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Influence of nutrient levels and bio-inoculants on growth parameters of Acid Lime (*Citrus aurantifolia* Swingle) cv. Kagzi under sandy loam soil conditions

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ABSTRACT

Organic manures and biofertilizers play a crucial role in improving soil physicochemical and biological properties, thereby enhancing the growth, yield, and quality of citrus crops (Khehra and Bal, 2016). The present study aimed to evaluate the combined effect of varying nutrient levels and bio-inoculants on the growth and physiological parameters of acid lime (*Citrus aurantifolia* Swingle) cv. Kagzi. The treatments comprised different doses of inorganic nutrients (100%, 75%, 50%, and 25% of the recommended dose of fertilizers, RDF) and organic sources, including vermicompost (5 kg/plant), Azotobacter + PSB (50 ml/plant), Biofertisol (200 ml/plant), and their various combinations. The experiment was conducted in a factorial randomized block design with three replications. Growth and morphological parameters were significantly influenced by nutrient management treatments. Vegetative growth improved progressively with increasing fertilizer levels and integrated nutrient applications. The application of 100% RDF (600:200:300 g NPK per plant) recorded highest plant growth, with maximum plant height (0.15 m), canopy spread (0.26 m East–West, 0.24 m North–South), shoot length (10.61 cm), and shoot diameter (5.79 mm). These results demonstrate that the integrated application of inorganic fertilizers and organic bio-inoculants exerts a synergistic effect, markedly enhancing vegetative growth. This integrated nutrient management strategy provides a sustainable and effective approach to improving the productivity and overall performance of acid lime.

KEYWORDS

Acid Lime, Canopy Spread, Inorganic Fertilizers, Bio-Inoculants, Azotobacter, Phosphorus Solubilizing Bacteria (PSB), Biofertisol

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Acid lime (*Citrus aurantifolia* Swingle) is a sub-tropical fruit crop that flowers three times a year, during January–February, June–July, and September–October. These flowering seasons are commonly known as Ambia bahar, Mrig bahar, and Hasta bahar, respectively. It is one of the most commercially important citrus crops and is widely cultivated in the tropical and sub-tropical regions of India. The fruits of acid lime are extensively used for preparing pickles and refreshing beverages, and are also processed into products such as syrup and squash. Acid lime belongs to the family Rutaceae. It is a rich source of vitamin C and contains about 6.3-6.6% citric acid. The crop is primarily cultivated for its multiple nutritional and medicinal benefits, which make it highly valuable among fruit crops. Its attractive appearance, distinctive and penetrating peel aroma, and excellent taste give acid lime a special place among fruits. As a result, it is widely cultivated across the world (Babu, 2001). Lime peel oil and peel powder are in high demand in the cosmetic industry.

Limes are considered nutritional powerhouses, as they are rich in vitamin C, antioxidants, and other essential nutrients. Their consumption may help strengthen the immune system, reduce the risk of heart disease, prevent kidney stones, regulate bilious disorders, enhance iron absorption, and promote healthy skin (Raman, 2019). In India, the production of acid lime was estimated at 3,548 million tonnes from an area of 327 million hectares, with an average productivity of 11 t/ha during 2020-21. In 2021-22, production was about 3,517 million tonnes from 322 million hectares, with an average productivity of 11.47 t/ha. In Madhya Pradesh, acid lime is cultivated over an area of 20.29 million hectares, with an annual production of 306.73 million tonnes and a productivity of 15.11 tonnes per hectare (Anonymous, 2021; Anonymous, 2022; National Horticulture Board, 2022).

At present, chemical fertilizers play an essential role in the nutrition of fruit crops. However, their excessive and indiscriminate use has led to serious environmental concerns, including soil degradation, water and air pollution, and negative impacts on animal and human health. Such practices have also adversely affected soil fertility, water quality, as well as the yield and quality of produce (Srivastava, 2012). Therefore, the use of organic manures and biofertilizers has gained significant importance in ensuring sustainable production and improving the physical, chemical, and biological properties of the soil. Organic manures and biofertilizers play a significant role in improving soil properties and enhancing the growth, yield, and quality of lemon fruits (Khehra and Bal, 2016). Organic manures, such as vermicompost, along with biofertilizers like Azotobacter, phosphorus-solubilizing bacteria (PSB), and biofertisol, serve as effective alternatives to reduce the excessive use of chemical. Soil microorganisms play a vital role in ecosystem processes, including nutrient cycling and maintaining ecological balance. They are involved in the decomposition of organic matter and contribute significantly to plant health and growth (Hadole *et al*., 2015).

Materials and Methods

The experiment was conducted at the Fruit Research Station, Imaliya, under the Department of Horticulture.

Chemical analysis of the fruits was carried out in the Post-Harvest Laboratory of the Department of Horticulture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.). The soil of the experimental site was medium black sandy loam with good drainage, uniform texture, and an average NPK status. It was sticky when wet and hard when dry. The region receives an average annual rainfall of 1,375 mm, mainly from the third week of June to mid-October due to the southwest monsoon. The mean maximum and minimum temperatures recorded were 46°C during summer and 10°C during winter, respectively. The average relative humidity reached up to 78%.

The experiment was laid out in a factorial randomized block design (RBD) with three replications and 24 treatment combinations. The treatments consisted of two factors: inorganic sources of nutrients (100%, 75%, 50%, and 25% recommended dose of fertilizers RDF of NPK) and organic sources of nutrients (vermicompost; *Azotobacter* + PSB; Biofertisol; vermicompost + *Azotobacter* + PSB; vermicompost + Biofertisol; and vermicompost + *Azotobacter* + PSB + Biofertisol). All treatments were applied as soil applications before flowering and fruit set, using soil drenching with 5 liters of water per plant. Four shoots in each direction were tagged to record growth parameters such as plant height (m), canopy spread (m) in East-West and North-South directions, and shoot length (cm). Standard orchard management practices were uniformly followed for all treatments. Data pooled over two years were analyzed using analysis of variance (ANOVA) appropriate for a factorial RBD. Treatment means were compared using the F-test at the 5% level of significance, and critical difference (CD at 5%) and standard error of mean (SEm±) were calculated as described by (Panse and Sukhatme, 1985).

Results and Discussion

The results showed that both individual and combined applications of inorganic fertilizers and organic bio-inoculants had a significant effect on the various growth parameters of acid lime (*Citrus aurantifolia* Swingle).

Table 1. Effect of nutrient levels and bio- inoculants on plant height, canopy spread, shoots length, shoot diameter

	Treatment Combination	Plant Height (m)	Canopy Spread (m)	Shoot Length (cm)	Shoot Diameter (mm)
			E-W	N-S	
T_1	100% RDF + vermicompost	0.12	0.19	0.16	8.71
T_2	100% RDF + Azotobacter + PSB	0.12	0.19	0.17	10.18
T_3	100% RDF + Biofertisol	0.14	0.21	0.22	10.39
T_4	100% RDF + vermicompost + Azotobacter + PSB	0.16	0.30	0.24	10.53
T_5	100% RDF + vermicompost + Biofertisol	0.17	0.31	0.29	11.56
T_6	100% RDF + vermicompost + Azotobacter + PSB+ Biofertisol	0.22	0.37	0.36	12.38
T_7	75% RDF + vermicompos	0.11	0.12	0.14	8.26
T_8	75% RDF + Azotobacter + PSB	0.12	0.14	0.16	8.85
T_9	75% RDF + Biofertisol	0.13	0.16	0.19	8.28
T_{10}	75% RDF + vermicompost + Azotobacter +PSB	0.15	0.21	0.21	9.20
T_{11}	75% RDF + vermicompost + Biofertisol	0.17	0.25	0.24	9.41
T_{12}	75% RDF + vermicompost + Azotobacter + PSB + Biofertisol	0.19	0.31	0.29	10.84
T_{13}	50% RDF + vermicompost	0.08	0.09	0.11	8.87
T_{14}	50% RDF + Azotobacter + PSB	0.1	0.11	0.14	8.73
T_{15}	50% RDF + Biofertisol	0.11	0.14	0.15	9.06
T_{16}	50% RDF + vermicompost + Azotobacter + PSB	0.13	0.17	0.19	8.70
T_{17}	50% RDF + vermicompost + Biofertisol	0.14	0.20	0.22	9.16
T_{18}	50% RDF + Vermicompost + Azotobacter + PSB +Biofertisol	0.16	0.25	0.26	9.64
T_{19}	25% RDF + vermicompost	0.07	0.07	0.10	8.81
T_{20}	25% RDF + Azotobacter + PSB	0.09	0.10	0.12	9.30
T_{21}	25% RDF + Biofertisol	0.10	0.12	0.15	9.19
T_{22}	25% RDF + vermicompost + Azotobacter + PSB	0.12	0.14	0.16	9.30
T_{23}	25% RDF + vermicompost + Biofertisol	0.13	0.18	0.18	9.71
T_{24}	25% RDF + Vermicompost + Azotobacter + PSB + Biofertisol	0.15	0.22	0.21	9.96
	SEm ±	0.005	0.007	0.006	0.12
	CD at 5%	0.015	0.021	0.017	0.342

Interaction between nutrient levels and bio-inoculants showed that the combination of 100% RDF + vermicompost + *Azotobacter* + PSB + Biofertisol was the most effective, resulting in the highest plant growth parameters: plant height of 0.22 m, canopy spread of 0.37 m (East-West) and 0.36 m (North-South), and shoot length of 12.38 cm. In contrast, the treatment with 25% RDF + vermicompost recorded the lowest values, with a plant height of 0.07 m, canopy spread of 0.07 m (East-West) and 0.10 m (North-South), and shoot length of 8.81 cm (table 1). The synergistic effect of these treatments likely promoted and enhanced plant growth. The positive impact of nitrogen is primarily due to its role in improving growth characteristics. Nitrogen, being a key component of fertilizers and a vital element in protein formation, is essential for the development of protoplasm, influencing cell division and elongation, which in turn increases vegetative growth. Higher nitrogen availability accelerates carbohydrate synthesis, which is subsequently converted into proteins and protoplasm, leading to cell enlargement. Additionally, plants treated with *Azotobacter*, a biological nitrogen-fixing bacterium, exhibit improved nitrogen use efficiency (Dutta *et al*., 2009). Moreover, potassium plays a vital role in regulating the permeability of cell membranes in acid lime, thereby helping to maintain cellular structure, while phosphorus is essential for energy transfer within the plant (Godage *et al*., 2013). Similar results were reported by (Trivedi *et al*., 2012 and Dudi *et al*., 2003) in kinnow mandarin.

The application of vermicompost, *Azotobacter*, PSB, and other bio-inoculants helps create favorable conditions for these beneficial microbes, which may enhance root development and nutrient uptake. This, in turn, promotes faster cell division and elongation, resulting in an increased plant canopy. The combined use of inorganic fertilizers, biofertilizers, and organic manures further supports plant height and canopy spread by improving the availability of NPK, organic carbon, microbial biomass, and dehydrogenase activity in the soil (Hazarika, 2011). Similar findings regarding the application of organic and inorganic nutrients along with biofertilizers have been reported by (Goramnagar *et al*., 2000) in Nagpur orange and by (Jagdish, 2021 and Priyanka *et al*., 2021) in acid lime. Although shoot diameter was not significantly affected, the maximum shoot length of 6.46 mm was observed in plants treated with 100% RDF + vermicompost + *Azotobacter* + PSB + Biofertisol. In contrast, the minimum shoot length of 4.80 mm was recorded in plants receiving 25% RDF + vermicompost + *Azotobacter* + PSB + Biofertisol, indicating the poorest performance.

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