

Climate Smart Livestock Farming for Sustainable Animal Production

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Abstract

Climate-smart livestock farming seeks to maintain animal production while improving resilience to heat, water scarcity, feed variability and extreme weather, and while reducing avoidable greenhouse-gas emissions. Livestock are affected directly by heat stress and indirectly through changes in forage yield, water availability, vector distribution and disease pressure. Adaptation begins with shade, ventilation, reliable drinking water, heat-tolerant housing and seasonal changes in feeding and work schedules. Fodder conservation, drought-tolerant forage crops, feed inventories and strategic supplementation help protect production when rainfall is uncertain. Breeding and selection can improve heat tolerance and disease resistance, but productivity and local adaptation must be balanced. Manure management, improved feed efficiency, reproductive performance and reduction of avoidable mortality can lower emissions per unit of milk, meat or eggs. Biogas and composting can further convert waste into useful energy and nutrients. Climate-smart management therefore combines adaptation and mitigation rather than treating them as separate goals. The most suitable practices depend on species, production system, farm resources and regional climate risk. Monitoring temperature-humidity conditions, water use, feed supply and health trends helps farms respond earlier and avoid severe losses.

Keywords: Climate-Smart Livestock, Heat Stress, Adaptation, Methane Mitigation, Fodder Security, Sustainable Animal Production

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Introduction

Climate change affects livestock through higher temperatures, more variable rainfall, irregular seasons and a greater frequency of extreme events. The impact is both direct and indirect. Direct effects include heat load, dehydration, reduced appetite, slower growth, lower milk yield and impaired reproductive performance. Indirect effects arise when drought reduces fodder availability, floods damage housing and feed stores, or warmer and wetter conditions favour vectors and infectious agents. Animals with high production potential may be especially vulnerable because their metabolic heat production is already high. Young, pregnant, recently transported and sick

animals also require additional protection. Climate-smart livestock farming begins by recognising these different risk pathways and by identifying the periods when animals are most exposed. Farm managers should observe weather forecasts, water availability, feed stocks, housing conditions and disease trends together rather than treating them as separate issues. This approach makes it possible to prepare before a heat wave, drought or flood becomes an emergency. Resilience is strengthened when basic needs such as shade, ventilation, clean water, safe shelter and reliable feed are secured in advance. Good climate management therefore starts with

practical husbandry, not with expensive technology.

Climate-smart livestock farming aims to improve resilience and resource efficiency while reducing avoidable emissions intensity. The practical focus is on measures that protect welfare and production under local conditions and that can be maintained economically by farmers. Adaptation and mitigation should be considered together because many good management practices support both goals. For example, improved feed quality can help animals maintain production during climatic stress while also reducing feed wastage and lowering emissions per unit of milk, meat or eggs. Better fertility and lower mortality reduce the number of non-productive animals that must be maintained for the same output. Efficient manure handling can reduce pollution while recovering nutrients or energy. However, no single practice is universally suitable. A cooling system that works well in a dry region may be less effective in very humid conditions, while a feed conservation strategy depends on local crops, storage facilities and labour. Climate-smart planning should therefore begin with a farm risk assessment. Farmers can list the main hazards affecting their enterprise, such as heat, water shortage, flooding, storm damage, feed scarcity or vector-borne disease, and then rank the likelihood and consequences of each. Priority should be given to actions that protect animals and production even under normal conditions.

Heat-Stress Management

Shade is the first line of defence against solar heat load. Natural shade from trees, well-designed roofs, shade cloth and open-sided housing reduce radiant heat before additional cooling is required. Roof orientation, height and insulation influence the amount of heat transferred to animals, while wide openings improve air movement. Fans enhance convective cooling and are particularly useful in holding areas, milking facilities and densely stocked sheds where natural airflow is limited. Sprinklers or misters can be effective when ventilation, humidity and drainage are appropriate, but excessive wetting without adequate evaporation may increase humidity and bedding moisture. Cooling is especially important for lactating dairy animals because

feed intake and milk production can decline rapidly when body heat cannot be dissipated. Heat stress should be recognised early through faster respiration, panting, increased standing, crowding near water or shade, reduced rumination and lower feed intake. Animals may also show changes in milk yield, fertility and activity before severe clinical signs appear. A practical heat-stress plan should define when fans, sprinklers or other measures are activated and who is responsible for checking equipment. Cooling systems need regular cleaning and maintenance because blocked nozzles, damaged fans or poor water pressure may reduce effectiveness. Backup arrangements are also important during power failure.

Management should shift feeding, milking, transport and animal movement toward cooler hours when high temperatures are expected. Diets may require greater nutrient density when feed intake falls, but fibre should not be reduced excessively because healthy rumen function remains essential. Offering fresh feed more frequently, pushing feed up regularly and avoiding spoiled material can encourage intake. Large meals during the hottest part of the day should be avoided when possible. Clean, cool water must be continuously available and trough space should prevent competition, particularly after milking. Water points should be easy to reach and located so dominant animals cannot block access. During hot weather, water consumption can increase substantially, so storage, pump capacity and refill rate should be checked before the season begins. Night-time cooling is also important because animals need an opportunity to dissipate heat accumulated during the day. If nights remain warm, continuous or extended ventilation may be necessary. Stocking density should be reviewed because overcrowding increases competition and reduces airflow. Special attention should be given to high-producing animals, late-pregnant animals, young stock and animals with respiratory or metabolic problems. Workers should be trained to recognise severe heat stress, weakness and dehydration and to seek veterinary assistance when required.

Fodder and Feed Resilience

Climate variability increases the need for feed planning. Drought-tolerant forage species,

diversified cropping and reserves of silage, hay or other conserved feed reduce dependence on a single season. A farm that produces only one major fodder crop may be highly exposed when rainfall fails or a flood damages that crop. Diversification spreads risk and can also provide forage of different nutritional qualities across the year. Feed inventories should be prepared before expected scarcity periods so managers know how long current stocks will last. The calculation should include likely animal numbers, expected intake, storage losses and a safety margin. Crop residues can support livestock when properly processed and supplemented, although low-quality residues alone may not meet the requirements of growing, pregnant or high-producing animals. Strategic supplementation with protein, minerals or energy may help maintain body condition when basal forage quality is poor. Storage conditions are equally important because mould, heating, water damage and pest infestation can destroy feed that was originally conserved well. Silage pits, hay stores and concentrate rooms should be protected from rain and floodwater and checked regularly. Purchasing plans should also consider the possibility that regional feed prices will increase during drought. Contracting or securing alternative suppliers in advance may reduce emergency costs.

Feed efficiency is also a climate measure because animals that convert nutrients efficiently require fewer resources for a given level of production. Better digestibility, balanced protein and mineral supply, good rumen function and effective parasite control allow more useful output from the same quantity of feed. Overfeeding nutrients does not automatically increase production and may raise feed cost and nutrient excretion. Rations should therefore be formulated according to species, body weight, physiological stage and production level. Regular analysis of forage dry matter and nutrient composition can improve ration consistency, especially when rainfall or harvest conditions alter crop quality. Sudden feed changes should be avoided because they may reduce intake and cause digestive disturbance. Avoiding spoiled feed and reducing storage, mixing and bunk losses are simple ways to improve resource use without purchasing new technology. Feed refusal

should be monitored so managers can distinguish normal selective feeding from excessive over-delivery or poor palatability. Maintaining animal health is equally important; disease, lameness and heat stress reduce feed efficiency because nutrients are diverted away from productive functions. In breeding herds, improved reproductive efficiency shortens non-productive periods and reduces the feed required per unit of lifetime output.

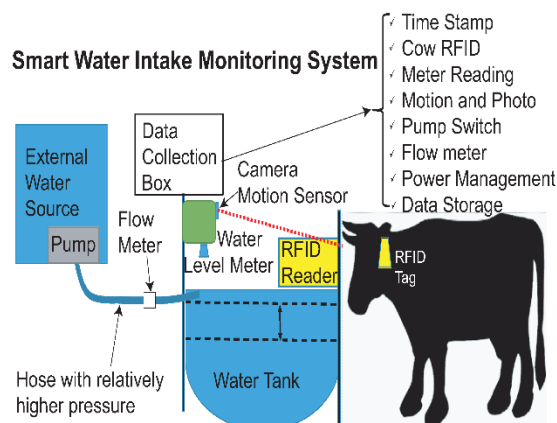
Table 1. Climate-smart livestock practices and expected benefits.

Practice	Expected benefit
Shade, fans and sprinklers	Lower heat load, improved feed intake, fertility and milk or growth performance.
Fodder conservation	Greater feed security during drought, flood or seasonal scarcity.
Drought-tolerant forage crops	More reliable biomass production under variable rainfall.
Improved feed efficiency	Lower feed cost and emissions intensity per unit of animal product.
Biogas / composting	Recovery of energy or nutrients and improved manure management.
Health surveillance	Earlier response to changing vector, parasite and infectious-disease risk.

Water-Smart Livestock Management

Water is required for drinking, cleaning, cooling and feed production, so livestock farms are highly sensitive to both shortage and poor water quality. Leaking troughs, poorly placed water points and excessive washing increase avoidable use and can create muddy areas that contribute to hoof and hygiene problems. Farms should monitor water availability before hot or dry seasons and maintain backup storage where supply is unreliable. Pumps, pipes, float valves and troughs should be inspected routinely so small faults do not become major failures during extreme heat. Water-demand planning should include changes in herd size and production level because high-producing and lactating animals have greater requirements. Location is also important: animals should not have to walk excessive distances or compete aggressively to reach drinking water. In grazing systems, water points can influence pasture use and soil damage, so their placement should distribute animals rather than concentrate them in one area. Water use for washing can often be reduced through dry scraping before hosing, high-pressure low-volume equipment and well-designed drainage. Reuse of suitable non-potable water for cleaning may be possible where hygiene and environmental rules are followed. A water emergency plan should

identify alternative sources, transport arrangements and priorities if supply is interrupted.



Water quality matters as much as quantity. High salinity, microbial contamination, excessive temperature or undesirable taste can reduce intake and performance even when troughs appear full. Water sources should be protected from manure, runoff, dead animals, chemicals and other contaminants, particularly after floods or heavy rainfall. Where quality is uncertain, periodic testing can help identify salinity, microbial or mineral problems that are not visible. Troughs require frequent cleaning because algae, feed particles and organic material can accumulate rapidly in warm weather. Water that becomes very hot in exposed pipes or tanks may be less attractive to animals and can limit intake during periods when demand is highest. Shade over storage tanks or troughs and appropriate pipe placement can help. Rainwater harvesting can support farm resilience where collection surfaces and storage systems are suitable. Stored rainwater should be protected from contamination and used according to its quality. Safe reuse of selected water streams may also be possible for non-drinking purposes, reducing pressure on high-quality water sources. In flood-prone areas, wells and surface-water sources should be assessed after inundation because contamination risk may increase sharply. The farm should have clear responsibilities for checking water points each day, especially during extreme weather.

Breeds, Genetics and Reproduction

Locally adapted breeds often tolerate heat, disease pressure, limited feed and harsh environments better than highly selected exotic

animals, although their maximum production may be lower. Climate-smart breeding seeks an appropriate balance between productivity and adaptation rather than pursuing output alone. Crossbreeding can combine desirable production traits with local resilience, but results depend on breed choice, management quality and the environment in which offspring will be raised. A genotype that performs well under intensive cooling and high-quality feeding may not be suitable where water, feed or veterinary support is limited. Breeding objectives should therefore include fertility, longevity, disease resistance, survival, heat tolerance and efficient use of local feed resources. Records are essential because selection cannot improve traits that are not measured. Farmers should record parentage where possible, calving interval, growth, milk or egg production, disease history, reproductive performance and reasons for culling. Animals that repeatedly maintain health and productivity during difficult seasons may be valuable breeding candidates even if they do not have the highest short-term output. Genetic improvement is a long-term strategy, so it should be combined with immediate adaptation through housing, nutrition and health management.

Heat stress can reduce estrus expression, semen quality, conception and embryo survival, making reproduction one of the most climate-sensitive parts of livestock production. Reproductive programmes should therefore include cooling, accurate heat detection, attention to body condition and early identification of postpartum or breeding disorders. Animals experiencing severe negative energy balance or dehydration are less likely to show strong reproductive behaviour, so nutritional management and water access directly influence fertility. Activity monitors can help detect weak estrus expression, but they should be interpreted alongside visual observation and health records. In breeding males, shade, cooling and adequate nutrition are also important because heat may impair semen quality for a period even after environmental conditions improve. Seasonal breeding can be useful in systems where feed availability and climate vary strongly across the year, allowing late pregnancy and early lactation to coincide with more favourable conditions. However, this

approach requires reliable planning of mating, replacement and feed reserves. Pregnancy diagnosis helps identify non-pregnant animals early so management can be adjusted before large amounts of feed and time are lost. Reproductive records should be reviewed for seasonal patterns; a rise in services per conception or longer calving intervals during hot months can indicate inadequate cooling or other stress.

Health, Biosecurity and Emerging Risk

Climate can change the season and distribution of vectors, parasites and pathogens. Warmer temperatures may extend the activity period of ticks, flies and mosquitoes, while altered rainfall and humidity can change breeding habitats and the survival of infectious agents. Surveillance should therefore be linked to local weather patterns and farm history rather than relying only on fixed calendar dates. Farmers and veterinarians should watch for changes in the timing, severity or geographic occurrence of familiar diseases as well as unusual clinical signs. Vaccination and parasite-control schedules may need review as local risks shift, but treatment should remain evidence-based and targeted to avoid unnecessary cost and antimicrobial or antiparasitic use. Biosecurity becomes particularly important when drought, flood or market conditions cause animals to move between farms or gather at shared water and feeding points. Purchased or returning animals should be assessed before mixing with resident stock. Equipment, vehicles and visitors can also introduce pathogens, so cleaning and access procedures should reflect the level of risk. Good housing ventilation, dry bedding, appropriate stocking density and prompt isolation of sick animals reduce transmission pressure even when climate conditions favour disease.

Emergency plans are important for floods, storms, heat waves, wildfire, prolonged drought and power failure. Farms should identify safe shelter, backup power, water, feed and animal evacuation options before an emergency occurs. Contact information for veterinarians, transporters, electricity services, local authorities and feed suppliers should be kept where workers can access it quickly. In flood-prone areas, feed stores, medicines, electrical equipment and important records should be

located above expected water levels when possible. Drainage routes and animal movement paths should be checked so stock are not trapped by rising water. During heat waves, backup generators may be essential for fans, pumps and automated milking or feeding systems. Drought plans should define when herd numbers may need adjustment if feed and water reserves fall below safe levels. Rapid reporting of unusual disease reduces the risk that climate-related movement or crowding will amplify outbreaks. Staff training is necessary because emergency protocols are only useful if workers understand their roles. Practice drills or seasonal reviews can reveal missing equipment or unrealistic assumptions. Animal identification and accurate inventories make evacuation and post-event assessment easier. After an extreme event, farms should inspect water quality, feed contamination, building safety, injuries and disease risk before returning to normal routines.

Table 2. Practical response to increasing heat stress.

Observation	Immediate management priority
Panting / increased respiration	Provide shade, ventilation and unrestricted cool drinking water.
Reduced feed intake	Offer fresh feed more often and shift feeding toward cooler periods.
Crowding near water or shade	Increase access points and reduce competition.
Lower milk or growth	Review cooling effectiveness, ration density and health status.
Poor conception	Strengthen cooling, heat detection and reproductive examination.
High night temperature	Use overnight ventilation because animals may fail to dissipate accumulated heat.

Manure, Methane and Resource Recovery

Enteric methane and manure emissions are important components of livestock greenhouse-gas output, but mitigation should be pursued in ways that preserve animal health and farm viability. Improving feed quality, digestibility and reproductive efficiency can reduce emissions per unit of product by decreasing non-productive days and the number of animals required for the same output. Animals that grow slowly because of disease or poor nutrition remain on the farm longer before producing saleable output, increasing lifetime resource use. Better health, lower mortality and efficient replacement management therefore contribute to emissions-intensity reduction. Ration formulation can also avoid unnecessary protein

or mineral oversupply that increases nitrogen or phosphorus excretion. Any feed additive promoted for methane reduction should be evaluated for safety, evidence, cost, availability and compatibility with the local ration rather than adopted solely on claims of environmental benefit. Grazing management can influence feed quality, soil cover and manure distribution, but appropriate systems depend on rainfall, land type and stocking pressure. Climate-smart mitigation does not mean reducing production by underfeeding animals; rather, it seeks to reduce waste and improve the amount of useful product obtained from feed, land and water. Measurement is important because changes in total animal numbers, milk yield, growth rate or fertility can affect apparent emissions performance.

Manure should be collected, stored and applied in ways that reduce nutrient loss, odour, water pollution and unnecessary greenhouse-gas release. The best system depends on herd size, housing type, climate, land availability and opportunities to use recovered energy or nutrients. Anaerobic digestion can produce biogas that may be used for cooking, heating, electricity or other farm purposes, while the remaining digestate can retain valuable nutrients for crop production when managed correctly. Composting can convert solid manure and bedding into a more stable material that is easier to transport and apply. Both systems require appropriate moisture, handling and maintenance; poorly managed manure can still create pollution or pathogen risks. Storage facilities should be designed to prevent overflow during heavy rainfall and to limit contaminated runoff into water bodies. Separating clean rainwater from manure-contaminated water can reduce the volume requiring treatment. Nutrient-management planning helps match manure application with crop demand, reducing the risk of over-application and fertiliser wastage. Timing matters because spreading before heavy rain can increase nutrient loss. In areas facing water scarcity, systems should minimise unnecessary dilution of manure. Biogas projects should be sized according to reliable manure supply and realistic energy demand so that digesters remain functional.

Measuring Climate-Smart Performance

A climate-smart intervention should be evaluated with production, resilience, welfare and resource-use indicators. Milk yield, growth, mortality and fertility are important, but so are water use, feed inventory, heat-stress events, manure handling, disease incidence and emergency losses. The purpose of monitoring is to determine whether a practice actually improves farm performance under local conditions. A cooling system, for example, can be assessed by observing respiration, feed intake, milk yield, conception and electricity or water use during hot periods. A fodder-reserve strategy can be evaluated by whether adequate feed remains available through the dry season without excessive spoilage. Indicators should be simple enough to collect consistently; complicated systems that workers cannot maintain are unlikely to support good decisions. Baseline records before an intervention provide a useful comparison. Farms can also compare performance between seasons while recognising that weather severity varies from year to year. Economic measures are essential because adaptation must remain affordable. The cost of fans, feed storage or water infrastructure should be compared with avoided production losses, disease, mortality or emergency feed purchases. Welfare outcomes should also be considered because an intervention that improves output but increases discomfort is not genuinely sustainable. Climate-smart performance therefore requires a balanced scorecard rather than one number.

Farm records help distinguish normal seasonal variation from a worsening trend. Simple temperature-humidity monitoring can guide cooling responses, while feed-budget calculations can identify shortages months before they become critical. Weather forecasts can be combined with farm thresholds to trigger early action, such as checking water storage before a heat wave or moving feed and equipment before heavy rainfall. Digital sensors, automatic weather stations and herd-management software can add detail, but basic paper or spreadsheet records may be sufficient for many farms. What matters is regular review. Records of daily milk yield, growth, mortality, reproductive performance, disease cases, water interruptions, fodder stocks and extreme-

weather events can reveal relationships that are difficult to remember accurately. Farm managers should note the actions taken during an event and the outcome so future plans can improve. For example, if animals continued to pant despite fans, airflow, stocking density or sprinkler operation may need revision. If feed reserves ran out early, inventory assumptions or storage losses should be reassessed. Periodic review with veterinarians, nutritionists or extension personnel can help interpret trends and identify realistic improvements. Climate monitoring should not create unnecessary paperwork; a small set of reliable indicators is better than large amounts of incomplete data.

Conclusion

Climate-smart livestock farming combines practical adaptation with improved resource efficiency. Cooling, fodder reserves, water planning, adapted genetics, preventive health and better manure management reduce vulnerability to climate stress and can improve productivity at the same time. The strongest programmes begin with essential husbandry: animals must have enough clean water, suitable feed, shade, ventilation, dry resting areas and timely health care. These foundations make advanced technologies more effective and reduce the risk that a failure of power, connectivity or equipment will immediately threaten animal welfare. Adaptation should focus on the major hazards affecting a particular farm rather than copying practices from very different production systems. Heat may be the dominant challenge in one area, drought and fodder shortage in another, and flooding or vector-borne disease elsewhere. Farmers can build resilience gradually by identifying critical weak points and addressing them in order of importance. Improving drainage, adding water storage, conserving more forage or revising emergency contacts may be more valuable than a costly technology if those actions solve the farm's main risk. Climate-smart management also benefits from cooperation among farmers, veterinarians, nutritionists, extension workers and local authorities because weather, disease and resource problems often extend beyond one farm.

No single technology fits every farm. The most durable strategies match local climate, species, production goals and available

resources, provide measurable benefits to welfare and farm income, and can be adjusted as conditions change. Farmers should avoid treating climate-smart agriculture as a fixed package. It is better understood as a continuous process of assessing risk, preparing resources, monitoring animals and modifying management when new evidence appears. Investment decisions should consider maintenance, labour, technical support and backup arrangements as well as purchase cost. Simple measures that workers understand and use consistently may provide greater long-term value than complex systems that are poorly maintained. Climate resilience also depends on healthy animals, because disease, lameness, infertility and poor nutrition reduce the ability to cope with heat, feed shortage or other stress. For this reason, routine preventive care remains central to climate adaptation. Mitigation goals should likewise support efficient production rather than encourage practices that reduce welfare or shift environmental problems elsewhere. By improving feed use, reproductive performance, manure handling and survival, farms can reduce waste while producing useful food and income. Regular records allow managers to test whether interventions are delivering real benefits.

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