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IMPORTANCE OF REMOTE SENSING IN PLANT BREEDING

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Food requirements are increasing as the global population increases exponentially. Plant phenotyping, which includes data collection, storage, analysis, and interpretation in an unbiased manner, is the primary concern for plant breeders. Early on, remote sensing was used to explore the natural hazards and analyse the natural resources. With the recent advances in spatial, spectral, temporal, and radiometric satellite imagery resolutions, acquiring high-quality satellite data from specialised companies is becoming a feasible task. Multiple researchers have reported success in the data collection for both qualitative and quantitative characters. Many satellites are used in this work, like WorldView-3, and different characteristics are included in remote sensing, like disease, pests, and yield. Remote sensing is now being used as an emerging plant phenotyping tool.

In this context, two areas of research, plant phenotyping and remote sensing, are becoming increasingly important. Field phenotyping refers to a quantitative description of a plant's phenotype—i.e., its anatomical, physiological, and biochemical properties—in its natural environment (Walter *et al*., 2017). Remote sensing in the agricultural context is the observation of vegetation by a remote device and the retrieval of its qualitative or quantitative properties. The traditional applications of satellite-based remote sensing in agriculture have been reported since 1970, such as flood damage monitoring (Benson and Waltz, 1973), yield prediction (Morain and Williams, 1975), crop type identification (Hoffman *et al*., 1976), Leaf area index (Price, 1993), plant height (Kurosu *et al*., 1995), weed classification (Backes and Jcobi, 2006), and other precision agriculture (Kayad *et al*., 2016). Traditionally, remote sensing is used to estimate spatial trends across the landscape, while plant phenotyping aims to remove spatial effects from their data in order to investigate the genetic effects of different plant varieties in response to the prevailing environmental conditions. On the one hand, field phenotyping has increasingly deployed imaging instruments traditionally used in remote sensing (Johansen *et al.*, 2019) to meet the need for increased throughput in field phenotyping (Araus and Cairns, 2014).

Principles

Special patterns of absorption, transmission, and reflection of photons are primarily determined by plant pigments, constituents, and structure (Espinosa *et al.*, 2018).

Types of Remote Sensing (Khargharia, 2021)

Based on Source of Energy

Passive remote sensing uses natural energy source radiated or reflected from an object. An active remote sensing has its own source of energy, which is focused on the target to collect data of the reflected energy.

Based on Platform Used

Satellite based remote sensing: It is a stable platform but need to wait a time for certain event and have fixed spatial resolution. Three types of Satellites are found, they are: Low Earth Orbits/Satellites, Sun-synchronous Orbits/Satellites, Geostationary Orbits/Satellites.

Aerial surveying: Collect data at any time with variable spatial resolution due to changing flight altitude and camera focal length.

Ground based remote sensing: Scientific experiment purposes like crop canopy studies, soil physico-chemical studies, soil pollution, etc.

Table 1: List of high-resolution satellite color and multispectral imagery sources (Zhang, *et al* 2020).

Source	Launch Year	Panchromatic (nm)	Spatial resolution	Multispectral	Spatial resolution	Temporal resolution
			(m GSD) *		(m GSD)*	**(days)***
WorldView-1	2007	NA	0.50	-	-	**1.7**
GeoEye	2008	450-800	0.46	R, G, B, NIR	1.84	**2.1**
WorldView-2	2009	NA	0.46	R, G, B, Y, RE, NIR1,	1.84	**1.1**
				NIR2, Coastal		
Pleiades-1A	2011	480-830	0.50	R, G, B, NIR	2.00	**1.0**
Pleiades-1B	2012	480-830	0.50	R, G, B, NIR	2.00	**1.0**
KOMPSAT-3[1]	2012	450-900	0.70	R, G, B, NIR	2.8	**1.4**
WorldView-3	2014	450-800	0.31	R, G, B, Y, RE, NIR1,	1.24 OR	**1.0**
				NIR2, Coastal [400-	3.70	
				1040 nm] + 8 SWIR		
				bands [1195-2365		
				bands]		
KOMPSAT-3A	2015	450-900	0.55	R, G, B, NIR	2.20	1.4

Importance

It has several advantages: rapid, precise, over time, diverse environments compared to conventional methods: slow, costly, technically challenging, and limited spatio-temporal dimensions of phenotypic dada (Espinosa *et al*, 2018). RS and GIS provide tools for an efficient screening of genotype populations, helping us to select the best performing lines and to understand the physiology underlying the plant's performance under different environments (Espinosa *et al*, 2018). RS and GIS enable the characterization of in-field and intra-field variability, facilitating precision agriculture at multiple spatial and temporal scales (Espinosa *et al*, 2018). RS and GIS are used at the local, regional, and global levels for crop modeling, as well as climate change oriented research with an emphasis on yield impacts, changes in suitability, socioeconomics, and crop mega environments (Espinosa *et al*, 2018).

Table 2: Crop traits phenotyped based on satellite imagery (Zhang, *et al* 2020).

Trait	Crop	Satellite	Resolution (m)	Accuracy or performance
Vegetation indices	Wheat	WorldView-2	0.46	***r*** **= 0.85 and 0.84 with proximal and UAS-based sensing**
Plant height	Corn	HJ-1 and	30 and 5.2 × 7.6	***r*** **= 0.62 – 0.69**
		RADARSAT-2		
	Rice	TanDEM-X	10 (spatial	**RMSE of 12 to 18 cm**
			resolution)	
Phenology	Rice	HJ-1A/B and	30 and 12 × 8[a]	**Accuracy up to 87.9%**
		RADARSAT-2		
Leaf area index	Corn	HJ-1 and	30 and 5.2 × 7.6	***r*** **= 0.70 – 0.72 and 0.61 – 0.67 for**
and biomass		RADARSAT-2		**LAI and biomass**
Diseases and	Wheat	Worldview-2 and	2 and 30	**Accuracy of 71% and 82% for**
Pests		Landsat 8		**models w/o and w environmental**
				Indices
Leaf/canopy	Corn and	Landsat 5 TM and	30	$\mathbf{R^2 = 0.35 – 0.69}$
chlorophyll content	soybean Potato	7 Sentinel-2	10 – 20	$\mathbf{R^2 = 0.58 – 0.82}$
Yield	Wheat	WorldView-2	0.46	***r*** **= 0.58 and 0.53 between NDVI**
				and biomass or yield
	Wheat	Landsat 5 TM, 7 and 8	30	**Moderate accuracy with RMSE of 0.79 Mg/ha.**

Conclusion

Plant phenotyping is one of the prerequisites of plant breeding to successfully run any crop improvement programme. This satellite is used as a tool for data collection, mapping, monitoring, measurement, and management across disciplines, including plant breeding. Many characters have been studied and validated by the researcher using remote sensing. It has several applications in precision agriculture. Satellite imagery can serve as an effective and useful phenotyping tool, saving users from equipment capital costs, and other technological challenges. Further, it can be potentially used for plant phenotyping in plant breeding for crop improvement programmes.

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