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Agronomic Biofortification of Fodder Crops to Enhance Livestock Nutrition: A Review

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ABSTRACT

Milk and milk products are the parts and parcels of human lives, therefore, plays pivotal role in day-to-day human life. In recent years many developing countries have found increased deficiency of macro and micronutrients in feed stuffs, leading animals to long for significant nutrients. Both macro and micro nutrients are very important for the metabolic functions of forage crops and the health of animals. Deficiencies in soil, especially in nitrogen, zinc and iron have a significant negative effect on forage productivity and quality. Agronomic biofortification is an innovative method designed to improve the nutritional quality of animal feed through farming practices. This review gathers research on various techniques to increase fodder yield, quality and profitability of dairy-based farmers via agronomic biofortification. Agronomic biofortification has produced some promising results, offering a quick and cost-effective way to improve forage and tackle animal malnutrition. Furthermore, the review looks at issues to be addressed in biofortification such as environmental factors, nutrient bioavailability and economic challenges. Overall, it highlights the importance of agronomic biofortification as a promising approach to boost the nutritional quality of fodder crops, thereby benefiting animal health and welfare, and contributing to food security and sustainable agriculture.

KEYWORDS: Dry matter, Fodder, Livestock, Microorganism, Nutrients, Yield

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INTRODUCTION

Livestock which are the backbone of Indian agriculture contributes 4% to national GDP. Agriculture which is an important sector of our country contributes 17% to total GDP. According to 20th livestock census report, total livestock population in India is 535.78 million which shows increase of 4.6% over livestock census 2012 (Anonymous, 2020). As the livestock population increases, requirement of feed and fodders also increases.

As of 2019, there were 192.49 million cattle, marking a 0.8% rise from the previous Census (Department of Animal Husbandry and Dairying, 2019). India stands as the leading milk producer globally, with the livestock sector contributing approximately 4.11% to the national GDP and 25.6% to the agricultural GDP, highlighting its economic significance. Dairy farming is especially prominent, with India producing around 188 million tons of milk annually. This sector not only ensures nutritional security but also creates substantial employment opportunities, especially for women and small holder farmers. Besides dairy, India is also a major producer of meat, eggs, and wool, serving both domestic and export markets. Fodders are crucial for livestock nutrition, delivering a well-rounded diet that supports animal health, growth, and productivity. They serve as primary energy sources, with grasses and cereals providing the carbohydrates necessary for maintenance and production. Leguminous fodders, such as alfalfa and clover, are high in protein and vital for muscle development, milk production, and overall growth. Furthermore, green fodders supply essential vitamins (A, D, E, and K) and minerals like calcium and phosphorus, which are important for various metabolic processes. The high fiber content of fodders aids in digestion and helps prevent digestive issues. Various types of fodders, including green fodder, silage, hay, and crop residues, offer flexibility in feed options, ensuring nutritional adequacy throughout the year. Green fodder is especially palatable and nutrient-dense, while silage and hay, preserved by fermentation and drying respectively, are crucial for off-season feeding. Crop residues, such as straw, are effectively utilized to minimize waste and enhance sustainability. Adequate nutrition from fodder boosts growth rates, reproductive health, milk production, and disease resistance, leading to greater productivity and profitability in livestock farming. Cultivating and using fodder is cost-effective, reducing reliance on pricey commercial feeds and supporting local agriculture. Sustainable fodder practices improve soil health through crop rotations and nitrogen fixation by legumes, increasing farm biodiversity and resilience to climate changes. Effective fodder management, including quality control and preservation methods, ensures a steady supply of high-quality feed, essential for animal well-being and optimal production. Promoting the use of locally grown fodders can help farmers lower their carbon footprint and foster sustainable farming communities, thus enhancing the economic viability and environmental sustainability of livestock farming. Although India is the world’s leading milk producer, its animal productivity (1538 kg/year) remains below the global average (2238 kg/year), which may be attributed to malnutrition resulting from a significant shortage of feed (Vijay et al., 2018). According to IGFRI Vision 2050, India has net deficit of 35.6% green fodder, 10.9% dry fodder and 44% feed. In India, 90% of the diet of livestock comprised of substandard quality roughages. As a result, livestock feeding on these roughages have poor health. For maintaining the good health of livestock, good quality green fodders are needed, which can increase the productivity of country’s livestock. The excessive use of chemical fertilizers lacking micronutrients to satisfy the rising forage demand has adversely affected soil health and reduced crop yields. As population pressures increase, more land is allocated for food and cash crop production, leaving limited arable land for fodder cultivation. This scarcity of fodder production is a current focus in agriculture. The indiscriminate and continuous application of high-analysis chemical fertilizers has led to negative impacts, causing a decline in productivity due to nutrient imbalances. Consequently, there are significant challenges in optimizing land use to produce sufficient and high-quality animal feed. Therefore, the primary aim of this review is to investigate various methods for biofortifying fodder crops through agronomic approaches.

SIGNIFICANCE OF LIVESTOCK NUTRITION

Livestock nutrition plays a crucial role in maintaining the health and productivity of farm animals, which serve as a primary food source globally (Kumar et al., 2018). Adequate nutrition is essential to provide animals with the required nutrients for vital bodily functions, growth, reproduction, and lactation. Balanced diets that meet the specific nutritional requirements of different livestock species and stages of development also enhance reproductive performance, leading to higher birth rates and healthier offspring. Inadequate nutrition, on the other hand, can result in stunted growth, decreased productivity, and increased susceptibility to illnesses, which can lead to significant economic losses. Moreover, the quality of animal products, such as meat and dairy, is directly influenced by the diet of the livestock; for instance, specific nutrients can affect milk composition and meat marbling.

Nutritional imbalances among animals, especially in dairy goats and cattle, pose a significant challenge in livestock management. These disorders result from inadequate or imbalanced nutrient intake, leading to a range of metabolic and health issues (Kumar, 2017). The cumulative impact of these deficiencies may have significant negative impacts on the health of humans and livestock. Preventive measures and treatment of these disorders can be achieved through proper diet and nutrition, including the avoidance of nutrient toxicities. Fodder and forage options are crucial elements of livestock nutrition, providing vital nutrients for growth, reproduction, and overall health

(Sidhu et al., 2011). The impact of nutrient deficiency in fodders is significant, as it can lead to reduced growth and development in fodder crops, affecting their yield and quality (Banik et al., 2023). This, in turn, can have a direct impact on the health and productivity of livestock, as well as on the nutritional value of the animal products consumed. To ensure the well-being and efficiency of both humans and animals, it's vital to tackle nutrient deficiencies in fodder through suitable management methods and agronomic interventions.

METHODS OF AGRONOMIC BIOFORTIFICATION

The macro and micronutrients contents of fodder crops becomes decreased mainly due to growing of high yielding varieties which leads to intensive mining of nutrients from the soil. So, the replenishment of nutrients by agronomic biofortification which includes external application of nutrients to the soil-plant system (Athar et al., 2020). A key component of biofortification, involves enhancing the nutrient content of crops through soil and foliar application of fertilizers, soil inoculation with beneficial microorganisms, and other techniques (Dhaliwal et al., 2023). Some of the proven methods are described.

Fertilization

One of the most significant factors that directly affect the quantity and quality of fodder is the application of fertilizer. The response of dry matter production maize to the fertilizer rate was linear (Kumar et al., 2016).

Nitrogen

Nitrogen is a critical nutrient that significantly enhances both crop improvement and fodder crop production. Nitrogen is essential for the formation of several structural elements, including molecules, proteins, amino acids, chlorophyll, and other components. Nitrogen fertilization is essential for improving the quality of forage, especially in terms of dry matter production and the concentration of crude protein (Maheswari et al., 2017). However, the impact of nitrogen on forage quality can vary depending on the specific crop and the presence of other nutrients such as phosphorus (Aydin and Uzun, 2005). For example, in cluster bean varieties, nitrogen application significantly increased forage yield and quality, with the variety BR-99 showing the highest yield and protein content (Ayub, 2010). Likewise, applying nitrogen fertilizer to native pasture overseeded with ryegrass enhanced forage qualities and the performance of beef calves (Brambilla et al., 2012a). These results emphasize the significance of nitrogen fertilization in improving forage quality, while also highlighting the importance of a balanced approach that considers theparticular crop and the presence of other essential nutrients.

When 25 t/ha FYM was applied, the number of micronutrients such as zinc, copper, manganese, and iron in fodder maize was improved by 15.3%, 7.5%, 28.4%, and 15.6% respectively relative to the control, but declined when the amount of nitrogen increased. They have also reported that the application of FYM 25t/ha and nitrogen120kg/ha results in increased Crude protein yield (kg/ha) by 33.78 % and 36.56 % respectively (Kalra and Sharma, 2016).Vennila et al. (2017) stated that the application of both organic and inorganic sources of nutrients to bajra Napier hybrid grass increases yield, yield attributes, and nutrient uptake. It was found that the application of nitrogen at the rate of 180 kg/ha results in maximum crude protein contents (10.52%) which might be due to enhanced production of amino acid resulting from nitrogen application and the highest percentage of crude protein (11.54%) and lowest percentage (7.84%) were observed at 45 and 65 days after sowing, respectively (Swathi et al., 2015). Significant increases in plant height, leaf area index, green fodder output, nitrogen content and uptake, zinc content and uptake, calcium content, and crude protein content have been observed with the application of nitrogen at a rate of 120 kg/ha in fodder maize (Krishna et al., 2022). Rashid et al.(2019) further emphasized the importance of integrated nitrogen management, showing that a combination of organic and inorganic nitrogen sources can lead to higher green fodder yield and improved quality. Nitrogen enhancement in forage for livestock has been shown to have a positive impact on forage production and livestock performance. Brambilla et al., (2012a) found that nitrogen fertilization increased forage accumulation rate and production, leading to improved livestock performance. Delevatti et al. (2019) similarly reported that increasing nitrogen levels in Marandu grass improved herbage mass, forage quality, and animal production. However, Jacobs and Ward, (2011) noted that the effect of nitrogen application on forage crops was limited by available moisture, with variable dry matter yield responses. (Rouquette and Smith, 2010) highlighted the role of biological nitrogen fixation in reducing input costs for forage production, particularly in cow-calf and stocker programs.

Zinc

Zinc plays a crucial role in the growth and development of fodder crops, particularly maize and cowpea, by improving their yield and quality. Increase in dry matter, hay and herbage yield might be because of zinc role in stabilizing RNA and DNA structure and involves in biosynthesis of growth promoting hormones such as indole -3- acetic acid (IAA) and Gibberellin. Also, zinc is an activator of many enzymes involved in photosynthesis, cell elongation and cell division (Rathore et al., 2015). Rathore et al. (2015) in Karnal observed that when Zn application increased from 0 to 20 kg/ha in fodder cowpea, the CP content increased from 15.23 to 17.56%. They also reported that Zinc application upto 30 kg ha^{-1} improved the EE level but after that EE content decreased with further increase in Zn dose. It might be because of Zn deficiency inhibited the activities of many antioxidant enzymes which leads to extensive oxidative damage to lipids membrane, henceforth, application of Zn increased EE. Furthermore, it has been noted that zinc is essential for various vital processes in plants, such as protein synthesis and gene expression (Ahmad and Tahir, 2017). Therefore, the inclusion of zinc in the fertilization and management of fodder crops is crucial for their optimal growth and nutritional value.application of 5 kg Zn/ha produced significantly higher forage and dry matter yield of berseem as compared to control. The increase in forage and dry matter yield of berseem due to 5 kg Zn/ha were 21.9 and 7.1 %, respectively over control (Gaur et al., 2018). The insufficient presence of zinc in forage can lead to substantial effects on livestock, including decreased growth and reproduction, as well as impaired health of bone and skin tissues. In poultry, zinc is particularly important for growth, immunity, and antioxidant capacity (Naz et al., 2016). Both organic and inorganic sources of zinc can have positive impacts on the health and performance of poultry (Abd El-Hack et al., 2017).The easiest and latest practice to deal with micronutrient deficiency in crops is the application of micronutrient fertilizers (Gupta et al., 2008).Enhancing the micronutrient content of fodder crops through foliar application is a promising and economical method of agronomic biofortification, which will improve animal health and productivity (Dhaliwal et al., 2023). The agro-qualitative characteristics of fodder are affected by the micronutrient contentthereby directly impacting animal productivity. Thus, fortification of plants with Zn and Cu is a better approach to tackle their deficiency in green and dry fodder (Kumar et al., 2016). When $ZnSO_4$ was applied to the soil @ 25 kg/ha+ 0.2% foliar spray at 25 DAS and 40 DAS, the crude protein yield and superior quality neutral and acid detergent fiber in plants were observed (Susheela et al., 2017). The effect of varying doses of zinc fertilizer on plant growth is different among the crops because the response of fodder crops depends on the application of zinc fertilizers (Mohan et al., 2015). The application of 20 kg/ha zinc sulphate as basal dose yields 31.3 and 50.9% higher zinc content and uptake, respectively over control and maximum CP, ether extract, and ash content in fodder maize (Kumar et al., 2017). In fodder maize, the application of Zinc @10 kg/ha, greatly enhanced plant height, leaf area index, and green fodder yield while N and Zn content and their uptake while Ca and crude protein content remain unchanged (Krishna et al., 2022). Higher crude protein yield which is due to the combined effect of more crude protein content in plants, dry-matter yield, and leafless plants, and higher digestible dry-matter yield because of higher digestibility % and higher dry-matter yield was recorded in fodder sorghum with the application of 5 kg Zn/ha (Verma et al., 2005). Kumar and Ram. (2021) stated that enrichment of Zn through the combined application of soil and foliar spraying is the best way to improve the quality of maize fodder, thus improving the Zn in animal nutrition.The combination of 25 kg/ha $ZnSO_4$ (basal dose) + 1% foliar spray of $ZnSO_4$ at 45 DAS and 1.5% foliar spray of $FeSO_4$ at 30 DAS recorded higher crude protein content of spring sown fodder maize (Sewhag et al., 2022).The combined application of nutrients (Ca at 3% + Zn at 2%+ Fe at 1%) increased plant height, leaf area per plant, stem diameter, number of leaves, fresh biomass, dry matter yield, dry matter contents, crude protein content, and ash contents as compared to control in forage sorghum (Abbas et al., 2020).Sharifi. (2016) demonstrated that nano iron chelates treatment increased plant height and total dry biomass (TDB), while nano zinc spraying improved TDB by 14.5% compared to control and 1.5% compared to chemical zinc. The concentrations of phosphorus, soluble carbohydrates, crude protein, and TDB rise when iron nanoparticles are used. In addition, the application of nano or chemical formulations of zinc resulted in a substantial increase in leaf chlorophyll index, plant height, TDB, crude protein, and soluble carbohydrates. Rajkumar and Shivkumar (2021) in fodder maize with application of 20 kg $ZnSO_4$ and 1% $ZnSO_4$as foliar spray at 45 DAS recorded significantly higher green fodder yield (47.4 t ha/). Tondey et al. (2021) reported that the use of zinc oxide nanoparticles and bulk zinc salt increased the vegetative and yield parameters of fodder maize, with the former showing more promising results. Similarly, Manisha et al. (2024) in an experiment conducted in Karnal found that growth, green fodder yield and dry matter yield enhanced with zinc fortification in berseem (Table 1, Fig. 1 and Fig. 2).

Table 1. Effect of Zn and Fe ferti-fortification on number of leaves, Leaf: Stem ratio and number of regenerated stems of berseem

Treatments	Plant height (cm)			No. of leaves			Leaf: Stem ratio			Number of regenerated stems		
	I Cut	II Cut	III Cut	I Cut	II Cut	III Cut	I Cut	II Cut	III Cut	I Cut	II Cut	III Cut
T1- Absolute Control	55.7	59.95	61.5	17.7	18.9	19.6	0.49	0.65	0.66	5.00	5.37	5.75
T2- 100% RDF	69.5	71.90	72.5	23.4	25.2	26.7	0.50	0.66	0.67	5.60	5.80	6.04
T3- 100% RDF + Zn (basal)	84.6	86.93	88.4	29.4	31.4	33.1	0.52	0.77	0.75	7.28	7.73	8.40
T4- 100% RDF + Fe (basal)	82.0	82.27	84.0	27.5	30.1	31.2	0.51	0.75	0.71	6.72	7.00	7.60
T5- 100% RDF + 0.5% foliar spray of Zn	81.3	81.57	83.2	26.2	27.6	29.0	0.50	0.73	0.69	6.07	6.57	6.87
T6- 100% RDF + 0.5% foliar spray of Fe	79.3	79.99	80.3	25.8	26.3	28.7	0.49	0.69	0.67	5.63	5.93	6.19
T7- 75% RDF + 0.5% foliar spray of Zn +0.5% foliar spray of Fe	80.5	80.73	81.0	26.0	27.3	28.9	0.50	0.72	0.68	6.02	6.30	6.67
SEm ±	3.63	4.11	4.03	1.02	1.19	1.37	0.02	0.03	0.02	0.19	0.24	0.22
LSD (*P* = 0.05)	11.2	12.65	12.4	3.15	3.66	4.21	NS	NS	NS	0.58	0.75	0.67

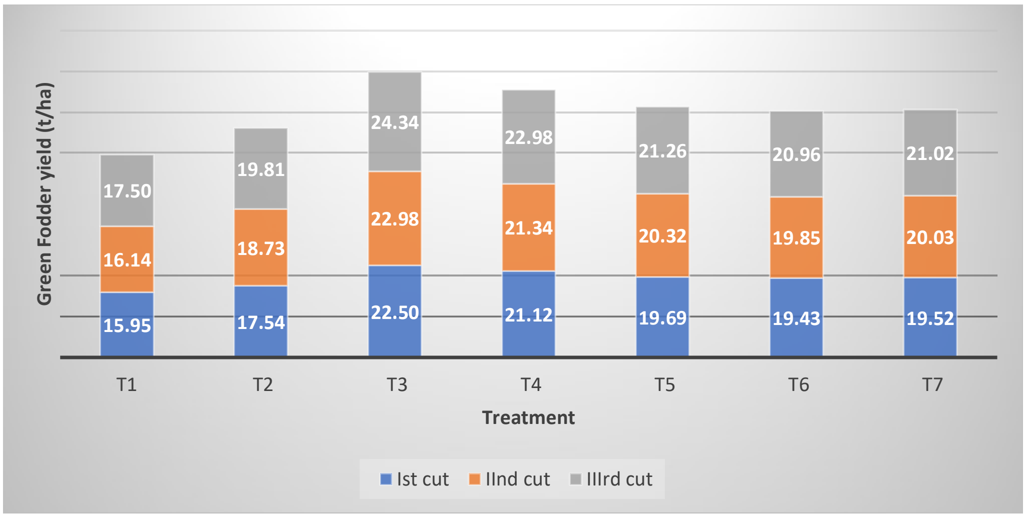

Fig 1. Green fodder yield of berseem at different cuts

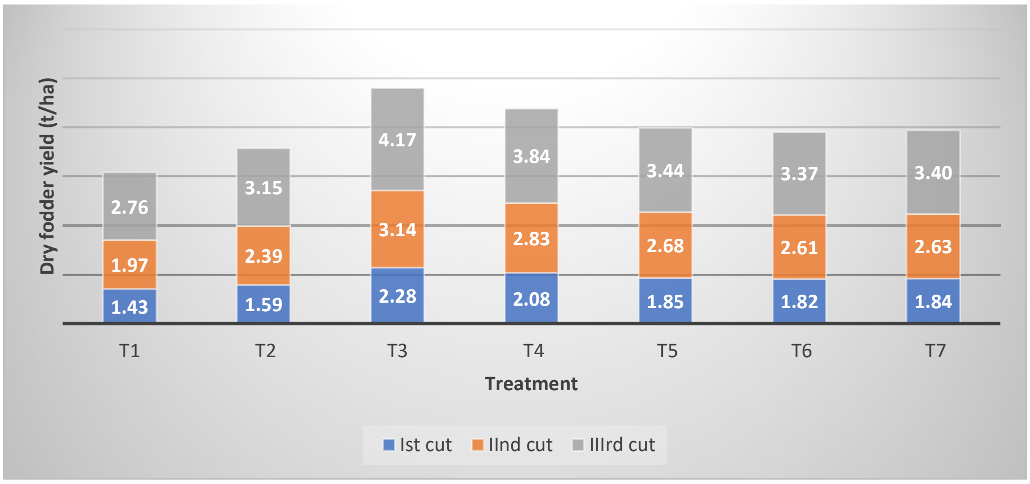

Fig 2. Dry fodder yield of berseem at different cuts

Copper

According to Sandhu et al. (2020) the application of Cu fertilization at 6 kg/ha caused a significant rise in crude protein levels in oat fodder of 22.5%. out of control. Conversely, a substantial reduction in CPC was observed by applying Cu fertilizer at a rate of 8 to 12 kg/ha. A significant rise in NDF and ADF content of the forage was observed with the foliar application of Cu (Kaur et al., 2015; Dhaliwal et al., 2023). The range of NDF content for the various Cu treatments was 46.5 to 55.3%, with the highest levels recorded while Cu application at 6 kg ha$^{/}$ (Sandhu et al., 2020). Sandhu et al. (2020) also found that foliar application of Cu at 0.2% at 60 and 90 days after sowing significantly enhanced oats growth, yielding maximum Cu enrichment, green fodder, and dry fodder with increased plant height and Cu uptake. Alternatively, three applications at 60, 90, and 110 days led to a 12% height increase, elevated Cu content to 21 mg/kg, and improved fodder quality with 28.9% higher yields of both green and dry fodder, along with the highest crude protein (8.7%) and crude protein yield (8.3 q/ha).

ii. Plant Growth Promoting Rizobacteria (PGPR)

While inorganic fertilizers, or chemical fertilizers, are the fastest and most efficient ways to boost crop growth and yield, prolonged use of them can harm the ecosystem and erode soil quality. Plant Growth Promoting rhizobacteria (PGPR)/microbial inoculants plays an important role in reducing the adverse environmental impacts exerted by chemical fertilizers and other agrochemicals. The term "PGPR" refers to the living micro-organisms that colonize the rhizosphere and stimulate growth by increasing the availability and supply of nutrients through a wide range of methods such as biological nitrogen fixation, phosphate solubilization, and production of siderophores and phytohormones (Verma et al., 2023). *Azotobacter* and *Azospirillium* sp. are promising biofertilizers that can improve the quality and yield of forage crops, reducing the need for excessive chemical fertilizers by biologically fixing nitrogen (Dar et al., 2010). Azotobacter has been utilized as a biofertilizer for crops such as barley, oats, and maize, as shown by (Wani et al., 2016). The microbial inoculants greatly enhancegrowth parameters of fodder crops such as the plant height (cm), germination count (m^{-2}), number of tillers (m^{-2}), number of leaves per plant, leaf area (cm^2), and leaf-to-stem ratio (Alori & Fawole, 2012). Saleem et al. (2015) reported that the seed inoculation with a combination of *Azotobacter* and *Azospirillium* sp. with S-2011 oat cultivator significantly increases the plant height (cm), germination count (m), no. of leaves per plant, no. of tillers (m^2), leaf area (cm^2), green forage yield (85.2 t/ha), dry matter yield (14.0 t/ha$^)$Jena et al. found that the application of Azotobacter + PSB + 75% N, P, and K and micronutrient Zn increases the crude protein content in fodder crops than both the control and recommended dose of fertilizers applied treatment. Bhakar et al. (2020) in an experiment in Karnal found that among nutrient management, treatments 100% RDF, 100% RDF+ PGPR and 100% RDF+ seaweed extract recorded higher fodder production as well as fodder quality in sorghum and guar intercropping.

iii. Cropping systems

Crop diversification, particularly through intercropping and diversified crop rotations, can promote resource-efficient production and enhance the delivery of ecosystem services, contributing to more sustainable cropping systems. The practice of growing two or more crops simultaneously on the same plot of land at the same time is known as intercropping (Guleria and Kumar, 2016).The intercropping systems of forage crops allowthe integrationof crops and livestock production as forages can be grown as intercrops together with grain crops (Maughan et al., 2009). In terms of combined green forage yield (sorghum + soybean) and dry matter biomass, sorghum was found to be superior when sown 18 days ahead of soybean in a 2:1 row proportion (Iqbal and Abbas, 2017).Tamta et al. (2019) demonstrated that the highest protein content, total green fodder, and ash yield were in a 2:1 ratio whereas maximum ether yield was recorded in a 1:2 intercropping ratio of maize and cowpea. However, the 1:2 intercropping ratio of maize and cowpea also results in the highest crude protein, ether extract, and ash content, along with the lowest NDF, ADF, and ADL levels in the crops. Regarding nitrogen levels, the highest yields and content of green fodder, crude protein, ether, and ash in both maize and cowpea are achieved with 120 kg N/ha. However, cowpea only responds significantly up to 60 kg N/ha. Using 120 kg N/ha also leads to the lowest levels of NDF, ADF, and ADL in both crops.

The intercropping system of corn-soybean in the ratio of 50:50 hasim proved the forage quality in terms of crude protein (CP) due to higher nitrogen availability for corn in intercropping compared with its sole crop (Halim et al., 2016).The maximum fresh and dry biomass was produced by sorghum-cowpea and sorghum-cluster bean intercropping in a 2:1 row ratio compared to other spatial arrangements (Iqbal et al., 2019).When sorghum and legumes were intercropped, the overall productivity increased by 9 to 55% as compared to solo sorghum (Iqbal et al., 2019). The digestibility and palatability of the fodder are enhanced by growing non-leguminous fodders in combination with legumes (Kumar et al., 2018). When maize is intercropped with soybean at different planting structures, the production of fresh fodder increases and the quality of silage is enhanced along with increased crude protein content and decreased NDF and ADF concentrations in the silage (Htet et al., 2016). Kizilsimsek et al. (2020) demonstrated that the NDF values of intercropped maize were higher when compared to that of pure maize which results in increase in DMI and also reported that growing legume crops along with maize even at a low rate could improve the silage quality in terms of DMR, NDF content, digestible dry matter (DDM) rate, DMI,and CP content. Meena et al. (2023) while working on eight fodder-based cropping systems (CS) in Indo-gangetic plain region (IGP) viz., sole napier bajra hybrid (CS_1), sole guinea grass (CS_2), napier bajra hybrid + cowpea (Kharif)/ berseem (Rabi) (CS_3), guinea grass + cowpea (Kharif)/ oats (Rabi) (CS_4), multicut sorghum-berseem (Rabi) (CS_5), cowpea-maize-oats (CS_6), baby corn-cowpea-chinese cabbage (Rabi) (CS_7), summer moong–multicut sorghum–ryegrass (Rabi) (CS_8) found that different cropping systems significantly influenced fodder yield, quality and economics for dairy based farmers as shown in Table 2 and 3 and Fig. 3 and 4.

Table 2. Quality parameters of different Kharif fodder crops (mean of two years)

Treatments	DM %	CP %	EE %	Ash %	NDF %	ADF %	ADL %	HC %
	………………	………………	………………	……… % ………	………………	………………	………………	………………
T1 (NBH grass)	19.4	9.73	2.58	10.9	68.3	39.0	3.49	29.3
T2 (Guinea grass)	24.7	8.26	1.64	11.8	71.3	41.4	3.25	29.9
T3 (NBH+ Cowpea*)	19.7 (17.4*)	10.0 (17.2*)	2.68 (2.96*)	10.9 (11.2*)	67.6 (46.6*)	38.4 (29.6*)	3.28 (8.10*)	29.2 (17.0*)
T4 (Guinea+ Cowpea*)	25.2 (17.4*)	8.53 (17.3*)	1.69 (2.92*)	12.0 (11.2*)	71.1 (46.9*)	41.0 (29.8*)	3.27 (8.20*)	30.1 (17.1*)
T5 (Multicut sorghum)	21.9	7.95	1.86	9.6	62.5	35.4	4.99	27.1
T6 (Cowpea)	16.9	9.48	2.86	9.2	46.7	29.3	8.20	17.4
T7 (Baby corn)	20.5	8.91	1.52	8.5	63.3	36.6	4.85	26.7
T8 (Maize)	21.6	15.9	1.64	10.9	70.7	41.3	4.89	29.4
SEm±	0.2	0.2	0.08	0.1	0.6	1.7	0.18	1.7
CD (P=0.05)	0.6	0.5	0.23	0.3	1.8	4.8	0.53	5.1

Table 3. Quality parameters of different Rabi fodder crops (mean of two years)

Treatments	DM	CP	EE	Ash	NDF	ADF	ADL	HC
	………………	………………	………………	………………	……… % ………	………………	………………	………………
T1 (NBH grass)	19.3	10.1	2.54	10.9	70.1	44.2	3.51	25.9
T2 (Guinea grass)	24.9	8.3	1.65	11.9	71.4	46.3	3.27	25.1
T3 (NBH*+ Berseem)	13.5 (19.3*)	16.6 (10.2*)	2.93 (2.58*)	11.4 (11.0*)	46.1 (69.5*)	35.4 (43.6*)	4.20 (3.47*)	10.7 (25.9*)
T4 (Guinea*+ Oats)	16.0 (24.7*)	12.3 (8.4*)	2.15 (1.72*)	10.1 (12.0*)	63.8 (71.4*)	43.1 (46.8*)	5.56 (3.30*)	20.7 (24.6*)
T5 (Berseem)	13.6	16.4	2.91	11.3	46.0	35.1	4.23	10.9
T6 (Oats)	16.1	12.1	2.19	10.0	63.6	42.8	5.51	20.8
T7 (Chinese cabbage)	--	--	-	-	-	-	-	-
T8 (Rye grass)	15.2	14.7	2.63	10.7	44.2	26.8	1.92	17.4
SEm±	0.3	0.4	0.09	0.2	0.3	0.2	0.04	0.4
CD (P=0.05)	0.8	1.1	0.27	0.5	0.7	0.6	0.11	1.1

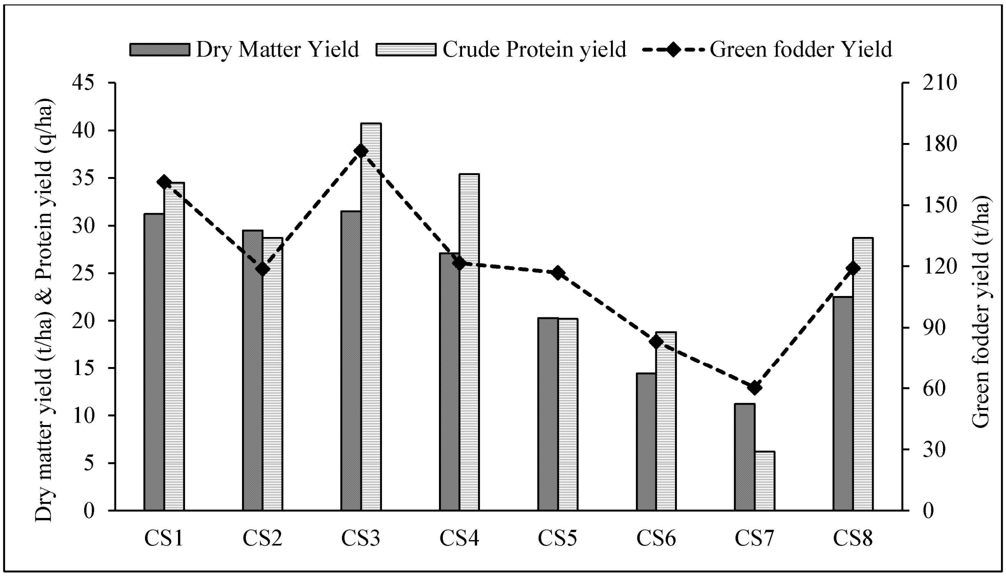

Fig 3. Total green fodder, dry matter and crude protein yield of different fodder cropping system (mean of 2 years data)

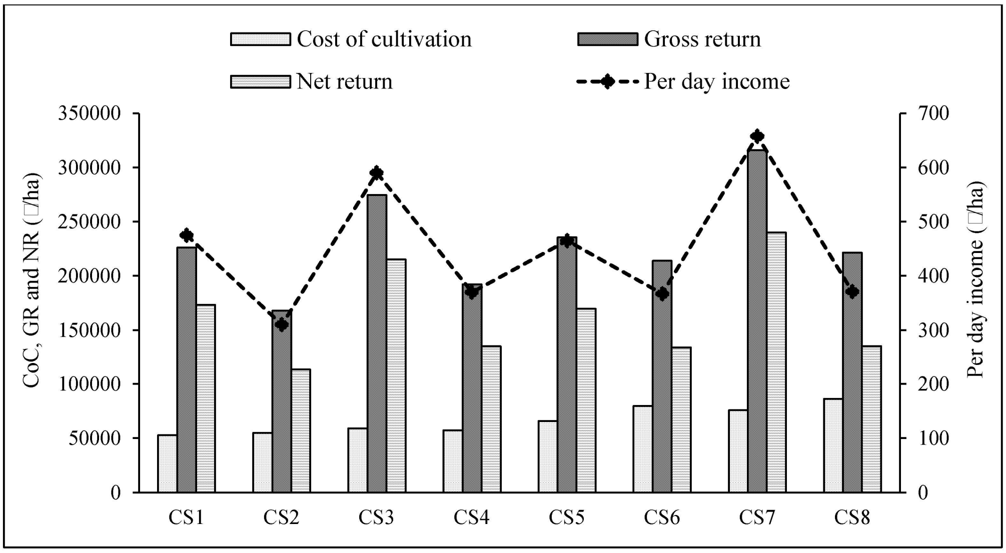

Fig 4. Cost of cultivation, gross return, net return and per day income of different fodder cropping system (mean of two years)

Challenges

Agronomic bio fortification of fodder crops aims to enhance the nutritional value of animal feed by increasing the concentration of essential nutrients in the crops. However, this approach faces several constraints that can limit its effectiveness.

Soil constraints

Many soils are naturally deficient in essential micronutrients such as zinc, iron, selenium, and iodine, which are crucial for successful biofortification (Alloway, 2013). This deficiency can significantly hinder the effectiveness of biofortification programs. Soil nutrient imbalances, where some nutrients are present in excess while others are deficient, can adversely affect the uptake of specific micronutrients. For instance, high levels of phosphorus can inhibit zinc absorption, which is detrimental to biofortification efforts (Cakmak, 2017).In alkaline soils (high pH), the availability of several micronutrients, including iron, zinc, manganese, and copper, is significantly reduced, posing a substantial challenge for biofortification (Kaur et al., 2015).Acidic soils (low pH) can lead to toxic levels of elements like aluminium and manganese, which inhibit root growth and nutrient uptake, complicating biofortification efforts (Fageria and Baligar, 2008; Neina, 2019).Soils with low organic matter content often have poor structure and water-holding capacity, limiting root growth and nutrient uptake. Organic matter is crucial for nutrient cycling and availability (Lehmann and Joseph, 2015; Lal, 2015).Rapid decomposition of organic matter in certain climates can reduce the long-term availability of nutrients, complicating sustained biofortification efforts (Lal, 2015).Soil compaction reduces pore space, limiting root growth and water infiltration, which hinders nutrient uptake and biofortification (Hamza and Anderson, 2015).Sandy soils have low nutrient-holding capacity, leading to quick leaching of applied micronutrients, thereby reducing their availability to plants.Soil microorganisms are essential for the cycling and availability of nutrients. Low microbial activity can limit the conversion of nutrients into forms that are available to plants. Beneficial soil microorganisms, such as mycorrhizal fungi and rhizobia, enhance nutrient uptake through symbiotic relationships. However, other microorganisms can immobilize nutrients, making them less available to plants. Both drought and excessive moisture affect nutrient availability and uptake. Dry soils reduce nutrient mobility, while waterlogged soils can lead to nutrient losses through leaching and denitrification (FAO, 2015).

Environmental Constraints

Agronomic biofortification of fodder crops faces significant environmental constraints that affect the effectiveness and sustainability of these efforts. Climate change poses a major challenge, with extreme weather conditions such as heat waves, droughts, and altered precipitation patterns disrupting nutrient uptake and crop growth (Dai, 2013). Soil erosion, driven by both water and wind, depletes the nutrient-rich topsoil essential for healthy plant development, thereby hindering biofortification (Montgomery, 2007). Soil degradation issues such as salinization and acidification, often exacerbated by unsustainable agricultural practices, further compromise soil health and nutrient availability (Schlesinger and Bernhardt, 2013; Munns and Tester, 2008). Additionally, pollution from heavy metals and pesticide residues can negatively impact soil microbial activity and nutrient cycling, thereby reducing the efficiency of nutrient uptake in plants (Alloway, 2013). Addressing these environmental constraints is crucial for the successful implementation of agronomic biofortification strategies in fodder crops.

Economic and Social Constraints

Economic and social constraints significantly impact the implementation of agronomic biofortification of fodder crops. High costs associated with micronutrient fertilizers and advanced agricultural technologies can be prohibitive for many small-scale and resource-poor farmers, limiting the adoption of biofortification practices. Additionally, the lack of access to credit and financial resources further exacerbates this issue. Social constraints, such as limited awareness and education about the benefits of biofortified crops, can lead to resistance from farmers and communities who may be hesitant to adopt new agricultural practices (Bouis and Saltzman, 2017). Moreover, cultural preferences and traditional farming practices often prevail over the adoption of biofortification strategies, slowing down their widespread acceptance (Bouis and Saltzman, 2017). Addressing these economic and social barriers through targeted education programs, subsidies, and support for farmers can enhance the uptake and success of agronomic biofortification initiatives.

Despite these challenges, agronomic biofortification has been found to be a promising and sustainable strategy for enhancing the nutritive potential of forage crops (Dhaliwal, 2023).

CONCLUSION

Several methods exist for agronomic biofortification of forage crops with nitrogen, zinc, iron and copper, including soil application, foliar application, soil plus foliar application, and seed priming. Soil application is the most preferred due to its ease of use, while foliar application is preferred during urgency to address nutrient deficiencies. Agronomic biofortification is a promising approach to enhance the nutritional quality of fodder crops, thereby improving livestock health and productivity. By using various agronomic practices such as soil management and crop selection, it is possible to increase essential nutrients like vitamins, minerals, and antioxidants in animal feed. This strategy not only addresses potential deficiencies in animal diets but also improves the nutritional quality of animal products consumed by humans. However, widespread adoption and effectiveness of agronomic biofortification require further research and development. Challenges such as nutrient bioavailability, environmental impact, and cost-effectiveness must be addressed. Long-term studies on the impact of biofortified fodder on animal health, reproduction, and performance are essential to establish its efficacy. Agronomic biofortification can enhance livestock welfare and productivity while contributing to sustainable agriculture and food security.

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