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Crop Health Monitoring through Remote Sensing: A Review

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Authors' contributions

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Review Article

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ABSTRACT

Agriculture is basis of livelihood for a major portion of world population. It provides food to humans. With the increasing population and climate change there is need to enhance production to fulfil the demand of growing population. Remote sensing technology has potential to predict nutrient requirement by providing various information related to plant and soil in quantitative terms thereby increasing productivity. It plays important role in monitoring crop health, crop growth and development, nutrient management, pest and disease management, water management and weed management. Evaluation of crop canopy provide various information regarding agronomic parameters. The data obtained from remote sensing provides a better alternative for natural management than traditional methods and this kind of management enhances efficiency of various resources by avoiding their overuse. By using this technology, we can improve traditional methods of agriculture and bring out changes in the field of agriculture. This paper reviews remote sensing technology for crop health monitoring, highlighting its importance with new ideas for agriculture.

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1. INTRODUCTION

Remote sensing is a technology that enables to acquire information about any object without coming into direct contact with the object under study [1]. Its application is transforming management and planning in the field of agriculture. With the introduction of new technologies, it seems a very bright future to move farm management to a next level of production and productivity. Agriculture production can be enhanced by proper use of major agricultural resources like water, fertilizer and pesticides, as when and where required. Fertilizer is one of the major resources that can affect crop health, thereby reducing yield and quality. Improper use of fertilizer leads to imbalance between organic content and nutrients in the crop. Hence, it is important to precisely apply nutrient to enhance the fertilizer use efficiency and reduce the loss from the farming system. This can be achieved by monitoring crop growth and development. Monitoring agricultural crop production during the growing season and estimating the potential crop yields are both important for the assessment of seasonal production [2]. Unfavorable climatic condition and growing conditions may result in variation of crop productivity. It was observed that effect of climatic variability on cropland productivity variation based on remote sensing observations in the Canadian Prairies was better than *in-situ* data [3]. Remote sensing helps to timely monitor these conditions and provide a model of crop with precision. The monitoring of crop health follows seasonal patterns in relation to biological life cycle of the crop. This technology enables to collect data timely with precision without destructive sampling of the crop. Remote sensing uses various sensors for recording data. These sensors sense the electromagnetic radiations. These sensors are available in two forms: passive sensors and active sensors. Passive sensors record the radiations that is reflected by the object or emitted from the earth surface. On other hand, active sensors (e.g., LIDAR, RADAR) are those which emits their own electromagnetic radiation [4]. In agricultural remote sensing, most of the sensors are designed to record a specific portion of the electromagnetic radiation. Interaction between the electromagnetic spectrum with any of the material can be used for the qualitative and quantitative analyses of various materials [5]. Remote sensing using space-borne sensors are tools for taking repetitive and synoptic observations. These data can be used for various assessment and management of field [4]. This technology has importance for the efficient utilization of available resources and to take appropriate measures to lower the appropriate loss caused by the climatic variation or any other stress factor. This paper reviews remote sensing and its application for crop health monitoring, its utility and future perspective in the field of agriculture.

2. CROP HEALTH MONITORING

Remote sensing is a tool for monitoring crop growth and development, nutrient deficiency, diseases, moisture stress, water management and weed management. It can be used to track the growth of crop at different time intervals. Timely information about crop can help to identify the problem by various vegetative factors. It is important to understand crop production response to agronomic management and environmental stress [6]. Vegetative indices like Normalized difference vegetative index (NDVI) measures the greenness over the time. It has been observed that NDVI is highly correlated with crop growth and health, and can be used for monitoring crop condition [7]. The crop condition can be monitored by (i) instantaneous monitoring method in which NDVI values of cropland is compared with those of the same period in the previous year and (ii) the crop growth process monitoring method that forms the crop growing profiles with time series NDVI images and assesses the crop condition by comparing inter-annual crop growth profile [8]. Leaf area index (LAI) and crop biomass are two crucial pointers of crop health and development [8,9]. Remote sensing data on these pointers can assist to obtain significant information on site specific properties (e.g., soils, topography), management (e.g., water, nutrients and other inputs), and various stress factors (e.g., diseases, weeds, water, and nutrient stress) [10]. The data obtained used to estimate LAI and biomass for various crops. Several studies showed that LAI and biomass were highly correlated with several Optical Spectral Vegetation Index (OSVIs) and Radar Polarimetric Parameters (RPPs) [11], the LAI can be assessed from both hyperspectral and the 3D canopy models [12], the Red Edge Position (REP) extracted from ground hyperspectral reflectance can accurately estimate the kinnow mandarin LAI and Chlorophyll content and this can be effectively used to assess crop health status in a wide range for real-time nutrition management in the orchard [13]. Crop health monitoring and quantifying crop stress due to biotic and abiotic stress can be done by using various indices for mapping and monitoring drought. Certain factors like evapotranspiration, soil moisture and vegetation conditions can be used to assess and monitor drought characteristics [14]. The indices for soil moisture status in rooting zone are given in Table 1.

From remote sensing, several drought indices can be obtained viz., Normalized Difference Water Index [20], Crop Water Stress Index [21], Water Deficit Index [22]. It can provide a good estimate of evaporative fraction, the ratio of ET and available radiant energy, with the AVHRR and MODIS data [23].

These indices can be used to assess the crop health and stress condition; hence these data can be used to analyse the quality of the crop [51].

Table 1. Various indices for soil moisture status in rooting zone

S. no.	Drought indices	Reference
1	PDSI (Palmer Drought Severity Index)	[15,16]
2	Drought Severity Index (DSI)	[17]
3	Evapotranspiration Deficit Index (ETDI)	[18]
4	Standardized Precipitation and Evaporation Index (SPEI)	[19]

Table 2. Some vegetative indices used in agriculture

Index	Application	References
Normalized difference vegetative (NDVI)	Biomass, breeding, phenotyping, yield, disease, nitrogen management, soil moisture, water stress.	[24,25,26,27,28,29,30]
Green NDVI (GNDVI)	Water stress, biomass, diseases	[31,9,32,33,34,35]
Red edge normalized difference vegetation index (RENDVI)	Yield, irrigation management, N-status/application, diseases	[36,37,38,39,40]
Soil adjusted vegetation index (SAVI)	Yield, biomass, diseases, N-concentration and uptake, water stress	[41,9,34,42,43,44]
Ratio vegetative index	Crop yield, biomass	[45,9]
Normalized pigment chlorophyll ratio index (NCPI)	Water stress	[46]
Chlorophyll absorption ratio index (CARI)	Chlorophyll content	[47]
Chlorophyll vegetation index (CVI)	Crop yield, biomass, N-uptake, soil moisture, water stress	[48,49,37]
Water balance index	Irrigation scheduling	[50]
Normalized difference water content (NDWI)	Vegetation water content	[49]
Normalized water index (NWI)	Soil moisture and crop yield	[29]

3. NUTRIENT MANAGEMENT

For proper growth and development of crop, sufficient amount of nutrients is required at right stage. Nutrient deficiency like in case of nitrogen, it reduces leaf chlorophyll content that results in low light absorption. Nutrient requirement of crop plant can be estimated by studying leaf optic properties such as fluorescence, reflectance and transmittance. Chlorophyll fluorescence gives quick and precise information related to stress based on the fluorescence emission pattern of leaves, tissues and even the whole plant [52]. This emission is captured when part of light energy absorbed by chlorophyll for photosynthesis is re-emitted when excited with UV- a near 340- 360 nm or blue-green light [53]. The fluorescence emission at different level of plant stress was successfully detected and imaged on different crops for deficiency of nitrogen and zinc on maize (*Zea mays*), as well as heat and water stress on Zalea (*Rhododendron sp*.) [54]. It was observed found that green chlorophyll index based on NIR (800 nm) and green (550 nm) wavelength were strongly related to Chlorophyll Concentration Index (CCI) as a measure of chlorophyll content [55]. Plant dry matter accumulation and grain yield were observed to be pointedly influenced by the absorption of Photosynthetically Active Radiation. It was positively related to yield production at tillering and panicle initiation stage [56]. Thermography is also used for nutrient deficiency. It can visualize stomatal movement without presence of an illuminizing source [57]. A high temperature for under fertilized barley (*Hordeum vulgare L*.) than well fertilized barley with nitrogen as reference nutrient was observed [58]. Reflectance in the red and near infrared region of the electromagnetic spectrum for estimating the nitrogen requirement of the crop using early season estimates of nitrogen uptake and potential yield have been developed [59]. It was observed that correlation of NDVI inflection point with Nitrogen content were found positive at maximum tillering stage followed by flowering stage, milky stage and least in tillering initiation. The results provide nitrogen estimation through hyperspectral instrument easily with less time consuming [60]. The NDVI increase with increasing leaf greenness and green leaf area, and can be used as a guide for in season nitrogen application [59]. [61] suggested that soil moisture, vegetation and soil crusts can contribute to the conservation of soil total nitrogen.

4. WATER MANAGEMENT

Remote sensing helps for precise application of irrigation water, estimation of soil moisture availability, water requirement at different growth stages and in mitigating water stress and hence, achieving optimum crop growth and yield. Remote sensing data can help to detect variation in the field and to apply variable irrigation with commonly used irrigation systems. This can help to overcome water stress resulting from extremely wet and dry condition, also to get maximum uniform yield in all the parts of the field while reducing water and nutrient losses [62,63]. Spectral reflectance in the visible region was observed higher in water stressed condition than the non-stressed condition. Vegetation indices like NDVI, RVI (Ratio Vegetation Index), PVI (Perpendicular Vegetative Index) and GI (Green Index) were found lower for stressed and higher for non-stressed crop [64]. [65] developed a high-resolution soil moisture soil temperature service that can be used for real time decision support system in precision agriculture. Thus, this technology plays major role in efficient use of water and it can be further enhanced by the development of hyperspectral sensors.

5. WEED MANAGEMENT

Remote sensing is an efficient way for mapping weed patches in crop for site specific weed management [66]. Remote sensing with precision agriculture helps for better weed management practices [64]. Spectral signature helps to identify and differentiate between weed and crop plant related to their phenological and morphological attributes that are different from the crop [67]. [68] observed that radiance ratio and NDVI values were maximum in solid stand and minimum in solid weed plots. It was also found that pure stand can be easily distinguished from pure weed stand of R. *spinosus* after 30 DAS. [69] noted that pure wheat can be distinguished from pure population of *Malva neglecta* after 30 DAS and remain distinguished upto 120 DAS and different levels of weed population can be differentiated amongst themselves after 60 DAS. Remote sensing technology thus can be used to identify weeds of different species and their infestation in field crops. Weed prescription maps can be prepared with Geographical Information system (GIS), on the basis of which farmers can be recommended for preventive control measures for weed control.

6. DISEASE AND PEST INFESTATION

Remote sensing is a tool for disease and pest identification, spectral reflectance for chlorosis, yellowing of leaves and foliage reduction can be used for making correlation and interpretation [70]. Hyperspectral remote sensing technology is helpful in rapid assessment of physico-chemical response of crops to biotic stress like disease infestation without destructive sampling [1]. [71] found remote sensing as an effective and inexpensive method for pest and disease affected plant in oat and concluded that the difference can be evaluated by canopy characteristics and spectral references. [72] worked on different types of vegetation indices on Landsat imagery before and after defoliation for differentiating between healthy and unhealthy vegetation cover. It monitors the disease efficiently in the early stages of disease development, when it is difficult to distinguish the symptoms with field monitoring. Various techniques using RGB, multi-spectral, hyperspectral, thermal, and fluorescence imaging have been used to identify diseases in a wide range of crops [73]. Specific disease indices will amend disease detection, identification and monitoring in precision agriculture applications [74]. Spectral disease indices have possibility to improve disease detection, identification and monitoring in precision agriculture applications [75]. Diseases can cause considerable loss of crop production and thus their detection at the beginning and its spatial extent can help to contain the disease spread and lower production losses [67].

7. CONCLUSION

On the basis of findings of different research workers, it can be concluded that remote sensing can improve crop assessment and crop monitoring which can help in crop growth, site specific nutrient management, water management, weed management and monitoring pest and disease. This technology collects real time data with accurate position that leads to an effective analysis of data. Thus, we can identify different problems and solutions. Farmers can easily apply the solutions for the identified problems. Further, there is need to develop more accurate and new methodologies to crop health monitoring, disease detection under diverse climatic condition and field condition. Hence, vegetative indices and remote sensing technology plays an important role in agriculture specially in the improvement of economy through crop health monitoring.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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