Climate Resilient Livestock Farming: Role of Technologies and Extension Strategies

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This e-book is a compilation of resource text obtained from various subject experts of ICAR – National Institute of Animal Nutrition and Physiology, Bengaluru & MANAGE, Hyderabad, on "Climate Resilient Livestock Farming: Role of Technologies and Extension Strategies". This e-book is designed to educate extension workers, students, research scholars, progressive farmers, and academicians about the Climate Resilient Livestock Farming: Role of Technologies and Extension Strategies. Neither the publisher nor the contributors, authors, and editors assume any liability for any damage or injury to persons or property from any use of methods, instructions, or ideas contained in the e-book. No part of this publication may be reproduced or transmitted without prior permission of the publisher/editors/authors. Publisher and editors do not give a warranty for any error or omissions regarding the materials in this book.

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FOREWORD

Indian livestock facing lot of problems due to non-availability of conventional good quality feeds and fodders. There is a growing competition between humans and livestock for grains and plant proteins, particularly maize grain and soybean meal (SBM) for which suitable alternatives need to be found. Similarly, due to drought and natural calamities, availability of dry fodder is also becoming limiting. Under these situations, alternate feed resources (AFR) will come to the rescue of farmers. Alternate feed technologies and innovative feed formulations are also available which can make these AFR suitable for livestock feeding. These feed resources can partly replace conventional feed ingredients thereby expanding the resource base and thus, reduces the gap between demand and supply. These alternate feeds are recommended depending up on the regional availability and suitability. Cost effective processing methods need to be developed for removing the anti-nutritional factors in non-traditional oil seeds like neem, karanja and castor. It would be a constant endeavor on our part to develop cost effective alternate feed formulations for sustainable livestock production. The reproductive health of dairy cattle is closely linked to micronutrients, especially the mineral balance. Deficiencies in micro-minerals such as zinc, copper, manganese, and selenium have been linked to fertility issues. These minerals play roles in hormone synthesis, ovarian function, and pregnancy maintenance. Proper mineral supplementation is essential for maintaining animal health, reproductive efficiency, and milk production in dairy cows. The most effective strategy is to provide area-specific mineral mixtures, which address localized deficiencies and avoid unnecessary supplementation. Emerging technologies such as chelated, organic and nano minerals offer more efficient absorption and utilization, improving overall animal performance and reducing environmental waste and policy makers to carry out advance research and framing policies.

Director
ICAR-NIANP

PREFACE

Livestock farming plays a pivotal role in global food security, livelihoods, and economic sustainability. However, climate change has emerged as a major challenge, threatening animal health, productivity, and the overall resilience of livestock-based systems. Rising temperatures, erratic weather patterns, and an increase in disease outbreaks necessitate urgent action to safeguard the future of the livestock sector. In this context, climate-resilient livestock farming has gained prominence as a crucial strategy for ensuring sustainable livestock production in the face of climate variability and change.

This e-book, "Climate Resilient Livestock Farming: Role of Technologies and Extension Strategies" explores innovative solutions that enhance the adaptive capacity of livestock systems. It delves into climate-smart technologies, improved breeding strategies, sustainable feeding practices, and advanced health management approaches that contribute to livestock resilience. Moreover, the role of extension strategies, policy interventions, and capacity-building programs in equipping farmers with climate adaptation tools is highlighted.

The book aims to serve as a comprehensive resource for livestock farmers, researchers, policymakers, extension professionals, and students seeking knowledge on climate resilience in livestock farming. By integrating scientific advancements with practical extension strategies, it offers insights into transforming challenges into opportunities for sustainable livestock development.

We hope that this e-book will inspire stakeholders to adopt climate-resilient livestock practices and contribute to a more sustainable and productive future.

Editors

Artabandhu Sahoo
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Livestock Production and Climate Change-An Overview

A. Sahoo, C. Devaraj, V. Sejian

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Introduction

Livestock production plays a crucial role both in India and globally, vitally contributing to economic stability, employment, nutritional security, and sustainable agricultural practices. In India, the sector contributes around 4.66% to the total GDP (presently GVA: Gross Value Added) and over 30% to the agricultural and allied GVA, providing livelihoods for millions of small and marginal farmers, particularly in rural areas where over 70% of the population resides. Livestock farming is a primary source of income for many, ensuring nutritional security through the supply of essential protein and calcium from dairy products, with India being the largest milk producer globally. Additionally, livestock holds significant cultural and social value, particularly cattle, which are integral to various traditional ceremonies and festivals. Sustainable agricultural practices are bolstered by livestock through the provision of manure for crop fertilization, reducing reliance on chemical fertilizers. Globally, livestock production is integral to food security, accounting for 40% of agricultural output and providing essential nutrients. It is valued at over $1.4 trillion annually and supports approximately 1.3 billion people, including smallholder farmers and pastoralists. The sector aids in poverty alleviation by offering regular income, food, and employment, especially in developing countries. Livestock contributes to environmental sustainability by recycling nutrients, maintaining pasturelands, controlling pests, and aiding in biodiversity and carbon sequestration.

Simultaneously, growing concerns about climate change and its impact on agriculture and allied sectors have emerged as a critical global issue. The scientific consensus is unequivocal: climate change is occurring and poses a significant threat, already affecting agricultural sectors worldwide, particularly the productivity of livestock. This has profound implications for future food security and livelihoods. The livestock sector is vulnerable in two primary ways: first, through the direct impacts of climate change on livestock production and performance, and second, through the necessity for the sector to adapt its operations to mitigate these effects. Various environmental factors, including temperature extremes, relative humidity, air quality, and the availability of natural resources like water and pasture, profoundly influence livestock productivity. Environmental changes, whether due to natural fluctuations or human activities, can significantly impact livestock growth performance, reproductive success, health, welfare, and overall productivity.

Climate change phenomena and livestock

Climate change refers to long-term change in the average weather patterns of the earth's local, regional, and global climates (Sahoo et al., 2013) Heat stress, a major consequence of environmental changes during extreme summer months in arid tropical regions, while cold stress occurs during extreme winter months at temperate regions including high-altitude regions of the world. A set of reasons attributed to climate change that include change is mainly linked to consequence of human behaviour, viz. greenhouse effect, global warming, urbanization, and deforestation. These impact temperature rise, increase in CO_2 concentration, seawater rise, ocean acidity etc. thereby altering the earth's ecosystem (Naz et al., 2022). Similarly, high humidity and poor air quality directly affect the health, welfare, and performance of living beings. Numerous up-to-date and improved global climate change models help in understanding of the past, present and future climate change, but it remains much uncertainty about magnitudes and impacts of climate change at any particular location and how best to prepare for these. Thornton et al. (2022) highlighted the potential magnitude and extent of the adaptation efforts, viz. switching to more heat-tolerant breeds and provision of shade, ventilation, and cooling systems that will be necessary to combat the effects of increasing heat stress on cattle production during this century if food security challenges are to be minimised. Increased frequency of extreme weather events, and the consequences or secondary manifestations are much more varied, including ecological, social, and economic impacts. Henceforth, people's ability to adapt depends on a variety of factors including availability of resources (both state and individual) for adaptation, motivation, and information about the changing state of the environment and the links between human decisions and the environment.

Climate change may affect animal agriculture in a variety of ways that include the ability to produce feed-grain, the quality of pastures and forage crop production, animal health, growth, and reproduction, and disease and pest distributions (Sahoo, 2021). Physiologically, animals need to conserve or shed heat outside their ideal temperature range to maintain productive. An excess of 2 to 3°C from optimum animal core body temperature is often maintained in all animal species, but beyond this may cause disruptions of performance, production, and fertility that limit an animal's ability to produce meat, milk, or eggs. These changes can slow animals' growth and reduce reproductive rates, which can increase costs for animal producers and consumers. The effects of climate change on the crops animals rely on, such as changes to availability, quality and price, can also have a big impact on animal agriculture. For example, higher temperatures increase lignin formation in plant tissues and thereby reduce the digestibility and rates of degradation of fodder and crop residues in the rumen of animals (NAAS, 2016). This will lead to reduced nutrient availability for animals and ultimately to a reduction in livestock production. Heat stress also adversely affects the function of the rumen microbiome and metabolism resulting in high lactate leading to health problems and an elevated risk of metabolic disorders, thus affecting the milk production (Zhao et al., 2019; Kim et al., 2022). The interactions between climate change and livestock production are still not well understood because of insufficient data on critical local studies and also, studies involving performance assessment of non-ruminants and desert adapted non-bovines. There is also a gap in research related to water availability for livestock production and understanding the relationship between heat stress and the rumen microbiome. Diversification of livestock animals (within species), using different crop varieties, and shifting to mixed crop-livestock systems seem to be the most promising adaptation measures (Rojas-Downing et al., 2017).

Livestock production and greenhouse gas emissions

Livestock production system significantly contributes to greenhouse gas (GHG) emissions, which is a major environmental concern. The sector is responsible for approximately 14.5% of global anthropogenic GHG emissions, primarily methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) which re the primary GHGs emitted by livestock. Enteric fermentation, manure management, and land-use change are the primary sources of these emissions. Methane, which has a much higher global warming potential than CO_2, is mainly produced through enteric fermentation in ruminants such as cattle, sheep, and goats. Manure management also contributes to both methane and nitrous oxide emissions, with the latter being particularly potent in terms of its global warming potential. Additionally, CO_2 emissions arise from land-use changes such as deforestation for pastureland and feed crop production. Thus, the environmental impact of livestock production is multifaceted. It includes direct GHG emissions from animals and indirect emissions associated with feed production, land use, and deforestation.

As the demand for animal-based products increases globally, the pressure on natural resources and the environment intensifies, highlighting the need for sustainable livestock management practices. To accurately assess the environmental impact of livestock production, life cycle assessments (LCAs) are employed. LCAs evaluate the entire production chain, from feed production to processing and distribution, to quantify GHG emissions and other environmental impacts. Understanding the specific contributions of different livestock species and production systems to GHG emissions is crucial for developing targeted mitigation strategies. For instance, ruminant livestock, such as cattle and sheep, produce more methane due to enteric fermentation compared to monogastric animals like pigs and poultry. By quantifying GHG emissions from livestock production, researchers and policymakers can identify hotspots for intervention and prioritize mitigation strategies. The livestock sector in low- and middle-income countries could contribute significantly to reduce the rate of growth and/or the level of greenhouse gas (GHG) emissions required to achieve the 1.5 °C target of the Paris Agreement (Bateki et al., 2023). Mitigation strategies include improving feed efficiency, optimizing manure management, and adopting practices that enhance carbon sequestration in pastures. Addressing GHG emissions from livestock is crucial for mitigating climate change and ensuring sustainable food systems. Efforts to reduce emissions through technological innovations, policy measures, and changes in dietary patterns are essential for achieving global climate targets.

Climate change and heat stress in livestock

Climate change is exacerbating heat stress in livestock, posing significant challenges to animal health, productivity, and welfare. Heat stress occurs when animals are unable to dissipate excess body heat, leading to physiological and behavioral changes that negatively impact their performance. Various physiological responses of livestock to heat stress and its potential economic impacts are described in table 1.

Table 1. Physiological responses of livestock to heat stress and its economic impacts

Physiological Responses	**Economic Impacts**
Increased respiration rate and panting	Decreased production efficiency
Elevated heart rate	Increased mortality rates
Reduced feed intake and milk production	Higher veterinary costs
Reproductive impairments (reduced fertility, increased embryonic loss)	
Weakened immune system	
Metabolic disorders	
Potential for reduced income for livestock producers	

The impact of heat stress varies significantly based on geographic location, breed, and production system. Regions with hot and humid climates are particularly vulnerable. For instance, dairy cows in tropical and subtropical regions face more severe heat stress compared to those in temperate climates. Understanding the physiological mechanisms underlying heat stress and the specific vulnerabilities of different livestock species is crucial for developing effective mitigation strategies.

Impact on livestock performance and productivity

Climate change poses significant challenges to livestock production systems worldwide. The direct impacts include increased heat stress, altered precipitation patterns, extreme weather events, and rising sea levels. These factors directly affect animal health, productivity, and welfare. Heat stress, in particular, is a major concern. Elevated temperatures can lead to reduced feed intake, decreased milk production, reproductive issues, and increased mortality rates. Moreover, changes in precipitation patterns, such as increased frequency and intensity of droughts and floods, disrupt feed availability and water resources, affecting livestock performance. Indirectly, climate change impacts livestock through changes in the quantity and quality of feed. Reduced forage production, altered crop yields, and increased prevalence of pests and diseases further exacerbate the challenges faced by livestock producers. It is essential to recognize the regional variations in the impacts of climate change on livestock. For instance, arid and semi-arid regions are more vulnerable to drought and heat stress, while coastal areas face the threat of rising sea levels and saltwater intrusion into freshwater sources. Understanding the specific impacts of climate change on different livestock species and production systems is crucial for developing effective adaptation strategies (Gaughan et al., 2018; Sejian et al., 2018, 2021). Fig. 1 describes various impacts of climate change on livestock production across the globe.

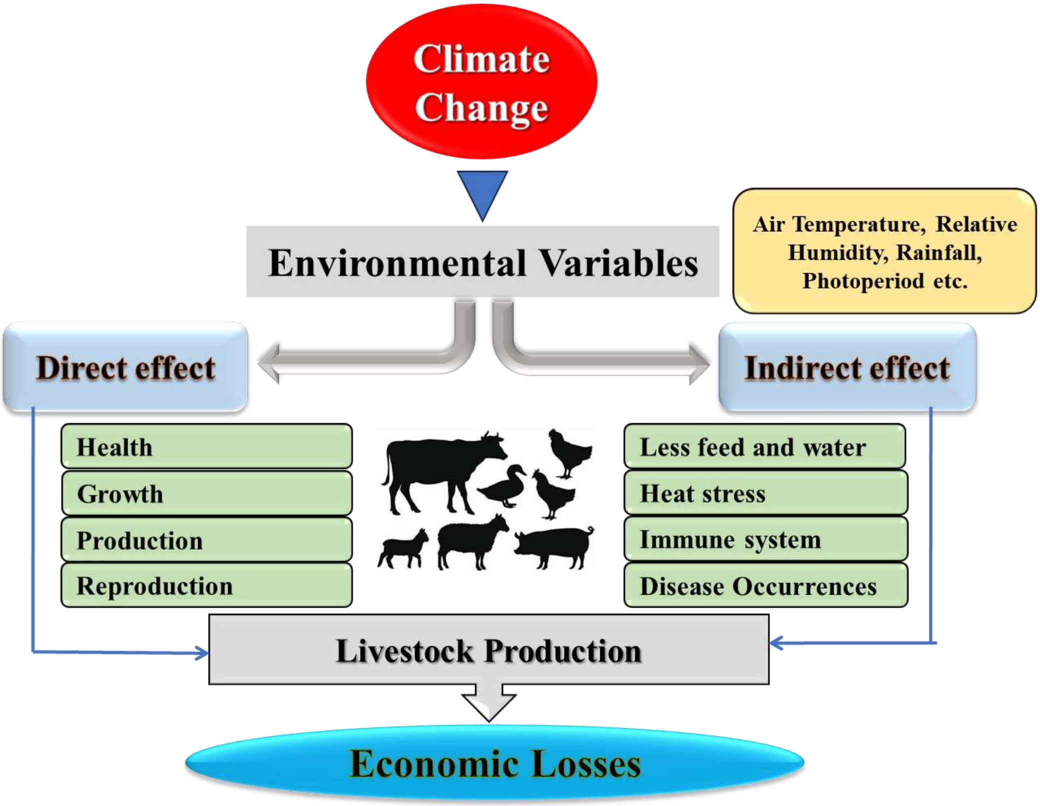

Fig.1. Impacts of climate change on livestock production

Climate change induced heat stress has significant adverse effects on various aspects of livestock productive performance, including growth, milk production, reproduction, and meat production. These impacts result from physiological, behavioral and metabolic disturbances caused by high temperatures, leading to economic losses in the livestock industry. Heat stress significantly affects animal growth and productivity. Heat stress disrupts the delicate hormonal balance causing abnormal expression of multiple hormones in livestock and poultry hinders the growth, development, and overall production performance (Chen et al., 2021). Heat stress negatively affects feed intake and digestion, leading to decreased nutrient absorption and utilization. However, the reduced dry matter intake (DMI) is considered an adaptive protection mechanism in heat-stressed animals. Feed intake is a major source of heat production in ruminants and other animals. This means that reducing feed intake in warm environments, while helping to decrease heat production, also creates a negative energy balance. This negative balance can lead to decreased body condition scores, milk production, and body weight of the animal. When the ambient temperature is higher than the optimum temperature of animals, the DMI decreases significantly due to HS acting on the appetite control center located in the hypothalamus resulting in the activation of temperature-sensitive receptors as well as the synthesis and release of a corticotrophin-releasing hormone that also associated with reduction of DMI.

Hot environments negatively impact ruminants by altering rumen function, pH, increasing metabolic disorders, and reducing heat production vital for body temperature maintenance (Kim et al., 2022). This can lead to decreased rumination, rumen activity, and digesta movement through the digestive system. HS could reduce ruminal pH and increase the level of lactate in the rumen which leads to decreases in the availability of energy, reduces ruminal pH, and inhibits pH-sensitive rumen bacterial growth, which gives rise to subacute ruminal acidosis (SARA), a well-known metabolic disorder that suppresses the production of milk in dairy cows. Heat stress disrupts rumen fermentation, leading to altered volatile fatty acid (VFA) profiles with increased propionate and butyrate and decreased acetate. To adapt, animals reduce roughage intake, further decreasing rumen activity, pH, and microbial diversity. This cascade of effects ultimately compromises animal production efficiency and health through reduced dry matter intake, saliva production, and overall digestive function. HS weakens the digestive tract's mechanical function in non-ruminants by slowing down gastric emptying and diminishing intestinal peristalsis. This leads to chyme accumulation and reduced appetite. Chemically, heat stress reduces the digestibility of carbohydrates, lipids, and proteins by inhibiting digestive enzymes like amylase, maltase, lipase, trypsin, and chymotrypsin (Meneses et al., 2021). Heat stress likely affects food intake and digestive functions through appetite control centers and enzyme activity, ultimately impacting growth performance.

The dairy industry is particularly vulnerable to climate change with dairy animals experiencing a significant drop in milk production and quality when temperatures rise above their tolerance level. Adverse climate substantially decreases the milk yield and affects its composition thus affecting its taste and marketability. Decreased feed intake due to HS might be directly responsible for reduced milk yields. It has been reported that HS can adversely affect immunity by compromising the milk yield and composition. High temperatures can hinder passive immunity transfer in calves, potentially due to reduced intestinal absorption of IgG from colostrum after birth. HS impairs maternal immunoglobulin transfer to colostrum and affects the colostrum quality by lowering the IgG, IgA, casein, fat, and protein levels. These changes, along with reduced blood flow to the mammary gland and nutritional restrictions, likely impede IgG and nutrient transfer from blood to the mammary gland. Climate extremities wreak havoc on livestock and their productivity, particularly in meat production. Both long-term and short-term heat stress studies demonstrate reduced meat production in livestock. It causes pale, soft, and exudate (PSE), and dark, firm, and dry (DFD) meat in livestock; and increases the foodborne disease outbreak (Chauhan et al., 2023).

Effect on reproductive function

Exposure of growing male and female animals to severe heat stress during the summer has detrimental effects on their growth, reproductive traits, disease resistance, and fertility, leading to significant economic losses in the livestock sector. Heat stress can disrupt the delicate hormonal balance required for optimal reproductive function in livestock (Ahmad Para et al., 2020). The summer season often induces summer sterility in animals due to prevailing hot and humid conditions. In females, heat stress impacts various aspects such as age at puberty, estrous signs, ovulation time, ova quality, conception rate, embryonic development, embryo size, and hormonal balance. Growing ovarian follicles are particularly sensitive to heat stress, which can later result in compromised maturation and developmental capacity of the ovulating oocyte. In males, exposure to heat stress affects sex hormone levels, spermatogenesis, libido, ejaculate volume, and both macroscopic and microscopic semen characteristics, leading to an increase in sperm abnormalities and dead sperm (Ahmad Para et al., 2020). To counteract the decline in fertility among dairy cattle and other livestock due to heat stress, several technologies have been developed. These encompass significant breakthroughs such as estrus synchronization, embryo transfer techniques, cryopreservation of gametes, genetic manipulation, and the utilization of nutraceuticals like feed additives, pre and probiotics, coupled with managerial adjustments. These innovations provide promising pathways for enhancing summer fertility in livestock.

Livestock health effects

Adverse climate particularly heat stress poses a significant threat to the health of farm animals, impacting them both directly and indirectly. Elevated temperatures can directly compromise animal well-being, leading to conditions such as dehydration, heat exhaustion, and respiratory distress. Indirectly, heat stress can contribute to reduced feed intake, impaired nutrient absorption and increased susceptibility to diseases, collectively influencing the overall health and productivity of farm animals. Heat stress weakens the immune system, making animals more susceptible to diseases and infections. It can also exacerbate existing health conditions and increase the risk of heatstroke. Additionally, heat stress can lead to respiratory problems, digestive issues, and other health complications, further jeopardizing animal well-being. High ambient temperature and high relative humidity during summer favour the growth of microorganisms responsible for mammary gland infections, which challenges the mammary defense capacity and induces bacterial growth. Therefore, understanding the mechanisms by which HS negatively affects dairy animals is vital for developing proper strategies for maintaining mammary gland health during the HS period.

Climate change and livestock welfare

Livestock farming system often faces the challenge of heat stress, where high temperatures with relative humidity inflict significant distress and discomfort on animals. This disrupts their well-being and raises ethical concerns about farming practices, particularly intensive farming. Animals may exhibit signs of stress, such as panting, excessive salivation, lethargy, and loss of appetite that indicate animals struggling to cope with the heat. Animals exhibit behavioral changes such as aggression, restlessness, and withdrawal signal underlying stress and discomfort. Thus, heat stress reduces vital resources for growth, reproduction, and maintaining proper body temperature. This hampers productivity, weakens the immune system, and increases susceptibility to illnesses. Ultimately, animals experience a lowered quality of life and increased risk of suffering. Confined environments often lack adequate ventilation and cooling systems, exacerbating heat stress. Intensive farming practices prioritize production over animal welfare, raising questions about ethical treatment. The disconnect between consumer perceptions and animal realities necessitates reevaluating and improving intensive farming practices. Heat stress in intensive farming is a critical issue demanding attention. Recognizing its impact on animal welfare and addressing it through improved management, innovative solutions, and prioritizing animal well-being are crucial steps toward more ethical and sustainable livestock production (Sejian et al., 2022a).

Amelioration strategies for sustainable livestock production

Addressing these challenges requires development of effective amelioration strategies, sustainable practices and technological advancements to mitigate the negative effects of environmental stressors on livestock productivity. These strategies may include the implementation of advanced management practices, selective breeding for heat tolerance, and the provision of adequate hydration and nutrition. Additionally, the use of technology, such as climate-controlled housing systems and precision livestock farming, will be highlighted as innovative approaches to enhance the resilience of livestock in the face of environmental pressures. Understanding the multifaceted relationship between climate change and livestock productivity is crucial for the development of sustainable agricultural practices. By identifying and addressing the key environmental factors that impact livestock, we can strive to improve not only the welfare of the animals but also the efficiency and sustainability of livestock production systems globally. Therefore, tackling the effects of climate change on the livestock production system necessitates a comprehensive approach, incorporating measures at multiple levels (Sejian et al., 2022b). Various amelioration strategies to sustain livestock production in the changing climate scenario is depicted in figure 2.

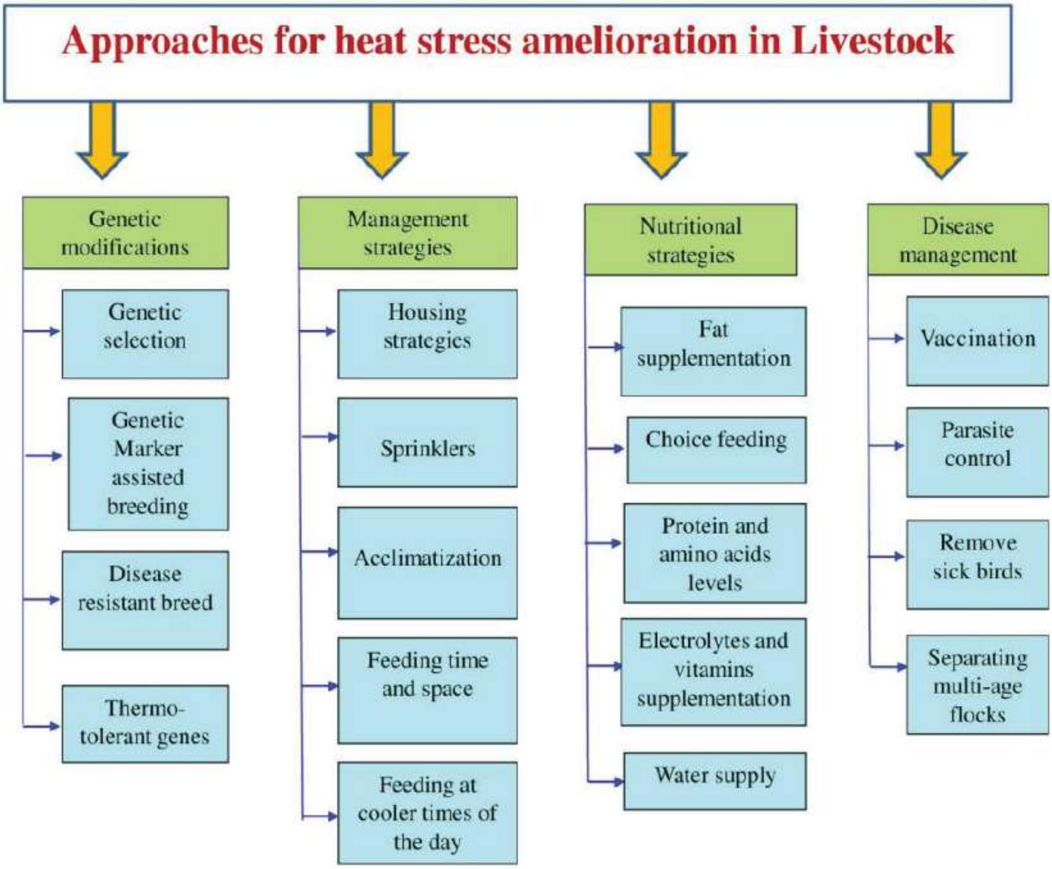

Fig 2: Various amelioration strategies to sustain livestock production in the changing climate scenario (Source: Sejian et al., 2018)

Environmental Management:

- **Shelter design**: Prioritize natural ventilation and shade access. Consider heat-reflective roofing, cooling systems like misters or fans, and landscaping for shade.
- **Water availability**: Ensure ample clean water for drinking and cooling through troughs, sprinklers, or wallows.

- **Feed adjustments**: Modify feed rations during hot weather, focusing on energy-dense, easily digestible options to reduce metabolic heat production.

Animal Management:

- **Selective breeding**: Implement breeding programs that prioritize heat tolerance traits.
- **Monitoring and early warning**: Regularly monitor animal health and behavior for signs of heat stress. Utilize technology like heat stress sensors and early warning systems for proactive intervention.
- **Feeding adjustments**: Adapt feeding times to cooler periods, like early morning or evening, to minimize heat stress during peak temperatures.

Nutritional Strategies:

- **Dietary supplements**: Provide electrolytes and vitamins to support thermoregulation and immune function during heat stress.
- **Probiotics and prebiotics**: Consider incorporating these to maintain gut health and nutrient absorption, which can be compromised by heat stress.
- **Water additives**: Adding electrolytes or palatability enhancers to drinking water can encourage hydration and water intake.

Research and development:

- **Heat-resistant breeds**: Invest in research and development of breeds with improved heat tolerance through genetic engineering or selective breeding.

- **Nutritional innovations**: Explore novel feed additives or formulations that can mitigate heat stress and improve animal resilience.
- **Precision livestock farming**: Utilize technology like sensors and artificial intelligence to personalize cooling strategies and resource allocation based on individual animal needs.

By implementing these strategies across various levels, livestock producers can build resilience against heat stress, protect animal welfare, and ensure the sustainability of their operations in a warming climate. Therefore, a multi-pronged approach holds the key to effectively mitigating the challenges posed by heat stress and promoting the well-being of livestock.

Conclusion

Changing climate poses a significant economic challenge to livestock production. By reducing growth rates, milk production, and reproductive efficiency, while increasing mortality, morbidity, and production costs, heat stress undermines the profitability of livestock enterprises. Effective management strategies, including improved shelter, nutritional interventions, and genetic selection, are crucial in mitigating the negative impacts of heat stress. However, the optimal approach will vary depending on specific production systems, geographic locations, and available resources. Continued research is essential to develop innovative and sustainable solutions to address the challenges posed by heat stress. This includes further exploration of the physiological mechanisms underlying heat tolerance, the identification of genetic markers for heat resilience, and the development of advanced technologies for monitoring and managing heat stress in livestock. By implementing a comprehensive approach that combines management practices, technological advancements, and genetic improvement, the livestock industry can enhance its resilience to climate change and ensure long-term sustainability.

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Alternate feed resources and technologies for their safe usage in livestock feeding

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Several newer feed resources have been evaluated and found useful for livestock feeding. Incriminating factors have been identified in some unconventional feeds and methods for their detoxification have been evolved. Protein cakes after oil extraction from seeds of neem, castor, and karanj have been evaluated and found suitable for feeding after detoxification. There is a need to upscale these technologies for wider application. Of late certain local feed resources like azolla, areca sheath, maize kadbi, fruit residues, ayurvedic residues, brewery and residues have been found useful and farmers have started using some of them in the ration with suitable processing techniques. Use of these alternative feed resources replacing part of conventional feed ingredients is an economical way for sustainable livestock production. Some of such potential feed stuffs are discussed in this chapter.

Dry fodder

Areca sheath

Over the years, in some regions of Karnataka, Kerala and Assam, the areca (*Areca catechu*) cultivation as a commercial crop has partly replaced the traditional paddy and other cereal crops due to higher economic returns. This has consequently resulted in deficit of dry fodder, especially in the costal zones of Karnataka and livestock farmers are procuring paddy straw from adjoining districts at much higher cost. The analysis of areca sheath for its nutritional composition has showed almost similar composition to paddy straw and content of some minerals like calcium, copper and sulfur are higher in areca sheath. No untoward effect was noticed due to feeding of dried areca sheath to sheep and cows. For efficient utilization of dried and chaffed areca sheath as mash in the form of total mixed ration along with suitable proportion of concentrate feed is recommended. Suitable machine to shredd the dried areca sheath is commercially available. In Andaman islands also areca sheath as dry fodder is becoming popular. In India, the potential availability of areca sheath is about 1.20 million tonnes.

Sugarcane trash

Sugar cane dry trash and is a part of sugar cane tops and is a major by-product of the sugarcane industry which is left in the field after cane harvest. The major states producing sugarcane are UP, Maharashtra, Karnataka, Tamil Nadu, Andhra Pradesh, Telangana, Bihar, Gujarat, Haryana, Uttarakhand and Punjab. With cane to dry leaf ratio of 2-3 %, about 6.8-10.3 million tonnes of sugar cane trash is expected to be available at the time of harvest in India. The trash can be fed to livestock as a replacement of dry fodder like paddy straw or finger millet straw in adverse climatic situations of drought. Sugarcane trash is very bulky material and occupies lot of space. This can be a major drawback during transportation. This can be avoided if trash is chaffed to small pieces with the help of mechanical chaff cutter (4-6 inches). Sugarcane trash is good source of fiber (NDF: 32.3%), and hemi-cellulose (26.9 %). However, contains less protein (3.54%), similar to paddy/finger millet straw (3.65%). It can replace cereal dry fodders for livestock feeding.

Maize cobs and stover

Maize crop is being cultivated on a large scale due to the high demand for maize grains for poultry feed, starch industry and distilleries. Maize stovers and cobs are the byproducts that are currently being either not utilized or underutilized. Stover and cobs can be used as roughage source in diets of cattle, buffalo, sheep and goats. Simple interventions like chaffing of maize stovers and cobs will facilitate the effective utilization of untapped feed resources. Maize stovers in general after harvesting the cobs are either left in the field itself or sometimes burnt in the field to make way for the next crop. The nutritive value is almost similar to any cereal dry fodder.

Hydroponic grain sprouts

Producing the green feed through germination of grains like maize, barley, oat or wheat produces consistent quantities of green feed throughout the year at the rate of about 4 to 6 kg per kg of seed within 10 days period. It is essentially a hydroponic technique, where the sprouted seeds spread over the trays grow into green feed in a 10 day cycle. There is about 20% dry matter loss and often mold growth is a problem. Soaking the seeds with 4% vinegar solution is quite effective in preventing mold growth. Quality of seeds, moisture management and control of predators (squirrel, rodents) are some of the issues in grain sprout production. Improved method of grain sprouts cultivation with straw bedding has been developed by scientists of ICAR-NIANP. It can be considered as a contingency strategic green feed supplement along with dry fodder rather than alternative to conventional green fodder source. On dry matter basis, the nutritive value of grain sprout in terms of protein, energy and fibre is almost similar to good quality wheat bran.

Azolla

Azolla (*A. Pinnata, A. nilotica,*) a water floating fern and triangular in appearance, consisting of roots, stems (rhyzomes) and leaves. Azolla grows in symbiotic association with a blue- green alga *Anabaena azollae*, a nitrogen fixing organism. Azolla is a promising supplementary green feed from the point of ease in cultivation, productivity and its nutritive value. Azolla is a protein rich green feed, leucine, lysine, arginine and valine are the predominant amino acids in Azolla, while tryptophan and sulfur containing amino acids are deficient. Azolla is also rich in vitamin A, vitamin B_{12}, Beta- carotene, growth promoting intermediaries, bioactive compounds and bio-polymers and azolla is well digested by livestock. Azolla generally grow best in less than full sun light. Optimum relative humidity for Azolla growth is 60-75% and pH range of water is 5.5-7. The use of Azolla as a green feed for fish, swine, poultry and cattle has been tested with favourable results. The chemical analysis of Azolla showed that it is a good source of protein (20-25%) and most of the minerals. Azolla can be used as a valuable green feed protein supplement mixed with crushed maize grain or wheat / rice bran. This is very useful under low input livestock production system.

Unconventional concentrate ingredients

Neem seed cake

Neem seed kernel meal is high in crude protein (36-38%) and found unsuitable feeding due to presence of bitter and toxic triterpenoids (azadirachtin, salannin, nimbin, nimbidiol etc.). Detoxification can be done by alkali treatment with 1.5% NaOH. Studies have indicated that detoxified neem cake can replace 50% soybean protein in total mixed rations of cattle.

Karanj seed cake

Karanja is a forest tree belonging to the family Leguminosae, grown in all parts of India, particularly in Tamil Nadu, Andhra Pradesh and Karnataka, for its ecological advantages. Cake is rich in protein, but unpalatable and toxic due to the presence of karanjin, pongamol and an unusual amino acid, glabrin. Detoxification of karanja cake can be done by complete removal of oil and refluxing with solvent. Detoxified material could replace 50% of soybean meal in total mixed rations dairy cattle.

Castor seed cake

Castor seed cake is a by-product of the castor seed industry, contains fairly good amounts of protein (CP: 35%). It can be a substitute of conventional oil cakes like soybean meal in livestock diets but for the presence of a toxic glycoprotein, ricin. Lime treatment (4.0%, w/w) followed by extrusion cooking results in ricin free castor seed cake. Such treated cake could be a protein supplement upto 10% level in the total mixed ration of cattle.

Guar seed meal

Guar meal is the by-product after extraction of gum from guar seeds. It consists of the outer seed coat and the germ of guar seeds. It is a potential source of protein and has been used to feed livestock and poultry. Guar meal has to be toasted before it is fed to livestock to destroy trypsin inhibitors. It can induce chronic diarrhoea when fed as the sole feed to growing calves. Guar meal has a residual gum which is an indigestible polysaccharide that leads to sticky faeces. It is a good source of amino acids like lysine, cysteine and glycine than ground nut cake but methionine content is comparable to standard protein sources. The guar seeds are toasted to high temperature to remove the trypsin inhibitor so that, the nutritive value improves. The meal is a by-product obtained after processing of seeds. Guar meal is one of the important ingredients used as cattle feed and contains upto 55% crude protein along with digesting content which makes it a reliable and safe ingredient for animals.

Rain tree pods

Rain tree is widely distributed in the tropics. A mature tree can yield 500-600 kg green forage foliage and 250-300 kg pods. Ripened pods are available from February to April when other fodders are scarce. Rain tree pods are a good source of crude protein (15.3%), sugars (69.9%) and low crude fiber (10.0%) and can be a substitute for good quality rice bran.

Brewer's grains

Brewer's grains are materials remaining after fermentation of grains during the liquor / beer making process. These materials can be fed in the wet form (wet brewer's grain) or dried form (dried brewer's grain). The nutritional content varies depending on the type of grain used (barley, wheat, corn, sorghum). Dried brewer's grain contains 22-25% protein. It is a good source of high quality bypass protein and digestible fiber. It is usually recommended to include dried brewer's grains up to 20-25% of the concentrate mixture and up to 15% of the total dietary dry matter of adult ruminant diet. Wet Brewer's grains have limitation of low shelf life (less than 2 days) and hence to be used without spoilage. Wet edible Brewer's grains can be mixed with crushed maize grain or wheat bran at 5 : 1 ratio and feed to cattle.

Reusable food wastes from different sectors

Food wastes from hotels and various sectors using vegetables, fruits, dairy, aqua, poultry and meat products offer a great scope to develop value added animal feeds and supplements. Additionally, with increase in processing of cereals, pulses, oilseeds, fruit and vegetables for value added food products for human consumption, more byproducts/waste are likely to be generated. Presently in India, the total availability of such waste is more than 30 million tons. India ranks second in the world in the production of fruits, vegetables and aqua products. A gradual shift in the cropping pattern from cereals to more remunerative fruits and other horticultural crops is expected to result in generation of huge quantity of fruit and vegetable wastes. Presently, most of these are either composted or dumped in landfills adding to the environmental pollution. But such non-conventional resources can be used as excellent source of nutrients for farm livestock. While the merits of using horticultural wastes include low disposal cost and better nutritive value, their high moisture content, rapid spoilage and added transportation cost pose some major drawbacks. Slaughtering of animals produce a meat yield of only 30% of the total weight,whereas the rest goes as byproducts and wastes.

Wastes like trimmings, inedible fat, blood, feathers, ruminal content, bone, egg shells etc. are generally used for producing pet foods, animal feeds, pharmaceuticals, fertilizer or biogas production. These waste materials are normally converted into intermediate products like Meat cum Bone Meal (MBM) or dicalciumphosphate (DCP) which are then mixed with different feed ingredients as feed supplements for poultry, fish and pets like dogs and cats. Hence, there is huge potential for establishing by-products and waste utilization facilities. Due to the policy restrictions, feed of animal origin cannot be used in the diet of ruminants.

Food wastes

Disposal of food waste generated by hotel industries is an enormous challenge. There is enormous opportunity for utilizing these wastes as feed for livestock. There should be a mechanism to collect food wastes from the hotels and transporting to livestock farms. The wastes can be fed to dairy animals along with other concentrates and roughages. However, the wastes need to be cooked or heat treated or microbiologically treated before offering to cattle to ensure that they are bacteria free. Generally left over food and vegetable in domestic kitchen are fed to cattle. Generally ruminant are fed food residues of vegetarian source and pig are fed mixture of both.

The constraints in utilizing food waste include the acidic nature of majority of the foods, presence of spices and condiments (masala) which inhibit the growth of the food grade organisms, and promote proliferation of spoilage organisms, and mixture of a wide variety like fried, baked, steamed and raw food material, and their variable combinations, leading to difficulties in standardization of feed stock, problem in balancing of solid to liquid ratio and deficiency in nitrogen content. Lacticacid bacteria (LAB), versatile in their sugar and nitrogen requirements, are ideal for treating the food wastefor feed to both poultry and farm animals. Low,medium, or high populations of LAB, as required, can be used in the feed.In urban hotel system, as well as other events feeding large numbers of people, there is a serious concern for disposal of food waste without polluting the environment. As per one case study in Bangalore, more than 940 tonnes of food is wasted annually during marriage functions. With proper planning, it is possible to recycle the edible parts of such food waste for feeding human population, whereas the remaining can be used for other purposes such as using in animal feed. By using the food waste, it is possible to farm the insects like black soldier flies and use these protein rich insects as the feed for poultry birds and fish. Similarly, there is also a possibility of recycling thewastage in food packaging industry by using the expired packaged food materials for insect farming.Though there is no accurate data on the extent of commercial food waste in India, packaged food sales in India during 2020 were 47 Million tons, and even at a conservative estimate of 2% loss, the wastage amounts to over 2,500 tons per day. Presently, there is no regulation to prevent this wastage. Responsible food waste management and disposal policy is needed for food processing industry.

Dairy waste

The dairy industry has been growing enormously, producing a large quantity of byproducts. The challenges for using these as animal feed include economic viability, collection and distribution logistics, feed safety and regular assessment of nutrient quality. Some of the strategies that can be employed are heat sterilization, drying, ensiling with or without addition of fermentation aides like bacteria and enzymes. Usage of byproducts from dairy industries can lower the feeding cost of the livestock. Skim milk and butter milk once considered as byproducts of the industry are now regarded as valued added products and marketed at the price of milk. The byproducts, produced in large quantities and not utilized appropriately are whey, ghee residue, buttermilk produced during churning of butter and butter serum produced during pre-stratification process of ghee manufacture. Skimmed milk powder waste can be used in monogastric and calf diets. Whey is generated in large quantities during cheese, paneer and chhana production. Approximately 8 L of whey is produced for every 10 L of milk utilized for the production of cheese, paneer and cottage cheese (chhana). Whey has about 6% solids (half of what is contained in milk) and some of the constituents such as whey proteins possess high nutritive value. Technologies have been developed to utilize this byproduct for the preparation of whey protein concentrates and whey powder. If whey is used for manufacturing of beverages and bakery products, it not only saves water required for production of such products but also adds nutritive value to the products. Further, India imports lactose, a major constituent of whey. This also gives scope for utilization of whey for lactose production, thereby reducing its import. Ghee residue is a good source of nutrients and antioxidants. Its brown colour and nutty flavour makes it highly suitable as an ingredient for the preparation of baked foods such as cookies and biscuits. A simple intervention can help to make value-added nutritive food products from it.Buttermilk produced during churning of butter as well as butter serum produced during the pre-stratification method of ghee production usually goes waste, which could be effectively blended with curd and used for the preparation of chhas and lassi.

Fruit and vegetable residues

India produced over 197 million tons of vegetables in 2021-22. The production will continue to increase in the future, making available various vegetable by-products and wastes for use as animal feed. In many Asian countries, there is a gradual shift in the cropping pattern from cereals to more remunerative fruit and horticultural crops. This results in generation of huge quantity of fruit and vegetable residues. Presently such residues are not effectively used and either composted or dumped in landfills causing environmental pollution. There is a need to develop suitable methods to convert waste to wealth and contribute to value added feed resources. Some of the potential fruit residues that can be used in feeding are mentioned below.

Apple : In India annually about 1.74 million tonne of apple is produced and waste consists of peels, seed and pulp, which represents 25-35% of fresh apple. The apple pomace on dry matter basis consist of 4.72% crude protein and 48-60% total sugar. It is a good source of energy (75%) and can replace 30% maize grain in ruminant ration. The residue contains high moisture and can be dried in sunlight or at 65% moisture level can be made as silage for preservation to use as feed.

Grape: Grape pomace is a by-product of wine industry comprising grape pulp, skin, stem and seeds accounting about 20% of the grape fruit. The annual production is about 1.6 million tonnes and limited quantity is processed for wine. On dry matter basis, grape pomace contains 11% crude protein, 27% crude fiber and 5% lignin. Due to lignified fiber, the digestibility and energy value is low. The dried pomace has phenolic anti-oxidant compounds. Due to lower nutritive value grape pomace can be used in smaller quantity in ruminants feeding.

Mango: Majority of the mango is consumed freshly and only about 2% is processed and generates 40-50% waste. The waste include peels, juice extraction waste, seeds, kernel. The waste has more sugar and moisture and hence need to be dried and made silage for preservation. The silage of peels and juice extraction waste is a good source of energy(70%). The seed kernel represent about 50% of the whole seed and contains 7-12% oil and 40% starch on dry matter basis. Boiling and autoclaving will remove certain anti-nutritional factors like cyanognic glycosides, oxalate and trypsin inhibitors. Though protein content of mango seed kernel is low and quality in terms of amino acids is good.

Banana fruit by-product

About 30-40% of whole banana is available for livestock feeding. The banana fruit waste like peels contains more moisture, low protein and more soluble sugars. This can be preserved as silage along with dry fodder and fed to cattle with other feeds.

Jack fruit residue

Jack fruit is a common horticultural crop in many Asian and African regions. In India about 1.2 million tonnes of jack fruit is produced leaving a residue of 0.8 million tonnes per year. This residue (skin, aerial parts) is inedible for human consumption and quickly putrifies due to high sugar and moisture content. Studies have shown that the jack fruit residue (JFR) residue contain crude protein (6-7% on DM basis), total sugars (60-65% on DM basis) and higher organic matter digestibility (70-78%). It is palatable and can be fed to ruminants as fodder source along with supplementary nitrogen(urea/tree leaves/oil cake). The chaffed fruit residue can be ensiled for preservation or dried to less than 10% moisture content and cruhsed to use as jack bran. Nutritive value of jack bran is better than any dry fodder and almost similar to medium quality green fodder.

India produced over 103 million tons of fruits in 2020-21. Currently, commercial processing of fruits and vegetables is extremely low at around 2.2% of the total production. Challenges in converting horticultural byproducts to feed include aggregation and segregation, perishability, seasonality, logistics, admixture with plastic as well as the waste from domestic sector. The engineering interventions for processing include mechanized ensiling process, cost effective energy efficient processes of moisture removal and densification and efficient anaerobic fermentation of biomass.

Citrus waste: The citrus pulp contains 60–65% peel, 30–35% internal tissues and up to 10% seeds. Due to the high moisture and sugar contents, and presence of mould and yeast, citrus pulp gets rapidly deteriorated and may cause environmental pollution.

Therefore, it should be sun dried and pelleted to increase density or should be ensiled. It contains 5–10% CP and 6.2% EE, 10–40% soluble fibre (pectins), 54% water-soluble sugars and a rich source of trace elements. Dried citrus pulp is used as a cereal substitute in concentrate diets because of its high OM digestibility (85–90%) and energy availability for lactating dairy cows. Dried citrus pulp can replace 20% concentrate in lactating dairy cattle. Kinnow mandarin (*Citrus reticulata*) waste (KW) constituted 50% of processed kinnows. KW could replace barley grains in concentrate mixture up to 50% level without affecting nutrient utilization, VFA production, ME availability and microbial biomass production. Fresh KW was mixed with wheat straw (WS) in 75:25 ratio and ensiled for 42 days in tube silo. The feeding of KW-WS silage based TMR did not show any adverse effect on blood profile, purine derivatives excreted in urine and N-retention in buffalo calves.

Pineapple fruit residue: The post-harvest processing of pineapple fruits yields crowns, peels, cores, fresh trimmings and the pomace as pineapple waste, which account for approximately 30–35% of the fresh fruit weight. Another waste product is the pineapple bran, which is the solid residue obtained after pressing macerated skins and crowns. The wet bran can be fed fresh to animals or ensiled. Pineapple waste contains 4–8% CP, 60–72% NDF, 40–75% soluble sugars as well as pectin, but it is poor in minerals. Pineapple waste can be mixed with hay, wilted grass or rice straw and then ensiled. A 75-day field trial on lambs offered total mixed ration(TMR) containing either maize or pineapple waste silage along with concentrate mixture in 62:38 proportion revealed comparable nutrients utilization, serum biochemical and mineral profiles and performance in both the groups (Gowda et al., 2015). Another 90-day feeding trial revealed significant increase in milk yield of crossbred cow fedTMRin which the green fodder was replaced with ensiled pineapple waste. Ensiling of pineapple waste not only reduced the cost of feeding but also helped in overcoming the disposal problem.

The use of FVWs in animal diet decreases cost of animal feed and increases livestock farmers' income. Furthermore, these unconventional feed resources are good alternative to maize and possibly other feed constituents that compete with human food. Their use will also decrease food–feed competition.Some of the FVWs are excellent source of antioxidants, pigments like carotenoids, lycopene, poly-phenolic compounds, as food additives, source of pectins, anti-carcinogenic compounds and essential oils. Some of these are excellent source of α-Amylase, hemicellulase and cellulase, lignin and manganese peroxidase and laccase etc.Some of the major constraints in the utilization of FVWsare the presence of heavy metals, pesticide and their residues,alkaloids, mycotoxins and anti-nutritional factors. Presence of these agents at high levels in the diet can adversely impact animal health and welfare. These toxic agents can get transferred to animal products, which may affect human health. Regular monitoring of the potential toxic agents is advocated before the FVWs are used in animal feeds.

Baby corn by-products: Baby corn is eaten both raw and cooked. In India, the average baby corn production is about 7.5–8.7 tonnes/ha. The production of by-products/wastes from baby corn is: husk and silk (5.56 tonnes/ha), stalks and leaves after harvesting ears (30 tonnes/ha) and masculine buds (3.13 tonnes/ha). These byproducts/wastes can be fed fresh or after ensiling and have comparable/ better nutritive value than maize fodder. Besides selling baby corn cob for human consumption, farmers can get additional income by selling baby corn fodder from baby corn plant.

Bottle gourd pulp: The residue after extraction of juice is called bottle gourd pulp. It is also a good source of bio-active components like 2, 2-diphenyl-1-picryl-hydrazyl-hydrate (DPPH), vitamin C, flavonoids and total phenolics. It can be conserved by sun-drying and then ground for feeding to animals. It is a rich source of protein (24.3%) and has a low concentration of cell wall constituents. It was concluded that it can be incorporated up to 50% in the concentrate mixture of adult ruminants.

Carrot by-products:These include cull carrots, carrot tops and carrot pomace after extraction of juice. Cull carrots are highly palatable and readily consumed by cattle. Fresh carrot contains 10% crude protein, 1.4% ether extract and up to 60% sugars, mostly sucrose on dry matter basis, which make carrots both highly digestible and palatable. Carrot is a rich source of vitamin C and carotene. Carrot is a staple diet of horses.

Empty pea pods*:* After shelling peas, the leftover material is empty PP constituting about 55% of intact pea pods, which contain 19.8% CP and 1.0% EE. These are rich in total soluble sugars (35.8%), total phenolics (9.4%) and macro- and micro-minerals. Empty pea pods could replace berseem hay in total mixed ration up to 50% level without affecting nutrient utilization, volatile fatty acids production, metabolizable energy availability and microbial biomass production.

Cull potatoes: The under or over-sized potatoes which do not meet the quality standards or grade, or are damaged, potato waste from cold storages, ensiled potatoes and potato hash wastes (PHWs) have wide applications as animal feed. The fresh cull potatoes contain 65–75% starch and 0.4% EE, but are low in CP (9.5–10%). PHW is a high-moisture (85%) by-product contains 70% starch, 10.5% CP and 5.85% CF with ME of 11.2 MJ/kg DM. Potatoes improve the appetite are palatable, laxative in nature, and are good for the digestion. As per the general recommendation, 4.5–5.0 kg potatoes are equivalent to 1.0 kg barley or corn grains. These can be incorporated in the ration up to 30% on DM basis.

Sarsonsaag waste: Sarsonsaag (an Indian dish) is prepared by steam-cooking leaves of Brassica campestris (mustard), Spinaceaoleracea (spinach) and Trigonellafoenum-graecum (fenugreek) in a 95:4:1 ratio. After thorough washing, the chopped leaves are steam-cooked. The pulp is sieved and processed for human consumption. The leftover fibrous fraction is a waste, called 'Sarsonsaag waste (SSW)'. It is dumped on the waste land posing a threat to the environment. SSW contains 14.5% CP and is a good source of water-soluble sugars (6%). It is concluded that SSW supplemented with mineral mixture is highly palatable, can serve as an excellent source of nutrients for ruminants and can be fed as a complete feed. Adult buffaloes can consume 50–55 kg fresh SSW in a day.

Tomato waste: It includes cull tomato and tomato pomace (TP). The mixture of skin, core and seeds left after the extraction of pulp from tomato processing industry is called TP, which constitutes 2-10% of processed tomatoes. TP can be fed fresh or preserved either by sun-drying or by ensiling. Because of the high moisture content, it cannot be ensiled alone. Therefore, it is recommended to mix with wheat/rice straw or maize stovers in 70:30 and then ensile. TP contains 19–22% crude protein and 11–13% ether extract. TP is a good source of lycopene, a pigment that gives colour to meat and is a known antioxidant and may help in relieving oxidative stress in ruminants. The sun-dried, ground TP could replace 50-100% concentrate mixture or 40-50% complete diet of buffaloes without any adverse effect. TP has significantly low methane production potential as compared to conventional cakes.

Cauliflower, cabbage and raddish leaves:Contain 17 to 20% CP, but contained very high moisture content (86-90%). Among protein fractions albumin constituted the major proportion followed by glutelins, globulins and prolamins in all these VWs. Most of the VWs were rich sources of Ca, P, Na, K, S, Zn, Mn, Mo and Co.

Some entrepreneurs have developed machinery suitable for utilization of horticultural waste along with the agriculture waste, such as paddy and wheat straw, soybean haulms etc. For example, M/s ChudekarAgro industries, Mumbai came out with a chopper cum grinder for grinding unsold fruits, fruit Peels and vegetable waste.

Agricultural waste are shredded and added to the ground horticultural waste in equal proportions and pellets are prepared for using as animal feed after steam sterilization..

Waste from aqua sector

Indian fish production during2020-21 isexpected to be about 15 million tons. Fish processing and domestic fish markets generate 30 to 55% of material as waste. Average waste generation in India is 3 million tons which is equivalent to 21% of total fish production.Fish waste contains valuable nutrients like proteins, lipids, minerals and vitamins. Further processing of aquatic waste is the source for production of several useful molecules such as chitin, collagen, keratin,PUFA and enzymes like proteolytic, chitinolytic and collagenolytic enzymes, and amino and carboxy peptidases. The lack of baseline data on availability and quality of aqua waste, scattered nature of domestic market fish waste, poor quality raw material, lack of cold chain facilities , indigenous processing plants of quality standards, poor industry -research institution partnershipandlack of focused policies are the major challenges impacting the secondary fish processing. There are opportunities to promote secondary fish processing to produce high value and specialty compounds as well as industrial and formulated products.ICAR-CIFT, Cochin has developed several technologies including edible value added products (battered/breaded products, pickle & soup)from fish waste,, protein based products (meal, protein concentrate, hydrolysates, fish peptone, functional peptides, collagen peptide, collagen concentrate & gelatin), lipid based products (body oil, liver oil, PUFA concentrate), minerals (fish bone calcium) and specialty products like chitin, chitosan, chitin derivatives, hydroxyapatite, astaxanthine and squalene.

Waste from meat processing

Appropriate waste disposal from the meat processing centers is important to prevent environment pollution and spread of diseases. The solid slaughterhouse waste is collected and dumped in landfills or open areas while the liquid waste is sent to municipal sewerage system or water bodies, thus endangering public health as well as terrestrial and aquatic life. The chemical composition of slaughterhouse waste water are similar to that of the municipal sewage, however the former is highly concentrated wastewater with 45% soluble and 55% suspended organic composition. Blood has a very high COD of around 375,000 mg/L, and is one of the major dissolved pollutants in slaughterhouse wastewater. In most of the developing countries, there is no organized strategy for disposal of solid and liquid wastes generated in abattoirs. By-products form the slaughter of food animals constitute about 50% of the live weight and their maximum utilization and value addition can ensure better returns to the stakeholders.Animal byproducts,particularly blood, is considered as liquid meat as it contains good amount of protein and has a perfect amino acid balance. Porselvam and Srinivasan, (2017) observed that anaerobic co-digestion was feasible and viable treatment technologycan be developed for utilizing wastes from the meat processing. Karthik et al (2010) studied the composition and storage stability of poultry feed, and observed that dry rendering is a safe method for destruction of microbes in the raw material and preparing good quality pet food for dogs by incorporating spent hen meal.

Ayurvedic medicinal residues

Indian ayurvedic industry has a turnover of around Rs. 3500 crores with 7-10 per cent annual growth rate. It is estimated that there are over 7800 medicinal drug- manufacturing units in India, includes 14 well-recognized and 86 medium scale manufactures of herbal drugs, producing ayurvedic preparations employing thousands of tons of herbs. Thailam (oil based) and Kasayam (decoction) are the major available Ayurvedic medicinal residues. The thailam residues have higher crude protein and oil content ranged from 21-27% and 11-23% respectively, whereas Kasayam residues were mostly fibrous with low protein content ranges between 5.5 to 6.5% on DM basis. The potential of Ayurvedic medicinal residues as livestock feed has not been explored. Study conducted in goat at ICAR-NIANP using Thailam Ayurvedic medicinal residues viz. Ksheerabala (K) and Dhanwantharam (D) has shown that 40% of Soybean and groundnut cake protein can be replaced with the above ayurvedic residues without adverse effects on health and production (22.7 kg Ksheerabala and 25.4 kg Dhanwantharam per 100kg concentrate mixture). The cost of feeding was also reduced by 18-20%.

Conclusion

Strategies for strengthening the feed / fodder base should focus on regional availability and suitability of potential resources. Use of certain non-traditional feed stuffs lessen the dependency on conventional ingredients. A major drawback in the use of the non-traditional oil seeds is lack of appropriate processing methods that are not only effective to neutralizing the toxins but are economical and simple enough to be taken up by the processing industries. Perception of end users about the technology and their involvement in technology validation is a key to its successful adoption. Local milk unions, krishi vigyana kendras, organised livestock farms and village level self-help groups should act as sub-centres of technology transfer and harness benefits of these innovations.

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Recent advances in selection of bulls for the breeding programme

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Introduction

Enhancing the reproductive efficiency of livestock with a specific emphasis on optimizing bull fertility holds paramount importance due to the potential for a single bull to sire thousands of females through artificial insemination. To augment overall dairy herd fertility, it is imperative to unravel the genetic basis of male reproductive traits that impact both male and female fertility. Utilizing this genetic information for selective breeding purposes has the potential to significantly enhance overall herd fertility (Butler *et al.,* 2019). The strategic identification and early-life selection of elite bull calves facilitated by physiological and molecular approaches coupled with tailored nutritional interventions to optimize post-pubertal reproductive potential, emerge as indispensable practices for maximizing the economic viability of livestock operations. While traditional methods, such as bull breeding soundness evaluation and analysis of frozen semen, effectively eliminate grossly infertile bulls. The inherent variability in fertility among samples classified as satisfactory necessitates a more nuanced approach. Advanced sperm function assays, designed to evaluate compensatory and non-compensatory (sub-microscopic) sperm traits have proven instrumental in predicting variations in bull fertility that may not be discernible through traditional methods. Furthermore, a profound understanding of the epigenetic modulations influencing sperm DNA, messenger RNA and proteins is deemed fundamental for refining and expanding the scope of sperm function assays. The evaluation of male fertility predominantly relies on the examination of thawed semen, employing traditional criteria like sperm motility, morphology, viability, enzyme release, membrane integrity and acrosomal integrity. Of these parameters, motility stands out as a crucial trait linked to the fertilization potential of sperm. In this context, we provide a summary of diverse approaches for evaluating semen quality and bull fertility.

Sperm kinematics by Computer-assisted sperm analysis (CASA)

Sperm motility is a critical factor linked to the fertilization capacity of sperm cells, serving as an indicator of their viability and morphological integrity. The utilization of CASA ensures meticulous and reliable data on various aspects of sperm kinematics. CASA has proven to be a valuable tool for objectively assessing sperm movement and studying the impact of various treatments on sperm kinematics (Mortimer *et al.,* 2013). The capacity of CASA to categorize different sperm sub-populations offers an opportunity to establish criteria for various functional aspects of sperm related to fertility. These aspects include the ability of sperm to reach the site of fertilization, penetrate cervical mucus, undergo capacitation and participate in fertilization. CASA can be deemed an efficient, precise and reliable tool for evaluating sperm quality and thus fertility.

Morphology and membrane integrity assessment

Assessing bull sperm morphology and membrane integrity is vital for evaluating fertility. Sperm morphometry is influenced by the integrity of the sperm membrane and acrosome. Damaged acrosomes result in smaller sperm heads, whereas intact acrosomes are associated with larger heads and acrosomes. The eosin-nigrosin staining method is extensively used to evaluate the quality of semen. This technique employs eosin and nigrosin dyes to assess viability and morphology of sperm population in semen ejaculate (Park *et al*., 2012).. This method widely adopted in semen banks and IVF centres for semen ejaculate qualification. This method plays a crucial role in appraising the reproductive health of bulls.

The Hypoosmotic Swelling-Giemsa (HOS-G) test evaluates individual sperm for both functional membrane and acrosome integrity. In a hypo-osmotic environment, sperm with intact plasma membranes swell, forming a hairpin bend in the principal piece of the tail's flexible motor apparatus. The water molecules are transported occurs across an intact cell membrane under hypoosmotic environment until equilibrium is reached between the inside and outside of the cell. Further staining with Giemsa (HOS-G test) further reveals acrosomal intactness (Selvaraju *et al.,* 2020). This HOS-G test assesses crucial sperm attributes reflective of functional membrane and acrosomal integrity which is essential for navigating the female reproductive tract, reaching the ovum and penetrating the zona pellucida for further fertilization process. In IVF centres, the HOST is routinely carried to select even nonmotile sperm for ICSI. This improves fertilization and cleavage rate after ART procedures.

Assessing mitochondrial membrane potential in bull sperm, using JC-1 or Rhodamine 123 fluorescent dyes offers insights into sperm vitality and energy status. Decreased fluorescence may signal potential issues critical for sperm motility and fertility, also emphasizing the importance of this assessment for understanding mitochondrial function. Techniques like flow cytometry or fluorescence microscopy are commonly used for this evaluation (Selvaraju *et al.,* 2020).

Sperm nuclear morphology assessment

Sperm DNA integrity could be considered as a biological indicator of sperm quality, fertilization potential, embryonic development and outcome of pregnancy. Any occurrence of DNA damage originating from the paternal genome can disrupt the normal progression of embryonic and fetal development. Incompatibilities arising from such genetic disruptions can significantly impede the healthy growth and maturation of the developing embryo and fetus. Assessment of such DNA damage is of utmost importance to predict sperm quality. Feulgen staining has been widely employed to identify and visualize irregular chromatin shapes, vacuoles and abnormal chromatin condensation. The TUNEL (Terminal deoxynucleotidyl transferase dUTP nick end labelling) test is an important method used to assess DNA fragmentation in sperm cells. This test relies on identifying damaged single or double stranded DNA fragments by microscopy application. Sperm chromatin structure assay (SCSA) is another important technique that evaluates the structural integrity of sperm chromatin, specifically focusing on DNA fragmentation. The method relies on the susceptibility of damaged sperm DNA to denaturation when exposed to heat or acid, in contrast to intact DNA.

Genomic selection of bulls

Bull fertility is a crucial economic trait in livestock production, impacted by genetic, epigenetic, and environmental factors. Research has shown that male fertility traits like scrotal circumference, semen quality, and DNA methylation markers are strongly correlated and play significant roles in bull fertility (Özbek et al., 2021). Genome-wide association studies have identified genetic variants associated with fertility traits, and the importance of considering the X chromosome linked genes influencing semen quality (Swathi et al., 2023). Integrative analyses combining genotypes and epigenetic changes helped identify biomarkers linked to bull fertility. Studies from this lab and elsewhere suggested that x-chromosome linked genes, genes regulating metabolism, immunity zinc finger protein families, and G protein-coupled receptors strongly regulate bull fertility and production traits. The study of single nucleotide polymorphisms (SNPs) for bull fertility has gained significant response due to its ability to predict merit animals for efficient and sustainable production (Özbek et al., 2021). Genome-wide association studies using high-throughput sequencing revealed crucial SNPs in candidate genes (TPT1, BOLA-DRA, CD74, RPS17, RPS28, RPS29, RPL14, RPL13, and RPS27A) associated with sperm functionality, survival, oxidative stress and overall bull fertility (Sinha *et al.,* 2023). These identified SNPs can be used for distinguishing high and sub fertile bulls.

Sperm transcriptomics

Sperm contains a diverse array of both mature and immature RNAs (mRNA, miRNA, rRNA, LncRNA, etc.), which is delivered to the oocyte during fertilization and manifest complex reproductive processes. Hence, profiling sperm RNAs has emerged as a promising non-invasive method to predict bull fertility, offering insights into spermatogenic events and embryonic development. Recent studies have found potential biomarkers, such as mRNA and miRNA, that differ between high- and low-fertility bulls, with implications for sperm chromatin structure and fertilizing ability (Selvaraju et al., 2023; Parthipan et al., 2017). Cryopreservation of bull spermatozoa has been shown to alter the transcriptomic composition, affecting genes involved in fertility-associated functions and pathways, potentially explaining reduced fertility in cryopreserved semen (Selvaraju *et al.,*). The recent studies found transcripts in bovine sperm, such as BMP2, TRADD, TMCO2, RPL36A, CCDC174 and OIT3 (Parthiban *et al.,* 2017; Selvaraju *et al.,* 2021) as fertility-regulating transcripts. These transcripts also play a key role in predicting successful embryonic development, pregnancy maintenance and well-being of the offspring (Selvaraju *et al.,* 2022). Research has identified dysregulated transcripts, proteins, and metabolites between high- and low-fertility bulls, highlighting the impact of sperm metabolism on fertility (Dasgupta *et al.,* 2022).

Sperm proteomics

Bull sperm proteomics involves the comprehensive analysis of sperm proteins in bulls to understand their role in fertility and reproductive success. Numerous sperm proteins have been identified in bulls, including albumin, SRN, bovine proacrosin, and SPADH1, which exhibit differential expression during various reproductive stages. Proteomic approaches have been essential in identifying seminal plasma proteins, such as osteopontin, binder of sperm proteins (BSPs), and heparin-binding proteins (HBPs), which positively impact sperm motility and fertilizing ability (Park *et al*., 2012). On the other hand, semen is a complex fluid with diverse proteins, including enzymes and signaling molecules. Identifying and confirming seminal plasma and sperm protein biomarkers is crucial for diagnosing male infertility, evaluating fertility treatment success, and understanding reproductive health. Notably, some proteins involved in protecting sperm membranes against cryopreservation such as calmodulin, dermcidin and sperm acrosome membrane-associated protein3 (Selvaraju *et al.,* 2016) in bovine. Studies on sperm proteomics have identified PEBP4, a protein present in bull gonads (Somashekar *et al.,* 2017), appears to play a role in regulating sperm maturation and function. Immune-infertility is a condition in which the immune system identifies gametes (sperm and eggs) as foreign entities, that hinders conception. Our previous laboratory research findings indicate that sperm auto-antigens, which possess potential immunogenicity to safeguard the membrane integrity and metabolic functions of sperm while exhibiting effective antioxidant capacity (Archana *et al.,* 2023).

Sperm Metabolomics

Metabolomics, a novel technology, investigates low molecular weight compounds in sperm to reveal regulatory mechanisms in fertilization. Bull sperm metabolomics is vital for understanding male fertility. Changes in metabolites and metabolic pathways within sperm cells and seminal plasma can affect sperm motility and energy acquisition and thereby influencing bull fertility. In astheno-oligozoospermic bulls, selenocysteine and deoxy uridine triphosphate in spermatozoa, and malonic acid and D-cysteine in seminal plasma are dysregulated suggesting potential metabolic disruptions that impact fertility(Li *et al.,* 2023). Recent research has primarily applied sperm and seminal plasma metabolomics to identify biomarkers in humans and cattle, with a focus on fertility. Notably, studies now explore the connection between seminal plasma metabolites and sperm quality, revealing associations with specific metabolites like leucine, taurine, and carnitine, which are linked to sperm fluid storage capacity (Mateo-Otero *et al.,* 2021). Studies on sperm and seminal plasma metabolites between normozoospermic and astheno-oligozoospermic bulls revealed changes in fatty acid metabolism and ketone body degradation pathways in astheno-oligozoospermic bulls (Dasgupta et al., 2022). These findings emphasize the importance of understanding sperm metabolomics in assessing bull fertility and suggest potential pathways for improving fertility outcomes in breeding programs.

Pheromone-based fertility assessment

The reproductive capacity of bulls holds significant importance, with various factors among which libido, mating ability and sexual interaction playing crucial roles. The presence of pheromones in various bodily fluids like urine, vaginal mucus, and skin gland secretions highlights the importance of chemical communication in influencing bull fertility and reproductive success in cattle. Recent studies have shown that acetic acid and propionic acid enhance sexual responses in bovine (Manikkaraja et al, 2020).

The incorporation of pheromone-based assessments into breeding programs holds the potential to revolutionize the selection process, facilitating the identification of bulls with elite fertility and consequently bolstering overall reproductive efficiency in livestock. Despite the promise this avenue holds, the utilization of pheromones for bull fertility assessment remains in its nascent stages. Ongoing studies aim to pinpoint steroids, aldehydes, ketones, and alcohol-based pheromone compounds intricately linked to various reproductive states in bulls.

Conclusion

To enhance bull fertility and decrease the cost associated with dairy herd maintenance, the selection of higher reproductive performance bulls through genetic selection is essential. Studies also indicate that bull fertility is genetically correlated with economically relevant traits like average daily gain and calving interval. Implementing comprehensive breeding strategies such as balanced nutrition and health management can enhance the reproductive capacity and resistance of stud bulls, ultimately improving fertility in the dairy cow population. By combining genetic selection with efficient management practices, producers can achieve improved bull fertility and cost-effectiveness in cattle reproduction.

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Mineral Supplementation Technologies for Dairy Animals

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Introduction

Minerals are inorganic elements required by the animal for optimum growth, production, reproduction, health and immunity. They are essential components of body enzymes, hormones and cells and needed for proper muscle and nerve function. The animals get a high proportion of their minerals from the feedstuffs and forages that they consume. The evaluation of feeds and feed supplements as sources of minerals depends not only on the total trace element content or concentration but also on how much can be absorbed from the gut and used by the animals' cells and tissue.

Depending on the quantities required by the animal, they can be grouped into macro (major) minerals and trace (minor) elements. Of the major minerals the most important are calcium, phosphorus, sodium, chlorine, potassium, sulphur and magnesium. The important trace elements are copper, cobalt, iron, iodine, zinc, manganese and selenium. Rations that contain a high percentage of forage usually supply adequate amounts of calcium but may be low in phosphorus. However, rations high in grain contain adequate phosphorus but may be deficient in calcium and other minerals. Micro or trace mineral deficiencies are associated with soil type and are usually geographically related.

Micronutrients have critical roles in the key interrelated systems of immune function, oxidative metabolism, and energy metabolism in ruminants. Micro minerals have a great impact on animal's reproductive physiology and its imbalance causes various problems leading to lowered reproductive efficiency and resultant monetary loss to the dairy farmers. Minerals are required by all dairy cows, and the amounts found in most feeds normally are inadequate for high milk production or growth. If these requirements are not met, deficiency symptoms can occur. Trace-elements have long been recognized as a requirement for reproduction due to their cellular roles in metabolism and growth. However, they also have specific roles and. requirements in lactating cows. Since many of the proposed reasons that trace element status reduces dairy cow fertility involve transition cow health and immunity, the trace element status of dry cows is very important for fertility in the following lactation.

Importance should be given to following aspects for mineral supplementation: -

- Mineral profiles in soil, water, feeds and fodders and compound feeds in the area
- Case record of diseases related to mineral deficiencies in the area
- Parasitic diseases in the area
- Any seasonal variation in mineral profiles in feeds and fodders in the area
- Bioavailability of mineral sources
- Age, breed, and Stage of production of animals

Importance of minerals on reproduction in dairy cattle

Reproductive efficiency is a major factor that affects profitability in ruminants. Trace minerals such as Zinc, Copper, Manganese, and Selenium are essential with classically defined roles as components of key antioxidant enzymes and proteins. Adequate micro minerals supplementation is required as most of the roughages, greens, concentrates and even most of commercial feeds available to Indian market are deficient in trace mineral elements.

Trace minerals are important for reproductive performance in livestock because their supplementation improves reproduction and improves conception. The ovarian activity of ruminants is influenced by mineral deficiency. They are also involved in synthesis of hormones that are important for reproduction. Their deficiency affects steroid hormone production. Trace element deficiency may be linked to problems such as retained foetal membranes, abortion, and weak calf syndrome. Micro minerals are involved in several biological processes, such as component of metallo- enzymes and enzyme co factors. Some of these are component of hormones and thus directly regulates endocrine activities. Due to its involvement in carbohydrate, protein and nucleic acid metabolism, any change in its level may alter the production of reproductive and. other hormones. Its improper level may affect embryonic development, postpartum recovery activities and over all fertility of animal may be

impaired. In male animals it may change spermatogenesis and reduce libido. Limited research indicated that chromium supplementation during the transition period may increase immunity and reduce the incidence of retained placenta.

Calcium and phosphorous

Calcium related disorders (deficiencies) are mostly very common during parturition or within few days following parturition. Ca and P deficiency cause prolongation of first estrus and ovulation, delayed uterine involution, increased incidence of dystocia, retention of placenta and prolapse of uterus. Delayed onset of puberty and

silent or irregular estrus in heifers, failure of estrus and long inter calving period in cows are observed in P deficiency. The appropriate ratios (Ca: P) should be between 1.5:1 and 2.5:1 for lactating cows.

Copper

Copper is one of the important mineral for reproduction and its deficiency is reported to be responsible for early embryonic death and resorption of the embryo, increased chances of retained placenta and necrosis of placenta and low fertility associated with delayed or depressed estrus.

Zinc

Zinc is known to be essential for proper sexual maturity (development of secondary sexual characteristics), reproductive capacity (development of gonadal cells) in males and all reproductive events (estrus, pregnancy, and lactation), more specifically with onset of estrus in female.

Selenium

Se causes weak, silent, or irregular estrus, retained fetal membranes, early embryonic death, still birth or weak offspring and abortions in females and reduced sperm mortality in males. Conception rate is improved on Se supplementation. Diets should contain at least 0.1ppm selenium on a dry matter basis.

Manganese

Deficiency causes poor fertility problem in male and female. It is responsible for silent estrus and anestrus or irregular estrus and decrease conception rate, birth of deformed claves and abortions in females and absences of libido and improper or failure of spermatogenesis in males. Manganese is important in cholesterol synthesis

which in turn is necessary for the synthesis of steroids like progesterone, estrogen, and testosterone.

Table 1. Function, deficiency and source of minerals for dairy cows

Mineral	Function	Deficiency	Feed sources for dairy cows
Calcium (Ca)	Bone and teeth formation, blood clotting, muscle contraction	Rickets, slow growth and poor bone development, reduced milk yield, milk fever	legumes, ground limestone, dicalcium phosphate, steamed bone meal
Phosphorus (P)	Bone and teeth formation, involved in energy metabolism	depraved appetite, poor reproductive performance, pica	Phosphates, steamed bone meal, cereal grains, grain by-products, oil seed meal
Sodium (Na)	Acid-base balance, muscle contraction, nerve transmission	Craving for salt, reduced appetite, incoordination weakness, shivering	Common salt
Magnesium (Mg)	Enzyme activator, found in skeletal tissue and bone	Irritability, tetany-increased excitability	Magnesium oxide, forages and mineral supplements
Sulfur (S)	Rumen microbial protein synthesis	Slow growth, reduced milk production, reduced feed efficiency	Elemental sulfur, sodium and potassium sulfates, legume forages
Potassium (K)	Maintenance of electrolyte balance, enzyme activator, muscle/nerve function	Decrease in feed intake	Legume forages, potassium chloride, potassium sulfate
Iodine (I)	Synthesis of thyroxine	Goiter	Iodized salt, trace mineralized salt and commercial supplements
Iron (Fe)	Part of hemoglobin, part of many enzyme systems	Nutritional anemia, pale mucus membrane	Forages, grains, trace mineralized salt
Copper (Cu)	Needed for manufacture of hemoglobin, coenzyme	Severe diarrhea, abnormal appetite, poor growth, coarse, bleached hair coat	Trace mineralized salt and commercial supplements
Cobalt (Co)	Part of vitamin B_{12}, needed for growth of rumen microorganisms	Failure of appetite, anemia, decreased milk production, rough hair coat	Trace mineralized salt and commercial supplements
Manganese (Mn)	Growth, bone formation, enzyme activator	Delayed or decreased signs of estrus, poor conception	Trace mineralized salt and commercial supplements
Zinc (Zn)	Enzyme activator, wound healing	Decreased weight gains, lowered feed efficiency, skin/wound problems	Forages, trace mineralized salt, zinc methionine

Micronutrients and udder health

Mastitis is still one of the three main diseases that affect the profitability of dairy farmers. The major impact of nutrition on udder health is via suppression of the immune system. Cows in negative energy balance are at a higher risk of ketosis and clinical ketosis is associated with a two-fold increase in the risk of clinical mastitis.

Micronutrients (Trace minerals and Vitamins) that can affect udder health are selenium and vitamin E, copper, zinc, and vitamin A and B- carotene.

Most cases of clinical mastitis were detected during the first week of lactation, so it is imperative that the immune system is functioning properly at this time of high stress for the cow.

Vitamin E and selenium (Se) are integral components of the antioxidant defence of tissues and cells. Selenium is an essential micronutrient present in tissues throughout the body and is important physiologically because it is an integral component of the enzyme glutathione peroxidise. High serum Se concentrations are associated with reduced rates of clinical mastitis and low milk SCC.

Vitamin E and Se deficiency leads to impaired PMN (polymorphonuclear neutrophils) activity. Dietary supplementation of cows with Se and Vitamin E results in a more rapid PMN influx into milk following intramammary bacterial challenge and increased intracellular killing of ingested bacteria by PMN, as well as lowering the frequency and shortening the duration of clinical mastitis. Supplementation of 0.3ppm of Se and 1000IU/ day of vitamin E can prevent the mastitis in dairy cows.

There is a potential role for dietary copper (Cu) in enhancing resistance to E. coli mastitis.

Zinc is required for keratin formation. Organic zinc is beneficial in enhancing resistance to mastitis pathogens because of postulated role of Zn in maintaining skin integrity and the keratin lining of streak canal. Zinc supplementation drastically reduces the SCC and intra-mammary infections.

Micronutrients in prevention of milk fever

Milk fever is most common disease for lactating cows during immediately after parturition. It occurs due to calcium deficiency during this transition period. Milking cows should always be provided adequate amounts of calcium to maximize production and minimize health problems.

A major concern in the mineral feeding of dry cows relates to providing optimum levels of calcium and phosphorus in order to decrease the occurrence of milk fever. Prevention of milk fever is an important consideration in maximizing reproductive efficiency.

Micronutrients and milk production

Some vitamins and trace minerals are clearly documented with their influence, while the impacts of supplementation of some micronutrients on milk performance are less clear. Selenium-yeast supplementation (150-300mg/kg) improves the milk yields. The recommended dose of Se is 0.3ppm in the diet. It has been found that supplementing cows with 360 mg Zn, 200 mg Mn, 125 mg Cu as amino acid complexes and 12 mg cobalt (Co) from Co-glucoheptonate daily resulted in a 6.3% increase in milk production, 6.4% improvement in fat yield, 6.5% improvement in crude protein yield, 5.8% improvement in production of milk solids, and a trend fora reduction in mastitis cases

Technologies for mineral supplementation

There are six common methods of supplementing cattle with minerals:

- offering free choice of individual mineral sources
- offering a mixture of minerals as a lick
- supplementing with minerals mixed with concentrates
- feeding a mixture of minerals individually to cows
- injections or oral dosing
- slow-releasing bullets

Most popularly minerals are supplemented either through concentrate feeds, or through mixture of minerals individually to cows. Minerals can also strategically be supplemented through locally available mineral-rich feeds and fodder. Recently, the concept of feeding area-specific mineral mixture has got importance for economic as well as correct supply of minerals to animal's point of view.

Area-specific mineral mixture

Traditionally, mineral mixture consisted of almost all the mineral salts were supplemented to animals irrespective of these minerals' deficiency or sufficiency in the diets. This approach of mineral supplementation to cows had been found very costly and provide more opportunity for interaction and imbalances among the minerals. On detailed survey for mineral status in soil, feeds, fodders, and blood of animals throughout the Karnataka state, it has been found that some of the minerals are present in excess in soil, plant, and animals in some of the regions which are not needed to supplement to animals. Hence, area-specific mineral mixture had been developed for different agro-eco zones of the state which were found to be cost-effective and beneficial in terms of animal production and reproduction. Judicious use of mineral salts based on mineral concentrations in soil, plants and animals in different agro-climatic zones is imperative. This area-specific mineral mixture is the most practical and cost-effective way of mineral supplementation for strategically providing the most deficient minerals. The detailed study conducted at NIANP, Bangalore has shown the major deficiency of Ca,P,Cu and Zn. in most agro -climatic zones of Karnataka

Table 2. Major mineral deficiency and locally available feed resources rich in minerals for feeding to animals in Karnataka

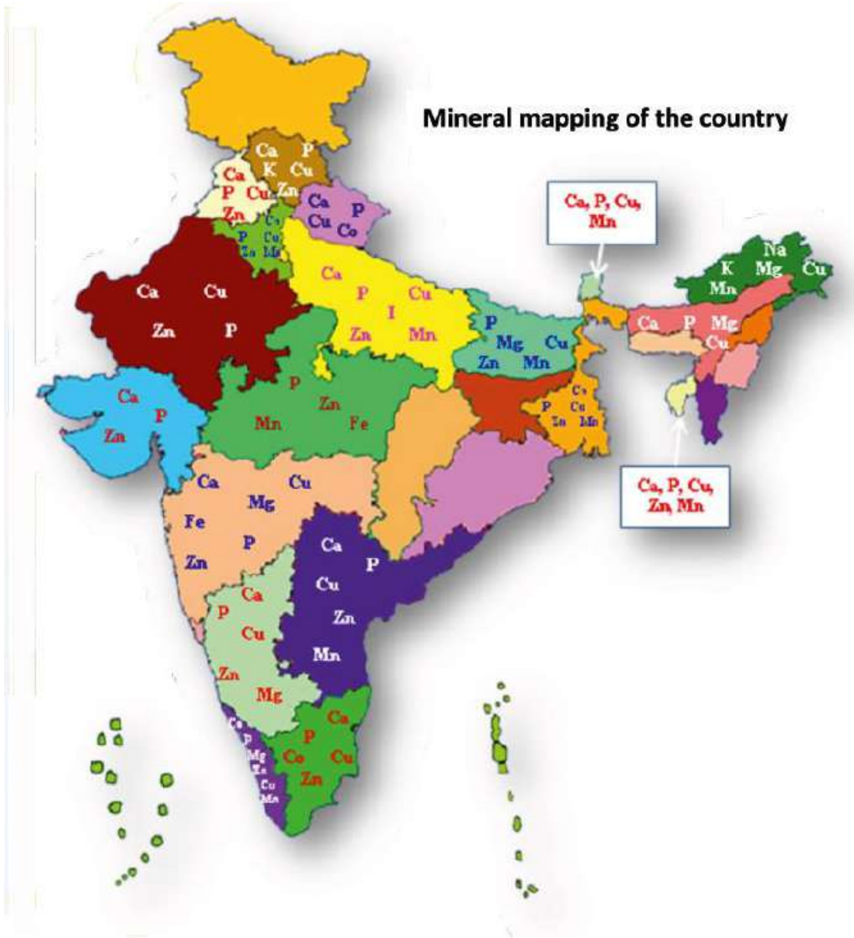
Agri —Eco Zone	**Major Deficiency**	**Natural Sources**
North east transition zone	Ca, P	Legumes, Tree Leaves, Green F grasses
North east dry zone	Ca, Zn	Legumes, Tree Leaves, Green Fodde
Northern dry zone	Ca, P, Mg, Cu, Zn	Legumes, Brans, Rice polish Tree le
Central dry zone	Ca, P, Mg, Cu, Zn	Legumes, Tree leaves, oil cakes, bra
Eastern dry zone	Ca, Cu	Legumes, Tree leaves, Green fodder
Southern dry zone	Ca, P, Zn	Brans, Cakes, Rice Polish, legumes
Southern transition zone	Ca, Cu, Zn, P	Legumes, Tree Leaves, grasses, Bra
Northern transition zone	Ca, P, Cu, Zn	Green Fodders, Local Grasses
Hilly zone	Ca, P, Cu, Zn	Cakes, Brans, Legumes, Tree Leaves
Coastal zone	Cu, Zn	Legumes, Tree Leaves, Local Grasse

Gubbi plant of KMF producing four different types of ASMM for four agro-climatic zones of Karnataka (Technology commercialized to KMF by NIANP, Bangalore)

Presently Karnataka is producing area-specific mineral mixture through Karnataka Milk Federation, Bengaluru and M/s Nandi Agro Vet PVT. Ltd., Bengaluru to supply the whole state for dairy cow feeding. This mineral mixture has been found improved the reproductive efficiency (80%) and enhanced the milk production from half to one liter per day with concomitant increase in fat percentage in dairy cows.

Mineral mapping of the country

Under All India Coordinated Project, the almost all the districts except few of whole country has been done and the respective state is preparing the area-specific mineral mixture for economic supplementation of minerals to livestock under different geographical areas.



Chelated minerals

Most of the positive effects of organic minerals on the performance of the animals appear mainly due to their higher bioavailability as compared with their inorganic sources. Studies observed that organic trace minerals improved immune response in dairy cows and calves, and also improved milk yield and reproductive performance. Chelation technology has been developed to increase mineral bioavailability by reducing the negative interactions between minerals. Organic trace elements have been used in dairy cow experiments, resulting in significant improvements in udder health, lameness and reproductive performance. Cows fed organic trace minerals also have greater milk fat yields than cows fed inorganic trace minerals. Several studies have suggested that organic trace minerals improve pregnancy percentage and services per conception because amino acid chelated sources of minerals increase the concentration of specific minerals in their uterine tissue. Pal et al. (2010) reported that the bioavailability of copper (Cu) and zinc (Zn) and their tissue accumulation was higher in ewes supplemented Cu and Zn from organic than inorganic sources. Supplementation of zinc with glycine chelate improves the growth performance of pigs (Wang et al., 2010) and broiler birds (Feng et al., 2009). Due to higher bioavailability of organic trace minerals, Nollet et al. (2008) and Bao et al. (2007) suggested that broiler performance and concentration of minerals in tissues could be achieved by supplementing less minerals from organic sources. Feeding sows organic trace minerals may improve sow reproductive performance (Peters and Mahan, 2008).

Therefore, supplementation of minerals through organic sources may be more effective in ameliorating the reproductive problems in ruminants.

Nano minerals

Another form to improve the bioavailability and reducing the excretion of trace minerals in the environment is nano minerals. The field of nanotechnology brings wide variety to biological research, therapeutic as well as addresses environmental concerns. Nano minerals can be synthesized by physical, chemical and biological methods. By virtue of its small size, it is easier to be taken up by the gastrointestinal tract, so are more effective than the larger size at lower doses Feng et al. 2009). Nano minerals have the capability to cross the small intestine and further distribute into the blood, brain, lung, heart, kidney, spleen, liver, intestine and stomach. The[functional activities such as chemical, catalytic or biological effects of NPs are heavily influenced by the particle size of the nanometals (Rosi and Mirkin 2005).

- Nanoparticles that tends to increase the surface area for better interaction with biological support
- Prolonged the compound residence time in gut
- Reduce the influence of intestinal clearance mechanisms
- Enable cells for efficient uptake
- Effective delivery of functional compounds to target sites and thereby better bioavailability

The absorption, distribution, metabolism and excretion of nanoparticles in the body rely on their physicochemical properties such as solubility, charge and size. The particle size of lesser than about 300 nm can reach the bloodstream, while particles that are smaller than 100 nm can get into various tissues and organs (Hett, 2004).

Nano Zn has been reported to reduce somatic cell count (SCC) in subclinical mastitis cow and improved mastitis conditioned with increase in milk production than other conventional ZnO sources (Rajendran, 2013). Supplementation of ZnO NPs had improved milk production in subclinical mastitis animal thus can be used as a preventive as well as curative agent. ZnO NP has been reported to enhance growth performance, improve the feed utility and provides good economical profit in weanling piglets (Yang and Sun 2006) and poultry (Mishra et al., 2014). Mishra et al. (2014) observed an improved growth rate in layer chicks than inorganic Zn supplemented groups due to supplementation of nZn at much reduced does. Many researchers have pointed out the antimicrobial action of metal oxide NPs. ZnO NPs have bactericidal effects on both Gram-positive and Gram-negative bacteria (Arabi et al., 2012) and it has the potential in reducing bacterial growth for practical applications in animal without the fear of antibiotic resistance and residues.

Trace element-enriched Microbes: Selenium-enriched yeast

Other sources of organic trace elements that show promise are mineral enriched yeast. Presently the most common is selenium yeast with selenium complexed with a methionine molecule (selenomethionine). Chromium enriched yeast also has gained popularity for improving animal production (Rao etal.,2012).

- Improve the immunity
    - Reduce the prevalence of retained placenta
    - Reduce severity & prevalence of clinical mastitis
    - Reduce milk somatic cell counts
    - Reduce calf mortality.
    - Improve the reproductive efficiency

So, research studies suggest that supplementing trace minerals (Cu, Zn, Mn, Cr, Fe and Se) from organic sources especially from chelated or nano forms or encapsulated forms of Cu, Zn, Fe and Se-yeast have major impact on animal health and production. Hence, there is scope to improve animal health, production and reproduction through better bioavailable micronutrients.

Yeast is capable of utilizing elemental Se to synthesize Se-

Methionine, Se-cysteine Se-methyl-Se-cysteine etc. (organic Se species) (Pal et al., 2012). Yeast can be enriched with selenium through growing it in a medium with a shortage of sulphur and a controlled amount of selenium. Most selenised yeast products contain 97-99% organic selenium of total selenium. Looking at all data from literature and published trials, it is generally accepted that SeMet is the most effective and active compound in selenized yeast.

Selenomethionine (Se-Met) is well absorbed and is either metabolized directly or is incorporated into body proteins in place of methionine. Se-Met is incorporated primarily into the proteins of the skeletal muscles, erythrocytes, pancreas, liver, stomach, kidneys, and gastrointestinal mucosa. Its release from body proteins is linked to protein turnover and occurs continuously. Se-Met provides all forms of bioactive Se needed for selenoprotein biosynthesis. The incorporation of Se-Met into body proteins could increase Se to toxic levels is not warranted because a steady state is established, which prevents the uncontrolled accumulation of Se.

These organic forms of Se are natural and rapidly metabolized within the body to yield high bioavailability and retention and thus increase Se storage in organs & tissues & greater accumulation in meat, milk & egg. Se-YEAST is an attractive Se supplementary source due to its cost effective and its ability to act as a precursor for Se-protein synthesis and it has high content of Se.

Impact of using chelated and nano minerals and trace minerals-enriched yeast on animal health and production

Trace minerals are essential for dairy cows and other livestock species and inadequate intake of trace minerals may result in lower reproductive efficiency, poor disease immunity, slower daily gains, and poorer feed conversion. Recently organic minerals sources (chelated minerals, nano minerals, trace minerals-enriched yeast)

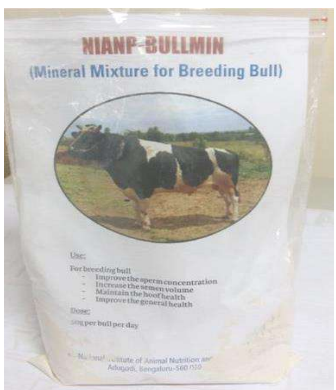
have begun to gain popularity because of a number of perceived benefits to their use over the inorganic salts (Ledoux and Shannon, 2005; Nollet et al. 2008; Bao et al. 2007; Peters and Mahan, 2008; Pal et al. 2010). As a result, the development of organic forms of trace minerals, such as minerals chelated with amino acids, nano form of trace minerals, and trace minerals-enriched yeast are an alternative to minimize the risk of mineral antagonism and enhance absorption efficiency and decrease of metals in environment.

Mineral Mixture for Breeding Bull

After energy and protein, minerals are the major nutrients and should be required in order to optimize reproduction in breeding bull. Trace minerals nutrition is critical, since even minute fluctuation in their levels will have significant impact on reproductive health and performance of animals. Requirements of minerals for reproduction and immunity are generally greater than maintenance requirement of bull which might require supplementation of that mineral. Trace mineral such as Selenium (Se), Zinc (Zn), copper (Cu), manganese (Mn), Cobalt (Co), Iron (Fe) and Iodine (I) are important in male fertility because of their importance in the functioning of different enzymes and protein. Adequate micro minerals supplementation is required for bull fertility because most of the roughages, greens, concentrates, unconventional feed and even most of commercial feeds available to Indian market are deficient in trace mineral elements, as in most parts of the India soils are deficient in trace element such as Cu, Zn, Fe and Mn. A deficiency of Zn in males reduces testicular development, sperm production, poor semen quality and libido. Synthesis of testosterone is dependent on adequate dietary Zn. It is a structural part of protein that involved in synthesis and secretion of testosterone. The Zn levels in seminal plasma are 10-15 folds higher than those in blood plasma of the bull. Testicular atrophy is the direct consequence of Zn deficiency. A positive correlation exists between testicular development and semen quality so Zn deficiency leads to poor semen quality. Selenium (Se) is involved in normal spermatogenesis and is involved in sperm formation by protecting spermatozoa from reactive oxygen species (ROS). Sodium selenite improves semen quality by increasing semen volume per ejaculate, spermatozoa motility and concentration and by decreasing percentage of dead spermatozoa, spermatozoa abnormalities, and acrosome damage. Deficiency of Cu leads to decreased libido, lower semen quality and induces severe damage to testicular tissue which may render the bull sterile. Proper supplementation of copper along with healthy ratio with other minerals is required for production of good quality semen. Trace mineral, manganese increases serum levels of puberty-related hormones. It is necessary for cholesterol synthesis, which ultimately is required for synthesis of the steroids, estrogen, progesterone and testosterone. Insufficient steroid production results in decreased circulating concentrations of these reproductive hormones resulting in abnormal sperm production in males. Iodine deficiency leads to delay in puberty, failure of fertilization, decrease in libido and deterioration of semen quality in males. Iron is trace elements that present in cells and tissues in the male reproductive system. Within the male reproductive system, Sertoli and Leydig cells are important reservoirs of ferritin. Fe plays an important role in the synthesis of nucleic acids and proteins, electron transport, cellular respiration, proliferation and differentiation, which are ultimately lead to spermatogenesis and spermatozoa metabolism. It is component of cytochrome enzyme which is important in electron transport chain and plays role in spermatozoa motility.

Bull reproductive efficiency can be improved through maintenance of proper trace mineral balances. Supplementation of trace minerals during active reproductive phase of the animal will improve their reproductive performance, however, care should be taken about the interaction with other minerals and over-supplementation. Organic Trace mineral supplementation produce better results due to its greater absorption and least interaction with other minerals. The feeding of antioxidant trace minerals (Zn, Se, Cu, Mn) during stress can improve health and fertility of the bull.

Considering the specific requirement for semen production by breeding bulls, ICAR-NIANP has developed a bull-specific mineral mixture. The developed bull mineral mixture has been validated with systematic studies and found beneficial to bull.



The spermatozoa count was observed higher in bulls supplemented with this specific mineral mixture which resulted in more number of frozen semen straws per bull. The average sperm concentration was 1.32 x 109 /ml of semen. The average number of straws per ejaculate was 400 and average number of straws per bull was 47520. The conception rate using the straws made of this semen was 55%. The technology is cost-effective in terms of low cost of mineral mixture and more numbers of semen straws per bull.

Sheep and Goat Mineral Mixture

Sheep and goats are mostly reared under extensive grazing system without supplementing concentrate ingredients. Under this system of rearing, there is every chance of macro and micro minerals deficiencies in sheep and goats. Further, due to extensive grazing, sheep and goats frequently get parasitic infestation which aggravated the minerals deficiencies. In addition, considering the special physiological requirements, sheep and goats need some of the minerals in excess and some in less due presence of adequate quantity in green herbages. Earlier the mineral mixture for cattle and buffalo had used to supplement to sheep and goats in reduced amount in half to one-third doses of cattle and buffalo which may not be right practice to supplement the minerals need of these small ruminants. Keeping these in view, ICAR-NIANP has come out with a mineral mixture specific for sheep and goats. This mineral mixture has been validated with systematic scientific studies and found beneficial at field level. Now this technology has been commercialized to M/s Nandi Agro Vet Pvt. Limited, Bangalore for large scale adoption to sheep and goat farmers in Karnataka.

Summary

Proper mineral supplementation in animal feeding programs is essential to animal health and performance. The long term effects on milk yield, animal health, and reproduction are of major concern and are the reason that we should try to ensure an adequate daily intake of all minerals through supplementation. If the requirements are not met, deficiency symptoms can occur. Subclinical or marginal deficiencies may be a larger problem than acute mineral deficiency because specific clinical symptoms are not evident to allow the producer to recognize the deficiency. To minimize costs involved with mineral feeding, nutritionists should try to maximize the percent of minerals provided by typical feedstuffs. The supplementation of area-specific mineral mixture based on mineral profiles in soil, feeds and fodders and animals in the area is most cost-effective approach for dairy animals' nutrition. Generally, supplemental trace minerals are supplied through inorganic sources, typically in the form of sulfates, phosphates, chlorides, carbonates or oxide forms of the trace mineral. Organic minerals are generally more expensive, but they may still be advantageous, particularly as related to immune and reproductive responses. Organic minerals can be included at much lower levels in the diet than the current recommendations for inorganic minerals, without any negative effect on animal performance.

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Optimizing Dairy Cattle Performance through Micro-Climate Modification

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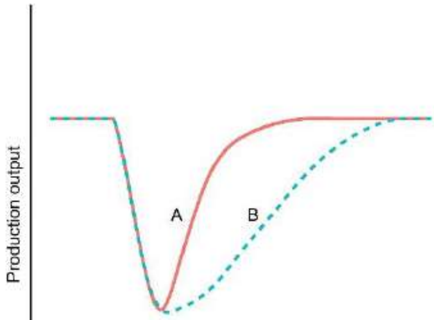
Optimizing dairy cattle performance in the face of fluctuating environmental conditions is a crucial aspect of modern dairy farming. As climate change intensifies and extreme weather events become more frequent, dairy farmers must adapt their management practices to ensure the well-being and productivity of their herds. Micro-climate modification—through techniques such as shading, ventilation, and cooling systems—plays a pivotal role in creating a conducive environment for dairy cows. By carefully managing micro-climate factors, farmers can enhance animal comfort, mitigate heat stress, and improve overall herd performance. This article explores various strategies for micro-climate modification, highlighting their impact on dairy cattle health, productivity, and farm profitability.

Environmental stress

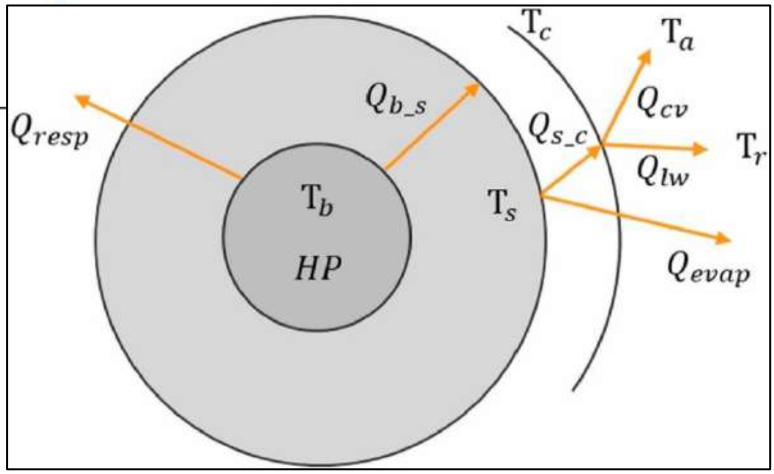
Thermoregulation is crucial for homeotherms to maintain homeothermy and homeostasis by balancing the production and loss of body heat (Kadzere et al., 2002). In dairy cows, heat production mainly arises from basal metabolism, rumen fermentation, nutrient absorption, growth, lactation, gestation, immunization, and exercise (Ouellet et al., 2019). Thermal stress occurs when a cow's ability to disperse heat produced through normal metabolism is compromised, usually due to ambient temperatures exceeding the thermoneutral zone (temperature range within which an animal can maintain its normal body temperature without having to adjust metabolic heat production). Heat stress is induced when a dairy cow is pushed above her thermoneutral zone at a Temperature Humidity Index of 68, forcing the cow to promote heat loss through sweating and panting and reduce heat production by limiting feed intake and decreasing milk production (Zimbelman et al., 2009). For lactating Holstein cows, the comfortable temperature range is between 4-24°C (Hahn, 1981). Heat stress compromises dairy production by decreasing feed intake and milk yield and may also alter milk composition and feed efficiency (Chen et al., 2024). The effects of heat stress on cows begin to be observed above 24°C, and milk yield decreases markedly above 27°C (Johnson, 1965).

The synthesis of milk in lactating cows depends on the secretory capacity of the mammary gland, including the number and activity of mammary secretory cells (Capuco et al., 2003). Studies have shown that exposure to high ambient temperatures leads to higher rates of programmed cell death in primary bovine mammary epithelial cells (Tao et al., 2018). This increased cell death may contribute to the decrease in the total number of mammary epithelial cells and lower milk production observed in lactating cows under heat stress conditions (Capuco et al., 2020). Furthermore, heat stress affects mitochondrial protein oxidation and DNA loss (Slimen et al., 2014), thereby impacting the body's energy metabolism. Mammary plasma flow plays a crucial role in nutrient supply and uptake in the mammary gland (Farmer et al., 2008) and is essential in supporting the synthesis of milk components. Resilience can be best defined as the ability of an animal to quickly regain its original state after being exposed to disturbance.



(Shirley et al., 2024)

Figure 1. Illustration of a greater degree of resilience (A) contrasted with a lower degree of resilience (B) for ruminants under environmental heat load.



(Zhou et al., 2024)

Figure 2. Schematic representation of the thermal balance model (Zhou et al., 2022). T_b: body core temperature (°C); T_s: skin temperature (°C); T_c: coat temperature (°C); T_a: air temperature (°C); T_r: radiant temperature of surrounding objects (°C); HP: metabolic heat production (W); Q_{resp}: heat loss through respiration (W); Q_{b_s}: conductive heat flow between body core and skin (W); Q_{evap}: evaporative heat loss through sweating from the skin surface (W); Q_{s_c}: conductive heat flow between skin and coat (W); Q_{cv}: convective heat flow from coat surface (W); Q_{lw}: long-wave radiative heat flow from coat surface (W). Conductive heat loss is not taken into account.

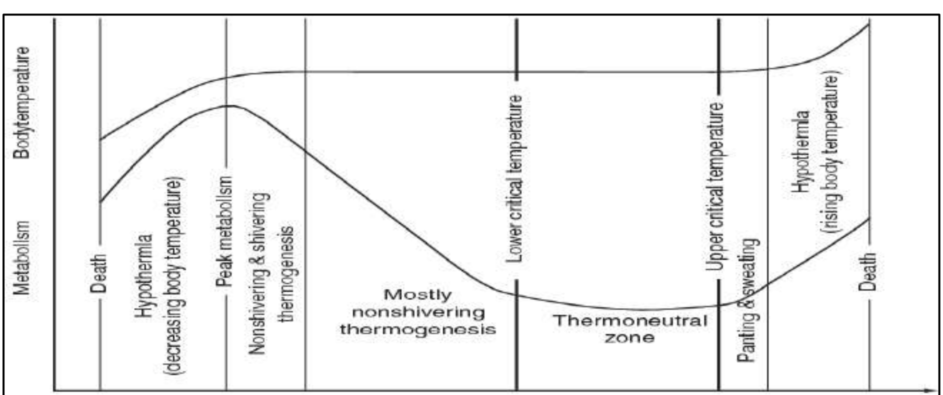
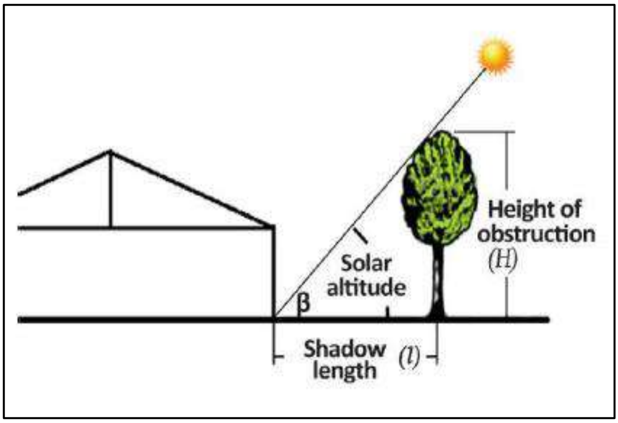


Figure 3. Effect of ambient temperature on animal metabolism and body temperature (Renaudeau et al., 2012

Micro-climate modification strategies

A well-designed shade can significantly reduce the radiant heat load experienced by dairy animals. Inadequate housing and ventilation, combined with overcrowding and unhygienic conditions, can severely impact the health and productivity of dairy cows. Therefore, an animal shelter must provide a comfortable, hygienic, and well-drained lying area, along with protection from adverse weather conditions. Additionally, sufficient floor space is essential to allow animals to move freely, minimizing the risk of injury and enabling the expression of normal behaviors. Physical structures that provide shade, such as trees, roofs, or cloth, help create more hospitable microclimates for cows by reducing solar radiation exposure and lowering ambient temperatures. The orientation of barns, depending on geographic location, can also play a crucial role in mitigating heat stress. By reducing direct sunlight and lowering stall surface temperatures, appropriate barn orientation enhances heat transfer from the cow's body to the environment. For instance, orienting the longer side of the dairy shelter along an east-west axis minimizes direct sunlight on the side walls, thereby reducing heat stress. Thus, effective micro-climate modification is vital for maintaining a comfortable environment for dairy cows, promoting their health and productivity.



$l = H \times \cot \beta$ where,

l= shadow length

H=height of obstruction (windbreak)

β= solar altitude

(Acharya et al., 2024)

Figure.4. Shade, height and orientation for dairy cows

Different types of materials such as thatch, earthen tiles, corrugated iron sheets, asbestos sheets, and iron sheets with aluminium paint can be utilized as roofing materials to reduce solar radiation and shield the animals from precipitation or inclement weather. However, metal roofs can transfer radiant energy, causing significant temperature differences. For instance, the underside temperature of bare metal roofs can be about 10°C higher than that of insulated roofs, with uninsulated roofs reaching up to 57°C compared to 37°C under insulated ones during peak heat. The quality of shade materials significantly impacts the micro-climate within the animal house. Ideal materials should be light, strong, durable, weatherproof, aesthetically pleasing, poor conductors of heat, and resistant to moisture condensation. To minimize radiant heat load, white paint can be applied to the upper side and black paint to the underside of metal roofs. Woven polypropylene shade cloths, which are cost-effective, can provide about 80 to 85% shading and have been noted to reduce heat stress and improve animal performance.

Side curtains can also be installed to block direct sunlight from entering the animal shade, particularly on the west side of the house. Additionally, an innovative method involves installing an extra wall layer at either end of the house. This setup includes a fixed, nontransparent curtain as the outer layer, placed 10 cm away from the inner wall, with vertical openings at both ends (Fang, 2007). The bottom opening allows cool air to enter, while the upper opening lets hot air exit. The 10 cm air gap between the walls acts as a thermal barrier, preventing conductive heat from entering the house. This double-wall approach is cost-effective and has proven effective in structural design. In summary, selecting the appropriate roofing and shade materials is crucial for maintaining a favourable micro-climate in dairy shelters, reducing heat stress, and enhancing animal welfare and productivity.

Ventilation: A well-ventilated animal shelter is essential for providing fresh, clean air to both animals and workers. Dairy animals require an optimal microclimate to maintain their health and production efficiency. Poorly ventilated shelters, with high moisture levels and harmful manure gases, create a detrimental environment that can negatively affect milk yield and quality. To improve conditions, outer coverings and shading, potentially combined with a roof spray, are effective strategies. Various roof systems can enhance natural ventilation through roof openings and the solar chimney effect. In an open-type dairy shed, a roof vent is crucial for allowing heat to escape. Key factors for natural ventilation include the size of the roof opening relative to the floor area and the vertical distance between the air inlet and outlet. For instance, a house six meters wide would require a roof vent at least 30 cm wide. In closed-type dairy barns, pads and fans can be installed at both ends to facilitate air circulation. Environmental modification often focuses on free-stall and loose housing barns with high, steeply pitched roofs. These barns, featuring open or capped ridge vents, minimize the transfer of infrared radiation, encourage the venturi effect as hot air rises and exits the ridge vent, and promote cross-ventilation due to the high eaves. Overall, proper ventilation systems are critical for maintaining a healthy environment in dairy shelters, ensuring the well-being of the animals, and optimizing their productivity.

Fans: Fan installations are effective in reducing environmental temperatures and mitigating heat stress by facilitating air movement and increasing convection. This helps decrease respiratory rates and rectal temperatures while increasing dry matter intake in dairy cows. Strategic positioning of fans is crucial to ensure optimal cooling. In holding areas and free-stall shelters, fans should be installed longitudinally, with spacing no more than ten times their blade diameter. They should be placed vertically and high enough to be out of the cattle's reach and not interfere with alley scraping or bedding operations. Proper air flow is essential for effective cooling. When air flows over the animal at a velocity between two and three meters per second, it significantly increases convective heat loss during stressful conditions. Additionally, the design of the shelter should allow for a larger floor area compared to the roof area, enabling animals to avoid direct sunlight. The minimum height of the roof should be 3.6 meters (or 4.3 meters for structures wider than 12.2 meters) to ensure sufficient air movement in the center of the shade. Overall, the proper installation and placement of fans are critical for maintaining a comfortable environment for dairy cattle, alleviating heat stress, and enhancing their well-being and productivity.

Sprinkler and Fan Cooling: The scientific literature reveals that different water application rates result in varied physiological and productivity responses from dairy animals. Different water application rates can significantly affect the physiological and productivity responses of dairy cows. Studies have shown that frequent and adequately timed water spraying can notably enhance milk yield and improve production efficiency. For instance, spraying cows for 1.5 minutes every 15 minutes can lead to substantial increases in milk yield. Cooled dairy cows demonstrate significantly reduced respiratory rates and improved production efficiency, primarily due to decreased energy expenditure for body cooling. Continuous day-long cooling in free-stall barns helps maintain lower body temperatures throughout the day, contributing to overall animal welfare. The effectiveness of cooling systems depends heavily on the frequency and duration of wetting. Short durations, such as 10 seconds, are less effective than longer durations of 20 or 30 seconds, which show similar effectiveness. Additionally, longer cooling periods can further reduce body temperatures, highlighting the importance of adequate cooling duration.

Low-pressure sprinkler systems that produce large droplets capable of soaking through the hair coat to the skin are more effective than misting systems. However, these systems require significantly more water, necessitating careful management of water usage. Innovations such as self-controlled showers, which cows can activate themselves, offer targeted cooling and reduced water consumption. Overall, integrating sprinklers and fans in dairy barns is an effective strategy to mitigate heat stress, improving cow comfort and productivity. Efficient water management and strategic placement of cooling systems are essential to maximize their benefits.

Evaporative Cooling: When ambient temperatures exceed the animal's body temperature, evaporative cooling becomes essential. This system utilizes high-pressure mist and large volumes of air to evaporate moisture and cool the surrounding environment for dairy animals. Evaporative cooling systems are particularly useful on farms in hot, dry regions where water availability is limited. Such systems have been shown to enhance the environment for lactating dairy cows in arid climates by removing heat energy through the evaporation of water (Ryan et al., 1992). Evaporative cooling can be achieved by passing air over a water surface, through a wetted pad, or by atomizing or misting water into the air stream (West, 2003). However, their effectiveness diminishes in climates with high relative humidity. Berman (2006) discovered that increasing air velocity on the animal's body surface might help mitigate humidity stress in sheltered areas with reduced exposed body surface, such as mangers and stalls, potentially extending the use of evaporative cooling to less arid environments. Zone cooling, a specific type of evaporative cooling, integrates high-pressure mist injected into the fan stream, with fans directed downward to blow cooled air directly onto the cows. While air conditioning and zone cooling are effective, they can be cost-prohibitive. Therefore, it is crucial to design animal shelters to provide maximum comfort and efficiently manage cooling systems to optimize dairy animal welfare and productivity.

Cold stress: During cold waves following snowfall in the western Himalayas, many regions in northern and eastern India experience ambient temperatures of around 0°C for varying durations, making the effects of cold stress on animal productivity and efficiency more pronounced (Kataktalware and Reddy, 2015). Wind chill and rain can lower the animal’s effective temperature below its critical level, leading to decreased weight gain, reduced milk yield, and increased milk fat content (Tarr, 2007). Newborn calves, calving cows, animals with low body condition, and sick animals are particularly vulnerable to cold stress. It is essential to provide some form of winter shelter for cold-sensitive younger animals, especially those up to one month of age. In colder regions, utilizing the warmth and insulation from baled straw or hay for calf housing has been recommended (Thomas and Sastry, 1991). Additionally, planting trees in a north-south direction can offer protection from prevailing north and southwesterly winds, further enhancing shelter effectiveness.

Conclusion: Addressing the health and performance of dairy animals under adverse environmental conditions is a critical challenge of our time. As climate change continues to impact agricultural practices, it is imperative to educate dairy farmers on effective adaptation strategies, including advanced shelter management. A well-designed animal housing system not only helps mitigate the effects of environmental stressors but also maximizes the genetic potential of dairy animals, leading to enhanced productivity and increased farm profitability. By adopting and implementing these strategies, dairy farmers can better navigate the challenges posed by climate change and ensure the long-term success of their operations.

Note: *The content of the lecture notes is prepared as reference material sourced mainly from Kataktalware et al (2021), various articles, online sources, etc. and purely for the education and training of the participants of the Online Training Programme.*

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Climate Change and Livestock Production: Emerging Concepts and Technologies for Sustenance

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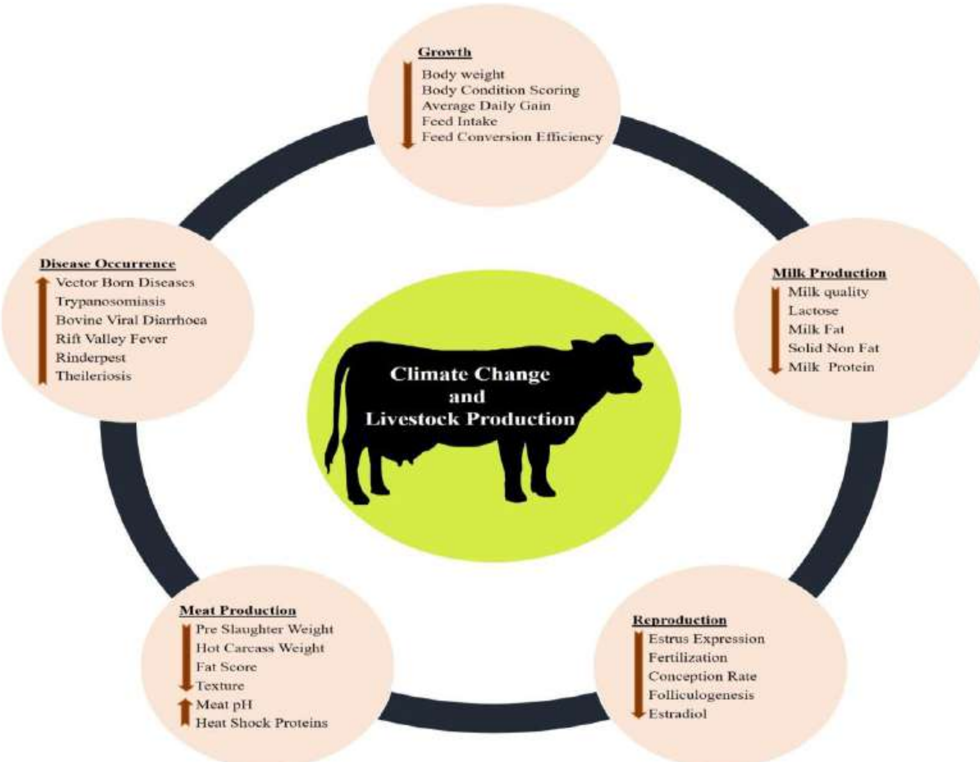
1. Introduction

While climate change is a global phenomenon, its negative impacts are felt more severely by poor people in developing countries, who rely heavily on the natural resource for their livelihoods. In arid and semi-arid areas, livestock are often considered to be one of the most important means of food and economic security for poor and marginal farmers. Elevated ambient temperature and inadequate and low quality feed are the major factors which contribute towards under-production of farm animals in tropical regions. Fig. 1 describes the various impacts of climate change on livestock production.

Given the significance of livestock to the economy of India in particular, efforts are needed to develop new concepts in animal science which could help understand the hidden intricacies of their responses to various environmental stressors which could aid in developing appropriate ameliorative strategies to improve production. This effort is therefore an attempt to project to the farming and scientific communities the various advances associated with climate change and livestock production and to highlight the various technologies available to sustain farm animal production in the changing climate scenario in the country in near future.

Fig.1.Various impacts of climate change livestock production



3. Emerging concepts in climate change associated livestock production

3.1. Goat as ideal climate resilient animal model

The projected increased temperature and reduction in fodder production can cause detrimental impact on farm animal production. In this context, goat offers greater scope for sustaining livestock production due to its advantages such as higher thermo-tolerance, drought tolerance, ability to survive on limited pastures and high disease resistance over other species. Further, goats possess the ability to walk for long distances in search of limited pastures. All these advantages imparts goat the potential to survive in varied geographical locations and are tipped to be climate resilient animal model in the changing climate scenario. In a recent review Reshma Nair et al. (2021) clearly projected goat to be the species to experience very minimal heat stress level as compared to other farm animals both by 2050 and 2100. Fig.2 projects the advantage of rearing goats over other species in the changing climate scenario.

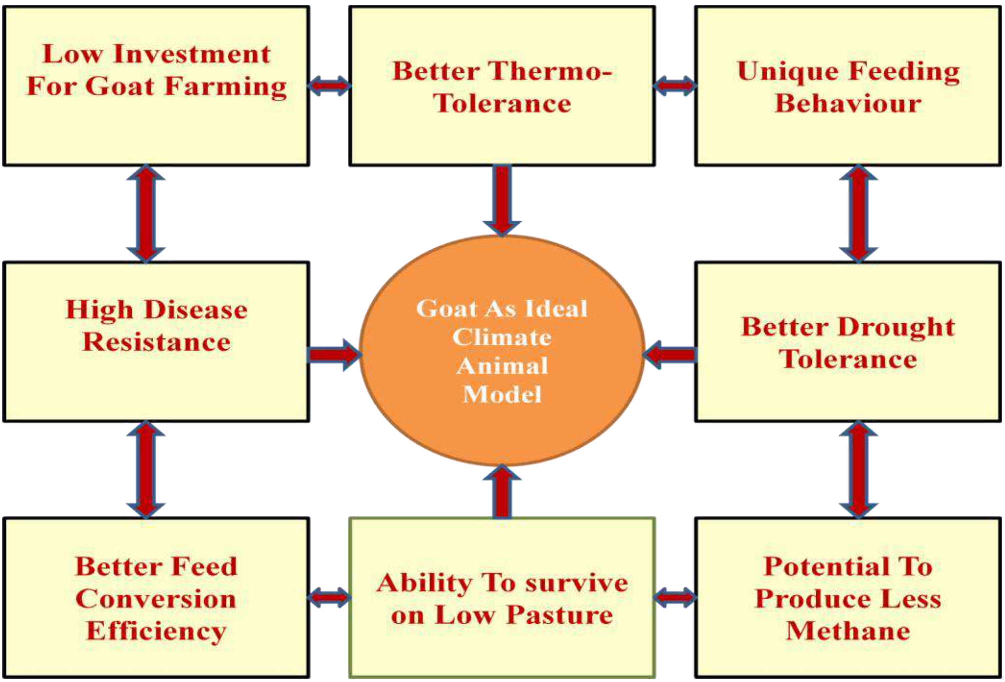


Fig.2. Scientific evidences for considering goat as ideal climate animal model (Information synthesised from International Journal of Biometeorology by Reshma Nair et al., 2021)

3.2. Concept of multiple stresses impacting farm animals

When exposed to one stress at a time, animals can effectively counter it based on their stored body reserves and without altering the productive functions. However, if they are exposed to more than one stress at a time, the summated effects of the different stressors might prove detrimental to these animals. Such a response is attributed to animal's inability to cope with the combined effects of different stressors simultaneously. In such a case, the animal's body reserves are not sufficient to effectively counter multiple environmental stressors. Fig. 3 describes the concept of multiple stressors impacting livestock production.

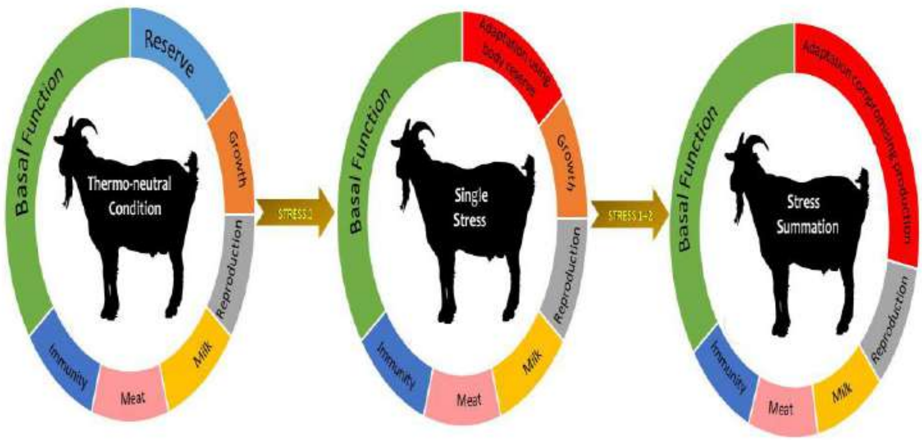


Fig.3. Pictorial representation of concept of multiple stressors on livestock production

3.3. Advanced thermal indices to quantify heat stress response

The temperature humidity index (THI) which is being widely used for quantifying heat stress response in farm animals has two drawbacks as it does not take into account solar radiation and wind speed. This has brought the drive in the scientific community to develop advanced thermal indices to address these drawbacks of THI indices. Heat load index is developed as an improvement which overcomes the perceived deficiencies in the THI index. The HLI uses two equations based on the threshold value of black globe thermometer:

$$HLI_{BG \geq 25} = 8:62 + (0.38 \times RH) + (1.55 \times BG) - (0.5 \times WS) + e^{(2.4 - WS)}$$

$$HLI_{BG < 25} = 10.66 + (0.28 \times RH) + (1.3 \times BG) - WS$$

Where, BG is the black globe temperature in °C, RH the relative humidity in %, WS the wind speed in m/s and e the exponential.

3.4. Infrared thermal imager applications in farm animals

Traditional body temperature measurement requires handling and restraining procedures may increase the average body temperature of the animals. Therefore, there is a need for identifying non-invasive methodology to quantify heat stress response in livestock. Infrared thermography (IRT) is one such non-invasive method which has the potential to record animal body temperature without the need to restrain or relocate animals. Thus, this technology offers scope for understanding in depth the thermo-regulatory mechanisms in heat stressed animals. Fig. 4 describes the different body parts surface temperature using infrared thermography in goat.

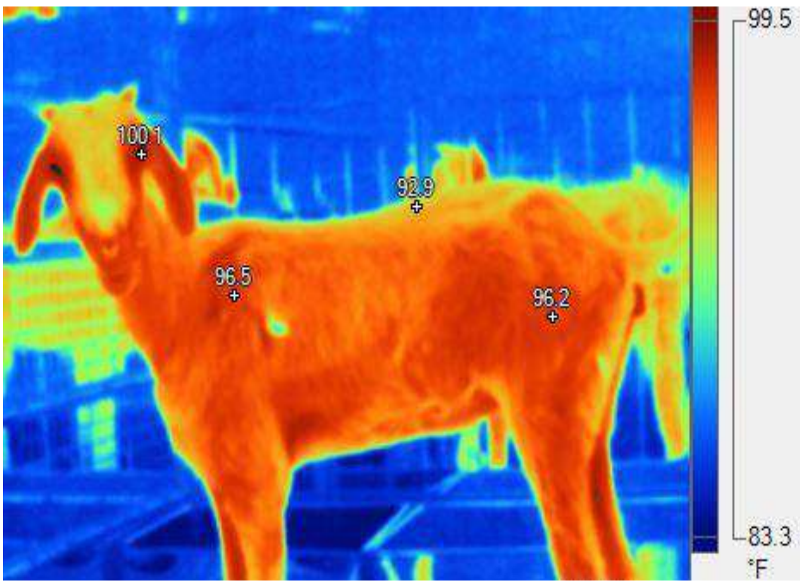


Fig.4. Surface temperature measurement in goat using infrared thermography

3.5. Agro-ecological zone specific breed identification

Sustaining livestock production in the changing climate scenario requires efforts to identify best indigenous breeds to survive in different agro-ecological zones. Such an effort could ensure that the most suited breeds to specific zones are recommended by the policy makers for dissemination to the local farmers. Therefore, promoting such recommended breeds among the local farmers may prove beneficial in improving their livelihood security. A classic example was provided by our own research which recommends Salem Black breed to be the ideal breed to survive in Southern India. This warrants more research efforts particularly in tropical regions to screen indigenous breeds for their climate resilience and to test their ability to survive in multiple locations.

3.6. Rumen microbes associaed adaptive potential

The ruminant animals and gut microbiota has evolved simultaneously while adapting to climatic and pastoral environments. Over the past few years, metagenomics has emerged as a powerful tool to study the rumen microbiome. Recent studies identifying rumen microbial community for novel enzymes, uncultured methanogens, and other metabolic pathways have opened new insights in this area. However, there are very few metagenomics studies conducted on heat stressed animals. This also is a potential area of research which could open up new pathways towards amelioration and mitigation of heat stress in farm animals.

3.7. Biomarkers for heat stress in goats

The following genes were found to be associated with thermo-tolerance in indigenous goat breeds. These genes could serve as biological markers for quantifying heat stress response in indigenous goat breeds. These markers are distributed across vital animal functions such as adaptation, growth, reproduction, metabolism and immunity. The identified traits are as follows: (1) Adaptation Traits: Heat shock protein 70 (HSP70), HSP90, HSP27, HSP110 & heat shock factor 1 (HSF1); (2) Growth Traits: Growth Hormone Receptor (GHR), insulin like growth factor 1 (IGF-1), Thyroid Hormone Receptor (THR), leptin receptor (LEPR); (3) Reproduction Traits: Prolactin Receptor (PLR), follicle stimulating hormone receptor (FSHR), leutinizing hormone receptor (LHR), estradiol receptor (ESTR); (4) Immune related traits: toll-like receptor 3 (TLR3), TLR6, TLR8, interleukin 10 (IL10), IL18, tumour necrosis factor α (TNF-α), interferon β (IFN-β), and IFN- γ. Fig. 5 describes the various biomarkers for quantifying heat stress response in goats.

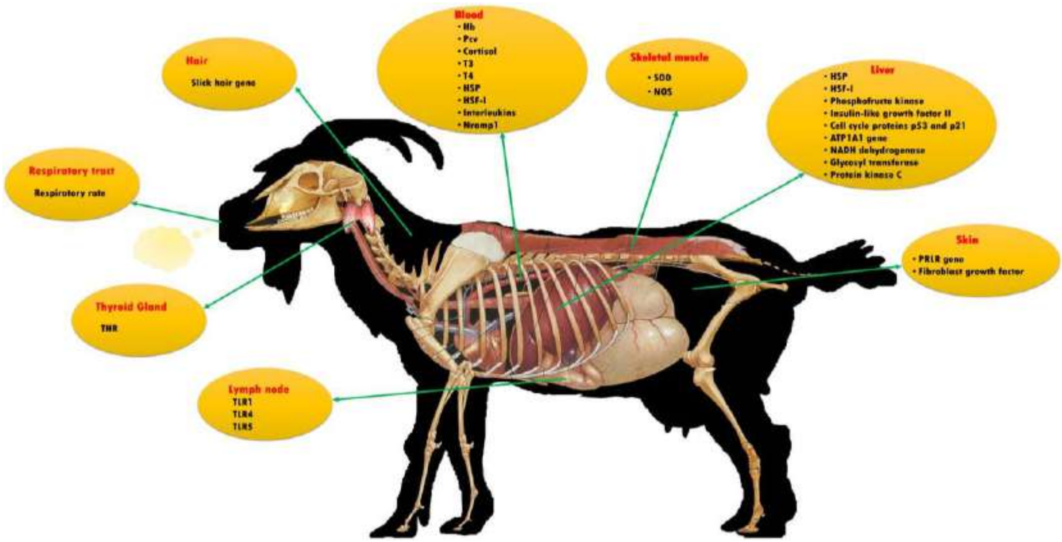


Fig. 5: Different biomarkers for heat stress in goats (Source: Sejian et al., 2018)

5. Technologies to ameliorate heat stress in farm animals

There are several ameliorative technologies that should be given consideration to prevent economic losses due to environmental stresses. Reducing the impact of climatic stresses on livestock production requires multidisciplinary approaches which emphasize Animal genetics, nutrition, housing, and health. Better management of livestock, may reduce the initiation of thermoregulatory mechanisms which allows for better energy utilisation for growth and/or production. In the face of climate change the continued development of heat stress management tools are needed to ensure the sustainability of animal based agricultural enterprises. Fig. 6 describes the various strategies to sustain livestock production in the changing climate scenario.

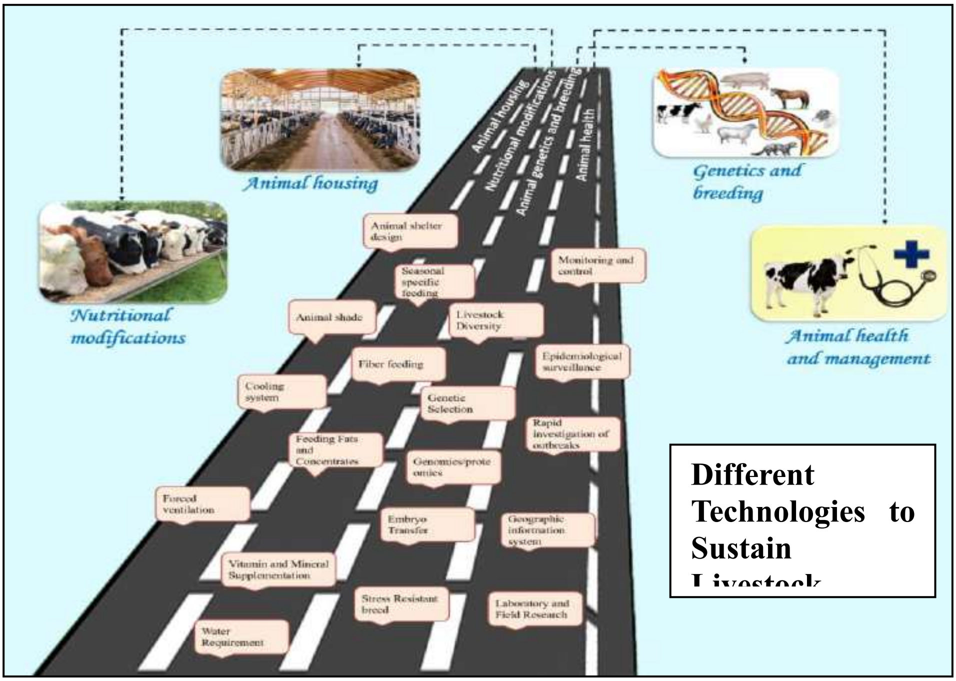


Fig.6. Various technologies to sustain livestock production in the changing climate scenario (Source: Sejian et al., 2018)

5. Conclusion and Future Perspectives

Responding to the challenges of global warming necessitate a paradigm shift in the practice of agriculture and in the role of livestock within the farming system. Scientific research can help the livestock sector in the battle against climate change. Therefore, the future research efforts involving various stakeholders including the policy makers must ensure the following aspects to sustain livestock production in the country:

- New indices that are more complete than THI to evaluate the climatic effects on each animal species must be developed and weather forecast reports must also be developed with these indices, to inform the farmers in advance.

- Advanced molecular biological tools should be employed to quantify the heat stress response in farm animals.
- The existing breeding programs have concentrated only on production traits. However in an effort to sustain livestock production in the changing climate scenario, the existing breeding programs must be redefined with the amalgamation of production, adaptation and low methane emission traits.
- Research must continue developing new techniques of cooling systems such as thermo-isolation.
- Above all appropriate agro-ecological zone specific breeds needs to be identified to disseminate it to farmers for ensuring optimum economic return which could improve the livelihoods of the poor and marginal farmers across tropical regions.
- Livestock farmers should have key roles in determining what adaptation and mitigation strategies they support if these have to sustain livestock production in changing climate.
- The integration of new technologies into the research and technology transfer systems potentially offers many opportunities to further the development of climate change adaptation strategies.

Suggested Reading

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Ready to use feed formulation tools for feeding of ruminant animals

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Feed constitutes over 70% of the operational costs in dairy production. Formulating a least-cost ration with optimal nutrients is a challenging task for farmers. Feeding an imbalanced diet can result in a deficiency of some nutrients while others, often expensive, are provided in excess. A deficiency of one or more nutrients can lead to reduced production and increased costs. Therefore, a balanced ration is crucial for achieving optimal production and reproduction while minimizing feed costs. Ration balancing tools are increasingly popular among farmers. Various tools are available on mobile and computer platforms, in addition to printed feed charts. Recently, NIANP has launched the ICAR-NIANP Feed Chart for cattle and buffaloes and "TMR Maker," an Excel-based software, both available on the Google Play Store and through their website.

Fig.1. Screen shot of ICAR-NIANP FEED CHART apps available in Google play store

ICAR-NIANP Software

1. Feed Assist
2. TMR Maker
3. Feed Chart on print, web and mobile media
4. Ration balancing tools for small ruminants

1. Feed assist

"Feed Assist" is an expert system to compute balance ration for dairy animals in least cost basis as per the nutrient requirements of various categories of cattle and buffalo using a choice of the feed resources available. This system has been developed using MS-Access as back-end tool and visual basic as front-end tool. By choosing the feed ingredients and providing the details of the animal with respect to the parameters like, body weight, average daily growth rate and milk yield, the farmer can obtain a balanced diet that gives the details of different ingredients and their proportions to be fed.

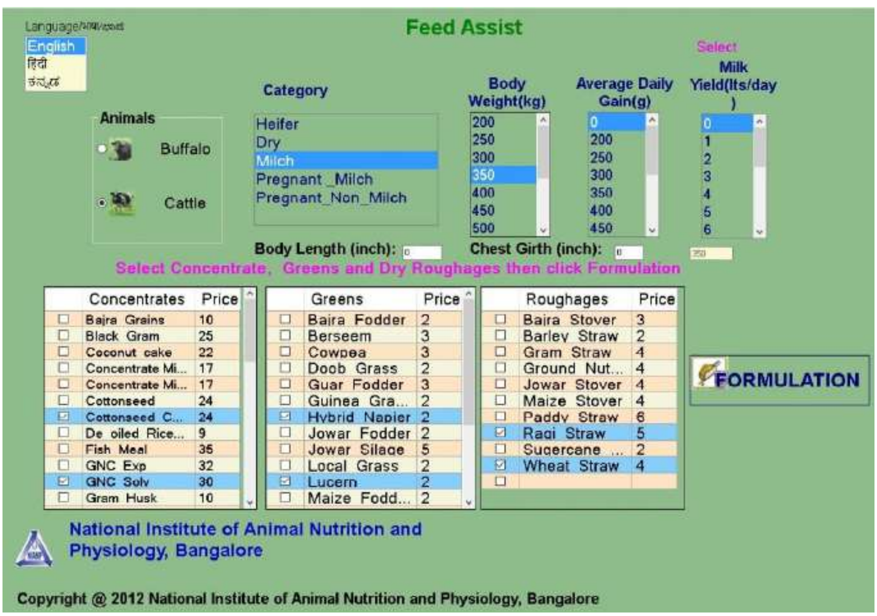

Fig. 2 Screen shoot of First page of Feed Assist

2. TMR Maker (Total Mixed Ration – Maker)

ICAR-NIANP has developed a software programme named "TMR Maker" to optimize the nutrients in the ration of dairy animal. The programme has advantage of cost controlling and optimizing nutrients in the diet. The farmer can formulate the ration by using least cost feed formulation method. This software is easy to use and farmer friendly as well.

Fig. 3. Screen shot of First page of TMR - Maker

What is total mixed ration (TMR)?

All the ingredients (roughage and concentrate) are mixed and offered to the animal per day basis is called as **total mixed ration (TMR)**. It ensures that the concentrate intake is spread uniformly over the day rather than only twice daily as practiced in the conventional feeding system. This enhances the digestibility of roughages, reduces the nutrient loss and thereby improves the productivity and profitability, particularly in intensive system. Preparation of TMR comprising of roughage / forage, concentrate and other supplementary nutrients in required proportion are made into uniform mixture either in the form of mash or pellets / blocks (complete feed). The required quantity of the concentrate, green and dry roughages and supplements Viz. Minerals, vitamins, feed additive can be calculated on least cost basis with optimum nutrient level using **TMR maker**.

However, preparing TMR or complete feed requires machinery (grinder and mixer), which involves investment.

3. Feed Chart

NIANP scientists have prepared farmer friendly tool called as "FEED CHART" for feeding of crossbred dairy cow and buffalo. This will suggest the calculated amount of concentrate; green roughage and dry roughages required per day for 400 kg crossbred cow /450 kg buffalo based on their milk yield. The provision is made for three categories of farmers, viz. farmers having high green grass, moderate green grass or less green grasses. The suggested ration according to milk yield may be followed by the farmer for reducing the cost of milk production.

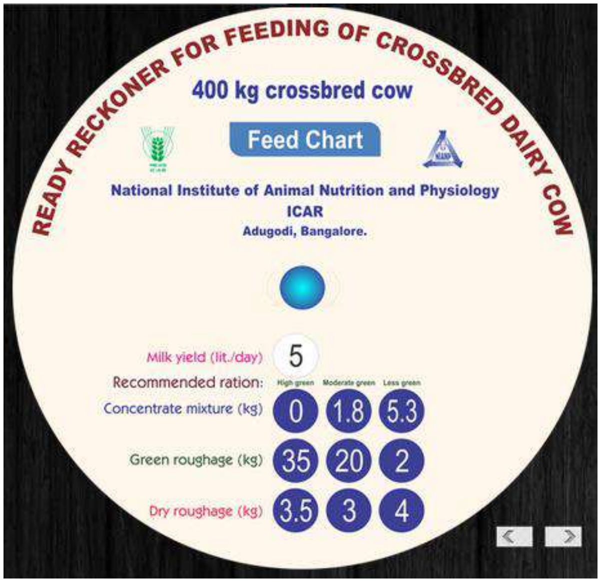

Fig 4. Feed chart for crossbred cow

Fig.5. Feed chart for buffalo

4. Ration balancing tools for Goat

NIANP has developed smart tool for formulation of least cost feed for small ruminants like sheep and goat. Requirement is calculated based on the average daily gain and body weight and feed is formulated on least cost basis.

Fig. 6 Screen shot of first page of Ratio balancing tools for goat.

5. Feeding chart for fattening lambs

Recently, NIANP released a feeding chart for fattening lambs, it is easy to use and calculate the required concentrate feed for fattening lambs for an expected average daily gain in two scenarios viz. semi-intensive and intensive system.

Fig.5. Feed chart for fattening lambs

Strategies to meet the energy requirement

Impaired energy balance in high producing animals is very difficult to overcome. Maintaining the energy intake at close up cow (21 days prior to calving) and increasing intake rapidly thereafter in fresh cow (calving to 21 days post calving) should be ensured. Recommended nutrient levels were calculated using TMR –Maker software developed at ICAR-NIANP is illustrated in the table 1.

Table 1. Recommended nutrients levels and illustrated TMR composition for feeding of cow pre, post 21 days of parturition, early, mid and late lactation period.

Feeding stage	**Details**	**Recommended Nutrients in diet**	**Illustrated TMR composition* for 100 kg diet (As fed Basis)**
Close up cow	21 days prior to calving	CP: 15-16 % TDN = 65-67 % NDF= 35-40 % NFC = 30 -35% Fat = 4 % Ca= 0.7 % P= 0.3 % DMI : 1.25-2.0%	Green Fodder: 71 kg Dry Fodder : 2 kg Con. Mix : 25.2 kg Fat/oil: 1.3 Salt :0.13 kg MM : 0.37 kg Calculated value: CP: 15% ;TDN; 65% Ca: 0.7% ; P: 0.48% DM:40.5% **Note: For 450 kg cow 23-25 Kg TMR is sufficient**
Fresh Cow	From calving to 21 days post calving	CP: 18 % TDN = 70-75 % NDF= 30-40 % NFC = 35 -35%	Green Fodder: 65 kg Dry Fodder : 1 kg Con. Mix : 4 kg

		Fat = 5 % Ca= 1.1 % P= 0.5 % DMI : 2.0-2.5%	Maize 10 kg Soya DOC 9.5 kg Cotton DOC 6 kg Fat/oil: 3.3 Kg Calcite 0.23 Kg Salt :0.13 kg MM : 0.84 kg Calculated value: CP: 18% ;TDN; 73% Ca: 1.1% ;P: 0.77% DM:44.8% **Note: For 450 kg with 15 lit milk yield cow 35-38 Kg TMR is sufficient**
Early lactation cow	Early lactating Cow (21- 100 days)	CP: 17-18 % TDN: 70-75 % NDF : 30-35 % NFC:30-40 % Fat: 5-6 % Ca:0.8-1.1% P: 0.5-0.9% DMI: 3.5-4 %	Green Fodder: 65 kg Dry Fodder: 1 kg Con. Mix: 6.5 kg Maize 10 kg Soya DOC 7 kg Cotton DOC 6.5 kg Fat/oil: 3.3 Kg Calcite 0.23 Kg Salt :0.13 kg

			MM : 0.85 kg CP: 17%; TDN; 73% Ca: 1.1%;P: 0.74% DM:44.8% **Note: For 450 kg with 20** **lit milk yield cow 38-40 Kg TMR is sufficient**
Mid lactation cow	Mid lactating Cow (101-200 days)	CP: 15-16 % TDN: 65-70 % NDF : 30-38% NFC:30-44% Fat: 4-6 % Ca:0.8-1.0% P: 0.4-0.8% DMI: 3.0-3.5 %	Dry Fodder : 3 kg Green Fodder: 63 Con. Mix : 9.2 kg Maize 9.6 kg Soya DOC 2.0 kg Cotton DOC 8.6 kg Fat/oil: 2.7 Kg Salt :0.14 kg MM : 1.0 kg Calculated value: CP: 15.2% TDN; 70% Ca: 1.0% P: 0.73% DM:45.5% **Note: For 450 kg with 15**

			lit milk yield cow 30-35 Kg TMR is sufficient
Late lactation	Late lactation (201-305 day)	CP: 13-15 % TDN: 60-65 % NDF : 33-43% NFC:30-45% Fat: 3-5 % Ca:0.7-0.9% P: 0.4-0.7% DMI: 2.8-3.3 %	Dry Fodder : 5.5 kg Green Fodder: 58.8 Con. Mix : 10.4 kg Maize 1.5 kg Cotton DOC 0.5 kg Wheat bran:12.5 Gram Chunnies10.5 Calcite:0.19 kg Salt :0.15kg MM : 0.42 kg Calculated value: CP: 13%;TDN; 61.5% Ca: 0.9%;P: 0.45% DM:47% **Note: For 450 kg with 15** **lit milk yield cow 28-30Kg TMR is sufficient**

*Calculated in NIANP- TMR –Maker software

As illustrated above, to increase energy density of the feed, fat is supplemented in the diet. The concentrate is to forage ratio increased in fresh cow diet to meet the TDN requirement of total mixed ration up to 70 -75 %. The crude protein, calcium, phosphorus content of the fresh cow diet is also increased to meet all these required nutrients for milk production. Supplementation of cereal grain like crushed ragi grain as energy source (@ 1kg per day) for 90 days to crossbred dairy cows during early to mid lactation period reduced the milk urea nitrogen level indicating a positive effect on energy utilization (Gowda et al., 2009). In small farms, availability of feed and fodder is major concern and it seems to the important factor to overcome negative energy balance. Prepared feed should be more palatable to ensure high dry mater intake apart from denser diet. To increase DMI, the animal should be allowed *ad lib* feeding and ensure availability of feed in the manger most of the time. Mature buffaloes maintained on a negative energy balance (NEB) diet had suppressed ovarian follicular turn over after 60 days of treatment and a decline in oocyte quality after 80 days (Campanile *et al.*, 1999). During the period of negative energy balance, the blood concentrations of non-esterified fatty acids (NEFA) increases, and the insulin-like growth factor- I (IGF-I), glucose and insulin are low. Selvaraju *et al.* (2002) reported that there is beneficial effect of insulin treatment on fertility in repeat breeding cattle. Studies evaluating the effects of supplemental fat on reproductive performance of buffaloes are limited however, the recent report (Campanile *et al*., 2010) suggested that buffalo heifers may potentially have the capacity to undergo metabolic adjustment and reduce their energy requirements when dietary energy is limiting.

Table 2. Suggested composition of concentrate mixture for different category of cows

Ingredients (%)	Level of milk production (Kg)			
	Low (5-10 kg)	Moderate to medium (15-20 kg)	High (20-25kg)	Very high (elite category) (>25kg)
Grains	18-20	28-30	38-40	45-50
Wheat bran	30-35	20-25	18-20	6-8
Oil cakes	15-18	22-25	28-30	32-35
Rice polish/ Rice bran	15-20	10-15	5-8	3-5
Gram husk	8-12	5-8	3-5	--
Molasses	5	5-7	8-10	10
Urea	0.50	1	1	1
Mineral Mix.	1	2	2	2
Common salt	0.5	0.5	1	1
Calcite	-	-	1	2

Sodium bicarbonate	-	-	0.5	1
Bypass fat	-	-	1	1.5
Vitamin premix	-	-	0.1	0.1
Chelated trace min.	-	-	0.01	0.02
CP in con mix.(%)	16-17	18-19	20-22	23-24(50-55% By pass protein)
TDN in con mix.(%)	62-63	64-65	71-72	73-74

By Pass Fat

In early lactating high producing animals, energy demand is enormous and increasing density of feed by supplementing fat up to a certain extent may be possible. If level of fat (ether extract) exceeds 5 % of the diet, it may leading to negative effects on cellulolytic bacteria and in turn cause decreased fibre fermentation and production of acetic acid in the rumen. Acetic acid is the precursor for milk fat synthesis, reduction in this VFA lead to depression of milk fat. Hence, to avoid suppression of fibre fermentation, supplemented fat may be added in the form of protected fat (by pass rumen digestion). This protected fat digested in the true stomach and subsequent gastrointestinal tract, which meet the energy demand of the animals and also improved milk fat content in the milk and improve reproductive performance, because fatty acids are needed for steroid hormone synthesis. Protected fat supplementation to cows maintained on natural feeding practices at field condition improved the milk production and reproductive efficiency in dairy cattle (Gowda *et al.*, 2013). For cattle, 20 g bypass fat per kg milk yield and for buffalo 15 g per kg milk yield can mixed in concentrate mixture and fed. However the total quantity should not exceed 200 g for cows and 150 g for buffaloes, to prevent adverse effect of residual free fat on rumen fermentation.

Nutritional and Mineral mixture supplements

The survey results indicated that majority of the animals are deficient in energy and certain other minerals. Feeding practice and nutritional status of dairy animals ultimately influence the productive and reproductive efficiency of the cow. On the basis of field survey data, animals having nutritional and reproductive problems from villages of Karnataka state, nutritional supplement comprising a source of energy, protein and an antimicrobial agent were formulated by ICAR-NIANP and were fed to the animals for a minimum period of 20 days. This supplement improved conception rate in repeat breeding and anestrus animals.

The ICAR-NIANP mapped the mineral profile of India in order to understand the soil-plant-animals relationship and to design area specific mineral mixture.

Managemental practices to reduce feed cost

- Individual feeding based on body weight, milk production and pregnancy.
- High level of green grass based feeding and low concentrate feeing i.e., High green diet based total mixed ration.
- Green fodder should be chapped to at least one inch thickness and fed to the animal.

- Feeding of total mixed ration instead of separate feeding of concentrate, green and dry fodder.
- Increasing the frequency of feeding at least 4 times in a day.
- Providing *ad lib* fresh clean drinking water for 24h.
- Energy is more deficient in cattle feeding. Hence energy deficiency has to be taken care.
- Sufficient quantity of mineral mixture feeing is necessary.
- One calf per year per cow to be followed.
- Avoid metabolic disorder *viz*. milk fever, ketosis etc.
- High grain feeding should be accompanied with sodium bicarbonate.

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Livestock Health Management in Changing Climate Scenario

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1. Introduction:

Livestock is integral to the Indian economy and agriculture sector, playing a critical role in rural livelihood and national economic stability. The interdependence between livestock and agriculture is essential for overall food security and the population's health as livestock farming supports agricultural operations by providing draught power and boosting crop productivity. Economically, it serves as a major income source for millions of rural households by selling animal products and generating significant employment in breeding, farming, processing, and marketing sectors. Livestock farming also contributes substantially to export earnings.

According to the 20th livestock census, India has a livestock population of 535.78 million, including 303.76 million bovines (Cattle, Buffalo, Mithun, and Yak), 74.26 million sheep, 148.88 million goats, and 9.06 million pigs (20th livestock census, DAHD, 2019). The livestock sector accounts for 25.6% of the agricultural GDP and 4.11% of the total GDP. Thus, the sector's growth is crucial for sustainable development and economic enhancement. Therefore, effective livestock health management is essential for sustainable and profitable farming, ensuring the well-being of animals and the profitability of farming operations. This includes preventive measures, regular monitoring, timely medication, balanced nutrition, and proper animal handling. Detailed record-keeping of health interventions and continuous education and training for farm workers on best practices are also vital components.

In addition to livestock health management, currently, climate change poses significant challenges to agriculture and livestock sectors, affecting their productivity and sustainability. Increased temperatures, altered humidity, and extreme weather conditions impact water resources essential for agriculture and livestock management. Livestock productivity, reproduction, and susceptibility to diseases are adversely affected by rising temperatures, while forage availability and quality decline. Climate change also alters pest and disease distribution, exacerbating their impact on animals. These combined effects threaten food security, livelihoods, and economic stability in agricultural communities.

This chapter will review the impacts of climatic changes and the required adaptive strategies such as developing climate-resilient crops, improving water management, and adopting sustainable livestock practices to mitigate the adverse effects on agriculture and livestock systems.

2. Climate Change and Its Impacts on Livestock Health:

Climate change describes the variation in the weather, temperature and environment over a given period, be it manifested through changes in mean temperatures or the occurrence of extreme weather events such as lower or higher rainfall, drought conditions and high or low temperatures (IPCC 2007). This encompasses a range of events that significantly affect the overall climatic conditions and result in global warming which is primarily driven by human activities, deforestation and burning of fossil fuels. Additionally, animal agriculture is also a major contributor to climate change, responsible for 18% of greenhouse gas emissions (9% CO_2, 37% methane and 65% N_2O) (Pankaj et al., 2013) which significantly contributes to global warming and thereby increases extreme weather events disrupting the natural cycles, our biodiversity and also the distribution of the species. The climate change affects livestock health through both direct and indirect mechanisms (Chauhan et al., 2014).

- ***Direct effects on livestock health:***

Heat stress is a major concern that directly impacts livestock health. Rising global temperatures are rapidly increasing ambient temperatures, leading to heat stress in animals. Factors such as temperature, humidity, breed, age, and gender influence the severity of heat stress (Chauhan et al., 2014). This condition alters the physiological and metabolic activity of the animals which reduces the production as well as the reproductive performance. The alteration in the immune system activities significantly affects the morbidity and mortality rates (Vitali et al., 2015). Heat stress causes decreased feed intake, weight loss and also reduced milk production (Hooda et al., 2010). In general, high-output breeds such as crossbreds, are more vulnerable to heat stress as compared to indigenous ones (Pankaj et al., 2013).

- ***Indirect effects on livestock health:***
  Climate change can indirectly affect livestock health through changes in feed availability and water scarcity (Lacetera, 2019). Due to the alterations in the temperature, humidity and other extreme weather events, the growth of forage crops and pastures is disrupted, reducing the quality and quantity of feed and also decreasing the availability of natural grazing lands, forcing livestock to depend on less diverse and nutritious feed sources. Water scarcity, driven by shifting climate conditions, exacerbates these challenges by limiting access to clean drinking water, essential for maintaining animal health and metabolic functions (Thornton et al., 2009). All these together lead to nutritional deficiencies, weakened immune systems, and increased vulnerability to diseases (Chauhan et al., 2014). These indirect effects strain the resilience of livestock, increasing stress levels and reducing overall productivity.
- ***Impact on disease patterns and prevalence:***
  A majority of livestock diseases are transmitted by vectors such as ticks, mosquitoes, and flies and are responsible for expansion and new outbreaks of diseases in areas that were

previously unaffected. Due to the changes in the climatic conditions, the increased temperature and humidity patterns create favourable conditions for the proliferation of these transmitting vectors and are responsible for many livestock diseases (Ali et al., 2020). This may also contribute to changes in the behaviour of the pathogens leading to new emerging and re-emerging diseases (Caminade et al., 2019). As a result, livestock face heightened risks of illness, reduced productivity, and increased management costs.

3. Physiological and Behavioural Responses of Livestock to Climate Change

- ***Physiological stress responses:***

  The changing climate imposes significant physiological stress on livestock, affecting their thermoregulation, immunity and overall health of the animals. Due to heat stress, animals exhibit an increased respiratory rate, perspiration, and changes in blood flow which ultimately affect the overall performance of the animals (Staples and Thatcher, 2011). It also impairs the functioning of the immune system, making the animals more susceptible to infections and also disrupts the endocrine functioning resulting in poor productive and reproductive performances (Talukder et al., 2018, Ali et al., 2020). Additionally, the combined effects of heat stress and nutritional deficiencies from reduced feed availability can further compromise immune function and overall health.
- ***Behavioural responses:***

  As a response to shifting environmental conditions, such as rising temperatures and changes in humidity patterns, the animals under stress adapt to certain behavioural patterns. To cope with the heat stress and reduced quantity and quality of the feed, the livestock adapt by changing their feeding, drinking, and resting behaviours (Zähner et al., 2004). For instance, they may prefer to consume feed during the cooler part of the day and increase water consumption. In such cases, where there is a reduction in the feed intake, more nutritious and more palatable feed is necessary to meet the overall body requirements of the animal. Further, to mitigate the heat stress, the animals may seek to rest in the shade or cooler areas and this may affect the overall activity and productivity of the animals. These changes in the behavioural patterns may strain the management system and require further adjustments in the farm practices.

- ***Species-specific responses and vulnerabilities:***
  Climate change has varying effects on different livestock species, reflecting their unique physiological and ecological traits. Cattle, for example, are especially prone to heat stress because of their huge body size and low surface-area-to-volume ratio, making it difficult for them to dissipate heat. This can cause reduced feed intake, decreased milk output, and poor reproductive function (Wolfenson et al., 2019). Sheep, on the other hand, are more heat tolerant, but reduce their wool quality and become more susceptible to parasites during warmer months (Sejian et al., 2017). Goats, being more adaptive to different habitats, may tolerate extreme temperatures (Lima et al., 2022), although they are still influenced by variations in fodder and water scarcity. The particular vulnerabilities of each species demand specialised management techniques to satisfy their individual needs and preserve their health and production in the face of climate change concerns.

4. Impact on Livestock Production Systems

Climate change has a significant effect on milk production, meat quality and reproduction among livestock species. It can lead to an overall reduction in milk production, as heat impairs feed intake and disrupts metabolic processes. It was estimated that it causes a significant monetary loss of nearly 2% of the total milk production in India (Chauhan et al., 2014). Additionally, it adversely affects the composition of the milk, potentially lowering its nutritional value and quality (Staples and Thatcher, 2011). For meat-producing animals, heat stress can lead to reduced growth rate and poor meat quality, affecting its fat composition and tenderness. In terms of reproduction, elevated temperatures can impair fertility across various species. In cattle, heat stress can lead to decreased conception rates and increased incidence of reproductive disorders. For sheep and goats, it affects the ovulation and lambing/kidding rates. Addressing these impacts requires implementing effective and optimizing management strategies to maintain productivity and ensure the health and welfare of livestock in a changing climate.

5. Strategies for Mitigating Climate Change Effects on Livestock Health

To mitigate the effects of climate change on livestock health, several strategies can be employed to enhance resilience and maintain productivity:

- ***Breeding and Genetic Improvement:***
  To withstand the stress caused by the chaining climate, selective breeding for traits such as heat tolerance, disease resistance and efficient feed conversion can produce animals that are more resilient to the changing environmental changes (Pankaj et al., 2013). This will help to enhance the overall health and ability to cope with the emerging challenges.
- ***Nutritional Management:***
  To ensure optimal growth and productivity under changing climatic conditions, the feed composition should be adjusted to match the nutritional needs of the animals to prevent any deficiencies (Ali et al., 2020). Supplementing diets with essential nutrients, vitamins, and minerals can address imbalances caused by reduced forage quality or availability (Sejian et al., 2024). Implementing precision feeding techniques and monitoring animal performance can further refine nutrition strategies and improve resilience.

- ***Water Management Strategies:***
  During heat stress, water management is critical for ensuring adequate hydration and maintaining livestock health during climate variability (Rojas-Downing et al., 2017). Further, quality control measures, including regular testing for contaminants and ensuring clean water sources, are essential for preventing waterborne diseases and promoting overall health. Additionally, investing in infrastructure such as rainwater harvesting and storage systems can enhance water availability during droughts and dry periods.
- ***Health Management Practices:***
  To protect the livestock species from the adverse effects of climate change, Comprehensive health management practices such as regular vaccination, and effective parasite control measures are crucial for maintaining the health and productivity of the animals (Chauhan et al., 2014). Also, implementing biosecurity protocols, such as controlling the movement of animals and maintaining clean environments, helps reduce the risk of disease outbreaks (Reddy et al., 2023). Regular health checks and early intervention strategies also play a key role in identifying and addressing health issues promptly.

6. Adaptation Practices in Livestock Management

Adaptation practices in livestock management are essential for maintaining productivity and ensuring animal welfare amidst the challenges posed by climate change. Here are some of the key practices to be considered:

- ***Climate-Resilient Farming Practices:***

  Practices such as rotational farming, involves alternative grazing of the forage area to prevent overgrazing and promote the growth of the pasture. This practice will enhance the overall forage quality and prevent soil erosion. Agroforestry, on the other hand, will integrate trees and shrubs with pasture or cropland, provide shade, improve soil health, and enhance biodiversity. These practices help maintain productive pastures and reduce the impacts of extreme weather events on livestock.

- ***Improved Housing and Shelter Designs:***

  Under the changing climatic conditions, enhanced housing and shelter designs are critical for protecting livestock from the adverse effects of climate change. The shelters should be modernized with features such as better ventilation, insulation, and cooling systems that can help mitigate heat stress and maintain comfortable conditions for the animals (Pankaj et al., 2013). To further withstand extreme weather conditions, elevated structures and reinforced materials should be included.

- ***Adoption of Technology and Innovation:***

  Incorporating technology and innovation into livestock management practices can enhance adaptability and efficiency. Technologies such as climate forecasting, sensors and data analytics will help to monitor animal health, behaviour and the changing environmental conditions which enables more effective management and early intervention. Further, innovations such as automated feeding and water management systems also contribute to more resilient and efficient livestock operations.

In addition to the adaptation practices in livestock management, traditional and Indigenous knowledge systems, such as rainwater harvesting systems to conserve water and prevent water scarcity, pasture management like seasonal and rotational grazing, and integrated farming systems will provide resilient and sustainable livestock farming amidst the changing climatic conditions. Further, support from governmental and non-governmental organizations will ensure efficient knowledge transfer, and improvement in the infrastructure and provide resources to the farmers that can help combat the challenges posed by the climatic conditions.

7. Conclusion:

This chapter has investigated the multifaceted effects of climate change on livestock health and management, emphasising the crucial importance of proactive interventions to maintain the resilience and sustainability of livestock systems. Key topics covered include the direct and indirect consequences of climate change on livestock health, such as heat stress, changing disease patterns, and changes in feed and water availability. Further discussed about several adaptation strategies, such as climate-resilient farming, improved housing and shelter designs, and the use of modern and innovative technologies to combat the changing climatic conditions. Proactive management and adaptation measures are critical for mitigating the negative impacts of climate change on animals. Stakeholders may reduce risks and improve livestock well-being by implementing resilient practices, focussing on technology advancements, and adapting policies to promote sustainable livestock management. The value of integrating conventional knowledge, investing in research, and encouraging cross-sector collaboration cannot be underscored.

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Assisted Reproductive Technologies for augmenting reproductive efficiency in domestic animals

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Introduction

With the increasing human population, by 2050 the global food demand is projected to increase by 46%, with a notable rise in demand for animal-based calories (Gouel and Guimbard., 2019). Reproduction plays a very important role in the animal production. Reproductive inefficiency is one of the most important causes of the economic losses in livestock sector. Improving productivity through augmenting reproduction in farm animals is the prime focus in livestock sector. Among domestic species, assisted reproductive technologies (ARTs) have been employed more extensively in cattle than in other species. Biotechnological procedures or advanced methodologies are used to improve reproductive efficiency and animal productivity. Male and female animal production potential have been accelerated with the upcoming assisted reproductive technology over the period of time improved the economic gain to the farmers. For example, artificial insemination is the most successful biotechnological tool that facilitated faster dissemination of the superior germplasm using simplified and streamlined management of breeding bulls. Also facilitates the cryopreservation and long distance transport of the elite germplasm. Other ART tools being used for improving animal reproductive efficiency are estrous synchronization, multiple ovulation and embryo transfer, *in-vitro* fertilization, animal cloning, sperm sexing technologies, sperm cryopreservation, genomic selection of animals through selection of genes and proteins (Hansen., 2014; Selvaraju *et al*., 2017b).Transgenic animal production, stem cell technology and cloning in livestock can be a feasible technology in the near future for male germ line modification and fertility research.

Artificial insemination

Artificial insemination (AI) technique for animal breeding is the process of collecting spermatozoa, diluting, and preserving outside the body through standard procedures and they can be reintroduced into the female reproductive tract in a way that results in an acceptable conception rate. A cow that is first seen in oestrus in the morning is inseminated in the afternoon of the same day, whilst a cow that is first seen in oestrus in the afternoon is inseminated early the next day. The use of frozen semen has revolutionized the AI program through worldwide dissemination of semen at a short duration of time over a large geographical area. AI has become important techniques for the genetic improvement of farm animals since then semen from genetically superior males are used to inseminate the female animals artificially and helps to eliminate the risk of diseases transmission. It has been most extensively used for breeding dairy cattle and buffaloes. India produced 63 million bovine frozen semen straws including over one million buffalo semen straws during 2010 to 2011, through 49 semen stations (Singh and Balhara, 2016). During 2019-20, NDDB produced the total annual semen production of around 37 million contributing more than 30 per cent of the total semen production of the country (https://www.nddb.coop/services/animalbreeding/animalreproduction/semenproduction).

Increased number of semen doses per bull in less time interval, the choice to choose the genetically superior breeds, less cost and reduced risk of veneral disease transmission. However, AI can lead to lowered conception rate due to poor oestrous detection efficiency and cryoinjury to sperms (Noakes., 2009). By using fresh semen, vaginal (peri-cervical deposition of semen) or cervical (intra-cervical deposition of semen) insemination techniques result in acceptable pregnancy rates. However, by using frozen semen, laparoscopic or trans-cervical intrauterine insemination (TCAI) techniques are the only means to achieve acceptable pregnancy rates because of the necessity of cryo-damaged sperm to deposit directly into the uterine lumen (Kershaw et al., 2005, Naqvi et al., 2005).

Oestrus detection

Oestrus detection is an important aspect of dairy herd management. Good oestrus detection necessarily guarantees good reproductive performance. Detection of oestrus using observational method is often poor, due to the reason that overt signs are prevalent in the night time, more prominent in winter than summer months. Improvement requires the awareness of farmers, proper identification of individual animals, good record keeping, regular and close observation of behavioural and physical signs. There is a need for technological interventions to improve the oestrus detections methods; alternatively nowadays the synchronization of estrus which bypasses manual efforts for oestrus detection is gaining importance (Selvaraju et al., 2018). The technique of tail painting, heat mount detectors like KaMar, radio-telemetric heat mount detectors, use of teaser bulls or androgenized cows, progesterone assay, pedometers, detection with collars, closed circuit television and biosensors have been developed to improve oestrus detection rate (Mottram et al., 2016).

Estrus synchronization

Synchronization of estrus is one of the herd managemental process through which the oestrus detection errors and managemental costs could be minimized and helps in large herd management. Oestrus synchronization procedure does not require the need to observe estrous symptoms during reproductive herd management. This methodology replaces the insemination at detected oestrus to the fixed time insemination. Intervention of oestrus cycle with the use of hormones such as PGF2α and GnRH, and other hormones like PMSG and estradiol benzoate have been developed. Different protocols such as ovsynch, double synch, heat synch and estra double synch are available. A survey revealed that 21 % of the dairy animals had reproductive disorders in the state of Karnataka including post-partum anestrous (22.8%) and silent heat (2.4%) (Selvaraju et al., 2017a). Due to the endocrine imbalance or deficiency, animals with adequate body condition either may not come to estrus or show adequate estrus behaviour. Under such circumstances, normally particular heat is missed and owner cannot inseminate the animal. Different estrus synchronization regimes (doublesynch, estradouble synch) are applied for the improving fertility in anoestrus and silent heat animals. Hormonal interventions and fixed time AI regimes were found effective in treatment of infertility cases in dairy cattle and buffaloes in India. Using this fixed time insemination programme, at the villages in Karnataka, we obtained more than 60% conception rate in dairy animals (Selvaraju et al. 2018).

In vitro embryo production

In vitro embryo production is carried out in three phases such as,*in vitro* maturation of oocytes (IVM), *in vitro* fertilization of oocytes with capacitated spermatozoa(IVF), and *in vitro* culture of the presumptive zygotes (IVC). Numerous IVF embryos were produced for research purposes. Oocytes are obtained either from slaughterhouse-derived ovaries or following ovum pick up method. Various applications include, quality embryos for transfer, embryo sexing, cloning, nuclear transfer and transgenesis, research on developmental potential of the embryos including the pattern of the gene expression. Though commercial *in vitro* production of bovine embryos is available, only 30-35% of immature bovine COC develop to the blastocyst stage.Research isneeded on molecular mechanisms regulating early embryonic development as well as on the composition and interactions of culture mediafor the qualityoocyte and embryo culture (Wrenzycki, 2016).Pregnancy rates following transfer of IVF embryos are generally lower (31-68%) than their *in vivo* method.

Multiple Ovulation and Embryo Transfer

Multiple ovulation and embryo transfer (MOET) is the biotechnological tools combining superovulation with subsequent transfer of fresh or cryopreserved embryos. A young lactating cow, with no history of the reproductive problems, would be chosen as the best donor for embryo transfer (ET) programme. The recipient must be in appropriate stage of estrous cycle with the donor, and should have a palpable corpus luteum. The various steps in the embryo transfer technology are the selection of the donor and superovulation of the donor using hormones mainly, follicle stimulating hormone or its analogue, insemination of the donor, flushing of embryos, evaluation of the embryos, preparation of the recipient and transferring of the embryos. About 500,000 embryos are produced from superovulated cows through embryo transfer technology worldwide every year. This technique has various advantages like transfer of embryos by freezing them, disease control, genetically improved offspring and production of high-quality breeds. The success rate are at times unpredictable owing to the variability of the superovulatory response, the poor fertilization associated with high ovulatory responses, early regression of corpora lutea and improper estrus synchronization of recipients.

Sex predetermination/sperm sexing

Control the sex of offspring or the production of desired sex animal, has been a research interest overtime in the breeding industry by separating X- and Y-bearing sperm. Many methods have been developed in attempts to meet this goal. The most effective tool was flow cytometry and flow sorted sperms are currently available for commercial purpose. The first report of the birth of a rabbit using sex sorted sperm was reported by Johnson et al., (1989). Since then offspring of the predetermined sex in domestic animals have been produced by this technology (cattle: Cran et al., 1993, sheep: Catt et al., 1996). Flow cytometric sorting of sperm is based on the measurement of sperm DNA content. Differences in DNA content of X and Y bearing sperm is the basis to differentiate between these sex-determining gametes and sort them into two subpopulation. Spermatozoa are stained with Hoechst 33342, a vital dye which binds to DNA molecules stoichiometrically, the bovine X-sperm contains approximately 4% more DNA than a Y-sperm and hence there would be 4% more dye in the X sperm. Flow cytometry would be used to recognize DNA content and based on differences of sperm subpopulations, the X and the Y spermatozoa are isolated. Presently, high operative and equipment cost, and low sort rate are the constraints in the technology . Also damages the sperm during the sorting process using flow cytometry, which can reduce sperm viability and fertility (Garner, 2006). Current sperm sexing technologies are expensive and require specialized equipment and expertise, limiting their accessibility to many farmers (Phiphattanaphiphop et al., 2020; Galli & Lazzari, 2021). Flow cytometry is effective but relatively slow, sorting only a limited number of sperm per hour, which limits its practicality for large-scale applications (Garner, 2006). Microfluidic devices separate sperm based on size and other physical properties. These devices offer a less invasive and potentially more efficient method of sperm sexing compared to flow cytometry (Phiphattanaphiphop et al., 2020).Other techniques for sperm sexing are swim up techniques, percoll and albumin gradient centrifugation, flow cytometry, sephadex columns, H-Y antigen, discontinuous albumin gradient and nutritional interventions (Arangasamy et al., 2015). Profiling of sex specific proteins for the separation of X and Y sperm is still under research.

Spermatozoa and embryo cryopreservation

Cryopreservation of spermatozoa involves semen dilution in extender along with cryoprotectants and controlled freezing of spermatozoa, for long term storage at -196°C. Cryopreservation of spermatozoa maintains the viability of the individual cells during storage by minimizing the metabolic rate. Semen extenders provide nutrients, acts as buffer, ensure appropriate physiologic osmotic pressure and concentration of electrolytes, prevent the growth of bacteria, protect from cold shock during freezing. The cryoprotectants reduce the amount of damage during freezing. Additives such as IGF-1 increase the cryotolerance during freezing and thawing process,prevents the acrosome damage and protects spermatozoal proteins (Selvaraju et al., 2016).Embryo freezing is an essential component in the commercial ET programme and enableslong term preservation of the embryo in the viable condition. Cryopreservation media contains cryoprotective agents such glycerol or ethylene glycol. The embryo/oocytes loaded in straws are cryopreserved under programmed freezing rate for minimizing cryo-damage under ultra low temperature. Cattle embryos at themorula, early blastocyst and blastocyste stage are more tolerant to low temperature preservation than earlier and later developmental stages. The vitrification as an alternatives to cryopreservation techniques is used for storage of oocytes and embryos (Noakes., 2009).

Stem cell technology

Stem cells related to reproduction can be classified as embryonic stem cells and adult stem cells such as, spermatogonial stem cells, oogonial stem cells, stem cells from fetal adnexa. Spermatogonial stem cell (SSC) research is an emerging technology for the treatment of infertility and in the conservation of endangered species. In livestock, though SSCs have numerous applications, SSCs isolation, enrichment and culture conditions have not been optimized yet. Differential plating using laminin in combination with BSA in sheep is used for enriching SSCs (Binsilaet al., 2018). Long-term culture system that supports, expands and maintains SSCs from agriculturally important animals has not yet been developed. In order to establish germ cell transplantation in agriculturally important animals, the identification of factors produced in the SSC niche that are essential to SSC maintenance and establishment of a reliable and robust culture system for SSCs is of utmost importance (González et al., 2017). Fertility can be induced in the infertile animals by the transplantation of SSCs obtained from the fertile donors. SSCs can also be cultured, expanded *in vitro* for the gene targeting and this genetically altered cells can be transplanted for transgenic animal production. Studying the SSCs biology provides important information for better understanding of male fertility, regenerative medicine, transgenic animal production, preservation of the genetic material from elite, superior or obtaining genetic material from those valuable animals and improving fertility. Embryonic stem cells are derived from inner cell mass of blastocysts from developing embryos. The inner cell mass as compared to other cells differ in their multi-differentiation potential *in vitro*. In the recent past, ES cell lines from porcine, bovine, caprine, ovine and equine have been generated. These have applications in transgenic animal's production, faster dissemination of superior germ plasm, regenerative medicine and cloning.

Animal cloning

Cloning animals is a reliable way of reproducing superior or highest quality livestock genetics. Animals can be cloned in different ways, such as embryosplitting, embryonic cell cloning and Somatic Cell Nuclear Transfer (SCNT). Many species have been cloned after the first mammal, Dolly(sheep). The major proportion of the cloned embryos fail to develop to term or die shortly after birth. Reproductive and other problems associated with cloning are placental abnormalities, fetal overgrowth, stillbirth, immune dysfunction, respirative failure etc. The application include diseases models (sheep or pigs) for various human diseases like Parkinson's, Alzhemers and other suspected or known genetic diseases. Transgenic animals are produced as bioreactors for the production of proteins such as human coagulation factor IX, human anti-thrombin and alfa-1-antitrypsin for therapeutic and medical applications. Due to close physiology between human and pigs, the later are ideal models for xenotransplantation (the transplantation of organs between distinct species) to the humans and potential for addressing human organ failures. In animal production sector, cloning created copies of animals with highly valued traits with high milk production, elite bulls for beef industry, bulls producing quality semen, cattle with increased resistance to mastitis, pig that has the capability to digest plant phytate (Vajta and Gjerris, 2006). Proper reprogramming of the somatic cell nucleus is critical but challenging. Incomplete or faulty reprogramming can lead to abnormal gene expression and developmental defects, particularly in ruminants (Menchaca et al., 2020). Cloning raises ethical questions regarding animal welfare and potential long-term impacts on genetic diversity. Regulatory frameworks are evolving, and public acceptance varies widely (Galli & Lazzari, 2021). CRISPR/Cas9 genome editing of embryos and stem cells are used to create genetically modified animals. This technology enables precise genetic modifications, such as disease resistance, improved growth rates, enhancing the overall quality of livestock.

Nanotechnology and animal production

Nanotechnology in the field of animal reproduction plays a significant leads in productive research with application perspectives. Nanotechnology has role in enhancing semen quality, nanobioimaging for real time imaging of the surface of cells, micro/nanofluidics for enhancing embryo culture, semen sexing, estrus detection, detection of antisperm antibody, sperm cryopreservation and fertility chip and transgenic animal production. Nanoparticles as gene transfer vectors into various cell types including spermatozoa for transgenic animal production. Nanotechnology also finds its application in improving semen sexing, with the help of the DNA-binding nanoparticles, to segregate male and female sperm for sex selection. Microfluidic system, MatRyx uses a nanotechnique in which tiny laser tractor beams trap individual sperm and then sort them by weight. MatRyx can sort around3,000 sperm per second (Sekhon, 2012).Nanopurification of semen enables to separate unhealthy sperms from the healthy sperms using magnetic nanoparticles that can be coated to antibodies against protein such as ubiquitin and thus improving conception rate. Supplementation with nano-Se enhanced the testis Se content and improved semen quality. The micro-channel culture systems using microfluidic technology provide an embryo culture environment that more closely mimics the in vivo environment (Cabrera et al., 2006).Nanotubes implanted into the animal skin to monitor the real time estradiol level in the blood and the central monitoring system aid in the estrus detection. Silica based nanomaterials in extender improved bovine sperm cryopreservation.

"Omics" techniques and animal reproduction

Spermatozoa also carry various classes of RNAs. Since sperm mRNAs are delivered to oocytes, the profiling and identifying fertility associated mRNA expression levels in spermatozoa could be a valuable diagnostic tool to predict the actual fertility status of a bull (Selvaraju et al., 2017b; Selvaraju et al., 2021). Cell free RNAs, probably from the extracellular vesicles are promising non-invasive diagnostic markers of health and diseases (Shilpa et al., 2017). The presence, absence or differential expressions of proteins in seminal plasma could be potentially responsible for the effects of seminal plasma on sperm fertility. Seminal plasma protein profiles were different between bulls of high and low fertility (Somashekar et al., 2016).The profiling of seminal metabolites such as reducing sugars, fatty acids, amino acids, phospholipids, glycoproteins (mucins), hormones (IGF1 and prostaglandins) and key minerals (calcium, boron, zinc, copper and selenium) are gaining importance in domestic animals (reviewed in Binsila et al., 2018b).

Conclusion

Animal production potential has been augmented with the adoption of some of the ARTs in domestic animals. AI, Oestrus detection and estrous synchronization are the most widely percolated ART tools at the field level for the faster dissemination of superior germplasm and efficient production. Moreover, other emerging and advanced technologies such ascryopreservation of spermatozoa and embryo, *in vitro* embryo production, MOET and animal cloning have been introduced to overcome reproductive problems. Though the sperm sexing through sorting is successful in production of female calves, the conception rate and the milk production of the progeny needs further investigations. In addition, the latest research is focusing on stem cell technology and, application of nanotechnology and "Omics" techniques in animal reproduction. The main goal of these technologies includes production of desired sex, high quality breeds, genetically improved offspring, to overcome infertility issues, control of diseases etc. Therefore, the advanced and powerful reproductive technologies could certainly play a significant role in the future perspective and visions for efficient reproductive performance in livestock.

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Precision feeding by Strategic supplementation of bypass nutrients for optimizing the productivity of dairy animals and nitrogen use efficiency

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Introduction

Livestock sector plays a vital role in rural and National economy and forms the backbone of farming activities. It provides livelihood security to resource poor farmers and also improves household nutrition and social status. Most of the Indian livestock feeding is dependent upon different crop residues, local grasses and grazing and other low/poor quality feeds. These low-quality feeds are utilized very poorly because of the unbalanced nutrients present in them leading to low productivity of animals. Hence, the fermentation of these poor-quality feeds gives rise to a reduced supply of protein / amino acids (especially in the form of microbial protein) and energy which are considered to be limiting nutrients for different productive purposes in the animals. It is projected that, the demand for animal products will be doubled at both the national and global level due to increased population, urbanization and per capita income. This increased demand has to be met by increasing the productivity of each animal to attain vertical increase. Feed cost accounts for more than half of the recurring cost of dairy production. For maintaining profitable Dairy production, the animals should be fed with proper rations with minimum cost. In general, the farmers in the villages feed their animals as per the availability of basal roughage resource in different seasons i.e., straws in summer and local grasses/grazing after rainy season. The animals are not fed as per the production potential but are fed routinely different supplements without looking into nutritive value. Under some circumstances the animals are fed more amount of protein to achieve higher production, leading to higher excretion of nitrogen leading to environmental pollution in addition to wastage of large quantities of nutrients. Hence, it is necessary that animals are fed balanced diets for maintaining profitable ruminant production systems. An overall comprehensive plan combining knowledge of the latest findings of research with balanced rations and adjustments to the individual situations will allow progress towards higher production goals. The nutrient requirement of animals varies with physiological stage and the level of production. Such variation demands appropriate tuning of feed supply to assure adequate nutrition.

Several feeding strategies have been developed to improve the productive performance of livestock in India, but met with varying degree of success. One of the approaches is to refine the existing feeding practices followed by farmers by strategic supplementation of bypass nutrients without altering much in the existing feeding practices, so that the new practices are easily acceptable to the farmers. In this context, the concept of strategic supplementation with bypass nutrients /supplements technology is useful not only for better utilization of nutrients but also minimize the ruminal fermentation losses there by reducing the wastage of nutrients in to the environment. Therefore, the potential of strategic supplementation of bypass nutrients in increasing the productivity of dairy animals, thereby the nitrogen use efficiency are discussed here in this paper.

Nutrient Requirements

The requirement of nutrients varies with the size of the animals (body weight) and the level of production. The requirement for maintenance, growth, reproduction and milk production are derived by conducting a number of experiments. The requirements of specific nutrients have been set in tables and are known as feeding standards. Different countries have evolved their own standards on the basis of experiments conducted with the animals under different agro-climatic conditions prevalent in that country. These standards are modified form time to time. The feeding standards developed by the Indian Council of Agricultural Research, New Delhi is given in Table 1 to 4.

Table 1. Maintenance requirements for DM, Energy and Protein of lactating cattle, buffalo/ day

BW (kg)	DM (kg)	TDN (kg)	ME (Mcal)	MP(g)	RDP (g)	CP (g)
300	6.48	2.62	9.47	191	298	351
400	8.64	3.27	11.82	137	370	436
500	10.8	3.88	14.04	280	438	515
600	12.96	4.47	16.15	321	502	591

Table 2. DM, Energy and Protein requirements for milk production/kg milk in cattle

Fat (%)	DM* (kg)	TDN (kg)	ME (Mcal)	MP(g)	RDP (g)	CP (g)
3	0.450	0.290	1.05	51	44	96
4	0.510	0.330	1.20	51	50	96
5	0.570	0.370	1.34	51	56	96
6	0.640	0.410	1.50	51	62	96

7	0.700	0.460	1.64	51	69	96

*65% digestible feed

Table 3. DM, Energy and Protein requirements for milk production/kg milk in buffaloes

Fat (%)	DM* (kg)	TDN (kg)	ME (Mcal)	MP(g)	RDP (g)	UDP (g)	CP (g)
4	0.550	0.360	1.29	66	54	60	124
5	0.610	0.400	1.43	66	60	53	124
6	0.670	0.440	1.58	66	66	46	124
7	0.740	0.480	1.73	66	72	39	124
8	0.800	0.520	1.88	66	78	31	124
9	0.860	0.560	2.02	66	85	24	124
10	0.930	0.600	2.17	66	91	17	124

*65% digestible feed

Table 4. DM, Energy and Protein requirements of female cattle and buffalo calves

BW (kg)	Weight gain(kg/d)	DM (kg)	TDN (kg)	ME (Mcal)	Total MP(g)	RDP (g)	RDP* (g)	CP (g)
100	0.5	3.1	1.75	6.32	221	345	142(81)	487
100	0.6	3.1	1.90	6.48	246	385	164(96)	549

200	0.5	5.6	2.74	9.90	267	418	108(34)	525
200	0.6	5.6	2.95	10.46	291	454	121(41)	575
200	0.7	5.4	3.16	11.39	314	490	133(46)	623
200	0.8	5.4	3.37	12.16	336	525	144(51)	669

*Values in this parenthesis are indispensable requirements of RUP, otherwise growth will decrease

In computation of ration, the prime consideration is to ascertain and meet the total requirement of the animal in terms of dry matter, protein, energy (TDN), minerals and vitamins. It is desirable to provide as much nutrients as possible through green fodder. The deficit nutrients can then be provided trough concentrate ingredients. A concentrate mixture has to be prepared with different ingredients depending upon their cost and availability.

Loss of protein or nitrogen in to the environment

In ruminants, 75 to 95% of the ingested N is excreted, with excess dietary N increasingly excreted in the urine, while dung N excretion remains relatively constant (Castillo *et al.* 2000; Eckard *et al.* 2007). Of the dietary N consumed by ruminants, <30% is utilised for production, with >60% being lost from the grazing system (Whitehead 1995). There is a direct link between N in feed and N in feces and urine. Therefore, the challenge for research is to develop technologies and strategies to improve the efficiency of the N utilization in ruminants which may lead to more efficient and sustainable production systems for the future.

Feeding Strategies

Strategies for improving the efficiency of protein/nitrogen utilization in dairy animals include through optimization of microbial protein synthesis, bypass protein in the ration i.e., balancing both *Rumen degradable protein* (RDP) and *Rumen un degradable protein* (UDP), amino acids supply etc apart from feeding and management of livestock on scientific lines, maintaining optimum number of productive animals and improved breeds. Some of the strategies are discussed hereunder.

Feeding strategies to optimize microbial protein synthesis, balancing RDP and UDP

The ultimate goal of rumen nutrition is to maximize microbial growth and the amount of RDP that is captured into rumen microbial cells. Maximizing the capture of degradable N not only improves the supply of AA to the small intestine, but also decreases N losses. Amino acids are supplied to the duodenum of ruminants by microbial protein synthesized in the rumen, undegraded dietary protein and endogenous protein (Schwab *et al.*, 2005). More than 50% of the amino acids absorbed in the ruminants are derived from microbial protein synthesized in the rumen, thus, the microbial protein forms a major source of protein to the ruminants under normal feeding conditions. Thus the feed protein in ruminants is categorized as rumen degradable protein (RDP), which is required by the rumen microorganisms for their growth thereby the microbial protein synthesis and rumen un degradable protein (RUP), which passes to the abomasum, hydrolysed in to amino acids, which then can be absorbed through the wall of the small intestine into the blood. Wastage of protein in ruminants can be minimized by optimizing the amount of *rumen degraded protein*, which is used to synthesize microbial protein, and *rumen undegraded protein*, which can supply AAs directly to the intestine. Therefore, the available feed resource needs to be utilized. judiciously with a minimum or no wastage of nutrients, nitrogen in particular. The RDP and UDP content of some of the commonly used feed stuffs (Sampath et al., 1999, Chandrasekharaiah et al 2001, 2002) based on result of the studies conducted in different parts of the world are given Table 5.

TABLE 5 Crude protein (CP), Rumen degradable protein (RDP) and undegradable protein (UDP) / bypass protein content of feeds and fodders

Feedstuffs	CP	RDP	UDP (bypass protein)
	-- gram per kg dry matter--		
Concentrates			
Bajra	120	38	82
Barley	100	79	21
Brewers grains	260	122	138
Coconut cake (solvent extracted)	270	62	208
Coconut cake (expeller)	240	173	67
Corn gluten meal (60% CP)	600	126	474
Corn gluten meal (40% CP)	400	148	252
Cotton seed	170	78	92
Cotton seed cake	350	179	171
Cotton seed cake (solvent extracted)	360	137	223
Distillers dried grain	290	133	157
Gingelly / sesame / til cake	350	266	84
Groundnut cake (expellar)	450	315	135

Groundnut cake (Formaldehyde treated 1g/100g CP)	450	194	256
Groundnut cake (Heat treated 130º C 3 Hrs)	450	194	256
Groundnut cake (Heat treated 130º C 2 Hrs)	450	234	216
Groundnut cake (Deoiled / solvent extracted)	480	408	72
Horse gram	240	137	103
Jowar	100	20	80
Karanja cake	320	173	147
Kokam cake	140	17	123
Linseed cake	280	162	118
Mahua seed cake	185	105	80
Maize bran	160	59	101
Maize grain	90	27	67
Mustard cake	350	263	87
Neem seed kernel cake	386	217	169
Niger cake	330	244	86
Oats	100	84	16
Rice bran	140	91	49
Rice bran extraction	160	64	96
Rice broken	110	35	75

Rice polish	120	61	59
Rubber seed cake	280	202	78
Safflower cake	220	141	79
Salseed meal	90	27	63
Silk cotton seed cake	370	289	81
Soyabean meal extractions	460	276	184
Sunflower meal	300	165	135
Roughages			
Alfalfa, dehydrated	200	80	120
Alfalfa fresh (*Medicago sativa*)	200	152	48
Berseem *(Trifolium alexndrium*)	259	127	132
Grass hay	29	13	16
Guninea grass	82	33	49
Maize early cut	165	96	69
Oats (*Avena Sativa*)	126	65	61
Para grass	71	34	37
Rice straw	40	15	25
Subabul *(Leucaena leucocephola*)	250	80	170
Sugar cane tops, chaffed, ensiled	68	10	58
Wheat straw	33	18	15

Bypass protein feeding

Usually most of the protein fed to the ruminants are degraded to ammonia in the rumen and becomes a source of nitrogen for microbial protein synthesis. This microbial protein synthesized in the rumen is digested in the abomasums and small intestine and provides amino acids to the animal. The dietary proteins which reach the lower tract without getting degraded in the rumen are called "Bypass proteins". In case of high yielding animals the amino acids obtained by the digestion of the microbial proteins may not be sufficient to meet the protein requirement of the animals. Therefore, it is desirable to incorporate the protein sources, which provide the bypass protein in the concentrate mixtures, especially during the early lactation. Ingredients such as cotton seed cake, solvent extracted coconut cake, maize gluten meal, fish meal, meat meal, rice bran, karanja cake, brewers grain, subabul leaf meal are good source of bypass protein (Table 5).

Efficiency of utilization of protein can be improved by balancing rations for RDP and UDP (bypass protein) rather than total crude protein, which will allow to maintain same or increased productivity with reduced protein intake and nitrogen excretion. Protection of proteins by heat treatment or other chemical treatment methods will reduce the degradation of protein in the rumen there by increasing the bypass protein value. Therefore, it is desirable to include feed materials of medium or high Bypass protein content in the ration of animals yielding large quantities of milk especially in the early stages of lactation. However, it is essential to ensure that sufficient amount of rumen degradable protein (50-60% of total crude protein) is supplied in the ration of these animals to maintain optimum rumen fermentation for better utilization of fiber/ energy. Feeding of bypass nutrients in the dairy animals resulted in increased gain, reproduction and milk yield (Dahiya et al.1991, Sampath et al.,1997, Garg et al., 2005, Sampath et al., 2004,Chandrasekharaiah et al., 2008, Chatterjee and Walli, 2003, Prajapatiet al.,1998, Bharadwajet al., 2000, Mishra et al., 2006). The results of the research conducted elsewhere in the world indicated that balancing rations for RDP and bypass proteins reduced nitrogen excretion by about 15 – 40 % in animals.

Supplementation of Limiting Amino Acids

Lysine and methionine are considered to be first or co-limiting amino acids for milk production in dairy animals. The other limiting amino acids are assumed to be one or more of the following– phenylalanine, histidine and threonine. Feeding of bypass protein sources that supply these limiting amino acids post ruminally may result in increased milk production. These can be included in the ration of high producing cows. Limited number of studies have been carried out in India on the amino acid content of feedstuffs as well as its post ruminal availability in ruminants. The essential amino acid content in different ruminant feedstuffs has been determined by Chandrasekharaiah*et al.,* (2003). The limiting amino acid content in bypass protein fractions of different feedstuffs have also been determined (Sampath*et al.,* 2003). Yulong and Bie, (2010) reported that the nitrogen excretion can be reduced by reducing the protein intake by balancing the digestible amino acid requirements. Bypass limiting amino acids such as lysine and methionine appears to reduce protein intake and nitrogen loss in manure by 35 and 48%, respectively in lactating cow. (Din et al., 1996).

Nitrogen use efficiency

Yulong and Bie, (2010) reported that the nitrogen excretion can be reduced by reducing the protein inake by balancing the digestible amino acid requirements. Bypass limiting amino acids such as lysine and methionine appears to reduce protein intake and nitrogen loss in manure by 35 and 48%, respectively in lactating cow. (Din et al., 1996). Increased milk production and nitrogen capture efficiency with reduced intake of protein without compromising the microbial protein synthesis in cattle was observed when the straw based ration was supplemented with strategic nutrient supplements formulated with bypass rich protein/amino acid and fat supplements (Chandrasekharaiah et al., 2017). The purine nitrogen index (PNI) and nitrogen capture efficiency NCE) are certain new potential parameters, which can be used for determining the overall efficiency of utilization of ruminant diets. The PNI, which refers to the ratio of PD nitrogen to total nitrogen in urine (Chen et al, 1999), could indicate the NCE. These parameters have been proposed as an index of utilization of nitrogen in the rumen compared to the amount wasted in the urine. The studies conducted by Chandrasehkaraiah et al (2010) indicated that these parameters (PNI and NCE) could be effectively used in evaluation of efficiency of nitrogen in Indian ruminant diets. The other indicator, to monitor protein utilization and nitrogen excretion in dairy cows is the use of milk urea nitrogen (MUN) analysis

Bypass fat supplementation

Bypass fat is defined as the fat source specially designed to resist bio-hydrogenation by rumen microbes and modify fatty acid profile of body tissues and milk.

It may be beneficial to add fat to a diet to increase its energy density and milk yield. However, addition of fats has certain disadvantages that include, inhibitory effects on ruminal fermentation leading to decrease in fiber digestibility, lower intestinal absorption at higher intake, low contribution to total oxidation of nutrients and sensitivity to nutrient imbalance causing reduced energy intake (Palmquist, 1994). So in order to use fats supplements for ruminants, they must be either protected from rumen fermentation or converted to soaps. Under these circumstances, bypass fats assume special significance in feeding of dairy animals.

Feeding of protected fats to dairy animals increase the energy density of the diet without compromising fibre digestion in rumen (Scott et al., 1995). Apart from increasing the energy intake of the animals, there is an added advantage of feeding protected unsaturated fat to cows, as the milk produced by such cows shall have higher unsaturated fatty acids in milk fat, which makes a softer butter, and is also safer for humans, especially the heart patients. Bypass fat can be supplemented to get designer milk with higher content of long chain unsaturated fatty acids for human beings (Gulati et al., 2001). The advantages of feeding bypass fat supplements include increased milk yield as well as milk fat in dairy animals. Apart from this, bypass fat supplemental feeding results in improved reproductive efficiency in dairy animals. Milk yield increased when bypass fats are fed to animals ((Naik et al., 2009, 2012). Increased economic returns were observed when farmers fed dairy animals with bypass fat in lactating animals (Vidhate et al. 2006, Vahora et al., 2013). Bypass fat technology and feeding of protected fat has much relevance under Indian feeding conditions as the diet are generally low in energy content and it is not possible to meet the energy requirement of high yielding animals as such.

Strategic limiting nutrient supplements

Strategic limiting supplements containing bypass protein sources rich in amino acids in combination with bypass fat were formulated. Several on–farm trials were conducted to study the effect of supplementation of strategic limiting nutrient supplements on milk production performance in medium yielding cows. The feeding practice followed by the farmers was refined by partly replacing the feed ingredients with bypass protein and limiting nutrient supplements. By this refinement, milk production increased and the cost of feed was reduced and the overall income of the farmers was increased. Increased milk production and nitrogen capture efficiency with reduced intake of protein without compromising the microbial protein synthesis in cattle was observed when the straw-based ration was supplemented with strategic nutrient supplements formulated with bypass rich protein/amino acid and fat supplements (Chandrasekharaiah et al., 2017). Milk production performance as well as net returns were increased (Mane et al., 2017, Gyanendra Singh Katiyar et al., 2019) when dairy animals were fed with combination of protected fat and protein.

Summary

The farmers feeding practices can be refined with simple scientific interventions through strategic supplementation of bypass nutrients since, the feeding of bypass nutrients such as bypass protein, limiting amino acids and bypass fat has the potential to increase productive as well as reproductive performance of dairy animals.

The concept of precision feeding with limiting nutrients/supplements has the potential to increase productive performance of ruminants in particular, dairy animals. The responses are more likely to be more favorable in high yielding animals in the early part of lactation or fast-growing animals. Though dairy animals use dietary protein more efficiently, more protein or nitrogen will be excreted (2-3 times) in manure than it is secreted in milk. Efficiency of utilization of protein can be improved by balancing rations for RDP and UDP (bypass protein) rather than total crude protein, which will allow to maintain same or increased productivity with reduced protein intake and nitrogen excretion. A key to reduce N or protein excretion and for efficient protein utilization is to formulate rations that optimize microbial protein synthesis and also supply amounts of bypass protein and amino acids needed for growth, production and reproduction in dairy animals.

Extension Strategies for Climate Resilient Farming

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Introduction

The effects of climate change on agriculture are seen all around the world, but India is particularly vulnerable because of its enormous population that depends on agriculture, its heavy reliance on natural resources, and its inadequate coping mechanisms. India's warming trend over the past century has shown a rise of 0.60°C. Given that agriculture accounts for 15 per cent of India's GDP, a 4.5 to 9.0 per cent decline in production suggests that the cost of climate change is around 1.5 per cent of GDP annually. Therefore, increasing agricultural productivity is essential for maintaining food and nutritional security for everyone; especially the small and marginal farmers who would be most impacted and are resource-poor (Jha et al., 2021). Climate change profoundly impacts agriculture, altering crop quantity and quality, adjusting doses of inputs like herbicides and fertilizers, and intensifying soil drainage issues. Erosion risks escalate, threatening agricultural stability. Climate-induced shifts in arable lands pose challenges to global food security. Organisms face new competitive landscapes, emphasizing the need for adaptive, sustainable agricultural strategies to mitigate climate change consequences (Dutta et al., 2023). Agriculture must become climate-resilient to address the issues caused by climate change. By tackling both the concerns of food security and climate change, climate-resilient agriculture (CRA) integrates economic, social, and environmental development. Extension providers can significantly contribute through the development of technologies and dissemination of information by strengthening the farmer's capacity (Kumar et al., 2022). Consequently, an agricultural extension can be summed up as the entire group of institutions that assist those involved in agriculture in their efforts to solve problems, connect with markets and other actors in the agricultural value chain, and acquire knowledge, skills, and technologies to better their lives (Davis, 2009; Mukherjee et al., 2012).

Climate change

Climate change" means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods (UNFSCCC). Climate change is the steady modification of temperature and weather patterns. These changes might be brought by many processes, like variations in the solar cycle. However, since the 1800s, human activity has been the main cause of climate change, particularly the burning of fossil fuels like coal, oil, and gas. Fossil fuel combustion produces greenhouse gas emissions that cover the planet like a blanket, absorbing solar heat and increasing temperatures. Carbon dioxide and methane are two examples of greenhouse gas emissions that contribute to climate change. Carbon dioxide emissions from burning fossil fuels behave like a blanket across the planet, collecting solar heat and rising temperature.

Climate change: a huge challenge

There are numerous ways to address climate change that can increase the economy, improve our quality of life, and protect the environment. The three primary categories of action include lowering emissions, funding essential adjustments, and adapting to the effects of climate change. We can reduce greenhouse gas emissions by moving from fossil fuels to renewable energy sources like solar and wind. But we need to start right away. A growing number of countries have committed to achieving net zero emissions by 2050, but in order to keep global warming to 1.5°C or less, it is necessary to achieve almost half of those reductions by 2030. Production of fossil fuels must drop by about 6% annually between 2020 and 2030. By adjusting to the effects of climate change, we can protect people, homes, businesses, livelihoods, infrastructure, and natural ecosystems.

Climate Resilient Agriculture (CRA)

Climate Resilient Agriculture (CRA) is a farming approach that assists farmers in adjusting to and dealing with the challenges posed by a changing climate. It is a sustainable way of adjusting and transforming farming to ensure food security in the face of climate change. It involves making changes and adopting strategies to adapt and mitigate the impacts of a changing climate. This practice reduces hunger and poverty in the face of climate change for forthcoming generations. Climate resilient agriculture (CRA) helps decrease hunger and poverty amid climate change for future generations. These practices can improve the current situation, ensuring sustainable agricultural production from local to global levels (Srinivasarao, 2021). Intense rain or droughts, sudden hailstorms, and more frequent extreme weather are expected due to climate change. To help communities endure, we can promote climate-resilient agriculture for food security and income (Singh et al., 2021)

Need for climate-resilient agricultural system

Global population data show that India's population reached 1.38 billion in 2020, making up 17.7 percent of the world's population. The basis for the nation's economic success is also provided by other businesses reliant on natural resources. Field crops, horticulture, cattle, fisheries, and poultry are some of its connected industries. These industries have strong ties to various Sustainable Development Goals (SDGs), including ending world hunger, improving nutrition, and combating climate change, among others. Climate change and its effects on a nation's food security in the form of extreme weather occurrences are major obstacles. By 2030, the temperature is expected to rise by 1 to 2.5 degrees Celsius, which would likely have a significant impact on crop output (Srinivasarao, 2021).

Innovative Extension Models to Boost Resilient Climate in Agriculture

A few such innovative models are discussed below:

1. Village Knowledge Centres: The Village Knowledge Centers (VKC) serve as a conduit for the dissemination of information, knowledge, and skills to rural communities by utilizing the best-fit Information and Communication Technologies (ICTs). Eight VKCs have been constructed as part of the ClimaAdapt initiative by the M.S. Swaminathan Research Foundation (MSSRF), with assistance from NIBIO and the Norwegian Embassy. The VKC's goal is to give the community access to a sustainable single-window knowledge platform that provides location-specific climate smart agro advisories and technologies to farmers for informed decisions as well as demand-responsive, comprehensive knowledge and information to the community at large based on their knowledge needs.

2. Extension model adopted under NICRA:

   National Innovation on Climate Resilient Agriculture (NICRA) is a Network project of Indian Council of Agricultural Research (ICAR) launched in 2011 with the objectives of 1) enhancing the resilience of Indian agriculture (including crops, livestock and fisheries) to climatic variability and climate change through strategic research on adaptation and mitigation, 2) demonstrating site specific technology packages on farmers' fields to cope with current climatic variability and 3) to enhance the capacity of scientists and other stakeholders in climate resilient agricultural research and awareness of impact.

3. (iii) HARITA-PRIYA: A Wireless Sensor Networks (WSN) based Disease Forewarning and Crop Advisory Model HARITA (Harmonized Information of Agriculture, Revenue and Irrigation for a Transformation Agenda)' - PRIYA (Precision Technology for Agriculture) is a 'Precision Agriculture' pilot study by the Centre for Development of Advanced Computing (C-DAC), Hyderabad and Government of Andhra Pradesh, to develop a replicable model to acquire micro-climate information from farmers' fields on a real-time basis using Wireless Sensor Networks (WSN) technology, thereby enabling the Agriculture Department to disseminate personalised advisory to farmers.

4. e-Arik (e-Agriculture): Using ICTs to Facilitate "ClimateSmart Agriculture" among Tribal Farmers of North East India A 'Village Knowledge Centre' was established under e-Arik project with a computer, internet link, printer, scanner, phone and TV at Yagrung village in Pasighat, Arunachal Pradesh. The eArik project staff regularly undertake field visits to observe crop conditions and to diagnosis pests, diseases, nutrient deficiencies and physiological problems. They digitally document these issues using ICTs in the field and, via email and webcam, communicate them to staff at the eArik Research Laboratory at the Central Agricultural University. Problems are analysed by the experts (who also sometimes undertake field/advisory visits) and recommendations are passed on to the eArik Village Knowledge Centre by email and then to the concerned farmers by phone or personal face to face communication by farmer facilitators. Dissemination of information and good practices was also addressed by innovative approaches such as farmer to farmer communication and local self-help groups.

National Climate Change Adaptation Programs

1. One of the eight missions within the National Action Plan on Climate Change (NAPCC), the National Mission of Sustainable Agriculture was adopted in 2010 to encourage the wise management of resources.
2. To solves the problems with water resources and offers a long-term solution that envisions Per Drop More Crop, the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) was introduced in 2015. It encourages micro/drip irrigation for the conservation of the most water possible.
3. The GOI established the Green India Mission in 2014 under the auspices of NAPCC with the primary goal of protecting, enhancing, and restoring India's dwindling forest covers, thereby decreasing the harmful consequences of climate change.
4. The Paramparagat Krishi Vikas Yojana mission was carried out in collaboration with the Indian Council of Agricultural Research and state governments of India to fully use the adaption of climate-smart practices and technologies.
5. The Soil Health Card program was established by the Government of India (GOI) to analyze soil samples from clusters and advise farmers on the fertility of their land.

Conclusion

Growing climate variability would intensify the problem of food and nutritional security of the growing population in India. However, with a strong extension strategies and appropriate extension methods, it is possible to enhance the capability of farmers towards adaptation of climate resilient technologies.

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Prospects and Challenges of Carbon Farming in Agriculture: An Indian perspective

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Introduction

The impact of climate change has become increasingly evident across various aspects of life on Earth. Scientific evidence strongly indicates that greenhouse gases (GHGs) play a significant role in global warming. The global mean surface air temperature has risen by approximately 0.74°C over the past century and is projected to increase by 0.3-2.5°C in the next fifty years and 1.4-6.4°C in the next century (IPCC, 2007). The radiative forcing of CO_2, CH_4, and N_2O during the current era is rising at a faster rate compared to the last 10,000 years, which can be attributed to the industrial revolution and increased human activities.

Carbon farming represents a strategic approach aimed at maximizing carbon sequestration and employing agricultural practices designed to enhance the absorption of carbon dioxide (CO_2) from the atmosphere while facilitating its retention in both plant biomass and soil organic matter. This process requires careful planning, monitoring, and adaptation to local conditions to maximize its effectiveness in mitigating climate change.

The significant role of greenhouse gases (GHGs) in driving climate change has prompted worldwide negotiations, leading to the recognition of carbon (C) as a tradable commodity. In response to the limited carbon space in the earth's atmosphere, emissions trading schemes and carbon trading have emerged with the primary goal of mitigating and reversing global warming and climate change (NAAS, 2014). Consequently, the global carbon market has expanded, giving rise to the concept of Carbon Farming through various initiatives aiming to reduce the carbon footprint across all facets of life, including agricultural and food production. The benefits of carbon trading depend on the widespread adoption of sustainable practices and the amount of carbon sequestration achieved, leading to the concept of Carbon Farming. Given that carbon trading operates as a market-based system, smallholder farmers stand to benefit from the implementation of sustainable farming practices.

Carbon Farming

Carbon Farming is a comprehensive agricultural approach that focuses on increasing carbon capture and storage in soil, crop roots, trees, and leaves through a combination of regenerative practices. This initiative aims to restore ecosystem health, improve agricultural productivity and soil health, and combat climate change by enhancing carbon storage and reducing greenhouse gas emissions within agricultural environments. Initiated in the US and Europe, this carbon sequestration endeavor serves as a vital component of climate-smart agriculture, with an emphasis on removing carbon dioxide from the atmosphere, enhancing soil and plant carbon storage, and simultaneously boosting soil fertility and farm productivity, recognizing soil carbon as pivotal to the physical, chemical, and biological aspects of soil.

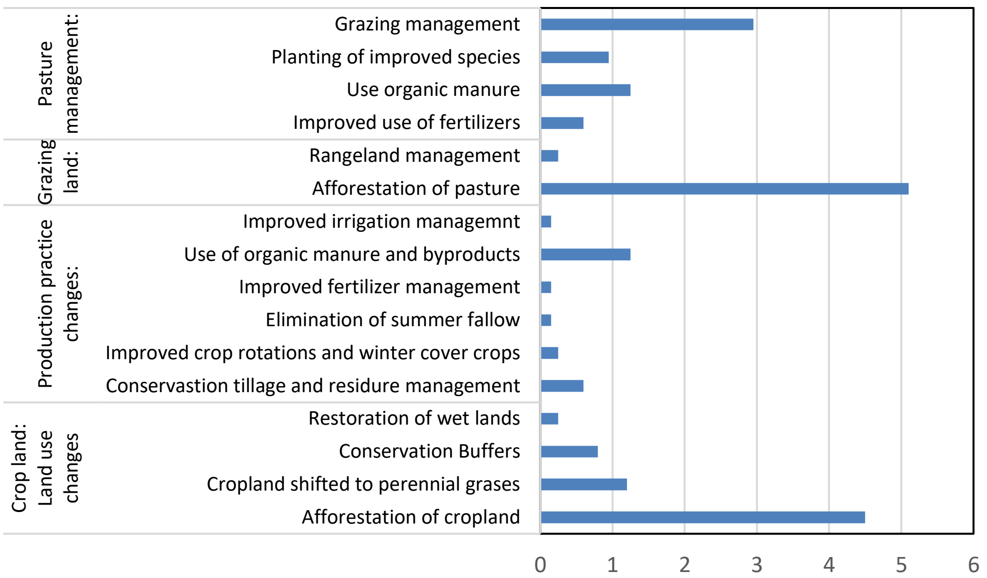
Soil profiles, soil carbon losses and climate

Wang et al. (2022) utilized an innovative approach that combined space-for-time substitution with meta-analysis to estimate the impact of future climate warming on steady-state soil organic carbon (SOC) stocks, finding that SOC stocks are projected to decrease by 6.0 ± 1.6%, 4.8 ± 2.3%, and 1.3 ± 4.0% at 0–0.3, 0.3–1, and 1–2 m soil depths, respectively, under 1°C air warming, with additional proportional losses for every additional 1 °C warming. The study highlighted that boreal forests experience the largest proportional SOC losses and emphasized that existing SOC levels are the primary determinant of spatial variability, with higher losses observed in SOC-rich soils. The cited work demonstrated that warming induced more proportional SOC losses in topsoil than in subsoil, particularly from high-latitudinal SOC-rich systems. Globally, soil carbon sequestration has about 89% of the total mitigation potential in agriculture sector (NAAS, 2014).

Initiation of Carbon Farming

Carbon Farming scheme began in US and Europe. A report published by Mitsui & Co. Global Strategic Studies Institute in April 2021 identified the carbon sequestration and carbon credit programs being promoted on farmland in Europe and the US as models that could become new schemes for supporting farmers through private funding, replacing traditional subsidies. In USA income from carbon sequestration has been estimated depending on the agricultural activity type with identified programs showcasing the market price that will evolve with new opportunities for farmers and ranchers in the future (Figure 1. ESG & Climate Research, 2022)

Figure 1: Carbon sequestration rates – Mt CO_2e/ace (ESG & Climate Research, 2022)



The focus has been now on the possibility of applying those western schemes in emerging countries where there are many low-income, smallholder farmers. Now, there is a discernible development to apply the schemes in the emerging country like India. A recently published review of such studies (West and Post, 2002) concluded that conversion of conventional tillage to no-till could sequesters an average of 0.57 ± 0.14 t C ha^{-1} $year^{-1}$.

Carbon Farming Practices

Agro-ecological approaches such as crop diversification and intercropping have benefits for ecosystem resilience. Livestock management strategies including rotational grazing, optimizing feed quality, and managing animal waste to reduce methane emissions and increase the amount of carbon stored away in pasture lands.

Agricultural methods for carbon farming for increasing the rate at which carbon is sequestered into soil and plant material include residue management and improving cropping practices by adopting following practices:

- Reduce/ conservation tillage or zero tillage, minimizing soil disturbance and synthetics: It minimizes mechanical soil disturbance, thereby preserve soil carbon and facilitate CO_2 fixation in the soil.
- Protecting the soil/ Permanent ground cover/ Planting and harvesting crops and keeping living roots in the soil.
- Maintaining agricultural infrastructure
- Using organic mulch or compost/working with biochar and terra preta: By using biochar to make homemade terra preta to improve soil fertility and improve crop yield can create more sustainable and resilient home and agricultural systems just like historical terra preta soils that benefit both people and the planet.
- Maximize biodiversity: This means biodiversity in the soil as well as on the soil surface, earthworms, bees, etc. through intercropped cash crops and high-diversity cover crops. Crop rotations and cover crops are basics of sustainable agriculture.
- Integrating animals: Grazing livestock adds diversity to the products produced on the farm, adds value to cover crops (really annual forage crops), and recycles nutrients through manure.

Livestock and Carbon Farming

Livestock production appears to contribute about 11%–17% of global greenhouse gas emissions. Livestock management is one aspect of carbon farming that can help reduce greenhouse gas emissions:

- Livestock grazing management: Rotational grazing manages livestock movement to prevent overgrazing and promotes pasture regrowth and can sequester carbon in the soil
- Feed additives: Can help reduce enteric emissions
- Feed quality: High quality feed can reduce methane released from enteric fermentation
- Manure management: Covering manure storage facilities can help reduce methane and nitrous oxide

Concept of Regenerative agricultural practices

Implementing regenerative agricultural practices that restore ecosystem health while improving agricultural productivity and soil health, and mitigating climate change by enhancing carbon storage in agricultural landscapes and reducing greenhouse gas emissions. The practice is easy to adopt across various agro-climatic zones. It can also help ameliorate soil degradation, water scarcity, and challenges related to climate variability. Regenerative agriculture can be viewed as follows:

Conservation Agriculture + Holistic Grazing + Enhanced Biodiversity + (Organic farming) = Regenerative agriculture (McGuire, 2018)

Forest management for Carbon Farming

Sustainable forest management is another way to carbon farming. Methods used in forestry include reforestation and bamboo farming. Modifying the practices for enhancing C sequestration might require additional costs. Hence some countries have framed government policies to offer financial incentives to encourage the farmers to adopt carbon farming methods. Agroforestry includes practices like silvopasture and alley cropping, diversifying income through carbon sequestration in trees and shrubs.

Reports on Carbon sequestration rate in Agroforestry

Carbon sequestration and net emissions of CH_4 and N_2O under agroforestry was summarized in a report earlier (Dong-Gill *et al.*, 2016). The report compiled and analyzed data from 109 earlier observations from 56 peer-reviewed publications of net rates of change of biomass and/or soil carbon (C) stocks in agroforestry systems, and from 26 data sets from 15 peer-reviewed publications of net changes in the emissions of methane (CH_4) and nitrous oxide (N_2O). It primarily assessed the changes in C storage and net GHG emissions between agriculture and tree-crop coexistence types where trees and agricultural crops were grown together. The study concluded that agroforestry stands sequestered 7.2 ± 2.8 t C ha^{-1} y^{-1} (70% in biomass and 30% in soil), oxidized 1.6 kg CH_4 ha^{-1} y^{-1} and emitted 7.7 kg N_2O ha^{-1} y^{-1} and was estimated to mitigate 27 ± 14 t CO_2 equivalent ha^{-1} y^{-1}.

Carbon Farming Opportunities in Indian Agriculture:

Globally nearly 5 billion hectares (1.2×1010 acres), 38% of the worlds' surface is farmland. India possesses 1.78 million square kilometers of agricultural land, ranking seventh in the world. On the other hand, besides large area of cropland, India has also got largest bovine population, hence it has got scope for environmental improvement and is likely to become the leading market for carbon farming credits (Nozaki, 2023). The contribution of Indian Agriculture sector to global greenhouse gas emission is 13% i.e. 776 metric ton CO_2 eq (Mitsui and Co. Global Strategic Studies Institute Monthly Report, February 2023). At the same time, this sector, which encompasses land use, land use change, and forestry (LULUCF), has enormous carbon sink potential (NAAS, 2014).

A study in north western India based on the GHG assessment of 10 cropping systems, 8 livestock farming systems and 9 production systems using the comparative agriculture and Life Cycle Assessment

(LCA) approaches showed that mineral fertilization, irrigation and methane from paddy fields are the main drivers of emissions at plot level. Livestock farming systems emitted from 4.7 tCO_2eq/female to 8.6 tCO_2eq/female, enteric fermentation being the first source of emission. Disparities at farm level were reported to be huge, ranging from 9 to 733 tCO_2eq. At village level, emissions yield 37 tCO_2eq/ha and livestock contributed to 60 % of GHG emissions. Agricultural GHG emissions in the studied village yielded 37 tCO_2eq/ha (Hemingway *et al.,* 2023).

Considering the vast agricultural base with large arable land and world's largest livestock population India has tremendous potentiality and scope for carbon farming and simultaneously also in the need for climate-resilient practices. The economic potentiality of agro-ecological practices has been estimated to have a potential of $63 billion from approximately 170 million hectares of available arable land in the country. Implementing a Carbon credit systems can provide additional income to farmers through environmental services, with agricultural soils potentially absorbing 3-8 billion tonnes of CO_2 equivalent annually over 20-30 years. In addition to this the Indo-Gangetic plains and the Deccan Plateau are favourable for carbon farming, whereas the Himalayan region and coastal areas face specific challenges such as mountainous terrain and salinization, respectively.

India need to take following initiatives for promotion and wider adoption of carbon farming:

Educating farmers about the benefits of carbon farming and provide training on sustainable practices, need to strengthen policy frameworks and develop and enforce policies that support sustainable agriculture and provide incentives for farmers, should invest more in research and development so to support agrarian research to innovate and improve carbon farming techniques suited to Indian conditions. Consequently help farmers gain access to carbon credit markets and ensure fair compensation for environmental services by facilitating access to markets. Addressing these areas can help India not only meet its environmental goals but also improve the livelihoods of its farmers and the sustainability of its agriculture sector.

Conclusion

Climate change and stagnating crop yields may cause a decline of SOC stocks in agricultural soils leading to considerable CO_2 emissions and reduced agricultural productivity. Regional model-based SOC projections are needed to evaluate these potential risks (Wiesmeier *et al.,* 2016). There are certain disadvantages to carbon farming, such as increased land clearing, monocultures, and biodiversity loss. Hence it is critical to remember while developing strategies for maximizing the environmental benefits of carbon farming by keeping in mind ecosystem services at the same time.

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