutritional security. Although the Green Revolution substantially improved food grain production and helped alleviate hunger, the excessive and continuous use of synthetic fertilizers and pesticides has resulted in soil degradation, nutrient imbalance, environmental pollution, and concerns regarding human health. Consequently, modern agriculture faces the challenge of sustaining high crop productivity while preserving natural resources and environmental quality.

Integrated Nutrient Management (INM) has emerged as a sustainable strategy that combines organic, inorganic, and advanced nutrient sources to optimize crop growth and maintain soil fertility. Recent studies have highlighted that INM improves nutrient-use efficiency, enhances soil biological activity, increases crop productivity, and promotes long-term sustainability in agricultural systems^[1]. Organic manures such as vermicompost and

farmyard manure (FYM) are important components of INM. Vermicompost is a nutrient-rich organic amendment containing essential macro- and micronutrients that improve soil structure, microbial activity, nutrient availability, and plant growth. Similarly, FYM contributes to soil organic matter accumulation, enhances water-holding capacity, and supports sustainable crop production.

In recent years, nano-fertilizers have gained considerable attention as an innovative approach to improving nutrient-use efficiency. Due to their small particle size, large surface area, and controlled nutrient release characteristics, nano-fertilizers facilitate efficient nutrient uptake and translocation within plants, thereby reducing nutrient losses and environmental contamination. Several studies have reported positive effects of nano-fertilizers on crop growth, yield, and quality, although their performance may vary depending on crop species, environmental conditions, and management practices [3].

Considering the nutritional, economic, and medicinal importance of red amaranthus and the growing need for sustainable nutrient management practices, the present investigation was undertaken to evaluate the effects of organic manures, inorganic fertilizers, and nano-fertilizers on the morphological, physiological, and yield attributes of red amaranthus. The study aims to identify an effective integrated nutrient management strategy that can enhance crop productivity while maintaining soil health and environmental sustainability.

Materials and Methods

The experiment was conducted at APHC Farm, Kalavai, Tamil Nadu, located at 12°33' N latitude and 79°33' E longitude. The region experiences a tropical climate with an average annual temperature of 30 °C, ranging from 25 °C during winter to 35 °C during summer, and receives an average annual rainfall of 953.4 mm. Red amaranthus (*Amaranthus tricolor* L.) variety 'Arka Arunima' was selected for the study, and the seeds were procured from Pudukai Agro Service, Pudukcherry. Farmyard manure (FYM) and vermicompost were obtained from APHC Farm, Kalavai, while nano-fertilizers were sourced from Tropical Agro System (India) Pvt. Ltd. These nutrient sources were applied according to the treatment schedule.

The experiment was laid out in a Randomized Block Design (RBD) comprising seven treatments and three replications with a total of 21 plots, each measuring 1.5 m × 1.2 m. The treatments included 100% Recommended Dose of Fertilizers (RDF), 100% FYM, 100% vermicompost, 100% nano-fertilizer, 50% RDF + 50% FYM, 50% RDF + 50% vermicompost, and 50% RDF + 50% nano-fertilizer. The field was ploughed thoroughly to obtain a fine tilth, levelled, and divided into plots. Pre-sowing irrigation was provided to ensure uniform germination. Seeds were broadcast uniformly in the plots, and standard agronomic practices such as irrigation, thinning, and hand weeding were carried out as required. Organic manures and fertilizers were applied as per the treatment schedule, and the crop was harvested at 45 days after sowing.

Observations on growth, yield, and physiological parameters were recorded from randomly selected plants in each treatment. The growth parameters included plant

height, stem circumference, shoot length, root length, leaf length, leaf breadth, number of leaves per plant, fresh weight, and dry weight of plants. Yield was assessed based on total yield per plot, while physiological performance was evaluated through Chlorophyll Content Index (CCI). The collected data were subjected to statistical analysis using DSAASTAT software. Analysis of variance (ANOVA) was performed, and treatment means were compared using the Critical Difference (C.D) test at the 5 per cent level of significance.

Results and Discussion

Growth parameters

The data revealed that plant height at 15 DAS was recorded the highest in treatment T₇ with 47.62 cm which received granular application of 50% RDF and 50% nano fertilizers. At final observation, during 30 DAS, the maximum plant height 46.87 cm was observed in T₇ with application of 50% RDF + 50% nano fertilizers. The data revealed that stem circumference at 15 DAS was 2.91 cm and during 30 DAS was 3.40 cm in treatment T₇. Similarly, T₇ recorded a maximum shoot length of 37.60 cm. The maximum length of the root 8.05 cm was found in treatment T₆ where 50% RDF was given along with 50% FYM.

Nano fertilizers, which utilize nanotechnology to deliver nutrients more efficiently, have been shown to positively impact plant growth, including the height of red amaranthus. Nano fertilizers can improve the availability and uptake of essential nutrients by the plant. Their small particle size allows for better penetration into the soil and easier absorption by plant roots. This can lead to improved growth and increased plant height [2]. This steady supply ensures that red amaranthus plants receive a continuous supply of essential nutrients, which supports consistent growth and can contribute to taller plants [3]. The nano-sized particles can enhance soil properties and create a more favourable environment for root development. Better root systems can support taller plant growth by providing improved anchorage and nutrient uptake. A healthier plant often results in a thicker stem circumference due to more robust growth. Nano fertilizers enable more precise and efficient utilization of nutrients. This can lead to increased cellular growth and development, which contributes to thicker, stronger stems. As plants grow faster and more vigorously, they often develop thicker stems to support their increased biomass. By enhancing the efficiency of photosynthesis through better nutrient supply, nano fertilizers enable plants to produce more energy for growth. This additional energy contributes to increased shoot length. Reduced stress as a result of application of nano fertilizer allows plants to allocate more resources to growth, including the extension of shoot length. Similar studies were revealed by [4, 5].

The maximum length of the root 8.05 cm was found in treatment T₆ where 50% RDF was given along with 50% FYM. The availability of essential nutrients support healthy root development and promote the growth of longer and more robust roots. Vermicompost helps the soil retain moisture which is crucial for root development, and well-hydrated soil supports the growth of longer and healthier roots. The results were in concordance with the findings of [6] in red amaranthus.

Table 1: Effect of integrated nutrients on the growth parameters of red amaranthus

S. No	Treatments	Plant Height (cm)		Stem circumference (cm)		Shoot Length (cm)		Root length (cm)	
		15 DAYS	30 DAYS	15 DAYS	30 DAYS	15 DAYS	30 DAYS	15 DAYS	30 DAYS
1	T ₁ - 100% RDF	25.25	30.01	2.30	2.45	21.56	28.82	4.70	6.42
2	T ₂ - 100% vermicompost	20.34	26.25	1.26	1.70	19.26	25.67	3.60	6.15
3	T ₃ - 100% FYM	10.23	15.11	1.05	1.30	12.40	16.20	4.80	6.81
4	T ₄ - 100% nano fertilizers	10.11	14.12	1.08	1.35	13.43	16.89	4.30	5.99
5	T ₅ - 50% RDF + 50% vermicompost	29.55	32.15	2.21	2.70	26.01	34.49	5.79	7.62
6	T ₆ - 50% RDF + 50% FYM	34.60	39.53	2.55	3.04	23.66	31.38	6.30	8.05
7	T ₇ - 50% RDF + 50% nano fertilizers	41.62	46.87	2.91	3.40	28.40	37.60	5.30	7.22
	C. D	4.65	4.78	0.28	0.27	2.30	3.06	0.37	0.41
	S. ed	2.21	2.40	0.14	0.13	1.16	1.56	0.23	0.21

RDF – Recommended Dose of Fertilizers

Yield and physiological attributes:

The treatment, T₇ (50% RDF + 50% nano fertilizers) recorded highest number of leaves (13.15), maximum leaf length of 11.50 cm, leaf width of 8.30 cm, fresh weight with 73.50 g and dry weight with 19.11 g. Nano fertilizers often provide a controlled and sustained release of essential nutrients. This steady supply supports continuous and balanced growth, which can result in longer leaves. The delivery of nutrients more efficiently at the cellular level results in better plant growth and larger leaves, including increased leaf breadth. Better photosynthesis, uniformity and robustness in leaf growth potentially increases the breadth of the leaves. The morphological changes in leaves, such as increased leaf area and breadth, can be influenced by the optimized delivery of essential elements. This was also reported by [7] in lettuce.

The presence of essential micro and macronutrients tends to produce healthier plants thereby producing higher vegetative growth. The influence of nano-fertilizers on the hormonal balance of the plants, particularly those of auxins and cytokinins boost hormonal production increasing the number of leaves. Similar findings were previously reported by [8] in green amaranthus. Increased photosynthesis and efficient nutrient use allow for more robust leaf growth which promotes an increase in biomass production. The delivery of nutrients at nanoscale enhances the absorption of nutrients by plants, which when dried results in higher dry weight. By improving the photosynthetic capacity of the

plant, nano fertilizers can boost carbon assimilation, leading to more dry matter accumulation [9]. The consistent nutrient supply from nano-fertilizers helps in the overall growth and development of the plant, including root, stem, and leaf biomass.

The total yield per plot was maximum in the treatment receiving 50% recommended dose of fertilizer along with 50% nano-fertilizers with 6.25 kg per plot. The increase in biomass, directly contributes to higher total yields per plot, as plants develop larger leaves and stems. This increased leaf production enhances the total yield per plot, as red amaranthus is harvested primarily for its leaves. By enhancing the nutrient status of the plant, nano-fertilizers improve photosynthetic rates, leading to more efficient energy conversion and growth. Increased photosynthesis supports greater biomass and higher yields. Similar results were reported by [10-12].

The highest values on total chlorophyll content index with 33.03 was observed in T₇. Higher nutrient efficiency supports the production of more chlorophyll molecules, thus improving the CCI. Nano fertilizers often include essential micronutrients that are directly involved in chlorophyll biosynthesis. For example, iron and magnesium are vital components of the chlorophyll molecule, and their enhanced uptake through nano-fertilizers can directly increase chlorophyll levels. Similar findings were previously reported by [13, 14].

Table 2: Effect of integrated nutrients on yield and physiology of red amaranthus

S. NO	TREATMENTS	Leaf length(cm)		Leaf breadth (cm)		Total number of leaves		Fresh weight (g)		Dry weight (g)		Chlorophyll Content Index (CCI)	Total Yield per Plot (kg/plot)
		15 DAS	30 DAS	15 DAS	30 DAS	15 DAS	30 DAS	15 DAS	30 DAS	15 DAS	30 DAS	30 DAS	30 DAS
1	T ₁ - 100% RDF	7.16	8.85	4.43	6.57	9.07	10.58	45.14	50.34	9.85	13.19	23.80	4.34
2	T ₂ - 100% vermicompost	5.82	6.85	2.86	3.50	8.30	9.68	28.23	31.67	7.34	7.61	26.10	3.45
3	T ₃ - 100% FYM	3.80	4.30	1.90	2.40	6.75	7.20	20.15	24.45	5.44	6.36	19.10	2.14
4	T ₄ - 100% nano fertilizers	4.08	4.38	2.70	2.90	7.60	9.30	37.53	41.89	9.38	11.31	28.30	3.24
5	T ₅ - 50% RDF + 50% vermicompost	6.45	7.84	3.86	5.75	9.82	11.39	52.25	58.07	11.51	15.22	20.10	4.52
6	T ₆ - 50% RDF + 50% FYM	7.88	9.89	5.01	7.40	10.53	12.30	59.86	65.80	15.16	17.18	29.70	5.43
7	T ₇ - 50% RDF + 50% nano fertilizers	8.60	11.50	5.90	8.30	11.30	13.15	67.70	73.50	16.90	19.11	33.03	6.25
	C. D	0.70	1.03	0.56	0.83	0.71	0.87	6.89	7.71	1.64	1.83	2.78	0.59
	S. ed	0.37	0.52	0.27	0.42	0.36	0.46	4.36	3.46	0.84	0.92	1.40	0.30

RDF – Recommended Dose of Fertilizer

Conclusion

The integrated application of 50% Recommended Dose of Fertilizers and 50% nano-fertilizers proved to be the optimal

nutrient management strategy for red amaranthus, outperforming sole chemical fertilization across growth, yield and chlorophyll indicators. By halving conventional

chemical fertilizer requirements through nano-enabled precision delivery, this approach improves plant physiological activity while reducing environmental nutrient losses. Integrating nano-fertilizers at a 50% replacement level presents a viable path towards sustainable leafy vegetable production, offering farmers improved crop performance with reduced synthetic inputs.

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