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STRATEGIES FOR SUSTAINABLE FODDER SECURITY THROUGH AGROFORESTRY IN CHANGING GLOBAL CLIMATE- A REVIEW

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SUMMARY

In Indian agriculture, livestock plays an essential role in the development and progress of mankind with crop production program as a complementary enterprise. However, livestock productivity is constrained by an acute shortage of feed and fodder. Estimate on demand-supply gap in fodder availability shows a net deficiency of 11.23% green fodder, 23.40% dry fodder and 28.90% concentrate feed materials in the country. By 2050, the demand for green and dry feed will be 1012 and 631 million tones, respectively. In the year 2050, with the current rate of expansion in forage supplies, there will be an 18.4% deficit in green fodder and a 13.2% shortfall in dry fodder. Agroforestry is latest advertise opportunity and sustainable climate-smart cultivation, land stewardship and environment for animals. Silvipastoral agroforestry practices are low-input intervention for the waste/ unutilized lands, to check the further degradation and supply the livestock fodder through tree leaves and forages besides fuel wood, small timber and pasture seeds. The potential of agroforestry seems to be substantial; but it remains under recognized as a greenhouse gas mitigation option for agriculture in the world.

Key words: Agroforestry, fodder, sustainable, climate change, mitigation

Sustainable fodder production is becoming critical in supporting the livestock sector, particularly in regions where agriculture is the backbone of rural livelihoods. India, with its diverse agro-climatic zones, faces acute challenges in maintaining fodder production due to the impacts of climate change and soil degradation. These challenges are amplified by the country's dependence on monsoonal rainfall, which is now becoming erratic and unpredictable. As the effects of climate change intensify, innovative and least invasive, nature-positive strategies must be implemented to ensure the resilience and sustainability of fodder production systems. Climate change has introduced severe disruptions to India's agricultural landscape, with notable impacts on fodder production (Singh *et al.*, 2022). The consequences of these climatic shifts are not only reflected in reduced yields but also in the deteriorating forage quality, which directly affects livestock productivity (Ressaissi *et al.*, 2023). Livestock sector is a vital subsector of agriculture and plays a prominent role in the socio-economic development of the country. The sector plays a significant role to empower rural women and youth, improve natural resource-use efficiency, and increase the resilience of households to cope with climate shocks (Kumar, 2022). In several countries across the world, the surging demand for livestock products is largely met by large-scale livestock production and associated food chains. Livestock sector contributes to nearly 40 per cent of total agricultural output in developed countries and 20 per cent in developing countries, supporting the livelihoods of at least 1.3 billion people worldwide (FAO, 2022). Thirty-four per cent of global food protein supply comes from livestock. International trade acts as an engine of economic growth. It promotes competition, flow of knowledge, capital and technologies and hence the efficient allocation of scarce resources. With expanding markets, the trade specialization on a large scale and enhance availability of goods at competitive prices leading to increase real income and consumption.

In India, almost entire feed requirement for livestock production is met extensively from crop residues/by-products, grasses, herbages, weeds and tree browses collected from cultivated/uncultivated fields and grazing on common property resources like forests, pastures, village commons and fallow lands (Rawat and Vishvakarma, 2011). The limited land allocation to fodder crops cultivation having only 4% of gross cropped area has resulted in severe deficit of feed supply, restricting efficient livestock production (Islam *et al*., 2021). Estimate on demand-supply gap in fodder availability shows a net deficiency of 11.23% green fodder, 23.40% dry fodder and 28.90% concentrate feed materials in the country (Roy *et al*., 2019). By 2050, the demand for green and dry feed will be 1012 and 631 million tones, respectively. In the year 2050, with the current rate of expansion in forage supplies, there will be an 18.4% deficit in green fodder and a 13.2% shortfall in dry fodder (Dhamodharan *et al*., 2024). Green forage supply must rise at a rate of 1.69% per annum to satisfy the deficit; however, the area under cultivated fodder accounts for only 4% of the total cultivated land (8.4 million ha) in the country, and has remained unchanged over last few decades. (Dagar, 2017), which is not adequate to meet the fodder demand. Besides, more emphasis on food grains further add to the fury by limiting area under fodder crops and resultant shortage of fodder production as well as supply of feed (Kumar *et al*., 2019). In the current scenario, where the probability of increasing area under fodder crops is nearly impossible, it is imminent to adopt a multi-pronged strategy for adequate fodder production to keep pace with the current demand and future challenges (Singh *et al*., 2022). Further, the impacts of climate change, including increasing temperatures, changing precipitation patterns, and the frequency of extreme weather events, further exacerbate the challenges faced by these regions, making it increasingly difficult to sustain traditional fodder production practices (Malhi *et al*., 2021). As a result, comprehensive strategies are required for sustainable fodder production which should be location specific, diversified and above all climate resilient

Agroforestry is latest advertise opportunity and sustainable climate-smart cultivation, land stewardship and environment for animals. Silvipastoral agroforestry practices are low-input intervention for the waste/unutilized lands, to check the further degradation and supply the livestock fodder through tree leaves and forages besides fuel wood, small timber and pasture seeds (Mathukia *et al.*, 2016). The silvipastoral agroforestry system envisages the production of fodder trees/crops (Martinelli *et al*., 2019), extending fodder cultivation to fallow and unutilized lands (Nahed-Toral *et al*., 2013), promotion of non-traditional fodder varieties/hybrids (Rivera *et. al*., 2013; Martinelli *et al*., 2019), supply of quality fodder seeds (Islam *etal*., 2021), postharvest technologies for fodder storage/preservation for off-season/exigency, optimizing land productivity (Brown *et al*., 2018) and conserving biodiversity, soils and nutrients (Blanc *et al*., 2019). The silvipastoral agroforestry models evolved, tried, perfected and tested on fields across the world (Jose and Dollinger, 2019) have already demonstrated the utility of these technologies for socioeconomic, cultural and ecological sustainability.

Significance of fodder trees

Cultivation of fodder trees and bushes has several advantages compared to seasonal fodder crops. Foremost is their adaptability to harsh agro-climatic conditions. Fodder trees utilize limited quantities of water while remaining productive for longer periods. As they require minimum maintenance after establishment, the cost of production is low. Flexibility in harvesting fodder from woody perennials is an added advantage; tree fodder is only used when other fodder resources are exhausted. The growth pattern of various crops over two-year period reveals that trees require care during the establishment phase and once it is established, they show more persistence and the yield increases over the passage of time. However, herbaceous/shrub legumes require more careful tending throughout the crop growing period and yield declines with subsequent cutting over years. Fodder trees are considerably less affected by dry conditions as they have deep root systems which enables in extraction of water and nutrients from soil even during dry season (Teferi *et al*., 2008). This characteristic enables these plants to retain fresh foliage into the dry season. Moreover, the hot and wet climate of humid tropical zone favors luxuriant growth of fodder trees.

The greatest value of fodder trees lies in their role as diet supplements rich in protein, energy, minerals and vitamins. Fodder trees have almost double the amount of protein (18 to 25%) and high levels of essential elements such as calcium, sodium and sulphur as well as critical micronutrients such as iron and zinc when compared to fodder grass species, which can save farmers expenses on purchased concentrate feeds (Moleele, 1998). Tree leaves are a rich source of supplementary protein, vitamins and minerals and their use in ruminants helps to enhance microbial growth and digestion (Cheema *et al*., 2011). Leguminous tree species are favoured than non-leguminous because of their high foliar protein content and ability to fix nitrogen (Gutteridge and Shelton, 1994), which in turn enrich the soil nutrient content. Jamala *et al.* (2013) claimed that leguminous species contain 25 to 50% more crude protein than non-leguminous plants. As per Mathukia*et al.* (2016) about 25% of the total annual diet of live stock is composed of trees and shrubs. Tree species for dry areas are *Acacia modesta, A. nilotica, Ailanthus excelsa, A. lebbeck, Leucaena leucocephala, Ziziphus mauritiana, Tecomella undulata,* etc. *A. nilotica* seeds contain crude protein (18.6%), whereas *L. leucocephala* seeds are the highest in protein (about 30%). Moreover, while integrating with existing cropping systems, maintaining fodder trees as hedges also regulates the possible competition to the main crop and facilitates easy harvesting of fodder (Raj *et al.*, 2019). The increased forage supply provided by such systems is projected to lessen grazing pressure, resulting in significant environmental benefits.

Status of tree fodders in India

In large parts of India, animals' feed on tree or shrub leaves, usually rich in protein therefore, used as a supplement for low-protein fodders. The value of trees for feeding animals necessitates the planting of multipurpose fodder trees, which are, otherwise, primarily grown for fuel and timber purpose. In India, several exotic and indigenous trees including fodder trees were introduced during 1950s, to the Central Arid Zone Research Institute (CAZRI), Jodhpur, Rajasthan. Amongst exotic fodder trees and shrubs, most promising one includes *Acacia tortilis, Cellophospermum mopane, Prosopis juliflora, Dichrostachys mutans, Brasilettiamollis, Pittosporum phillyraesides, Schirueus mole, Atriplex spp.*, and *Zizyphus spinacristi w*hile, successful indigenous introductions were *Ailanthus excelsa, Albizia amara, Cardio roti, Albizia lebbek, Acacia nilotica, Hardwickia binata, Azardirachta indica, A. excelsa, and Prosopis cineraria* (Raghavan, 1989). The leaves of most of these trees are rich in nutrients. This type of fodder becomes more relevant during drought period, when there is scarcity of fodder. Exotic and indigenous fodder trees were introduced either due to lack of availability of such useful trees or their slow growth and inability to meet feed requirements of the area (Patil *et al.*, 1983). However, most of the areas and vegetations, which could serve as fodder for animals, are mainly found in semi-arid regions of the country (Raghavan, 1989).

Choice of tree species

Not all types of trees and shrubs can be used for fodder production. When farmers select trees for fodder production they should look for several characteristics: Leaves and pods should have a high nutritive value, which means that they contain a lot of protein. Trees should produce many leaves and re-grow easily after frequent pruning. Edible parts of the tree should not contain too much toxins. Tree leaves need to have a high palatability, which means that the animals like to eat them and can digest them well. Trees must preferably be tolerant to drought, pests and diseases. Trees should not compete too much with other crops. With proper management and propagation techniques, this fodder can be a viable feed resource to supplement the income of small and landless farmers. In mixed farming systems, trees and shrubs can have a stabilizing effect on prices as farmers have a longer holding capacity and are not forced into selling animals in periods of drought (Knipscheer *et al.*, 1987). Both trees and shrubs also provide multiple benefits (fuel, wood for furniture and other uses, leaves and shoots for use by animals, etc.). In addition, they also help to stabilize the soil and improve the environment. In harsh environments, particularly in dryland ecosystem, there is considerable scope to encourage the use of trees and shrubs by further educating farmers (Winrock International, 1991). Basic characteristics required of an alley farming tree species include the following: fast-growing, nitrogen-fixing, nitrogen-rich leaves, tolerance to pruning, ability to coppice vigorously and good fodder value (Atta-Krahand Sum berg, 1988). In addition to these, such other characteristics as high foliage productivity, vigorous tap root development, and dry season leaf retention are advantageous (Rachie, 1983). India launched the much-needed National Agroforestry Policy (NAFP) in 2014, the NAFP is a path-breaker in making agroforestry an instrument for transforming lives of rural farming population, protecting ecosystem and ensuring food and fodder security through sustainable means (Chavan *et al.*, 2015). In this silvi-pastoral system of agroforestry, various multipurpose trees (protein rich trees) are planted on wasteland and rangelands for cut and carry fodder production to meet the feed requirements of livestock during the fodder deficit period in winter. About 25% of the total annual diet of livestock is composed of trees and shrubs.

Fodder production through agroforestry

Agri-silvi-pastoral approach integrates crop, fodder, trees, and livestock in the same unit of land through intercropping, aiming at complementarities among the component crops. The integration can promote land sparing and eco-efficiency of agricultural production, reduce soil degradation, recuperate pastures, and protect environment; improve system productivity and quality of rural employment (Venkatesh *et al*., 2024); reduce production cost and multiple outputs that reduce the market risks, alleviate the risks of crop failure under extreme weather events (Choudhary *et al*., 2022) ; increase purchasing power and food stability; and lessen vulnerability resulting in sustainable systems compared to non-integrated monocultures or land-use systems (Aarssen, 1997). It is also reported that growing of fodder crops along with food crops and trees improves fodder palatability and digestibility (Kumar *et al*., 2018). Inclusion of fodder trees along with fodder and crops can meet the food and fodder requirements of farmers and livestock (Mishra *et al*., 2010). The fodder trees in the agri-silvi-pastoral systems can provide income from timber and can alleviate some of the deficit of green fodder (Nair *et al*., 2021). They are hardy and perennial and thus can potentially provide feed for the livestock throughout the year. It has been reported that fodder leaves from tree can improve the performance of dairy animals as well as small ruminants in rainfed environments. The leaves of leguminous fodder trees are considered as highly nutritious feed with high digestibility and high protein (Bakshi and Wadhwa, 2012; Mishra, 2019). The fodder availability from crops is highly seasonal, being abundant in wet season and scarce in dry season. The tree tops however can be an excellent source of green fodder during the scarce months in dry season. However, the importance of trees as a fodder source and as an integral component of ruminant diet in times of scarcity in rainfed environments is seldom realized (Dagar, 2017). Combination of arable crop for grains, legume for fodder and fodder trees in a single unit of land has numerous advantages, like improving soil health, water infiltration, reduced soil erosion, improved soil fertility through enhanced carbon sequestration and reduced nutrient leaching (Vaishnav *et al*., 2025). Inclusion of perennial fodder legumes increases stability and hydraulic properties of the soil through there fine and fibrous root structure, and fixes atmospheric nitrogen, which is essentially important in rainfed areas (Ghosh *et al*., 2016). Leguminous fodder trees in agri-silvi-pastoral systems, can enhance soil fertility through biological nitrogen fixation, translocation of nutrients from deeper soil layers and water retention in smallholder rainfed farming environments (Nair, 2011). Main problems include overcoming competition for sun and nutrients for the trees and crops (Raj *et al*., 2024). Silvoarable systems entail planting trees in lines and arable crops in the intervals between the trees (Lawson *et al*., 2019). These systems improve soil conservation, biodiversity, and carbon sequestration. They require complicated management regimes to balance tree and crop productivity. The organization of an agroforestry system may be characterized in terms of its elements and their proposed roles (Nair, *et al*., 2010). This categorization considers the organization of elements, such as the spatial arrangement of perennial woody plants, vertical layering of various elements, and their temporal organization.

Nutritional value of some fodder trees and shrubs

Leguminous species are found to contain 25 to 50% more crude protein than non-leguminous plants. Mokoboki *et al.* (2005) reported the nutritional values, the type and amount of tannins of acacia tree foliage (*Acacia karroo, Acacia nilotica, Acacia tortilis, Acacia galpinii, Acacia sieberiana, Acacia hebeclada and Acacia rhemniana)*. Almost all species had crude protein levels above 100 g/kg dry matter (DM), ranging from 103 g/kg DM for *A. rhemniana*to 183 g/kg DM for *A. sieberiana.* Crude protein (CP) levels of this magnitude in a diet are adequate to support the requirements of cattle, sheep and goats at low to medium production levels. Mokoboki *et al.* (2005) concluded that all the species except *A. galpinii, A. karoo and A. tortillis*are of good nutritive value. *Dichrostachys cinerea* is a valuable fodder tree and there are various beneficial effects resulting from supplementing ruminants with *D. cinerea*. Smith *et al.* (2005) reported improved performance of goats resulting from supplementation with *D. cinerea* fruits. Basha *et al.* (2009) reported *D. cinerea* to have 123.2 g/kg CP, and low tannin content (57.9 g/kg). The chemical composition of combretum species (*C. apiculatum, C. molle and C. zeyheri)* was well determined by Lukhele and Van Ryssen (2003). Mean values CP concentration varied from 92 g/kg DM for *C. molle* to 141 mg/kg DM for *C. mopani*. These values are comparable to those reported for acacia species (Mokoboki *et al*., 2005). *Ficus sycomorus* is also among the identified browse species since it provides fruits and leaves. Nutritional status of this species was determined by Nkafamiya *et al.* (2010). Results obtained for proximate composition showed protein content of 17.24 ± 0, 71% and it has a high percentage of crude fibre (31.54 ± 0, 11%). They concluded that *F. sycomorus* can serve as a good source of nutrients. *Diospyros mesipiiformis* was found to have low levels of CP (5.46 g/kg) but high levels of total carbohydrates (77.21%) (Ezeagu *et al.*, 2002). The crude protein content varied between 10.44 to 1.71 per cent in dry regions of fodder trees and shrubs of Maharashtra (Gaikwad *et al.*, 2017). It was the highest in *Nyetanthes arbortritis* (10.44%) and the least in *Acacia nilotica* (1.71%). *Moringa olifera*, *Ziziphus mauritina*, *Psidium guajava*, *Sesbania sesban* and *Leucana leucocephala* were recorded the protein content 7.08, 7.03, 6.74 and 6.41 per cent, respectively. Leucaena, moringa, mulberry, calliandra, sesbania, gliricidia, erythrina, and kadamba are some good fodder tree species suitable to be grown as fodder bank in humid regions (Patrick *et al.*, 2020). Naveli *et al.* (2022) studied the seasonal variation in nutritive values of different fodder trees and found that *Morus serrata* had the highest relative nutritive value index in spring and summer, while *Grevia optiva* during autumn and winter. Similarly, L*eucaena leucocephala* had the highest palatability (97.86%), while *Meliacomposita* (38.47%) had the lowest one. Additionally, *G. optiva* was the most favored MPT for livestock among farmers, while *M. composita* was the least ones. The outcome of the study will help policy makers, planners and farm managers in establishing large scale plantations of highly nutritious and palatable species, like *G. optiva*, *L. leucocephala*, *B*auhinia *variegata*, and *M. serrata* for year-round supply of green leaves and as a supplement to low-quality feed. Fodder trees exhibit higher nutrient content than grasses, even during the dry season, as they retain their greenness when most grasses and herbs dry out (Ayenew, 2021). They are considered as drought reserves and a source of protein-rich fodder (Manoj *et al.*, 2021). Moreover, fodder trees possess multiple socioeconomic benefits and can provide several of other products and services that are advantageous to household. Fodder trees yield more per unit area and can be cultivated on small plots of land that are typically not used for crop production. However, the presence of high concentrations of antinutritional factors (ANFs) in fodder trees can deter herbivore consumption (Naumann *et al.*, 2017). These ANFs reduce feed intake, impede nutrient digestibility, and consequently, decrease nitrogen retention within herbivores. Their effects on livestock can range from beneficial to toxic and fatal (Wondimu *et al.*, 2024)

Carbon Sequestration Potential

Agroforestry plays vital roles in mitigation of atmospheric accumulation of GHGs (Dhillon and Wuehlisch, 2013). Carbon sequestration rates are very encouraging for complex agroforestry, boundary planting, hedgerow intercropping, and 'home gardens' (Calfapietra *et al.*, 2010). Nevertheless, highest carbon storage results are found in "multistory/compex" agroforestry systems (Sajwaj *et al.*, 2008) that have many diverse species using ecological "niches" from the high canopy to bottom story shade-tolerant crops. Examples are shade-grown coffee and cocoa plantations, where cash crops are grown under a canopy of trees that sequester carbon and provide habitats for wildlife. Simple intercrops are used where tree-crop competition is minimal. In fact, there is a need to develop agroforestry models as per differential value of tree crop species and also as per soil and climate differences. The silvipastoral system in a natural grassland in the semi-arid state of Uttar Pradesh, where introduced species of *Albizia procera*, *Eucalyptus tereticornis*, *Albizia lebbeck*, *Embilica officinalis* and *Dalbergia sissoo* accumulated 8.6, 6.92, 6.52, 6.25 and 5.41 t/ha/yr of biomass (Rai *et al.*, 2009). The carbon storage in the system was 1.89-3.45 t C/ha in silvipasture and 3.94 t C/ha in pure pasture. Kaur *et al.* (2002) observed that an increase in organic carbon of 1.7 to 2.3 times in a silvipastoral system connecting *Leucaenea leucocephala*, *Cenchrus ciliaris* and *Stylosanthes hamata* as compared to a control. Alike studies have observed that the higher organic carbon levels in dry sub-humid and arid ecosystems when grass species are intercropped with annual crops in a silvipastoral system with no increase in organic carbon with grasses in an arid ecosystem (Venkateswaralu, 2010). In a silvipastoral system, carbon flux in net primary productivity increased due to the integration of *Prosopis juliflora* and *Dalbergia sissoo* with grasses (Narain, 2008). The potential of agroforestry seems to be substantial; but it remains under recognized as a greenhouse gas mitigation option for agriculture in the world (Vaishnav *et al.*, 2025).

Extension strategies for increasing fodder production

Several factors affect the adoption of innovative farming practices, including socioeconomic barriers, lack of access to knowledge, and limited support from institutions. However, opportunities exist to improve adoption through better extension services, financial incentives, and targeted training programs. One of the most significant barriers to adopting sustainable fodder systems is the lack of knowledge about innovative practices. The awareness programmes have shown that farmers often have limited awareness of the benefits of strategies like fodder tree technology. Poor dissemination of information about new agricultural practices impedes adoption, with a large portion of smallholder farmers being unaware of the potential benefits (Halli *et al.*, 2018). Many sustainable fodder strategies require significant initial investment, such as the adoption of hydroponic systems or the installation of drip irrigation. Study indicated that high installation costs were a major barrier to wider adoption by the farmers adopting hydroponic fodder production, despite the long-term benefits of this technology (Uddin and Dhar, 2018). Similarly, the purchase of seeds, fertilizers, and other inputs required for salt-tolerant species can be expensive and limiting adoption among resource poor farmers. Insufficient extension services aggravate the challenges of adopting sustainable practices. Farmers require ongoing support to learn and implement new strategies, but in several agro-climatic regions, extension services related to sustainable supply of fodder to the animalsround the year is underdeveloped. This gap results in a lack of technical knowledge transfer to farmers and poor access to sustainable practices like fodder conservation or bioremediation techniques. The lack of reliable markets for fodder-related products, including carbon credits and sustainable farm outputs, further deters adoption. While systems like agroforestry offer long-term benefits such as carbon sequestration, the short-term market returns may not be enough to incentivize farmers to invest in these strategies. Farmers, particularly smallholders, often operate on thin margins and prioritize immediate profitability over long-term sustainability benefits. Strengthening extension services is a critical step toward improving adoption rates of sustainable fodder strategies. Programs aimed at training farmers in climate-resilient practices and fodder conservation techniques, such as silage-making, can significantly increase knowledge transfer. It is necessary to address the opportunities related to increasing the fodder yield of cultivated fodder crops and efficient use of crop residues. The selection and application of fodder production technologies should conform to the framework of sustainability criteria. Potentially important technologies that can make a significant increase in productivity of both crops and animals within the system should be promoted. This shall consequently increase farmers' income and also meet the demand of raising human population. The participatory approaches for introduction of forage production technologies with smallholder farmers in selected areas are to be advocated based on experiences gained through conduction of on-farm research. Emphasis should be placed on farmer-led, farmer-to-farmer extension, with volunteer farmers serving as resource persons in development and promotion of interventions. Exposure visits and dialogue can also used as a guiding principle, involving open discussion among farmers, NGO workers and researchers. Apart from this, focused group discussions and diagnostic surveys should also be undertaken in order to obtain full information at various stages of implementation. Thus, making available several intervention options allowed the farmers to choose what was most appropriate in their circumstances (Misra *et al.,* 2022).

Future perspective

The eco-friendlystrategies for fodder production are useful, particularly under the increasing pressures of climate change and soil degradation. Integrating agro-ecological methods such as crop rotation, intercropping, and multiple systems, along with agroforestry, offers a promising pathway toward ensuring both productivity and resilience of fodder systems. These strategies not only improve soil fertility and structure through biological nitrogen fixation and enhanced organic carbon, but also promote biodiversity and ecosystem services, such as carbon sequestration and improved water use efficiency. Agroforestry, in particular, stands out as a holistic solution, combining tree species with fodder crops to create systems that not only increase fodderyield but also contribute significantly to soil health, erosion control, and carbon capture, therebymitigating the adverse effects of climate change. Shifting from chemical fertilizers to integrated practices, combining organic amendments likefarmyard manure (FYM) with biofertilizers, providesa sustainable way to enhance fodder yields whilecombating soil degradation and nutrient depletion.Water management strategies, including efficient irrigation techniques and the use of rainwaterharvesting, further complement these efforts bymitigating the impacts of water scarcity in arid andsemi-arid regions. The use of salt-tolerant tree and fodder species and amendments such as gypsum and biochar mitigate soil salinity and acidity, whileimproving soil structure and nutrient availability. Selection of new genotypes and varieties of food crops having high forage value without reduction in food grain yield needs to be developed on a continuous basis. There is need to promote fodder production through improved agronomic practices and use of improved seed. An array of technologies- feed, fodder and feeding interventions have been developed and tested to improve the productivity of animals with varying degrees of success. Several of them have been successfully demonstrated at field level. There is need to upscale and out scale their adoption through state government departments, *Krishi Vigyan Kendras* and other extension agencies. Information technology platform may be used extensively to reach to the farmers with information related to feed, fodder and feeding interventions at individual farm level. A well established communication network would help the agroforestry, plant breeders' and animal nutrition scientists to understand the problems of the dairy farmers and offer suitable interventions.

CONCLUSION

Livestock is an integral component of farming systems in India. Fodder scarcity, high cost of feeds and low net returns are the major constraints faced by small and medium farmers in these systems. The undisputed role of fast-growing fodder trees as a livestock feed resource and nutrient supplement has been established. Agroforestry is a resilient and adaptive method of coping with climate change while maintaining the long-term sustainability of fodder, food and fuel wood in India. Apart from addressing fodder issue, tree fodder banks could be a practical approach for mitigation of global warming via carbon sequestration and the revival of biodiversity and sustainability of humid tropical regions, which has been dwindling at alarming rates in recent decades due to socio-economic changes. Such tree-based systems can bring a transformational change to the conventional land use and agricultural practices and can be extended to the wastelands and degraded areas for their restoration. In order to realize the full potential of agroforestry, there is a need to strengthen favorable policies, invest in research and development, and directly involve farmers through awareness generation programs, incentives, and capacity-building. An organized and inclusive agroforestry approach will help ensure ecological sustainability, economic stability, and climate resilience for generations to come.

REFERENCES

Aarssen, L. W., 1997: High productivity in grassland ecosystems: effected by species diversity or productive species, *Oikos*, **80**(1): 183-184.

Atta-Krah, A.N. and J. E. Sumberg, 1988: Studies with *Gliricidia sepium* for crop-livestock production systems in West Africa, *Agroforestry Systems*, **6**:97-118.

Ayenew, A., A. Tolera and A. Nurfeta, 2021: Assefa Farmers' preference and knowledge on indigenous multipurpose browse species towards their feed value in north western Ethiopia, *Agroecosystems*, **24**: 3124.

Bakshi, M. P. S. and M. Wadhwa, 2012: Comparative nutritional evaluation of forest tree leaves and wild grasses of semi hilly arid zone in Punjab, *Ind. J. Anim. Sciences*, **82**: 918-921.

Basha, N. A. D., P. F. Scogings and I. V. Nsahlai, 2009: Diet selection by Nguni goats in the Zululand Thornveld, *South African J. Anim. Science*, **39**: 33-36.

Blanc, S., C. M. Gasol, J. Martý´nez-Blanco, J. Mun˜oz, J. Coello, P. Casals, A. Mosso and F. Brun, 2019: Economic profitability of agroforestry in nitrate vulnerable zones in Catalonia (NE Spain), *Span. J. Agric. Res.*,**17**(1): 1-17.

Brown, S. E., D. C. Miller, P. J. Ordonez and K. Baylis, 2018: Evidence for the impacts of agroforestry on agricultural productivity, ecosystem services, and human well-being in high-income countries: a systematic map protocol, *Environmental Evidence*, **7**: 24.

Calfapietra, C., B. Gielen, D. Karnosky, R. Ceulemans and G. S. Mugnozza, 2010: Response and potential of agroforestry crops under global change, *Environ. Pollut.*, **158**:1095-1104.

Chavan, S. B., A. Keerthika, S. K. Dhyani, A. K. Handa, Ram Newaj and K. Rajarajan, 2015: National Agroforestry Policy in India: a low hanging fruit, *Current Science*, **108** (10): 1826-1834.

Cheema, U. B., M. Younas, J. I. Sultan, M.R. Virk, M. Tariq and A. Waheed, 2011: Fodder tree leaves: An alternative source of livestock feeding. *Advances in Agril. Biotechnology*, **2**: 22–33.

Choudhary, M., S. R. Kantwa, S. K. Chowdhary, Rajiv Agarwal, A. K. Dixit, P. D. Vekariya, N. Kumawat, D. V. Bhagat, S. V. Khadatre, O. P. Girothia and P. K. Pankaj, 2022: Enhancing fodder production in rainfed regions, *Indian Farming*, **72**(8): 42-45.

Dagar, J. C. 2017: Potentials for fodder production in degraded lands. In: *Approaches towards fodder security in India*, P. K. Ghosh, S. K. Mohanta, J. B. Singh, D. Vijay, R. V. Kumar, V. K. Yadav and S. Kumar (eds.). Studera Press, New Delhi. pp. 333–364.

Dhamodharan, P., J. Bhuvaneshwari, S. Sowmiya and R. Chinnadurai, 2024: Revitalizing fodder production: challenges and opportunities, *Int. J. Res. Agronomy*, **7**: 201-217.

Dhillon, R.S. and G. Von. Wuehlisch, 2013: Mitigation of global warming through renewable biomass, *Biomass and Bioenergy*, **48**(1): 75-90.

Ezeagu, I. E., C. C. Metges, J. Proll, K. J. Petzke and A. O. Akinsoyi-znu, 2002: Chemical composition and nutritive value of some wild-gathered tropical plant seeds, *Food and Nutri. Bulletin*, **17**(3):104.

FAO, 2022: Dairy Market Review: Overview of Global Dairy Market and Policy Developments in 2021, *Food and Agriculture Organization of United Nations*, Rome p. 1-21.

Gaikwad, U. S., A. B. Pawar and A. D. Kadlag, 2017: Nutritional status of fodder tree leaves and shrubs of scarcity zone of Maharashtra, *Advances in Life Sciences*, **7**(1): 11-14.

Ghosh, P. K., D. R. Palsaniya, and R. Srinivasan, 2016: Forage research in India: issues and strategies, *Agricultural Res. J.*, **53**(1):1-12.

Gutteridge, R. C. and H. M. Shelton, 1994: The role of forage tree legumes in cropping and grazing systems. In: *Forage Tree Legumes in Tropical Agriculture*. CAB International, UK. 389 p.

Halli, H. M., S. S. Rathore, N. Manjunatha and V. K. Wasnik, 2018: Advances in agronomic management for ensuring fodder security in semi-arid zones of India - A review, *Int. J. Current Microbiology and Applied Sciences,* **7**(2): 1912–1921.

IGFRI Vision 2050: Indian Grassland and Fodder Research Institute, Jhansi (UP). p. 40.

Islam, M. A., J.A. Mugloo, A. Raj, J. M. Bhat, A. A. Wani, A. A. Gatoo, A. P. Malik, N. A. Pala and M. Shah, 2021: Agroforestry Strategy for Revitalizing Fodder Security in Kashmir Himalaya, India. *Agricultural Research*, **11**(3): 528-538.

Jamala, G. Y., I.L. Tarimbuka, D. Moris and S. Mahai, 2013: The scope and potentials of fodder trees and shrubs in agroforestry, *IOSR Journal of Agriculture and Veterinary Science,* **5**(4): 11-17.

Jose, S. and J. Dollinger, 2019: Silvopasture : A sustainable livestock production system, *Agroforestry Systems*, **93**(1):1–9.

Kaur, B., S. R. Gupta and G. Singh, 2002: Carbon storage and nitrogen cycling in silvipastoral system on sodic soil North Western India, *Agroforestry Systems*, **54**: 21-29.

Knipscheer, H.C., R. D. Hart, and G. Baker, 1987: Socioeconomic aspects of small Ruminant activity. In: *Proceedings of Fourth International Conference on goats*, Brasilia, March 8-13.

Kumar, A., A. Kumar, C. Lata, S. Kumar, S. Mangalassery, J. P. Singh, A. K. Mishra and D. Dayal, 2018: Effect of salinity and alkalinity on responses of halophytic grasses, *Ind. J. Agric. Sci.*, **88** (8): 149-157.

Kumar, A., S. S. Kadam, R. P. Yadav and R. Srinivassan, 2019: Tree fodder as an alternate land use option for sustaining forage security in India, *Int. J. Chemical Studies*, **7**(2): 202-207.

Kumar, V., 2022: Pattern and composition of livestock products' export in the context of the WTO. *Working Paper 2022-2,* NABARD, Mumbai. pp. 1-37.

Lawson, G. C., Dupraz and J. Watté, 2019: Can silvoarable systems maintain yield, resilience, and diversity in the face of changing environments? In: *Agroecosystem Diversity*. Academic Press; 2019, Cambridge, UK. pp. 145-168.

Lukhele, M. S. and J. B. J. Van Ryssen, 2003: The chemical composition and potential nutritive value of the foliage of four subtropical tree species in Southern Africa for ruminants, *South African J. Animal Science,* **33**(2): 132-141.

Malhi, G.S., M. Kaur and P. Kaushik, 2021: Impact of climate change on agriculture and its mitigation strategies: A review, *Sustainability*, **13**: 1318.

Manoj, K.N., B.G. Shekara, S. Sridhara, P.K. Jha and P.V.V. Prasad, 2021: Biomass quantity and quality from different year-round cereal-legume cropping systems as forage or fodder for livestock, *Sustainability*, **13**: 9414.

Maraseni, T.N., G. Cockfield and J. Maroulis, 2009: An assessment of silvipasture potential in southeast Queensland. Australia Australasian, *J. Regional Studies*, **15**(3): 297–310.

Martinelli, G.D.C., M. M. Schlindwein, M.P. Padovan and R. M. T. Gimenes, 2019: Decreasing uncertainties and reversing paradigms on the economic performance of agroforestry systems in Brazil, *Land Use Policy*, **80**(1): 274–286.

Mathukia, R.K., B. K. Sagarka and D. M. Panara, 2016: Fodder production through agroforestry : A boon for profitable dairy farming, *Innovare. J. Agril. Sciences*, **4**(2):13–19.

Mishra, A. K. 2019: Fodder Production and Utilization Strategies for Sustainable Livestock Development in India, *Annals of Arid Zone*, **58** (1&2): 1-11

Mishra, A.K., C. A. Rama Rao and K. Ravishankar, 2010: Analysis of potentials and problems of diary production in rainfed agro-ecosystem of India, *Indian J. Animal Sciences,* **80**(11): 1126-1133.

Mishra, A.K., D. D. Sinha, D. Grover, S. Mishra, R. Tyagi, H. S. Sheoran and S. Sharma, 2022: Regenerative agriculture as climate smart solution to improve soil health and crop productivity thereby catalysing farmers' livelihood and sustainability. In: *Towards Sustainable Natural Resources: Monitoring and Managing Ecosystem Biodiversity*, Cham: Springer, Switzerland. pp. 295-309.

Mokoboki, H. K., L. R. Ndlovu, J. W. Ng'ambi, M.M, Malatje and R. V. Nikolova, 2005: Nutritive value of Acacia tree foliage growing in the Limpopo province of South Africa, *South African J. Animal Science,* **35**: 221-228.

Moleele, N. M., 1998: Encroacher woody plant browse as feed for cattle. Cattle diet composition for three seasons at Olifants Drift, south-east Botswana, *J. Arid Environment,* **40**(3): 255-268.

Nahed-Toral, J., A. Valdivieso-Perez, R. Aguilar-Jimenez, J. Camara-Cordova and D. Grande-Cano, 2013: Silvopastoral systems with traditional management in South-Eastern Mexico: A prototype of livestock agroforestry for cleaner production, *J. Clean. Prod.,* **57**(1):266–279.

Nair, P. K. R., 2011: Agroforestry Systems and Environmental Quality: Introduction, *J. Environmental Quality*, **40**(3): 784-790.

Nair, P.K. R., B. M. Kumar and V. Nair, 2021: Classification of agroforestry systems. In: *An Introduction to Agroforestry: Four Decades of Scientific Developments*. Kluwer Academic Publishers, London. pp. 29-44.

Nair, P.K. R., V. D. Nair, B. M. Kumar and J. M. Showalter, 2010: Carbon sequestration in agroforestry systems, *Advances in Agronomy*, **108**:237-307.

Narain, P., 2008: Dryland management in arid ecosystem, *J. Ind. Society of Soil Science*, **56**: 337-347.

Naumann, H.D., L.O. Tedeschi, W.E. Zeller and N.F. Huntley, 2017: The role of condensed tannins in ruminant animal production: advances, limitations and future directions, *Rev. Bras. Zootec.*, **46** : 929-949.

Navele, M. R., D. R. Bhardwaj, R. Bishist, L. Thakur, S. Sharma, P. Sharma and D. Kumar, 2022 : Seasonal variations in the nutritive value of fifteen multipurpose fodder tree species: A case study of north-western Himalayan mid-hills, *Plos*, **17**: 1-23.

Nkafamiya, I. I., S. A. Osemeahon, U. U. Modibbo and A. Aminu, 2010: Nutritional status of non-conventional leafy vegetables, *Ficus asperifolia* and *Ficus sycomorus*, *African J. Food Science*, **4**: 104-108.

Patil, B.D., R. Deb Roy and P. S. Pathak, 1983: Climatic consideration in introducing and propagating exotic and indigenous fodder trees. In: *Top Feed Resources, their Production, Utilization and Constraints*, M. Singh (ed.). Central Sheep and Wool Research Institute, Avikanagar, India. pp.77-83.

Patrick, A., 2019 : Productivity of tree fodder banks in selected homegardens of Central Kerala.' M.Sc. thesis, Kerala Agricultural University, Thrissur, p.120 .

Patrick, A., A. Raj, A. K. Raj, T. K. Kunhamu, V. Jamaludheen and A. V. Santhoshkumar, 2020: Productivity of tree fodder banks in a typical homegarden of Central Kerala, *Ind. J. Agroforestry*, **22**(1): 17–23.

Rachie, K.O., 1983: Intercropping tree legumes with annual crops. In: *Plant Research and Agroforestry*, P.A. Huxley (ed.). ICRAF, Nairobi, Kenya. pp. 103-116.

Raghavan, G.V., 1989: Availability and use of shrubs and tree fodders in India. In: *Shrubs and Tree Fodders for Farm Animals*, C. Devendra (ed.). Proceedings of a workshop in Denpasar, Indonesia, 24-29 July. pp. 196-210.

Rai, P., Ajit, R. Singh and U.P. Singh, 2009: Biomass production in multipurpose tree species in natural grasslands under semi-arid conditions, *J. Tropical Forestry*, **25**: 11-16.

Raj, A., M. K. Jhariya, A. Banerjee, R. K. Jha and K. P. Singh, 2024: *Agroforestry*. John Wiley & Sons, New Jersey, USA. 576 p.

Raj, R. M., A. K. Raj, T. K. Kunhamu and A. Prakash, 2019: Fodder yield and nutritive value of mulberry (*Morusindica*L.) under varying plant density and pruning frequency in coconut garden, *Range Management and Agroforestry*, **40**(2): 255–261.

Rawat, Y. S. and S. C. R. Vishvakarma, 2011: Pattern of fodder utilization in relation to sustainability under indigenous agroforestry systems, North-Western Himalaya, India. Environment and We, *Int. J. Sci. and Tech.*,**1**(6): 1–13.

Ressaissi, N., M. T. Sanchez-Ballesta, and M. Badri, 2023: Influence of drought and heat stresses in fodder legumes productivity and nutritive value, *J. Oasis Ag. and Sustainable Development*, **5**:18-26.

Rivera, L., I. Armbrecht and Z. Calle, 2013: Silvopastoral systems and ant diversity conservation in a cattle dominated landscape of the Colombian Andes, *Agr. Ecosyst. Environ.***181**: 188-194.

Roy, A. K., R. K. Agrawal, N. R. Bhardwaj, A. K. Mishra and S. K. Mahanta, 2019 : In: Indian Fodder Scenario: Redefining State Wise Status (eds. A. K. Roy, R. K. Agrawal, N. R. Bhardwaj). ICAR AICRP on Forage Crops and Utilization, Jhansi, India, pp. 1-21.

Sajwaj, T., M. Harley and C. Parker, 2008: Eliasch review: Forest Management Impacts on Ecosystem Services, *Report to the Office of Climate Change, EAT/ENV/R/2623/Issue*, **1**: 1-31.

Singh, D. N., J. S. Bohra, V. Tyagi, T. Singh, T.R. Banjara and G. Gupta, 2022: A review of India's fodder production status and opportunities, *Grass and Forage Science*,**77**: 1-10.

Smith, T., V. Mlambo, J. L.N. Sikosana, V. Maphosa, I. Mueller-Harvey and E. Owen, 2005: *Dichrostachys cinerea* and *Acacia nilotica* fruits as dry season feed supplements for goats in a semi-arid environment, *Animal Feed Science and Technology*, **122***:* 149-157.

Teferi, A., M. Solomon and N. Lisanework, 2008: Management and utilization of browse species as livestock feed in semi-arid district of North Ethiopia, *Livestock Res. and Rural Devel.*, **20**: 2342-2363.

Uddin, M.T. and A. R. Dhar, 2018: Socioeconomic analysis of hydroponic fodder production in selected areas of Bangladesh: prospects and challenges, *SAARC J. Agriculture*, **16**: 233-247.

Vaishnav, R., K. Mallikarjun, R. Pradhan, B. N. Paul, A. G. Kartik, S. Dhiman, A.P. Singh and A. Kumar, 2025: Agroforestry for climate resilience: A holistic and sustainable approach for India: A comprehensive review, *Int. J. Adv. Biochemistry Research*, **9**(2): 390-402.

Venkatesh, G., K. A. Gopinath, D. B. V. Ramana, V. Vishal Kumari, I. Srinivas, A. K. Shanker, K. V. Rao, J. V. N. S. Prasad, K. Sammi Reddy, K. B. Sridhar, B. Sarkar, B. M. K. Raju, B. Rajkumar and J. Timsina, 2024: Agrosilvopastoral systems for improved crop and fodder productivity and soil health in the rainfed environments of South India, *Agricultural Systems*, **214**: 103812.

Venkateswaralu, J., 2010: *Rainfed Agriculture in India: Research and Development Scenario*. Indian council of Agricultural Research, New Delhi. pp 508.

Winrock International 1991: *Interim Report of the Assessment of Animal Agriculture in Sub-Saharan Africa*. The Technical Advisory Committee of the Consultative Group on International Agricultural Research, Petit Jean Mountain, Morrilton, Arizona, USA.

Wondimu, B., Y. Tadele and A. Tonamo, 2024: Fodder trees: Identification, leaf biomass yield, nutritional quality and socioeconomic importance in Essera district, Dawuro zone, Southwest Ethiopia, *J. Agriculture and Food Research*, **18**: 101371.