

The Synergistic Effect of Integrated Management on Broiler Production Performance, Physiological Status, and Economic Viability under Extreme Heat Stress Conditions in Iraq

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Abstract:

The Iraqi poultry industry has a critical problem of extreme summer heat with temperatures exceeding 45°C, which results in severe heat stress on broilers, and subsequently, production losses greater than 30%. Standard management strategies that are segregated and disjointed are insufficient to address this type of complex problem.

The current research measured the impact of a synergistic integrated management system (IMS) incorporating the latest in environmental control and management systems, optimized potable water management, and precision feeding on the overall performance of broilers during the extreme heat of the summer in Iraq. Methods: A 35-day summer trial was conducted with 480 Ross 308 chicks assessed in a completely randomized design with four treatments: T1 (conventional), T2 (environmental control), T3 (T2 + water management), and T4 (comprehensive IMS). Assessed parameters included production metrics, environmental stress indicators (cortisol – note: assay shows high cross-reactivity with chicken corticosterone, thyroid hormones), immune function (antibody titers, organ indices), and a full economic assessment.

Across all metrics ($P < 0.01$), T4 demonstrated the greatest results. Final body weight T4: (2.48 kg, 13.8% increase) vs. T1: (2.18 kg). Feed conversion ratio T4: (1.61, 12.5% improvement) vs. T1: (1.84). Mortality: T4: 2.3% (70.5% reduction) vs. T1: 7.8%. Physiological metrics showed reduced stress (cortisol: 5.2 vs. 12.8 ng/mL) and enhanced metabolic activity (T3: 2.02 vs. 1.45 ng/mL) in T4. Enhanced immune competence was demonstrated by higher NDV titers (7.1 vs. 5.2 log₂) and bursa weight (0.27% vs. 0.18% BW). Although T4 had increased initial costs compared to T1, it had the greatest economic benefit-cost ratio (1.88) and return on investment (29.8%).

For Iraqi broiler production, the application of an integrated model of environmental, water, and nutrition management reduces heat stress and improves productivity, welfare, and profitability, which is valid from scientific and economic standpoints. This provides valuable lessons for the poultry industry in other arid and hot regions.

Keywords: Broiler, Heat stress, Integrative management, Thermal comfort, Stress physiology, Economic sustainability, Iraqi agriculture.



Introduction:

The poultry industry is crucial for Iraq's food security and rural employment, providing 40% of the country's animal protein and employing over 500,000 people directly and indirectly (FAO 2023). Broiler management faces some of the hottest summer temperatures, with maximum temperatures in the south reaching 52°C, causing further stress in the already vulnerable industry. Food consumption by broilers reduces by 15 - 30%, weight gain reduces by 20 - 35%, and death rates of the already stressed broilers increase by 15%, resulting in a total economic loss of 200 million USD within the affected countries (Al-Muthanna, K. A. *et al.* 2023), (Al-Zubaidy, R. I. *et al.* 2022).

Extreme temperatures further cause stress and a breakdown of the endocrine system of broilers, resulting in permanent high levels of stress and low levels of growth hormones. The combination of stress and poor immune system functions creates a metabolic breakdown of broilers and the industry. (Lara, L. J. *et al.* 2013), (Saeed, M., *et al.* 2019). The current methods of treatment in Iraq of poor ventilation and stressful conditions, only focus on one aspect of the problem and result in partial treatment methods (Al-Jumaili, A. S. *et al.* 2023). These methods include poor dietary supplements and inefficient methods such as evaporative cooling (Al-Samarrai, G. F. *et al.* 2022), (Al-Mosawi, H. J. *et al.* 2023).

The use of Integrated Management Systems (IMS) focuses on a single approach to climate control, production management, and improved nutrition within the system. The One Health approach allows this type of system to be used and provides benefits to all affected. The Iraqi summer is one of the extreme climates that demand inventive approaches. Improved systems with good economic analysis to demonstrate benefits are lacking in this area (OHC. 2023), (Berckmans, D. 2017).

This study's objective was to bring innovative solutions and approaches to three fields: respectively, (1) progressive IMS systems using environmental engineering with tunnel ventilation with evaporative cooling, (2) water management engineering using sanitization and temperature control, and (3) precision nutrition (the enzyme-probiotic-vitamin matrix). Given the partial measures and control groups, we expected this novel, integrated method to be the most effective at reducing heat stress and improving production performance and economic returns while enhancing the physiological and immune response status of the subjects.

Under authentic field conditions, we aimed to analyze production performance, stress responses, immunological responses, and economic parameters as a comprehensive measure.

Materials and Methods:

Ethical Statement

The study protocol was approved by the University of Diyala Animal Care and Use Committee (Reference No. Vet Medicine 2427, June 2024, A, A and T).

Description of the research site and climate

Data collection took place at the Abu Ghreib Poultry Research Station in Baghdad, Iraq, from June 15 to July 20, 2024. The research site's latitude and longitude are 33.17°N, 44.14°E, with an elevation of 34 m. The Abu Ghreib site has a hot desert climate. During the trials, the ambient conditions were measured with a Certified Weather Station (Davis Instruments Vantage Pro2, Catalog No. 6152, Hayward, CA, USA). The recorded maximum mean daytime temperatures were $46.8 \pm 2.3^{\circ}\text{C}$, with a range of 42.3 to 49.1°C. The mean minimum night time temperature was $30.2 \pm 1.8^{\circ}\text{C}$. The relative humidity was in the range of 18 to 42%. For the 35-day production period, the temperature humidity index (THI) at the research site was over the critical limit of 75 for 8 to 10 hours on a daily basis.

Management and design of the experiment

A total of 480 male and female one-day-old Ross 308 broiler chicks were obtained from a single commercial hatchery (Al-Watania Poultry, Baghdad) with assured health status and uniform parent stock. The chicks were individually wing-banded and had a mean initial body weight of $42.5 \pm 1.2\text{g}$. The chicks were randomly assigned to one of 4 different treatment groups in a completely randomized design (CRD), with each treatment group containing 4 replicates (pens) of 30 chicks per pen (stocking density of 12 chicks/m²).

The treatments were as follows:

T1 (Control): Conventional management according to Iraqi standards. This consisted of open-sided housing with manual drinkers and well water at 28-32°C. A three-phase diet was provided according to standard practice.

T2 (Environmental Control - EC): T1 + climate-controlled housing with tunnel ventilation (1.5-2.0 m/s) and evaporative cooling pads (CELdek® 7090-15, Munters, Amesbury, MA, USA). This was managed by an automated controller (Chore-Time Commander Pro, CTB Inc., Milford, IN, USA).

T3 (EC + Water Management - WM): T2 + comprehensive water management system including filtration, chlorination (0.5 ppm ClO₂ using Prominent Dulcotech D1Cb, Heidelberg, Germany), and cooling to 18-22°C using in-line chillers and insulated lines.

T4 (Integrated Management System - IMS): T3 + Precision Nutrition: the basal diet supplemented with a proprietary feed additive matrix containing *Bacillus subtilis* 1×10^9 CFU/kg, phytase 500 FTU/kg, xylanase 2000 U/kg, vitamin C 200 mg/kg, and vitamin E 100 IU/kg. All birds received the same biosecurity protocols and vaccination programs (Marek's on day 1, Newcastle + Infectious bronchitis on days 7 and 21, and Gumboro on day 14). Apart from these protocols, the birds were managed according to Ross 308 specifications. Water and feed were provided ad libitum. The lighting program was according to Ross 308 specifications: 23L:1D (0-7 days), reduced to 18L:6D (22-35 days).

Dietary Composition

The diets were designed to meet or exceed the nutrient specifications outlined for Ross 308 (See Table S1, Supplementary Materials). For T1-T3, the base diet was a three-phase maize-soybean meal system. The phases were: starter (days 1-10, 3000 kcal ME/kg, 22% CP), grower (days 11-24, 3100 kcal ME/kg, 20% CP), finisher (days 25-35, 3150 kcal ME/kg, 18.5% CP). For T4, the additive matrix was added to the same base diet. Feed samples were collected weekly and analyzed for proximate composition using AOAC methods (AOAC International, 2019).

Data collection and analysis procedures

Production Performance

Bird weights were recorded weekly to the nearest gram. Feed intake was recorded per pen. We recorded mortality daily and determined the cause of death using necropsy. The following performance metrics were calculated:

- Feed conversion ratio (FCR) = feed (kg)/weight gain (kg)
- European Production Efficiency Factor (EPEF) = [(liveability %) × (live weight kg)] / (age (days) × FCR) × 100

Environmental Monitoring

Microclimate data were collected using data loggers (HOBO MX2301A, Onset Computer Corp., Bourne, MA, USA) set at bird height in each pen. Data were collected in 10-min intervals for dry bulb temperature (°C) and relative humidity (%), and calculated THI. Air quality data were collected two times a week using a portable gas analyzer (PGM-7320, RAE Systems, San Jose, CA, USA) for ammonia (NH₃) and a laser particle counter (DustTrak DRX 8533, TSI Inc., Shoreview, MN, USA) for PM_{2.5} and PM₁₀. Litter samples were collected weekly to determine moisture content of the litter and were dried for 24 hours at 105°C in an oven.

Physiological and Immunological Assays

On day 35, blood samples were collected from 10 randomly selected birds per treatment (2-3 per replicate) by brachial vein puncture. Samples were centrifuged to separate serum which was stored at -80°C until analyzed.

Stress and Metabolic Hormones:

Cortisol (Note: While corticosterone is the primary avian glucocorticoid, the ELISA kit used [Abcam ab154996] has high [79%] cross-reactivity with chicken corticosterone, as validated by the

manufacturer and previous poultry studies (Quinteiro-Filho *et al.*, 201). Results are therefore reported as cortisol equivalents.) : Measured using a competitive ELISA kit (Catalog No. ab154996, Abcam, Cambridge, UK). Intra- and inter-assay CVs: 4.2% and 7.1%.

Triiodothyronine (T3) and Thyroxine (T4): Measured using chemiluminescent immunoassays (Catalog No. 33560 & 33550, Beckman Coulter, Brea, CA, USA) and analyzed on an Access 2 Immunoassay System

Immunologic parameters:

Antibody Titers: We measured serum antibodies against Newcastle Disease Virus (NDV) and Infectious Bursal Disease Virus (IBDV) using ELISA kits (IDEXX Laboratories, Westbrook, ME, USA; Catalog No. 99-09263 & 99-09269). Results are presented as log₂ titers.

Immune Organ Indices: The spleen and bursa of Fabricius were excised and weighed.

Health and Welfare Assessment

On days 21 and 35, footpad dermatitis (FPD) was assessed using the Welfare Quality® protocol (0 = no lesions, 4 = severe lesions) by two blinded evaluators ($\kappa = 0.87$). Standard protocol was followed for post-mortems to determine the cause of death.

Economic Analysis

The following variables were considered:

Variable costs: Chicks, feed, utilities (water, electricity for cooling), supplements, veterinary costs.

Fixed costs: Housing, equipment (cooling systems, water chillers), and labor.

Revenue: Based on dress weight at 0.70 USD/kg.

Financial metrics were computed as follows:

Gross margin = Revenue – Variable costs

Benefit-cost ratio (BCR) = Total benefits / Total costs

Return on investment (ROI) = (Net profit / Total investment) × 100

Payback period = Initial investment / Annual net cash flow

A sensitivity analysis was performed with market and feed cost variations of 0% and -20%.

Statistical Analysis

Data were analyzed using SAS 9.4 (SAS Institute Inc., Cary, NC, USA). The experimental unit for production and environmental parameters was the pen (n=4 per treatment), while for physiological and immunological parameters, the individual bird was the unit (n=10 per treatment). Normality (Shapiro-Wilk test) and homoscedasticity (Levene's test) were verified. Significant differences (P<0.05) were determined using Tukey's HSD test. Economic data were analyzed descriptively. Correlation analysis among environmental, physiological, and performance variables was performed. Results are presented as least squares means ± standard error of the mean (SEM).

Sample Size Justification: Based on preliminary data ($d = 1.2$ for weight gain, $\alpha = 0.05$, power = 0.90), the minimum sample size required was 24 birds per treatment. Our design (120 birds/treatment) provided sufficient power (>0.95) to detect significant differences.

Results:

Production Performance

The progressive implementation of a series of management strategies resulted in significant improvement in all metrics of production (Table 1). T4 (IMS) attained the highest final body weight of 2.48 kg, a 13.8% increase over T1 that had 2.18 kg ($P < 0.001$). There was a clear treatment gradient for feed conversion ratios with improvement from 1.84 in T1 to 1.61 in T4 ($P < 0.001$). Mortality was dramatically different with T4 having 2.3% and T1 having 7.8% ($P < 0.001$). T1 had the primary cause of death as heat stroke. The synergistic benefits were reflected in the composite EPEF index, which improved from 315 in T1 to 452 in T4 ($P < 0.001$).

Table 1: Production Performance of Broilers Under Different Management Systems During 35-Day Summer Trial

Parameter	T1 (Control)	T2 (EC)	T3 (EC+WM)	T4 (IMS)	SEM	P-value
Final Body Weight (kg)	2.18 ^d	2.31 ^c	2.40 ^b	2.48 ^a	0.02	<0.001
Average Daily Gain (g/d)	62.3 ^d	66.0 ^c	68.6 ^b	70.9 ^a	0.6	<0.001
Total Feed Intake (kg/bird)	4.01	3.97	4.01	3.99	0.02	0.374
Feed Conversion Ratio	1.84 ^a	1.72 ^b	1.67 ^c	1.61 ^d	0.01	<0.001
Mortality (%)	7.8 ^a	5.1 ^b	3.4 ^c	2.3 ^d	0.3	<0.001
EPEF	315 ^d	372 ^c	408 ^b	452 ^a	8.1	<0.001

¹Means within a row with different superscripts differ significantly ($P < 0.05$, Tukey's HSD).

²Acronyms: EC: Environmental Control, WM: Water Management, IMS: Integrated Management System

³Acronyms: EPEF: European Production Efficiency Factor, EPEF: European Production Efficiency Factor.

Parameters of the Environment

The integrated systems positively affected the micro-environment (Table 2). T4 had the lowest average temperature (26.8°C vs. 31.8°C in T1, $P < 0.001$) and the most consistent thermal conditions (cv: 8.2% vs 15.7%). There was a 70% drop in ammonia concentration and an almost 60% decrease in particulate matter (PM_{2.5}) in T4 compared to T1 (7.8 vs. 26.3 ppm, $P < 0.001$). T4 was optimal for foot health as litter moisture was better than T1 (23.8% vs 39.2% in T1, $P < 0.001$)

Table 2: Micro-Environmental Parameters during the Experimental Period

Parameter	T1 (Control)	T2 (EC)	T3 (EC+WM)	T4 (IMS)	SEM	P-value
Temperature (°C)	31.8 ^a	27.5 ^b	27.1 ^b	26.8 ^b	0.3	<0.001
Relative Humidity (%)	67 ^a	60 ^b	58 ^b	56 ^b	0.9	<0.001
THI	82.3 ^a	76.1 ^b	75.4 ^b	74.8 ^b	0.5	<0.001
Ammonia (ppm)	26.3 ^a	14.8 ^b	9.6 ^c	7.8 ^c	1.1	<0.001
CO ₂ (ppm)	2150 ^a	1650 ^b	1420 ^c	1280 ^c	72	<0.001
PM _{2.5} (µg/m ³)	38.2 ^a	24.1 ^b	19.3 ^c	16.1 ^c	1.8	<0.001
Litter Moisture (%)	39.2 ^a	29.5 ^b	25.8 ^c	23.8 ^c	0.9	<0.001

Physiological and Immunological Status

Physiological markers showed mechanistic differences in performance (Table 3). Total circulating cortisol which signals stress, decreased steadily over the treatments, with T4 showing the lowest value which is 59% lower than T1 (5.2 vs 12.8 ng/mL, P<0.001). In contrast, T3 and T4, the thyroid hormones in T4 case shows positive metabolically active response. T4 birds had better NDV vaccine response with titers 36% higher than T1 (P<0.001). Immune organ development was also better as bursa weight was higher in T4 than T1 by 50%.

Table 3: Physiological and Immunological Parameters at Day 35

Parameter	T1 (Control)	T2 (EC)	T3 (EC+WM)	T4 (IMS)	SEM	P-value
Cortisol (ng/mL)	12.8 ^a	9.1 ^b	6.8 ^c	5.2 ^d	0.5	<0.001
T3 (ng/mL)	1.45 ^d	1.68 ^c	1.86 ^b	2.02 ^a	0.04	<0.001
T4 (µg/dL)	8.2 ^d	9.5 ^c	10.8 ^b	12.1 ^a	0.2	<0.001
NDV Titer (log ₂)	5.2 ^d	5.8 ^c	6.4 ^b	7.1 ^a	0.1	<0.001
IBDV Titer (log ₂)	3.8 ^d	4.3 ^c	4.9 ^b	5.5 ^a	0.1	<0.001
Spleen (% BW)	0.12 ^d	0.14 ^c	0.16 ^b	0.18 ^a	0.003	<0.001
Bursa (% BW)	0.18 ^d	0.21 ^c	0.24 ^b	0.27 ^a	0.004	<0.001

Health and Welfare Indicators

Welfare metrics correlated with physiological results (Table 4). The occurrence of serious footpad dermatitis (score ≥ 3) declined from 31% in T1 to 3% in T4 (P<0.001). Analysis of the dead demonstrated that heat-related mortality (heat stroke, ascites) was 82% of deaths in T1 and only 28% in T4.

Table 4: Health and Welfare Indicators

Indicator	T1 (Control)	T2 (EC)	T3 (EC+WM)	T4 (IMS)	P-value
FPD Score (0-4)	2.8 ± 0.3 ^a	1.9 ± 0.2 ^b	1.2 ± 0.2 ^c	0.9 ± 0.1 ^c	<0.001
% Birds with Severe FPD (≥3)	31.2 ^a	15.4 ^b	6.3 ^c	2.8 ^c	<0.001
Heat-Related Mortality (% of total)	82.1 ^a	58.3 ^b	34.6 ^c	28.1 ^c	<0.001

Economic Analysis

Although T4 required a higher initial investment than T1 (Table 5), T4 delivered better financial results. Even though production cost per kg in T4 was 13.6% higher than in T1, revenue per bird was 32% higher, resulting in a gross margin that was 56.6% higher. Furthermore, T4's benefit-cost ratio of 1.88 was better than T1's 1.51. Most importantly, T4 achieved a 29.8% ROI with a payback period of 1.8 production cycles (approximately 10 months). Sensitivity analysis showed that IMS remained the most profitable system under all variable cost and revenue scenarios

Table 5: Economic Analysis of Different Management Systems (USD/bird basis)

Economic Parameter	T1 (Control)	T2 (EC)	T3 (EC+WM)	T4 (IMS)
Variable Cost	2.78	2.92	3.01	3.18
Fixed Cost	0.90	1.24	1.36	1.54
Total Cost	3.68	4.16	4.37	4.72
Revenue	5.20	5.88	6.28	6.86
Gross Margin	2.42	2.96	3.27	3.68
Benefit-Cost Ratio	1.41	1.41	1.44	1.45
ROI (%)	17.5	22.3	26.1	29.8
Payback Period (cycles)	-	2.4	2.1	1.8

Correlation Analysis

Environmental, physiological, and performance parameters showed notable correlations (Figure S1, Supplementary Materials). Ammonia level had a strong positive correlation with cortisol ($r = 0.84$, $P < 0.001$) and a negative correlation with weight gain ($r = -0.79$, $P < 0.001$). Bursa weight was positively correlated with NDV titers ($r = 0.76$, $P < 0.001$) and was negatively correlated with mortality ($r = -0.82$, $P < 0.001$).

Discussion

Findings from this study indicate that integrated and holistic management strategies mark a new stage for integrated management strategies for severe heat stress in broilers. There is clear synergy in combining the elements of environmental management with water and nutrition management. This is evidenced by the positive changes from T1 to T4 in all the areas of production, physiology, immunology, welfare, and economics.

Production Performance: More than Stepping Stones

From a production potential point of view, the 13.8% increase in final weight and the 12.5% improvement in FCR in T4 should not be viewed as stepping stones, but rather as heat stress breakthroughs. These results stand in stark contrast to the majority of single focused intervention studies performed in the same or comparable climatic conditions. The 70.5% reduction in mortality is even more impressive, and Integrated Management is specifically aimed at dealing with the thermal homeostasis of heat stress and the physiological stress of heat. The overall improvement in the efficiency of the system is shown by the increase in EPEF of 43% in T4.

The stress response and its underlying physiology

Looking at the physiology involved sheds light on the mechanisms. The decrease in cortisol from T1 to T4 means there was a stress moderator effect from IMS, increasing the perception of high temperature stress being low [15]. Interestingly, T4 was the only treatment where T3 and T4 were both elevated while cortisol was reduced, indicating that metabolic functions were maintained, thus explaining the increased growth rates under unfavorable environmental conditions [16]. If our hypotheses are correct, the energy that would have been dedicated to managing the stress response and thermoregulation would be available to improve feed conversion efficiency. The findings on the immune system are particularly important. The development of immune organs and enhanced vaccine responses in T4 suggest that the heat stress impact on the immune system was mostly eliminated. Elevated levels of cortisol are known to affect the proliferation of lymphocytes and the production of antibodies. Due to the IMS's reduction of cortisol, immune function was maintained, which explains the decreased mortality and the improved vaccine responses along with the strong positive correlation between bursa weight and NDV titers ($r = 0.76$).

Environmental Optimization: Building Resilience Against Micro-Climate Stressors

Environmental monitoring data shows that the IMS creates a protective micro-climate. A decrease in temperature (31.8°C to 26.8°C) allowed birds to remain in a thermoneutral zone more often. Of particular note was the decrease in temperature variability (CV 15.7% to 8.2%). This likely allows

for the stability of physiological processes and a decrease in the variability of stress responses. The improvement in the air quality indicators is important, as the combination of stressors synergistically roasts and causes respiratory distress. In T4, litter moisture (23.8%) improved foot health, decreased ammonia, and improved air quality.

Economic Viability: From Technical Success to Commercial Adoption

This section considers the economic viability of IMS. While there are high upfront costs, IMS has a payback period of less than 2 cycles with a 29.8% ROI, and therefore, a reasonable investment. The results of a sensitivity analysis show that even with extreme cost fluctuations, IMS is a good investment. This good result is in line with the literature on the economics of climate adaptation in livestock systems, where, in general, there is a strong business case for climate resilience.

Relevant aspects of Sustainable Production

We also highlight the sustainability of the system in addition to the productivity gains. As FCR in T4 improved, less resources were used per every unit of output created, which leads to a decrease in the environmental footprint (per kilogram) of meat production. In addition, decreased mortality reflects improved welfare for the animals and better resource sustainability. The model illustrates that the convergence of productivity and sustainability is plausible with the use of precision management. This is a vital contribution to the food systems of the future.

Restrictions and Future Research

This study is detailed, yet has its boundaries. The 35-day timeframe only represented one full production cycle. The impact of this study on barn microflora, equipment wear, and overall economic return remains to be assessed. This study was conducted with birds of the Ross 308 line, and there is a need to evaluate line-specific responses to IMS. Other studies may focus on the sustained improvements that may be achieved via the use of renewable energy (solar to provide cooling), digital management (IoT sensors), and circular economy practices (water, litter, and nutrient management).

Summation

Sustainable alleviation of extreme heat stress in broiler production can be achieved by Integrated Management Systems, such as those detailed in this study, which incorporate advanced control of the environment, and temperature stress, as well as management of water, feed, and nutrition at the broiler production level. The system also provides considerable benchmark improvements in growth (13.8% greater), feed efficiency (FCR improved by 12.5%), and welfare (mortality decreased by

70.5%), and a 29.8% positive economic impact. These improvements are supported by physiological and immunological data and system-wide mitigation of heat stress.

Iraqi poultry producers and those in similarly positioned climates now have these findings as a scientifically substantiated foundation for climate resilient poultry production. Adopting these systems means a diversification of poultry business for these producers; it will also mean a commitment to more sustainable and more profitable poultry production. As the climate crisis continues, the systems will be of growing importance to livestock production.

Conclusions:

This research conclusively proves that extreme heat stress can be alleviated through the integrated management system of advanced environmental control, optimized water management, and precision nutrition at all levels of broiler production. The system provides significant benchmarking improvements in reasonable growth performance (final weight 13.8% higher), feed (FCR 12.5% better), animal welfare (mortality 70.5% lower), and economic returns (29.8% ROI). The system level mitigation of heat stress is what has been supported by the physiological and immunological evidence.

These findings serve as a scientifically validated roadmap for climate resilience for Iraqi poultry producers (and those in other regions of similar climate). Implementation of these systems is more than just a technical improvement; it is a strategic commitment to sustainable and profitable production. As global temperatures continue to rise and extreme weather events become more common, this type of system will be increasingly important for livestock production

Recommendations:

1. Invest particularly in evaporative cooling and tunnel ventilation systems.
2. Manage water quality in terms of its temperature (keeping it in the range of 18-22° C) and its level of sanitation.
3. Implement precision nutrition systems that include gut health alleviators and antioxidants.
4. Consider footpad dermatitis and the determined cause of death as Welfare Performance Indicators.
5. Conduct economic analyses of your farm to assess the value of the integrated systems.

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