Research Biotica 2021, 3(1):28-32

DOI: 10.54083/ResBio/3.1.2021.28-32

Review Article

***Article ID:* RB0025**

Application of Ground-Based Remote Sensing in Identifying Biotic Stress: A Review

Jitendra Kumar[1*], Ananta Vashisth[2], Nishant K. Sinha[1], M. Mohanty[1], Alka Rani[1] and R. S. Chaudhary[1]

[1]ICAR- Indian Institute of Soil Science, Nabibagh, Bhopal, Madhya Pradesh (462 038), India
[2]ICAR- Indian Agricultural Research Institute, Pusa, New Delhi, Delhi (110 012), India

Open Access

Corresponding Author

Jitendra Kumar

e-mail: jitendra.iari@gmail.com

Keywords

Biophysical attributes, Biotic stress, Hyperspectral Remote sensing, Satellite

How to cite this article?

Kumar *et al*., 2021. Application of Ground-Based Remote Sensing in Identifying Biotic Stress: A Review. *Research Biotica* 3(1), 28-32.

Abstract

The remote sensing technique has been used for diverse applications in agriculture. An array of continuous narrow wavebands in the hyperspectral remote sensing provide an understanding of the subtle changes in biochemical and biophysical attributes of crops and their different physiological processes. Hyperspectral remote sensing has also been used in discrimination of crops and their cultivars, assessing abiotic and biotic stresses, quantitative estimation of crop nutrient status and soil health. Knowledge of biotic and abiotic conditions over large areas bears the potential to reduce agricultural losses in terms of productivity. Therefore, this article aims to present an overview of the quantification of different biotic and abiotic stress by remote sensing techniques and focuses on future directions for researchers.

1. Introduction

Biotic stress in plants is caused by living organisms, specifically fungi, nematodes, insects, arachnids, viruses, bacteria, and weeds. It causes a significant deviation from the optimal conditions for plant growth. In agriculture, biotic stress is a substantial cause of pre- and postharvest losses, which can reduce production capacity significantly. Oerke and Dehne (2004), estimated a 14% loss of world food production by diseases, insects, and weeds.

The identification of the stress and their symptoms on time is very crucial. Assessment of loss by pest and disease of crop plants is being traditionally done by a visual approach, i.e., relying upon the human eye and brain to assess their incidence. The problem with the traditional approach is that they are often time-consuming, labour-intensive, and sometimes erroneous. The recent advances in remote sensing technologies offer ample scope for exploiting these technologies towards developing an alternate means that can enhance or supplement the traditional approaches. Besides, precise knowledge is also needed to apply the right amounts of agricultural chemicals to the affected areas at the right time, thereby increasing the economic and environmental benefits (Datt *et al.,* 2006).

The use of remote sensing for crop disease monitoring and assessment started a long time ago. During 1920's, aerial photography was used in detecting cotton root rot. Taubenhaus *et al.* (1929) and Colwell (1956) first reported the use of infrared photographs in determining the prevalence of certain cereal crop diseases. Toler *et al.* (1981) used aerial colour infrared photography to detect root rot of cotton and wheat stem rust. The airborne cameras used in these studies to record the reflected electromagnetic energy were analogue films covering broad spectral bands. Since then, remote sensing technology has changed significantly.

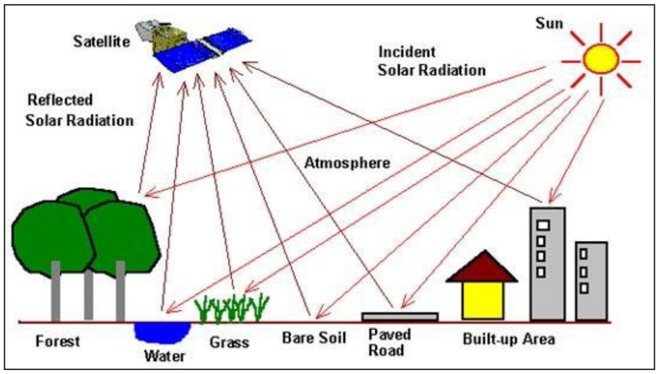

Figure 1: Illustration of the principle of remote sensing

The Satellite-based imaging sensors, equipped with improved spatial, spectral, and radiometric resolutions, offer enhanced capabilities over those of previous systems. Plant pathogens and pests can induce physiological stresses and physical changes in plants, such as chlorosis or yellowing (reduction in plant pigment), necrosis (damage of cells), abnormal growth,

Article History

RECEIVED on 16th January 2021 RECEIVED in revised form 28th February 2021 ACCEPTED in final form 01st FebruaryMarch 2021

wilting, stunting, leaf curling, *etc*. (Nutter and Litterell, 1996). These infestations change the reflectance properties of plants. The reflectance of healthy green vegetation is relatively low due to strong absorption by pigments such as chlorophyll in plant leaves in the visible region of the electromagnetic spectrum. The crop under the attack of pests and disease results in loss of leaf pigments thereby changes in the reflectance characteristics of plant leaves. Vigier *et al.* (2004) found that reflectance in the red wavelengths (675–685 nm) contributed the most in the detection of sclerotinia stem rot infection in soybeans. At about 700-1300 nm [the near-infrared portion (NIR)], the reflection of healthy vegetation is significantly high. The overall reflectance in the NIR region is expected to be lower from the damaged/ infected leaves due to the cell collapse. Ausmus and Hilty (1972) studied the maize dwarf mosaic virus using the NIR region of electromagnetic radiation and concluded that these wavelengths are useful in the characterization of crop disease. How can we use the different parts of the electromagnetic radiation in crop research is presented in Table 1.

Table 1: Crop canopy state variables accessible from remote sensing observations in various spectral domains

Biophysical variables	Visible and near Infrared	Near and short wave infrared	Thermal infrared	Active waves (radar)	Passive waves
Canopy structure					
Leaf area (LAI)	+++	+++	+	++	+
Cover fraction	++++	++++	++	++	+
fAPAR (fraction of absorbed PAR)	++++	++	++	++	+
Leaf orientation	++	++	+	+	+
Dimensions/height	+	+	+	+	+
Canopy water content		++		++	++
Leaf					
Water content		+++		+	+
Temperature			++++		+
Chlorophyll content	++++				+

The number of '+' indicates the potential accuracy with which the variable can be estimated. Adopted From Baret *et al.* (2006).

Kumar *et al.* (2013) also reported that the aphid infestation was negatively correlated with NDVI whereas positively correlated with Aphid index. The spectral properties of vegetation are dominated by water absorption bands. Less water on leaves and canopies will increase the reflectance. Dutta *et al.* (2008) developed a model for mapping spatially distributed zones of aphid pest (*Liphaphis erisimi*) at a regional level.

2. Identification of Pest and Disease by Vegetation Index

Developing the vegetation indices are a common method in which reflectance data transformed into indices are used to detect pests and diseases. Hence, many spectral vegetation indices have been proposed that exhibit high correlations with the ecological variables collected under different environment condition. Spectral vegetation indices have the ability to decreases the noise or disturbing factors with reflectance and characteristics of the target objects. The most widely used and best known indices are developed that combine near-infrared (NIR) and red light in their construction. Examples of these type of indices are the Normalized Difference Vegetation Index (NDVI) = (NIR − RED) / (NIR + RED) developed by Rousel *et al.* (1973) and Simple Ratio (SR) = NIR / RED proposed by Jordan (1969). Many other indices have been designed (Table 2) using different or rearranged wavebands to diagnose the changes in plant phenology and physiology.

3. Differentiating Stress Induced by Greenbugs and Russian Wheat Aphids using Remote Sensing

The spectral vegetation indices were used for detecting Russian wheat aphid greenbug stresses by Riedell and Blackmer (1999) and Yang *et al.* (2005). A greenhouse study by Riedell and Blackmer (1999) found that leaf reflectance in the 625-635 nm and the 680-695 nm range were good indicator of chlorophyll loss; moreover, the normalized total pigment to chlorophyll a ratio index (NPCI = [R680 – R430) / (R680 + R430)] in which R680 and R430 are the reflectance values from band centres at 680 nm and 430 nm, respectively) also indicated loss of chlorophyll and leaf senescence caused by greenbug and Russian wheat aphid feeding on a wheat leaf. A multispectral study by using hand-held radiometer to predict greenbug densities in a greenhouse was done by Nino (2002). This study revealed that the correlation coefficients (r) between greenbug density and vegetation indices varied from weak (r = 0.31) to very strong (r = 0.98). A recent greenhouse study by Yang *et al.* (2005) examined the feasibility of a hand-held radiometer to detect greenbug damage in wheat. In their study, the band centred at 694 nm and the vegetation indices

Table 2: Vegetation index and indicator stress

Index Name	Formula	Association with Relevant Plant Pigment	Reference Example
Normalized Difference Vegetation Index (NDVI)	$NDVI\_705 = \frac{(R750-R705)}{(R750-R705)}$	NDVI is a very typical index. Positive values suggest vegetated areas.	Tucker *et al.* (1979)
Photochemical Reflectance Index (PRI)	$PRI = \frac{(R570-R531)}{(R570-R531)}$	PRI index is a function of the reflectance related to xanthophyll activity. If xanthophyll activity is high, the light use efficiency is low, that indicates possible stress.	Penuelas *et al.* (1995); Trotter *et al.* (2002)
Anthocyanin Reflectance Index (ARI)	$ARI = \left(\frac{1}{R550}\right) - \left(\frac{1}{R700}\right)$	ARI index is useful to estimate the stack of anthocyanin in aged and stressed leaves	Gitelson *et al.* (2001)
The Structure Insensitive Pigment Index (SIPI)	$SIPI = \frac{(R900-R445)}{(R900-R690)}$	The SIPI index is the ratio of carotenoids to chlorophyll. It is very practically useful when the leaf area index is inconsistent.	Blackburn (1998)
Modified Chlorophyll Absorption Integral (mCAI)	$mCAI = \frac{(R545-R752)}{2(752-545)-(\sum 545-752(1.159R))}$	The mCAI is sensitive to the chlorophyll content.	Laudien (2005)
Zarco-Tejada Miller (ZTM)	$ZTM = \frac{R750}{R710}$	ZTM is a Red edge index highly correlated to chlorophyll content.	Zarco-Tejada *et al.* (2001); Underwood *et al.* (2003)
The ratio of the Transformed Chlorophyll Absorption in Reflectance Index and Optimized Soil-Adjusted Vegetation Index (TCARI/OSAVI)	$TCARI=3((R700-R670)-0.2(R700-R550)(R700/R670))$ $OSAVI = \frac{(1+0.16)(R900-R670)}{(R900+R670+0.16)}$	It is resistant to variations in Leaf Area Index (LAI) and sensitive to chlorophyll content variations and its underlying soil background effect.	Haboudane *et al.* (2002)

computed using bands centered at 694 and 800 nm were more sensitive to greenbug damage in wheat crop. Further study is required to validate this study in the field condition.

4. Rice Sheath Blight Detection using Multispectral Remote Sensing

Among various applications of remote sensing in rice crop, most studies were focused on field area mapping and production estimation. Hyperspectral remote sensing is being used to study rice canopies for the estimation of plant growth by Shibayama *et al.* (1993). He investigated canopy water deficit in rice crop using a high-resolution field spectroradiometer, further Shibayama and Akiyama (1989) examined rice canopy spectra with relation to Leaf Area Index (LAI) and above ground biomass in the visible, near-infrared and mid-infrared regions. Estimation of chlorophyll content in rice canopies and above ground net production was examined by Hong *et al.* (1997). When plants were infected with pathogens, their stress is expressed in reduced growth, change in canopy structure, and morphology of leaves. This is due to internal damage in the chlorophyll pigments and tissue structure for photosynthesis and metabolism. Consequently, the diseased plants will have different spectral features from healthy plants. Remote sensing discriminates this spectral difference to identify the diseased plants or patches in the field (Zhang *et al.* 2003).

Despite this potential ability, examinations of rice disease with remote sensing technology are not many up to present. One example in this aspect was the research of Yamamoto *et al.* (1995), who reported that infrared thermal image can detect the occurrence of rice blast disease. Blast and sheath blight are the two most important rice diseases that impact rice farming in the world (Ou, 1985). The diseased plants behave differently in spectral reflectance and thermal emission from healthy ones. Zhang *et al.* (2003) emphasized the possibility of remote sensing technology to identify the diseased plants through quantitative analysis of their spectral differences.

5. Early Detection of Douglas-Fir Beetle Infestation with Sub-Canopy Resolution Hyperspectral Imagery

In the Western United States, British Columbia, and Mexico, douglas-fir beetle is considered as a deadly pest for forests that adversely affect the physiology and growth of trees by often killing them (Schmitz and Gibson, 1996; Thompson *et al.,* 1996). These beetles normally attack and kill small groups of trees, but during outbreaks, attacks on tree groups as large as 100 or more are very common, especially in the dense forest. Early evidence of infestaion is indicated by entry holes in the tree trunk. After many weeks, they showing symptoms like chlorosis by turning yellow, then sorrel, and then finally reddish-brown, after that leaves began to fall from infested trees the year following attacks resulting in changes in leaf physiology and photosynthetic efficiency that affect the reflectance response of vegetation (Sampson *et al.,* 1998). Therefore, the shape of the reflectance spectra and variables in width, depth, skewness, and symmetry of absorption features can be measured and can be to detect canopy stresses. In healthy, green vegetation, the edge is sharp and steep, but as the vegetation becomes stressed or senescence starts, the width of the absorption band decreases, and the red edge shifts towards shorter wavelengths (Clark *et al.,* 1995). He also reported that red edge shifts have also been related to stress in crops that were sprayed with defoliant or water-deprived. Along with red edge, other indices were used to estimate physiologic responses in vegetation, such as the Physiological Reflectance Index (PRI), which is calculated in the visible wavelengths which are highly correlated to xanthophylls pigment content. This pigment is involved in the part of the CO_2 assimilation process in vegetation and is a measure of photosynthetic efficiency. Substitution of other reflectance bands in the PRI calculation has resulted in better correlation with photosynthetic efficiency in pine (Held and Jupp, 1999). While these previous studies have shown that tree stress is detectable spectrally, most have been based on laboratory spectra.

6. Conclusion

The characterizing biotic stress using hand-held multispectral radiometry is being done since long. The emergence of hyperspectral radiometry makes it possible to have more detailed information and a better understanding of the crop stress induced by insect pests and diseases. It is also possible to differentiate between biotic and abiotic stresses with reasonable accuracy using hyperspectral radiometry. The reflectance data generated through ground-based remote sensing provides a piece of vital information to understand spectral interactions between pests damage on the host plants. This information also enable the interpretation of remote sensing data obtained from hand held remote sensing as well as from a satellite. We access data from large spatial studies, but it has certain limitation like temporal and spatial resolution, and more importantly, availability of cloud-free data. Though the application of RS for biotic stress has been done in quite a large, but it is yet to find wide usage in many of the developing countries. One of the main reasons could be the high cost involved, availability of suitable sensors and technical operation.

7. References

Ausmus, B.S., Hilty, J.W., 1971. Reflectance studies of healthy, maize dwarf mosaic virus-infected, and Helminthosporium maydis-infected corn leaves. *Remote Sensing of Environment* 2, 77-81.

Baret, F., Houles, V., Guerif, M., 2007. Quantification of plant stress using remote sensing observations and crop models: the case of nitrogen management. *Journal of Experimental Botany* 58(4), 869-880.

Blackburn, G.A., 1998. Spectral indices for estimating photosynthetic pigment concentrations: a test using senescent tree leaves. *International Journal of remote sensing* 19(4), 657-675.

Clark, R.N., King, T.V., Ager, C., Swayze, G.A., 1995. Initial vegetation species and senescence/stress indicator mapping in the San Luis Valley, Colorado using imaging spectrometer data.

Colwell, R., 1956. Determining the prevalence of certain cereal crop diseases by means of aerial photography. *Hilgardia* 26(5), 223-286.

Datt, B., Apan, A., Kelly, R., 2006. Early detection of exotic pests and diseases in Asian vegetables by imaging spectroscopy. *Rural Industrial Research and Development Corporation (RIRDC) Publication* (05/170).

Dutta, S., Bhattacharya, B.K., Rajak, D.R., Chattopadhyay, C., Dadhwal, V.K., Patel, N.K., Verma, R. S., 2008. Modelling regional level spatial distribution of aphid (*Lipaphis erysimi*) growth in Indian mustard using satellite-based remote sensing data. *International Journal of Pest Management* 54(1), 51-62.

Gitelson, A.A., Merzlyak, M.N., Chivkunova, O.B., 2001. Optical properties and nondestructive estimation of anthocyanin content in plant leaves. *Photochemistry and photobiology* 74(1), 38-45.

Haboudane, D., Miller, J. R., Tremblay, N., Zarco-Tejada, P.J., Dextraze, L., 2002. Integrated narrow-band vegetation indices for prediction of crop chlorophyll content for application to precision agriculture. *Remote sensing of environment* 81(2-3), 416-426.

Held, A.A., Jupp, D.L.B., 1995. Forest monitoring with high spectral/spatial remote sensing tools: case studies.

Hong, S., Rim, S., Lee, J., Kim, J., 1997 (August). Remote sensing for estimating chlorophyll amount in rice canopies. In *IGARSS'97. 1997 IEEE International Geoscience and Remote Sensing Symposium Proceedings. Remote Sensing-A Scientific Vision for Sustainable Development* 1, 89-91. IEEE.

Jordan, C.F., 1969. Derivation of leaf-area index from quality of light on the forest floor. *Ecology* 50(4), 663-666.

Kumar, J., Vashisth, A., Sehgal, V.K., Gupta, V.K., 2013. Assessment of aphid infestation in mustard by hyperspectral remote sensing. *Journal of the Indian Society of Remote Sensing* 41(1), 83-90.

Laudien, R., 2005. Entwicklung eines GIS-gestützten schlagbezogenen ührungsinformationssystems für die Zuckerwirtschaft (Development of a field-and GIS-based management information system for the sugar beet industry). *University of Hohenheim*.

Nino, E., 2002. *T*he Use of a Multispectral Radiometer to Detect Greenbug, Schizaphis Graminum (Rodani) Damage in Winter Wheat, *Triticum Aestivum* L (Doctoral dissertation, West Texas A & M University).

Nutter, W.F., Litterell, R.H., 1996. Relationship between defoliation canopy reflectance and pod yield in the peanut late leaf spot pathosystem. *Crop Prot* 15, 135–142.

Oerke, E.C., Dehne, H.W., 2004. Safeguarding production-losses in major crops and the role of crop protection. *Crop protection* 23(4), 275-285.

Ou, S.H., 1985. Rice Diseases. Commonwealth Mycological Institute. *Kew, Surrey, England*, pp. 109-200.

Penuelas, J., Filella, I., Gamon, J.A., 1995. Assessment of photosynthetic radiation-use efficiency with spectral reflectance. *New Phytologist* 131(3), 291-296.

Penuelas, J., Gamon, J.A., Fredeen, A.L., Merino, J., Field, C.B., 1994. Physiological Changes in Nitrogen-and. *Remote Sens Environ* 48, 135-146.

Riedell, W.E., Blackmer, T.M., 1999. Leaf reflectance spectra of cereal aphid-damaged wheat. *Crop Science* 39(6), 1835-1840.

Rondeaux, G., Steven, M., Baret, F., 1996. Optimization of soil-adjusted vegetation indices. *Remote sensing of environment* 55(2), 95-107.

Rousel, J.W., Haas, R.H., Schell, J.A., Deering, D.W., 1973 (December). Monitoring vegetation systems in the great plains with ERTS. In *Proceedings of the Third Earth Resources Technology Satellite-1 Symposium; NASA SP-351*, pp. 309-317.

Sampson, P.H., Mohammed, G.H., Colombo, S.J., Noland, T.L., Miller, J.R., Zarco-Tejada, P.J., 1998. Bioindicators of Forest Sustainability Progress Report, Ontario Forest Research Institute. *For. Res. Info. Paper* (142), 18.

Schmitz, R.F., Gibson, K.E., 1996. Douglas-fir Beetle. USDA For. Serv. For. Insect & Dis. Leave. 5. R1-96-87. Washington, D.C.

Shibayama, M., Akiyama, T., 1989. Seasonal visible, near-infrared and mid-infrared spectra of rice canopies in relation to LAI and above-ground dry phytomass. *Remote Sensing of Environment* 27(2), 119-127.

Shibayama, M., Takahashi, W., Morinaga, S., Akiyama, T., 1993. Canopy water deficit detection in paddy rice using a high resolution field spectroradiometer. *Remote Sensing of Environment* 45(2), 117-126.

Taubenhaus, J.J., Ezekiel, W.N., Neblette, C.B., 1929. Aeroplane photography in the study of cotton root rot. *Phytopathology* 19(6), 1025-1029.

Thomson, A.J., Goodenough, D.G., Barclay, H.J., Lee, Y.J., Sturrock, R.N., 1996. Effects of laminated root rot (Phellinus weirii) on Douglas-fir foliar chemistry. *Canadian journal of forest research* 26(8), 1440-1445.

Toler, R.W., Smith, B.D., Harlan, J.C., 1981. Use of aerial color infrared photography to evaluate crop disease [Remote sensing]. *Plant Diseases*.

Trotter, G.M., Whitehead, D., Pinkney, E.J., 2002. The photochemical reflectance index as a measure of photosynthetic light use efficiency for plants with varying foliar nitrogen contents. *International Journal of Remote Sensing* 23(6), 1207-1212.

Tucker, C.J., Holben, B.N., Elgin Jr, J.H., McMurtrey III, J.E., 1981. Remote sensing of total dry-matter accumulation in winter wheat. *Remote Sensing of Environment* 11, 171-189.

Underwood, E., Ustin, S., DiPietro, D., 2003. Mapping nonnative plants using hyperspectral imagery. *Remote sensing of Environment* 86(2), 150-161.

Vigier, B.J., Pattey, E., Strachan, I.B., 2004. Narrowband vegetation indexes and detection of disease damage in soybeans. *IEEE Geoscience and Remote Sensing Letters* 1(4), 255-259.

Yamamoto, H., Suzuki, Y., Iwano, M., Hayakawa, S., 1995. Remote sensing of occurrence place of rice blast disease by infrared thermal image. *Japanese Journal of Crop Science* 64(3), 467-474.

Yang, Z., Rao, M.N., Elliott, N.C., Kindler, D., Popham, T.W., 2005. Using ground based multispectral radiometry to detect stress in wheat caused by greenbug (Homoptera: Aphididae) infestation. *Computers and Electronics in Agriculture* 47(2), 121–135.

Zarco-Tejada, P.J., Miller, J.R., Noland, T.L., Mohammed, G.H., Sampson, P.H., 2001. Scaling-up and model inversion methods with narrowband optical indices for chlorophyll content estimation in closed forest canopies with hyperspectral data. *IEEE Transactions on Geoscience and Remote Sensing* 39(7), 1491-1507.

Zhang, M., Qin, Z., Liu, X., Ustin, S.L., 2003. Detection of stress in tomatoes induced by late blight disease in California, USA, using hyperspectral remote sensing. *International Journal of Applied Earth Observation and Geoinformation* 4(4), 295-310.