

The role of geospatial in plant pests and diseases: an overview

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Abstract. Loss in crop production gives a significant impact to food security. The decreasing in crops production has produced imbalance between the food demand of world population and the global agriculture output. There are many factors that may affect agriculture productivity. Abiotic and biotic constrains including water scarcity, poor soils, unsuitable temperatures and the pests, diseases and weeds attacking crops are among the causes that reduce the productivity of food crops. Hence, these lead to the low efficiencies of input use, suppressed crop output, and ultimately reduced food security. The plant pests, diseases and weeds have given significant impact on plant health and causing a great loss in crop production. Therefore, this paper presents a comprehensive review from the available literatures to provide understanding of the role of geospatial technology in combating plant pests and diseases outbreaks. Geospatial data and technologies including Geographic Information System, remote sensing and Global Navigation Satellite System (GNSS) and have been used in collecting, mapping, analysing the distribution and predicting the events. The geospatial technology has been used from the early tasks of surveying the status of crop health until forecasting when the disease likely to be occurred. Although many big challenges are facing by the global and local agricultures to produce good outputs and to secure the world food population, however the rich of geospatial data and advancement of technologies have playing certain roles, particularly assisting the decision makers in forming strategies for combating various pests and diseases that affecting plant health and food crops.

1. Introduction

Malnutrition during the early years is a critical concern because it has the potential to hinder the long-term development of the child and the economic growth of the country [1]. In developing countries, nearly one-third of children are underweight or stunted; meanwhile, undernutrition is the cause of more than one-third of deaths among children under 5 years of age. Undernutrition comprising of micronutrient deficiency, also known as hidden hunger, is due to improper dietary intake and disease, originating from food insecurity, poor maternal child care practices, inadequate access to safe food and clean drinking water, quality health services and sanitation [2]. Furthermore, in 2008 the imbalance between the growing food demand of the world population and global agriculture output, combined with incongruity between supply and demand at the regional, national and locales scales worsened the situation [3].



There are many factors that can affect agriculture productivity. Abiotic and biotic constraints, including water scarcity, poor soils, unsuitable temperatures and crop pests/diseases/weeds, are the cause of reduced productivity of food crops, leading to low efficiencies of input use, suppressed crop output and, ultimately, reduced food security [4]. Furthermore, the climate change has an enormous impact on agriculture productivity and the most affected areas are the LDCs of the tropical zones [5].

Due to the current climate change occurring globally, food production, particularly in agriculture output, is anticipated to decline by 20% by 2080. The situation presents a significant impact on developing countries, including Malaysia, since it still relies on the agricultural sector as the backbone of the country's economic development [5]. Climate change impacts on agricultural commodities, including production and productivity, and negatively affects food supply and food security. Climate change contributes to extreme event, heat stress, droughts and flood, all of which have a profound impact on crop yields. These changes also increase the emergence of new pest and disease outbreaks [5]. Direct yield losses caused by diseases, animals and weeds are estimated to be responsible for losses ranging between 20% and 40% of global agricultural productivity. Plant protection against crop diseases is now playing a vital role to meet the sufficient needs of food quantity and quality

There is a need to modernise the discovery and processes involved in plant protection that are currently challenged by the extent of globalisation. The formalisation of the World Trade Organization (WTO) in 1995 to promote trade liberalisation between intercontinental and intra-continental activities has also increased the biosecurity risks faced by many countries [6]. Openness in import and export trading worldwide facilitates the movement of invasive alien species that disturb the native and exotic plant ecosystems between regions. Both climate change and trade liberalisation have also increased the emergence of new pest and disease outbreaks [7].

However, given the vast of development of technology, there are many ways of overcoming loss in crops yield. Nowadays, the technology of GIS and Remote Sensing are widely used to collect accurate crop information and to analyse the data collected. This paper reviews the role of geospatial technology in tackling the effects of pests and plant disease on plant health. It is envisaged that this paper will provide additional knowledge on how geospatial technology can be implemented in agriculture to combat this problem.

2. Pest and Disease Affecting Plant Health

A plant is said to be healthy or normal when it can perform its physiological activity to the best of its genetic potential. Whenever plants are disrupted by insect pests or pathogens, their physiological functions are intervened with beyond a certain divergence from the usual [8]. Most pest/disease will lower the biomass and, hence, yield. This may happen in four ways. Firstly, by killing the plants, leaving a gap in the stand over ability of neighbours to atone, for example, different soil fungi, vascular breakdown and some boring insects. Secondly, by general stunting due to metabolic severance, nutrient drain or damage of root, such as caused by aphids, eelworms and various viruses. Thirdly, by extermination branches, such as, some fungal diebacks and various boring insects. Lastly, by eradication of the leaf tissues, such as by different rusts, blights, leaf spots, mildews and some boring insects. Otherwise, attacks from pest/disease are more general, including damage to crop yield originated in the field, but are frequently more apparent after reaping and in the effects on quality.

The cumulative shock of pest and disease is usually dramatic and widespread [9]. Globally, the damage induced by invasive forest diseases and pests can have a significant impact on a range of ecosystem services, altering natural landscapes and their recreational or cultural value, decreasing wildlife habitat and biodiversity as well as affecting the forest ability to sequester carbon, combat desertification or protect watershed [10,11]. The outbreaks of pest and disease can have many significant impacts on forest health, the economies of forest-based communities at provincial scales and regional and carbon stocks [12]. Thus, the implication of pests and disease not only affects crops productivity, but also the economy and sustainability of forest.

2.1. Pest Effect on Agricultural Plant

Agriculture pests are known as animals that destruct or kill plants [13]. The term 'pest' appertains to "... any species, animal or pathogenic agent, strain or bio type of plants or plant products" [14]. The notion of 'pests' has arisen out of human agricultural practices and the concupiscence to preserve food security by protecting crops from ubiquitous insects, such as the locust [15]. Those pests mostly belong to insect species and some of them are from the class of arachnids. *Helicoverpa armigera* has a severe impact to crop productivity as it is one of the most devastating pests, wherein it can proliferate by duplication up to eleven generations in a year under suitable conditions [16]. The main reason pests can be harmful to agricultural plants is the pest hosts on the plants. Pest also can be detrimental to plant health through nesting over planted field, animal migration or embedding eggs in plant tissues. Generally, plant tissue breakage is due to gnawing pests, such as rats, feeding on it. Breakage in plant leaves can lead to shrinkage of the comprehensive surface area, while also slowing water transportation and nutrition to the other parts due to damage in the stems. If the root parts are damaged, it will affect the absorption of minerals and water from the soil. Thus, it will have a negative impact on the plant's health, slowing down the plant growth and causing parts of the plant tissue to rot.

In the majority of cases, the apparent integrity of plants is not damaged by sucker pests. Usually, to identify pathological changes in the affected area, they will identify spots on the surface of the plants as the indicator. A sucking pest is a pest that damages the plant by using their mouthpart and inserting it into the plant tissue and extracting the juice out from the plants [17]. In addition, the biochemicals in plant cells and tissues will be changed when the pest injects its salivary glands' secretion when sucking. Thus, plants that have been infested heavily will wilt, become yellow, stunted or deformed and may eventually die. There are also some sucking insects which, while feeding on the plant, inject toxic materials and transmit disease organisms. A common sucking pest is Aphids also known as plant lice, blackflies, greenflies, whiteflies or ticks (Trombidiformes), true bugs (Hemiptera) and thrips (Thysanoptera) [18].

The damage that occurs to the plant without any preliminary preparation by pest is usually because the pest generally feeds on the plant as it is. Topical bites, deep bites into the root's body, roots crops and cavities and tunnels inside of the roots, and damage inside plant bulbs may all be the cause of damage to the parts of the plant that are underground and roots. The damage might occur on stems and trunks of crops through drilled channels where there is a hole inside of the woody stems and trunks of grassy plants, deep bites and bite marks at the base of the stems and trunks, and other damage or distortion. Meanwhile, leaf damage might be through partial eating, for example, skeletisation, where, the eating of tissues is between the veins, nibbled edges of leaves and the scrubbing of soft pulp. Also, the damage might be rough and show random traces of eating, change of colour in sucking spots, leaf contortion due to uneven growth of tissue and mining, such as the formation of mines between layers of epidermis (primary integumentary tissues).

There are many plants in Malaysia and each plant has its own pest that affects its health. For example, Brinjal borer (*leucinodes orbonalis*) is a pest that feeds on brinjal [19]. *Plutella xylostella*, sometimes called cabbage moth, is an insect pest that infests cabbage [20] and belongs to the Plutellidea family and *Plutella* genus. Meanwhile, there are about 80 species of arthropods pest that have the potential to feed on oil palms. Each country has its own species that attack. In America, pests that attack palm oil are *Rhynchophorus Palmarum* and *Alurnus humeralis*, while, in India, the species is heavy with the population of coccinellidae on the spear region and, in Kerala, the pest recorded was *Rhynchophorus ferrugineus* [21]. Meanwhile, in Malaysia, there are rats, bagworms, nettle caterpillars, rhinoceros beetle and bunch moth. Thus, the increase of pests in agricultural activity will cause great economic losses.

2.2. Disease Effect on Agricultural Plant

Any harmful condition that affects a plant's function or appearance is known as plant disease [22]. Disease in plant can be caused by living or non-living thing. Whereby, biotic diseases are caused by living organisms and non-living environmental conditions, such as wind, frost, soil compaction, soil,

salt damage and girdling roots, cause abiotic disease. Fungi, bacteria, oomycetes, viroids, viruses, virus-like organisms, nematodes, phytoplasmas, parasitic plants and protozoa are organisms that cause biotic plants disease [23]. However, the most destructive plant disease is fungal pathogen, whereby it imposes major losses on the production system and nature [24].

Almost every plant is host for several fungal pathogens and each pathogen can attack one or many kinds of plants. Fungi are an organism classified in the fungi kingdom wherein they lack conductive tissue and chlorophyll. Fungi are known as parasites or saprophytes because they cannot produce their own food, but, rather, feed on decaying organic matter. Fungi damage a plant by killing cell plants or causing plant stress. As an example, synchytrium endobioticum is the fungus that causes potato wart disease and was listed as a weapon on the bioterrorism list in the U.S. in 2002 [25]. Black bread mould, known as *Rhizopus Stolonifer*, is found on the surface of bread and damages its nutrients. It grows in temperatures between 15°C and 30°C.

An example of biotic disease is Moko disease, which attacks the banana plant. Moko disease, also known as the banana and plantain bacterial wilt, is caused by *Ralstonia Solanacearum* (*Pseudomonas solanacearum*) bacteria [26]. Moko disease is an environmentally and economically important threat that causes large losses in many tropical countries. If there is no movement to control the disease, it will lead to a severe loss. Next is *Rhizopus* rot, a common fungal disease that attacks the flowers and fruit of *Artocarpus heterophyllus*, also known as jackfruit [27]. The disease is caused by plant-pathogenic fungi of the genus *Rhizopus*, namely *Rhizopus artocarp*, *Rhizopus oryzae* and *Rhizopus stolonifera*. Usually, the plant pathogenic fungi live under warm, wet weather and humid conditions. The disease is most likely found in high-rainfall areas or during and after stormy periods. *Rhizopus* rot can cause total loss if the condition is ideal for the plant-pathogenic fungi that causes the disease and coincides with the flower and fruiting season.

Meanwhile, abiotic disease is a disease caused by non-pathogenic and abiotic factors, such as wind, frost, soil compaction, etc., but it cannot be transferred to healthy plants from affected plants [28]. Usually, unfavourable environment, such as inadequacy, glut, imbalance or deleterious interaction of the physical or chemical factors essential for healthy plant growth, are the reason for an abnormal plant development. For example, the disease can be affected by low humidity. When the humidity level decreases, evaporative demand will increase and this will stress on plants' moisture, even when there is plenty of root water supply. Thus, the result is tissue damage. Other than that, atmospheric gases, temperature and light can also be a factor for abiotic disease [29].

3. The Role of Geospatial Technology in Agriculture

The use of geospatial technology in agriculture began at the start of 1990s [30]. and, now, farmers can measure the spatial and the temporal variability in soil, relief and vegetation through the capability of using global navigation satellite system (GNSS) technology in locating the agricultural machinery and increasing the quality and availability of geographic information in digital form. By using mobile technology, farmers can keep their farm diaries and field records in the device. Thus, farmers can enter and retrieve information on site [31]. GPS and GIS technology are used to generate a georeferenced map for different crop and properties of soil to provide field professionals and growers with a new set of communication tools and management [32]. Today's increasing variety of map production is helping in improving the management of crops. Soil maps for instance, are used to give a better understanding on the property of the land. The basic information related to agriculture parcels, such as yield, and records of operations, such as fertilisation and ploughing and usage type, have an inherent spatial and, normally, also temporal reference [33].

3.1. GIS in Plant Health

Geographical Information System (GIS) is a technology used to store, capture, analyse and visualise data that describe a part of the Earth's surface, the technical and administrative entities, as well as the findings of geoscience, economics and ecological applications [34]. Typically, GIS offers functions for retrieval and storage, visualisation, query, geometrical and thematic analysis, transformation etc

[35]. GIS can be categorised into four categories: data capture systems, analysis systems, administration systems and presentation systems. Parallel with the vast of technology development, there are many options which can be chosen to capture the data. For example, Global Positioning Systems (GPS) and Geodetic Surveying, laser scanning, photogrammetry and satellite-based remote sensing, etc.; therefore, we can say that monitoring of plant health has become easier with the development of geospatial technology.

GIS has been used widely in accommodating the biosecurity assessment of plant health [36]. According to [37], to face the problem of production of monoculture cotton loss up to 40 % cause by *Rotylenchulus reniformis* infested to the crops, Brazil employed geo-statistics technique to produce a spatially differentiated nematode risk map in the field. Whereas, this method is less cost rather than using protection by nematicides.

In some cases, GIS is also used to improve the way New Zealand farmers manage their inputs [38]. Ravensdown, known as one of New Zealand's largest manufacturers and distributors of fertilizers, is using geospatial technology to guide the farmers in decreasing the amount of wasted resources that can potentially cause harmful runoff into streams and waterways. This method not only can save the environment, but also, at the same time, save their total fertilizer expenditure by up to 10% per year.

Moreover, GIS is known as a software application that is used to manage and analyse spatial data. It is able to store, retrieve and transform spatial information relating to productivity and agronomy. Case studies in India have proven that, by using the GIS Based Decision Support System, it will help all farmers in taking the day-to-day decisions whereby agricultural experts suggest the selection of crop based on geography through an understanding of all the risks. In addition, this system helps in analysing past records or databases with reference to the geographical maps which can be used in producing various models for agricultural practices. Thus, GIS acts like a tool that can help the decision-makers in identifying the sites which are already being used for cultivation and analysing the details of potential sites that can be used for various means of agriculture, such as floriculture, etc. [39].

In Malaysia, Pohl et al. [40] found that GIS has been implemented in support of decision-making and monitoring to increase sustainability of oil palm plantation, whereby all spatial layers collected from various sources are geocoded and fed into the Geographical Information System. Then, an appropriate method in GIS is used to analyse all the data. In addition, [41] used GIS for paddy cultivation management. Their study developed a web-based system to monitor growth of the paddy in which all the data collected were converted into spatial information and stored. Then, a map was created and published into the ArcGIS server. The database is available in Internet Information systems as a web browser and ArcGIS servers are used to publish spatial layers as map series.

3.2. Remote Sensing in Agriculture

Remote sensing is the approach of getting information about an object without direct contact with the object and it is an old technology in collecting. Electromagnetic radiation is the information carrier in remote sensing, whereby it travels in a vacuum in the form of waves of various length and at the speed of light. There are two types of remote sensing, active and passive remote sensing, whereby passive remote sensing sensors record incident rays reflected or emitted from objects while active sensors emit their own radiation by interacting with the target to scrutinise and return to the measuring device [42]. The spectrometer field in remote sensing is usually used in agriculture to solve problems in the nutritional requirement of plants, detection of pest damage, forecasting yield, water demands and weed control.

Remote-sensing technology has a variety of applications, including environmental monitoring, site-specific agronomic management (SSM), land cover classification, climate- and land-use-change detection, and drought monitoring. The ability of a remote sensor to detect subtle differences in vegetation makes it a useful tool for quantifying within-field variability, evaluating crop growth and

managing fields based on current conditions that may be overlooked using typical ground-based visual scouting methods.

According to [43], remote sensing can also be used to determine the nutritional requirements of plants. A study of two sets of cucumber plants (*Cucumis Sativus*) grown in a controlled environment was performed wherein one set was inoculated with bacterial wilt (*Ralstonia Solanacearum*) and the other set was the experiment control. During the pre-symptomatic stage, both sets of cucumber plants were subjected to changes that can be applied in the field, such as nutrient content, water content and light exposure. Spectral reflectance of the cucumber was measured using a spectroradiometer. In this case, remote sensing instruments measure electromagnetic radiation that is reflected or emitted from an object of interest. If two different objects reflect the same electromagnetic energy, these two objects would appear the same in a remotely sensed image. Meanwhile, when a plant is infected by bacteria, virus or fungi, there is a period during which there are no visible symptoms of infection on the plant. This is usually because the plant has a resistance mechanism against infection or the pathogen takes time to develop within the plant [44].

Additionally, remote sensing has also been used to forecast crop yields based primarily upon statistical–empirical relationships between yield and vegetation indices. Information on expected yield is very important for government agencies, commodity traders and producers in planning harvest, storage, transportation and marketing activities. If this information is available, the lower the economic risk, translating into greater efficiency and increased return on investments [43].

In Malaysia, [45] tracked the dynamic conditions of a plant in a glimpse form and the soil using remote sensing technique, whereby, it measured visible and invisible features of a farm or a group of farms and turned it into point estimation of continuous spatial information [40] used a multitemporal and multisensory approach to monitor oil palm plantations. They used various technology in collecting data, such as UAV for detection and counting of oil palm trees, multimodal satellite data comprising VIR to provide spectral signatures on plant growth, plant health and other physical parameters, SAR to provide information of texture, plantation tree height and height anomalies, and high-resolution WorldView-2 image. Whereby, the information was then extracted from the images using image and data fusion to assist plantation managers in improving current practice in oil palm harvesting, planting and maintenance.

On the other hand, remote sensing technology has also been implemented in Rice Field Management [46]. Their study used high-resolution satellite image with resolution of 0.5m-1.0m overlaid with an integrated cadastral map to define the actual planted area and differentiate which were the paddy and non-paddy fields, such as roads, fishponds and others. The purpose of this study was to use high-resolution images to manage rice field management. Satellite imagery has not only been used for mapping, but also to keep track and observe the activities during the growth phase, starting from land preparation to harvest.

3.3. Global Navigation System Satellites (GNSS) in Plant Pest and Diseases

The Global Navigation System Satellites (GNSS) has been used for various types of applications, such as location, navigation, tracking, mapping and timing. The Global Positioning System (GPS) is the common GNSS that was developed in the 1980s, and becoming fully operational in 1995 [47]. The ground receiving units can receive this location information from several satellites at a time for use in calculating a triangulation fix, thus determining the exact location of the receiver [48]. GNSS has now become of significance to the agricultural sector not only for research, but also in practical use [49]. Accurate and current information, either spatial or non-spatial data, is needed in agricultural management to help in planning and executing activities to improve the efficiency in productivity of the land and input use [50].

Typically, GNSS technology is used in precision farming to collect point of data, georeferenced and more. Usually, DGNS or RTK-GNSS is chosen due to their ability of precision up to submeter accuracy. In management of plant pest and disease, [51] used advanced digital imaging technology embedded with GPS coordinates and timestamp to produce geo-tagged images. This technique enables

to the monitoring or mapping of pest and plant disease locations through time and space, whereby a geo-coded image can be seamlessly transferred to a computer through metadata called Exchangeable Image File Format (EXIF) for a mapping system. The mapping process can be performed seamlessly with integration mapping software, combining web mapping with digital imaging technologies and can enhance the ability to track pest and plant disease through time and space.

In managing plant pest and disease, [52] employed GPS technology in providing the location of areas with positive Plum Pox Virus (PPV) and all PPV-negative prunus block. PPV is one of the most threatening pathogens, as it will cause a huge reduction in the production of fruit yield and quality. Meanwhile, to combat Panama disease that infected banana in the Middle East [53] used GPS to obtain the location of the areas infected with Panama disease and non-infected areas and mapped the data. [54] used a geo-location method with GPS technology for in situ habitat characterisation in managing banana insect pest in Mindanao, in the Philippines. Every month for six months, the area was monitored for insect pest incidence. Then, each location was compared to analyse insect pest that infest on the crops. In Malaysia, [55] used handheld GPS for data collection enabling locations identified as areas infected with pest and disease.

4. Conclusion

The use of geospatial data and technology plays a significant role in improving the production of yield and overcoming food security issues. As the population grows, the production of crop needs to be increased as well to ensure all the people in whichever country or region get enough nutrients. This paper has reviewed the role of geospatial technologies to tackle the issue of pest and disease affecting plant health that has a big impact on crop yield production in producing food for the world population. Geospatial technology has been used, from the early tasks of surveying the status of crop health to managing the collected data. From the review, there are many studies which have applied remote sensing technology in monitoring plant health for large groups that become commodities for a country, such as oil palms, paddy and wheat, whereas less study has been applied on the crops planted on a small scale, such as in the orchard. This might be due to the high cost to use the technology, which might not be feasible to apply for a small area. Moreover, it is not easy to detect plant health for crops that are planted randomly on the ground, especially on a mixed land use, from the satellite images. Therefore, GPS technology has been applied to complement the ground crew during field survey to automatically record the location of affected plants for further action. Distribution of pest and disease incidence on the affected crops has been mapped to visualise the events from a large-scale view. The power of spatial analysis has been used in predicting the possibilities of incidence likely to be occurred in a few years time. Global trade liberalisation and climate changes have presented major challenges for the local crops to produce good products and to secure food for the world population generally. Nevertheless, the advancement of geospatial technology has made the activities of combating various pests and diseases affecting plant health much easier than before.

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