Dr. Verghese Kurien Commemoration Lecture
Reducing Emissions and Sequestering Carbon in India's Dairy Farms*

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Abstract

Green and White Revolutions are exemplary success stories of India's agriculture, which also increased overall GDP of agriculture at 3% per annum since 1991. India contains 13% of the world's cattle population and 57% of the world's buffalo population. Based on strategies implemented by Dr. Verghese Kurien, India's milk production increased from 21.2 million metric ton in 1968-69 to 108.5 in 2008-2009 and 210.0 million metric tons in 2021. Three critical factors in the success of White Revolution involved: enhanced cooperation of the milk value chains, adoption of appropriate technology to improve procurement along with storage and supply to distant consumers, and creation of markets for milk products. However, India's dairy industry is faced with the challenges of low yield per cattle, low overall productivity, low rate of technology acceptance and adoption, among other issues. Overgrazing can alter community structure as well as ecosystem functioning including primary productivity. Overgrazing is leading to soil degradation, water pollution, loss of biodiversity, and emission of greenhouse gases (GHGs). Among major challenges which need to be addressed include reducing emission of GHGs (CH_4, N_2O, CO_2, NH_3), alleviating scarcity and pollution of water, increasing the low milk productivity, and transforming of waste (manure and wastewater) into assets for restoration of soil health and sequestration of carbon in perennial forages and land-based sinks. An important strategy is to develop integrated systems which can enhance productivity per cattle, restore soil health, adapt and mitigate the anthropogenic climate change, and advance Sustainable Development Goals of the Agenda 2030 of the United Nations. Improved management of dairy industry to accentuate the White Revolution, along with transformation of traditional Green Revolution technologies, are important to making India a key player in addressing global issues of the 21st Century.

Introduction

India has 2.4% of world's land area and 4% of world's water resources, but 17.8% of the world population in 2023 and 15% of the world's livestock population. India faces the challenge of increasing productivity without compromising household food security while increasing income equitably and sustaining/enhancing the resources base (Wright *et al*, 2012). Green Revolution of 1960s, with exclusive aim of improving grain production, provided an incomplete understanding of the total food production and its future potential in India. Thus, accomplishments of the Green Revolution must be complemented with those of the other Revolutions. Indeed, both White and Blue Revolutions are also important components of India's exemplary success in achieving food security. Yet, gains in milk production (Tables 1a,b, White Revolution) are as impressive as those of grain production (Green Revolution). Thus, developing integrated systems of food production (Basu and Scholten, 2012) may be a resource-efficient and environment-friendly strategy.

Dr. Verghese Kurien, popularly known as the "**Father of the White Revolution**" and the "**Milkman of India**", received the World Food Prize in 1989. Since 2001, June 1 is observed World Milk Day. In India, the birthday of Dr. Verghese Kurien (November 26) is observed as National Milk Day. The National Gopal Ratna Award is given on 26th November, the birthday of Dr. Kurien. Dr. Kurien's work in framing the milk cooperative helped to empower milkmen not only in India but all over the world. Similarly to the Green Revolution in which total food grain production increased from 50 million ton in 1947 to 330 million ton in 2023 (TAAS, 2023), the White Revolution is among the greatest success stories in India by which the milk production increased from 17 million ton in 1951 to 210 million ton in 2021.

Picture Credits :- Indian autobiography

The Indian dairy sector employs more than 80 million households. India is the world's largest milk producing country. Annual milk production in India increased from 142 million ton in 2016 (Chopde *et al*, 2016) to 210 million ton in 2020-2021 while the demand is estimated at 240 million ton. The growth rate of milk production in India is 6% per year compared with that of 2% per year in the world (GOI, 2022). India contributes 23% of global milk production (**Tables 1a, b**). Milk production has been increasing rapidly during the decade of 2010 (**Table 1b**).

The White Revolution increased the dairy milk consumption from 107g per capita in 1970 to 427g per capita in 2020-21 compared with the world average of 322g per capita (GOI, 2022). Kaur and Singla (2018) observed that around 57% of growth of milk production is contributed by increase in livestock population and 31% due to rise in milk yield of the milch animal. In irrigated systems, livestock constitutes about 39% of total income of marginal farmers while its share was only 8% for large farmer in UP (Singh *et al*, 2009). However, dairy business has large scope for all farm size categories (Singh *et al*, 2009).

The cooperative sector ushered in The White Revolution in milk through Operation Flood in 1970s and 1980 as implemented in three phases outlined in column 2 of **Table1a**.

Therefore, major objectives of this article are to identify strategies of improving dairy production while also restoring the environment with specific focus on: (a) reducing emission of GHGs, (b)increasing milk productivity per cattle, (c) sequestering atmospheric CO_2 in land-based sinks for small holder dairy farmers of India, (d) identifying effective systems of manure management for recycling plant nutrients, and (e) making dairy industry as a part of the solution to addressing anthropogenic global warming.

Table 1a: Temporal Changes in Milk Production in India from 1951 to 2021 (Adapted from GOI, 2022)

Year	Milk Production (Million ton per annum)
1951	17.0
1961	20.0
1971	22.0
1981	31.6] Phase I: Sale of SMP
1985	42.7] Phase II: Milk sheds
1991	53.9] Phase III: Dairy cooperatives
1996	67.2
2001	80.6
2011	121.8
2016	142.0
2021	210.0

Table 1b: Increase in Milk Production in India for the decade of 2010 (Adapted from Srinivasarao *et al* (2016a;b)

Year	Milk Production (Million ton per annum)
2010-11	121.8
2011-12	127.9
2012-13	132.4
2013-14	137.7
2014-15	146.3
2015-16	155.5
2016-17	165.4
2017-18	176.3

Livestock Population in India

India has a livestock population of 537 million, of which 96% is in rural areas (Chander *et al*, 2023). Majority of farm holdings are < 2 ha and account of 85% of all farming population. Cattle and buffalo are symbols of wealth in rural India (Nair *et al*, 2020). Projected estimate of cattle and buffalo population in India show some declining trends from 2010 to 2050 (**Table 2**).

The data in **Table 3** shows the total livestock population in India from 1951 to 2023. During this period, the cattle population increased from 155 M in 1951 to 194 M in 2023. Similarly, the buffalo population increased from 43 M in 1951 to 114 M in 2023. Importance of

Table 2: Cattle population in India (Adapted from Nair *et al*, 2020)

Year	Cattle (Million)	Buffalo (Million)
2010-11	194.2	—
2020-21	187.7	116.7
2030-31	188.2	127.8
2040-41	188.2	138.9
2050-51	188.2	148.9

buffalo to achieving White Revolution cannot be over-emphasized (Selokar *et al*, 2019) because of both high milk yield and high fat content. Consequently, the total bovine population increased from 198 M in 1951 to 308 M in 2023.

India has a high total livestock population and it has an increasing trend since 1951 (see last row in **Table 3**). Cattle population in India is projected to increase over the four decades from 2010 to 2050 (**Table 3**). Total livestock population increased from 293 M in 1951 to 537 M in 2023, an increase of 83.3% over 72 years. Buffaloes are producing more than half of India's milk with lesser population (36.6% of total bovine population). Buffaloes are contributing 3.73 Tg of CH_4 annually, which is 40% of total livestock CH_4 emissions (Balhara *et al*, 2017). The states of Haryana and Punjab have more than 60% of their livestock in the form of buffaloes. Because of higher feed efficiency and higher values of produce, buffaloes are preferred by farmers (Balhara *et al*, 2017). Thus, there is a projected increase in buffalo population between 2020 and 2050 and not that of cattle (**Table 2**). In addition to buffalo, Sahiwal and Gir are two important breeds of dairy cattle in India, but their population are decreasing due to indiscriminate cross breeding (**Table 2**) (Pathak and Chander, 2012). Systems based on principles of integrating livestock with crops and trees are proposed (Choudhary *et al*, 2020; Palsaniya *et al*, 2022; Srinivasarao *et al*, 2014; 2016b), it may be pertinent to build these upon traditional Jhum-based systems where the terrain/climate conditions are challenging (Bhagwati *et al*, 2015).

The large livestock population, and relatively low productivity, has caused some severe problems of soil and environmental degradation which cannot be ignored and must be effectively addressed. In addition to the genetic improvement in livestock through adoption of modern techniques of animal breeding, integrated management of natural resources deserves a high priority. Integration of livestock with crops and trees (Lal, 2020a) is a viable strategy which must be promoted through policies which are pro-nature, pro-agriculture and pro-farmer.

Soil and Environmental Degradation in India

Despite the unique success of Green Revolution and White Revolution, there exists a severe problem of soil degradation affecting 147 million ha (M ha) of cultivated land (Bhattacharyya *et al*, 2015, ICAR/NAAS, 2010). Because of the severe vulnerability of natural resources to anthropogenic and natural factors of degradation (**Fig. 1**), the strategies of agricultural/livestock management must be redefined with focus on soil and water conservation, integrated nutrient management (INM), and making farming system an integral part of the solution to the current and emerging issues (**Fig. 2**). Integration of livestock with crops and trees (Lal, 2020a), for identification of site-specific regenerative systems with consideration of basic principles of agro-ecology, include the following: (i) adopting site-specific measures of soil and water conservation, (ii) increasing carbon sequestration in land-based sinks, and (iii) adopting practices of INM based on judicious combination of diverse sources of plant nutrients including recycling of the livestock manure (**Fig. 1, 2, and 3**).

The overall strategy of developing integrated livestock systems with crops and trees is focused on: (i) reducing vulnerability of soil and other natural resources to changing and uncertain climate, (ii) achieving high factor productivity, (iii) increasing and sustaining farm profitability, (iv) producing safe and nutritional food, and (v) improving environment quality (**Fig. 4**).

While ruminants have played an important role in human civilizations and wellbeing, the negative and unintended consequences of rearing ruminants for food cannot be

Table 3: Livestock Population in India (in Millions) (Adapted from National Dairy Development Board, 2017; Bhogal and Beillard *et al*, 2023, Maini, R. and Beillard, 2023; Office of Agric. Affairs, New Delhi, 2023)

Species	1951	1961	1972	1982	1992	2003	2007	2012	2019	2023
Cattle	155	176	178	193	205	185	199	191	193	194
Buffalo	43	51	57	70	84	98	109	110	110	114
Total Bovines	198	227	235	263	289	283	308	301	303	308
Total Livestock	293	337	353	420	471	485	530	512	536	537

Fig. 1: The problem of soil degradation in India by different processes. The data on extent of degradation is from Bhattacharyya *et al* (2015).

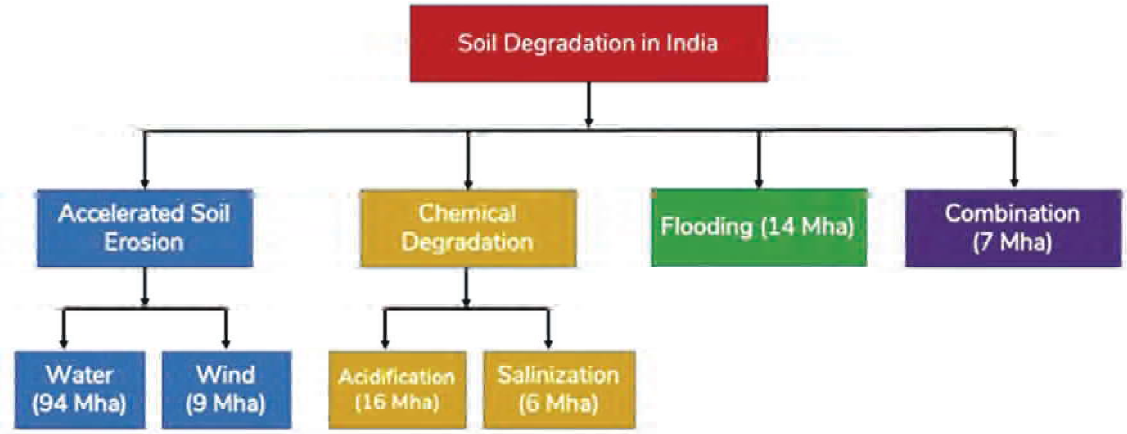
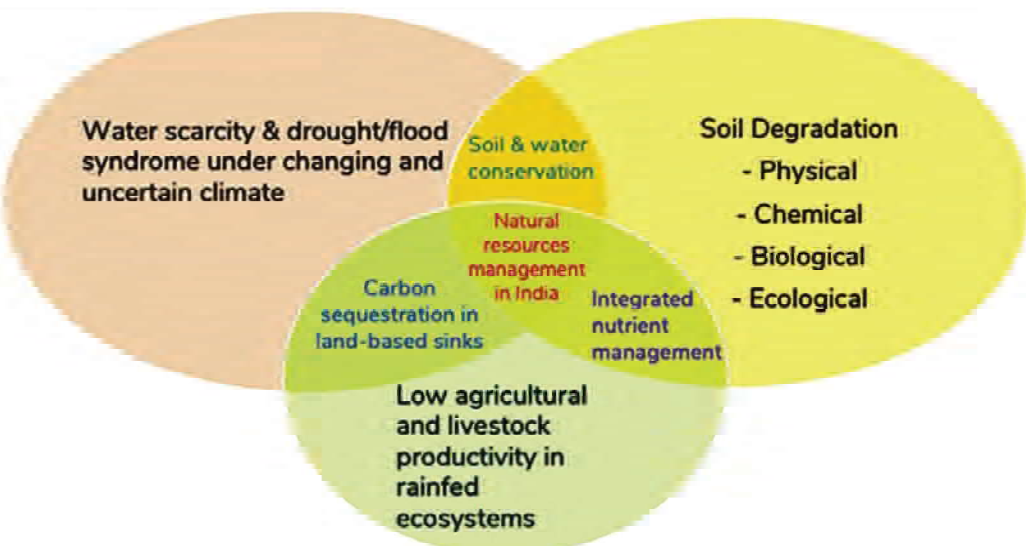


Fig. 2: Major issues of natural resources management in India and strategic interventions for small land holders (< 2 ha) accounting for 85% of the farming population.



ignored. Important among these consequences are GHG emissions, species extinction, deforestation, food insecurity, cardiovascular diseases, obesity, cancer and diabetes (Mlambo and Mnisi, 2019). While milk and dairy products are amongst the safer products, it is important to develop strategies and technologies that can address some of the negativities of raising ruminants. Thus, the mission of dairy science and industry is to adopt environment-friendly and consumer-centric dairy products to advance nutrition security and restore the environment.

Indiscriminate dependence on ruminants can be the root cause of ill effects such as global warming, species extinction, deforestation, food insecurity, and human health issues. Judicious use of ruminants, such as for dairy industry, can deliver environmentally friendly ecosystem services (Mlambo and Mnisi, 2019). Integrated ruminant-crops-tree systems can play a critical role in advancing Sustainable Development Goals of the Agenda 2030 of The United Nations (Lal, 2020b).

Gaseous Emission from Dairy Farming

Globally, livestock emits 8.1 Pg(Gt) CO_2 eq/yr. and accounts for two-thirds of global NH_3 emissions (IPCC, 2022; Singaravadivelan *et al*, 2023). Enteric fermentation is a major source of CH_4, N_2O and CO_2, and ruminants account for three-quarters of total CO_2 eq emissions from the livestock sector. The global dairy production emits 4% of global anthropogenic emissions (Singaravadivelan *et al*, 2023). India has the largest dairy industry in the world and contributes a significant share of global emission of CH_4 (**Table 4**). Therefore, judicious management of livestock is needed to reduce the GHG footprint (Ghosh *et al*, 2020). Dairy industry

Fig. 3: Structural and functional diversification of livestock with crops and trees to develop complex systems

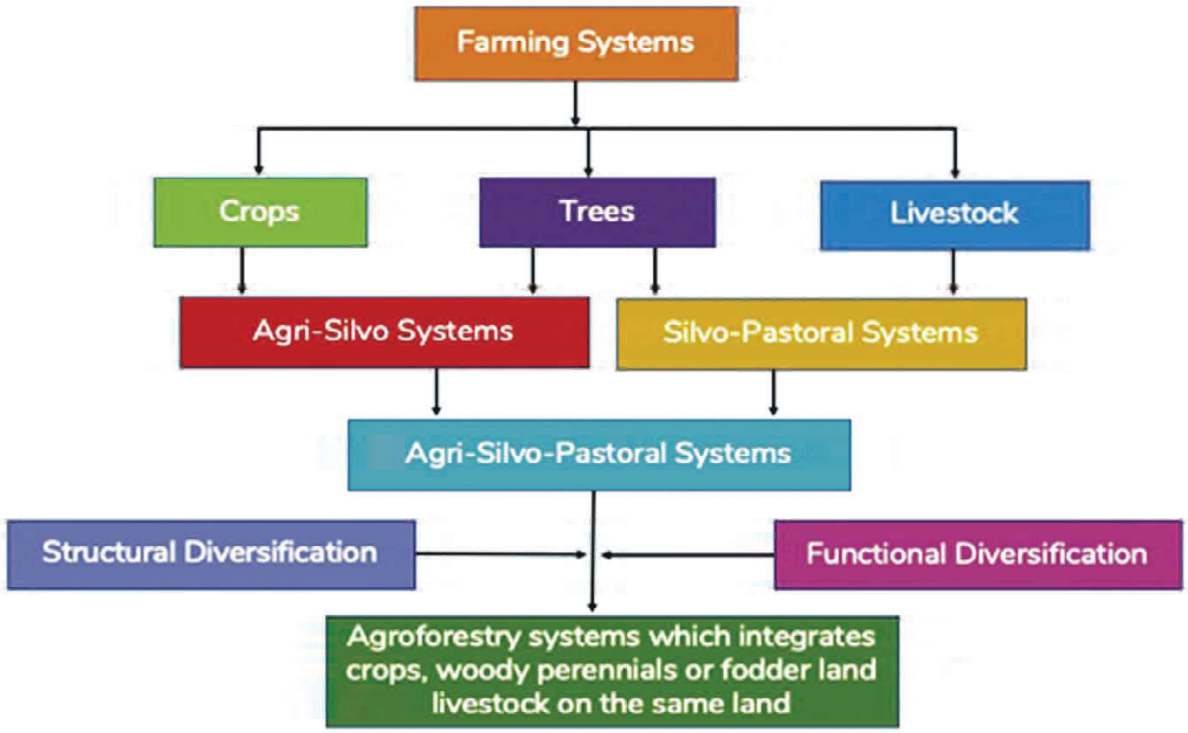


Fig. 4: Benefits of integrated farming systems to meet multiple demands of small land holders and resource-poor farmers of India and elsewhere in the world. Examples of integrated systems include Agro-silvo-pastoral systems of dairy farming

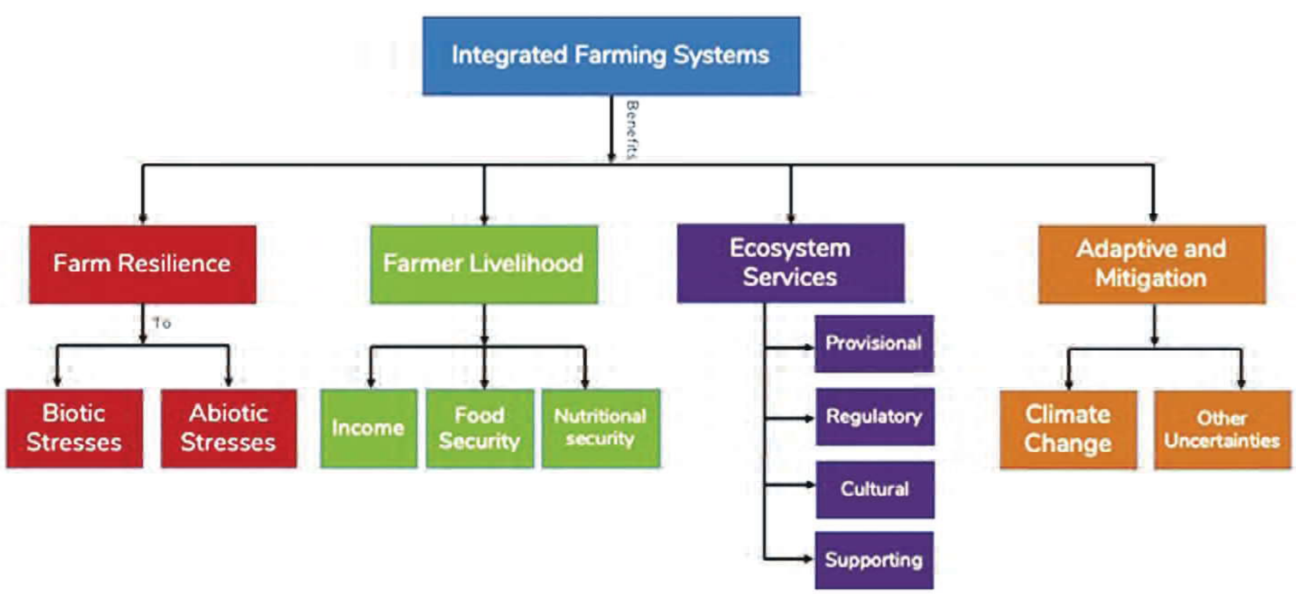


Table 4: Emission of GHGs from livestock based systems in a village in semi-arid alluvial plain of Gujrat (Adapted from Hemingway *et al*, 2023)

Output	Village GHG Emission for Each
Animal output	3
Milk	57
Rice straw	3
Millet	2
Banana	3
Tobacco	20
Rice	12

contributes strongly to CH_4 and N_2O emission (Patle *et al*, 2013). Because of the GHG emissions, the eco-efficiency of dairy system can be low (Nayak *et al*, 2023). The C footprint of fat and protein corrected milk (FPCM) has been estimated at 2.13 kg CO_2 eq/kg FPCM (Kumar *et al*, 2023) and enteric fermentation contributed around 35.5% of the total emission, followed by manure management (13.8%), and soil management (8.2%). Pradeep *et al* (2022) estimated CH_4 emission of 0.72 kg CO_2 eq/kg of FPCM. Vetter *et al* (2017) used the Cool Farm Tool to estimate GHG emission for different food products in India, and reported that livestock and rice were the primary source of GHG emission in Indian agriculture with national average of 5.65 kg CO_2 eq/kg of rice, 45.54 kg CO_2 eq/kg of mutton, and 2.4 kg CO_2 eq/kg of milk. In comparison, production of cereals (except rice), fruits and vegetables contributed less GHG emission in India. In addition to emission of GHGs, dairy industry also uses a large amount of water and causes water pollution (Raghunath *et al*, 2016). Pradeep *et al* (2022) developed a Methane Calculator for Indian livestock sector for dairy farms in the tropical coastal districts of Kerala. Pradeep and colleagues calculated a mean CH_4 emission of 0.72 kg CO_2 eq per kg of fat and protein corrected milk with a high variability among farms (63.3%). Hemingway *et al* (2023) conducted GHG assessment of 10 cropping systems, 8 livestock farming systems, and 9 production systems using comparative agriculture and Life Cycle Assessment (LCA) approaches. Hemingway and colleagues reported that livestock farming systems emit 4.2 Mg CO_2 eq/female to 8.6 Mg CO_2 eq/female, and enteric fermentation is the first source of emission. There are also wide variations at farm level ranging from 9 to 73.3 Mg CO_2 eq/female.

Most of the emissions in **Table 4** are due to milk, tobacco (*Nicotiana tabacum*), and rice (*Oryza sativa*). At village level, emissions are estimated at 37 Mg CO_2 eq/ha, and livestock contributes 60% of the emissions. The livestock population is high and is fed on highly emissive fodder and concentrates, but have low milk yield.

Integrated Livestock, Crop, Forestry Systems

The demand for livestock products will continue to increase over the next few decades in India. Thus, smallholder fixed farming systems will have to be intensified. Potentially useful techniques to reducing GHG emissions include livestock management including change in animal diets, and reuse of gas produced from manures along with frequent and complete manure removal from animal housing (Ghosh *et al*, 2020). Establishing Guinea grass (*Megathyrsus maximus*) and tussock grass (*Poa labillardierei*) on degraded soils can decrease soil bulk density (1.11 - 1.23 Mg/m^3), increase soil water content (14.0 - 17.8%), increase soil organic matter (SOM) content (0.38 - 0.73%) compared to the barren land (1.38 Mg/m^3, 13%, and 0.28%, respectively) (Halli *et al*, 2022). Well-managed silvo-pastoral systems with high tree density have a high potential for forage production and climate change mitigation via C sequestration in the humid tropics (Varsha *et al*, 2019). Perennial fodder crops are also useful to C sequestration in acid soils of northeast India (Sarkar *et al*, 2018; Rai *et al*, 2023), and elsewhere (Kumar *et al*, 2022a;b).

Challenges and Opportunities in Dairy Production in India

Eco-efficiency is usually low in dairy farms (Nayak *et al*, 2023), and the challenge lies in improving both productivity and eco-efficiency. Because, animals, environment, and sustainability are inter-connected, there is a strong need for a nexus or a wholistic approach. Livestock can play a critical role in transferring nutrients from ecologically more sustainable ecosystem (forest/rangeland/grassland) to ecologically vulnerable cropland and in recycling of nutrients in cultivated lands (Singh and Rastogi, 2021). However, overgrazing can alter community structure as well as ecosystem functioning including primary productivity. Overgrazing can lead to soil degradation, water pollution, loss of biodiversity, and emission of GHGs (Singh and Rastogi, 2021). This is why, India's dairy industry is faced with the challenges of low yield per cattle, low overall productivity, low rate of technology acceptance and adoption, health detection of milch animals, animal data recording and presence of dairy products in global market (Kaushik *et al*, 2023). Based on personal interviews with 60 dairy farms across Haryana, Punjab and UP, Kaushik *et al* (2023) identified 12 challenges, including three listed below:

1. Lack of government support,
2. Lack of educational opportunities in dairy-based education,
3. High cost, huge investment and low acceptance of decision makers are challenges of technology adoption.

Thus, the goal is to bring about performance improvement. Water intake in dairy cattle is another issue which must be addressed. The availability of water for cattle (and human) is getting scarce. Water intake is affected by several factors such as body weight, genetic disposition, mineral and dry matter content of feed, milk productivity, environment and water quality (Das *et al*, 2016; Singh *et al*, 2022).

Heat stress, another factor being aggravated by the current and projected global warming, adversely affects milk productivity of dairy cattle. Based on a study conducted in Bengaluru's rural-urban interface, Velayudhan *et al* (2022) highlighted the importance of considering ecological, social and climatic factors simultaneously to improve functional and primary breed-specific traits of dairy cattle under challenging environments. Under changing and uncertain climate, there is a strong need for climate-resilient dairy cattle production by application of genomic tools and statistical models (Silpa *et al*, 2021).

There is a sense of growing importance of acclimatizing the dairy sector to the emerging socioeconomic, environmental and technological dynamics. Judicious management of dairy sector is critical to strengthening food and nutritional security, enhancing agricultural growth, decreasing rural poverty, addressing vulnerability of farm households to shocks, and to providing employment and empowerment to female farmers (Saxena *et al*, 2019). Thus, there is a need for efficient and effective extension services, adequate feed and fodder, affordable and effective animal health services, and incentives to transform subsistence to entrepreneuring livestock in conjunction with efficient chains for livestock marketing and trade (Saxena *et al*, 2019).

In view of these challenges, new farming systems will have to be developed in view of the local forage resources, cattle type which can be grown on marginal agricultural land not needed for crops, and basic principles of agroecology (Pflimlin and Faverdin, 2014). Reducing carbon footprint of cattle milk in smallholder cattle farm is a critical environmental issue (Kumar *et al*, 2023).

Integrated Sustainability Index

Based on a study of 120 dairy farmers in Rajasthan, Chand *et al* (2015) developed a Sustainable Dairy Farming Index (SDFI). The SDFI was developed in consideration of three dimensions of sustainability: ecological, economic, and social. Chand and colleagues observed that important attributes to be considered in improving SDFI are food productivity, management of animal genetic potential, and gender equality which are particularly weak in India. In addition to Chand *et al*'s listing of three dimensions of sustainability, there are a total of seven dimensions of sustainability. These are: climatic, pedological, environmental, cultural, economic, social and institutional.

An optimal number of dairy animals for small farms is 5 to 6 (rather than 1 to 2). A sustainability index of sugarcane (Saccharum officinarum) based dairy farming was also developed by Prasad *et al* (2016). Organic dairy farming (raising animals on organic feed and pastures cultivated without the use of fertilizers or pesticides along with restricted use of antibiotics and hormones) is another option to be considered (Oruganti, 2011; Hamadani and Khan, 2015; Maji and Meena, 2018). However, potential and constraints of organic dairy need to be carefully evaluated. Low productivity and lack of organized certification system are among major constraints to adopting organic dairy farming in India.

India also occupies the first position in goat milk production in the world, and commercial dairy goat production has gained momentum. The goat milk has therapeutic, nutraceutical and medicinal benefits, and has a large export potential (Singh *et al*, 2023).

Carbon Sequestration in Soil

Agriculture in India contributes about 17% of nation's GHG emissions (Patle *et al*, 2013). Thus, sequestration of atmospheric CO_2 in soil may offset emission of CH_4 and N_2O due to dairy farming and agriculture. Adoption of system-based conservation agriculture can lead to a positive soil/ecosystem C budget while improving use efficiency of inputs (*e.g.*, irrigation, fertilizers, pesticides) (Patle *et al*, 2013). A study by Singh *et al* (1995) on Alfisols in Meghalaya showed that the overall sustainability in restoration and maintenance of soil fertility followed the trend dairy farming > tree-based land use > cereal-based cropping. In other words, dairy- and tree-based land uses showed self-sustainable systems for soil productivity because of an effective recycling mechanism even with minimal use of chemical fertilizers and amendments on sloping land conditions.

There are two types of carbon in soil. Soils of the humid region predominantly contain soil organic carbon (SOC) and those of dry climate contain soil inorganic carbon (SIC). Management of dairy cattle can affect both SOC and SIC. Sequestration of SOC can be enhanced by using dairy affluent as a soil amendment. The affluent is rich in some plant nutrients can increase SOC sequestration (Kaur *et al*, 2018). Integrated management systems have positive effects on soil carbon sequestration (Srinivasa Rao *et al*, 2014; 2016 b; Choudhary *et al*, 2020). There is a close relation between SOC and SIC in arid and irrigated agroecosystems. Farming carbon, growing carbon (both SOC and SIC stocks) in pastures and agroecosystems through improved management, can create another income stream for farmers through payments for ecosystem services and trading carbon credits. In addition to government policies, private sector can also reward farmers for making dairy industry environment-friendly.

Manure Management

A key question is how can the environmental burden be allocated to livestock products and to manure that can be reused for agronomic production. Thus, manure must be considered as a co-product rather than wasted or disposed of, or applied in excess of crop nutrient needs and thus treated as waste (Leip *et al*, 2019). Compost developed from dairy farms is a rich source of plant nutrients. Compost made from dairy farms can supply 45,000, 7300, and 9100 mg/kg of N, P, K, respectively (Srivastav *et al*, 2023).

A long-term experiment with application of farm yard manure (FYM) at 80 Mg/ha increased SOC sequestration at 4.2 Mg/ha.yr and also increased concentration of labile carbon. Inorganic fertilizer use with FYM of 20 Mg/ha influenced SOC sequestration similarly (Dixit *et al*, 2020). Animal manure can supply nutrient input for crops, and crop residues are the basic feed source for animals. The integrated systems can also enhance water productivity compared with growing crops alone. Indeed, mixed and integrated systems create more flexible and profitable use of carbon and other limited resources (Wright *et al*, 2012).

Conclusions

The White Revolution, ushered in by Dr. Verghese Kurien the World Food Prize Laureate of 1989, is a global success story. India's milk production increased from 17 million ton in 1951 to 210 in 2021.

Similarly to the adverse effects of Green Revolution, the White Revolution has also contributed to environmental degradation including decline in soil health, pollution and scarcity of water, emission of GHGs especially those of CH_4 and N_2O and dwindling of biodiversity.

India's dairy industry is faced with the challenges of low yield per cattle, low overall productivity, low rate of technology acceptance and adoption. Eco-efficiency is usually low in dairy farms and the challenge lies in improving both productivity and eco-efficiency.

Improved management must be identified for site specific condition to decrease emission of GHGs especially those of CH_4 and N_2O.Manure management and use of appropriate feed stocks can reduce enteric fermentation and decrease emission of CH_4. The strategy of management is to reduce CH_4 emission per liter of milk production.

There is a tremendous scope for improvement in India's dairy industry and making it a part of the solution to improving the environment and advancing Sustainable Development Goals of the United Nations Agenda 2030.

Important issues to be addressed through research and development are: (i) reducing vulnerability of soil and other natural resources to changing and uncertain climate, (ii) achieving high factor productivity, (iii) increasing and sustaining farm profitability, (iv) producing safe and nutritional food, and (v) improving environment quality.

Sequestration of SOC and SIC can also be enhanced by using dairy affluent as a soil amendment. The affluent is rich in some plant nutrients and its application can lead to increase in SOC and SIC stocks. Carbon farming through improved dairy industry can create another income stream for farmers.

References

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