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Tharapureddi Bhargavi
Department of Agronomy, Agricultural College, ANGRAU, Andhra Pradesh, India

Manikyala Bhargava Narasimha Yadav
Department of Soil Science and Agricultural Chemistry, UAS, Dharwad, Andhra Pradesh, India

Polagani Nagarjuna
Department of Agronomy, Agricultural College, ANGRAU, Andhra Pradesh, India

Corresponding Author
Tharapureddi Bhargavi
Department of Agronomy, Agricultural College, ANGRAU, Andhra Pradesh, India

A review on integrated nutrient management practices for enhancing productivity in pearl millet

Tharapureddi Bhargavi, Manikyala Bhargava Narasimha Yadav and Polagani Nagarjuna

Abstract
Pearl millet is a main dual purpose crop, its grain used for human consumption while the fodder used for livestock, have a ability to withstand high temperatures outperforms all other cereals, making it a climate resilient crop. Due to inadequate soil fertility and a lack of appropriate soil nutrient replenishment techniques, along with irregular rainfall patterns, the average yield of pearl millet is low when compared to its potential yields. Poor economic conditions of the farmers in the arid regions prevent them to use costly fertilizers. Moreover, continuous and sole use of chemical fertilizers has resulted in numerous problems so integrated nutrient management help in resolving these concerns, which has been proposed as a promising strategy for addressing such challenges Balanced use of organic, inorganic and biofertilizers is essential to maintain a good soil physical and chemical environment and also serve as energy source for the soil microbial biomass. This review examines the concepts, objectives, principles of INM. A comprehensive literature search revealed that INM enhances growth and yield of pearl millet and improves soil fertility.

Keywords: Climate resilient, chemical fertilizers, INM, biofertilizers

Introduction
Pearl millet (*Pennisetum glaucum* [L.] R.Br.) is the most important coarse grain crop native to Africa, belongs to the Gramineae (poaceae) family and is mostly grown semi-arid to arid zones where soils predominately have sandy textures, low organic matter and nutrient levels; rainfall is limited and erratic; air and soil temperatures are high; and the growing season length is short and varies greatly across years (Manson *et al*., 2015) [1]. Pearl millet outperforms all other cereals, allowing it to tolerate temperatures as high as 42 degrees Celsius during the reproductive stage and making it a climate-resilient crop also known as bajra, bulrush millet, spiked millet and poor man's crop. Because the grain is used for human consumption and the fodder is used for livestock feeding, it is an important component of the agricultural and animal husbandry-dominated rural economy of India's dryland areas (Bijarnia *et al.*, 2020) [2]. Being cultivated as dual purpose crop it provides food, fodder and fuel and nutritionally superior to many cereals because it is a rich source of proteins (11%), carbohydrates (69.4%), fats (5%), moisture (12.2%), fiber (2%), minerals (2.3%) and has higher digestibility. After rice, wheat, maize and sorghum, pearl millet is India's fifth most important multipurpose grain, and it is a staple diet for millions of people living in dry areas. India is the leading producer of pearl millet both in terms of area (7.48 million hectares) and production (9.09 million tonnes) with an average productivity of 1231 kg ha^{-1} (www.indiastat.com, 2017-18). More than 95% of bajra production is used as food and rest is being used as cattle feed and other uses (seed, bakery products, snacks, etc.). Pearl millet is mainly cultivated in Rajasthan (46%), Maharashtra (19%), Gujarat (11%), Uttar Pradesh (8%) and Haryana (6%).
The majority of pearl millet growing areas in India are rainfed. The average yield of pearl millet is low when compared to its potential yields due to poor soil fertility and erratic rainfall patterns (Suzuki *et al.*, 2017) [3]. The lack of appropriate soil nutrient replenishment interventions and an inherent low soil organic matter status are the main reasons of soil fertility loss. Mineral fertiliser has been promoted as a viable soil fertility remedy that could result in higher crop yields. Combining mineral fertilizer with organic resources, according to Thumar *et al.* (2016) [4], could be an effective strategy for boosting soil fertility and crop output while using less resources. A ton of pearl millet grain output can remove 26.6 kg N, 9.4 kg P and 32.6 kg K from the soil, in addition to nutrient losses during the cropping season (Khairwal *et al.*, 2007) [5]. One of the causes for such a large gap in pearl millet could be a lack

of critical minerals. As a result, production without fertilizer application occurs at the expense of soil stored nutrient levels, resulting in a low yield. This needs the incorporation of organic manures, which serve as a reservoir of nutrients (both macro and micro) for boosting pearl millet's long-term productivity. Using organic fertilizers in combination with chemical fertilizers had a stronger beneficial effect on microbial biomass and consequently soil health, according to Dutta *et al.* (2003) [6], than using organic fertilizers alone. Integrated nutrient management has been shown to be useful in not only maintaining productivity but also enhancing soil microbial load and hence stabilizing agricultural production. Farmers are unable to use costly fertilizers due to weak economic situations and irregular rainfall in dryland areas. Furthermore, the continued and exclusive use of chemical fertilizers has resulted in a slew of issues, including micronutrient deficiency, nutritional imbalances in soil and plant systems, pest infestations, environmental degradation, and soil health deterioration (Kumar *et al.*, 2012) [7]. Therefore, for dryland areas, combining inorganic and organic fertilizers may be more advantageous than using them alone. Since ancient times, various organic plant materials such as farmyard manure (FYM), oil cakes, pressmud cake, vermicompost, green manure, and legumes as intercrops have been investigated for usage as nutrition sources.

Integrated Nutrient Management and its Concept

Primarily, INM refers to blending old and new nutrient management approaches into an environmentally sound and economically optimal agricultural system that judiciously, efficiently, and interestedly utilizes the benefits of all conceivable sources of organic, inorganic, and biological elements. It optimizes all aspects of nutrient cycle, including N, P, K, and other macro- and micronutrient inputs and outputs, with the goal of coordinating crop nutrient demand and environmental release.

Objectives of INM

The objectives of integrated nutrient management

- To increase nutrients availability to the plants from all sources in the soil during growing season.
- To minimize reduce the inorganic fertilizer requirement.
- To match the nutrients demand by the crop and supply nutrients from all sources.
- To optimize functioning of the soil biosphere.
- To reduce nutrient loss in to environment through volatilization, denitrification, surface runoff and leaching.

Need of INM

- Decline in crop productivity due to decrease in effective nutrient supply.
- Poor utilization of nutrients by crop.
- Accelerated appearances of micronutrient deficiencies associated with more N fertilizer use.
- Decline in soil organic matter associated with continuous application of chemical fertilizer.
- Changing land use pattern from the forest ecosystem to agro ecosystem is responsible for depletion in SOM, impoverishment of soil fertility.

Components of INM

The major components of integrated nutrient management are

- Integration of fertility restoring crops like green manures, legumes etc.
- Crop residues recycling.
- Use of organic manures like FYM, vermicompost, compost, biogas, poultry manure, bio-compost, press mud cakes.
- Use of Bio fertilizers.
- Balanced use of fertilizer as per crop requirement and target yields.

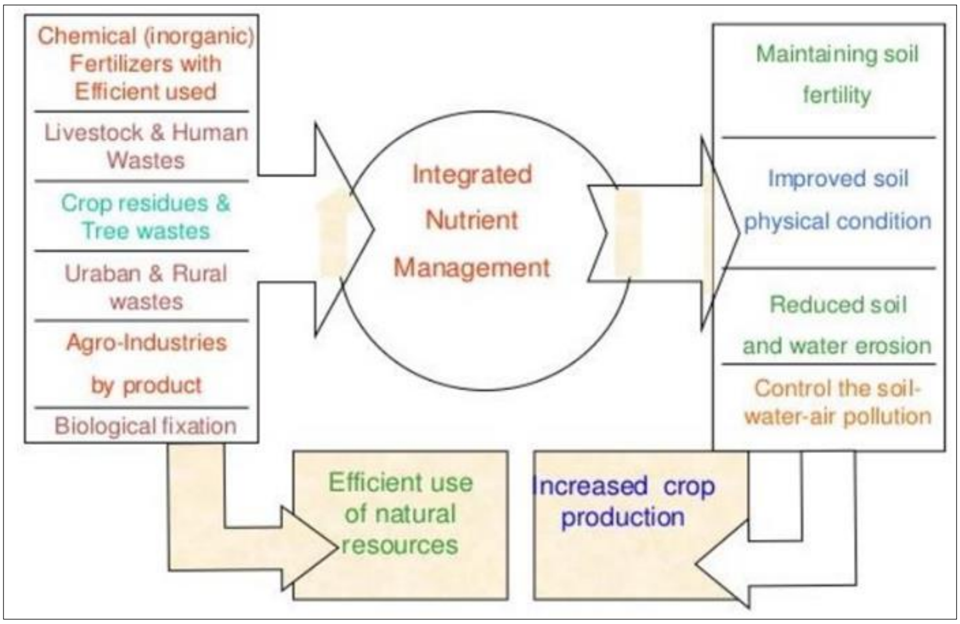

Fig 1: Schematic representation of the resources of INM and their role in soil productivity (Joy *et al.*, 2018) [8]

Effecting of INM on growth of pearl millet

Vegetative growth is a vital factor that determines the productivity. Nitrogen (N), phosphorus (P) and potassium (K) are considered as primary nutrients and are very important for the growth and development. Nitrogen is responsible for vegetative growth, improving the leaf area index, chlorophyll synthesis, increasing photosynthesis and assimilating production in plants. Phosphorus is known for its role in root growth, root development, and reproduction. Potassium, though not a constituent of organic structures of plants, is very important for plant strength, resistance to biotic and abiotic stresses, and stomatal activity. Many research workers have reported that imbalance use of chemical fertilizers affects the crop productivity.

Bijarnia *et al*. (2020) [2] from Jalore observed a marked improvement in growth attributes (Tabla 1) *i.e*., plant height and tillers per plant due to addition of FYM and biofertilizers in recommended dose of fertilizers. 5 t FYM + 100% of RDF recorded significantly taller plants over control, 100% of RDF, 5 t FYM + 50% of RDF, 5 t FYM + 75% of RDF. They also observed that the treatment 5 t FYM +100% of RDF remained on par with 5 t FYM + 50% RDF + biofertilizer and 5 t FYM + 75% RDF + biofertilizer which indicated that the nutrient supplying capacity of the biofertilizers was not to the extent being added by 50% RDF and 75% RDF. Similar results were investigated by Saharan *et al.* (2017) [9] who revealed that application of FYM and biofertilizers in combination with 100% RDF resulted in significantly higher growth parameters.

Table 1: Effect of integrated nutrient management on plant height and tillers per plant of Pearl millet

Treatments	Plant height (cm)	Tillers per plant (no.)
Control	115.3	3.49
100% of RDF	129.0	3.90
5 t FYM + 50% RDF	126.0	3.81
5 t FYM + 75% RDF	132.0	3.98
5 t FYM + 100% RDF	149.0	4.52
5 t FYM + 50% RDF + Biofertilizers	140.0	4.21
5 t FYM + 75% RDF + Biofertilizer	143.3	4.29
SEm±	3.8	0.14
CD (p=0.05)	11.7	0.45

Abdullahi *et al.* (2014) [10] investigated the effect of biofertilizers in combination with poultry manure or cow dung and conclude that combination of biofertilizer with poultry manure produced plants with highest growth biometrics *i.e*., plant height, no of tillers per plant, shoots and root biomass which was due increased availability of energy source to microbes through organics and in turn increased the biological activity and availability of nitrogen, P mobilization and growth promoting hormones. Similarly positive growth response in pearl millet to biofertilizer treatment compared to inorganic chemicals was observed by Galbiatti *et al.,* 2011 [11]. Integrated application of FYM at the rate of 10 t ha^{-1} along with inorganic fertilizers (100% NPK + Zn + S ha^{-1} recorded significantly higher growth parameters than the application of chemical fertilizer alone which was due to due to increased efficiency of applied chemical fertilizers by organic manures (Kumar *et al*., 2014) [12]. Application of FYM @ 10 t ha^{-1} along with 75% of the RDF gave higher plant height at all growth stages in fodder bajra than the application of 100% RDF without organics (Lattief, 2011) [13]. In another study, Choudhary *et al*. (2014) [14] reported that the plant height and tillers per metre row length was increased successively with increasing dose of vermicompost and RDF to pearl millet which was due to supply of essential plant nutrients by vermicompost besides improving soil physical and biological properties. Bana *et al.* (2016) [15] in an experiment at New Delhi for three years under rainfed conditions observed that application of leaf compost @ 10 t ha^{-1} resulted in improved plant growth, dry matter accumulation followed by FYM @ 10 t ha^{-1}, leaf compost mixed cow dung compost (10 t ha^{-1}) and 100% RDF, respectively.

Effecting of INM on yield attributes and yield of pearl millet

The yield components of pearl millet are the number of ear heads per unit area, number grains per earhead, weight of earhead which are positively associated with grain yield. From the study Narolia *et al*. (2009) [16] reported that with increasing the levels of vermicompost from 0 to 2 tones ha^{-1} have progressively increased the yield attributes in pearl millet and found that drilling of 2 t ha^{-1} vermicompost was found more effective than the incorporation. Vermicompost manuring when drilled at higher rate of 2 t ha^{-1} recorded higher increased effective tillers, ear length, seeds per ear and test weight over control by 33.4, 29.4, 28.8 and 8.4%. Improvement in grain yield may be due to increased yield attributes like earheads m^{-2}, earhead weight, earhead length and test weight coupled with the higher crop drymatter observed with these treatments due to increased availability of nitrogen to plant through inorganic nitrogen source initially and then by organic manures like vermicompost and FYM during the later stages of crop which corresponds to the need of crop throughout the growing season by slow mineralization of nutrients, mainly nitrogen from organic source may be the most probable reason of higher grain yield.

Kathuria *et al*. (2003) [17] have also reported the similar results who have shown significant improvement in yield attributes due to vermicompost application in pearl millet. While Kugedera and Kokerai (2019) [18] from their experiment in Zimbabwe conclude that grain yields of pearl millet were higher with application of cattle manure and ammonium nitrate @ 562 kg ha^{-1} for first harvest and 620 kg ha^{-1} for second harvest showing a superiority over other treatments and the Gateri *et al.* (2011) [19] found that cattle manure increased pearl millet yields by providing plant essential nutrients and increasing the soil‘s capacity to hold those nutrients and also by improving soil physical properties such as the water holding capacity and infiltration rates. From a two year study on pearl millet and wheat crop sequence at Bichpuri, Agra the study indicated superiority of 100% NPK + FYM at 10 t ha^{-1} + 25 kg S ha^{-1} + $ZnSO_4$ at 25 kg ha^{-1} on grain yield of pearl millet and wheat (Shrivastava *et al*., 2015) [20]. Higher values of yield attributes (ear length, ear growth, test weight *etc*.) in pearl millet was reported with combined application of inorganic fertilizers and FYM or green manure recorded over NPK levels alone by Singh and Chauhan (2016) [21] (Table 2).

Table 2: Effect of integrated nutrient management on yield attributing characters of pearl millet

Treatments	Effective tillers per plant	Ear length (cm)	Ear girth (cm)	Ear weight (g)	Weight of grain per ear	1000 grain weight (g)
T_1 Control	1.3	24.9	12.7	25.2	24.4	11.6
T_2 50% NPK	1.4	26.7	13.5	26.7	25.4	11.9
T_3 75% NPK	1.5	27.2	13.8	27.5	26.9	12.1
T_4 100% NPK	1.9	28.3	14.0	30.0	28.9	13.5
T_5 50% NPK + 8t FYM ha^{-1}	1.5	28.4	13.3	27.0	25.0	12.2
T_6 75% NPK + 4t FYM ha^{-1}	1.9	29.0	14.6	29.5	27.6	12.0
T_7 50% NPK + 5.5 t GM ha^{-1}	1.6	27.8	13.1	27.3	24.8	12.8
T_8 75% NPK + 2.75 t GM ha^{-1}	1.9	28.8	14.7	30.0	28.0	13.2
T_9 FFP (40 kg N ha^{-1})	1.5	24.9	12.3	27.2	24.8	11.7
CD (P=0.05)	0.5	3.7	1.6	8.5	11.5	2.2

In another study significantly the higher number of effective tillers $plant^{-1}$ (4.13), earhead length (24.99 cm), earhead girth (3.20 cm) and test weight (9.76 g) was observed with the integrated treatment RDF (120-60-00 NPK kg ha^{-1}) + FYM 2.5 t ha^{-1} + *Azotobacter* + PSB and the higher grain and stover yield was also recorded with the similar treatment. This might be due to the fact that the fertilizer increases nutrient availability whereas FYM improves the soil-physical properties, and also the availability of NPK, which promoted plant growth and development and resulting in yield increase of pearl millet. Use of bio-fertilizer (*Azotobacter* + PSB) led to higher availability of N and P as well as promoted the root growth, which is promoted yield attributes characters (Thumar *et al.*, 2016) [4]. Similar results were reported by the Parihar *et al.* (2010) [22] who concluded that integrated nutrient management of 50% RDF + 6 t FYM to pearl millet recorded higher yield of both crops in pearl millet - mustard sequence over individual applications from a two years study conducted at New Delhi.

Higher yield attributes and yield of pearl millet *viz*., number of effective tillers, number of grains per ear and test weight, grain yield and stover yield were recorded with application of vermicompost @ 2.5 t/ha + ½ RDF, poultry manure @ 2 t/ha + ½ RDF and FYM @ 6 t/ha + ½ RDF as compared to other treatments. Due to release of macro and micro nutrients under favorable environment might have helped in higher uptake of nutrients (Togas *et al*., 2017) [23]. Khambalkar *et al.* (2012) [24] conducted at a long term field experiment on integrated nutrient management (INM) was initiated during *kharif* season 1997 at Gwalior under pearl millet - mustard cropping sequence. The treatment 100% NPK + Farmyard manure @ 10t ha^{-1} + *Azotobacter* + PSB provided highest yield of straw (8.60 t ha^{-1} and 6.79 t ha^{-1}) and grain (4.07 t ha^{-1} and 2.34 t ha^{-1}) in pearl millet and mustard respectively. They found that continuous application of organic manure combined with an optimal fertilizer dose improved crop productivity and soil fertility, and that seed inoculants (*Azotobacter* and PSB), FYM in combination with chemical fertilizers, and FYM in combination with other fertility combinations showed positive influx of N, P, and K over unfertilized control and other fertility combinations.

Effecting of integrating organic manures on soil nutrient status in pearl millet

In the arid and semi-arid regions of the tropics and subtropics, soil organic carbon (C) is a limiting factor and also poor physical properties thus the retention capacity of nutrients is low, especially N. Therefore, improvement of the soil carbon pool through different organic manures helps to improve soil fertility and sustain yields. Basumatary and Talukdar (1998) [25] indicated that continuous application of chemical fertilizer alone decreased the pH, organic carbon, cation exchange capacity and available N content of soil, whereas an improvement over initial value resulted under integrated treatments receiving both inorganic and organic sources of fertilizer. Based on 6 years long-term experiment in pearl millet–wheat cropping system Moharana *et al.*, (2012) [26] found that continuous application of FYM, alone or in combination with NPK, resulted in significantly higher total SOC buildup in the 0-15 cm soil layer than unfertilized control plots. TOC in surface soil were in the order of FYM > FYM + NPK (11.08 g kg^{-1}) > NPK > unfertilized control, increase in TOC in FYM and FYM + NPK treatments in surface layer was 52.5 and 47.1% over unfertilized control, while they were 35.0 and 30.3% greater over NPK treatment, respectively (Fig 2) and concluded that for long-term crop production and soil quality, organic manure, such as FYM, is critical and should be promoted in the nutrient management of intensive cropping systems to improve soil fertility and biological characteristics. Tolanur and Badanur (2003) [27] found that applying 50% N through organic manure and 50% RDF to a pearl millet-pigeonpea cropping system enhanced soil organic carbon content, accessible N, P and K contents.

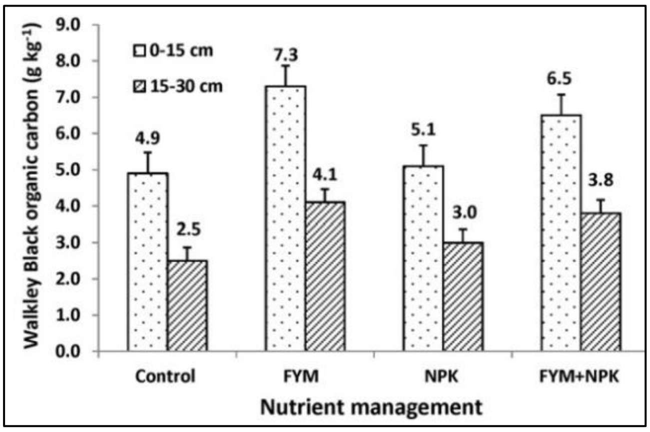

Fig 2: Effect of integrated nutrient management on soil organic carbon

Continuous application of organic manure in combination with an optimal fertilizer dose (100 percent NPK+FYM @10t ha^{-1}) improved crop productivity and soil fertility. Over the unfertilized control and other fertility combinations, treatments receiving seed inoculants (*Azotobacter* and PSB), and FYM in combination with chemical fertilizers, exhibited positive influx of N, P and K. (Khambalkar *et al*., 2012) [24]. It was found that application of 50% RDN through poultry manure and 50% RDN through inorganic fertilizer recorded highest N, P, K status in the soil which was due to the presence of high N, P & K contents in the poultry manure compared to other organic manures whereas higher organic carbon content in the soil was observed with integrated application of FYM, Vermicompost and Poultry manure (Choudhary *et al*., 2011) [28]. The beneficial effect of FYM on OC was a due to high amount of residue in it, high OC content by PM was due to higher litter content in it and in vermicompost due to release of earthworms which have make the soil porous and increased decomposition of the residues.

Conclusion
Integrated nutrient management holds great promise in meeting the growing nutrient demands of pearl millet and maintaining productivity at higher levels with overall improvement of soil health. Balanced use of organic, inorganic and biofertilizers is essential to maintain a good soil physical and chemical environment and also serve as energy source for the soil microbial biomass. Therefore, integrated nutrient management practices are well suited but need to be quantified either 25 or 50 per cent on equivalent basis.

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