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Agronomic Interventions for Optimizing Productivity in Millets: A Review

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ABSTRACT

Climate-resilient crops are pivotal in guaranteeing food security in the face of climate change. Millets can effectively adjust to the prevailing climatic conditions in a specific geographic area. Millets offer a range of benefits that make them a valuable component of sustainable and resilient agricultural systems. The factors that can harm millet productivity and crop yields include delayed sowings, using low yielding crop varieties, poor plant population, cultivating crops on nutrient deficient soils without fertilizers, unprofitable farming systems, weed infestation and insufficient protective irrigation. To optimize the productivity of millets some agronomic interventions are necessary. For productivity enhancement of millets, modified land configuration techniques will address the soil related problems. An ideal crop geometry ensures the establishment of a healthy and uniform stand in the main field. Development of low-cost input technologies such as microdosing, balance fertilisation will be necessary for productivity optimisation. Soil test based balanced nutrition by applying organic nutrient sources along with NPK and micronutrients will enhance the productivity over the application of only fertilizers. Optimum irrigation and integrated weed management help to improve millet productivity. Millets can assure agricultural sustainability in drylands under intercropping system. Intercropping millet with various pulses and oilseeds offers a significant opportunity to make the most efficient use of land and other resources. This diversification can enhance agricultural productivity and better address the needs of a growing population.

Key words: Climate-resilient, Diversification, Millets, Productivity, Sustainability.

To address the food security of future generation, it is necessary to develop a climate resilient food system across the world. Millet plays a pivotal role in the millet diversification and resilience of farming system for addressing the climate variability (Sukanya *et al.,* 2022).

Millets are important crops that are commonly consumed by low-income families in both Africa and Asia (ICRISAT, 2018). Various types of minor millets can effectively adjust to the prevailing climate locality. Among millets, major millets were sorghum and bajra; others classified under small millets (Maitra, 2020).

India is the lead producer of millets accounting 80% of Asia's and 20% of the world production (FAO, 2021). Among millets, pearl millet has the highest area of cultivation followed by sorghum and finger millet. Area of millet production enhances to 12.29 in 2013-14 to 15.48 million hectares in 2021-2022.

Millets have less water requirement compared to other cereal crop like rice and wheat. Millets capture carbon and thereby decrease the burden of greenhouse emission (NAAS, 2013). Consequently, they are often regarded as climate-smart crops (Maitra *et al.,* 2020).

Due to their early maturity, millets were exceptionally well-suited for contingency crop planning and farming systems. Major staple foods will decline due to rising temperatures and an increase in the frequency of extreme climate events, such as heat waves, which are observed in many parts of the world. Grain from millets can withstand temperatures as high as 42°C. Furthermore, some pearl millet can withstand temperatures as high as 64° (ICRISAT, 2022). The climate and soil requirement range of different millets are shown in Table 1.

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When it comes to nutrient availability, millets are shown to be more cost effective than cereals (Sai and Meera, 2023). We should incorporate millets into our diets because of their higher nutrient content. It is enhancing blood lipid profile, blood glucose clearance and gastrointestinal health (Divya and Garg, 2024). Millets are beneficial for the prevention and treatment of diabetes because they are devoid of gluten, high in protein and antioxidants and have a low glycaemic index. Finger millet has three times the calcium content of milk, while pearl millet is a great source of iron (ICRISAT, 2018). Foxtail millet has excellent gulabjamun-making potential and highly appealing sensory attributes (Sahana *et al.,* 2024).

Louhar *et al.* (2020) stated that in India, the cultivation of millets has seen a notable decline over the past four to five decades. This decline can be attributed to two primary factors: The relatively low productivity of these crops and the limited economic returns, which have hindered their widespread adoption. It is necessary to develop and implement better genotypes as well as better management techniques in order to increase productivity (Dubey *et al.,* 2023).

Agronomic constraints in millet production include delayed sowings, lack of availability of high yielding varieties, poor plant population, grown on poor soils without any fertilizers, non-profitable cropping systems, Weed infestation: With regard to sorghum, pearl millet and finger millet, uncontrolled weed infestation considerably lowers crop output by 15 to 83%, 16 to 94% and 55 to 61%, respectively, depending on crop cultivars, weed infestation type and severity, management techniques and environmental factors (Mishra *et al.,* 2014) and lack of protective irrigation: Insufficient water levels have a detrimental impact on pearl millet growth throughout its various developmental stages, affecting both its physical characteristics and biochemical processes (Murty *et al.,* 2007).

Agronomic interventions for optimising productivity in millets

To optimize the productivity of millets the following agronomic interventions are necessary.

Sowing window

Productivity can be enhanced by sowing high yielding varieties and appropriate planting time and establishment techniques.

Srikanya *et al.* (2020) reported that cultivation of foxtail millet varieties SiA 3085 and SiA 3156 resulted in higher productivity and these varieties were found to be most suitable when sown before or on August 30th as part of a contingency cropping strategy. Gavit *et al.* (2017) revealed that when proso millet was sown in the 25th meteorological week, the grain output was at highest and was noticeably higher than in the 23rd and 27th meteorological weeks. Compared to the other establishing strategies used by local practice, proso millet transplanting achieved a maximum and noticeably greater grain and straw output.

Transplanting at 20 × 15 cm along with application of 100 kg N ha^{-1}, which should be increased by equal split at transplanting and 30 and 60 days after transplanting resulted in higher productivity in *kharif* season in the south Konkan region of Maharashtra (Chavan *et al.,* 2017).

Crop geometry plays a pivotal role in achieving increased production by optimizing resource utilization and consequently enhancing the production of photosynthates. An ideal crop geometry ensures the establishment of a robust and uniform stand in the plot leading to higher productivity. Ragi can be successfully cultivated in sandy loam soils of South Odisha and to achieve higher productivity and enhance nutrient uptake by the crop, it is advisable to use a plant geometry of 25 cm × 25 cm and transplanting 3-week-old seedlings (Kumar *et al.,* 2019).

Nandini and Sridhara (2019) observed that the combination of a 20 cm × 10 cm spacing with the SIA 2644 genotype of foxtail millet yielded the higher growth and, yield and quality attributes.

Seed priming increases yield and physiological quality of millets. Iswariya *et al.* (2019) reported using of bio primed seeds with Azophos+ *Pseudomonas fluroscens* @ 20% for 8h had a beneficial effect on biochemical, physiological and quality characters.

Nutrient management

Integrated approach to nutrient management is a key aspect of sustainable and productive agriculture (Meena *et al.,* 2017). The application of organic nutrient sources in conjunction with optimal NPK and micronutrient fertilisers, in line with the principles of integrated nutrient management approach, balances nutrition and boosts millet output

Table 1: Climatic and edaphic conditions suitable for different millets.

Millets	Climate	Soil
Finger millet	Tropical and subtropical climate Altitude: 2100 m above MSL. Mean temperature: 26-29°C	The best soil is alluvial, loamy and sandy soil with good drainage.
Foxtail millet	Tropical and subtropical climate Altitude: 2100 m above MSL. Mean temperature: 26-29°C	Best soils are Alluvial, loamy and sandy loamy soil with good drainage.
Little millet	Grown in tropical, subtropical and even in temperate areas Altitude: 2000 m above MSL. It can withstand both drought and water logging. Average rainfall: 30-50 cm.	Grown on all types of soil with proper drainage. However, crop prefers well fertile loamy textured soils.
Proso millet	It is highly drought resistant and can be grown in areas where there is a scanty rainfall.	Grown both in heavy and poor soils but well drained loam or sandy loam soils.
Kodo Millet	Grown in warm and dry climate. Annual rainfall: 40 to 50 cm.	Loamy fertile soils rich in organic matter with good drainage are preferred.

(Sukanya *et al.,* 2022).

compared to the application of fertilisers alone (Louhar *et al.,* 2020).

In places with adequate rainfall and moisture availability, 50% of the necessary nitrogen should be applied at the time of sowing, with the remaining 50% applied in two equal splits at 25-30 and 40-45 days after sowing (Pavankumar *et al.,* 2021).

Thumar *et al.* (2016) concluded that significantly improved growth and yield attributes were obtained by applying FYM at a rate of 2.5 t ha^{-1}, together with balanced fertiliser dose of 120 kg N + 60 kg P_2O_5 ha^{-1} and inoculating seeds with Azotobacter and phosphorus-solubilizing bacteria.

Gafoor (2021) revealed that integrating organics with inorganics was observed to improve the nutritional quality of finger millet. Considering the yield and comparable economics, 75% RDN application as inorganic in conjunction with 25% RDN as vermicompost on nitrogen equivalent basis, supplemented with PGPR Mix-I (talc-based formulation at 30 kg ha^{-1} in three split application (basal, 15 DAS, 30 DAS) could be recommended for the cultivation of finger millet during the summer season in southern Kerala.

Application of 40 kg N ha^{-1} and 20 kg K_2O ha^{-1} produced significantly more grain and straw yield in little millet as compared to 20 kg N ha^{-1} and 0 kg K_2O ha^{-1}, respectively Charate *et al.* (2018). Application of FYM @ 6 t ha^{-1} + NPK 60:30:20 kg ha^{-1} resulted higher productivity of foxtail millet (Ojah *et al.,* 2018).

According to Namade *et al.* (2017), the integrated approach was more effective than the inorganic one. The best practices for attaining the highest growth and yield attributes for individual crops as well as the entire cropping system were found to be applying 75% RDN through inorganic fertiliser + 25% RDN through FYM, treating seeds with PSB + Azospirillum for kharif sorghum and growing rabi chickpea without the recommended fertiliser dosage.

Irrigation management

Millets need less water than wheat and rice, they are regarded as drought-tolerant crops (Sukanya *et al.,* 2022). Pre-flowering, post-flowering and grain-filling stages were the key periods in millet cultivation, when two to three light irrigations should be applied due to reduced water requirements (Aruna *et al.,* 2023). Improved moisture use efficiency was observed when irrigation was applied solely during the flowering stage in sorghum and bajra (Nazma *et al.,* 2019).

The implementation of moisture conservation techniques, such as altering land configuration with ridge and furrow cultivation, using plastic mulching and applying seed hardening with 0.02% KNO_3, resulted in significant increases in pearl millet grain yield by 22.21%, 48.82% and 10.50%, respectively (Kanwar *et al.,* 2015).

According to Shubham *et al.* (2018), summer pearl millet output increased considerably when irrigation was applied at 100 mm CPE. The best benefit-cost ratio and net return were obtained when hybrid Proagro 9444 was planted with irrigation set at 100 mm CPE.

Utilizing less saline water consistently and then transitioning to more saline water after 65 days post-sowing enhances water efficiency and lowers leaf temperature in millet crops (de. CÓ *et al.,* 2023).

Weed management

During the wet season, weeds provide a significant challenge to improving millets' yield. According to Dubey and Mishra (2023), millets are not as a good competitor for weeds in the early phases of crop growth. Managing weeds appropriately would increase output and input use efficiency. Combined chemical and mechanical approaches result in more effective weed control (Pradhan *et al.,* 2024).

After seeding, millets often reach a critical period of 15- 42 days. During early phase, millet crops are infested by a variety of weeds, including broad-leaved, sedge and grasses (Dubey *et al.,* 2023). For millets, application of atrazine or isoproturon @ 1.0 kg *a.i.* ha^{-1} as pre-emergent spray is effective. Broadleaved weeds can be effectively controlled by using 2, 4-D Na salt (80%) at 1.0 kg *a.i.* ha^{-1} 20-25 days after sowing as post emergence (Pavankumar *et al.,* 2021).

Dubey and Mishra (2023) listed different weed management options such as prevention stale seed bed, row spacing, mulching, legume intercropping, intercultural operations by weeding and use of herbicides. Mathukia *et al.* (2015) reported that pearl millet intercropping with black gram and green gram leads to a significant reduction in weed population and biomass. One row of bajra followed by three rows of groundnuts not only suppresses weeds effectively but also maximizes the benefits of intercropping.

Cultivating pearl millet under conservation tillage (ZT+R) with either two manual -weeding at 30 and 50 DAS or atrazine at 0.75 kg/ha PE fb 2,4-D at 0.75 kg/ha PoE was found to be an energy-efficient and eco-friendly approach for achieving optimizing productivity under rainfed conditions (Chinyo *et al.,* 2023).

For increased yield and net return from finger millet intercropped in coconut gardens, the optimum weed control strategy could be to use pyrazosulfuron ethyl 20 g ha^{-1} as a pre-emergent on the day of sowing and then wheel hoe weed at 25 DAS (Sneha, 2022).

The highest net returns and benefit-cost ratios were obtained from the pre-emergence application of atrazine at 0.5 kg ha^{-1} and one-hand weeding at 35 DAS, or post-emergence treatment of atrazine at 0.4 kg ha^{-1} and one-hand weeding at 35 DAS (Girase *et al.,* 2017).

Ramadevi *et al.* (2021) reported that two hand weedings at 20 and 40 days after transplanting (DAT) produced decreased biomass and weed density with higher grain yield, benefit-cost ratio and weed control efficiency. Among post-emergence herbicides, penoxsulam 20 g ha^{-1} produced a greater grain yield and benefit-cost ratio while controlling broad-spectrum weeds.

Striga is a root parasite which parasitizes millets like sorghum, pearl millet and finger millet. The application of (N 92 kg) and cattle manure (20 t h^{-1}) gave the highest (1.23 t) grain and (13.49 t h^{-1}) biomass with the lowest striga counts (Woldemariam *et al.,* 2021).

Millet based cropping system

We can ensure agricultural sustainability in drylands through the use of intercropping systems, with millets which are vital to the food and nutritional security of our nation (Maitra, 2020). Intercropping millet with various pulses and oilseeds offers a significant opportunity to make the most efficient use of land and other resources. This diversified approach can enhance agricultural productivity and better address the needs of a growing population (Meena *et al.,* 2017).

According to Sammauria *et al.* (2020), groundnut-wheat cluster bean-rabi onion and pearl millet-wheat-cluster-bean-barley were the most productive, sustainable, resource-efficient and profitable cropping systems in the semi-arid plain zone of Rajasthan, India.

Cereal-legume based cropping systems treated with micro doses of N and P could be used for sustainable means of soil fertility and the productivity of low-inputs cropping systems (Bado *et al.,* 2022).

Intercropping cowpea in ragi [*Eleusine coracana* (L.) Gaertn] inoculated with AMF in the ratio 4:1, produced higher crop equivalent yield and economics (Reddy, 2020).

Intercropping of finger millet with black gram, groundnut and soybean recorded significantly higher finger millet equivalent yield at 4:2 ratio than sole finger millet (Kumar and Ray, 2020). Gautam *et al.* (2022) stated that in the Indo-Gangetic plains of India, the pearl millet-wheat farming system is the second most significant after the rice-wheat cropping system.

CONCLUSION

A series of agronomic interventions, such as modified land configuration, optimizing the sowing windows, using improved high-yielding varieties, adjusting plant geometry, balanced nutrition, integrated weed management, protective irrigation at critical stages and diversified cropping system approach can enhance the productivity of millets. When these agronomic interventions are applied appropriately, they contribute to increased productivity and the sustainability of millet cultivation. In order to promote millets as a crucial part of the food basket, the International year of millets offers a special chance to boost worldwide production, guarantee effective processing and consumption, encourage better crop rotation utilisation and foster improved connectivity throughout food systems.

Conflict of interest

All authors declared that there is no conflict of interest.

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