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Ecosystem service perspectives and accounting in fodder-based agri-food systems

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Fodder-based agri-food systems play a critical role in sustaining agricultural productivity, livestock production, ecosystem health, and rural livelihoods in India, particularly in semi-arid and rainfed regions. This article examines their contribution through four major ecosystem service categories of provisioning, regulating, supporting, and cultural services. Evidence from farming system research demonstrates that integrated crop-fodder-livestock systems can enhance fodder and food production, farm income-employment, soil health, nutrient cycling, water regulation, biodiversity, and soil biological activity. These systems also conserve traditional knowledge and strengthen livelihood resilience, particularly among rural communities and women. Despite challenges such as fodder shortages, water scarcity, shrinking grazing lands, and climate variability, opportunities exist through improved forage varieties, grass–legume systems, round the year fodder production systems, climate resilient food-fodder systems, agroforestry, residue recycling, and fodder conservation. Ecosystem services accounting can support recognition of these multiple benefits and guide India towards more circular, climate-resilient, and resource-efficient agriculture.

Keywords: Climate change, Food-fodder systems, Integrated farming, Livelihood security, Resources recycling

INDIAN agriculture is not only a food production system but also a provider of diverse ecosystem services supporting soil health, water conservation, nutrient cycling, agro-biodiversity, livestock productivity and rural livelihoods through integrating crop production with livestock and other farm resources. Fodder crops, grasses, legumes, trees and crop residues are therefore important not only as feed resources but also as components of resilient and sustainable farming systems. In India's semi-arid and rainfed regions, fodder-based farming can simultaneously address feed shortages, soil degradation and climate-related risks. Research shows that integrating fodder trees and grasses into degraded landscapes can improve soil carbon sequestration and biological activity, while long-term grass-legume systems can enhance soil organic carbon and contribute to soil restoration. When integrated with food crops, livestock and natural-resource management, fodder systems can further improve sustainability. For example, fodder sorghum + cowpea–wheat system under conservation tillage can enhance soil organic carbon, water-holding capacity, energy efficiency and profitability. Similarly, *Sesbania*-based food-fodder systems with reduced tillage and mulching can improve productivity, profitability, forage quality and energy-use efficiency under rainfed conditions. Grass-legume intercropping also supports biological nitrogen fixation, carbon and phosphorus cycling, efficient land use and nutritionally balanced livestock feed. Integrated approaches combining rainwater harvesting, agroforestry, crops, fodder and livestock demonstrate how farms can generate multiple provisioning, regulating, supporting and cultural ecosystem services while strengthening livelihood security in the diverse agro-ecosystems. The ecosystem services accounting of such systems provides a useful framework for making these often-overlooked benefits visible. It moves beyond conventional indicators such as crop yield and farm income to include carbon sequestration, nutrient cycling, soil conservation, water management, biodiversity, livestock feed and livelihood benefits. For Indian agriculture, such an approach can better demonstrate the true value of fodder-based agri-food systems and support a transition towards more circular, climate-resilient and resource-efficient farming.

Ecosystem services from fodder-based agri-food systems

Fodder-based agri-food systems are multifunctional farming systems integrating fodder, livestock, crops, trees and soil to deliver numerous ecosystem services including sustainable productivity, regular employment, improved soil health, efficient waste recycling, carbon sequestration, water infiltration, biodiversity, etc. These diverse benefits can be grouped into four major categories:

***Provisioning services*:** These are the direct products obtained from fodder-based agri-food systems, including green and dry fodder, food grains, milk, meat, fruits, fuelwood and farm income. Evidence from Indian semi-arid farming demonstrates the substantial production potential of integrated food-fodder systems. For example, combining *Pennisetum* trispecific hybrid (TSH), *Sesbania sesban*, fodder sorghum + cowpea, and barley has been reported to produce about 78.5 t/ha green fodder, 20.0 t/ha dry fodder, and 2.0 t/ha barley grain, with the potential to support 3–4 milch animals when forage provides the complete dry-matter requirement. The reported net return was about ₹75,914/ha, with a benefit-cost ratio of 1.98.

A long-term rainfed integrated farming system combining fodder crops, food crops, trees, and livestock produced 5,926 kg/ha chickpea-equivalent yield, generated ₹86,281/ha/yr net returns, and provided multiple products, including grains, fruits, straw, green fodder, milk, meat, and fuelwood. Importantly, the system generated income throughout the year, ranging from ₹9,165 to ₹33,085 per month, illustrating how diversification can strengthen farm-level livelihood security.

Research on *Sesbania* alley-based food–fodder systems further reported system productivity of 59.4 t/ha in the *Sesbania* + sorghum–mustard system and 58.7 t/ha in the *Sesbania* + sorghum-barley system, with economic returns of approximately ₹32,760/ha. *Sesbania* also provides additional fodder and mulch resources without necessarily compromising the production of winter food crops. Sorghum single cut berseem wheat (late sown) food-fodder system produced 18% greater wheat equivalent yield compared with a popularly adopted sorghum–wheat system (8.9 t/ha). Thus, provisioning services represent the visible economic outputs of fodder-based agriculture while demonstrating how crop–fodder livestock integration can diversify production, improve fodder availability, and generate more stable income for Indian smallholders.

***Regulating services*:** These are an important component of fodder-based agri-food systems, as they improve soil quality, store atmospheric carbon, regulate water movement, and enhance farm resilience to climatic stresses.

In a long-term grass-legume experiment at ICAR-Indian Grassland and Fodder Research Institute (IGFRI), Jhansi, application of farmyard manure at 80 t/ha increased the soil carbon sequestration rate to 4.2 Mg C/ha/yr, with a carbon management index of 264, demonstrating the potential of fodder-based systems to build and stabilise soil carbon in semi-arid environments. It also increased different soil carbon pools by 60–126% compared with the control. Similarly, restoration using fodder trees and grasses in degraded soils increased microbial biomass carbon by 2–2.5 times after nine years, demonstrating enhanced biological functioning of the soil.

Furthermore, an ecological restoration study reported that fodder trees such as *Ficus, Morus, Acacia*, and *Leucaena* increased surface-soil total organic carbon by approximately 63%, 105%, 87%, and 81%, respectively, compared with fallow land after nine years. Fodder grasses, including *Cenchrus, Panicum*, and *Chrysopogon*, increased total organic carbon by about 84%, 91%, and 77%, respectively. Soil microbial biomass also increased by 2–2.5 times, indicating improved biological functioning of restored soils. Importantly, a smallholder dairy-based integrated farming system in India recorded 19% higher soil organic carbon, enhanced saturated infiltration capacity, and 552% greater carbon sequestration than a conventional groundnut-wheat system. These findings indicate that integrating fodder grasses, legumes, trees, and livestock can simultaneously improve carbon storage, soil fertility, and water regulation, making regulating services an



Climate resilient food-fodder production system



Pennisetum TSH + *Sesbania* + (cowpea-barley) food-fooder system



Organic manure based long-term grass-legume production system



Smallholder dairy based integrated farming system

important component of ecosystem-services accounting for Indian farming systems.

***Supporting services*:** These form the ecological foundation of fodder-based agri-food systems. They include nutrient cycling, soil microbial activity, biodiversity and recycling of farm wastes into manure. These processes maintain soil fertility and enable farms to produce fodder and food over the long term.

The inclusion of single cut berseem (legume) in sorghum–wheat food-fodder system improved the soil organic carbon (23%) and available nitrogen (15%) compared with cereal-cereal systems. However, a smallholder dairy-based integrated farming system recycled approximately 20.4 t/ha of farmyard manure and 1.98 t/ha of farm compost annually. It also returned about 100 kg N, 45 kg P, and 80 kg/ha/yr to the production system through nutrient recycling compared with a conventional groundnut–wheat system in a semi-arid region. The system recorded higher populations of earthworms, fungi, and bacteria, indicating improved soil biological activity and biodiversity. Thus, food-fodder systems create a circular nutrient pathway: crops produce fodder, livestock convert fodder into milk and manure, and manure and crop residues return nutrients and organic matter to the soil. Accounting for these supporting services is essential because they underpin the productivity and resilience of Indian farming systems.

***Cultural services*:** These are the less visible but socially important benefits generated by fodder-based agri-food systems. In India, livestock are deeply embedded in rural livelihoods, traditions, household responsibilities and indigenous knowledge. Fodder management often rests on knowledge passed down through generations, including selection of preferred fodder species, seasonal fodder calendars, tree-lopping practices, and feeding according to animal age, health and production stage. This knowledge has an important gender and social dimension with rural women have traditionally collected fodder, fed animals and managed livestock, and hold detailed knowledge of local feed resources and animal preferences. Research among the *Bhangalis* of the western Himalaya documented 47 fodder species, of which 32 were actively used, and found that older people and women possessed significantly greater traditional knowledge, while increasing market integration was associated with declining knowledge. Fodder-livestock systems also strengthen social resilience and livelihood security, as livestock provide food, employment, income and assets that can be mobilised during crop failure or financial stress; historically they have been sources of milk, manure, draught power, emergency cash and social status. The cultural value of fodder-based agriculture therefore extends beyond monetary returns to traditional knowledge, community identity, intergenerational learning, women's roles, human-animal relationships and the continuity of rural farming traditions.

Recognising these services in ecosystem services accounting helps ensure that policies for sustainable intensification do not erode the cultural knowledge and social institutions that sustain India's livestock-based farming communities.

Challenges and opportunities for sustainable fodder-based agri-food systems

Despite their multiple ecosystem services, fodder-based agri-food systems in India face major challenges, including shortage and seasonal availability of quality fodder, shrinking grazing lands, small and fragmented holdings, water scarcity and competition between food, feed and other crops. Recent ICAR information indicates that India continues to face a substantial fodder gap, with about 11% deficit in green fodder and 23% in dry fodder. Climate variability further increases the risk of fodder shortages during droughts and other extreme-weather events. However, these challenges also create opportunities.

Fodder trees, grass-legume mixtures, improved forage varieties, silvopastoral systems, crop-residue conservation and integrated crop–livestock farming can increase fodder availability while improving soil carbon and nutrient cycling. For example, ICAR has reported improved forage varieties with green-fodder yields exceeding 80–90 t/ha under suitable conditions. Better residue management, fodder banks, silage and locally appropriate water-efficient technologies can further strengthen year-round feed security and make Indian



Grazing-based agri-food system

farming more circular, climate-resilient and resource-efficient.

Policy pathways and future perspectives

The TEEBAgriFood framework provides a practical pathway for mainstreaming the multiple benefits of fodder-based agri-food systems into agricultural policy by linking changes in natural, human, social and produced capital with ecosystem-service flows and wider outcomes. Policy entry points include the National Livestock Mission, programmes promoting fodder development and quality seed production, agroforestry, watershed and natural-resource management, sustainable agriculture and climate-resilient farming. Ecosystem service indicators should be incorporated into programme planning, monitoring and evaluation. Systematic estimation and, where appropriate, valuation of these services can support targeted investments, payments for ecosystem services, carbon-based incentives and stronger farmer institutions, promoting circular, climate-resilient and resource-efficient fodder-based agri-food systems.

SUMMARY

Fodder-based agri-food systems in India are multifunctional systems that extend beyond feed and livestock production to deliver diverse ecosystem services. The findings demonstrate their potential to enhance farm productivity and income while improving soil carbon, nutrient cycling, water regulation, biodiversity and livelihood resilience. Integrated crop–fodder–livestock systems, grass–legume mixtures, fodder trees, residue recycling and agroforestry can therefore contribute to more sustainable use of land and natural resources, particularly in semi-arid and rainfed regions. The TEEBAgriFood framework provides an integrated approach to recognize and assess these multiple benefits by linking changes in natural, human, social and produced capital with ecosystem service flows and wider economic, environmental and social outcomes. Incorporating this framework into ecosystem service accounting can make these often-invisible benefits visible in agricultural decision-making. Practically, improved forage varieties, fodder banks, silage, community resources and efficient residue management can strengthen year-round feed security, while TEEBAgriFood-based assessment can support policies for circular, climate-resilient, resource-efficient and sustainable agri-food systems in India.

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