THE ROLE OF ARTIFICIAL INTELLIGENCE AND DRONES IN SILAGE AND CATTLE NUTRITION

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ABSTRACT

A newly initiated research project (NAZV QL26010434, 2026–2030) is developing an integrated system combining artificial intelligence (AI) and unmanned aerial vehicles (UAVs) for optimisation across the entire forage production chain – from crop cultivation through ensiling to cattle feeding. The consortium (Institute of Animal Science Prague-Uhříněves, NutriVet Ltd., Brno University of Technology) addresses critical gaps in current precision agriculture by creating a closed-loop data integration platform linking field monitoring, fermentation control, and feed optimisation.

Keywords: unmanned aerial vehicles, precision agriculture, machine learning, IoT sensor networks, forage quality prediction

INTRODUCTION

Precision agriculture has revolutionised crop production through GPS guidance, variable-rate technology, and remote sensing, yet the forage conservation chain – from field to feed-out – has remained largely outside the scope of integrated digital systems. Individual components have been studied separately: UAV-based biomass estimation (Hunt *et al.*, 2019), IoT sensor networks for fermentation monitoring (Nishida *et al.*, 2021), and machine learning for silage quality prediction (Ferraretto *et al.*, 2020, Janoušek *et al.*, 2023). However, no end-to-end system linking field data to fermentation management and then to feed ration optimisation has been validated in practice.

This contribution presents project NAZV QL26010434 AISilageFeeding (2026–2030), funded by the Czech Ministry of Agriculture under the ZEMĚ II applied research programme. The project builds on earlier NAZV work (QK1810137 on precision agriculture in silage and cattle feeding) and introduces a genuinely integrated data management system.

MATERIAL AND METHODS

The project is structured as a 5-year multi-institutional effort with clearly defined roles. The Institute of Animal Science (VÚŽV) leads fermentation biology, nutritional analysis, and animal performance trials. NutriVet Ltd. provides applied expertise in cattle nutrition, ration formulation, and practical farm integration. The Faculty of Electrical Engineering and Communication at Brno University of Technology (VUT) contributes sensor hardware development and wireless protocols.

The methodological framework encompasses five integrated components described in Table 1. AI model development follows a structured three-phase approach: (a) training on historical fermentation databases and laboratory experiments (60% of dataset); (b) validation on independent data withheld from training (20%); and (c) field testing under real farm conditions (20%). Model performance is evaluated using RMSE, MAE, and R^2 metrics. Target accuracies are: nutritional parameter prediction >90%, harvest timing ±2 days, fermentation pH prediction ±0.1.

RESULTS AND DISCUSSION (PRELIMINARY)

The project was launched in early 2026. Preliminary activities focus on three foundational tasks. First, the sensor integration architecture has been designed: low-power IoT nodes measuring pH, temperature, moisture and volatile metabolite proxies, communicating via LoRaWAN with 15-minute sampling intervals and a target battery life of ≥60 days in challenging silage-pit conditions. Second, historical fermentation databases from VÚŽV (>15 years of silage records, including continuous DS1922L temperature monitoring data from recent projects) are being structured for baseline AI model training. Third, the UAV flight protocol for multispectral crop monitoring has been specified, combining RGB and multispectral (NDVI, NDRE) imaging for maize and grass forage crops.

These activities build directly on established research conducted within the consortium. The integration of precision livestock farming tools with dairy herd management has been validated in practice (Loučka *et al.*, 2023), and on-farm comparisons of portable NIR spectrometry with laboratory chemical analysis for maize quality assessment have provided both methodological insight and experimental datasets suitable for AI model training (Loučka *et al.*, 2022). Together, these studies demonstrate that digital monitoring tools can reliably capture the variability in forage quality that the AISilageFeeding system is designed to predict and optimise.

Tab. 1: Project components, technical approaches and expected outputs

Component	Technical approach	Expected output / milestone
UAV multispectral monitoring	RGB + multispectral cameras; NDVI/NDRE indices; GPS-tagged data collection	Optimal harvest timing model; targeted additive application maps
Wireless sensor networks	pH (±0.05), temperature (±0.2 °C), moisture (±2%), volatile metabolites; 15-min interval; 60-day battery	Continuous fermentation profile; anomaly alerts; data stream for ML training
Machine learning algorithms	60% training / 20% validation / 20% field testing; RMSE, MAE, R^2 metrics; target >90% accuracy	Predictive models for nutritional parameters, harvest timing (±2 days), fermentation pH (±0.1)
Dynamic feed optimization	Real-time silage quality data + individual animal records (milk yield, lactation stage, health)	Personalized TMR formulation; ≥5% feed cost reduction; ≥15% additive savings
Integration platform	Cloud-based data aggregation from UAVs, sensors, labs, dairy management systems	Unified dashboard; economic ROI models per farm size; functional sample

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Tab. 2: Project timeline, partner responsibilities, and key deliverable milestones

Year	Component	Technical approach	Expected output / milestone
2026	Fermentation assessment methodology; baseline database	Sensor samples; UAV integration; network architecture	AI fermentation methodology (6/2026); sensor testing (9/2026)
2027	Full fermentation monitoring; silage quality database	Optimised sensors; data measurement; economic analysis	First predictive models (9/2027); ≥5% feed cost reduction demonstrated
2028	Semi-pilot experiments; feed ration trials	Model validation; functional prototype build	Integrated system samples; >90% prediction accuracy validated
2029–2030	On-farm validation; animal performance assessment	Commercial-scale testing; economic modelling	ROI models; utility model patents; extension publications

The innovation of the AISilageFeeding system lies in its end-to-end data linkage. UAV-derived pre-harvest data (crop maturity indices, spatial variability maps) will inform not only harvest timing but also fermentation management decisions – for example, directing higher additive doses to zones with elevated moisture or disease risk. In turn, fermentation sensor data will drive real-time feed ration adjustments, connecting silage quality monitoring to dairy herd nutrition management. This closed-loop architecture is conceptually distinct from existing partial systems such as Dairy Precision Farming (Netherlands) or John Deere GrowSmart (USA), which address individual phases in isolation.

Economic modelling, initiated in Year 1, projects that integration of AI-assisted harvest timing and targeted additive application alone could reduce additive costs and improve NEL on farms >500 ha. For a herd of 100 dairy cows consuming 15 kg DM silage/day, a 0.3 MJ/kg DM improvement translates to approximately 0.4–0.6 kg additional milk per cow per day, representing a substantial economic benefit during the 180-day winter feeding period. Full ROI models stratified by farm size will be delivered by end of Year 2 (December 2027).

CONCLUSION

Project AISilageFeeding (NAZV QL26010434) represents the first comprehensive attempt to integrate AI and UAV technologies across the complete forage production and utilisation chain in Czech conditions. The project addresses four critical knowledge gaps: (1) end-to-end data integration from field to feed-out, (2) predictive modelling of fermentation outcomes from pre-harvest UAV data, (3) real-time adaptation of feed rations to actual measured silage quality, and (4) economic quantification of precision forage management benefits across farm size categories. Targeting >90% prediction accuracy for nutritional parameters and ≥5% feed cost savings, the system will deliver functional on-farm prototypes by 2028 and commercially applicable tools by 2030. The closed-loop optimisation architecture – where field monitoring data inform fermentation management and fermentation outcomes drive feed formulation – is unprecedented in forage conservation research and directly responds to the challenges of climate change adaptation, resource efficiency, and precision livestock nutrition.

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