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Climate Change and Livestock Nutrient Availability: Impact and Mitigation

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Abstract

Livestock is an integral part of any agricultural system all over the world. Optimized livestock production is depended upon many factors like environmental stresses, climatic factors, health status, nutrient availability, and genetic potential. In the changing climate scenario, nutritional stress act as the most important indirect stress affecting livestock leading to decreased performance, lower efficiency, increased mortality and it also affects the immune system. The animals in tropics faces the problem of low feed availability during summer and this leads to severe nutritional stress to livestock grazing in the low pasture lands. Under nutrition reduces the quality and quantity of milk production, effects growth potential and reduces body condition score (BCS), induces seasonal weight loss (SWL) and it also declines the reproductive capacity of the animals, it reduces the fertility rate, embryo quality, expression of oestrus behaviour, altering follicular development, compromising oocyte competence, and inhibiting embryonic development, reduced calf birth weight, reduced sperm output, decreased sperm motility and an increased proportion of morphologically abnormal spermatozoa in the ejaculate. The reduced nutrient availability also alters the endocrine and hormonal activity in livestock leading to physiological changes and decline in reproductive efficiency. The animals exposed to environmental stress are found to cope up with the adverse effects of the stress when the nutritional requirements are not compromised. Thus in order to sustain the productivity, suitable nutritional interventions are to be adopted like management of forage for the dry period, utilization of the non-conventional feed resources as alternatives, antioxidant supplementations during the stress period, and also water management strategies for both surface and ground water resources, at both local and national levels, as fresh and contamination free water is crucial for animal production. These efforts will ensure economically viable returns in livestock farms in the changing climate scenario.

Keywords: Antioxidant; Forage; Nutrition; Stress; Unconventional feeds

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. Rural poor communities depend a lot on agriculture and livestock for their survival. Further, animal agriculture is amongst the most climate-sensitive economic sectors in India. Dairy farming provides employment, sustainable income and social security to a large population across the globe. Climate change and global warming cause great threat to entire livestock population across the world. Impact of climatic extremes and seasonal fluctuations on herbage quality and quantity are considered as imperative source of influence on the well-being of livestock in extensive production systems. This can result in impairing reproduction and production efficiency of grazing animals. The extreme heat during summer months negatively impacts grazing animals, and is capable of inducing nutritional imbalances. 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. Inadequate and low quality feed is a major factor in under-production of animals in arid and semi-arid tropical regions. Under-nutrition in livestock can occur in late spring and summer due to increased energy output for thermoregulation and concurrent reduction in energy intake. While understanding the science of animal nutrition continues to expand and develop, most of the world's livestock, particularly, small ruminants in pastoral and extensive mixed systems in many developing countries, suffer from permanent or seasonal nutritional stress.

Climate change has both direct and indirect stresses on livestock production. The direct stresses result from atmospheric parameters like temperature, humidity, solar radiation, wind velocity and rainfall, whereas the indirect stresses comprises of pests and pathogens, occurrence of diseases ,reduced nutrient quality in fodder crops , low availability of pasture lands and less availability of feed and water. Thus, nutritional stress is the most important indirect stress that emerges due to climate change which impacts livestock leading to decreased performance, lower efficiency, and increased mortality. Hence, in the changing climatic scenario the livestock needs to be protected against the adverse effects of environmental stresses to maintain production and performance, by providing optimum nutrition, proper management practices and health care. Adverse environments can increase the nutritional requirements of animals directly or they may reduce the supply and quality of the feed [1]. This review is an attempt to collate information on different nutritional strategies to improve livestock production under the changing climate scenario.

Impact of nutritional stress on livestock

All animals require energy, amino acids, fatty acids, fat soluble vitamins (A, D, E, and K), water soluble vitamins (B-vitamins), trace elements and macro minerals for both health and growth. When availability of any of these nutrients is limited, deficiency symptoms occur most quickly in tissues with the highest rates of protein synthesis or metabolic activity. The immune system is particularly sensitive to nutrient deficiency because any immune response requires rapid

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synthesis of proteins for immune cells and immune products. The nutritional requirements of animals play a crucial role in the biological and maintenance activities. An animal exposed to heat stress will perform well if optimum nutritional requirements are met [2]. Therefore compromising the nutritional requirement will reduce the production potential of the animal. Grazing animals in arid and semi-arid regions are generally subjected to periods of under nutrition during extreme hot environment due to non-availability of feed and poor pasture conditions caused by lower availability of nutrients, which in turn results in low productivity. The animals suffer severe nutritional stress in the dry-season when the natural pasture is of low nutritional value and usually in scarce supply. During this time of the year, animals also waste a lot of energy, as they have to walk long distances in search of food and water [1]. (Figure 1) describes the effect of climate change on nutrient availability and its impact on livestock production. The major body functions and productive parameters that are affected due to nutritional stress are:

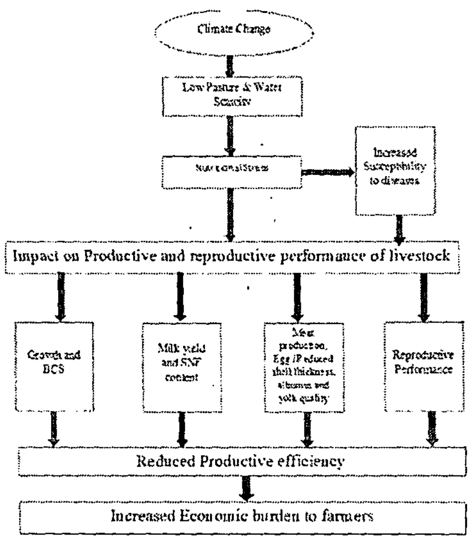

Figure 1: Effect of climate change on nutrient availability and its impact on livestock production

Milk production

Reduction in milk production is one of the major economic impacts of climate stress in dairy cattle. Reduction in milk yield is further intensified by decrease in feed consumption by the animals to compensate the high environmental temperature. During summer the feed intake reduces considerably than the actual need of the animal, which results in disturbing the energy balance of the animal thus affecting the activity of mammary gland. Reduced milk production due to heat stress is attributable only partly to decrease in feed intake. The reduction in dry matter intake during heat stress accounts for approximately 40-50% of decline in milk production and 50-60% can be explained due to hyperthermia induced changes [3]. Other factors resulting in reduced milk production during heat stress are decreased nutrient absorption, changes in rumen functions, hormonal status and increased maintenance requirement resulting in reduced net energy supply for production. Milk production in cow has been found to be reduced when ambient temperature and temperature humidity index increases above critical threshold. Heat stress during 60 days prepartum period negatively affects postpartum milk production and cow parturating during summer produce less milk as compared to other season. Similarly, quantity of milk protein and fat, somatic cell count (SCC) and solid not fat (SNF) have been found to be reduced during heat stress in dairy cattle.

In general during summer the availability of green grasses or forages decreases leading to increased concentrate feeding to livestock. As the proportion of the concentrate in the ration increases above 50-60%, milk fat % tends to decline. This is mainly because of the lower ruminal production of acetate and butyrate which are the precursors of milk fatty acid synthesis in the mammary gland, associated with feeding high concentrate diets. The extent of milk fat depression is influenced by other feeding practices such as frequency of feeding and feeding system. Further, if the concentrates are fed separately from the forage results in reduced ruminal acetate: propionate ratio which in turn can result in reduced milk fat %.

The combined effect of temperature and humidity, known as the THI index or discomfort index plays a crucial role in declining milk productivity. Heat stress affects higher producing cows more than lower producing cows. High producing cows eat and metabolize more feed, this generates more heat in these cows decreasing their feed intake and lowering milk production. Humidity and high temperatures increase plant growth rate, which increases the neutral detergent fibre (NDF) content of plants and reduces potential intake.

Growth

Nutritional restriction leads to decline of growth potential. Severe and prolonged intra-uterine growth retardation may result in slower growth of cattle throughout life. In cattle the post natal growth is severely affected if the maternal nutrition is restricted from day 80-90 of pregnancy until parturition. The effect of nutritional restriction on birth weight was more pronounced in heifers than cows when the period of restriction encompassed mid and late gestation [4,5] rather than late gestation alone [4,6]. The visceral organs have different growth and metabolic rates compared with other organs and the feed quality and quantity affect their growth [7]. An animal which is known to be well adapted to nutritional stress can tolerate relatively large reductions in body weight [7,8]. Stress induced fat mobilization and insufficient fat storage results in reduced body condition score (BCS), in feed restricted animals [2]. This low BCS affects the fertility and reduced reproductive efficiency of livestock [7,9]. The nutritional status of animals is difficult to measure, and this complicates interpretation of nutrition x reproduction interactions [10]. An animal's nutritional status is usually assessed on changes in its live weight and body condition. Animals living in tropics are generally of low body weight due to lack of nutrients during the dry period. This leads to low reproductive efficiency in these animals and further the severe nutrient deficiency leads to seasonal weight loss (SWL) [11]. In addition, growth and metabolism are regulated by multiple hormones and growth factors. Among these are thyroid hormones, glucocorticoids, sex steroids and a number of locally produced growth factors are very important endocrine factors influencing growth performance in livestock [12,13].

Reproduction

Poor nutrition delays puberty, decreases conception rate and increases pregnancy losses in heifers and also leads to hypogonadism [14]. In nutrient restricted animals the blood flow is diverted from the internal organs, to the peripheral tissues in an attempt to reduce the

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body temperature by increasing heat losses. This mechanism leads to a reduction of blood flow, aimed at internal organs such as the uterus, fallopian tubes and ovaries, decreased blood supply to these organs also implies low nutrient availability and therefore low functional capacity [15]. Climate change could alter reproductive efficiency of livestock both due to direct as well as indirect effects. Most of the indirect effects of climate change on livestock reproduction are mediated through nutritional deficiency [15,16,17]. Lamy *et al.* [11] reported negative impacts of SWL on sperm cell abnormalities, testicular volume and scrotal circumference. Lawson and Cahill [18] stated that variations in the physiological range of peripheral progesterone concentration due to management factors such as nutrition may induce asynchrony between the embryo and uterus resulting in failure of establishing pregnancy. Further, under nutrition in ewes before and after mating can increase embryonic mortality which consequently reduces the lambing rate [19,20,21]. Stress response consists of the release of Adrenocorticotropic hormone (ACTH) by the posterior pituitary gland and release of cortisol by the adrenal cortex [21,22,23]. High cortisol concentration in the system hinders the pituitary response to gonadotropin releasing hormone (GnRH) [21,24]. Further, cortisol decreases gonadal activity by reducing pulse frequency and amplitude of the Luetinizing hormone (LH) released by the gonadotrophs [21,24,25]. In males, under nutrition causes hypogonadism and infertility. This is mainly attributed to the decrease in GnRH release from the hypothalamus [26]. In the context of nutritional stress and reproduction, it is important to understand the role of leptin. Leptin is otherwise known as the obesity hormone produced by adipocytes and acts as a signalling molecule in the brain imparting information about the nutritional status of the body [26,27]. Under nutrition results in low leptin levels in the circulation which probably signals the brain to suspend reproduction [26,28].

Adaptation of livestock to low pasture

Under the conditions of restricted nutrition the metabolic rate is reduced. Feed restriction leads to the reduced metabolic state and involves the reduction in body temperature. This decrease in body temperature further reduces metabolic rate as per Vant Hoff's rule [7,29]. The pulse rate is an indicator of general metabolic status and the reduction in pulse rate could be due to decrease in metabolic rate as a result of restricted feeding. Reports show that in desert goats there is decrease in energy expenditure with feed restriction [7,30] and the reason for this is due to decreased oxygen consumption by peripheral skeletal muscles. Samad *et al.* [7] and Hyder, [29] and observed a decrease in respiratory rate in the feed restricted bucks and they attributed this to the reduced metabolic requirements and decreased oxygen consumption. Sejain *et al.* [13] reported that the decrease in physiological parameters like reduced respiratory rate in under fed sheep and attributed this to the decrease in thyroid activity. The Physiological responses like rectal temperature, heart rate and respiration rate were significantly reduced in bucks under restricted feeding which is attributed to the low rate of metabolism [7]. Whereas, normally fed animals had higher concentrations of the amino acids Alanine, Tyrosine, and Citruline, while animals subjected to SWL showed higher concentration of Valine, Isoleucine, Leucine, Threonine, Methionine, Taurine, Ornithine, Lysine, Hydroxyproline, and 3-metyl histidyne, while Glycine, Serine, Glutamate, Arginine, Histydine, Aspartate and Proline were similar in both diets and also myofibrillar protein degradation of protein C and a-actinin. The C16:0 as free fatty acid in the plasma showed a significant increase during under nutrition and C18:1 showed a relative decrease in muscle fatty acid as incorporated in triacylglycerols in nutrition restricted goats [11]. Red blood corpuscles (RBCs), Packed Cell Volume (PCV) and Haemoglobin (Hb) are good indicators of both heat [31] and nutritional [13] stress in sheep. Sejian *et al.* [13] and Sejian *et al.* [31] further added that the level of plasma glucose decreased in the nutrition deprived animals and the nutritional stress of higher magnitude decreases plasma protein level and plasma albumin level under restricted feed conditions [13,32]. The reduction in total plasma protein concentration was assumed to be due to glucose synthesizing by inducing hepatic gluconeogenesis in order to cop up to the stress. Likewise, plasma cortisol level was also significantly higher in the feed deprived and heat stress group. [13,33]. Further, total plasma cholesterol levels also decreased significantly in stress groups and they postulated that this decrease might be due to increase in the utilization of fatty acids for energy production as the levels of glucose in the feed restricted animals will be lower.

In small ruminants the nutritional state is closely regulated to hormonal and neuroendocrine cues. The level of cortisol is less in the nutritionally deprived animals. According to Kong *et al.* [34] energy balance can also play a major role in affecting the decrease in plasma Thyroid hormone (TH) levels in small ruminants as during the stress period the level of Triiodothyronine (T3) and Thyroxine (T4) decreases, thus indicating the importance of optimum nutrition for maintaining proper TH levels in sheep [31,35]. Consistent with this statement, kafi *et al.* [36] and Kong *et al.* [34] stated that the plasma TH concentrations are correlated with feed intake in several ruminant species. Silva, [37] stated that the thyroid hormones can directly depict the nutritional status of an animal.

Food availability is the main factor that influences mammalian reproduction because under nutrition slows down development of ovarian follicles and reduces lifetime reproductive performance in livestock [21,38]. Changes in dietary intake promote variations in concentrations of metabolic hormones and reproductive hormones and consequently affect the developing ovarian follicle and/or the composition of reproductive tract secretions which provides histiotrophic nutrition to early embryos. Heat stress and feed scarcity often occur simultaneously and are the major predisposing factors that cause low livestock productivity in tropical environment. Under nutrition of ewes results in lower bodyweight and body condition score with a negative effect on oocyte quality such as low rates of cleavage. In addition to that the low BCS affects hormone production, fertilization, and early embryonic development [2,21,39,40,41]. Reports indicate that the level of feeding affects the oocyte quality in ewes [21,42]. Pisani *et al.* [43] found that ewes fed 50% of their maintenance requirements for two weeks had reduced expression of glucose transporter 3, sodium/glucose co-transporter, and Naþ/Kþ ATPase mRNA in oocytes, while expression of PTGS2, HAS2, and the leptin receptor in granulosa cells was found to be increased. Reduced expression of glucose transporter 3 is potentially important in the light of its substantial role in post-implantation embryonic development [21,44].

Managing feed resources in the changing climate scenario

Among the major constraints faced regarding livestock production is inadequate feed supply. Seasonal variations in feed quantity and quality can cause fluctuations in animal nutrition throughout the year. Seasonal fluctuation of feed resources in the tropics follow the pattern

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of vegetation growth that is modified by availability of rainfall and this results in seasonal pattern of wet season gain and dry seasonal live weight and production loss. A common production problem faced by pastoralists, agro-pastoralists as well as smallholders is the seasonality in the quantity and quality of animal feeds; particularly natural pastures and crop residues. Crop residues are only about 20% available, relative to their maximum, early in the cropping season, peak towards 100% at the end of the cropping season and then decline to about 60% in the post-harvest season. Natural pasture supply begins to rise during the cropping season. At the beginning of the cropping season the availability of pasture is only 30% which peaks towards 100% and then declines to about 50% during the post-harvest season. Forage quality depends on soil fertility and biomass yield depend on soil humidity which in turn depends on the amount of rainfall that infiltrates the soil [45]. Ruminant livestock in most parts of the tropics graze intensively on naturally growing forages which are poor in quality. These tropical forages compared to those in the temperate pasture usually contain less nitrogen and are less digestible [46]. The quantity and quality of these grasses become more critical in the dry season imposing more serious constraints to the development and productivity of these animals [46,47].

Role of forages

Forages are the vegetative parts of plants containing a high proportion of fibre. They are required in the diet in a coarse physical form because they: Stimulate rumination and salivation, which are important processes in maintaining a healthy rumen environment, Stimulate ruminal contractions and the passage rate of digesta through the rumen, which improves the efficiency of rumen bacterial growth and also they help in countering milk fat depression that occurs in dairy cattle when they are fed rations high in concentrates. Rations that contain less than about 35 % forages will result in milk of low fat content. The major contributions from the forages towards the ration are fibre and carbohydrates, which are a source of energy.

Managing forage

In order to stretch forages and increase the growth of pasture, consider the following strategies:

Increasing forage growth

The Addition of adequate moisture and organic fertilizers to the soil can increase forage growth. Forage and pasture grass growth also depends on daylight lengths and favourable temperature. Limpograss, Stargrass, and other warm season perennials have a higher potential of growth during the fall period and will provide more forage production. The drought resistant grasses like Bahia grass can also be grown during the summer. Growing annual leguminous fodders like Cowpea or horse gram etc inter planted with perennial fodders like Co-3, C0-4, APBN-1 varieties of hybrid napier in kharif and intercropping of the grasses with Berseem, Lucerne, etc. during Rabi season [48] can be a suitable practice for management of forage during the deficit period. Planting annual forages such as rye, oats, wheat, and ryegrass can produce good yields of high-quality forages. Also crop residues can be used as feed. Growing micro-green fodders is one of the modern practices which is easy and requires very little water, space, time and efforts. It involves the growing of the fodder through germination of grains like barley, oat or wheat produces consistent quantities of green throughout the year at the rate of 6 to 8 kg per 1 kg of seed within one week period.

Grazing by rotation

Grazing the herd on different pastures by rotation instead of constantly grazing the cattle on the same pasture may have huge advantage of maintaining the pasture throughout the year in some part of grazing land. This will allow a suitable period for the remaining grasses to grow to proper height and to recover before being grazed again before the subsequent grazing.

Feeding hay

During scarcity period converting grasses into hay and preserving them for future use is a common practice widely followed around the world. It is possible to use the hay harvested from pasture instead of buying high priced hay from other sources. However, while preparing hay in-house sufficient care has to be taken to store the hay in a proper manner protecting them from adverse weather conditions.

Importance of feeding fats and concentrates

The addition of fat to the diet of lactating dairy cows is a common practice, and the higher energy density and the potential to reduce heat increment of high-fat diets may be particularly beneficial during hot weather [49]. There are studies demonstrating that dietary fat can be added to the ration at up to 3-5% without any adverse effects to ruminal microflora [50].The primary role of concentrate feeds is to provide the livestock with concentrated sources of necessary nutrients for production. Apart from macro-nutrients of energy and protein these also include important nutrients such as amino acids, fatty acids, enzymes, vitamins, minerals and others. There are two specific consequences of feeding concentrates which are important in the context of environmental impacts of feed utilization. The first is that improvements in livestock productivity which are generally associated with improved biological efficiency of feed use; the second is the role of concentrate feeds in promoting better utilization of roughage feeds for ruminant livestock.

Significance of utilizing unconventional feed resources

There are many alternate or unconventional feeds that can be utilized during the scarcity period. The unconventional feed resources include a variety of feeds not widely used in commercial livestock diets. Among these some of them may be considered as concentrate feeds after processing, such as dried Lucerne (alfalfa) leaf meal, dried cassava leaf, cassava pulp, processed pea and bean meals, sal and rubber seed meals, citrus pulp wastes and others. But the important thing to be considered before the usage of unconventional feed resources is that many of these contain a wide range of anti-nutritional factors, which are to be processed in order to reduce the deleterious effect on animals when given as ration. These processing will help in better digestibility and reducing the wastage of feed materials. (Table 1) describes the different types of unconventional feed that are given to different livestock species during scarcity period.

Unconventional feed resources	Species	References
Neem Seed Cake (NSC)	Ruminants	[51,52]
Castor Bean Meal (CBM)	Ruminants	[52,53]
Karanj Cake	Ruminants	[51,52]
Coconut Meal	Cattle	[53]

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Tomato Pulp	Cattle	[53]
Banana rejects/ Pineapple pulp	Cattle, Sheep	[51]
Cottonseed Meal(CSM)	Ruminants	[53]
Azolla	Fish, Swine, Poultry and Cattle	[54]
Areca Sheath	Sheep and cattle	[51,52]
Jatropha Meal	Small Ruminants	[52]

Table 1: Different types of unconventional feed fed livestock species during scarcity period

Antioxidant supplementation to reduce the environmental stress impact

During extreme environmental conditions the oxidative balance gets disturbed in livestock. Antioxidants are compounds or systems that delay oxidation by inhibiting the formation of free radicals or by interrupting propagation of the free radical by several mechanisms [31,55]. This inturn helps to protect cellular damage during any stressful condition. Selenium and vitamin E are essential nutrients that function as antioxidants to minimize cellular damage caused by endogenous peroxides [56]. Antioxidant supplementation comprises less milk waste in the form of free radicals as well as reducing the number of somatic cells in milk. Cows supplemented with selenium were found to have increased concentrations of the oligoelement in milk. Further, antioxidants can potentially promote meat tenderness as well [57].

Vitamin E, also known as α-tocopherol, is the best-researched dietary antioxidant. It is an essential nutrient for the growth and health of animals by functioning as an antioxidant in various biological systems. Vitamin E prevents free radicals from reacting with other biological compounds such as proteins and lipids, ultimately protecting meat from oxidative damage. Vitamin E (α-tocopherol) is the most frequently used lipid soluble free radical scavenger administered as nutritional supplement contributing to the stability of beef muscle [57].

Selenium is a key component of certain enzymes, such as glutathione peroxidase, which has strong antioxidant properties and can work synergistically with vitamin E. Glutathione peroxidase, protects cells from toxic radicals and peroxides, thereby preventing oxidative damage to the body. Dietary supplementation of organic selenium in cattle has been shown to increase glutathione peroxidase activity and improve oxidative stability of fresh meat during storage [58].

Free radical oxidation is activated in animals under various types of stresses and lipid peroxidation products accumulate in various organs [59,60]. Lower levels of the antioxidant vitamins are associated with poor fertility and production levels in ruminants [61]. Antioxidant defenses in the female reproductive tract may have some regulatory role in fertility. Antioxidant supplementation would reduce the incidence of infectious disease in the uterus and also reduced incidence of Dystokia. Reducing incidence of retained placenta should also reduce uterine infections because occurrence of retained placenta predisposes cows to uterine infections. A significant increase in estrus incidences was in sheep given Vitamin E–selenium injections [31,62].

Significance of water to improve livestock production under changing climate scenario

Climate change can have a variety of impacts on surface water, drinking water, and ground water quality. Higher water temperatures and changes in the timing, intensity, and duration of precipitation can affect water quality. Higher air temperatures (particularly in the summer), earlier snowmelt, and potential decreases in summer precipitation could increase the risk of drought. Reduction of water results in lower milk, meat, and egg production. Deprivation of animals to water immediately results in loss of appetite and weight loss with death occurring after a few days when the animal has lost 15 to 30% of its weight. It also leads to reducing the animal performance than other nutrient.60-70% of the animals live weight consists of water and consuming water is more important than consuming food. Signs of dehydration are tightening of the skin, loss of weight and drying of mucous membrane and eyes.

Water is a critical nutrient for livestock and poultry. As with feed ingredients, livestock water should meet the nutritional needs of the animal. An adequate and safe water supply is essential to the production of healthy livestock and poultry. There are several measures that need to be taken to ensure quality drinking water to livestock in the changing climatic condition. These include: (i) understand climate change impact on water quantity and quality; (ii) renewed water harvesting technology-technically sound, appropriate design and economically feasible; (iii) integrated water resource management (iv) national adaptation program-local knowledge and flexible funding.

Conclusion

Studies show that animals subjected to environmental stress can tolerate the adverse effects if nutrition is not compromised. Thus nutrition is the most important factor affecting the animal production and performance in the changing climate scenario. The major reasons for nutritional stress are environmental stress (especially heat stress, where animals voluntarily reduce feed intake) and pasture scarcity. Under the changing climate scenario livestock production is affected by low pasture availability during the summer, and changes in temperature, precipitation and increased CO_2 levels have resulted in declining grain quality of crops. Reduced nutritive value of fodder crops is one of the primary indirect effects of climate change on livestock production. Hence various alternative strategies are to be adopted to maintain productivity especially during the deficit period or summer when the availability of pasture and water declines. Thus in order to sustain the productivity, suitable nutritional interventions are to be adopted like management of forage for the dry period, utilization of the non-conventional feed resources as alternatives, antioxidant supplementations during the stress period, and also water management strategies for both surface and ground water resources, at both local and national levels, as fresh and contamination free water is crucial for animal production. These efforts will ensure economically viable returns in livestock farms in the changing climate scenario.

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