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Agronomic Management of Foxtail millet (*Setaria italica* L.) in India for Production Sustainability: A Review

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ABSTRACT

Since ancient period, different small millets are in use as food and animal feed. But during last few decades, fine cereals and their value-added products were promoted in India and millets were neglected. Recently, small millets are recognized as nutri-cereals due to their nutritional values. These crops are ecologically sound, can enrich agro-diversity, check erosion in arid regions, sequester carbon and assure food and nutritional security to smallholders in drylands. But productivity of small millets is less compared to other cereals. Like other small millets, foxtail millet (*Setaria italica* L.) is also rich in nutrients and as a short duration crop it fits to different cropping systems. Sufficient research work has not been carried out on agronomic management targeting higher productivity. An initiative has been taken to gather information from available literature on improved agronomic management of foxtail millet and presented in the article. Further, the article highlighted the future scope of research on the crop.

Keywords: Foxtail millet, agronomic management, varieties, nutrient management, cropping system, sustainability, drylands

Millets are ancient grains used as food, feed and forage since the Neolithic age. Among different millets, pearl millet (*Pennisetum glaucum* L.) and sorghum (*Sorghum bicolor* L.) are known as major millets and rest are grouped into small millets. India is the leading country in small millets production with acreage of around 7.0 lakh ha and productivity of 633 kg ha^{-1} (Maitra and Shankar, 2019). The small millets are cultivated as mainly rainfed in uplands of arid and semi-arid regions with sub-optimum level of management (Maitra *et al.* 1997; 1998). In India, after green revolution main focus was given on production of fine cereals, namely, rice and wheat and millets became neglected grains. Further, urbanization, increase of income and change of food habit also made millets as poor-man's food. But during recent time, millets have regained their lost pride due to re-evaluation of nutritional qualities (Maitra, 2020). Small millets are rich in protein, energy, dietary fibre and having neutraceutical properties (Banerjee and Maitra, 2020). Moreover, small millets are known as miracle-crops because of their multiple uses. Presently, agriculture is facing tremendous problem due to climate change and global warming. The main effects of climate change are increase in temperature, uncertainties in rainfall and enhancement of greenhouse gasses emission (mainly carbon-dioxide). As C_4 plants, millets can use enhanced atmospheric CO_2 and convert into biomass (Brahmachari *et al*. 2018). Millets are the ecologically sound crops which can withstand

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under warm and drought conditions with low carbon footprint in agriculture and hence these are considered as climate-smart crops.

Among different small millets, foxtail millet (*Setaria italica* L.) has the heritage of Asian origin and was domesticated in central China during ancient period (Miller *et al*. 2016). Like other millets it belongs to *Poaceae* family and a member of the subfamily *Panicoideae*. Foxtail millet is nutrient rich and each 100 g of edible portion contains fibre2.4g,protein 12.3g,carbohydrates 60.9g, fat 4.3g,calcium 31mg,iron 2.8mg,phosphorus 290mg, minerals 3.3g and food energy 331 KCal (Vanithasri *et al*. 2012; Banerjee and Maitra, 2020).Foxtail millet is mainly cultivated in dry regions of India as rainfed crop as the crop shows great tolerance under drought conditions. In India, the cultivation of foxtail millet is confined southern states, namely, to Andhra Pradesh, Karnataka, Tamil Nadu and Telengana, also to some extent grown in Bihar, Uttar Pradesh and Uttarakhand. The average productivity of small millets including foxtail millets is less, but presently improved varieties have been developed which are having enough potential. Choice of improved varieties and proper agronomic management are key concerns to maximize productivity of foxtail millet and research in the line of agronomic management may be intensified. In the present article, an initiative has been taken to review the agronomic management practices based on available literature for boosting yield of foxtail millet.

Improved varieties and uniform stand establishment

Foxtail millet can be grown in tropics as well as in temperate regions. But in India, it is cultivated in drylands of tropics in marginal lands mainly under rainfed conditions as it has tolerance to moisture stress. Generally, small and marginal farmers cultivate local varieties of foxtail millet with sub-optimal level of management and inferior plant stand. Stand establishment is important to obtain satisfactory yield and it is dependent on sowing of quality seeds at optimum spacing and uniform germination. There are some state specific improved varieties in India which can be cultivated for better productivity (Table 1).

The field experiments conducted at different locations clearly indicated that improved varieties of foxtail millet yielded more than the average productivity of small millets. Navya Jyothi *et al*. (2016) observed that the foxtail varieties SiA 3088, SiA 3085, SiA 3156 and Srilaxmi produced grain yield of 1001 to 1141 kg ha^{-1} under rainfed conditions in *kharif* season at Tirupati, Andhra Pradesh. In another experiment at Naira, Andhra Pradesh, Ramyasri *et al*. (2018) observed that the variety SiA 3156 yielded more (1290 kg ha^{-1}) than other two varieties, namely, SiA 3085 and SiA 3088 during *rabi* season. Foxtail millet variety SiA 2644 performed better than HMT-1 and local varieties in red sandy clay soil of southern transition zone of Karnataka during kharif season (Nandini and Sridhara, 2019a). But at Prayag, Uttar Pradesh, the variety SiA 326 (Prasad) gave more yields in *kharif* season than SiA 3156 in sandy loam soil (Selectstar Marwein *et al*. 2019).

Foxtail millet is generally cultivated as *kharif* crop and before onset of monsoon preparatory tillage is made. After onset of monsoon, field is harrowed or ploughed and seeds are sown. The resource poor farmers usually broadcast the seeds (15 kg ha^{-1}), but line sowing is always preferred as less seeds are required (810 kg ha^{-1}) and optimum

Table 1: Foxtail millet varieties cultivated in different states of India

State	Vatieties of foxtail millet
Andhra Pradesh	SiA 2644, SiA 3085, SiA 3088, SiA 3156, SiA 3085, Lepakshi, SiA 326, Narasimharaya, Krishnadevaraya, PS-4, Srilaxmi
Karnataka	SiA 326, HMT 100-1, PS 4,Narasimharaya, SiA 3088, SiA 3156, SiA 3085, DHFt-109-3
Tamil Nadu	TNAU 43, TNAU-186, TNAU 196, CO 1, CO 2, CO 4, CO 5, K2, K3, SiA 3088, SiA 3156, SiA 3085, PS-4
Rajasthan	PrathapKangani (SR 1) and SR 51, SR 11, SR 16, SiA 3085, SiA3088, SiA-3156, PS 4
Uttar Pradesh	PRK 1 and PS 4, SiA 326 (PRASAD), SiA 3156, SiA 3088, SiA 3085, Sreelaxmi, Narasimharaya, S-114, PS-4
Uttarakhand	PS 4 and PRK 1, Sreelaxmi, SiA 326, SiA 3088, SiA 3156, SiA 3085, PS 4
Bihar	RAU-1, SiA 3088, SiA 3156, SiA 3085, PS 4

Source: *Chapke et al. (2018) and others.*

stand establishment can be obtained. In case of line sowing, a row to row of 25–30 cm and within row between plants 8–10 cm distance is maintained (Chapke *et al*. 2018). But Nandini and Sridhara (2019a) in a study obtained more grain yield of foxtail millet with a spacing of 20 cm × 10 cm in Karnataka which was probably due to more plant stand. In an experiment, using tractor drawn seed drill for line sowing gave higher grain yield (55 %) compared to farmers practice (AICRPSM, 2017).

In Andhra Pradesh and Maharashtra, foxtail millet is sown between first and third week of July. But in Uttar Pradesh and Bihar sowing starts from mid-June. However, in Karnataka, June– August is considered as sowing period for foxtail millet. In Tamil Nadu two crops are grown, *kharif* crop is sown in June–July, whereas summer irrigated crop is seeded in January. In general during *rabi* season foxtail millet is sown during September–October. Experimental results revealed that sowing time has a great impact on productivity of foxtail millet. Mubeena *et al.* (2019) recorded that sowing of foxtail millet during second fortnight of June and first fortnight of July yielded more than the crop sown during second fortnight of July or first fortnight of August in black soils of Raichur, Karnataka. Similarly, Nandini and Sridhara (2019b) also noted the crop sown on June 30 found to produce significantly more grain yield (2049.25 kg ha^{-1}) and straw yield (4261.56 kg ha^{-1}) as compared to July 30 and August 30 sown foxtail millet in an experiment carried out at Shivamogga, Karnataka.

Seed priming

In dry regions, seed priming with growth regulating chemicals and bio-inoculants is effective for seedling vigour, growth and productivity as noted in small millets (Maitra *et al*. 1999). Gangadharayya *et al.* (2019) observed that seed priming in foxtail millet was effective in terms of growth and productivity of foxtail millet as they observed that seed priming with *Azospirillum* (20 %) + *Pseudomonas fluorescens* (20 %) + Phosphobacter (20 %) + Zn SO_4 (0.1 %) + Boron (0.1 %) recorded enhancement of growth and productivity of foxtail millet during *kharif* season. In the study hydro-priming was also yielded more than without priming (1610 and 1480 kg ha^{-1} respectively).

Nutrient management

Foxtail millet is cultivated in India in resource-poor soils and best agronomic management is not provided. But improved varieties of foxtail millet respond well to fertilizers. To obtain good productivity as well as to maintain soil health, adoption of Integrated Nutrient Management (INM) is advised. In general, application of 5 to 10 t FYM and 40 kg N, 20 kg P_2O_5 and 20 kg K_2O is recommended (Chapke *et al*. 2018). FYM is applied during primary tillage and half of N, entire quantity of 20 kg P_2O_5 and 20 kg K_2O are applied as basal fertilizer. Remaining half of N is applied after 3 to 4 weeks of sowing. Agronomic trials revealed that foxtail millet yield more with higher dose of N application than recommended. In Andhra Pradesh, at Tirupati application of 50 kg N gave more productivity (Nandini *et al*. 2018), however, at Naira maximum yield was obtained with 80 kg N (Ramyasri *et al*. 2018). Further, combined application of N and P_2O_5 @60 kg and 40 kg ha^{-1} resulted in higher productivity of foxtail millet in south Odisha (Reddy *et al.* 2019). Upendranaik *et al.* (2018) observed that a combination of different organic manures along with mulching increased growth and productivity of foxtail millet. Rafi *et al*. (2012) and Rafi and Charyulu (2016) reported that inoculation of *Azospirillum* sp. and phosphate solubilizing bacterium (PSB) individually and combined inoculation improved the yield of foxtail millet. Experimental results indicated that INM in foxtail millet yielded better. Application of 50% RDF + 25% N as neem cake + *Azophos* recorded higher grain yield in sandy loam read soils at Madurai, Tamil Nadu than 100% RDF (44:22:0 kg $N:P_2O_5:K_2O$ ha^{-1}) and absolute control (Monisha *et al*. 2019). However, Kumaran and Parasuraman (2019) recorded that INM increased grain yield of foxtail millet at Tiruvannamalai, Tamil Nadu and combined application of farmyard manure, recommended dose of fertilizer and foliar application of 3% Panchagavya at 20 days after sowing gave the maximum grain yield (1652.5 kg ha^{-1}). INM with 75% RD N through Urea + 25% N through PM + *Azospirillum* seed inoculation gave maximum grain yield (2.31 t ha-1) at Prayagraj, Uttar Pradesh (Selectstar Marwein *et al*. 2019).

Weed management

Generally, grassy, sedges and broad leaves weed are observed in foxtail millet field (Table 2). Inter-cultivation for two times and one hand weeding in line sown crop and two hand weeding in broadcost crop are useful for effective weed control. Moreover, post-emergence application of 2, 4-D sodium salt (80%) @ 1.0 kg a.i. ha^{-1} at 20-25 days after sowing (DAS) is effective for controlling broadleaved weeds. Isoproturon @ 1.0 kg a.i. ha^{-1} as pre-emergence spray is also effective in weeds control (Chapke *et al.* 2018). But AICRPSM (2017) stated that pre-emergence application of Oxadiargyl @ 70 gm/ha or Pretilachlor @0.75 kg/ha was effective in weed management of foxtail millet.

Table 2: Common weeds of foxtail millet

Category	Scientific name
Grass	*Echinochloa colonum, Enhinochloacrus gulli, Dactyloctenium aegypticum, Elusine indica, Setaria glauca, Cynodon dactylon, Phragmites karka, Cyperus rotundus, Sorghum halepanse*
Sedge	*Cyperus rotundus* (motha)
Broad-leaved	*Celosia argentia, Commelina benghalensis, Phylanthusniruri, Solanum nigrum and Amaranthus viridis*

Water management

As a rainfed *kharif* crop foxtail millet is cultivated in drylands. But intermittent gap between rainy spells may occur and life-saving irrigation can be given if water is available. But where it is grown in *rabi* season, crop should be irrigated. Chapke *et al.* (2018) suggested providing two irrigations, at 25–30 and 45–50 DAS. Experimental results revealed that pre- sowing irrigation and irrigation at 20–25 and 40–45 days after sowing of foxtail millet was found to significant and gave higher productivity (AICRPSM, 2017).

Cropping system

Foxtail millet is such a crop which can be included easily in different sequential cropping. Growing of foxtail millet-mustard, foxtail millet-green gram, foxtail millet-pigeon pea and foxtail millet-sunflower are profitable than mono-cropping of foxtail millet. Relay cropping can also be practiced. In Andhra Pradesh, if monsoon sets early, foxtail millet is sown with a row spacing of 45 cm and *rabi* sorghum is introduced as relay crop when foxtail millet is close to maturity stage (Chapke *et al.* 2018).

Foxtail millet is a suitable crop for intercropping. Intercropping is advantageous in many ways as it assures greater resource use, reduction of population of harmful biotic agents, higher resource conservation and soil health and more production and sustainability of the system (Maitra *et al.* 2019). In intercropping system, more than one crop are grown together on the same land and utilize the soil nutrients, soil moisture, atmospheric CO_2 and sunlight. The resource conservation and soil health aspects are also positive effects of intercropping system as it checks run-off of water, soil erosion and less nutrient loss from the soil. Moreover, it facilitates soil fertility enhancement when small millets are intercropped with legumes and enables diversity of beneficial soil microorganisms. In intercropping system, complementarity among the species cultivated is very much important for increasing crop yields. Under dryland conditions intercropping system provides a natural insurance against total crop failure and thus production sustainability. Though enough research work on foxtail millet based intercropping system was not carried out, the advantages of intercropping was noted by researchers over sole cropping. Experimental results revealed that intercropping of green gram or black gram with foxtail millet at 3:3 ratios is beneficial (AICRPSM, 2017). In Andhra Pradesh, intercropping system with foxtail millet + ground nut (2:1) and foxtail millet + cotton (5:1) are very common, whereas at Rayalseema region of Andhra Pradesh, intercropping of foxtail millet and pigeon pea (5:1) is preferred.

Himasree *et al*. (2017) carried out an experiment in late *kharif* conditions in acidic soils of Rayalseema region of Andhra Pradesh and concluded that more gross and net incomes and benefit-cost ratio were obtained with the sowing of foxtail millet + pigeonpea (5:1) with sowing during first fortnight of August. Further, the land equivalent ratio (LER), Area Time Equivalent Ratio (ATER) and foxtail millet grain equivalent yield were more with the intercropping system of foxtail millet + pigeonpea (5:1) sown during the first fortnight of August

in late *kharif*. In another study, Manjunath and Salakinkop (2017) showed that intercropping of soybean + foxtail millet at row proportion of 2:1 and 4:2 recorded that advantageous LER values (1.49 and 1.50 respectively) and higher benefit: cost (B:C) ratio (2.39 and 2.45 respectively). Manjunath *et al.* (2018) reported that superiority of intercropping pigeonpea + foxtail millet (1:2) as higher net returns (₹ 111457 ha^{-1}) and benefit cost ratio of 3.79 were recorded over sole cropping. Moreover, groundnut + foxtail millet (6:1) registered more land resource use efficiency as marginal increase of LER value (1.14) and higher B:C ratio (2.23) as against B:C ratio of sole groundnut of 2.14 and sole foxtail millet of 1.23 (Shwethanjali *et al.* 2018). The studies clearly indicated yield advantages, efficient utilization of resources and economic returns with foxtail millet with different intercrop combinations.

Future scope of research

The research evidences and literary sources clearly indicate that enough research has not been carried out on foxtail millet. Considering the importance, present demand and nutritional value of the crop, research work should be carried out in the following directions.

- Varietal improvement and evaluation of promising varieties of foxtail millet should be conducted for different agro-climatic regions under different cropping systems.
- Research may be intensified on time of sowing, spacing and plant population for assuring optimum stand.
- Efficient nutrient management trials like soil test crop response and site specific nutrient management may be carried out for target yield.
- Studies on response to different micro-nutrient and management are needed considering the deficiency occurred in different soils.
- Contingency measures and need-based agronomic management with manipulation of planting geometry, plant population and nutrient management under aberrant situation should be in focus for drylands.
- Water management studies for *rabi* crop is also needed.
- Intensive study on cropping system and intercropping should be carried out targeting production sustainability of drylands.

CONCLUSION

Yield enhancement of foxtail millet can be made possible through release of location specific varieties and their adoption at farmers' level. Moreover, adoption of appropriate agronomic management like proper sowing time and spacing to assure uniform stand, nutrient, water and weed management are important to boost productivity of foxtail millet. Cropping system and intercropping system can help in achieving more yield and return and provide income and livelihood security in drylands. But, there is enough scope for further research on foxtail millet like nutrient management trials based on soil test crop response (STCR) and site specific nutrient management (SSNM) for target productivity, micro-nutrient management, contingency crop management and intensive study in intercropping combinations and proportions for sustaining productivity of drylands.

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