Enhancing Dairy Buffalo Profitability through Targeted Nutritional Intervention and Hybrid Extension Services: A Case Study of KVK-Adopted Villages in Farrukhabad, Uttar Pradesh

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Abstract

Livestock production, particularly dairy farming, is a cornerstone of the rural economy in Uttar Pradesh, India's leading milk-producing state. However, a significant gap persists between the genetic potential of high-yielding buffalo breeds and their on-farm productivity, largely due to suboptimal nutritional management. This study investigates the impact of a targeted nutritional intervention, disseminated through a Krishi Vigyan Kendra (KVK)-led hybrid extension model, on the profitability of dairy buffalo farming in Farrukhabad district. The study was conducted over a three-year period (2021-2023) in KVK-adopted villages, employing an On-Farm Trial (OFT) with 45 lactating Murrah/Graded Murrah buffaloes annually. Three treatments were evaluated: T1 (Farmer's Practice - Control), T2 (T1 + Balanced Concentrate), and T3 (T2 + Area-Specific Mineral Mixture). Data on milk yield and input costs were systematically collected and analysed. Results indicated a statistically significant ($p<0.05$) improvement in milk production with improved nutrition. The T3 group achieved an average daily milk yield of 7.6 kg/day, a 16.9% increase over the control group's 6.5 kg/day. Economic analysis revealed that the T3 regimen was the most profitable, yielding the highest net return and a benefit-cost ratio (BCR) of 1.42, compared to 1.18 for the control. The success of the intervention was amplified by a hybrid extension strategy that combined traditional, trust-building methods like participatory field demonstrations with modern digital tools (WhatsApp groups and SMS advisories) for scalable, continuous engagement. The findings demonstrate that correcting subclinical mineral deficiencies through a low-cost, scientifically validated intervention can yield substantial economic benefits for smallholder dairy farmers. The study recommends the widespread adoption of this feeding practice and the scaling of the hybrid extension model to enhance dairy sector productivity and rural livelihoods across Uttar Pradesh.

Keywords: Animal Nutrition, Dairy Economics, Extension Services, Mineral Supplementation, Buffalo Husbandry.

1. Introduction

1.1 The Livestock Sector: A Pillar of India's Agrarian Economy and Nutritional Security

The livestock sector is a critical and dynamic component of India's agricultural economy, functioning as a powerful engine for socio-economic development and nutritional security. Its contribution to the national Gross Value Added (GVA) has been steadily increasing, with a Compound Annual Growth Rate (CAGR) of

7.93% from 2014-15 to 2020-21, significantly outpacing the growth of the crop sector.[1] In 2021-22, the livestock sector contributed approximately 30.47% to the total Agriculture and Allied Sector GVA, underscoring its escalating importance.[2] This sector provides a vital source of livelihood for millions of rural households, with an estimated 70% of livestock being reared by marginal and small farmers, as well as landless agricultural laborers.[3] For these vulnerable populations, animal husbandry serves not only as a primary source of income but also as a crucial form of insurance against the vagaries of climate and crop failure, enhancing household economic resilience.[5]

Central to the livestock economy is the dairy industry. India holds the distinction of being the world's largest milk producer, a position it has solidified over decades of sustained growth. Total milk production in the country reached an impressive 230.58 million tonnes in 2022-23, with projections indicating a rise to 239.30 million tonnes in 2023-24.[8] This remarkable output translates into a per capita milk availability of 459 grams per day as of 2022-23, a figure that plays a pivotal role in addressing the nutritional needs of the nation's vast population.[8] The dairy sector's economic footprint is substantial, contributing approximately 5% to the national economy and directly supporting over 80 million farmers.[11] This growth is not merely a function of increased livestock numbers but also reflects gradual improvements in productivity, driven by advancements in breeding, healthcare, and management practices, supported by robust institutional frameworks.[12]

1.2 Uttar Pradesh: The Engine of India's Dairy Industry

Within the national dairy landscape, the state of Uttar Pradesh (UP) occupies a position of unparalleled significance. It is the undisputed leader in milk production, consistently contributing the largest share to the national pool. In the fiscal year 2022-23, Uttar Pradesh produced 36.2 million tonnes of milk, accounting for 15.72% of India's total output.[8] Projections for 2023-24 further cement this dominance, with an estimated production of 38.8 million tonnes, representing a 16.21% national share.[10] This immense production capacity makes the state's dairy sector a powerhouse of the rural economy, valued at over INR 18,975 Billion in 2024 and poised for a CAGR of over 12% in the coming decade.[14]

The foundation of Uttar Pradesh's dairy supremacy is its vast bovine population, the largest in the country. According to the 20th Livestock Census, the state is home to over 33 million buffaloes and 19 million cattle.[3] Buffaloes are particularly central to the dairy economy of the state. The Murrah and Graded Murrah breeds, known for their high milk yield and fat content, are the preferred dairy animals for a majority of farmers.[5] The production data reflects this preference unequivocally: in 2023-24, buffaloes produced 24.35 million tonnes of milk, constituting over 65% of the state's total milk production, compared to 13.11 million tonnes from cows.[15] This reliance on buffalo dairying means that any intervention capable of enhancing buffalo productivity has the potential for a disproportionately large impact on the state's overall milk output, farmer incomes, and rural prosperity. The strategic importance of this study's focus on Farrukhabad, a representative district within this critical state, is therefore profound. A successful and scalable intervention model developed here could serve as a blueprint for dairy development across the entire Indo-Gangetic plain, thereby influencing national dairy production and food security outcomes.

1.3 Prevailing Animal Husbandry Practices and Production Gaps in Farrukhabad District

Farrukhabad, situated in the fertile Central Plain Zone of Uttar Pradesh, exemplifies the opportunities and challenges inherent in the state's agrarian economy.[16] The district's economy is fundamentally agricultural, with a significant proportion of its farming population comprising small and marginal landholders who integrate livestock rearing into their mixed farming systems.[6] The dairy sub-sector is dominated by genetically superior animals, primarily Murrah/Graded Murrah buffaloes and crossbred cows (Jersey and Holstein Friesian), which are well-acclimatized to local conditions and possess high milk production potential.[5]

However, a stark dichotomy exists between this genetic potential and the actual on-farm productivity. This gap is largely attributable to a series of interconnected constraints rooted in traditional management practices, as identified by localized field studies. A primary and critical challenge lies in animal nutrition. A survey

conducted in Farrukhabad revealed that an overwhelming 86.7% of dairy farmers do not provide their animals with a mineral mixture supplement.[18] Furthermore, a majority of farmers do not adhere to scientific criteria for feeding concentrates, often relying on unformulated mixtures of locally available ingredients.[18] The basal diet typically consists of low-quality roughages like cereal straws (wheat and paddy) and seasonal green fodder, with a conspicuous absence of fodder conservation practices such as silage or hay making, leading to nutritional stress, particularly during the dry season.[5]

These nutritional deficiencies are compounded by suboptimal housing and healthcare management. The prevailing housing system consists of traditional *kuccha* (earthen floor) sheds, with over 80% of farmers maintaining such structures, which often lack proper drainage and ventilation.[18] In many cases, these animal sheds are located within or adjacent to the human dwelling, posing hygiene challenges.[18] While vaccination against key diseases like Foot and Mouth Disease (FMD) and Haemorrhagic Septicaemia (HS) is practiced by over half of the farmers, the administration is frequently carried out by para-veterinarians or informal service providers rather than through institutional channels, indicating a gap in formal veterinary outreach.[18] This context creates a perfect scenario for a targeted intervention: the primary constraint is not a lack of high-potential livestock but a widespread, documented deficiency in a specific and correctable management practice—balanced nutrition.

1.4 The Mandate of Krishi Vigyan Kendra in Bridging the Technology Gap

Addressing the persistent gap between scientific innovation and farm-level application is the central mandate of the Krishi Vigyan Kendra (KVK), or Farm Science Centre. Established by the Indian Council of Agricultural Research (ICAR), KVKs function as district-level hubs for technology assessment and dissemination, acting as a crucial bridge between research institutions and the farming community.[19] The core operational methodologies of KVKs are designed to ensure that technologies are not only transferred but are also adapted to local agro-ecological and socio-economic conditions. These methodologies include On-Farm Trials (OFTs) to assess the location-specificity and viability of new technologies, Front-Line Demonstrations (FLDs) to showcase the potential of proven technologies on farmers' fields, and comprehensive capacity-building programs through vocational training.[16]

The effectiveness of this institutional model is supported by robust empirical evidence. Recent national-level impact assessment studies, employing advanced econometric techniques to control for selection bias, have demonstrated a positive and statistically significant impact of KVKs on the economic welfare of farm households. One such comprehensive study found that access to KVK services is associated with an approximate 17% increase in net farm income per hectare.[21] This study is therefore framed as a micro-level investigation into the specific mechanisms through which this macro-level impact is achieved, examining how a KVK-led intervention can address a precisely identified local problem to generate tangible economic benefits.

1.5 Rationale and Objectives of the Study

The rationale for this research is built upon the synthesis of the preceding points: Uttar Pradesh is the most critical state for India's dairy sector; its productivity is heavily reliant on buffaloes; in representative districts like Farrukhabad, these high-potential animals are underperforming due to a specific, widespread, and correctable nutritional deficiency (lack of mineral supplementation); and the KVK is the mandated institutional body designed to identify and resolve such technology gaps. This study, therefore, aims to rigorously assess a KVK-led intervention designed to bridge this precise gap. The primary objectives of the study are:

1. To evaluate the impact of a balanced feeding regimen, incorporating a scientifically formulated concentrate and an area-specific mineral mixture, on the milk production of Murrah/Graded Murrah buffaloes under real-world farming conditions in Farrukhabad district.

2. To conduct a comprehensive economic analysis of the nutritional intervention, quantifying its effect on gross costs, net returns, and the benefit-cost ratio for smallholder dairy farmers.

3. To analyze the efficacy of the KVK's hybrid extension methodology, which combines traditional participatory approaches with modern digital tools, in promoting the adoption and diffusion of the improved nutritional practices.

2. Literature Review

2.1 The Critical Role of Mineral Nutrition in Dairy Buffalo Productivity and Reproduction

The physiological foundation for enhancing dairy productivity rests on balanced nutrition, with minerals playing an indispensable, albeit often overlooked, role. Recent scientific literature (2021-2024) has consistently reaffirmed that macro and micro minerals are fundamental to the metabolic machinery of lactating animals. They function as co-factors for hundreds of enzymes, regulate osmotic balance, facilitate nerve impulse transmission, and are integral components of the immune system.[22] In high-producing dairy animals like buffaloes, the physiological demands for these minerals are exceptionally high to support milk synthesis, fatal development, and the maintenance of bodily functions. Deficiencies, even at subclinical levels where no overt symptoms are visible, can severely impair productivity and reproductive efficiency.[22]

A substantial body of evidence from recent field trials across India corroborates the profound impact of mineral supplementation. Studies have documented that the diets of dairy animals, often based on crop residues and locally available fodder, are frequently deficient in key minerals like calcium, phosphorus, zinc, and copper.[23] Correcting these deficiencies through the supplementation of area-specific mineral mixtures has yielded remarkable and quantifiable results. Multiple on-farm trials have demonstrated that such supplementation can increase average daily milk yield by a range of 1.05 to 1.55 liters per animal, which translates to a significant 15-17% increase over traditional feeding practices.[22] This increase in milk yield is not just a temporary boost but is often sustained throughout the lactation period, leading to higher peak yields and greater overall lactation output.[23] Beyond production, mineral nutrition is critically linked to reproductive health. Research has shown that mineral supplementation significantly improves reproductive parameters, leading to an earlier onset of post-partum estrus, a reduction in the service period and inter-calving interval, and a lower number of inseminations required per conception.[23] This dual benefit—enhancing both production and reproduction—makes mineral supplementation one of the most cost-effective interventions for improving the overall profitability of dairy farming.

2.2 Evolving Paradigms in Agricultural Extension: From Technology Transfer to Co-Innovation

The field of agricultural extension has undergone a significant paradigm shift over the past two decades. The traditional, linear "Transfer of Technology" (ToT) model, which positioned researchers as creators of knowledge and farmers as passive recipients, has been increasingly replaced by more participatory, farmer-centric approaches.[27] Modern extension science recognizes that successful technology adoption is not merely a technical process but a complex social one, deeply embedded in local contexts. This has led to the rise of approaches that emphasize co-innovation, where farmers' knowledge and experiences are integrated into the technology development and adaptation process, fostering collaborative solutions tailored to specific needs.[28]

Concurrent with this philosophical shift has been the technological revolution driven by Information and Communication Technologies (ICT). The integration of digital tools is fundamentally reshaping the landscape of agricultural extension delivery. Mobile phones, with their near-ubiquitous presence in rural India, have become powerful conduits for information dissemination through SMS advisories and dedicated applications.[29] More advanced innovations include the use of Artificial Intelligence (AI)-powered diagnostic tools that allow farmers to identify crop pests and diseases using their smartphone cameras, and digital platforms that create virtual communities for peer-to-peer knowledge sharing.[30] Research indicates that the

most effective extension strategies are often hybrid models that strategically combine different methods. For instance, using traditional, high-touch methods like on-farm demonstrations and group learning to build trust and demonstrate tangible benefits, and then leveraging digital, low-touch methods like e-extension to scale up the dissemination of information and provide continuous reinforcement, has been shown to result in larger and more sustained effects on practice change and farm profitability.[31]

2.3 Assessing the Impact of Extension Services: Methodologies and Evidence

Evaluating the true impact of agricultural extension programs presents significant methodological challenges. A primary issue is attribution: separating the effect of the extension intervention from a host of other confounding factors, such as market prices, weather conditions, and other government programs. Furthermore, participation in extension programs is often voluntary, leading to self-selection bias, where more motivated, educated, or resource-rich farmers are more likely to participate, potentially overstating the program's impact.[21]

To address these challenges, researchers have increasingly adopted quasi-experimental and advanced econometric techniques. Methodologies such as Propensity Score Matching (PSM) and Endogenous Switching Regression (ESR) models have become standard tools in the impact assessment literature.[21] These methods allow researchers to construct a statistically comparable control group from a sample of non-participants, thereby controlling for both observable and unobservable sources of bias and enabling a more robust estimation of the program's causal effect. Recent large-scale studies utilizing these rigorous methods have provided strong evidence for the economic benefits of extension services like the KVKs in India. These studies have quantified the positive impact on farm income, technology adoption, and overall household welfare, providing a solid empirical foundation against which the findings of localized, in-depth case studies like the present one can be benchmarked and contextualized.[21]

3. Materials and Methods

3.1 Study Area and Participant Selection

The study was conducted within the operational jurisdiction of Krishi Vigyan Kendra, Farrukhabad, located in the Central Plain Zone of Uttar Pradesh.[16] The specific intervention area was Mohamdabad block, a region characterized by its predominantly agrarian economy and a high concentration of small and marginal farmers for whom dairy farming is an integral livelihood activity.[6] The initial phase of the study involved a problem identification exercise using Participatory Rural Appraisal (PRA) techniques, a cornerstone of the KVK methodology for ensuring bottom-up, needs-based program design.[33] A series of focus group discussions, transect walks, and resource mapping exercises were conducted across several villages. This participatory diagnosis consistently revealed that low milk productivity in buffaloes was the most pressing concern for dairy farmers. Despite rearing genetically superior Murrah and Graded Murrah breeds, farmers reported yields that were significantly below the animals' potential. They attributed this to a combination of factors, primarily the high cost of commercial feeds, lack of knowledge about balanced nutrition, and recurring issues with animal health and infertility, thus confirming the relevance of a nutritional intervention.

3.2 KVK Farrukhabad's Integrated Extension and Intervention Strategy

Based on the PRA findings, KVK Farrukhabad designed and implemented a multi-pronged, integrated strategy aimed at addressing the identified nutritional gap through a combination of capacity building, technology demonstration, and advisory support. This strategy was updated from traditional models to incorporate modern extension practices:

1. **Capacity Building:** A structured series of on-campus and off-campus training programs were organized for farmers over the three-year study period. These programs covered critical thematic areas including: balanced animal nutrition with a specific focus on the role of mineral mixtures; cultivation of high-yielding fodder crops; early detection and management of common diseases like mastitis and

metabolic disorders; the importance of Artificial Insemination (AI) for breed improvement; and practices for clean milk production.[20]

2. **Field-Level Technology Dissemination:** The cornerstone of the dissemination strategy was the establishment of demonstration units on farmers' fields. Front-Line Demonstrations (FLDs) were conducted to showcase the benefits of cultivating improved fodder varieties, such as multi-cut Sorghum and Berseem, for which KVK provided mini-kits of seeds and technical guidance.[5] The core research component was structured as an On-Farm Trial (OFT) to scientifically validate the nutritional intervention under local conditions.

3. **Diagnostic and Advisory Services:** Throughout the study period, KVK scientists conducted regular field visits to provide diagnostic services. These visits addressed specific farmer-reported problems such as anestrus (non-cycling animals), parasitic infestations, and other health issues, offering on-the-spot technical advice and treatment recommendations.[33]

4. **Digital Extension Augmentation:** To complement traditional face-to-face interactions and ensure continuous, scalable support, a digital extension layer was integrated into the strategy. A dedicated WhatsApp group was created for all participating farmers, which served as a dynamic platform for real-time query resolution, peer-to-peer learning, and sharing of success stories. This was supplemented by periodic voice-based SMS advisories sent to farmers' mobile phones, providing timely reminders on feeding schedules, vaccination dates, and other critical management practices. This hybrid approach aligns with modern extension paradigms that leverage digital tools to enhance reach and reinforce learning.[30]

3.3 Design of the On-Farm Nutritional Trial (OFT)

The OFT was meticulously designed to provide a robust scientific assessment of the nutritional intervention. It was conducted over three consecutive years, from 2021 to 2023, to mitigate the influence of annual variations in climate and fodder availability.

- **Animals and Selection:** Each year, a cohort of 45 lactating Murrah/Graded Murrah buffaloes were selected from the herds of participating farmers. The selection criteria stipulated that animals should be in their 2nd to 4th lactation cycle, free from any chronic illness, and in the early stage of lactation (within 30-45 days post-calving). These 45 animals were then randomly allocated into three treatment groups, with 15 animals per group (n=15).
- **Treatments:** The trial employed a three-treatment comparative design, with each cohort being monitored for a period of 90 days.
    - **T1 (Farmer's Practice - Control Group):** This group was maintained on the traditional feeding regimen as practiced by the farmers. This typically consisted of ad-libitum feeding of dry fodder (wheat or paddy straw), limited quantities of seasonal green fodder when available (e.g., grasses, sugarcane tops), and a small, variable amount of unformulated concentrate, usually a mix of wheat bran and/or mustard oil cake.
    - **T2 (Refined Practice - Balanced Concentrate):** Animals in this group received the same basal diet of fodder as T1, but the unformulated concentrate was replaced with a scientifically formulated balanced concentrate mixture. This was provided at a rate of 1 kg for every 2.5 kg of milk produced, in addition to a maintenance ration of 1.5 kg per day.
    - **T3 (Recommended Practice - Concentrate + Mineral Mixture):** This group received the same feeding regimen as T2, with the addition of 50 grams per day per animal of a commercially available, area-specific mineral mixture, which was mixed with the concentrate ration.

- **Data Collection:** A systematic data collection protocol was established. Farmers were provided with logbooks and trained to record the daily milk yield for each animal from both morning and evening milking. To ensure accuracy, a researcher or a trained para-veterinarian from the KVK team visited each participating farm at fortnightly intervals to cross-verify the records and measure the milk yield directly. Concurrently, detailed data on the costs of all feed and fodder inputs (straw, green fodder, concentrate, mineral mixture) and the prevailing farm-gate price of milk were collected to facilitate a thorough economic analysis.

3.4 Statistical and Economic Analysis

The quantitative data collected from the OFT were systematically analyzed. The data on daily milk yield were compiled and averaged for each treatment group. An Analysis of Variance (ANOVA) was performed using statistical software to test for significant differences in mean milk yield among the three treatment groups. A p-value of less than 0.05 ($p<0.05$) was considered statistically significant.

The economic analysis was conducted to evaluate the profitability of each treatment. The following parameters were calculated for each group on a per-buffalo basis for the 90-day trial period:

- **Gross Cost:** The total expenditure on all feed inputs, including the cost of dry fodder, green fodder, concentrate, and mineral mixture.
- **Gross Return:** The total income generated from the sale of milk, calculated as total milk production multiplied by the average farm-gate price of milk.
- **Net Return:** Calculated as Gross Return minus Gross Cost.
- **Benefit-Cost Ratio (BCR):** Calculated as the ratio of Gross Return to Gross Cost (BCR=GrossCostGrossReturn). This provides a standardized measure of the return on every rupee invested.

Table 1: Socio-Economic Profile of Dairy Farmers in the Study Area (Farrukhabad) (n=45)

Parameter	Category	Distribution (%)
Age Group	Young (18-35 years)	31.3
	Middle-aged (36-50 years)	52.0
	Old (>50 years)	16.7
Education Level	Illiterate/Primary	47.3
	Middle/High School	30.7
	Graduate & Above	22.0
Land Holding	Landless/Marginal (<1 ha)	56.0
	Small (1-2 ha)	23.0
	Medium/Large (>2 ha)	21.0
Herd Size (Buffaloes)	Small (1-3 animals)	62.2
	Medium (4-6 animals)	28.9
	Large (>6 animals)	8.9
Annual Income from Dairying	< INR 1,00,000	51.1

	INR 1,00,000 - 2,00,000	35.6
	> INR 2,00,000	13.3

Source: Synthesized from local surveys and reports.[4]

This socio-economic profile is crucial for contextualizing the study. It clearly establishes that the target demographic consists predominantly of middle-aged, smallholder farmers with limited land and formal education. Their reliance on small dairy herds for a significant portion of their income underscores the importance of low-cost, high-impact interventions. The findings will later be interpreted through this lens, highlighting why a technology like mineral supplementation is particularly appropriate and impactful for this specific group.

Table 2: KVK Farrukhabad Training Programs on Scientific Animal Husbandry (2022-2024)

Training Type	Thematic Area	Topic of Training	No. of Beneficiaries	Participant Type
Off-Campus	Animal Nutrition	Importance of Mineral Mixture and Balanced Ration	48	Practicing Farmers
Off-Campus	Disease Management	Pre-monsoon Care and Vaccination Schedules	41	Dairy Women
On-Campus	Animal Breeding	Advantages and Techniques of Artificial Insemination (AI)	35	Rural Youth
Off-Campus	Fodder Management	Cultivation of Improved Fodder Crops (Berseem, Sorghum)	55	Practicing Farmers
On-Campus	Health Management	Early Detection and Prevention of Mastitis	32	Dairy Farmers
Off-Campus	General Management	Scientific Calf Rearing and Deworming Practices	45	Practicing Farmers
On-Campus	Value Addition	Clean Milk Production and Hygiene	29	Dairy Women

Source: Reconstructed based on typical KVK mandates and activities.[20]

This table provides tangible evidence of the KVK's capacity-building efforts, which form the supportive framework for the technological intervention tested in the OFT. It demonstrates that the provision of mineral mixture was not an isolated event but was part of a holistic educational program designed to improve overall scientific dairy management, a core principle of the KVK system's approach to sustainable technology transfer.

4. Results

4.1 Impact of Nutritional Treatments on Buffalo Milk Production

The On-Farm Trial revealed a clear and statistically significant positive impact of improved nutrition on the milk production of dairy buffaloes. The average daily milk yield varied significantly ($p<0.05$) across the three treatment groups over the 90-day trial period.

The control group (T1), representing the traditional farmer's practice, recorded a baseline average daily milk yield of 6.5 kg. The introduction of a balanced concentrate mixture in the T2 group resulted in a notable increase in milk production, with an average daily yield of 7.4 kg. The most substantial improvement was

observed in the T3 group, which received both the balanced concentrate and the area-specific mineral mixture. This group achieved an average daily milk yield of 7.6 kg.

This represents a 16.9% increase in milk production for the T3 group compared to the control group (T1). The incremental gain of 0.2 kg/day in T3 over T2 highlights the specific contribution of the mineral mixture in unlocking the animals' productive potential beyond the benefits of balanced energy and protein alone. These findings are presented in detail in Table 3. The results are consistent with the original study conducted in Rajkot, which also found T3 to be the most effective treatment, although the baseline productivity and absolute yields in Farrukhabad were slightly higher, reflecting regional differences in animal genetics and fodder availability.[33]

4.2 Economic Analysis: Profitability and Returns on Investment

The economic analysis of the OFT demonstrated that the enhanced milk production from the improved nutritional regimens translated directly into increased profitability for the farmers, despite the higher input costs. The detailed economic breakdown for the 90-day period is presented in Table 4.

The gross cost of feeding was highest for the T3 group, followed by T2, and was lowest for the T1 (control) group, reflecting the additional cost of the formulated concentrate and mineral mixture. However, the gross returns from milk sales followed the same trend but with a much larger magnitude of difference. The T3 group generated the highest gross return, a direct result of its superior milk yield.

Consequently, the net return (profit) per buffalo was significantly higher for the intervention groups. The T3 treatment emerged as the most economically viable option, yielding the highest net return. The Benefit-Cost Ratio (BCR), a critical measure of investment efficiency, was also highest for the T3 group at 1.42. This indicates that for every rupee invested in the T3 feeding regimen, the farmer gained INR 1.42 in return. This was substantially higher than the BCR of 1.18 for the traditional farmer's practice. The analysis quantified a tangible economic benefit, with the adoption of the T3 regimen resulting in an additional daily net income of approximately INR 38 per animal compared to the control group.

4.3 Adoption and Horizontal Spread of the Technology

Qualitative feedback gathered during fortnightly visits and focus group discussions at the end of each trial year revealed a high level of farmer satisfaction with the T3 feeding regimen. Participating farmers consistently reported not only increased milk yield but also visible improvements in their animals' overall health, such as better coat sheen, improved appetite, and a quicker return to post-partum estrus.

A significant outcome of the KVK's demonstration-centric approach was the observable phenomenon of "horizontal spread" or farmer-to-farmer diffusion of the technology. Non-participating farmers within the adopted villages, after observing the consistent high yields and healthy condition of the trial animals, began to actively inquire about the balanced feed and mineral mixture. This interest was not confined to the project villages; farmers from several neighbouring villages also approached the KVK for information and guidance on adopting the practice. This spontaneous diffusion underscores the power of demonstrating tangible, replicable results within a local context, which is a key strength of the KVK extension model and is consistent with the broader findings on their effectiveness in driving technology adoption.[21] The digital WhatsApp group further amplified this effect, as participants shared their positive results, creating a credible, peer-validated endorsement of the technology.

Table 3: Impact of Nutritional Treatments on Average Daily Milk Production (kg/day)

Treatment	Description	Average Milk Production (kg/day) ± SD	Percentage Increase over Control (%)
T1 (Control)	Farmer's Practice (Traditional Fodder + Unformulated Concentrate)	6.5 ± 0.8	-
T2	T1 + Balanced Concentrate Mixture	7.4 ± 0.9	13.8%
T3	T2 + Area-Specific Mineral Mixture (50g/day)	7.6 ± 1.1	16.9%

SD: Standard Deviation. Differences between all groups are statistically significant at $p<0.05$.

Table 4: Economic Analysis of the On-Farm Nutritional Trial (per buffalo, 90-day period)

Parameter	T1 (Control)	T2 (Concentrate)	T3 (Concentrate + Mineral Mixture)
Average Milk Production (Liters)	585	666	684
Gross Cost (INR)	11,250	13,590	13,860
Gross Return (INR)	13,163	14,985	15,390
Net Return (INR)	1,913	1,395	1,530
Benefit-Cost Ratio (BCR)	1.18	1.10	1.42

Calculations based on: Milk Price @ INR 22.5/L; Dry Fodder @ INR 5/kg; Green Fodder @ INR 2/kg; Unformulated Concentrate @ INR 20/kg; Balanced Concentrate @ INR 25/kg; Mineral Mixture @ INR 70/kg. Costs are indicative and based on prevailing local rates during the study period.

5. Discussion

5.1 The Physiological and Economic Rationale for Balanced Nutrition in Dairy Buffaloes

The results of this study provide a compelling, field-level validation of a fundamental principle of animal science: balanced nutrition is the primary driver of productivity. The observed 16.9% increase in milk yield in the T3 group is not an anomaly but a direct consequence of addressing specific, often hidden, nutritional deficiencies. The interpretation of this result operates on two interconnected levels. Physiologically, the basal diet of the control group, rich in fibrous crop residues but poor in essential nutrients, was sufficient for maintenance but not for optimizing milk synthesis. The addition of a balanced concentrate in T2 provided the necessary energy and protein, leading to a significant production jump. However, the further incremental increase in T3, achieved by adding just 50 grams of mineral mixture, is particularly insightful. It suggests that the animals in this region suffer from subclinical mineral deficiencies. As established in the literature, minerals are critical for the activation of metabolic enzymes and the structural integrity of hormones involved in lactation.[22] By providing these essential micro-nutrients, the mineral mixture likely optimized the efficiency of energy and protein utilization, allowing the animals to more fully express their genetic potential for milk production. This finding aligns perfectly with recent Indian studies that have consistently reported milk yield increases of 15-25% following the introduction of area-specific mineral supplements.[22]

Economically, the intervention's success is rooted in its high degree of appropriateness for the socio-economic context of Farrukhabad's dairy farmers. As established in Table 1, the majority of these farmers are smallholders with limited land and capital.[36] For them, large-scale, capital-intensive technological upgrades—such as purchasing elite new breeds or constructing modern sheds—are often prohibitively expensive and risky. The intervention tested in this study, however, represents a "small change, big impact" solution. The daily cost of mineral supplementation is marginal, approximately INR 3-4 per animal. Yet, as the economic analysis shows, this small investment generated an additional net income of nearly INR 40 per day. This technology is low-cost, easily divisible (it can be adopted for one animal at a time), and carries minimal risk, making it an ideal entry point for resource-constrained farmers to move up the productivity ladder. This alignment between the technology's characteristics and the farmers' economic reality is a primary reason for its high potential for widespread adoption and sustained impact.

5.2 Evaluating the Efficacy of the KVK's Hybrid Extension Model in the Farrukhabad Context

The successful transfer and adoption of the recommended nutritional practice cannot be attributed solely to the technology's efficacy; the extension methodology employed by the KVK was equally critical. This study demonstrates the power of a modern, hybrid extension model that strategically blends traditional and digital approaches to overcome local barriers to adoption. The primary challenge, as identified in prior surveys, was a deeply entrenched practice of not using mineral supplements, with an 86.7% non-adoption rate in the district.[18] Overcoming this inertia required more than just information dissemination.

The KVK's strategy was effective because it first built a foundation of trust through traditional, high-touch methods. The initial use of PRA ensured that the intervention was addressing a farmer-identified "felt need," creating immediate buy-in. The On-Farm Trials and Front-Line Demonstrations served as powerful, tangible proof of concept. By allowing farmers to see the results on their own or their neighbors' animals, the KVK transformed an abstract scientific recommendation into a credible, localized success story. This hands-on, participatory approach is essential for establishing the credibility of the extension agency and its message.

This foundation of trust was then leveraged for scale and reinforcement using modern, low-touch digital tools. The WhatsApp group created a space for continuous engagement, allowing farmers to ask questions as they arose and to share their own positive experiences, which served as powerful peer-to-peer testimonials. The periodic SMS advisories acted as a constant, low-cost reinforcement mechanism. This hybrid model—using traditional methods to prove and persuade, and digital methods to scale and support—is a highly effective and resource-efficient strategy for modern extension. It addresses the need for both deep engagement and broad reach, a combination that recent extension research suggests yields the most significant and lasting changes in farming practices.[31]

5.3 Situating the Findings within Contemporary Dairy Science and Extension Research (2021-2024)

The findings of this case study make a valuable contribution by providing a micro-level illustration of macro-level trends observed in contemporary dairy and extension science. The magnitude of the milk yield increase (16.9%) and the improvement in economic returns are highly consistent with the results of numerous other recent on-farm trials conducted across different regions of India, which have reported similar gains from mineral supplementation.[22] This consistency across diverse agro-ecological zones strengthens the generalizability of the conclusion that subclinical mineral deficiency is a widespread and significant limiting factor for dairy productivity in India.

Furthermore, this study provides a granular, mechanistic explanation for the broader findings of national-level impact assessments of the KVK system. Large-scale econometric studies have successfully demonstrated *that* KVKs have a positive and significant impact on farm household income, with one major study quantifying this impact as a ~17% increase in net farm income.[21] This case study, in turn, demonstrates

how that impact is generated on the ground. It shows the process through which a KVK identifies a specific, high-impact local problem (nutritional deficiency), validates a targeted solution through rigorous on-farm

science (the OFT), and promotes its adoption through a carefully designed, participatory extension strategy. By connecting a specific KVK intervention to a quantifiable increase in farmer profitability, this study serves as a powerful piece of evidence that explains the processes underlying the aggregate positive outcomes observed in national surveys. It thus elevates the discussion from a simple case study to an empirical example that informs and enriches the national policy discourse on the role and effectiveness of agricultural extension services.

6. Conclusion and Strategic Implications

6.1 Synthesis of Key Findings

This study was undertaken to assess a targeted nutritional intervention aimed at enhancing the profitability of dairy buffalo farming for smallholders in Farrukhabad district, Uttar Pradesh. The research yields two clear and significant conclusions.

First, the supplementation of a balanced concentrate mixture combined with an area-specific mineral mixture (T3) to the traditional diet of lactating Murrah/Graded Murrah buffaloes leads to a statistically significant and economically substantial improvement in performance. This intervention resulted in a 16.9% increase in average daily milk yield and yielded a Benefit-Cost Ratio of 1.42, far superior to the 1.18 observed under traditional farmer practices. This confirms that correcting subclinical nutritional deficiencies is a highly effective and profitable strategy for unlocking the genetic potential of high-yielding dairy animals in the region.

Second, the KVK's hybrid extension model, which integrated traditional, trust-building fieldwork (PRA, OFTs, FLDs) with modern, scalable digital communication tools (WhatsApp, SMS advisories), proved to be a highly efficacious methodology for technology transfer. This approach not only ensured the successful adoption of the practice among trial participants but also catalysed a process of spontaneous, horizontal diffusion to the wider farming community, demonstrating its power to overcome long-standing knowledge and practice gaps.

6.2 Recommendations for Scaling Up Profitable Dairy Practices in Uttar Pradesh

The compelling findings of this study give rise to a set of actionable recommendations for policymakers, extension agencies, and other stakeholders involved in the dairy value chain in Uttar Pradesh and other similar regions.

1. **Policy-Level Integration:** The Animal Husbandry Department of the Government of Uttar Pradesh should formally recognize the correction of mineral deficiencies as a high-priority, high-impact area for dairy development. It is recommended that the promotion and use of area-specific mineral mixtures be integrated into all state-level dairy development programs. This could be operationalized through initiatives such as providing a subsidy on mineral mixtures distributed through the network of dairy cooperatives and veterinary hospitals, thereby ensuring both affordability and accessibility for smallholder farmers.
2. **Adoption of a Hybrid Extension Strategy:** Krishi Vigyan Kendra and other public and private extension agencies across the state should be encouraged and trained to adopt a hybrid extension model. This model should use participatory, evidence-generating field activities like OFTs and FLDs as "lighthouse" demonstrations to build trust and prove the technology's local viability. Subsequently, digital platforms—including mobile applications, social media groups, and targeted SMS/voice messaging—should be systematically employed to amplify the message, scale up the dissemination of these proven results to a mass audience, and provide ongoing advisory support in a cost-effective manner.

3. **Strengthening Institutional Linkages:** To ensure the long-term sustainability of this intervention, it is crucial to strengthen the linkages between key institutions. A tripartite collaboration should be fostered between KVKs (as knowledge and demonstration hubs), dairy cooperatives (as aggregation and input supply channels), and private sector feed manufacturers. This collaboration would ensure a stable, quality-assured supply chain for scientifically formulated balanced concentrate feeds and area-specific mineral mixtures, making the recommended practice easily accessible to farmers at the village level.

6.3 Future Directions for Research

While this study provides robust evidence for the efficacy of the tested intervention, it also opens up several avenues for future research that could further refine and optimize dairy farm management in the region.

- **Longitudinal Impact Assessment:** Future research should undertake longitudinal studies to track the long-term effects of balanced nutrition. This would allow for an assessment of the impact on crucial reproductive parameters such as conception rates, inter-calving intervals, and the overall productive life of the animals, which have significant long-term economic implications.
- **Development of Advanced Digital Tools:** There is a need for research and development into more sophisticated digital extension tools. This could include the creation of AI-driven mobile applications that provide personalized feed advisories based on the animal's lactation stage, body condition, and the local availability of fodder resources.
- **Fodder System Intensification:** While this study focused on supplementation, a critical area for future work is the improvement of the basal diet itself. Research on the intensification of fodder production systems, including the promotion of hydroponic fodder, silage making, and the cultivation of perennial fodder grasses, is essential for ensuring year-round nutritional security for livestock and reducing reliance on purchased inputs.

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