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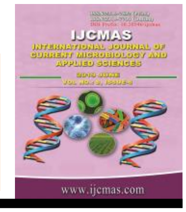

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Assessment of Carrot Response to Nutrient Management using an Nutrient Integrated Performance Index in Southern Telangana, India

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ABSTRACT

Integrated nutrient management (INM) influences carrot productivity through simultaneous effects on growth, yield, quality, and economic returns, making single-trait evaluation inadequate. The present study aimed to develop an Integrated Nutrient Management Performance Index (INMPI) for comprehensive assessment and ranking of INM treatments in carrot (Daucus carota L.) cv. Kuroda Improved under Southern Telangana conditions. Pooled mean data on growth, yield, quality, and economic parameters were standardized using Z-score normalization, and an index was constructed with weighted contribution of traits (growth 0.20, yield 0.40, quality 0.25, economics 0.15). INMPI values revealed clear differentiation among treatments. The integrated application of recommended dose of fertilizers combined with farmyard manure, vermicompost, and biofertilizers (T9) recorded the highest INMPI (1.55), followed by partial integration of organic manures (T8, 1.06). Treatments receiving sole nutrient sources recorded lower index values. The index-based approach provided a holistic, objective evaluation of INM practices, offering a practical tool for identifying superior nutrient management strategies for sustainable carrot production.

Introduction

Carrot (*Daucus carota* L.) is recognized as a significant root vegetable due to its high nutrient content, particularly carotenoids and various vitamins. Its cultivation is prevalent across temperate regions of India, where the soil and climatic conditions are conducive to optimal growth. Central to maximizing the growth, yield, quality, and economic viability of carrot production is effective nutrient management. Integrated Nutrient Management (INM) has emerged as a sustainable farming practice that synergistically combines inorganic fertilizers with organic manures and biofertilizers, thereby enhancing both crop productivity and soil fertility (Šink et al., 2017; El–Nasr & Ibrahim, 2011; Graham et al., 2017).

The conventional methods for evaluating the effectiveness of INM treatments in carrot often center on discrete parameters, such as yield or quality traits. However, the growth and productivity of crops like carrots are complex phenomena governed by a multitude of interrelated traits. A treatment that excels in one specific trait may not necessarily outperform others when evaluating a broader spectrum of characteristics. Hence, a composite approach is essential for a nuanced assessment of INM strategies, enabling a comprehensive overview of their effects on multiple growth dimensions Graham et al., 2017; Blaise et al., 2006; Kołodziej et al., 2015).

Composite indices have gained traction in agricultural research for their utility in condensing multidimensional traits into a singular quantitative measure. This facilitates a more straightforward comparison and ranking of different treatments or management practices. Although there is significant evidence supporting composite indices in various fields, there is a discernible gap in their application in evaluating INM practices specifically for carrots.

This inadequacy underlines the necessity for the current study, which aims to develop an Integrated Nutrient Management Performance Index (INMPI). Such an index would serve to both evaluate and rank INM treatments based on an integration of growth, yield, quality, and economic parameters, ultimately contributing to a more sustainable agricultural practice Graham et al., 2017; Balakrishnan et al., 2016; Kołodziej et al., 2015).

In summary, the relevance of developing a performance index specific to INM practices in carrot cultivation is underscored by the need for a holistic evaluation framework. By utilizing composite indices, the complexities inherent in agricultural productivity can be examined more holistically, ensuring that nutrient management practices not only enhance yield and quality but also maintain soil health and economic viability for farmers (Srinivasarao et al., 2012; El–Nasr & Ibrahim, 2011; Graham et al., 2017; Kołodziej et al., 2015).

Materials and Methods

Experimental site and treatments

Data were derived from a field experiment conducted during the rabi season of 2017–18 at the College of Horticulture, Mojerla, Sri Konda Laxman Telangana State Horticultural University. The experiment consisted of nine nutrient management treatments:

- T1 – RDF (NPK @ 50:40:50 kg ha^{-1})
- T2 – FYM 12 t ha^{-1}
- T3 – Vermicompost 6 t ha^{-1}
- T4 – Biofertilizers (AZB + PSB each 7 kg ha^{-1})
- T5 – 50% RDF + 50% FYM
- T6 – 50% RDF + 50% Vermicompost
- T7 – 50% RDF + 50% Biofertilizers
- T8 – 25% RDF + 50% FYM + 50% Vermicompost
- T9 – 25% RDF + 50% FYM + 50% Vermicompost + 50% Biofertilizers

Data on growth, yield, quality, and economics were collected.

Parameters used for index construction

Parameter category	Traits included	Nature of trait
Growth parameters	Plant height (cm), Number of leaves/plant, Fresh leaf weight (g)	Desirable
Yield parameters	Root length (cm), Root diameter (cm), Fresh root weight (g), Root yield (t ha^{-1})	Desirable
Quality parameters	TSS (%), Ascorbic acid (mg/100 g), Carotene (mg/100 g), Cortex : core ratio	Desirable
–	Root cracking (%), Root forking (%)	Undesirable
Economic parameter	Benefit:Cost ratio	Desirable

Data standardization and INMPI calculation

All parameters were standardized using Z-score normalization:

$$Z = \frac{X - \bar{X}}{SD}$$

Where:

- Z= Standardized value
- X= Observed value of a trait for a given treatment
- $\bar{X}$ = Mean value of desirable trait across all treatments
- SD = Standard deviation of that trait

Undesirable traits (root cracking and forking) were inverse-standardized:

$$Z = \frac{\bar{X} - X}{SD}$$

Where:

- Z= Standardized value
- X= Observed value of a trait for a given treatment
- $\bar{X}$ = Mean value of undesirable trait across all treatments
- SD = Standard deviation of that trait

Weights were assigned based on relative importance:

- Yield: 0.40
- Quality: 0.25
- Growth: 0.20
- Economics: 0.15

The **INMPI** was calculated as:

$$\text{INMPI} = 0.20(\overline{Z}_{growth}) + 0.40(\overline{Z}_{yield}) + 0.25(\overline{Z}_{quality}) + 0.15(Z_{BC})$$

Z = Mean **standardized Z-score**

Results and Discussion

This study assessed the impact of nine distinct nutrient management strategies on carrot (*Daucus carota* L.), emphasizing a comprehensive evaluation of growth, yield, quality, and economic performance through the Integrated Nutrient Management Performance Index (INMPI). The treatments spanned from sole applications of organic and chemical sources to various integrated combinations, reflecting real-world agricultural practices.

Vegetative Growth Performance

The results were recorded in Table 1indicated a pronounced sensitivity of plant growth to the nutrient sources applied. Treatment T9, which combined 25% Recommended Dose of Fertilizer (RDF), 50% farmyard manure (FYM), 50% vermicompost, and 50% biofertilizers, yielded the most vigorous growth metrics: a plant height of 53.50 cm, a leaf count averaging 16.40 per plant, and a fresh leaf biomass of 62.46 g. These findings are consistent with existing research that supports the benefits of integrated nutrient strategies in enhancing vegetative development (Ahmad et al., 2016; (Mohammed et al., 2018). In comparison, Treatment T8, which omitted biofertilizers, still benefited from the dual organic amendments, suggesting that organic inputs significantly contribute to growth even in reduced chemical scenarios. Conversely, sole applications (T2: FYM, T3: Vermicompost, T4: Biofertilizers) resulted in significantly stunted growth (38-49% less height than T9), underscoring the inadequacy of organic sources to meet the immediate nutrient needs of rapidly growing seedlings (Šink et al., 2017).

Root Yield and Component Analysis

Results were recorded in Table2.Confirming trends observed in vegetative growth, root yield parameters also reflected the nutrient sources' efficiency. Treatment T9 produced the highest root length (19.76 cm), diameter (3.96 cm), individual root weight (81.33 g), and yield of 18.60 t ha^{-1}. This yield was notably 29% greater than the conventional control (T1, 14.43 t ha^{-1}) and 147% greater than the lowest yield recorded in T2 (7.53 t ha^{-1}). Such findings corroborate the established link between nutrient management and root yield, affirming the critical role of balanced nutrient application in achieving optimal yield outcomes (Mohammed et al., 2018). The integrated nutrient strategies in T9 and T8 promoted effective photosynthesis and translocation of photosynthates, which aligns with previous studies highlighting the importance of balanced nutrient availability for root crops (Ahmad et al., 2016; Rani et al., 2017).

Root Quality and Economic Viability

Results were recorded in Table 3, The quality of the harvested roots varied significantly across treatments, affecting both nutritional characteristics and economic returns. Notably, Treatment T9 exhibited superior nutritional quality, characterized by the highest Total Soluble Solids (12.40%), ascorbic acid (5.33 mg/100g), and carotene content (4.73 mg/100g). These parameters are indicative of favorable health benefits associated with carrot consumption, as supported by research demonstrating the nutritional advantages of enhanced carotenoid content in organically managed crops (Šink et al., 2017).

Interestingly, the physical quality of roots also displayed disparities, with sole organic treatments exhibiting fewer defects, such as cracking and forking, highlighting the role of organic matter in enhancing soil structure and moisture retention (Potter et al., 2011). In terms of economic viability, Treatment T9 achieved the highest Benefit-Cost (B:C) ratio of 4.13, followed closely by T8 and T1, underscoring the profitability of integrated nutrient strategies despite their potentially higher initial costs. In contrast, the economically non-viable ratios associated with sole-source treatments (T2, T3) reinforce the necessity for integrated nutrient approaches to ensure sustainable production (Kumar & Pandita, 2015).

Integrated Performance Index (INMPI) and Ranking

Results were recorded in Table 4,5. The application of the INMPI allowed for a nuanced understanding of the treatments, ranking them according to a holistic assessment of growth, yield, quality, and economic returns. Treatment T9, with an INMPI value of 1.55, emerged as the superior strategy, reflecting its consistent performance across all measured parameters. Treatment T8 followed suit at 1.06, while the 50% RDF combinations clustered around a medium performance range.

Table.1 Growth traits of carrot (*Daucus carota* L.) under integrated nutrient management

Treatment	Plant height (cm)	Leaves/plant	Fresh leaf weight (g)
T1	45.43	13.50	51.66
T2	28.00	8.66	34.57
T3	35.00	10.33	39.00
T4	33.00	9.96	38.56
T5	39.33	11.86	43.33
T6	41.66	12.16	45.00
T7	40.00	12.00	44.66
T8	49.56	15.06	58.00
T9	53.50	16.40	62.46

Table.2 Yield traits of carrot (*Daucus carota* L.) under integrated nutrient management

Treatment	Root length (cm)	Root diameter (cm)	Root weight (g)	Root yield (t ha^{-1})
T1	17.50	3.73	74.23	14.43
T2	12.17	2.23	44.33	7.53
T3	14.00	2.66	53.33	9.43
T4	13.66	2.73	49.66	8.76
T5	15.66	3.16	62.66	12.00
T6	15.80	3.26	67.73	12.66
T7	15.73	3.20	64.33	12.33
T8	18.33	3.80	78.00	16.53
T9	19.76	3.96	81.33	18.60

Table.3 Quality traits and economic returns of carrot (*Daucus carota* L.) under integrated nutrient management

Treatment	TSS (%)	Ascorbic acid	Carotene	Root cracking (%)	Root forking (%)	B:C ratio
T1	9.10	2.93	3.57	7.17	8.00	3.95
T2	10.50	4.23	3.10	3.83	4.60	1.38
T3	10.53	4.50	3.30	5.57	3.70	1.34
T4	10.43	4.13	3.13	4.16	3.80	2.05
T5	9.80	3.60	4.10	6.57	7.26	2.95
T6	9.60	3.63	4.53	6.20	5.66	2.64
T7	9.30	3.33	3.67	6.43	6.50	3.26
T8	11.46	4.93	4.67	5.20	4.53	3.57
T9	12.40	5.33	4.73	4.63	4.03	4.13

Table.4 Integrated Nutrient Management Performance Index (INMPI) values and ranking of treatments in carrot (*Daucus carota* L.)

Treatment	Growth score	Yield score	Quality score	Economic score	INMPI value	Rank
T1	0.00	0.00	-0.87	0.31	0.31	III
T2	-1.66	-1.73	-0.12	-1.18	-1.18	IX
T3	-0.88	-1.02	-0.06	-1.23	-0.73	VIII
T4	-0.99	-1.04	0.15	-0.70	-0.70	VII
T5	-0.39	-0.33	-0.22	-0.18	-0.18	VI
T6	-0.23	-0.19	-0.06	-0.01	-0.01	IV
T7	-0.30	-0.24	-0.39	-0.12	-0.12	V
T8	0.88	0.66	0.76	1.06	1.06	II
T9	1.94	1.33	1.08	1.55	1.55	I

Table.5 Performance classification of nutrient management treatments based on Integrated Nutrient Management Performance Index (INMPI)

Performance category	INMPI range	Treatments
High performance	> Mean + SD	T9
Medium performance	Mean ± SD	T5, T6, T7, T8
Low performance	< Mean − SD	T1, T2, T3, T4

Conversely, the sole-source treatments and the control (T1-T4) were classified as low performers. This index effectively quantified the multifaceted trade-offs that can be obscured in simpler yield or economic analyses, offering a robust tool for future assessment of nutrient management strategies (Šink et al., 2017; Adesemoye et al., 2008; Zhang et al., 2011).

In Conclusion, the findings of this study provide compelling evidence that integrated nutrient management practices significantly enhance carrot production systems. Specifically, Treatment T9 (25% RDF + 50% FYM + 50% Vermicompost + 50% Biofertilizers) stands out as the most effective regimen, delivering remarkable yield (18.60 t ha^{-1}), nutritional quality, minimal physical defects, and optimal economic returns (B:C ratio 4.13). This strategy illustrates the synergistic benefits of combining chemical and organic inputs, facilitating not only an immediate nutrient supply but also promoting sustained soil health and productivity. Such outcomes highlight the critical need for adopting integrated nutrient management practices in sustainable agricultural systems, reinforcing the positive implications for both farmers and consumers.

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