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Research Article

Decadal Changes in Cultivated Area Over the Indo-Gangetic Plains by using Multi-temporal MODIS Data

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ABSTRACT

The role of cultivated land conversion on food security of the country has often been talked. This has special relevance to Indo-Gangetic Plains (IGP) for ensuring sustainable food grain production. This study used MODIS land cover products (500m) of 2001, 2006, and 2012 to examine the changes in the land use and cultivated areas over the entire IGP. There was an increase (2.20%) during 2001-06 and a decrease (0.6%) over 2006-2012 in the cultivated land. The area under forest and plantation increased by 0.38%, while grassland decreased by1.51% during 2001-2012 period. MODIS offers a quick estimate of the major changes in LULC happening over a large area and therefore aids in the decision and developing policy guidelines.

Key words: Indo-Gangetic Plains, temporal change, cropland, MODIS

Introduction

Land cover refers to the observed biophysical cover on Earth's surface (Gergario, 2016), while land use implies to the actual use of the cover (Cihlar and Jansen, 2001). Together, the land use and land cover (LULC) map help in understanding the current landscape information of an area, and the change dynamics. It also provides a scope for analyzing the future change direction and the man-environment relationship (Lu *et al*., 2019). It is reported that in as many as 20 states in India, cultivable land decreased by 790 thousand ha between 2007-08 and 2010-11 (Anonymous, 2013). Urban area of India was reported to increase by ~25% during the 1990s, and the expansion is at rates faster than the growth of urban population (Seto *et al*., 2011). A significant loss in agricultural lands in different districts of India has been widely reported *viz*. Vadodara, Saharanpur, Hyderabad, and Aligarh (Sandhya Kiran and Joshi, 2013; Fazal, 2000; Wakode *et al*., 2014; Farooq and Ahmad, 2008). Policy makers and scholars have started to debate its consequences. There has been increased awareness of the conversion, and a large number of studies have been directed to understand the nature of LULC Change (Roy *et al*., 2015; Naikoo *et al*., 2020).

The Indo-Gangetic Plains (IGP) covering 16% total geographical area of India is known as the

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country's 'food basket' due to its contribution to 50% of it's food grain production. It is also very highly-dense populated region in the country (447 million; Census 2011). Conversion of cultivable land into built-up is a critical factor that affects the food security of any country (Barati *et al*., 2015; Gutzler *et al*., 2015). Growing population over time over IGP led to appreciable changes in LULC and more specifically, the changes in cultivated area over the past few decades. Change in LULC over IGP may be resulted from multiple factors like increasing population growth, developmental activities and government policies, migration of rural population to urban areas, and changes in agricultural activities over the years. Spatial and temporal change mapping of LULC in the IGP using remote sensing data is necessary to identify the change drivers, plausible impacts on the environment as a whole, and to the food security of the country. It also helps in developing policies for ensuring sustainability in crop production.

With this backdrop, the present study was planned to analyze the spatiotemporal changes in LULC in the IGP by using MODIS 'Land Cover Type' Products over IGP of India at periods of intervals (2001-02/2006-07/2012-13).

Materials and Methods

Description of the study area

The study area covers the entire IGP of India which extends between 24°10′ N to 32°29′ N latitudes and 73°52′ E to 89°51′ E longitudes and covers 5,14,938 km^2 (nearly 16%) of the total area of India and consists of five states, namely Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal (Fig. 1).

Data acquisition

Moderate Resolution Imaging Spectro-radiometer (MODIS) 'Land Cover Type' product was used for LULC change detection. A brief description of the data is given below:

MODIS Land Cover product (MCD12Q1) data are provided every year with 500 m spatial resolution and sinusoidal projection. This MCD12Q1 data product gives global land cover types at yearly basis from 2001 to 2012, and is derived from six different classification schemes (Sulla-Menashe and Friedl, 2018) using supervised classifications of MODIS Terra reflectance data (Friedl *et al*., 2002, 2010). Detailed metadata of MCD12Q1 was downloaded from the USGS site (https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mcd12q1).

These classifications then experience further post-processing that includes antecedent knowledge and ancillary data to improve each class so that it gives a near-to-real picture of the earth's surface (https://lpdaac.usgs.gov/products/mcd12q1v006/). Out of six classification schemes, we used the International Geosphere-Biosphere Programme

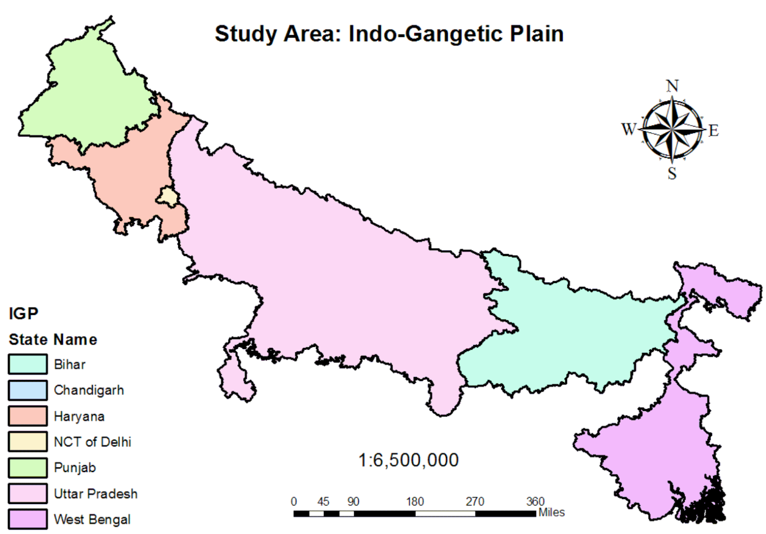

Fig. 1. Study area: Indo-Gangetic Plains of India with constituting states

(IGBP) legend for LULC classification in this study for its being comprehensive and adopted globally.

Processing of MODIS data and change detection

The data used in this study were converted from HDF to *.tiff format and re-projected from sinusoidal to geographical coordinates by using MODIS Conversion Toolkit (MCTK). Then, ArcGIS software was used to change the projection of the datasets to the UTM coordinates. The remotely-sensed MODIS land cover product images for the years 2001-02, 2006-07, and 2012-13 were finally used for this study. The software ENVI 4.8 was used for necessary image processing. Considering the "IGBP" and the goal of this study, the land use types were divided into six categories: cropland, forest and plantation, grassland/savannas/shrubland, water body, built-up, and others (rest, unclassified). For the detection of LULC changes, a decision tree was used. A change matrix was produced with the help of ENVI-4.8 software. This study applies the accuracy assessment method to the classified LULC maps.

Results and Discussion

MODIS data product revealed that out of a total 5,24,984 km^2 area of IGP, 85.6% was under cropland in 2001. This increased to 87.8% in 2006 and again reduced to 87.2% in 2012 (Fig. 2; Table 1). An increase of 2.2% in cropland was recorded between 2001 and 2006, although during 2006-2012, cropland decreased by 0.6%. In the 2001 image, 1.65% (8680 km^2) area of IGP was covered under forest, 4.91% (25781 km^2) under grassland, 1.93% (10112 km^2) as urban and 0.29% (1508 km^2) as water body. Areas under forest, grassland, urban and water bodies were recorded as 1.71% (9001 km^2), 3.47% (18217 km^2), 1.93% (10111 km^2) and 0.23% (1202 km^2), respectively in 2006; and 2.03% (10667 km^2), 3.40% (17838 km^2), 1.93% (10112 km^2) and 0.29% (1505 km^2) in 2012. The decrease in cultivated area in IGP has corroboration with the study conducted by Gupta (2014). Between 2001 and 2006, 11136 km^2 of cropland increased while 3156 km^2cropland was lost between 2006 and 2012 (Tables 2, Figs. 3 and 4). Similarly, 322 km^2 and 1666 km^2 area increased during 2001-2006 and 2006-2012, respectively. The MODIS data product, therefore, appears to be an effective and rapid way to record the variations in LULC over a large area like IGP. It helps in exploring possible interventions for promoting sustainable land use.

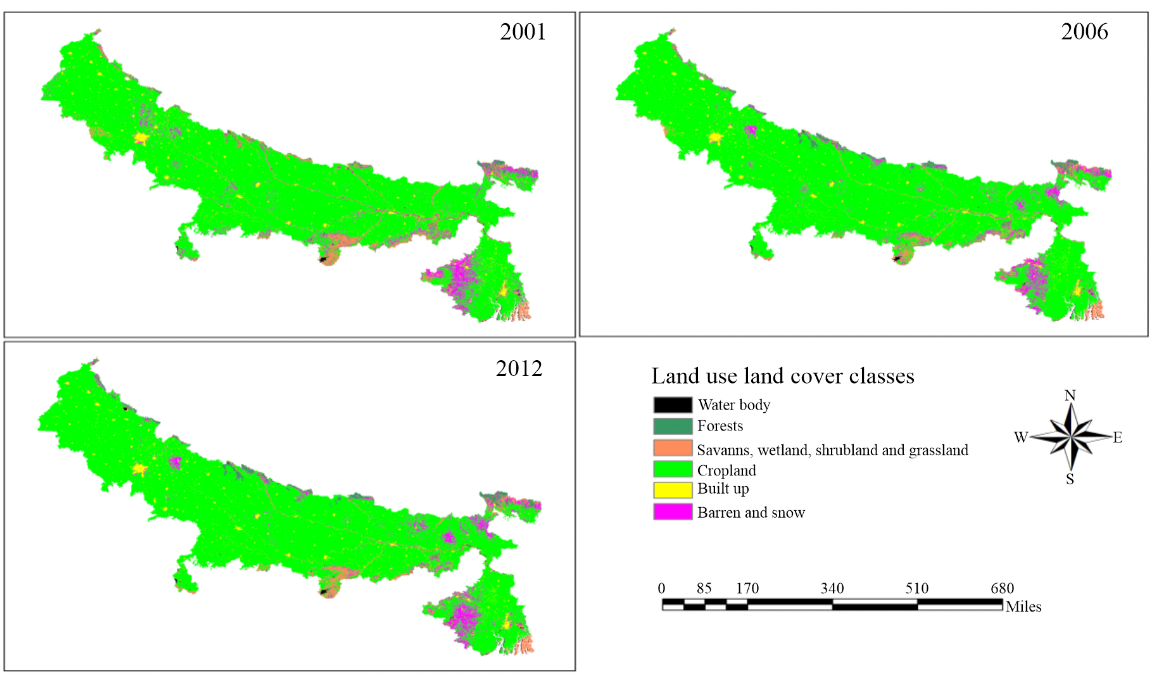

Fig. 2. Land cover classes of IGP extracted from MODIS Land cover product

Table 1. Comparison of changes areas under different LULC

LULC classes	Area in square kilometer			Area in percent		
	2001	2006	2012	2001	2006	2012
Cropland	449629	460765	457609	85.6	87.8	87.2
Forest	8680	9001	10667	1.65	1.71	2.03
Grassland	25781	18217	17838	4.91	3.47	3.40
Water body	1508	1202	1505	0.29	0.23	0.29
Urban	10112	10111	10112	1.93	1.93	1.93
Others	39386	35798	37365	5.58	4.89	5.19
Total	524984	524984	524984	100	100	100

Table 2. Comparison of changes areas under different LULC

LULC class	Changes 2001-06 Area in square kilometer	Changes 2006-12 Area in square kilometer	Percentage of changes	
			2001-06	2006-12
Cropland	11136	3156	48.6	44.6
Forest	322	1666	1.40	23.6
Grassland	7563	379	33.0	5.36
Water	306	303	1.33	4.29
Others	3588	1567	15.7	22.2
Total	22915	7070	100	100

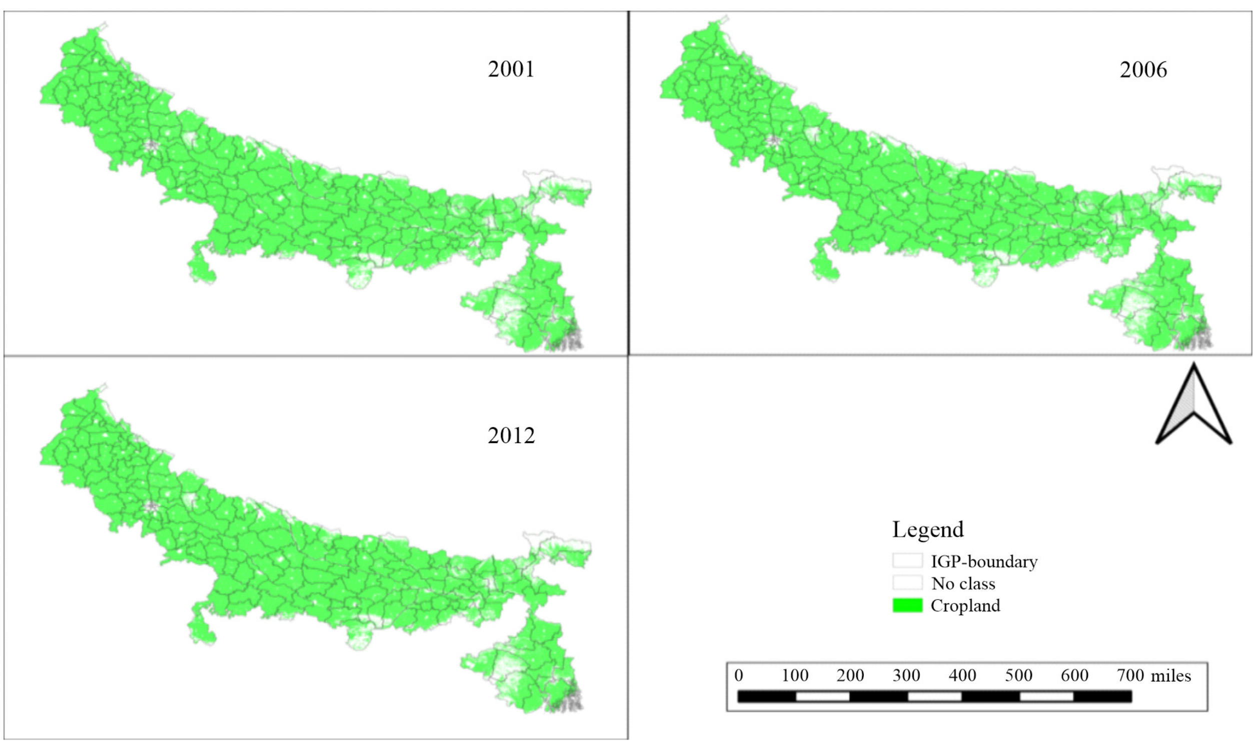

Fig. 3. Extracted cropland of IGP for 2001, 2006 and 2012 (MODIS 500m land cover product)

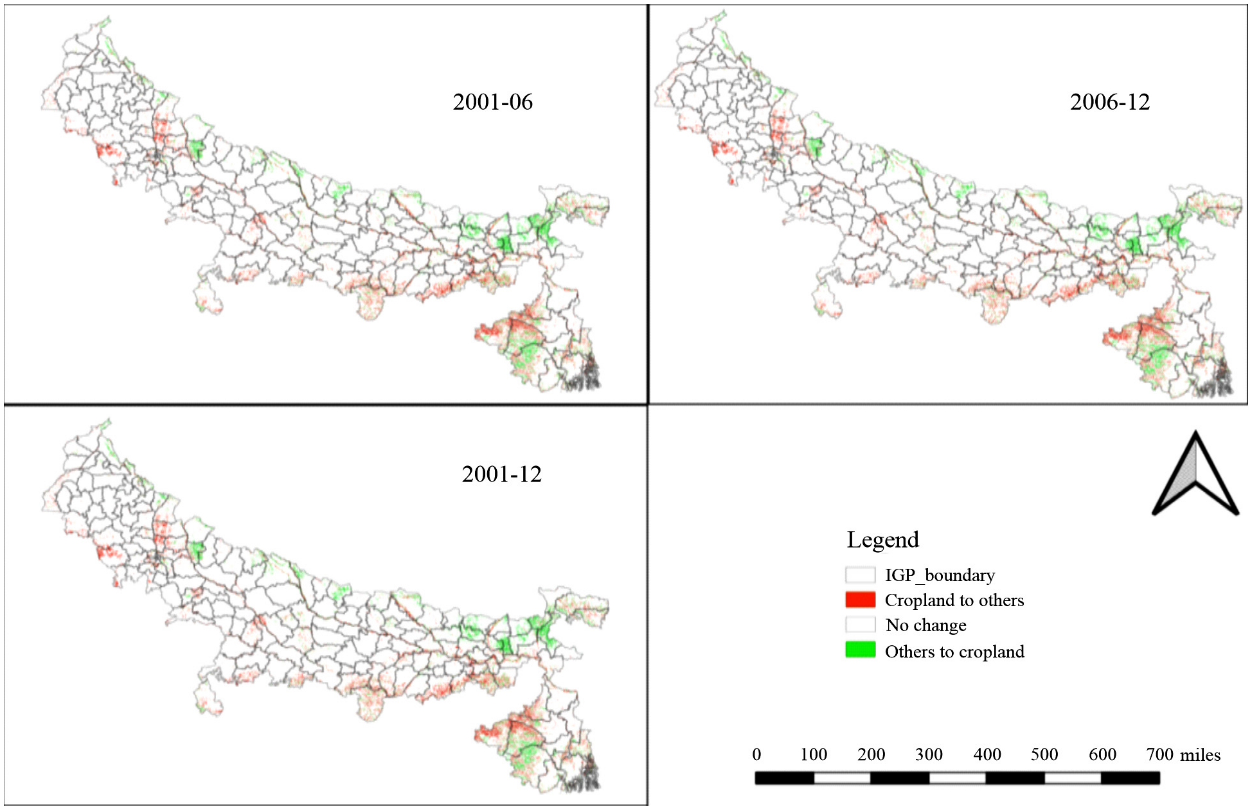

Fig. 4. Conversion in cropland area and others from 2001 to 2006, 2006 to 2012 and 2001 to 2012

LULC change patterns over the period of 2001–2006

To understand land infringement for various LULC classes during the last decades, a change detection matrix (Table 3) was prepared, which showed that during the period 2001–2006, major changes happened from cropland to 'others' LULC classes (the area that could not be classified). About 3.3% of cropland changed to 'others' while 51.6% of 'others' class shifted to cropland category. About 30, 15 and 5% of areas of grassland, forest and water body respectively converted to cropland. The area under forest increased by 12.3% due to the conversion of parts of grassland to forests possibly by reforestation. Nearly 33, 15 and 10% per cent

Table 3. LULC change detection matrix between 2001 and 2006 in the IGP of India

Year		2001						
	LULC class	Water	Forest	Grassland	Cropland	Urban	Others	Row Total
	Water	**68.1**	0.07	0.18	0.003	0	0.17	100
	Forest	0.42	**42.0**	12.3	0.15	0	0.87	100
2006	Grassland	11.1	33.1	**45.0**	1.07	0.02	13.1	100
	Cropland	4.97	15.3	30.0	**95.5**	0.002	51.6	100
	Urban	0.04	0	0.001	0	**99.9**	0	100
	Others	15.4	9.56	12.6	3.30	0	**34.3**	100
Class Total		100	100	100	100	100	100	
Class Changes		31.7	58.0	55.1	4.53	0.02	65.7	
Image Difference		-20.3	-5.30	-26.10	3.40	-0.01	-8.06	

area increased under grassland, forest, and water body categories respectively, from the forest area. Around 13% area from 'others' category converted to grassland. About 95.5%, 42%, 45% and 34.3% of areas of cropland, forest, grassland and others respectively remained as such during this period.

LULC patterns over the period of 2006–2012

Forests and 'others' area showed increasing trends during this time period, in contrast, to a decrease in areas under cropland and grassland (Table 4). Similar to the changes observed during 2006–2012, 12.9% area was converted from grassland to forest, this may be due to the reforestation, forest conservation projects, and policy changes implemented in the area (Pathak *et al*., 2014). Changes from the cropland to forest and vice versa were also recorded and could be due to the implementation of agroforestry systems in the study area (Verma *et al*., 2017; Deb *et al*., 2018). Around 0.2% of cropland area has been converted to forest, 37.2 per cent and 14.5% area under other land converted to cropland and grassland while 1.2% area changed to the forest.

LULC patterns over the period of 2001–2012

Overall, forest area had increased over a decade (2001-2012), and a decrease in grassland was seen (Table 5). Around 13% of the area converted from forest to cropland. Xu *et al*. (2014) reported that terrain, soil, water and livestock are the primary drivers for the conversion of forest into agricultural land in South and southeast countries like India. Similar to the changes observed during 2006–2012, 15% of area converted from grassland to forest, 0.3 and 12.6% of area changed from cropland to forest, and vice versa. Fifty-three and 12% areas under the 'others' LULC class converted to cropland and grassland, while 1.3% of area moved to the forest category.

Table 4. LULC change detection matrix between 2006 and 2012 in the IGP of India

Year		2006						
	Land use class	Water	Forest	Grassland	Cropland	Urban	Others	Row Total
	Water	**86.6**	0.048	0.267	0.012	0.008	0.56	100
	Forest	1.48	**72.1**	12.9	0.218	0	1.23	100
2012	Grassland	6.68	23.1	**58.4**	1.52	0.006	14.5	100
	Cropland	2.75	3.24	20.9	**94.7**	0.004	37.2	100
	Urban	0	0	0.006	0	**99.9**	0	100
	Others	2.48	1.53	7.49	3.53	0.002	**46.5**	100
Class Total		100	100	100	100	100	100	
Class Changes		13.4	27.9	41.6	5.28	0.02	53.5	
Image Difference		16.5	20.9	-0.447	-0.603	0.006	0.183	

Table 5. LULC change detection matrix between 2001 and 2012 in the IGP of India

Year		2001						
	Land use class	Water	Forest	Grassland	Cropland	Urban	Others	Row Total
	Water	**71.5**	0.08	0.30	0.01	0.004	0.31	100
	Forest	0.753	**45.9**	14.9	0.29	0	1.33	100
2012	Grassland	12.8	34.3	**44.5**	1.12	0.006	12.3	100
	Cropland	9.5	12.6	30.2	**94.8**	0	53.2	100
	Urban	0.01	0	0.001	0	**99.9**	0	100
	Others	5.48	7.12	10.1	3.84	0	**32.8**	100
Class Total		100	100	100	100	100	100	
Class Changes		28.5	54.0	55.5	5.25	0.01	67.2	
Image Difference		-7.13	14.4	-26.4	3.27	-0.002	-7.89	

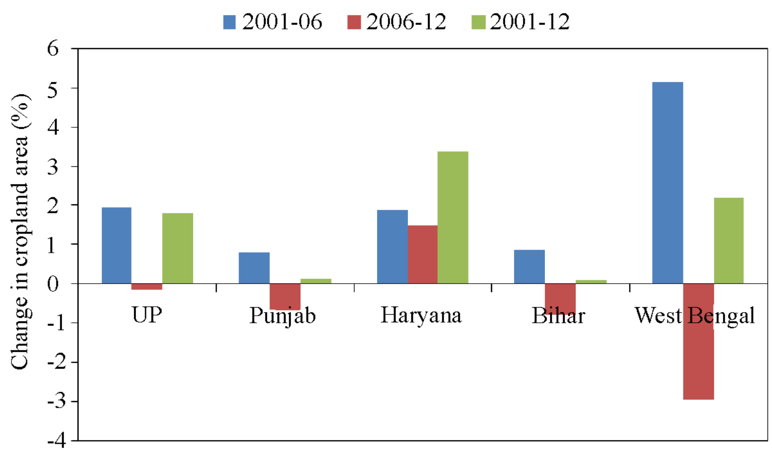

Fig. 5. State-wise changes in cropland area over the IGP

Similar changes in LULC for selected parts of IGP of India were reported by Gupta (2014), Pandey and Seto (2015) and Roy *et al*. (2015). An increase in agricultural land and decrease in non-agricultural (barren land, cultural wasteland and fellow land) in Uttar Dinajpur district of West Bengal was documented between 2001 and 2006 (Sarkar, 2018).

However, a state-wise breakup indicated an increase in cropland in West Bengal in the first half followed by a decrease in the other half of the period of 2001-2012 (Fig. 5). The satellite image also revealed a large increase in cropland in UP and Haryana during this period, but a small increase in Punjab.

Conclusions

The study conducted in Indo-Gangetic Plains advocates the use of multi-temporal satellite data for rapid estimation of LULC and changes between major classes over a period. We have used MODIS 500 m data, which is coarser and cannot resolve details of changes happening over small patches. However, these datasets are freely available, and one can use them for general monitoring and quick surveillance. For more accuracy and details, finer resolution satellite data products (e.g., MODIS 250 m, and even Sentinel 10 m) could be used. Multispectral Sentinel-2 has been successfully used for in-season crop mapping (e.g., Prashanthika *et al*., 2019).

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