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Potential of Biofertilizers in Sustaining the Productivity of Forage Crops: A Review

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ABSTRACT

The most important constraint limiting crop productivity in many parts of the world and especially among resource-poor farmers, is poor soil fertility. Maintenance of soil quality on sustainable bases can reduce the problems of soil degradation, decreasing soil fertility and rapidly declining factor productivity, a common concern in large parts of the world in today's agriculture production systems. Minerals, organic manures and microorganisms are three major components contributing for sustaining soil fertility and productivity. Among these, biofertilizers are the products containing different beneficial microorganisms which helpto meet the nutritional requirement of crops with minimum investments. Forages are least priority crops with many farmers. Thus, biofertilizers can be an important source to meet out the nutritional requirement of forage crops which are grown with minimum input supply. Commonly used bio-agents are nitrogen fixers, phosphorus and potassium solubilizers. Biofertilizers would play key role in maintaining soil productivity on sustainable basis and also in protecting the environment as eco-friendly and cost-effective inputs. Biofertilizers can improve productivity in a relatively short time, consume smaller amounts of energy and promote antagonism and biological control of phytopathogenic organisms.

Key words: *Azospirillum, Azotobacter,* Biofertilisers**,** Forage crops, PSB, *Rhizobium*, VAM.

Rural economy of many developing countries in the world is agrarian based. The livelihood of resources poor farmers is supported by agriculture and animal husbandry. Country like India occupy about 2 per cent of the total world's geographical area and sustains livestock population of 536.76 million(Anonymous, 2022). In recent years the growth of human and livestock population has posed a tremendous pressure on land resources. Indian agriculture is oriented towards mixed farming in which role of livestock form an integral part of rural India. Livestock productivity in India is far below the desired level due to considerable gap between the requirement and availability of quality fodder.

At present, the country is facing a deficit of 11.24 per cent in green fodder, 23.4 per centin dry fodder and 28.9 per cent in concentrates (Roy *et al.,* 2019).The regional deficits are more important than the national deficit, especially for fodder which is not economical to transport over long distances. The pattern of green and dry fodder deficit/surplus varies in different parts of the country. In India, Union territories face a deficit of 76.2 per cent, North East zone of 23.1 per cent, East zone of 41.2 per cent, Hill zone of 24.9 per cent, the North zone experiences an overall surplus of 133.05 per cent, West zone faces a modest deficit of 6.3 per cent, the Central zone faces a deficit of 4.8 per cent and the South zone faces a significant deficit of 43.9 per cent in green fodder. Among the dry fodder availability, Union territories face a deficit of 59.1 per cent, North East zone experiences an overall surplus of 14.0 per cent, East zone faces an overall deficit of 43.9 per cent, West zone of 43.5 per cent, Central zone of 16.4 per cent, in Hill zone there exists an overall surplus of 55.9 per cent, in North Zone faces an overall surplus of 31.7 per cent and an overall deficit of 27.0 per cent in South zone (Roy *et al*., 2019).

Sufficiency of nutrients to forage crops is vital for ensuring higher crop productivity and better animal nutrition. Forage plants, especially the high biomass producing perennial ones, are heavy feeders of plant nutrients and remove large amount of nutrients from soil. Perennial grasses have been found to remove 9.4, 1.45, 14.2, 4.6, 2.65 and 1.95 kg N, P, K, Ca, Mg and S, respectively for each tonne of dry matter produced (Hazra, 1994). Development of a manageable association between different forage crops (Table 1) and beneficial organisms would greatly increase forage production efficiency.

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Biofertilizers

Biofertilizers, more commonly known as microbial inoculants, are artificially multiplied cultures of certain soil organisms

Table1: Important annual and perennial forage species.

Cereals fodder	Legumes fodder	Tropical pasture grasses	Tropical pasture legumes
Maize (*Zea mays*)	Egyptian clover (*Trifolium alexandrinum*)	Buffel grass (*Cenchrus ciliaris*)	Siratro (*Macroptilium atropurpureum*)
Sorghum (*Sorghum bicolor*)	Lucerne (*Medicago sativa*)	Bird wood grass (*Cenchrus setigerus*)	Axillaris (*Macrotyloma axillare*)
Pearlmillet (*Pennisetum pedicellatum*)	Persian clover (*Trifolium resupinatum*)	Blue buffel grass (*Cenchrus glaucus*)	Butterfly pea (*Clitoria ternatea*)
Teosinate (*Zea mexiacana*)	Cowpea (*Vigna unguiculata*)	Sewan grass (*Lasiurus hirsutus*)	Centro (*Centrosema pubescens*)
Oats (*Avena sativa*)	Cluster bean (*Cyamopsis tetragonoloba*)	Rhodes grass (*Chloris gayana*)	Desmodium (*Desmodium intortum*, *Desmodium uncinatum*)
Deenanath grass (*Pennisetum americanum*)	Ricebean (*Vigna umbellata*)	Yellow panic (*Panicum antidotale*)	Stylosanthes (*Stylosanthes hamata,S. guianesis, S. humilis,S. scabra* and *S. viscosa*)
Napier-Pearl millet hybrid (*Pennisetum purpureum* x *P. americanum*)	Lablab beans (*Lablab purpureus*)	Dharaf grass (*Chrysopogon fulvus*)	
Guinea grass (*Panicum maximum*)		Marvel grass (*Dicanthium annulatum*)	
Timothy grass (*Phleum pratense*)			

Table 2: Important nitrogen fixing bacteria observed in the rhizosphere of grasses.

Bacterium	Plant
Azotobacter paspali	*Paspalum notatum*
Azotobacter sp.	*Cynodon dactylon, Zea mays*
Beijerinckia sp.	*Cynodon dactylon, Digitaria decumbens, Cyperus* and other grasses
Derxia sp.	Tropical grasses
Azospirillum sp.	Most tropical forage grasses including maize
Bacillus macerans	*Agrostis tenuis* and *Festuca sp.*
Enterobacter cloacae,E. aerogenes	*Zea mays, Panicum maximum, Juncus balticus, Agrostis tenuis, Andropogon gerardii, Panicum virgatum*
Klebsiella pneumoniae	*Panicum maximum* and *Chloris divaricate*
Clostridium	*Digitaria smutzii*

that can improve soil fertility and crop productivity. Although the beneficial effects of legumes in improving soil fertility was known since ages and their role in biological nitrogen fixation was discovered more than a century ago. Biofertilizers has a potential to substitute the quantum of organic and inorganic source of nutrients in agricultural production systems. Bio-fertilizer contains microorganisms which promote the adequate supply of nutrients to the host plants and ensure proper growth by regulating plant physiology. Living microorganisms are used in the preparation of bio-fertilizers. Microorganisms which have specific functions to enhance plant growth and development and make the nutrients available to the plants are used as bioagents for the preparation of biofertilisers. Presence of various N fixers in the rhizosphere of different grasses has been documented by Hazra in 1994 (Table 2). Biofertilizers play a significant role in improving the soil fertility and plant growth by fixing atmospheric nitrogen through symbiotic and non-symbiotic association, solubilising insoluble soil phosphates and also producing plant growth stimulating substances.

Microorganisms as biofertilizers

Organisms that are commonly used as biofertilizers are nitrogen fixers (N-fixer), phosphorus solubilizer and potassium solubilizer as sole culture as well in combination with few moulds or fungi (Table 3). Most of the bacteria used in biofertilizer have close relationship with plants and these bacteria possess ability to fix atmospheric nitrogen (Table 4).

Rhizobia

Rhizobia are a group of symbiotic nitrogen-fixing (SNF) bacteria that have the capability to form nodules on the roots and in certain instances, on the stems of their host plants in particular of legumes. The symbiotic relationship between rhizobia and host plants is mutually beneficial, in which both bacteria and host plants are benefitted (Sprent, 2008). Legumes host rhizobia and supply them with carbon and energy sources, while in return, these plants receive ammonia from the rhizobia (Lindstrom and Mousavi, 2020). Through symbiosis, atmospheric nitrogen is converted into a form that can be easily assimilated by the host plants

Table 3: Different types of microbial biofertilizers.

Types of biofertilizer	Bacterial strain	Application for crops	References
Nitrogen-fixing	*Azotobacter chroococcum, Azotobacter vinelandii Azospirillum lipoferu, Azospirillum brasilens, Gluconoacetobacter diazotrophicus*	Wheat, sorghum, maize, mustard, cotton, vegetables, horticulture crops, flowers,orchids, plantation crops, ornamental and forest plan.	Chakdar and Pabbi (2020)
Phosphate-solubilizing/ mobilizing	*Bradyrhizobium japonicum*, *Rhizobium leguminosarum*, *Pseudomonas striata*	All crops	Garcia-Fraile *et al.* (2017)
Potassium-solubilizing	*Bacillus megaterium*, *Bacillus mucilaginous*, *Bacillus subtilis*, *Bacillus circulans*	All crops	Dash *et al.* (2017)
Zinc-solubilizing	*Frateuria aurantia*, *Thiobacillus thiooxidans*	Wheat, paddy, pulses, citrus, ginger etc.	Mehnaz (2016)
Sulphur-oxidizing	*Thiobacillus thiooxidans*, *Delftia acidovorans* and *Bradyrhizobium japonicum*	For cereals, oilseeds, fiber . crops, plantation crops, medicinal crops, vegetables, flowers, orchards, forage crops and ornamentals.	Adesemoye *et al.* (2017)
Plant growth promoting	*Pseudomonas chlorapsis*, *Azotobacter chroococcum* and *Pseudomonas fluorescens*	All crops	Minaxi Saxena *et al.* (2013)

Table 4: Amount of nitrogen fixed by different microbial strains

Category	Biofertilizers	Amount/ha/year	References
Free-living	*Azotobacter*	20–40 kg N	Thomas and Singh (2019)
	Blue green algae	20–40 kg N	Singh et al. (2016)
Symbiotic	*Rhizobium*	50–300 kg N	Brahmaprakash and Sahu (2012)
	Azolla-Anabaena	30–60 kg N	Kollah et al.(2016)
	Frankia	89.7 kg N	Brahmaprakash and Sahu (2012)
Associative	*Azospirillum*	20–160 kg N	Okumura *et al.*,2013; Pathak *et al.*,2017
	Acetobacter diazotrophicus	20- 150 kg N	Boddey et al., 1995

(Gothwal *et al.,* 2007). The specificity of this symbiosis varies among different *Rhizobium* strains and legume species. To better understand the compatibility between *rhizobium* and legume hosts, scientist have categorised them into cross-inoculation groups. These groups consist of legume species that can share compatible *rhizobium* strains, meaning they can develop nodules when inoculated with bacteria from any member of the same group. The concept of cross inoculation groups helps streamline the selection of appropriate *rhizobium* strains for legume crops, optimizing nitrogen fixation and overall plant productivity. Cross-inoculation groups of *rhizobium* are pivotal in agricultural practices, aiding in the selection of optimal strains for inoculating specific legume crops. These groups categorize *rhizobium* strains based on their compatibility with particular legume hosts. For example, *R. japonicum* adept at nodulating and fixing nitrogen in soybeans, whereas, *R. leguminosarum* exhibits greater efficacy with peas or clover (Table5).

Nitrogen-fixing bacteria (NFB) transform inert atmospheric N_2 to ammonia through their biological processes, and this reaction is catalysed by the oxygen-sensitive enzyme nitrogenase, present in the bacteria (Bakulin *et al.,* 2007; Maitra *et al.,* 2023).*Rhizobium* inoculation is a well-known agronomic practice to ensure adequate N supply for legumes with an objective to minimize inorganic nitrogen requirement. In plant root nodules, the O_2 level is regulated by special haemoglobin called leg haemoglobin. This globin protein is encoded by plant genes but the haem co-factor is produced by the symbiotic bacteria upon infection of the plant with *Rhizobium*. The process of nitrogen fixation does indeed require specialized cells with organelles containing cytoplasmic compartments known as symbiosomes. Within these symbiosomes, rhizobia ultimately differentiate into a specialized cell type called bacteroids, which then fix atmospheric nitrogen for the plant in exchange for sugars (Kumar *et al.,* 2020).

Recent studies have revealed that rhizobia beyond their symbiotic association with leguminous plants also function as endophytes and enhanced the growth and productivity of various plants through multiple processes such as solubilization of inorganic compounds and phytohormone production (Gopalkrishnan *et al.,* 2015). Long term studies under ICAR-All India Coordinated Research Project (Forage Crops) on inoculation of *Rhizobium*in diverse

Table 5: Rhizobia and the cross-inoculation groups of legumes

Rhizobium species	Crops
R. leguminosarum	Peas (*Pisum sativum*), Lathyrus, Vicia, Lentil (*Lens culinaris*)
R. Tripoli	Berseem (*Trifolium alexandrinum*)
R. phaseoli	Kidney bean (*Phaseolus vulgaris*)
R. lupini	Lupinus
R. japonicum	Soybean (*Glycine max*)
R. meliloti	Melilotus, Lucerne (*Medicago sativa*), Fenugreek (*Trigonella foenum-graecum*)

Table 6: Effect of *Rhizobium* inoculation on productivity of important forage species.

Crops	Green forage yield (q ha^{-1})		Per cent increase
	No inoculation	*Rhizobium* inoculation	over no inoculation
Cultivated legumes			
Cowpea (*Vigna unguiculata*)	392	457	17
Rice bean (*Vigna umbellata*)	215	245	14
Cluster bean (*Cyamopsis tetragonoloba*)	257	285	11
Lablab beans (*Lablab purpureus*)	225	247	10
Egyptian clover (*Trifolium alexandrinum*)	685	83	21
Persian clover (*Trifolium resupinatum*)	610	765	25
Alfalfa (*Medicago sativa*)	592	757	28
Indian clover (*Melilotus alba*)	237	272	15
Pasture legumes and shrubs			
Stylosanthes (*Stylosanthes hamata)*	360	455	26
Siratro (*Macroptilium atropurpureum*)	195	220	13
Butterfly pea (*Clitoria ternatea*)	317	415	31
Centro (*Centrosema pubescens*)	228	285	25
Hedge lucerne (*Desmanthus virgatus*)	235	269	14
Subabool (*Leucaena leucocephala*)	338	377	11
Shevari (*Sesbania sesban*)	325	363	12

cultivated fodder legumes, pasture legumes and shrubs, indicated increase in green fodder yield of cultivated forage legumes to the tune of 10 to 28 per cent, whereas, the magnitude of increase in pasture legumes and shrubs was 11to 31 per cent over non-inoculated control (Table 6). *Rhizobium* inoculation demonstrated a favourable response in yield of multi-cut species like alfalfa, Egyptian clover and Persian clover compared to single cut species. Among perennial species butterfly pea, Stylosanthes and Centro showed better response to *Rhizobium* inoculation (Hazra, 1994). However, *Rhizobium* inoculation had positive effect on the growth and yield of cowpea in clay loam soil of Ankara (Turkey) with appreciable economization of inorganic nitrogen application (Albayrak *et al.,* 2006).

Under prevailing ecological challenges of climate change and environmental degradation due to excessive use of chemical fertilizers the *rhizobium* inoculation of alfalfa seed along with application of poultry manure, rock phosphate and phosphobacteriaenhanced the herbage yield appreciably *vis-à-vis* mitigated the adverse effects of inorganic fertilizers on the soil health (Bama, 2016).

Bio-inoculants had favourable effects on the growth, development, yield attributes and yield of fodder crops by enhancing the availability of nutrients to the crops. This has been very well demonstrated by Dahiya *et al.* (2019) and Ijaz *et al.,* (2019)when appreciable increase in fodder yield of Egyptian clover was observed with the application of *Rhizobium* + PSB. Various studies have established the positive effects of bio-inoculants on soil health. In zero tilled soils *Rhizobium* inoculation of cowpea improved soil health, fodder yield and minimise the dose of inorganic nitrogen up to 25 per cent (Mallikarjun *et al.,* 2022). In sandy loam soils *rhizobium* inoculation of cowpea had notable response of plants to inoculation owing to better nodule development, increased nitrogen fixation and improved yield. Although, *Rhizobium* inoculation had favourable effect on crop yield but studies have also established the positive role of inoculation on protein, total phenolic, chlorophyll and beta carotene contents in cowpea (Kandil and Unlu, 2023).

Phosphate-solubilizing bacteria (PSB)

Phosphorous is one of the most prevalent elements in the crust of the earth and can be found in both inorganic and organic forms in soils (Gyaneshwar *et al*., 2002). Plants absorb it in the inorganic form i.e. orthophosphate ($H_2PO_4^-$ and HPO_4^{2-})(Hinsinger, 2001). Phosphorous nutrition plays a crucial role in photosynthesis, energy transfer, signal transduction, nitrogen fixation in legumes, crop quality, and resistance to plant diseases(Khan *et al*., 2014). Acidic soils of tropical and subtropical regions are severely deficient in phosphorus, with significant capacities for phosphorus sorption. Phosphorus is only present in micromolar or lower proportions in soil solution, although the majority of mineral nutrients are often present in millimolar amounts (Ozanne, 1980).The strong reactivity of soluble phosphate with aluminium ions in acidic soil and calcium ions in alkaline soils is the cause of the low phosphorus availability**.** Many heterotrophic microbes released organic acids that solubilize P, chelate cationic companions of P ions and release the P directly into solution (Ingle and Padole, 2017). PSB constitute 1 to 50% of the total microbial population in soil, whereas *Penicillium*, *Aspergillus*, *Rhizoctonia solani*, and *Trichoderma*, make up only 0.1 to 0.5% of the P solubilization potential (Chen *et al*., 2006). PSB inoculation of maize seed increased the green fodder yield, dry fodder matter yield, crude protein and crude fibre content by 3.67%, 5.4%, 7.1 % and 2.1%, respectively, over uninoculated check (Ayub *et al*., 2014) (Table 7).

Microbes affect soil fertility by mineralization, decomposition and conversion of P from inorganic form to its accessible forms.PSB + *Trichoderma* with 50% recommended dose of fertilisers and 10tFYM/ha increased fodder yield of oat, economise inorganic fertilisers doses due to rapid decomposition of organic matter, higher availability of nutrients, increased availability of phosphorus due to mineralisation and prevention of crop from seed borne diseases (Singh *et al*., 2015).In sandy loam soils of Ranchi (Chhattisgarh), application of 75% of recommended fertilizer (RDF) along with *Azotobacter* and PSB was as efficient in promoting growth and yield of oat crop as of 100 per cent recommended dose of fertilizer (Kumar and Karmarkar, 2015).PSB inoculation in lablab bean (*Lablab purpureus* Linn.) sown in sole stand or in combination with cenchrus grass (*Cenchrus setigerus*, Vahl.) enhanced fodder yield and crude protein content owing to mineralisation of fixed phosphorus by P solubilising micro-organisms and make it available to crop plants (Sharma *et al*., 2015).

Vesicular Arbuscular Mycorrhiza (VAM)

Among various bio-agents, vesicular arbuscular mycorrhiza is recognised for its ability to accelerate physiological activities that enhance the growth and health of plants (Johansson *et al.,* 2004). Vesicular arbuscular mycorrhiza exhibits a symbiotic relationship between fungi and the roots of higher plants. These fungi colonize near plant roots forming a network of hyphae that extends into the soil, increasing the root length, thereby enhancing water uptake and nutrient absorption by the plants. It is believed that Arbuscular Mycorrhizal Fungi (AMF) have the potential to reduce the use of chemical fertilizers up to 50 per cent and achieving optimal crop production (Begum *et al.,* 2019).

VAM enhances nutrient uptake, improves tolerance to drought and salinity and also regulates plants defence mechanism (Hause *et al.,* 2007). VAM also stimulates plant growth through physiological effects or by mitigating the severity of diseases caused by soil pathogens (Gupta, 2004). Mycorrhizal fungi play crucial role in enhancing forage production and restoring soil fertility. Early studies indicated that mycorrhizal association increased the herbage yield of guinea grass by 24 per cent under hot and dry weather conditions of Bundelkhand region of India (Hazra, 1994).VAM inoculation also hold very good potential in tropical environment of coastal region of India which was evident from vigorous growth and higher forage yield of guinea grass (George *et al.,* 1998).

In nutrient-deficient soils, mycorrhizal association play a vital role in plant nutrition due to their ability to absorb nutrients and in particular of phosphorus from the soil, consequently decreasing the reliance on expensive phosphatic fertilizers. Several fodder crops underwent testing with mycorrhizal association, demonstrated an increase in fodder yield of 5 to 18 per cent in annual fodder legumes, 3 to 5 per cent in annual cultivated cereal fodders, 13-33 per cent in perennial range legumes and 8-12 per cent in perennial grasses (Table 8). VAM has also been reported to have synergistic effect with other bioagents. In sandy loam soils dual inoculation of *Rhizobium* and AM fungi significantly enhanced the nodulation, nodule biomass and fodder production in *Stylosanthes* species. Furthermore, the treated plants had elevated levels of crude protein and total digestible nutrients, alongside reduced neutral detergent fibre and acid detergent fibre contents (Mishra *et al.,* 2009).

Azotobacter

Azotobacter is a group of Gram negative, free-living, nitrogen fixing aerobic bacteria inhabiting in the soil capable of fixing an average of 20 kg N/ha per year (Gandora *et al*., 1998). In 1901, the Dutch botanist and microbiologist Beijerinck made the discovery of the *Azotobacter* genus. These bacteria utilize atmospheric nitrogen to fuel the synthesis of their cellular proteins, which gets mineralized in the soil and increase the availability of nitrogen to crop plants. They have positive effects on crop growth and yield through the development of phytopathogenic inhibitors, rhizospheric microbial induction, modification of nutrient uptake, and ultimately enhancement of biological nitrogen fixation. Besides, nitrogen fixation, *Azotobacter* also produces

Table 7: Effect of phosphorous and microbial inoculation on yield attributes of maize fodder.

Treatments	GFY (q/ha)	DFY (q/ha)	CP (%)	CF (%)
Seed inoculation				
No inoculation	56.04	15.11	8.10	29.26
PSB inoculation	58.10	15.93	8.68	29.89
CD (5%)	0.75	0.76	0.44	0.50

Table 8: Effect of VAM inoculation on some selected forage crops in red soils.

Crops	Green forage yield (q ha^{-1})		% increase yield
	No inoculation	VAM inoculation	over no inoculation
Annual cultivated legumes			
Lablab beans (*Lablab purpureus*)	176	192	9
Cluster bean (*Cyamopsis tetragonoloba*)	214	227	5
Cowpea (*Vigna ungiculata*)	287	325	13
Ricebean (*Vigna umbellata*)	197	223	13
Egyptian clover (*Trifolium alexandrinum*)	786	925	18
Lucerne (*Medicago sativa*)	566	692	22
Indian clover (*Melilotus alba*)	187	196	5
Persian clover (*Trifolium resupinatum*)	695	818	18
Annual cultivated cereals			
Sorghum (*Sorghum bicolor*)	416	438	5
Maize (*Zea mays*)	378	389	3
Teosinate (*Zea mexicana*)	356	368	3
Pearlmillet (*Pennisetum americanum*)	310	322	4
Perennial range legumes			
Stylosanthes (*Stylosanthes hamata)*	338	392	16
Butterfly pea (*Clitoria ternatea*)	305	407	33
Centro (*Centrosema pubscens*)	280	332	19
Siratro (*Macroptillium atropurpureum*)	195	220	13
Perennial grasses			
Congo signal grass (*Bracharia ruziziensis*)	525	580	10
Napier bajra hybrid (*Pennisetum purpureum* × *P. americanum*)	1248	1370	10
Guinea grass (*Panicum maximum*)	780	885	13
Timothy grass (*Setaria sphacelata*)	710	850	12
Buffel grass (*Cenchrus ciliaris*)	295	320	8

various growth hormones like, riboflavin, indol acetic acid and gibberalin (Jnawali *et al*., 2015).

In sandy loam soils ecosystem, integrated use of organic and inorganic sources of nutrients with biofertilizer resulted in significantly higher green fodder yield of maize over organic and inorganic treatments owing to the higher availability of nutrients indicating beneficial effect of *Azotobacter* owing to its ability to fix atmospheric nitrogen also helps to enhance nutrients availability in the root zone during the early growth stages of the crop. Use of *Azotobacter* culture in integration with inorganics and organics had more pronounced effects on the growth and fodder yields of the crops (Kumar *et al*., 2016). Seed inoculation with *Azotobacter* also indicated complimentary effects with micro-nutrients application on the productivity of crops. Foliar application of $ZnSO_4$ @ 1% at 20 and 40 DAS + inoculation of seeds with *Azotobacter* significantly improved the productivity of maize over no inoculation. (Tejaswi *et al*. 2021). Studies have also established the beneficial effect of *Azotobacter* on the quality constituents like crude protein, acid detergent fibre and neutral detergent fibre contents of fodder crops. Crude protein content is an important constituent in forages and acts as an indicator of quality of fodder produced by different crops (Aseefa and Ledin, 2001). *Azotobacter* also established its superiority in fodder maize crop grown with recommended primary and micro-nutrient application. Crude protein an important constituent in forages acts as an indicator of quality of fodder. Higher crude protein indicates better quality of the fodder. Acid Detergent Fibre (ADF) and Neutral Detergent Fibre (NDF) represent the fibre constituents in the forage and govern the digestibility and intake potential, respectively (Zhang*et al*., 2022). Studies have reported beneficial effect of *Azotobacter* biofertilizers on crude protein, acid detergent fibre and neutral detergent fibre contents of fodder crops. In sandy soils *Azotobacter* also hold its potential for the improvement of herbage quality constituents. Better dry matter and crude protein yields of oat were obtained in sandy soils with *Azotobacter* inoculation by Sharma (2009). Nitrogen fixation and phosphorus mobilization by *Azotobacter* and PSB, respectively improved input use efficiency of inorganic nitrogen and phosphorus sources in fodder crops like oats and sorghum. Studies advocated the substitution of about 25 % recommended doses of nitrogen in forages by *Azotobacter* which resulted in better economic returns and economic efficiency of production systems (Patel *et al*., 2018).

Azospirillum

Azospirillum is the foremost common plant growth-promoting rhizobacteria, generally associated with grasses and other

Table 9: Green fodder yield of *Pennisetum* hybrid as influenced by nitrogen and *Azospirillum* strains.

N (kg ha^{-1})	Green fodder yield (t ha^{-1})			
	Control	Strain ACD-15	Strain ACD-20	Mean
0	44.8	60.2	67.2	57.4
25	54.9	55.2	70.5	60.2
50	54.0	56.9	57.4	56.1
75	61.5	55.7	74.1	63.8
Mean	53.8	57.0	67.3	
CD (P=0.05)	10.6			

crops like rice, wheat and sugarcane *etc*. (Suhameena *et al.,* 2020). This bacterium is rod-shaped, gram-negative and aerophilic. *Azospirillum* fix the atmospheric nitrogen in the rhizosphere but also known to promote plant growth by enhancing plant root growth, uptake of water and nutrients by plants, due to the production of phytohormones, polyamine and trehalose. The efficiency of *Azospirillum* effect on plant growth and development under varied conditions depends on soil and climatic conditions. Beneficial effects of *Azospirillum* have been obtained consistently in variety of crops. After the discovery the diazotrophic *behaviour of Azospirillum*, several studies have established its capacity to fix N_2 and to replace N-fertilizers requirement when associated with grasses and cereals like paddy, wheat and sugarcane. Some *Azospirillum* strains can solubilize inorganic phosphorus, making it more readily available to the plants and resulting in higher yields and another important feature of *Azospirillum* is related to biological control of plant pathogens.

The potential effect of *Azospirillum* on crop productivity depends on the strain specificity used in a particular crop. Variable response of *Azospirillum* strains on the green fodder yield (Table 9) of *Pennisetum* trispecific hybrid (*P. typoides* × *P. purpureum* × *P. squmulatum*) in sandy loam soil was observed by Ramamurthy (2002).

Under integrated nutrient management system, *Azospirillum* inoculation maintained its significant superiority over no inoculation in terms of crop yield (Patil, 2014). Complimentary effects of *Azospirillum* with *Azotobacter* as well with PSB on yield attributes *viz.* plant height, number of leaves, leaf area index and leaf stem ratio as well as green and dry yields of fodder crops. This bioinoculants has also shown equal response as of *Azotobacter* in different studies (Verma *et al*., 2014; Yadav*et al*., 2010; Gawai and Pawar, 2007). *Azospirillum* has shown its ability to substitute about 25% recommended dose of nitrogen in forage crops (Patil *et al*., 2008). Although, *Azospirillum* had positive effect on crop productivity but studies have also reported an improvement in quality attributes i.e. enhancement of protein content and reduction in fibre constituents (Yadav*et al*., 2007).

Constraints in adoption of bio-fertilizers

- Availability of improper, less efficient strains for production.
- Unawareness amongst the consumers.
- Lack of knowledge about the application of technology.
- Practical difficulties in implementation and adoption of technology.
- Non-availability of inoculants at the time of requirement.
- Short shelf-life of inoculants.
- Problems in the adoption of the technology by the farmers due to different methods of inoculation.
- No immediate visual difference in the crop growth like that of inorganic fertilizers
- Unreliable results may be due to lack of proper quality, improper method of application and adverse edaphic conditions.

CONCLUSION

Bio-fertilizers play vital role in maintaining long term soil fertility and sustainability by fixing atmospheric nitrogen, mobilizing fixed macro and micro nutrients or convert insoluble forms of nutrients in the soil and make them available to plants, there by increases their efficiency and availability. Bio-fertilizers are recyclable, eco-friendly, less expensive with additional advantages as compare to that of conventional fertilizers. In context of both the cost and environmental impact of chemical fertilizers, excessive reliance on the chemical fertilizers is not viable strategy in long run. Under the situation, biofertilizers would be the viable option to increase and sustain productivity of forage crops.

Conflict of interest

All authors declared that there is no conflict of interest.

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