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SUSTAINABLE FORAGE STRATEGIES FOR YEAR-ROUND DAIRY NUTRITION

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Forage constitutes the biological and economic foundation of ruminant production. However, seasonal fluctuations in forage availability driven by climatic volatility pose a significant threat to livestock productivity. In the Indian dairy, the Forage gap is the most significant structural barrier to achieving the genetic potential of both indigenous and crossbred bovines. This gap is not just a seasonal shortage it is a chronic deficiency in both the quantity of biomass and the quality of available nutrients. One of the main issues facing the global livestock business is the supply of feed as the world's population expands and the demand for animal products rises. Nonetheless, dairy and beef feed make up over 19% of the 1.29 billion tons of animal feed produced worldwide (Alltech, 2024). This percentage is much greater in some areas, especially when it comes to feeding ruminant livestock, who mostly depend on roughage and fodder. The sustainable growth of agriculture and livestock husbandry depends on the provision of adequate and superior feed (He *et al*., 2023). Ensuring year-round production requires a transition from reactive feeding to a proactive forage management strategy, integrating both high-tech cultivation and advanced preservation techniques.

Demand and Supply of Forage

India is the world's largest milk producer, yet it faces a persistent deficit in animal feed. As per IGFRI VISION 2050, there is approximately 35.6%, 10.5% and 44% deficiency of Green fodder, Dry fodder and Concentrate. The gap is exacerbated by the fact that only about 4–5% of India’s total cultivable land is under fodder production. In India, the forage gap occurs in two distinct lean periods which are Summer Gap (April–June) occurs in Post-Rabi harvest due to extreme thermic stress and water scarcity and Winter Gap (November–December) in which the transition between Kharif and Rabi crops. Traditional grazing systems often fail to meet the metabolic demands of high-yielding bovines during thermal stress or drought as the forage gap is often filled with crop residues like paddy straw or wheat straw. While this satisfies

the animal's physical hunger, it leads to nutritional dilution as a result of lignification which prevent rumen microbes from accessing energy, Anti-Nutritional factors: which interfere with calcium absorption, leading to milk fever and poor bone health and producing significantly more methane per liter of milk, increasing the environmental footprint of Indian dairy.

Constraints in Fodder Production

Fodder production in India faces multiple interlinked constraints that limit sustainability and productivity. The most fundamental challenge is land scarcity, as area dedicated to fodder has stagnated at only 4–5% of cultivable land for decades (Meena *et al*., 2018). Genetic erosion along with a low seed replacement rate (often below 20%) and limited availability of improved, climate-resilient seed varieties beyond select regions (Parihar, 2010). Water stress is another major barrier, since high-protein fodders such as lucerne and berseem demand intensive irrigation, yet much of India's fodder production remains rain-fed and vulnerable to erratic monsoons. Post-harvest inefficiencies also lead to significant wastage such as paddy straw burning, nutrient losses during sun-drying, and poor adoption of silage technology among smallholders. Additionally, most dairy farmers are smallholders who cannot afford dedicated fodder cultivation, extension services remain fragmented and the absence of organized fodder markets makes fodder cultivation a risky venture.

Strategies for Year-round Fodder Production

A. Cropping systems

- **Silvopastoral Systems:** Integration of fodder trees like *Leucaena leucocephala* (Subabul), *Moringa oleifera* (Shehjan) and *Azadirachta indica* (Neem) provide a deep-rooted nutrient source that remains green during summer lean period when ground grasses are dormant, while offering shade to mitigate heat stress. Their deep root systems can access groundwater from deeper soil strata, ensuring that the farm produces green biomass even during prolonged drought cycles.
- **Multiple cropping:** Intercropping is the strategic cultivation of two or more crop species simultaneously on the same piece of land. Intercropping had been found to increase crop yield (Li *et al*., 2020) and resource use efficiency (Liu and Zhao, 2023). Intercropping can increase crude protein content by 11–51 % compared to monocropping (Meng *et al*., 2022). Relay cropping is a multiple cropping system that consists in planting a second crop into a standing first crop prior to its harvest. Relay

cropping include increased crop productivity, net economic returns, land use efficiency, soil fertility, efficient nutrient cycling and pest control (Lamichhane *et al*., 2023).

- **High yielding and drought resistant varieties:** Species such as Napier grass (*Pennisetum purpureum*), Berseem (*Trifolium alexandrinum*), Lucerne (*Medicago sativa*) and Sorghum (*Sorghum bicolor*) are scientifically recognized for their exceptional biomass productivity and resilience to climatic fluctuations. These cultivars offer nutritional superiority, enhanced crude protein levels and digestibility profiles that directly optimize livestock growth and lactational output. Furthermore, the integration of specifically bred climate-resilient varieties provides a critical biological buffer against abiotic stressors, ensuring consistent forage availability during lean periods (Jain *et al*., 2021).

B. Intensive Cultivation Technologies and Precision irrigation:

- **Hydroponic Fodder Production:** Hydroponic fodder crops are produced from seeds or grains that are sprouted and grown under optimum conditions in a closed, controlled system within a short period of time. The hydroponic fodder system is a potential solution in areas where arable land is scarce and where pasture land is either limited or non-existent. Hydroponic fodders are highly digestible, palatable and fed by the animals as they are enzyme-rich feeds (Shipard, 2005). Growing cereal grains (Barley, Maize) in controlled environments produces high-quality green succulent feed in 7–10 days with 90% less water than field crops.
- **Sub-surface Drip Irrigation:** Subsurface drip irrigation technology consists of buried drip line fitted with emitters that release water directly to the plant's root zone, reducing surface evaporation and runoff (Camp, 1998) maximizes water-use efficiency and ensures consistent biomass production regardless of rainfall patterns.

C. Preservation of fodder

- **Community Fodder Banks:** Community fodder banks acts as a collective repository which facilitate resource optimization through the high-density conservation of forage during peak production cycles. They acts as a robust risk mitigation mechanism, providing a critical nutritional safety that insulates smallholder farmers from the volatility of droughts, pest outbreaks and fodder market inflations.
- **Fortification of Residues:** Crop residues and dry grasses are the major forages used for feeding livestock in India. These crop residues are low in nitrogen, minerals,

vitamins and high in fiber and lignin which restrict intake and digestibility in animals. The use of Urea Molasses Mineral Blocks (UMMB) for supplementing crop-residue-based diets for livestock has the potential to increase livestock production and net daily income. UMMB can be fed throughout the year but are more beneficially utilized during the dry season or when the animals are grazing low quality fodder.

- **Ensilage:** Silage is a preservation technology that involves anaerobic fermentation of green fodder under sealed conditions, helps maintain forage quality over extended periods (Villalobos and Serva, 2024). It is a prevailing way to preserve and supply year-round availability of moist feedstock. Silage plays a critical role in the rearing of dairy and beef cattle and it is an important source of nutrients, particularly energy and digestible fiber. Given the rising costs of feed, farmers increasingly prefer this efficient and economical source of nutrition (Akintan *et al*., 2024).

D. Utilization of Unconventional Feed Resources

- Unconventional feed sources can lessen dependency on conventional sources and diversify the fodder base. These resources include aquatic plants, tree leaves, agro-industrial byproducts, and non-traditional forages. Agro-industrial by-products including oil cakes, brans, molasses, and distiller's grains are examples of unconventional feed resources that are high in nutrients and can be added to conventional fodder. Minerals and protein are abundant in the leaves of trees including banyan, neem, and mango. To supply more feed, aquatic species such as duckweed and water hyacinth can be grown in bodies of water (Kumar et al., 2020).

Conclusion

The sustainability of India’s dairy sector depends on bridging the forage gap through a transition from reactive feeding to proactive management. To achieve nutritional perenniality, the industry must adopt climate-resilient cropping systems, such as silvopasture and high-yielding intercropping, which provide a biological buffer during lean periods. Furthermore, intensive technologies like hydroponics and subsurface drip irrigation offer high-quality succulent feed with minimal resource use. However, production must be balanced with preservation; the adoption of community fodder banks and ensilage is essential to save monsoon surpluses for summer scarcity. Ultimately, integrating these technological and social innovations will secure animal welfare and ensure a food-secure future for millions of smallholder dairy farmers.

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