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Integrated nutrient management in finger millet (*Eleusine coracana* (L.) Gaertn.): Implications for growth, yield, nutrient uptake and soil health: A review

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Abstract

Finger millet (*Eleusine coracana* (L.) Gaertn.) is an important small millet cultivated widely in semi-arid and rainfed regions of Asia and Africa. In India, it ranks third among millets in terms of cultivated area and production and plays a crucial role in ensuring food and nutritional security. Despite its resilience and nutritional superiority, finger millet productivity remains relatively low due to poor soil fertility and inadequate nutrient management practices. Integrated nutrient management (INM), which involves the combined use of organic manures, inorganic fertilizers, and beneficial microorganisms, has emerged as a sustainable strategy to enhance crop productivity while maintaining soil health. Organic manures such as farmyard manure and vermicompost improve soil physical properties, enhance microbial activity, and increase nutrient availability. Inorganic fertilizers provide readily available nutrients necessary for rapid crop growth and yield formation. Additionally, plant growth-promoting rhizobacteria (PGPR), including *Azospirillum*, phosphate-solubilizing bacteria, and potassium-solubilizing bacteria, play an important role in improving nutrient mobilization and plant growth through biological processes. Several studies have demonstrated that integrated application of organic and inorganic nutrient sources significantly improves growth parameters, yield attributes, nutrient uptake, soil fertility, and economic returns in finger millet cultivation. This review summarizes current research findings on the influence of organic manures, inorganic fertilizers, and integrated nutrient management practices on growth, yield, nutrient uptake, soil fertility, and profitability of finger millet production systems. The findings emphasize that integrated nutrient management is a sustainable approach for improving productivity and maintaining long-term soil health in finger millet-based rainfed agroecosystems.

Keywords: Finger millet, integrated nutrient management, organic manures, farmyard manure, vermicompost, PGPR, nutrient uptake, soil fertility, sustainable agriculture, millets

Introduction

Finger millet (*Eleusine coracana* (L.) Gaertn.) is an important small millet widely cultivated in semi-arid and rainfed regions of Asia and Africa. In India, it ranks third among millets in terms of both cultivated area (about 2 million ha) and production (1.98 million tonnes), after sorghum and pearl millet (Anon., 2014) [3]. The crop is well known for its exceptional adaptability to adverse environmental conditions, particularly its ability to grow in soils with poor fertility and limited water-holding capacity. Because of its resilience to drought and climatic variability, finger millet is considered one of the most reliable crops for rainfed agriculture.

In addition to its agronomic advantages, finger millet is recognized for its superior nutritional quality. The grains are rich in carbohydrates and proteins and are particularly valued for their high calcium and iron content. Compared with other cereals, finger millet contains significantly higher levels of dietary fibre and essential minerals, making it an important component of balanced diets. The crop serves as a staple food for millions of people in India and Africa, particularly among resource-poor populations. Owing to its low glycaemic index and high fibre content, finger millet is also considered beneficial for individuals suffering from diabetes and other lifestyle-related health disorders. Consequently, the crop plays an important role in ensuring food and nutritional security and is increasingly recognized as a climate-resilient crop suitable for future agricultural systems (Anon., 2014; FAO, 2023) [3, 10].

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India is the largest producer of finger millet globally, with major cultivation concentrated in states such as Karnataka, Tamil Nadu, Andhra Pradesh, Odisha, Jharkhand, Maharashtra, and Uttarakhand. Among these states, Karnataka accounts for the largest share of the total cultivated area and production. The crop occupies nearly 1.3 million hectares in the state, representing approximately 54% of the national area under finger millet, and contributes about 60% of the country's total production with an average productivity of around 1325 kg ha⁻¹ (Anon., 2014) [3]. Within Karnataka, finger millet is predominantly cultivated under rainfed conditions in districts such as Bengaluru, Kolar, Tumakuru, Mysuru, Hassan, Mandya, and Chitradurga. Despite its importance in these regions, productivity levels remain relatively low compared with its genetic yield potential.

One of the major reasons for the low productivity of finger millet is inadequate nutrient management. The crop is frequently grown on marginal and less fertile lands where soil fertility levels are inherently low. In many farming systems, fertile lands are allocated to high-value crops such as rice, maize, groundnut, sorghum, and pigeon pea, while finger millet is relegated to poorer soils with minimal external inputs. Consequently, the crop often receives limited attention in terms of fertilizer application and agronomic management practices. In several cases, farmers apply only a basal dose of fertilizers, such as diammonium phosphate (DAP), at the time of sowing, whereas some farmers rely solely on locally available organic manures. Such practices result in suboptimal nutrient availability and consequently restrict crop growth and yield.

Efficient nutrient management is therefore essential for enhancing productivity and sustaining soil fertility in finger millet-based production systems. A high degree of synchronization between nutrient release from soil and plant nutrient demand is necessary for efficient nutrient utilization. Maintaining adequate levels of soil organic matter plays a critical role in this process because it improves soil structure, enhances water-holding capacity, and supports microbial activity. Soil microorganisms are fundamental to nutrient cycling and mineralization processes; however, their activity depends largely on the availability of organic substrates in the soil. Organic matter thus functions as both a reservoir of nutrients and a medium that facilitates efficient nutrient utilization by crops.

Traditionally, farmyard manure has been the most commonly used organic nutrient source in Indian agriculture. However, its availability has declined in recent decades due to several factors, including a reduction in livestock population, alternative uses of cattle dung, and increased demand for organic inputs in high-value cropping systems. Similarly, other organic manures such as sheep, poultry, and goat manure are often limited in supply and are insufficient to meet the nutrient requirements of crops. Under these circumstances, there is an increasing need to explore alternative organic nutrient sources and promote on-farm composting practices to supplement nutrient supply.

Organic manures are known to improve soil fertility and crop productivity by increasing soil organic carbon, enhancing microbial activity, and improving nutrient availability. However, due to their relatively low nutrient concentration, large quantities of organic manures are required to meet the nutrient demands of crops. On the other hand, excessive reliance on chemical fertilizers without the addition of organic inputs may adversely affect the physical, chemical, and biological properties of soil, leading to a gradual decline in soil fertility and productivity. Therefore, the integration of organic and inorganic nutrient

sources has been widely recommended as an effective strategy for maintaining soil health and improving crop productivity.

Under rainfed farming conditions, farmyard manure often remains the primary organic nutrient source available to farmers. In addition, locally available farm residues and organic wastes can be utilized for compost preparation. Vermicomposting, for example, provides an efficient method for converting organic wastes into nutrient-rich manure through the activity of earthworms. Agricultural residues such as coconut fronds and other farm wastes can also be composted to produce valuable organic amendments. These practices not only improve soil fertility but also reduce production costs, generate rural employment, and promote sustainable agricultural systems.

In recent years, considerable attention has been given to the use of plant growth-promoting rhizobacteria (PGPR) in sustainable crop production. PGPR are beneficial microorganisms that colonize plant roots and stimulate plant growth through various mechanisms. These include biological nitrogen fixation, solubilization of phosphorus and potassium, production of plant growth-promoting substances, and suppression of soil-borne pathogens in the rhizosphere (Mishra *et al.*, 2005) [20]. Root-colonizing bacteria that exert beneficial effects on plant development through such mechanisms are collectively referred to as plant growth-promoting rhizobacteria (Kloepper and Schroth, 1980) [17]. Numerous studies have reported significant improvements in crop growth, nutrient uptake, and yield following inoculation with PGPR.

In this context, the integration of organic nutrient sources such as farmyard manure, vermicompost, and frond compost with microbial consortia comprising plant growth-promoting rhizobacteria (*e.g.*, *Azospirillum*, phosphate-solubilizing bacteria, and potassium-solubilizing bacteria) has considerable potential to enhance soil fertility, nutrient availability, and crop productivity in finger millet-based systems. Such integrated nutrient management strategies are increasingly recognized as sustainable approaches for improving productivity while maintaining soil health and ecological stability in rainfed agroecosystems.

Review of Literature

Organic Manures and Their Influence on Growth and Yield of Finger Millet: Organic manures have long been recognized as a crucial component of sustainable agriculture due to their ability to improve soil structure, enhance microbial activity, and provide essential nutrients for plant growth. Farmyard manure (FYM), one of the most widely used organic inputs in India, consists of decomposed animal dung, urine, bedding materials, and crop residues. According to Gaur (1982) [12], FYM supplies essential nutrients such as nitrogen, phosphorus, sulphur, and micronutrients through microbial decomposition, thereby improving soil fertility and biological activity.

Several studies have demonstrated the beneficial effects of FYM on crop productivity. For instance, Chatterjee *et al.* (1979) [7] and Sharma and Mithra (1989) [33] reported significant increases in grain and straw yield of rice with FYM application compared with control treatments. Similar responses were observed in finger millet cultivation. Chellumuthu and Kodandaraman (1980) [8] reported that application of FYM at 7 t ha⁻¹ significantly enhanced grain yield of finger millet grown on black soils of Coimbatore. Long-term experiments conducted at GKVK, Bangalore showed that continuous application of FYM at 10 t ha⁻¹ produced yields comparable to those obtained with recommended chemical fertilizers after ten years of cultivation (Parvathappa *et al.*, 1988) [26].

Mani (1991)^[19] further demonstrated that FYM application at 10 t ha⁻¹ produced grain yields comparable to those obtained with recommended NPK fertilizers in sandy loam soils, while also increasing the number of fingers per ear head. Enrichment of FYM with rock phosphate and phosphate-solubilizing microorganisms further improved crop productivity, resulting in significantly higher grain yields compared with untreated FYM (Nayak, 1993)^[23]. Similarly, Singh (1994)^[34] reported significant improvements in plant height and tiller number with FYM application.

Vermicompost has also been widely studied as a nutrient-rich organic amendment. It contains considerable amounts of organic carbon, nitrogen, phosphorus, potassium, and beneficial microorganisms that enhance nutrient availability (Rajkhowa *et al.*, 2000; Srikanth *et al.*, 2000)^[29, 35]. Vermicompost is known to contain growth-promoting substances and microbial populations capable of nitrogen fixation and phosphorus solubilization (Sudha and Chandini, 2003)^[37]. Several researchers have reported improved growth and yield of crops following vermicompost application. For example, Godhawale and Dahipale (2007)^[13] observed higher grain yield of rice with vermicompost application compared with untreated control plots.

Overall, the literature consistently indicates that organic manures such as FYM and vermicompost enhance crop growth and productivity by improving soil fertility, increasing nutrient availability, and stimulating microbial activity.

Influence of Inorganic Fertilizers on Growth and Yield of Finger Millet

Inorganic fertilizers are essential for providing readily available nutrients required for rapid plant growth and development. Among the major nutrients, nitrogen plays a particularly critical role in determining crop productivity by promoting vegetative growth and increasing biomass accumulation.

Early studies indicated that phosphorus application enhances plant height in finger millet by improving nitrogen uptake and promoting vegetative growth (Ramaiah *et al.*, 1970)^[30]. Subramanian *et al.* (1971)^[36] reported that nitrogen application at 60 kg ha⁻¹ significantly increased plant height and the number of ear-bearing tillers compared with control treatments. Similar observations were made by Krishnamurthy (1973)^[18], who reported increased grain yield and yield attributes with increasing nitrogen levels up to 90 kg ha⁻¹.

Nitrogen fertilization also influences dry matter accumulation and yield components. Puttaswamy and Krishnamurthy (1975)^[27] found that nitrogen levels of 75-125 kg ha⁻¹ enhanced dry matter production in finger millet, particularly during the heading and grain-filling stages. Similarly, Pandusastry (1977)^[24] reported significant increases in dry matter accumulation with higher nitrogen levels.

Phosphorus and potassium fertilizers also contribute to yield improvement. Kadrakar and Bhosale (1981)^[14] observed significant increases in grain yield with phosphorus application at 50 kg ha⁻¹ compared with control treatments. In addition, Reddy *et al.* (1986)^[32] reported that nitrogen fertilization improved productive tillers, finger number per ear head, thousand-grain weight, and grain yield.

These findings collectively highlight the importance of balanced fertilization in achieving optimal growth and productivity of finger millet.

Integrated Use of Organic and Inorganic Nutrient Sources

The integrated application of organic and inorganic nutrient

sources has been widely recognized as an effective strategy for improving crop productivity while maintaining soil health. Studies have shown that combining organic manures with chemical fertilizers enhances nutrient availability, improves soil physical properties, and increases crop yield.

Ramaiah *et al.* (1970)^[30] reported that application of FYM along with nitrogen, phosphorus, and potassium fertilizers significantly increased finger millet grain yield compared with fertilizer application alone. Similarly, Chellumuthu and Kodandaraman (1980)^[8] observed higher grain yield when FYM was applied in combination with nitrogen fertilizer.

Long-term experiments have demonstrated the sustainability benefits of integrated nutrient management. For instance, experiments conducted at Bangalore revealed that the application of FYM along with recommended NPK fertilizers increased mean yields by approximately 11% compared with chemical fertilizers alone (Anon., 1996)^[4]. Basavaraj and Rao (1997)^[6] also reported higher grain yield with combined application of FYM and chemical fertilizers compared with recommended NPK alone.

Integrated nutrient management has also been shown to enhance root development and nutrient uptake. Paramesh *et al.* (2013)^[25] reported that combined application of chemical fertilizers and vermicompost significantly increased root length, root weight, and nutrient uptake in finger millet.

These results suggest that integrated nutrient management practices improve both crop productivity and soil sustainability.

Nutrient Uptake by Finger Millet under Different Nutrient Management Practices

Nutrient uptake is a critical factor influencing crop growth and yield. Organic manures improve nutrient uptake by enhancing soil microbial activity and increasing nutrient availability.

Dayananda *et al.* (1977)^[9] reported that FYM application increased nitrogen, phosphorus, and potassium uptake in finger millet compared with untreated plots. Similarly, Anil Kumar (2000)^[2] found significantly higher uptake of N, P, and K in treatments receiving compost compared with control.

Inorganic fertilizers also influence nutrient uptake patterns. Khatri and Mehta (1962)^[16] observed that nitrogen accumulation occurs throughout the growth stages of finger millet, whereas phosphorus uptake is highest between pre-flowering and milking stages. Increasing nitrogen levels have also been shown to enhance uptake of N, P, and K in both grain and straw (Muthuswamy, 1985)^[22].

When organic and inorganic nutrient sources are applied together, nutrient uptake increases significantly. Kavalappa (1989)^[15] reported higher N, P, and K uptake in treatments receiving FYM along with recommended NPK fertilizers compared with fertilizer alone. Similar findings were reported by Ravindra Singh and Agarwal (2004)^[31], who observed increased nutrient uptake with integrated nutrient management practices.

Effect of Nutrient Management on Soil Fertility

Organic manures contribute significantly to the improvement of soil fertility by increasing soil organic carbon, enhancing microbial activity, and improving nutrient availability.

Studies have shown that continuous application of FYM increases available nitrogen, phosphorus, and potassium in soil (Parvathappa *et al.*, 1988; Gajanana *et al.*, 2000)^[26, 11]. In addition, FYM application improves soil physical properties and promotes microbial activity, leading to enhanced nutrient mineralization (Muthuvel *et al.*, 1990)^[21].

Integrated nutrient management practices further enhance soil fertility. For example, Kavalappa (1989) ^[15] reported significantly higher available N, P, and K levels in soils receiving FYM along with recommended NPK fertilizers compared with chemical fertilizers alone. Long-term experiments also indicate that combined application of FYM and fertilizers maintains soil fertility and sustains crop productivity over extended periods.

Role of Plant Growth Promoting Rhizobacteria (PGPR)

Plant growth promoting rhizobacteria (PGPR) play an important role in improving crop productivity by enhancing nutrient availability and stimulating plant growth. These microorganisms facilitate biological nitrogen fixation, phosphorus solubilization, and production of growth-promoting substances.

Azospirillum species have been widely studied for their beneficial effects on cereal crops. Agarwal and Tilak (1988) ^[1] reported successful colonization of *Azospirillum* in the roots of finger millet. Similarly, studies have shown that phosphate-solubilizing bacteria improve phosphorus availability in soil (Bagyaraj *et al.*, 2000) ^[5].

Application of PGPR in combination with organic manures and fertilizers has been shown to improve crop yield and nutrient uptake. Rajesh *et al.* (2013) ^[28] reported increased grain yield and nutrient uptake in rice when biofertilizers were integrated with organic and inorganic nutrient sources.

Economic Implications of Integrated Nutrient Management

Economic viability is a critical factor in determining the adoption of nutrient management practices by farmers. Several studies have shown that integrated nutrient management practices improve profitability in crop production.

Basavaraj and Rao (1997) ^[6] reported higher net income and benefit-cost ratio in finger millet cultivation with combined application of FYM and chemical fertilizers compared with fertilizers alone. Similarly, Anil Kumar (2000) ^[2] observed higher gross returns and benefit-cost ratio with the application of compost along with recommended fertilizer doses.

Although organic inputs may increase the cost of cultivation, the resulting improvements in crop yield and soil fertility often lead to higher net returns and sustainable production systems.

Future Research Perspectives

Although several studies have demonstrated the benefits of integrated nutrient management in finger millet cultivation, further research is needed to optimize nutrient management strategies under diverse agro-climatic conditions. Future research should focus on developing location-specific nutrient management practices that efficiently combine organic, inorganic, and biological nutrient sources. There is also a need to explore the potential of newer biofertilizer strains and microbial consortia that can enhance nutrient availability and improve soil microbial diversity.

In addition, greater emphasis should be placed on recycling agricultural residues and farm wastes for compost production to reduce dependency on chemical fertilizers. Advances in precision agriculture and soil nutrient diagnostics can also help improve nutrient use efficiency in finger millet production systems. Furthermore, long-term experiments are necessary to evaluate the sustainability of integrated nutrient management practices and their impact on soil health, carbon sequestration, and climate resilience. Such research will contribute significantly to the development of sustainable nutrient management strategies for finger millet-based cropping systems.

Conclusion

Finger millet is an important climate-resilient crop that plays a significant role in ensuring food and nutritional security in rainfed agricultural regions. However, its productivity is often limited by poor soil fertility and inadequate nutrient management practices. The findings from various studies reviewed in this article indicate that organic manures such as farmyard manure and vermicompost improve soil structure, increase soil organic carbon, enhance microbial activity, and promote nutrient availability, thereby contributing to improved crop growth and yield.

Inorganic fertilizers supply readily available nutrients essential for rapid crop growth and development; however, their continuous and exclusive use may adversely affect soil health over time. Integrated nutrient management practices, involving the combined use of organic manures, chemical fertilizers, and biofertilizers such as plant growth-promoting rhizobacteria, have been shown to improve nutrient uptake, enhance yield attributes, and sustain soil fertility in finger millet cultivation. Moreover, integrated nutrient management practices contribute to higher economic returns and improved benefit-cost ratios compared with the sole application of chemical fertilizers.

Therefore, adoption of integrated nutrient management strategies is essential for achieving sustainable finger millet production, particularly in rainfed agroecosystems. Such approaches not only improve crop productivity but also ensure long-term soil health and environmental sustainability.

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