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HARNESSING BIOFERTILIZERS FOR SUSTAINABLE FODDER PRODUCTION : A REVIEW

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ABSTRACT

India accounts for a livestock population of 535.82 million, reflecting a 4.82 per cent increase over the 2012 census. This rapid growth intensified the fodder demand, while the country faces severe shortage of 61.10 per cent in green fodder and 21.9 per cent in dry fodder. The continuous use of chemical fertilizers has resulted in reduced soil fertility and increased production cost in fodder crops. In agricultural systems, microorganisms act as organic fertilizers, plant growth promoters and soil builders. They assist in biological nitrogen fixation, solubilization of unavailable forms of phosphorus and potassium, production of plant growth-promoting substances and simulation of soil microbial activity. Therefore, biofertilizers are promising agents for enhancing fodder crop production while maintaining soil fertility. This review discusses the various roles of biofertilizers in fodder production, focusing mainly on their classification, important biofertilizers used in fodder crops and their effects on crop growth, yield, quality, soil properties and farm economics. The results show that biofertilizers enhance green and dry fodder yields, crude protein content, nutrient uptake, photosynthetic efficiency and soil biological activity.
Keywords **:** Biofertilizer, Sustainability, Fodder crops, Microorganisms, Soil fertility, Productivity.

Introduction

Green Revolution in India significantly enhanced crop productivity, reduced hunger and establish a strong foundation for self-sufficiency in staple food production. In contrast, fodder production has not witnessed a comparable improvement over these years, despites India accounting for nearly 20 per cent of world livestock population (Singh *et al*., 2022). As the world's largest milk producer, the country contributes approximately 25 per cent of global milk output with a total production of 239.3 million tonnes. Milk and meat production in India are growing annually at rates of 3.78 per cent and 4.95 per cent respectively (DAHD, 2024). Despite these gains, the country faces a net deficit of 61.1 per cent green fodder and 21.9 per cent dry fodder (Pandey *et al*.,2020). Therefore, enhancing the productivity of existing agricultural land through improved agronomic practices has become an urgent priority.

The continuous use of chemical fertilizer to meet the crop nutrient requirements adversely affect the soil fertility (Oberoi *et al.*, 2020). To reduce the dependency on chemical fertilizers, biofertilizer play a major role in enhancing soil nutrient availability and promoting sustainable crop productivity (Jat and Ahlawat, 2006). Biofertilizers are living microorganisms that colonize in the rhizosphere of plants and help increasing the availability of nutrients required for plant growth (Bhattacharjee and Dey, 2014). They improve soil fertility and plant growth by fixing atmospheric nitrogen, solubilizing insoluble phosphates and producing growth promoting substances (Daniel *et al*., 2022).

Biofertilizers

Biofertilizers are organic substances that contain beneficial microorganisms capable of increasing soil productivity and plant growth (Sadhana, 2014). These products consist of active or dormant microbial strains that enhance nutrient availability and plant uptake through their activity in plant rhizosphere. They can be applied through seed inoculation or by soil application (Khanna *et al*., 2019). Application of biofertilizer enhanced plant growth and increased dry forage yield by 15.6 per cent in fodder sorghum (Sadafzadeh *et al.*, 2023).

Types of Biofertilizers

Biofertilizers are grouped based on their functional role in nutrient transformation and availability. A simplified classification of major biofertilizer groups along with representative microorganisms are presented in Table 1.

Table 1 : Classification of biofertilizers based on function and examples

Groups	Category	Examples
Nitrogen (N_2) fixing Bio fertilizers	Free living	*Azotobacter, Clostridium, Anabaena, Nostoc*
	Symbiotic	*Rhizobium, Frankia, Anabaena azollae*
	Associative Symbiotic	*Azospirillum*
P-Solubilizing Bio fertilizers	Bacteria	*Bacillus subtilis Pseudomonas striata*
	Fungi	*Penicillium sp., Aspergillus awamori*
P-Mobilizing Bio fertilizers	Arbuscular Mycorrhizae	*Glomus sp., Gigaspora sp*
	Ectomycorrhiza	*Laccarai sp., Pisolithus sp., Boletus sp., Amanita sp.*
	Orchid Mycorrhiza	*Rhizoctonia solani*
K- solubilizers	Bacteria	*Frateuria aurantia, Arthrobacter spp, Bacillus sp.*
	Fungi	*Aspergillus niger*
K- mobilizers	Bacteria	*Bacillus spp*
	Fungi	*Aspergillus niger*
Micronutrient solubilizers	Silicate and Zinc solubilizers	*Bacillus sp., Thiobacillus spp.*

Effect of Biofertilizer in Fodder Crops

1. Growth Parameters

Seedling emergence

Seed inoculation with biofertilizer such as *Azospirillum* and Arbuscular Mycorrhizal (AM) consortia exhibited higher germination rate of 48-58 per cent compared to 31 per cent over control (uninoculated) and other treatments in guinea grass (Mishra *et al.,* 2008). Among different Plant Growth Promoting Rhizobacteria (PGPR) concentration (0,5,10 and15 ml L^{-1}) and seedling density (0.26, 0.33, 0.40 and 0.47 g cm^{-2}), treatment receiving PGPR at rate of 15 ml L^{-1} and seedling density of 0.47 g cm^{-2} has increased seed germination. This was due to their ability to synthesize indole-3-acetic acid, an auxin that stimulates seed germination and early seedling growth (Utamy *et al*., 2025). Seed inoculation with *Bacillus licheniformis* or *Streptomyces kostiense*, either individually or in combination resulted in higher seed germination and seedling growth in *Acacia senegal*. This enhanced effect was attributed to the presence of gibberellins produced by the microorganisms (Singh *et al*., 2011). Application of Biophos 10 g kg^{-1} seed as seed treatment before sowing and 25.0 kg ha^{-1} through broadcasting was found to increase germination density in fodder maize to 33.0 m^{-2}, compared to control (no Biophos; 30.33 m^{-2}) (Brohi *et al.,* 2021).

Plant height

Plant height is a key growth attribute that is directly associated with forage yield and overall plant productivity. In semi-arid regions of south India, among different fodder grasses Bajra Napier hybrid variety BN2 seeds inoculated with *Azospirillum lipoferum* 1001 reported the tallest plants (282 cm) compared to control (without inoculation; 209 cm) (Sebastinraj *et al*., 2008). Seed inoculation with PGPR 1 (*Azotobacter brasilense* + *Pseudomonas fluorescens*) showed maximum plant height (186.58 cm) over no inoculation and PGPR 2 (*Azotobacter chroococcum* + *Pseudomonas fluorescens*) in fodder sorghum. This might be due to the synthesize of phytohormones by PGPR which promote plant growth by effective nutrient absorption (Chattha *et al*., 2017). Application of 100 per cent recommended dose of fertilizer (RDF) with biofertilizer (*Azospirillium* and Phosphorus solubilizing bacteria (PSB)) resulted in higher plant height (254.38 cm) compared to the control, 75 per cent RDF and 50 per cent RDF (Aditi *et al.,* 2019).

Number of leaves per plant

The higher number of leaves per plant is directly related to the plant productivity as it enhances the photosynthetic capacity. The integrated application of inorganic fertilizers (100% Recommended dose of nitrogen) and biofertilizers (*Azotobacter* + *Azospirillum*) increased the number of leaves per plant compared to the application of inorganic fertilizer alone in fodder sorghum (Verma *et al.,* 2014). The treatment receiving 90 per cent RDF + 5kg Zn ha^{-1} + *Azospirillum* produces a greater number of leaves (8.45) over rest of the treatments in baby corn (Hekmat *et al.,* 2019). The combined application of 100 per cent RDF and PGPR enhanced the number of leaves per plant (15.3) over absolute control (10.0) in fodder pearl millet (Kumar *et al.,* 2024).

Leaf area

Leaf area indicates the net photosynthetic capacity of the plant, as an increase in leaf area provides a large surface for light interception and photosynthesis. In fodder maize, the combined application of farm yard manure (FYM) along with *Azotobactor* soil application yielded larger leaves with an area of 93.5 cm^2 over control (73 cm^2) (Khushali *et al.*,2015). Similarly, seed inoculation with *Azotobactor spp* resulted in a higher leaf area (229.5 cm^2) compared to *Azospirillum spp* (219.9 cm^2) in fodder oats variety Sargodha-2011. This increase was attributed to the ability of *Azotobactor* to fix atmospheric N_2 and to produce phytohormones such as auxins and gibberellins (Saleem *et al.*,2015). The application of Nitrobine biofertilizer in combination with 60 or 90 kg mineral nitrogen resulted in greater leaf area over application of mineral nitrogen fertilizer alone (Habiba *et al.*,2018).

Stem diameter

Among different nitrogen and phosphorous levels combined with biofertilizer (*Azotobacter* and *Azospirillum*), the maximum stem diameter (2.72 cm) was recorded with the application of 90 kg N ha^{-1} and 40 kg P ha^{-1} along with biofertilizer, which was significantly higher than stem diameter observed under $N_{60}P_{40}$ + BF, $N_{30}P_{20}$ + BF and control in multicut fodder sorghum variety CSH 24 MF (Kushwaha, 2016). Seed inoculation with phosphorous solubilizing bacteria (PSB) resulted in higher stem diameter (1.22 cm) compared to uninoculated seeds (1.16 cm) in fodder maize (Ayub *et al.,* 2014). Seed inoculation with PGPR1 (*Azotobacter brasilense* + *Pseudomonas fluorescens*) gave the highest stem diameter (1.13 cm) over uninoculated seed (0.94 cm) in fodder sorghum. This might be due to the phytohormone production by PGPR1 which enhance nutrient use efficiency (Chattha *et al.*, 2017).

2. Yield Parameters

Green fodder yield

The application of biofertilizers improves water and nutrient uptake and enhances vegetative growth, thereby contributing to higher green fodder production (Asoegwu *et al.,* 2020). The combined application 100 per cent RDF, 5 t vermicompost ha^{-1} and Azotobacter + PSB inoculation recorded the maximum green fodder yield in fodder sorghum. In addition, the residual effect of this treatment resulted in maximum green fodder yield of barley (Kumar *et al.,* 2022). Similarly, the fodder sorghum variety GFS-5 fertilized with 80 kg N ha^{-1} and seed subjected to seed treatment with *Azospirillum* and PSB recorded higher green fodder yield in fodder sorghum (Tandel *et al*., 2020). The integrated application of 150 per cent RDF and PSB produced more green fodder yield (27.09 t ha^{-1}) control (17.33 t ha^{-1}) in maize (Singh *et al.*, 2018).

Dry fodder yield

In fodder sorghum, seed inoculation with *Azospirillum* resulted in 5.48 per cent increase in dry matter production compared to the uninoculated seed (Meena *et al*.,2010). The application of 100 per cent RDF along with FYM 2.5 t ha^{-1} and dual inoculation of *Azotobacter* and PSB recorded higher dry fodder yield (7492 kg ha^{-1}) over other treatment in pearl millet (Thumar *et al.,* 2016). Similarly, the application 75 per cent RDF along with *Azotobacter* and PSB resulted in higher dry fodder yield (68.2 q ha^{-1}) comparable with those obtained with 100 per cent RDF (71.7 q ha^{-1}) in fodder oat (Kumar and Karmakar, 2015). In forage maize the combined application of 100 per cent RDF along with *Azotobacter* and PSB recorded higher dry fodder yield (116 q ha^{-1}) over 100 per cent RDF (Jadav *et al.,* 2018).

3. Quality Parameters

Crude protein content

Crude protein is a major quality parameter consider in fodder crops, as it indicates the nitrogen content in the cattle feed. Among different levels of nitrogen, the treatment receiving 120 kg N ha^{-1} and co-inoculation of *Azotobacter* and *Azospirillum* resulted in higher crude protein content (11.15 %) over other N levels (0,40 and 80 kg N ha^{-1}) and un inoculation in fodder oat (Bilal *et al.*,2017). The integrated application of 75 per cent RDF, vermicompost @ 2 t ha^{-1}, PSB @ 15 kg ha^{-1}, *Azotobacter* @ 10 g kg^{-1} seed and $ZnSo_4$ @ 20 kg ha^{-1} recorded an increase in crude protein content (14.9 %) compared to absolute control (8.44 %) in dual purpose oats (Mondal *et al.,* 2025). Among the nutrient levels, the highest crude protein content was obtained from the treatment $N_{90}P_{40}$ + BF (8.37 %) over rest of the treatment in fodder sorghum (Kushwaha *et al.,* 2018).

Crude fibre

The combined application of 75 per cent RDF and biofertilizers (*Azospirillum*, PSB and KSB) recorded a decrease in crude fibre content (31.4%) compared to 100 per cent RDF (32.8 %) in fodder sorghum. Fodder containing low fibre content indicates the good palatability of the feed (Yamalapalli *et al.*, 2023). The integrated application of higher N fertilizer (200 kgN ha^{-1}) with *Azotobacter*, Mycorrhiza and *Azospirillum* resulted in lower crude fibre content (30 %) over the treatment with no nitrogen and biofertilizer (44 %) in maize (Karimi *et al.,* 2025). In fodder berseem, higher crude fibre content was recorded in dual application of *Rhizobium* and PSB (22.02 %) compared to single and no biofertilizer inoculation (Dhahiya and Tomar, 2018).

4. Physiological Parameters

Chlorophyll content

Plants inoculated with biofertilizers such as AM fungi and PSB exhibited an increase in leaf chlorophyll content (Patra *et al.,* 2019). The combined application of *Rhizobium spp* and L-Tryptophan resulted in higher chlorophyll a and b (0.98 µg mL^{-1} and 0.40 µg mL^{-1}) compared to control (100-60 kg NP ha^{-1}) in fodder maize (Qureshi, 2013). The integrated fertilization with biofertilizers (*Azotobacter* var 1 and *Phosphobacter* var 2) along with chelated nano fertilizer Fe and K recorded a significant increase in chlorophyll a (1.59 mg g^{-1}) and chlorophyll b (5.31 mg g^{-1}) in fodder sorghum (Mir *et al.,* 2015).

Photosynthetic efficiency

The co-inoculation of AM fungi with *Azotobacter chroococcum* or *Thiobacillus spp.* resulted in higher relative water content, which led increased photosynthetic efficiency in smooth vetch (Heydarzadeh *et al*., 2022). The combined application of PSB and *Rhizobium* at 5mL kg^{-1} seed each recorded a higher crop growth rate (CGR), which depends upon amount and intensity of energy intercepted and photosynthetic efficiency in chickpea-fodder sorghum cropping sequence (Chaudhari *et al.,* 2021).

Plant nutrients (NPK)

The treatment receiving 75 per cent RDF+ 25 per cent N through FYM along with *Azotobacter* resulted in higher plant NPK content (1.05% N, 0.15% P and 1.12% K) and its uptake in forage maize, and was at par with treatment having 100 per cent RDF through inorganic fertilizer (Kumar *et al.,* 2016). The triple inoculation of biofertilizers such as *Rhizobium spp.*, PSB and VAM recorded higher NPK content (0.87% N, 0.13% P and 2.56% K) in straw of faba bean compared to rest of the treatments (Bhardwaj *et al.,* 2021). Similarly, the combined application of biofertilizer (*Azospirillum brasilence* and Mycorrhiza) recorded the highest shoot N (3.92 %) and P (0.52 %) concentration compared to all other treatments in pearl millet (Abdullahi *et al.,* 2014).

5. Effect of Biofertilizer in Soil Parameters

Soil Physical Properties

Biofertilizer application in soil help in improving the physical structure of the soil such as production of soil aggregates, improved soil bulk density, soil temperature and soil moisture (Sharma *et al.*, 2012). The application of 100 per cent RDF along with *Rhizobium* seed inoculation (20 g kg^{-1}) recorded maximum pore space (54.22 %) and water holding capacity (55.92 %) of soil compared to other treatments involving vermicompost and inorganic fertilizers in cowpea cultivated field (Singh *et al.,* 2017). The combined application of inorganic fertilizers and biofertilizer (*Rhizobium*) in chickpea resulted in lower bulk density (1.226 Mg m^{-3}) compared to absolute control (Kumar *et al*., 2024).

Soil chemical properties

The application of biofertilizer *Azospirillum sp.* Along with 50 per cent RDN supplied through cow dung slurry and coconut leaf vermicompost (1:1) reduced soil acidity, increasing the soil pH to 6.7 compared to control in a field cultivated with hybrid napier (Nihad *et al.,* 2023). The integrated application of compost, AMF and *Rhizobium* recorded a higher electrical conductivity (0.82 mS cm^{-1}) under stress condition compared to control (0.21 mS cm^{-1}) in field cultivating fodder alfalfa (Ben-Laouane *et al*., 2020).

Organic Carbon

The combined application of compound effective microorganism (CEM) 20 g kg^{-1} biochar resulted in higher soil organic carbon content (28.08 g kg^{-1}) compared to other treatments having different rates (10,20 and 30 g kg^{-1}) of biochar and CEM in alfalfa (Cui *et al*., 2022). The treatment receiving 100 per cent RDN through FYM.+ PGPR.+ 3 per cent foliar spray of panchagavya (M)-PGPR + 3 per cent foliar spray of panchagavya (B) resulted in higher soil organic carbon (5.0 %-13.3%) in all 3 years over the control treatment with RDF in fodder maize-berseem cropping sequence (Onte *et al.,* 2025). Application of biofertilizer along with 75 per cent inorganic fertilizer resulted in highest organic carbon content (0.59 %) compared to other treatments in setaria- white clover system (Kumar *et al.*, 2020).

Soil Nutrients (N, P and K)

Among different treatments, the application of 25 per cent N through FYM + 50 per cent N and 100 per cent P, K through inorganic fertilizer along with biofertilizer (*Azotobacter*/ *Rhizobium*) resulted in a higher N content (253.43 kg ha^{-1}) compared to control (100% RDF) in sorghum+ cowpea-lucerne forage cropping system (Pathan and Kamble, 2012). Application of 50 kg P_2O_5 along with seed inoculation with PSB resulted in higher soil N (361 and 364 kg ha^{-1}) and P (13.23 AND 13.36 kg ha^{-1}) in fodder sorghum (Dubey *et al.*, 2018).

Soil Enzyme Activity

Among the various treatments involving individual application of algal extract, *Rhizobium*, *Trichoderma asperellum* and their combined application, the treatment with *Rhizobium* alone exhibited higher nitrate reductase activity (20 % higher) compared to other treatments (Perez-Alvarez *et al*., 2024). The combined application of organic matter (20 m^3) and biofertilizers (*Azotobacter* and *Azospirillum*) resulted in higher dehydrogenase activity compared to control in Maruit-1 (Ahmed and El-Shazly, 2021).

6. Economics of Cultivation

The combined application of biofertilizer (*Azospirillum* and *Phosphobacterium*) and 75 per cent inorganic N and P fertilizer resulted in higher net return with BCR 1.39 compared to 100 per cent inorganic N and P fertilizer (BCR- 1.09) in fodder bajra (Chellamuthu ,2000). In fodder maize- berseem cropping system seed inoculation with biofertilizer recorded higher benefit-cost ratios (1.88 and 3.07) compared to no inoculation (1.57 and 2.63) (Suryavanshi *et al*., 2020). In multicut fodder oats, the application of NPK consortia along with 100 per cent RDF resulted in higher BCR (3.14) over other treatments (Badi *et al*., 2023).

Conclusion

Biofertilizers are the potential source for addressing the persistent fodder deficit in context of rapidly expanding livestock and diary sectors. Through the mechanisms such as biological nitrogen fixation, nutrient solubilization, phytohormone production and enhancement of soil microbial activity, they consistently improve growth, yield, quality and physiological performance of fodder crops, while simultaneously increase soil health and overall farm productivity. Integrated nutrient management practices combining biofertilizers with reduced levels of chemical fertilizers emerge as a sustainable and economically viable strategy to enhancing fodder production without compromising soil fertility. Due to the increasing pressure on limited land resources and the need for environmentally friendly farming practices, wider adoption of biofertilizers in fodder-based cropping system is essential. Future research should emphasize the development of location-specific biofertilizer combinations, long-term field studies and large scale on farm demonstrations to strengthen their adoption and contribution towards sustainable livestock production systems in India.

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