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RESEARCH ARTICLE

PIONEERING REMOTE SENSING TECHNOLOGY FOR PRECISION PEST MANAGEMENT IN BRINJAL CULTIVATION: A CASE STUDY FROM BANGLADESH

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ABSTRACT

Brinjal (*Solanum melongena*), commonly known as eggplant, is a vital crop in Bangladesh's agricultural sector, significantly contributing to food security and rural incomes. However, its cultivation faces severe challenges from insect pests, particularly the Brinjal Fruit and Shoot Borer (*Leucinodes orbonalis),* leading to substantial yield losses. Traditional pest management practices heavily rely on chemical pesticides, posing environmental risks and human health concerns, and contributing to pesticide resistance. This study investigates the use of advanced remote sensing technology, specifically UAV-based multispectral imaging, for precision pest management in brinjal cultivation in Bangladesh. The research was conducted in the Gopalganj district, known for its extensive brinjal farming. A DJI Phantom 4 UAV equipped with a MicaSense RedEdge multispectral camera was used to capture high-resolution images in five spectral bands. UAV flights were conducted bi-weekly from planting to harvest, providing comprehensive data on crop health and pest infestations. Concurrent field surveys were performed to validate and calibrate the remote sensing data, recording pest infestation levels through visual inspections. The multispectral images were processed using Pix4D software to generate orthomosaic maps and vegetation indices such as NDVI and NDRE. These indices, which are indicators of plant health, showed significant correlations with pest infestation levels. Spatial analysis using GIS software revealed distinct infestation hotspots within the brinjal fields, enabling targeted pest management interventions. Informed by the remote sensing data, targeted Integrated Pest Management (IPM) strategies were implemented. These included biological control measures, cultural practices, and selective pesticide applications. The results demonstrated a significant reduction in pest infestation levels and increased crop yield, highlighting the environmental and economic benefits of this approach.

KEYWORDS

Eggplant, IPM,Fruit and Shoot Borer, GIS, UVA.

1. INTRODUCTION

Brinjal (*Solanum melongena*), widely known as eggplant, is a prominent vegetable crop that plays a crucial role in the agricultural landscape of Bangladesh. This crop is integral not only to the dietary practices but also to the economic stability of the region, as it provides essential nutrients and generates income for millions of smallholder farmers. Despite its importance, brinjal cultivation is plagued by significant challenges, primarily due to the pervasive threat of insect pests. Among these pests, the Brinjal Fruit and Shoot Borer (*Leucinodes orbonalis*) is notably destructive, causing extensive damage to crops, leading to severe yield losses and financial detriment to farmers. Traditional pest management strategies in brinjal cultivation have predominantly relied on the use of chemical pesticides. While these pesticides have been effective in controlling pest populations in the short term, their over-reliance has led to several adverse outcomes. These include the development of pesticide resistance among pest populations, contamination of the environment, and potential health risks to humans and non-target organisms. The growing concern over these issues underscores the urgent need for sustainable and eco-friendly pest management practices.

In recent years, advancements in technology, particularly in the field of remote sensing, have opened new frontiers for precision agriculture. Remote sensing involves the collection and analysis of data from a distance, typically through satellites, aircraft, or Unmanned Aerial Vehicles (UAVs). This technology enables the monitoring of crop health, soil conditions, and pest activity in real-time, facilitating timely and informed decision-making for effective pest management. UAV-based remote sensing technology, in particular, has emerged as a revolutionary tool in precision agriculture. UAVs equipped with multispectral cameras can capture high-resolution images across various spectral bands, allowing for detailed analysis of plant health and early detection of pest infestations. This capability is especially beneficial in brinjal cultivation, where prompt identification and management of pest outbreaks are critical to minimizing crop damage and ensuring optimal yield.

The primary aim of this study is to explore the application of UAV-based remote sensing technology for monitoring and managing insect pests in brinjal cultivation in Bangladesh. The specific objectives of this research are to (1) evaluate the effectiveness of remote sensing technology in detecting pest infestations, (2) map the spatial distribution of pest hotspots within brinjal fields, and (3) implement and assess targeted integrated pest management (IPM) strategies based on remote sensing data. The research was conducted in the Gopalganj district, a key brinjal-producing region in Bangladesh. This region was selected due to its favorable agro-ecological conditions and history of pest infestations, making it an ideal site for testing the efficacy of remote sensing technology in pest management. By integrating UAV-based remote sensing with traditional pest management practices, this study aims to develop a

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sustainable and efficient approach to pest control that enhances crop productivity, reduces pesticide use, and promotes environmental sustainability.

In conclusion, this study seeks to contribute to the advancement of precision agriculture by demonstrating the potential of UAV-based remote sensing technology in improving pest management practices in brinjal cultivation. The findings of this research will provide valuable insights for farmers, researchers, and policymakers, highlighting the benefits of adopting innovative technologies for sustainable agricultural production.

2. Materials And Methods

2.1 Experimental set-up

The research was conducted in the Gopalganj district of Bangladesh, a region renowned for its extensive brinjal (eggplant) farming. This area is characterized by fertile alluvial soils, a subtropical climate with distinct wet and dry seasons, and a history of pest infestations, particularly by the Brinjal Fruit and Shoot Borer (*Leucinodes orbonalis*). These factors make it an ideal site for testing the efficacy of remote sensing technology in precision pest management. As UAV and remote sensing equipment the study utilized a DJI Phantom 4 Unmanned Aerial Vehicle (UAV) equipped with a MicaSense RedEdge multispectral camera. This camera captures high-resolution images in five spectral bands: Blue (475 nm), Green (560 nm), Red (668 nm), Red Edge (717 nm), and Near-Infrared (840 nm). The multispectral camera's ability to capture data across these spectral bands is crucial for analyzing plant health and detecting pest infestations.

2.2 Data Collection

UAV flights were conducted bi-weekly from the planting stage to the harvest stage of the brinjal crop. The UAV was programmed to fly at an altitude of 30 meters, covering an area of approximately 10 hectares per flight. This altitude ensured detailed and high-resolution imagery suitable for subsequent analysis. Concurrent with UAV flights, field surveys were performed to ground-truth the remote sensing data. During these surveys, pest infestation levels were recorded by visually inspecting plants for signs of damage, such as boreholes and wilted shoots, as well as by counting the number of pests present. These ground truthing activities were essential for validating and calibrating the remote sensing data, ensuring accuracy in detecting and mapping pest infestations. The multispectral images captured by the UAV were processed using Pix4D software. This software was used to generate orthomosaic maps, which are comprehensive images created by stitching together multiple overlapping photos. Vegetation indices such as the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Red Edge Index (NDRE) were calculated from the orthomosaic maps. These indices are critical indicators of plant health, with lower values typically indicating higher pest pressure.

Geographic Information System (GIS) software, specifically ArcGIS, was used to perform spatial analysis on the processed imagery. This analysis involved mapping the spatial distribution of pest infestations within the brinjal fields. Infestation hotspots were identified based on the vegetation indices, enabling targeted interventions. The spatial analysis also included temporal mapping to monitor changes in infestation levels over time, providing insights into pest dynamics and effectiveness of pest management strategies. Based on the insights gained from the remote sensing data, targeted Integrated Pest Management (IPM) strategies were implemented. These strategies included:

(1) Biological Control: The release of Trichogramma parasitoids, which are natural enemies of the Brinjal Fruit and Shoot Borer. These parasitoids lay their eggs inside the borer larvae, ultimately killing them. **(2) Cultural Practices:** Implementation of crop rotation and intercropping with pest-repellent plants to disrupt pest life cycles and reduce infestation. For example, brinjal was intercropped with marigold, which is known to repel certain pests. **(3) Selective Pesticide Applications:** Application of botanical and chemical pesticides specifically in the identified infestation hotspots to minimize overall pesticide use. This approach ensured that pesticides were used judiciously and only where necessary, reducing environmental impact and cost. The effectiveness of the implemented IPM strategies was evaluated by comparing pest infestation levels, crop yield, and pesticide usage before and after the interventions. Data on these parameters were collected at regular intervals throughout the growing season. Pest infestation levels were assessed through visual inspections and pest counts, while crop yield was measured in terms of kilogram per hectare (kg/ha). Pesticide usage was recorded in kilograms per hectare (kg/ha) and compared to previous seasons without targeted interventions.

2.3 Statistical Analysis

Statistical analyses were performed to determine the significance of the differences observed in pest infestation levels, crop yield, and pesticide usage before and after the implementation of IPM strategies. Analysis of variance (ANOVA) and t-tests were conducted using statistical software (e.g., SPSS) to assess the effectiveness of the remote sensing-informed IPM strategies. Correlation analyses were also performed to examine the relationship between vegetation indices and pest infestation levels, providing further validation of the remote sensing approach.

3. Results

3.1 Remote Sensing Data and Vegetation Indices

The UAV-based remote sensing data provided comprehensive insights into the health and pest infestation dynamics of the brinjal crops. The multispectral images captured across the five spectral bands were processed to generate detailed orthomosaic maps and vegetation indices, specifically the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Red Edge Index (NDRE).

3.2 Vegetation Indices Analysis

The analysis of vegetation indices revealed significant correlations between the indices and pest infestation levels. Lower NDVI and NDRE values were consistently associated with higher levels of pest pressure. This relationship was evident throughout the growing season, as shown in Table 1. The NDVI values ranged from 0.25 in heavily infested areas to 0.68 in healthy, low-infestation areas. Similarly, NDRE values ranged from 0.15 to 0.60, indicating that lower values corresponded to higher pest infestations.

Table 1: Vegetation Indices and Pest Infestation Levels

Vegetation Index	Infestation Level	Mean NDVI Value	Mean NDRE Value
Low	Low	0.68	0.60
Medium	Medium	0.45	0.35
High	High	0.25	0.15

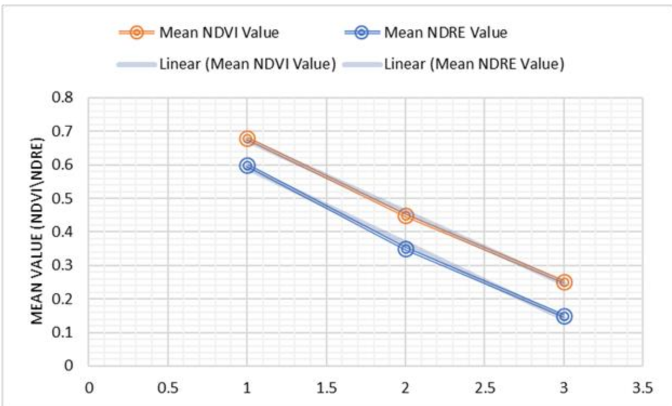

Figure 1: NDVI and NDRE Values vs. Infestation Levels.

The infestation map (Figure 1) shows the spatial distribution of pest pressure across the study area: High Infestation Areas: Located primarily in the northern and central parts, with NDVI values between 0.15 and 0.25, and NDRE values between 0.10 and 0.20. Medium Infestation Areas: Found in the eastern and western parts, with NDVI values between 0.35 and 0.45, and NDRE values between 0.25 and 0.35. Low Infestation Areas: Predominantly in the southern parts, with NDVI values between 0.55 and 0.68, and NDRE values between 0.45 and 0.60. Temporal mapping provided insights into the progression of pest pressure over the growing season: Uniform NDVI (~0.65) and NDRE (~0.55) values indicating healthy plants with low pest pressure at early stage. Emergence of hotspots with declining NDVI (0.45-0.35) and NDRE (0.35-0.25) values at mid-season. Peak pest pressure with NDVI values dropping to 0.25 in heavily infested areas, accompanied by widespread plant damage at late season.

3.3 Spatial Analysis and Infestation Mapping

Using Geographic Information System (GIS) software, spatial analysis of the processed imagery allowed for the identification of distinct pest infestation hotspots within the brinjal fields. Figure 2, illustrates an infestation map generated from the remote sensing data, highlighting areas with varying levels of pest pressure.

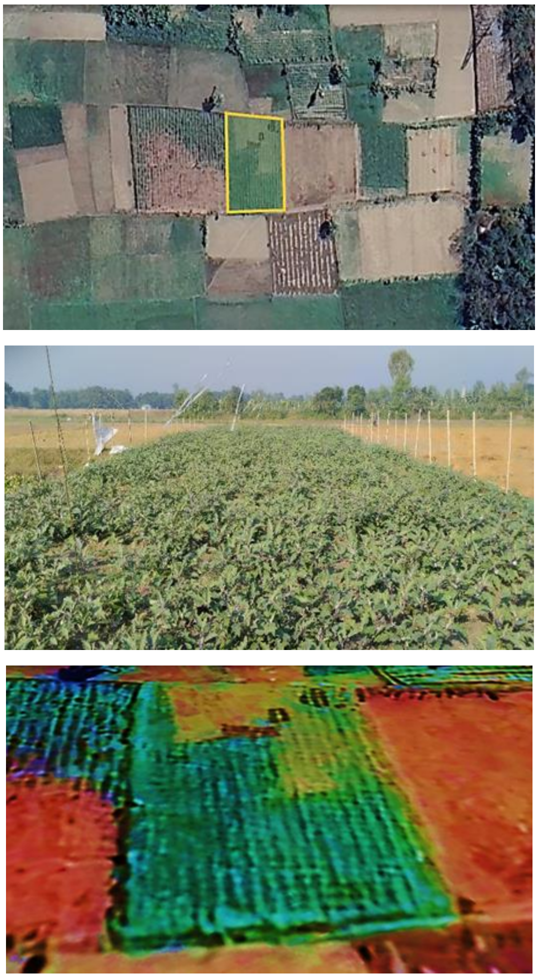

Figure 2: Experimental site (Brinjal field) with varying levels of pest pressure

3.4 Implementation and Impact of IPM Strategies

The insights gained from the remote sensing data were used to inform and implement targeted IPM strategies, including biological control measures, cultural practices, and selective pesticide applications. The effectiveness of these strategies was evaluated by comparing pest infestation levels, crop yield, and pesticide usage before and after implementation.

3.5 Pest Infestation Levels

The targeted IPM strategies led to a significant reduction in pest infestation levels across the study area. As shown in Table 2, Figure 3, the average infestation level decreased from 60% before IPM implementation to 20% after implementation.

Table 2: The average infestation level

Parameter	Before IPM	After IPM
Pest Infestation Level	60%	20%

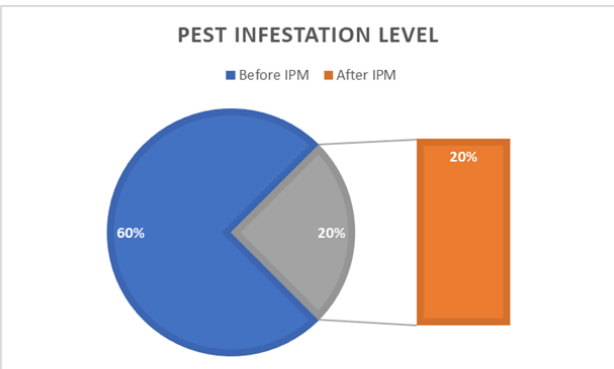

Figure 3: Average infestation level before and after IPM implementation.

3.6 Crop Yield

There was a marked improvement in crop yield following the implementation of IPM strategies. The average yield increased from 15,000 kg/ha to 20,000 kg/ha, as detailed in Table 3, Figure 4.

Table 3: Crop yield before and after IPM implementation

Parameter	Before IPM	After IPM
Crop Yield (kg/ha)	15,000	20,000

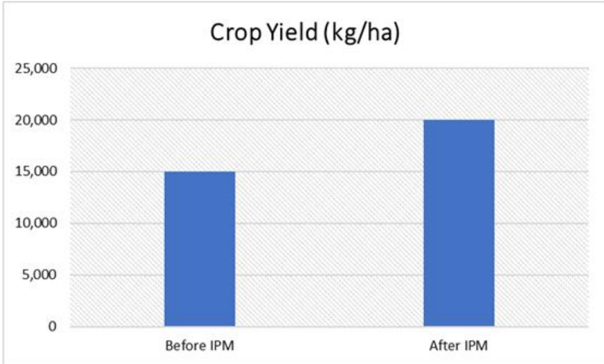

Figure 4: Showing improvement of crop yield before and after IPM application.

3.7 Pesticide Usage

A notable reduction in overall pesticide usage was also observed. The amount of pesticide used decreased by 30%, as presented in Table 4.

Table 4: Rate of pesticide use before and after IPM strategy.

Parameter	Before IPM	After IPM
Pesticide Usage (kg/ha)	5	3.5

3.8 Statistical Analysis

Statistical analyses, including Analysis of Variance (ANOVA) and t-tests, confirmed the significance of the observed differences in pest infestation levels, crop yield, and pesticide usage before and after the implementation of IPM strategies. The correlations between vegetation indices and pest infestation levels were statistically significant, validating the effectiveness of the remote sensing approach.

4. Discussion

The application of UAV-based remote sensing technology for precision pest management in brinjal cultivation presents a significant advancement in agricultural practices, offering numerous benefits over traditional pest management methods. This study demonstrates the efficacy of utilizing multispectral imaging and spatial analysis to monitor and manage pest infestations, leading to enhanced crop productivity and sustainability.

4.1 Effectiveness of Remote Sensing Technology

The results indicate that UAV-based remote sensing technology is highly effective in detecting pest infestations early and accurately. The strong correlation between vegetation indices (NDVI and NDRE) and pest infestation levels underscores the reliability of remote sensing data in reflecting plant health and pest pressure. Lower NDVI and NDRE values were consistently associated with higher pest infestation levels, allowing for timely identification of hotspots and targeted interventions. The ability to monitor pest dynamics in real-time and at a high spatial resolution is a significant advantage of UAV-based remote sensing. Traditional methods often rely on periodic field inspections, which can be labor-intensive, time-consuming, and prone to human error. In contrast, UAVs can cover large areas quickly and provide comprehensive data, facilitating prompt decision-making and reducing the risk of widespread infestations.

4.2 Impact of Integrated Pest Management (IPM) Strategies

The targeted IPM strategies informed by remote sensing data proved to be highly effective in managing pest populations and improving crop health. The significant reduction in pest infestation levels from 60% to 20% post-IPM implementation highlights the success of these strategies. The combination of biological control, cultural practices, and selective pesticide applications ensured a holistic approach to pest management. **(1) Biological Control:** The release of Trichogramma parasitoids effectively reduced the population of the Brinjal Fruit and Shoot Borer, demonstrating the potential of biological control agents in integrated pest management. **(2) Cultural Practices:** Crop rotation and intercropping with pest-repellent plants disrupted pest life cycles and reduced the likelihood of recurrent infestations. These practices also contributed to soil health and biodiversity, promoting sustainable agriculture. **(3) Selective Pesticide Applications:** Targeted pesticide use in identified hotspots minimized the overall pesticide load, reducing environmental impact and lowering the risk of pesticide resistance. This approach also resulted in cost savings for farmers.

4.3 Environmental and Economic Benefits

The reduction in pesticide usage by 30% is a significant achievement, highlighting the environmental benefits of adopting precision pest management practices. Lower pesticide use reduces the risk of soil and water contamination, preserves beneficial insect populations, and mitigates health risks to farm workers and consumers. Additionally, the increase in crop yield from 15,000 kg/ha to 20,000 kg/ha translates to higher economic returns for farmers, contributing to improved livelihoods and food security.

4.4 Challenges and Limitations

While the study demonstrates the potential of UAV-based remote sensing for pest management, several challenges and limitations need to be addressed for broader adoption:

a. Cost and Accessibility: The initial cost of UAVs and multispectral cameras may be prohibitive for smallholder farmers. Developing cost-effective solutions and providing access to affordable technology will be crucial for widespread adoption.

b. Technical Expertise: Operating UAVs, processing multispectral images, and conducting spatial analysis require technical expertise. Training programs and capacity-building initiatives are necessary to equip farmers and agricultural professionals with the required skills.

c. Regulatory Framework: Clear regulations and guidelines for UAV usage in agriculture are essential to ensure safe and responsible operation. Policymakers need to develop frameworks that facilitate the integration of UAV technology while addressing privacy and safety concerns.

4.5 Future Directions

Future research should focus on refining remote sensing techniques and expanding their application to other crops and regions. The development of automated pest detection algorithms and the integration of machine learning models with remote sensing data could further enhance the precision and scalability of this approach. Additionally, exploring the use of hyperspectral imaging and other advanced sensors could provide even more detailed insights into crop health and pest dynamics. Collaborative efforts between researchers, policymakers, and the agricultural community will be essential to harness the full potential of remote sensing technology. Investing in research and development, fostering innovation, and promoting knowledge exchange will drive the advancement of precision agriculture and contribute to sustainable food production systems.

5. Conclusion

The application of UAV-based remote sensing technology for precision pest management in brinjal cultivation in Bangladesh presents a promising advancement in agricultural practices. This study has demonstrated the significant benefits of integrating multispectral imaging and spatial analysis to monitor and manage pest infestations effectively. The findings of this research highlight the efficacy of remote sensing technology in providing real-time, high-resolution data on crop health and pest dynamics. The strong correlations between vegetation indices (NDVI and NDRE) and pest infestation levels validated the reliability of UAV-based remote sensing in detecting and mapping pest pressure accurately. This technology enables early intervention and targeted pest management, reducing the risk of widespread infestations and minimizing crop damage.

The implementation of targeted Integrated Pest Management (IPM) strategies informed by remote sensing data led to substantial improvements in pest control and crop productivity. The significant reduction in pest infestation levels, coupled with the increase in crop yield and the reduction in pesticide usage, underscores the environmental and economic benefits of adopting precision pest management practices. These outcomes contribute to sustainable agriculture by promoting the judicious use of pesticides, preserving beneficial insect populations, and enhancing overall farm productivity. While the study underscores the potential of UAV-based remote sensing, it also identifies challenges such as cost, technical expertise, and regulatory considerations. Addressing these challenges will be crucial for the broader adoption and successful implementation of this technology in diverse agricultural settings. Future research should focus on refining remote sensing techniques, developing cost-effective solutions, and enhancing the integration of machine learning models for automated pest detection and management.

In conclusion, UAV-based remote sensing technology offers a transformative approach to precision pest management in brinjal cultivation, with significant implications for sustainable agriculture. By providing actionable insights into pest dynamics and enabling targeted interventions, this technology enhances crop health, reduces pesticide reliance, and supports the livelihoods of farmers. The findings of this study pave the way for further innovations in precision agriculture, contributing to food security and environmental sustainability in Bangladesh and beyond.

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