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Application of geospatial technologies towards pest management in agriculture

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Abstract

Agriculture plays a foremost role in the progress of the Indian economy's contribution. Agricultural production is threatened by various factors around the agricultural ecosystem such as abiotic and biotic factors. Under biotic living organisms, pests and disease are significant makes damage on different stages of crops and reducing the crop yield and income. Pest monitoring, forecasting, and management tactics have been assimilated part of the crop production system to manage pests. The extensive adoption of geospatial technologies, which include remote sensing and geographic information systems (GIS), has resulted in a notable paradigm change in the area of pest control in recent years. This review article explores the foundational ideas and processes of remote sensing and GIS, with a particular emphasis on their uses in agricultural pest control. Geospatial technologies provide real-time and accurate information on pest infestations, their geographical distribution, and the variables driving their dynamics, opening up a multitude of potential in pest control. This helps farmers and other agricultural stakeholders to build timely pest management programs and make educated decisions. Additionally, these technologies provide early warning systems, making it possible to take preventative steps against prospective insect outbreaks, decreasing the need for chemical pesticides and lowering their environmental effect. In conclusion, the present paper highlights how geospatial technologies, in particular remote sensing and GIS, have fundamentally changed agricultural pest control tactics. Utilizing these technologies has the potential to increase agricultural output, sustainability, and resilience to pest-related concerns.

Keywords: Remote sensing, geographic information systems, agriculture, pest management, early warning

1. Introduction

The modern agricultural landscape is marked by an unprecedented surge in human population, precipitating a dire need for the substantial augmentation of agricultural production (Seelan *et al.*, 2003) [13]. Concurrently, the globalization of trade and the facilitated exchange of pests, weeds, and disease agents across borders (Oerke, 2006) [8] has led to an alarming proliferation of crop pests worldwide. The deleterious consequences of these pests on crop yields and, consequently, on agricultural incomes, are acutely felt. Mitigating such losses hinges upon our ability to gain early insights into pest incidences, thereby enabling the timely deployment of effective control measures.

Within the realm of plant protection technologies, there is a resolute emphasis on curtailing the impact of major pests, a strategic imperative to achieve sustainability in agriculture (Pratap *et al.*, 2000) [10]. In recent years, the integration of geospatial technology into pest management strategies has given rise to a novel concept - pest forecasting. This practice involves the prediction of future trends in pest populations and encompasses a spectrum of activities aimed at informing and empowering the farming community. By providing early estimates of insect pest populations and prescribing appropriate control measures, pest forecasting has become an indispensable component of Integrated Pest Management (IPM) strategies.

In the pursuit of enhancing our pest management capabilities, remote sensing emerges as a pivotal science. It encompasses the collection of information about objects or phenomena through the analysis of data acquired by instruments devoid of any direct contact with the subject under scrutiny on the Earth's surface (Prabhakar *et al.*, 2012) [9]. The precision, speed, and accuracy afforded by remote sensing far surpass the capabilities of human visual assessments when it comes to detecting plant responses to biotic stresses. It leverages instruments capable of measuring and recording changes in electromagnetic radiation, providing a superior means of identifying and quantifying biotic stressors, including pest and disease infestations, compared to conventional visual methods.

Among the many applications of remote sensing, its role in the agricultural crop production system stands as one of the most promising. Geospatial technologies, including remote sensing and geographic information systems (GIS), have revolutionized the acquisition of critical information pertaining to crop identification, area measurement, stress assessment, pest damage evaluation, and pest forecasts in agriculture. This review comprehensively explores the application and integration of geospatial technologies, particularly remote sensing and GIS, in the domain of agricultural pest management, with a specific focus on the advances made within the context of Indian agriculture.

2. Principle and methodology of remote sensing and geographic information system

The propagation of electromagnetic energy through the atmosphere occurs as a harmonic wave pattern, characterized by the velocity of light. This wave-like behavior of electromagnetic energy is essential to understanding its movement, although its tangible effects become apparent only when it interacts with matter. Interestingly, electromagnetic energy exhibits dual characteristics, resembling both waves and particles, with discrete units known as photons, possessing attributes such as energy and momentum (Sabins, 1976) [12].

In the realm of remote sensing, the utility of electromagnetic energy becomes evident through the acquisition of data from aerial photographs and satellites, subsequently analyzed to derive valuable information regarding the objects or phenomena under scrutiny. This process encompasses multifaceted operations, including data collection, storage, verification, and visualization within a computer system framework. Satellites serve as pivotal platforms for this endeavor, harnessing energy from self-emission or the vast energy source, the sun, and propagating it through the atmosphere, encountering losses due to absorption and scattering, among other factors.

Crucially, every object within the purview of remote sensing exhibits a unique response to incident electromagnetic energy, primarily contingent on its physical properties. Some objects reflect or scatter a portion of this energy, while others emit radiation based on their temperature and emissivity characteristics. This phenomenon is pivotal in the establishment of spectral signatures, which serve as distinctive patterns for individual objects. For instance, healthy plants typically exhibit a higher reflectance in the near-infrared region and a lower reflectance in the visible region, whereas infested or stressed plants demonstrate an opposite trend. This discrepancy is attributed to variations in chlorophyll content and the absorption of visible light in response to plant stressors.

Geographic information systems (GIS) and remote sensing techniques play a pivotal role in the acquisition and analysis of such crucial information, particularly concerning their application in agriculture and crop pest management. The foundational principles of remote sensing, coupled with the inherent potential to discern spectral variations, enable the identification of stressors and pests in agricultural contexts. This review elucidates the multifaceted role of electromagnetic energy in remote sensing and its invaluable applications in agriculture, underscoring its significance in monitoring and managing crop health and pest-related challenges.

Electromagnetic energy travels through the atmosphere at the speed of light, following a harmonic wave pattern. This wave theory helps us understand how electromagnetic energy moves, but its effects become apparent only when it interacts with physical substances. Electromagnetic energy exhibits characteristics akin to particles, with numerous discrete entities known as photons. These photon particles possess properties resembling those of particles, such as energy and momentum.

3. Application of remote sensing in pest management

Remote sensing emerges as a rapid, non-invasive, and cost-efficient approach for examining the biophysical and biochemical characteristics of vegetation across extensive spatial extents. In areas where traditional maps are unavailable, remote sensing, including aerial photography, offers invaluable ground-level information essential for land-use assessments and various spatial planning activities. Furthermore, it serves as a critical input for modeling alternative land use scenarios, as emphasized by Leeuw *et al*. in 2010. [6].

3.1 Remote sensing

Remote sensing holds significant promise in the realm of research and management, with a particular focus on strategic applications. These strategic applications entail tailored responses to specific conditions that evolve throughout the crop growth cycle, particularly in the context of insect pest management. On the other hand, tactical inquiries often revolve around the dynamic changes occurring within a field, such as the early detection of emerging pest populations. To address this, remote sensing involves the frequent acquisition of images and their comparison with prior images, enabling the detection of alterations within specific locations. Calibration of remotely sensed images is predominantly achieved through the deployment of well-defined reference panels with known properties, which subsequently manifest in the captured images. Notably, the normalized difference vegetation index (NDVI) stands as the most commonly employed index for multispectral data resolution. In the agricultural domain, the utility of remote sensing extends comprehensively to pest monitoring, detection, early warning, and management as follows:

3.1.1 Ecological Assessment and Locust Prediction

In recent years, the strategies employed in controlling Desert Locust infestations have shifted from reactive measures to proactive deterrence, emphasizing the need to identify and manage locust threats before they coalesce into formidable hopper bands and swarms. Achieving this necessitates the continuous monitoring of locust breeding habitats and the rapid deployment of localized control interventions across the 60 nations susceptible to Desert Locust outbreaks. It is only in the current century that our comprehension of Desert Locust behavior and its nexus with the environment has evolved sufficiently to enable enhanced monitoring and control strategies (Tucker *et al*., 1985) [14]. Tucker *et al*. (1985) [14] demonstrated the potential of satellite remote sensing to assess ecological conditions conducive to Desert Locust activity, facilitating better-informed preemptive measures (Acharya & Thapa, 2015) [1]. These remote sensing-based locust data have enabled the prioritization of areas of paramount interest for locust ecology research and proactively managing this species.

3.1.2 Pest Infestation Assessment through Crop Phenology

Various remote sensing techniques have been developed for detecting stress in rice crops induced by infestations of Brown Planthoppers (BPH). Early detection of pest infestations using remote sensing serves as a cornerstone for precision farming practices, offering insights into the health of crops. Utilizing indices such as the Normalized

Difference Vegetation Index (NDVI), Standard Difference Indices (SDI), and Ratio Vegetation Index (RVI) through software tools like ENVI 4.8 and SPSS, researchers can establish thresholds for identifying pest outbreaks (Ghobadifar *et al*., 2014) [3].

3.1.3 Early Detection of Wild Hosts and Population Control

Remote sensing techniques have proven valuable in the early identification of wild host plant areas at the beginning of the season. Additionally, remote sensing aids in detecting pest infestations within cotton fields and assessing crop maturity levels, which are linked to pest populations during the cropping season. Early pest infestation detection can substantially reduce the overall use of pesticides, particularly when employing variable rate application technology, resulting in cost savings for producers.

3.1.4 Identifying Pest Infestation Hotspots in Crops

Preliminary remote sensing studies have successfully revealed distinctive reddish hot spot patterns in cotton fields affected by spider mite infestations, distinguishing them from healthy and drought-stressed cotton crops in 1999. This information holds promise for targeted precision pesticide applications. Given that spider mites and aphids tend to inhabit heterogeneous regions within fields, remote sensing can effectively differentiate them from other sources of variation, primarily by leveraging near-infrared wavelengths (Acharya & Thapa, 2015; Reisig & Godfray, 2006) [1, 11].

3.1.5 Monitoring Conditions Favorable for Pest Outbreaks

The intensification of cultivation practices, monocropping, changing weather patterns, and indiscriminate pesticide use have all contributed to recurrent outbreaks of crop pests and diseases, resulting in substantial crop losses. Mitigating these losses is essential for enhancing grain production. Remote sensing technology plays a crucial role in monitoring extensive areas frequently and assessing weather and ecological conditions conducive to crop pests and disease outbreaks. Parameters such as temperature, relative humidity, sunshine hours, and wind play significant roles in influencing pest population densities and interactions with their natural predators (Acharya & Thapa, 2015) [1].

3.1.6 Surveying Insect Pests of Crops

Aerial photography and computerized area assessment methods have proven instrumental in surveying insect pests of crops. Utilizing photographs captured from various altitudes, researchers have successfully measured the extent and locations of pest attacks. For instance, sooty mold has been employed as an indicator of the presence of corn leaf aphids (*Rhopalosiphum maydis*) and sweet potato whiteflies (*Bemicia tabaci* Glover). Sooty mold induced by whiteflies on cotton plants has been detectable from altitudes of 300 meters, with photographs taken from 2000 meters yielding high-resolution images of mold growth patterns. Moreover, wavelengths in the near-infrared (NIR) spectrum have demonstrated moderate accuracy in predicting aphid and mite infestations in cotton crops (Acharya & Thapa, 2015; Reisig & Godfrey, 2006) [1, 11].

3.1.7 Facilitating Precision Farming

Precision Farming, also known as site-specific crop management (SSCM), represents an integrated approach to farming designed to enhance long-term production efficiency, productivity, and profitability while minimizing unintended impacts on pest and disease infestations through the use of remote sensing tools (Earl *et al*., 1996) [2]. The core principle of Precision Farming revolves around optimizing input resources based on field-specific variability to maximize yields and reduce production costs and environmental impacts. Advances in satellite and aerial hyperspectral imagery have revolutionized the capacity to discern multiple crop characteristics, including pests, diseases, nutrient levels, water availability, weed distribution, biomass, and canopy structure (Acharya & Thapa, 2015) [1].

3.1.8 Rainfall and Pest Outbreak Correlation

Concentrated by convergent winds associated with rain, flying moths, such as the African armyworm (*Spodoptera exempta*), lead to massive outbreaks of destructive caterpillars that ravage crops. Remote sensing techniques for monitoring rainstorms in susceptible areas provide insights into the potential occurrence of outbreaks. This information can be harnessed to implement timely control measures in response to pest outbreaks (Holt *et al*., 2000) [4].

3.2 Geographic Information System (GIS)

Computer systems that acquire, compile, analyse, store, alter, and display spatially related information use Geographic Information Systems as a complete framework. It abstracts the real environment into layers of geographical and attribute data by including spatial coordinates and qualities in a database. These layers stand in for various thematic elements or motifs, which can be combined and examined singly or collectively. For instance, the National Centre for Integrated Pest Management (NCIPM) has used remote sensing and GIS to create district-level geographical maps outlining the spread of rice and cotton pests (Kanojia *et al*., 2000) [5].

3.2.1 Mapping Geographic Pest Distribution with Geographic Information System

GIS provides a useful method for identifying hotspots and mapping the spatial spread of pests. Remote sensing and digital cartography are two main subcategories of GIS technology. Fundamentally, GIS employs data abstractions to represent real-world phenomena analytically, classifying features into thematic layers. Each layer can be assessed independently, and the integration of features across multiple layers facilitates comprehensive analyses. Additionally, remote sensing, in conjunction with GIS, has been employed to monitor changes in crop conditions. Geographical maps at the district level have been developed to chart the distribution of rice and cotton pests (Kanojia *et al*., 2000) [5].

3.2.2 Characterizing Habitat Susceptibility to Outbreaks and Census Data Compilation

Digitized historical maps of defoliation caused by the Douglas-fir tussock moth in British Columbia from 1924 to 1986 have been used to create outbreak frequency maps.

These maps were then overlaid with forest type and biogeoclimatic data to discern correlations between forest type, climate, and outbreak frequency.

3.2.3 Utilizing Insect Census Data with Geographic Information System

GIS has been employed to interpolate gypsy moth trap counts and egg mass densities in an integrated pest management program, aiding in insect census efforts. The mapping of these data is valuable for planning pest suppression activities and has been utilized in the development of GIS-based Desert Locust Management Systems (Liebhold, 1996) [7].

3.2.4 Rainfall and Pest Outbreak Correlation

The aggregation of African armyworm moths, facilitated by convergent winds associated with rain, can lead to mass egg-laying events, resulting in devastating outbreaks of crop-devouring caterpillars. Remote sensing of rainstorms in susceptible regions enables the early detection of potential outbreaks. This information can inform timely pest management strategies (Holt *et al*., 2000) [4].

4. Conclusion

Therefore, the most promising utilization of remote sensing technology lies in its ability to gather data pertaining to agricultural crop production systems. Through the integration of geospatial technology into agriculture, the need for extensive ground sampling diminishes substantially, as it enables the identification and measurement of crop areas, assessment of crop stress, evaluation of pest damage, and the forecasting of pest outbreaks, among other essential parameters. Looking ahead, it becomes evident that the application and integration of geospatial technologies, including remote sensing and geographic information systems, will evolve into even more adept tools for pest management, aligning with the ongoing advancements in Indian agriculture.

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