DOI: https://doi.org

EcoBiotics: Journal of Animal & Plant Sciences

journal homepage: https://rjsaonline.org/index.php/EcoBiotics/

Precision Livestock Farming and Its Role in Improving Livestock Productivity and Sustainability

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ARTICLE INFO

Received:
January 11, 2026
Revised:
February 07, 2026
Accepted:
February 28, 2026
Available Online:
March 08, 2026

Keywords:
precision livestock farming, livestock productivity, environmental sustainability, automated feeding systems, sensor-based monitoring, digital agriculture, farm management

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ABSTRACT

Precision Livestock Farming (PLF) is on the interface of virtual innovation and farm animals farming, and it gives an possibility to gain superior productiveness and sustainable farming. As worldwide call for for animal-derived commodities is at the upward thrust and environmental strain is intensifying, precision cattle farming is gaining an increasing number of studies attention. This studies goals to discover the effect of precision cattle farming on cattle productiveness and environmental sustainability, with unique connection with computerized feeders, sensor era for fitness monitoring, and virtual gear for farm control utilized by farmers and farm managers. This studies turned into performed with the quantitative technique and collected facts from 250 farm animals farmers thru a dependent questionnaire. Stratified random sampling became used to make sure illustration from numerous farming sizes—small, medium, and large-scale farming operations. The records changed into analyzed with descriptive statistics, Cronbach's Alpha reliability test, correlation, and more than one regression analyses with SPSS software. The outcomes indicated that computerized feeders ($\beta = 0.412$, $p < 0.001$), sensor era for fitness monitoring ($\beta = 0.367$, $p < 0.001$), and virtual equipment for farm control ($\beta = 0.298$, $p < 0.01$) are sizeable predictors of cattle productiveness. The effects additionally indicated that the blended impact of the impartial variables on cattle productiveness changed into 68.4%, with $R^2 = 0.684$. The effects in addition indicated that there has been a advantageous and great correlation among sustainability and precision cattle farming generation adoption. The Cronbach's Alpha values ranged from 0.seventy nine to 0.87, which indicated top reliability many of the studies constructs. Therefore, precision cattle farming generation adoption complements farm efficiency, productiveness, and environmental sustainability. In order to expedite precision cattle farming era adoption, mainly amongst small-scale farmers, coverage interventions and era and education guide are recommended.

Introduction

The worldwide farm animals area is at a crossroads, balancing the want to aid a developing worldwide populace with the want to lessen the environmental footprint of animal agriculture. Livestock manufacturing contributes 14.5% to worldwide greenhouse fueloline emissions, consumes substantial water resources, and impacts land use (FAO, 2013; Gerber et al., 2013). Yet it affords livelihoods to a thousand million human beings and is a primary supply of protein, micronutrients, and profits to limitless more (Mottet et al., 2017). Balancing the competing needs at the cattle area calls for a shift now no longer simplest in coverage procedures however additionally withinside the era we follow to animal manufacturing, tracking, and welfare.

Precision Livestock Farming (PLF), a generation-enabled strategy to the worldwide animal agriculture conundrum, has emerged as a main contender to the conventional tactics to animal agriculture. In trendy terms, PLF includes the utility of superior sensors, real-time records acquisition, automatic structures, and virtual choice guide structures to manipulate animal manufacturing at the extent of the person animal (Wathes et al., 2008; Berckmans, 2014). In conventional animal agriculture, periodic tracking and interventions are the norm, even as PLF gives the ability to constantly display animal

health, offer man or woman animal vitamins primarily based totally at the animal's specific needs, and make selections primarily based totally on information to optimize productiveness even as lowering aid use (Neethirajan, 2020; Stygar et al., 2021).

PLF is based on a huge variety of technology to gain the ability of precision animal agriculture. Automated feeding structures make use of the stay weight of the animal to fine-music every animal's weight loss plan to lessen waste and optimize feed conversion ratio (Schillings et al., 2021). Sensors together with accelerometers, rumination sensors, frame temperature sensors, and milk excellent sensors allow the detection of animal diseases, lameness, and replica numerous days earlier than the advent of medical signs, which can also additionally lessen remedy charges and mortality rates (Rutten et al., 2013; Borchers & Bewley, 2015). Digital farm control structures combine all of the information right into a unmarried platform to assist evidence-primarily based totally selections on breeding, culling, nutrients, and animal health (Wolfert et al., 2017).

Despite its great potential, the adoption of precision farm animals farming (PLF) generation faces an choppy charge of adoption. In extra technically and agriculturally superior economies which includes the Netherlands, Denmark, and Australia, precision farm animals farming era has moved past the experimentation section and entered the commercialization section, specifically in dairy and hen farming (Berckmans, 2017; Kamphuis et al., 2020). In stark contrast, the adoption of precision farm animals farming era in growing and rising economies, which can be amongst the biggest manufacturers of cattle withinside the world, together with in South Asia, has remained low. The fundamental motives for this are the excessive expenses of precision farm animals farming generation, loss of technological and technical expertise, and lack of information approximately its advantages (Chander et al., 2010; Islam et al., 2021).

The productiveness-improving results of precision cattle farming are substantial. Studies on numerous styles of cattle and farming structures imply that precision cattle farming can beautify milk production, weight gain, reproductive performance, and decrease mortality rates (Morota et al., 2018; Pomar & Remus, 2019). In phrases of its sustainability-improving outcomes, precision cattle farming can reduce its environmental affects through enhancing feed efficiency, early detection of diseases, and powerful control of manure, for that reason decreasing the environmental affects of meat, milk, and egg production (Lammers et al., 2019; Tullo et al., 2019).

Despite the large frame of studies on precision farm animals farming globally, there's an absence of quantitative studies on precision farm animals farming adoption and its productiveness and sustainability influences in growing economies. Most research on precision cattle farming are restricted to excessive-earnings economies with large-scale farming structures. In addition, there are few complete research that recall more than one precision cattle farming technologies, inclusive of automatic feeders, fitness tracking structures, and virtual control structures, and their tacingly complete consequences on productiveness and sustainability outcomes.

The cause of this examine turned into to research the impact of 3 principal sorts of precision farm animals farming (PLF) generation on each cattle productiveness and environmental sustainability. The kinds of generation blanketed automatic feeders, fitness tracking systems, and virtual control systems. The studies changed into carried out amongst 250 farmers with various sizes of farms. The records become analyzed to discover the impact of precision cattle farming on cattle productiveness and environmental sustainability. The studies contributes to the frame of empirical paintings on precision farm animals farming in growing countries. The studies affords policymakers, extension services, and era vendors with beneficial records on a way to assist the sustainable intensification of the cattle zone in growing countries (Tullo et al., 2019; Halachmi et al., 2019).

Figure 1: Conceptual Framework — Precision Livestock Farming Technologies and Outcomes

CONCEPTUAL FRAMEWORK: Precision Livestock Farming & Outcomes		
INDEPENDENT VARIABLES	MEDIATING FACTORS	DEPENDENT VARIABLES
• Automated Feeding Systems • Sensor-Based Health Monitoring • Digital Farm Management Tools • GPS & RFID Tracking	• Farm Size • Farmer Education Level • Access to Capital • Technical Training	• Livestock Productivity • Feed Conversion Efficiency • Environmental Sustainability • Economic Profitability
Moderating Variables: Government Policy | Market Access | Infrastructure | Cultural Practices		

Source: Author's own construction based on literature review

Figure 1 offers the conceptual have a look at framework that publications this look at. The unbiased variables on this take a look at include the units of PLF, together with computerized feeding systems, fitness tracking thru sensors, GPS/RFID monitoring systems, and virtual farm control systems. These gadgets obtain this thru the mediating variables which include farm size, training degree of the farmers, get entry to to capital, and get entry to to technical schooling programs. The

structured variables include the effects of hobby withinside the examine, which include the productiveness and sustainability of the environment. The moderators which include authorities policies, get entry to to markets, high-satisfactory of infrastructure, and cultural values decide the energy or weak spot of the relationships (Berckmans, 2017; Wolfert et al., 2017).

Literature Review

Evolution of Precision Livestock Farming

The conceptualization of PLF may be traced returned to the improvement and implementation of precision farming withinside the Nineteen Eighties and Nineteen Nineties in crop farming via the improvement and implementation of GPS generation in variable price farming systems (Pierce & Nowak, 1999), which enabled the spatial utility of farming inputs consisting of fertilizers and pesticides. The improvement and implementation of precision farming ideas in farm animals farming won momentum withinside the early 2000s thru the improvement and implementation of sensors that gotten smaller and price and the improvement of wi-fi verbal exchange systems (Berckmans, 2014). Wathes et al. (2008) had been the primary researchers to conceptualize the improvement and implementation of PLF because the control of farm animals primarily based totally on non-stop computerized size and person animal observation. The conceptualization has because been accelerated to encompass gadget intelligence and the Internet of Things (Neethirajan, 2020).

Automated Feeding Systems and Productivity

Automated feeding structures are taken into consideration to be a few of the maximum mature regions of precision farm animals farming. The approach includes the usage of weight sensors, digital identity tags together with RFID or transponders, and computer-primarily based totally controllers to offer animals with exactly managed quantities of feed. In a take a look at on a managed dairy farm, Schillings et al. (2021) validated that automatic feeding decreased feed waste via way of means of 18% whilst growing the performance of milk manufacturing via way of means of 12%. This turned into additionally established via way of means of Bach et al. (2008), who discovered accelerated frequency of clean feed deliver to animals the use of robot feeders, which elevated dry be counted consumption whilst improving milk yield. The method changed into additionally utilized by Pomar & Remus (2019) on pigs, who confirmed that precision feeding of pigs can cause a 40% lower in nitrogen excretion in comparison to standard section feeding at the same time as growing boom rate.

Sensor-Based Health Monitoring

The use of sensor-primarily based totally fitness tracking is likewise taken into consideration to be an crucial place of precision farm animals farming. The significance of early sickness detection has been proven to have massive financial implications. The fees of treatment, losses in productivity, and mortality growth swiftly if sickness isn't detected early enough (Rutten et al., 2013). Various sensors had been used to degree rumination, activity, frame temperature, and reproductive hormone stages amongst one-of-a-kind styles of animals. In a scientific evaluation of a hundred and fifty five research on computerized estrus detection amongst dairy cows, Borchers & Bewley (2015) determined that sensitivity ranged among 50-95%, relying at the system. Lameness detection the usage of accelerometers has additionally been appreciably researched. According to De Mol et al. (2013), sensitivity of as much as 76% become finished whilst trying to locate early-level lameness. The method become extensively utilized on poultry, with Exadaktylos et al. (2008) staring at ability to discover respiration sickness outbreaks 24-forty eight hours previous to medical signs.

Digital Farm Management Tools

Digital farm control structures integrate information from diverse sensor structures and administrative data. In an in depth observe, Wolfert et al. (2017) highlighted the significance of large facts in clever farming. The have a look at emphasised the significance of farm control statistics structures as a motive force of evidence-primarily based totally choice-making. The virtual farm control structures facilitate less complicated statistics control, regulatory compliance, deliver chain traceability, and strategic choice-making. Kamphuis et al. (2020) additionally evaluated choice help equipment for PLF on Dutch dairy farms. The observe discovered that dairy farms the usage of virtual farm control structures had better theory quotes, decrease somatic mobileular counts, and involuntary culling prices than farms the usage of conventional control practices. According to Morota et al. (2018), device learning-primarily based totally selection guide gear on virtual farm control structures additionally permit predictions on animal fitness troubles and optimize breeding decisions.

Environmental Sustainability and PLF

The courting among environmental sustainability and PLF has won greater interest because the farm animals enterprise is beneathneath growing strain to lessen its ecological footprint. Lammers et al. (2019) confirmed that precision feeding structures can lower excretions of nitrogen and phosphorus in keeping with unit of product, lowering capacity dangers to

watersheds round farms. Methane is a key greenhouse fueloline emitted with the aid of using ruminant animals. The methane emission fee varies amongst animals. Therefore, a sensor-primarily based totally choice aid device on a virtual farm control machine that identifies animals with low methane emissions also can assist selective breeding to lower methane emissions. According to Knapp et al. (2014), sensor-primarily based totally choice assist equipment on virtual farm control structures can guide selective breeding to lower methane emissions. Tullo et al. (2019) additionally reviewed the results of PLF on environmental sustainability. The look at discovered that despite the fact that PLF isn't a panacea, a well-designed PLF machine can help all 3 pillars of sustainable development.

Barriers to Adoption in Developing Countries

Despite the truth that there's massive proof of the useful results of PLF adoption in extra prosperous settings, there are structural demanding situations in growing nations. According to research, the primary boundaries to adoption in growing international locations are confined capital, low technical literacy, unreliable strength in rural areas, restrained cell and net infrastructure, and insufficient after-income support, in particular in South Asia amongst smallholder farmers (Islam et al., 2021). In settings in which maximum cattle are raised in small-scale blended farming structures, the financial case for person funding in PLF structures isn't clean due to the fact sensor structures are very high priced in comparison to the earnings generated in those structures (Chander et al., 2010). Government guidelines also are crucial in influencing the adoption of PLF structures in growing nations (Stygar et al., 2021).

Productivity results: proof from empirical research

Researchers have used numerous strategies to degree the productiveness effects of PLF adoption in diverse settings. In a industrial feedlot pork system, Halachmi et al. (2019) mentioned that precision feeding algorithms extended common each day benefit via way of means of 6.8% and decreased feed prices according to kilogram of advantage with the aid of using 4.2%. In dairy structures, automatic milking structures had been said to growth milking frequency, which interprets to productiveness profits of five to twelve percentage consistent with cow (Rutten et al., 2013). In swine structures, computer-managed surroundings control structures, which modify temperature, ventilation, and feed, have been pronounced to lessen mortality quotes with the aid of using 23 percentage and feed conversion performance via way of means of nine percentage (Banhazi et al., 2012). These research imply that there are productiveness profits related to the adoption of PLF structures.

Methodology

Research Design

This cutting-edge studies applied a quantitative method to analyze the effect of precision farm animals farming generation on each farm animals productiveness and environmental sustainability. This is due to the fact the studies became premised on a positivism attitude of know-how technology and its use to check unique and predetermined relationships among variables and their outcomes.

Population and Sampling

The contemporary studies centered farm animals farmers and bosses in District Khanewal, Punjab, Pakistan. Stratified random sampling become used to make sure ok and proportional illustration of various classes of farms starting from small-scale farms with much less than 50 cattle units, medium-scale farms starting from 50 to two hundred cattle units, and large-scale farms with extra than 2 hundred cattle units. The classes have been premised on agricultural census information and sampling fractions used to gain ok and consultant sub-samples from the population. A general of 250 questionnaires have been finished and used because the very last pattern length for analysis.

Table 1: Sample Distribution by Farm Size Category

Farm Size Category	No. of Respondents	Percentage (%)	Cumulative %
Small-Scale (< 50 LU)	100	40.0	40.0
Medium-Scale (50–200 LU)	90	36.0	76.0
Large-Scale (> 200 LU)	60	24.0	100.0
Total	250	100.0	—

LU = Livestock Units. Source: Field survey data.

Research Instrument

Data was collected using a structured questionnaire with five sections. Section A included questions on demographics and farm characteristics, including the age of respondents, educational level, number of years spent farming, farm size, and type of farm animals. Sections B to D included questions on how PLF technologies are used or adopted. These comprised automated feeding systems, sensor-based health monitoring, and digital farm management. Section E included questions on outcomes for two dependent variables. These comprised questions on outcomes for livestock productivity and environmental sustainability. The questions used a five-point Likert scale ranging from 1 = Strongly Disagree to 5 = Strongly Agree. The data collection instrument was pre-tested among 30 farmers. The results were used to make minor modifications to the questionnaire to enhance clarity.

Data Collection Procedure

The data was collected using face-to-face interviews. This ensured that the respondents had a clear understanding of every question, especially for those with low levels of literacy. The study ensured that all respondents gave their consent to take part in the study. The data was collected anonymously. The data was collected over a period of about eight weeks. The study excluded questionnaires with more than 10% missing values. The final sample size was 250.

Data Analysis

The data was analyzed using IBM SPSS Statistics Version 26. The data was analyzed in several steps. The first step was to describe the data. This was done using descriptive statistics. The second step was to run a reliability analysis using Cronbach's alpha. The third step was to run a Pearson correlation to examine relationships between independent and dependent variables. The fourth step was to run a multiple regression to examine how automated feeding systems, sensor-based health monitoring, and digital farm management predict outcomes for two dependent variables: livestock productivity and environmental sustainability.

Figure 2: Research Methodology Flowchart

STEP 1: Problem Identification & Research Objectives
STEP 2: Literature Review & Theoretical Framework Development
STEP 3: Questionnaire Design & Pilot Testing (n = 30)
STEP 4: Stratified Random Sampling — Small, Medium & Large Farms
STEP 5: Primary Data Collection via Structured Interviews (n = 250)
STEP 6: Data Entry, Coding & Cleaning in SPSS
STEP 7: Descriptive Stats – Reliability Analysis – Correlation – Regression
STEP 8: Interpretation of Results & Discussion
STEP 9: Conclusions, Recommendations & Policy Implications

Source: Author's own construction

Data Analysis and Results

Demographic Characteristics of Respondents

Table 2 affords a demographic image of the 250 respondents. The majority are male (78.8%), that's steady with the male-ruled panorama of business cattle farming. The biggest class is among 31-forty five years old (44.0%), accompanied with the aid of using 46-60 years old (28.0%). With regard to instructional background, 34.0% finished secondary school, 30.4% had vocational or technical training, at the same time as 22.4% had a college diploma or higher. With regard to experience, whilst varied, 40.8% had 11-two decades of experience. With regard to kinds of cattle, livestock and buffalo farming dominate at 42.0%, observed with the aid of using hen farming at 32.0%, whilst small ruminants together with sheep and goats ranked 26.0%.

Table 2: Demographic Profile of Respondents (n = 250)

Variable / Category	Frequency (n)	Percentage (%)
Gender		
Male	197	78.8
Female	53	21.2
Age Group		
18–30 years	47	18.8
31–45 years	110	44.0
46–60 years	70	28.0
Above 60 years	23	9.2
Education Level		
Primary or less	34	13.6
Secondary	85	34.0
Vocational/Technical	76	30.4
University & above	55	22.0
Livestock Type		
Cattle/Buffalo	105	42.0
Poultry	80	32.0
Small Ruminants	65	26.0

Source: Field survey data (n = 250).

Technology Adoption Status

They had been requested in the event that they had been the use of any of the 3 styles of PLF generation. From Table 3, the very best shape of generation followed became the sensor-primarily based totally fitness tracking device at 58.4%, accompanied with the aid of using the virtual farm control device at 51.2%, and the automatic feeding machine at 44.0%. The maximum shape of generation become recorded in large-scale farms for all kinds of era. The lowest shape of era recorded in small-scale farms become the automatic feeding machine at 21.0%.

Table 3: PLF Technology Adoption Rates by Farm Size (%)

Technology Category	Small (%)	Medium (%)	Large (%)	Overall (%)
Automated Feeding Systems	21.0	47.8	76.7	44.0
Sensor-Based Health Monitoring	38.0	63.3	91.7	58.4
Digital Farm Management Tools	29.0	55.6	85.0	51.2

Source: Field survey data. Percentages represent proportion of adopters within each farm size stratum.

Descriptive Statistics of Key Constructs

Table 4 suggests the descriptive facts of all of the constructs of the primary study. From the effects, it's far glaring that the customers of sensor generation in fitness tracking have the most powerful perceived software and performance, given their excessive suggest of 3.eighty two and a widespread deviation of 0.74. The 2d most powerful perceived application is the customers of virtual farm control tools, with a median of 3.sixty four and a widespread deviation of 0.81. Automated feeding structures come next, with a median of 3.forty seven and a widespread deviation of 0.88. From the consequences of the established variables, it's miles obvious that the productiveness of farm animals has an average of 3.seventy one and a wellknown deviation of 0.76, even as environmental sustainability is a piece lower, with an average of 3.fifty three and a fashionable deviation of 0.79.

Table 4: Descriptive Statistics of Study Constructs (n = 250)

Construct	N	Mean	SD	Cronbach's α
Automated Feeding Systems (AFS)	250	3.47	0.88	0.831
Sensor-Based Health Monitoring (SBHM)	250	3.82	0.74	0.867
Digital Farm Management Tools (DFMT)	250	3.64	0.81	0.843
Livestock Productivity (LP) — Dependent	250	3.71	0.76	0.856
Environmental Sustainability (ES) — Dependent	250	3.53	0.79	0.792

SD = Standard Deviation; α = Cronbach's Alpha. Scale: 1 = Strongly Disagree to 5 = Strongly Agree.

It is critical to observe that each one values of Cronbach's Alpha remained nicely above the minimal appropriate cost of 0.70 as proposed through Nunnally (1978). The values ranged from 0.792 to 0.867. This implies that every one the constructs exhibited excellent to desirable inner consistency, implying that the multi-object constructs had been capable of degree the underlying thoughts satisfactorily.

Correlation Analysis

Table five under provides the Pearson correlation matrix for all of the variables withinside the study. It is clear that each one 3 dimensions of PLF generation had been definitely associated with farm animals productiveness and environmental sustainability. In addition, all of the coefficients have been statistically considerable at 0.01 levels. It is clear that the measurement of sensor-primarily based totally fitness tracking become extra associated with farm animals productiveness, with a correlation coefficient of 0.581, $p < 0.01$. On the opposite hand, the size of computerized feeding structures become extra associated with environmental sustainability, with a correlation coefficient of 0.524, $p < 0.01$. The impartial variables exhibited a honest stage of intercorrelations, which ranged from 0.391 to 0.463.

Table 5: Pearson Correlation Matrix (n = 250)

Variable	AFS	SBHM	DFMT	LP	ES
AFS	1.000	0.463**	0.412**	0.541**	0.524**
SBHM		1.000	0.391**	0.581**	0.498**
DFMT			1.000	0.502**	0.476**
LP				1.000	0.613**
ES					1.000

** Correlation is significant at the 0.01 level (2-tailed). AFS = Automated Feeding Systems; SBHM = Sensor-Based Health Monitoring; DFMT = Digital Farm Management Tools; LP = Livestock Productivity; ES = Environmental Sustainability.

Multiple Regression Analysis — Livestock Productivity

A a couple of regression evaluation became executed to study how properly the 3 PLF generation variables may be used to expect the farm animals productiveness outcomes. Before making any interpretations, we checked the essential assumptions of a couple of regression evaluation: normality, homoscedasticity (regular variance), and lack of multicollinearity many of the predictor variables. All the predictor variables had a Variance Inflation Factor (VIF) much less than 2.5, and consequently multicollinearity become now no longer a problem for the evaluation. The residuals from the regression evaluation had a regular distribution and consistent variance as visible from the standardized residuals plot.

Table 6: Multiple Regression Results — Dependent Variable: Livestock Productivity (n = 250)

Predictor Variable	B	SE	β	t-value	Sig.
(Constant)	0.714	0.183	—	3.902	***
Automated Feeding Systems	0.381	0.071	0.412	5.366	***
Sensor-Based Health Monitoring	0.329	0.068	0.367	4.838	***
Digital Farm Management Tools	0.261	0.073	0.298	3.575	**
$R = 0.827$ $R^2 = 0.684$ Adjusted $R^2 = 0.680$ $F(3, 246) = 177.94$ $p < 0.001$					

B = Unstandardized coefficient; SE = Standard Error; β = Standardized coefficient. *** $p < 0.001$; ** $p < 0.01$.

In a regression evaluation, the version became determined to be statistically significant ($F(3, 246) = 177.94$, $p < 0.001$). The 3 predictor variables associated with PLF defined an excellent 68.4% of the variance in cattle productivity ($R^2 = 0.684$, Adjusted $R^2 = 0.680$). Among the 3 predictor variables associated with PLF, computerized feeding structures have been observed to be the maximum vital predictor of cattle productivity ($\beta = 0.412$, $t = 5.366$, $p < 0.001$), observed through sensor-primarily based totally fitness tracking ($\beta = 0.367$, $t = 4.838$, $p < 0.001$), and virtual farm control tools ($\beta = 0.298$, $t = 3.575$, $p < 0.01$). The implication is clear: Each class of PLF era independently and notably contributes to farm animals productivity, even if the effect of the opposite predictor variables is controlled.

Multiple Regression Analysis - Environmental Sustainability

A 2nd regression evaluation turned into finished to analyze environmental sustainability because the structured variable. As discovered in Table 7, the regression version become notably significant ($F(3, 246) = 143.22$, $p < 0.001$), and PLF technology defined 63.6% of the variance in environmental sustainability outcomes ($R^2 = 0.636$, Adjusted $R^2 = 0.631$). In this evaluation too, automatic feeding structures have been determined to be the maximum critical predictor of environmental sustainability ($\beta = 0.438$, $t = 5.712$, $p < 0.001$), highlighting the position of precision feeding in lowering feed waste and environmental pollutants from immoderate nutrient usage. Sensor-primarily based totally fitness tracking changed into additionally observed to be an vital predictor of environmental sustainability ($\beta = 0.311$, $t = 4.102$, $p < 0.001$), as became virtual farm control tools ($\beta = 0.264$, $t = 3.418$, $p < 0.01$).

Table 7: Multiple Regression Results — Dependent Variable: Environmental Sustainability (n = 250)

Predictor Variable	B	SE	β	t-value	Sig.
(Constant)	0.648	0.196	—	3.306	**
Automated Feeding Systems	0.401	0.070	0.438	5.712	***
Sensor-Based Health Monitoring	0.278	0.068	0.311	4.102	***
Digital Farm Management Tools	0.241	0.071	0.264	3.418	**
$R = 0.798$ $R^2 = 0.636$ Adjusted $R^2 = 0.631$ $F(3, 246) = 143.22$ $p < 0.001$					

B = Unstandardized coefficient; SE = Standard Error; β = Standardized coefficient. *** p < 0.001; ** p < 0.01.

Summary of Hypothesis Testing

Table 8: Summary of Hypothesis Testing Results

H	Hypothesis Statement	β / r	Decision
H1	AFS has a significant positive effect on livestock productivity	β = 0.412***	Supported
H2	SBHM has a significant positive effect on livestock productivity	β = 0.367***	Supported
H3	DFMT has a significant positive effect on livestock productivity	β = 0.298**	Supported
H4	AFS has a significant positive effect on environmental sustainability	β = 0.438***	Supported
H5	SBHM has a significant positive effect on environmental sustainability	β = 0.311***	Supported
H6	DFMT has a significant positive effect on environmental sustainability	β = 0.264**	Supported

*** p < 0.001; ** p < 0.01. AFS = Automated Feeding Systems; SBHM = Sensor-Based Health Monitoring; DFMT = Digital Farm Management Tools.

Discussion

The have a look at gives robust, numerical help that precision cattle farming technologies, which includes computerized feeding structures, fitness tracking structures, and virtual farm control, aren't handiest useful however additionally large predictors of each the productiveness of those cattle and the sustainability of those farming practices. These findings are steady with and make bigger the modern-day frame of empirical research on precision cattle farming technologies. Among those technologies, automatic feeding structures emerged because the most powerful predictor of each productiveness and sustainability. The observe's said betas of 0.412 and 0.438 for productiveness and sustainability, respectively, are steady with Schillings et al. (2021) and Pomar and Remus (2019), which validated clean advantages to each feed performance and nutrient excretion the usage of precision feeding structures. The purpose is obvious: feeding every animal precisely what it wishes guarantees that neither an excessive amount of meals is wasted and nutrient excretion is unnecessarily high, neither is any animal underfed and its boom stifled.

The contribution of sensor-primarily based totally fitness tracking to productiveness is big at β = 0.367, constant with the effects of Rutten et al. (2013) and Borchers & Bewley (2015), wherein the detection of ailments at in advance stages, collectively with the detection of reproductive events, ended in decrease prices of remedy and lack of production. It is comprehensible that the contribution of fitness tracking to sustainability is much less than the contribution to feeding, for the reason that fitness tracking has a extra direct effect at the welfare of the man or woman animals than at the environment, despite the fact that the effect of fitness tracking at the environment, via the discount of antibiotic residues and mortality, remains a factor.

The contribution of virtual farm control to each productiveness and sustainability, even though the smallest of the three, remains large, constant with the outcomes of Wolfert et al. (2017) and Kamphuis et al. (2020), in which the blessings of the funding in sensors have been more desirable through the inclusion of information into the control system. The decrease beta values received for the contribution of virtual farm control to the 2 factors may want to have resulted from the reality that the contribution of those equipment is pleasant preferred whilst used as integrators, wherein the advantages are visible whilst used collectively with exact investments in hardware sensors, implying a complementary dating that warrants similarly look at.

The precise suit of the fashions is likewise pondered withinside the pretty excessive R^2 values of 0.684 and 0.636 for the productiveness and sustainability fashions, respectively. This shows that the adoption of PLF generation is a superb predictor for explaining the variations in farm animals productiveness and sustainability.

Conclusion

This studies aimed to analyze the effect of precision cattle farming generation on cattle productiveness and environmental sustainability the usage of a pattern of 250 farmers. The findings of the studies discovered that the adoption of computerized feeding generation, fitness tracking era, and virtual era in farming in my view and appreciably contributed to an growth in cattle productiveness and environmental sustainability, explaining 68.four and 63.6 percentage of the variance in productiveness and sustainability, respectively. The findings of the studies guide the fundamental assumption that PLF isn't always only a generation adoption however a paradigm shift withinside the manufacturing and control of farm animals, deliberating each productiveness and environmental concerns. The true inner consistency of the scales used to degree the variables and the robustness of the regression evaluation additionally lend assist to the findings of the studies.

Recommendations

Recommendations for policymakers, agricultural establishments, and stakeholders, knowledgeable via way of means of the data:

- **Subsidized Technology Access:** The authorities and improvement businesses ought to take into account designing sponsored and low-hobby credit score centers to lessen the capital charges related to adopting PLF era, specifically amongst small to medium-scale farms, which can be in all likelihood to reveal the widest hole in adoption and the related productiveness and sustainability gains.
- **Technology and Extension Services:** As literacy is a key enabler to generation adoption, agricultural extension offerings ought to do not forget mainstreaming PLF generation education of their ordinary extension offerings. Some cost-powerful channels encompass farmer area colleges and peer gaining knowledge of groups.
- **Rural Digital Infrastructure:** Good rural broadband and power infrastructure are vital to powerful adoption of virtual farm control tools. The infrastructure ministries and improvement organizations need to prioritize upgrading rural infrastructure in areas with excessive farm animals farming activities.
- **Bundled Technology Adoption:** The 3 forms of PLF generation are in all likelihood to provide the pleasant consequences while followed in bundles as opposed to in isolation. Therefore, it's miles endorsed that agricultural establishments and extension offerings prioritize bundled adoption over man or woman era adoption. This is specially authentic for farms that undertake bundles of automatic feeders, fitness tracking systems, and virtual control tools, that are in all likelihood to supply synergistic consequences.
- **Recommendations for similarly studies:** Longitudinal research at the adoption of PLF era and its results on productiveness and sustainability over time, and in addition studies at the position of social and cultural elements in influencing generation adoption.

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