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Spatial Products for Crop Monitoring and Sustainable Agriculture

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Abstract

The spatial cropland products are of great importance in water and food security assessments, especially in India, which is home to nearly 1.4 billion people and 160 million hectares of net cropland area. In India, croplands account for about 90% of all human water use. Cropland extent, cropping intensity, crop watering methods and crop types are important factors that have a bearing on the quantity, quality and location of production. Currently, cropland products are produced using mainly coarse-resolution (250-1000 m) remote sensing data., our study was aimed at producing three distinct spatial products at 30m and 250m resolution that would be useful and needed to address food and water security challenges. The first of these, Product 1, was to assess irrigated *versus* rainfed croplands in India using Landsat 30 m data in GEE platform. The second, Product 2, was to map major crop types using MODIS 250 m data. The third, Product 3, to map cropping intensity (single, double and triple cropping) using MODIS 250 m data. For the *kharif* season (the main cropping season in India, Jun-Oct), 9 major crops (5 irrigated crops: rice, soybean, maize, sugarcane, cotton; and 5 rainfed crops: pulses, rice, sorghum, millet, groundnut) were mapped. For the *rabi* season (post rainy season, Nov-Feb), 5 major crops (3 irrigated crops: rice, wheat, maize; and 2 rainfed crops: chickpea, pulses) were mapped. The irrigated versus rainfed 30 m product showed an overall accuracy of 79.8% with the irrigated cropland class providing a producer's accuracy of 79% and the rainfed cropland class 74%. The overall accuracy demonstrated by the cropping intensity product was 85.3% with producer's accuracies of 88%, 85% and 67% for single, double, and triple cropping respectively. Crop types were mapped to accuracy levels ranging from 72% to 97%. A comparison of the crop type area statistics with national statistics explained 63-98% variability. The study highlights production of multiple cropland products to support food security studies using multiple satellite sensor big-data, and RF machine learning algorithm that were coded, processed, and computed.

Key words: Dry agriculture; Spectral bank; crop signatures; geospatial tools

Methodology

Our study was aimed at three remote-sensing products that capture important cropland characteristics (**Figure 1**)

1. Irrigated and rainfed cropland area;
2. Crop type.
3. Cropping intensity (the number of times a crop is grown on the same plot of land in a year);

Methods for product 1: Mapping irrigated and rainfed cropland using RF Machine Learning algorithm

In making Product 1 to delineate irrigated croplands from rainfed croplands with Landsat 30m and ground data, we adopted the RF machine learning algorithm and computing was performed on the GEE cloud platform, which is equipped with hitherto unheard-of petabyte-scale big data analytics. The RF machine learning algorithm is a pixel-based supervised classifier. The method involves the following steps:

- Reference training data collection.
- Knowledge base creation
- Running machine learning algorithms

Method for Product 2: Crop type mapping using quantitative spectral matching technique

MODIS 250 m data was used to classify and identify crop types using quantitative spectral matching techniques (SMTs). The SMTs involved developing ideal spectral signatures (ISSs), classifying images and obtaining class spectral signatures (CSSs), and matching class spectra with ideal spectra to identify and label crop type classes (Thenkabail *et al.,* 2007) (**Figure 2**). Methodological steps involve the following steps:

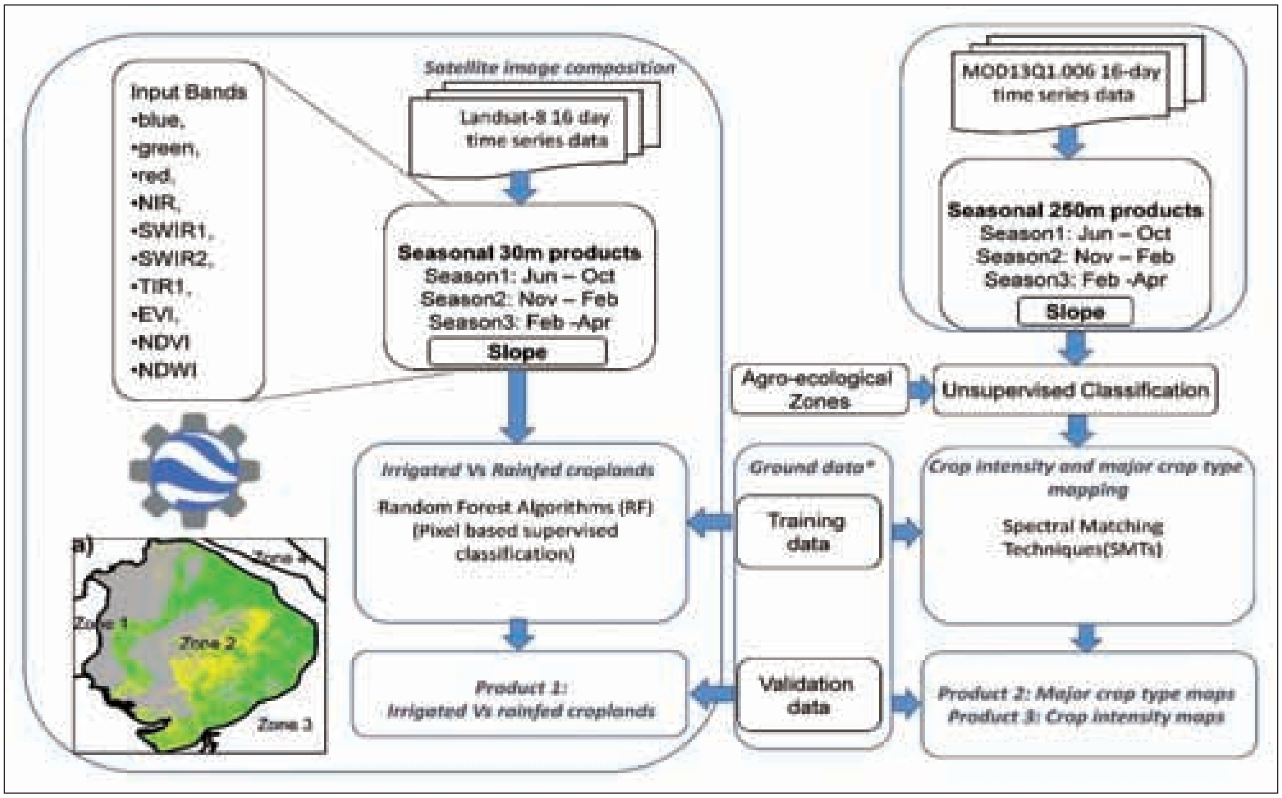

Figure 1: Methodology used for mapping three cropland products

Product 1: Irrigated croplands *versus* rainfed croplands using Landsat 8 data at 30 meters resolution in GEE interface. **Products 2 and 3:** Cropping intensity and crop type using MODIS 250 meters data

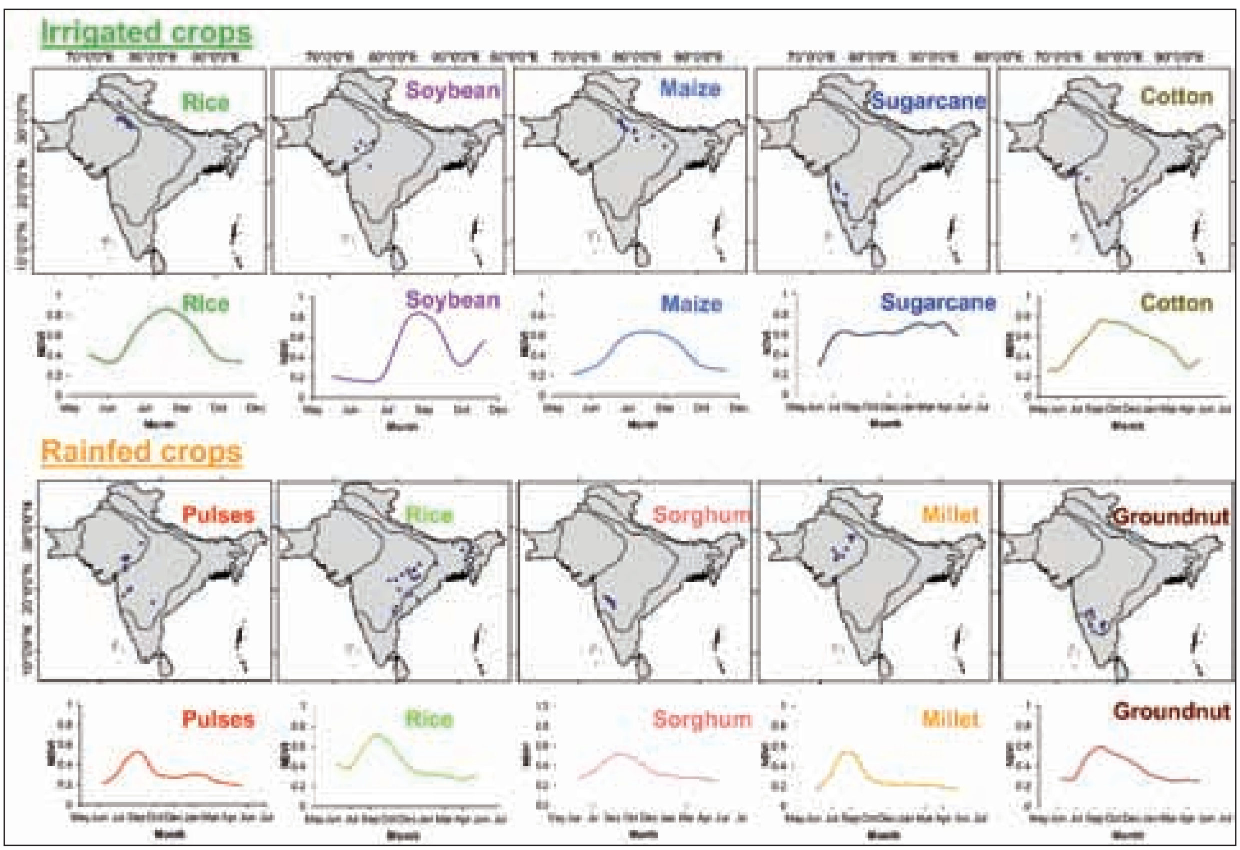

Figure 2: Spectral signatures of major crops obtained using MODIS NDVI time-series data

- Generation of Ideal spectral signatures
- Class spectra generation
- Matching of class spectra on the basis of ideal spectra to group classes using SMTs. (**Figure 3**)

Method for Product 3: Cropping intensity map

Cropping intensity was mapped with the help of a spectral signatures that involves time-series NDVI profiles (**Figure 4**).

Cropping intensity was identified by analysing the peaks of the temporal NDVI profiles of the classes that obtained during the unsupervised classification.

Results

Irrigated vs. Rainfed Cropland

The spatial distribution map of irrigated and rainfed croplands of South Asia derived using Landsat 30 m data is shown in Figure 5. There is a total of 160 million hectares of croplands in India (**Figure 5**) of which 55% is irrigated and 45% is rainfed. While most of the irrigated croplands is located below the Himalayan mountain ranges dominated by the Ganges and the Indus river basins as well as by the major river basins throughout India. These river basins provide irrigated water through reservoirs created by major, medium, and small dams, run of the river diversions through barrages, and riverine water through flows throughout the years either due to runoff from rainfall or from snowmelt from Himalayan Rivers.

Major sources of water for irrigation also comes from ground water (wells on deep acquirers and shallow acquirers), and tanks or small reservoirs along the low order streams. Rainfed crops are found in some concentration in Rajasthan and Odisha states of India and in parts of southern and northeastern India.

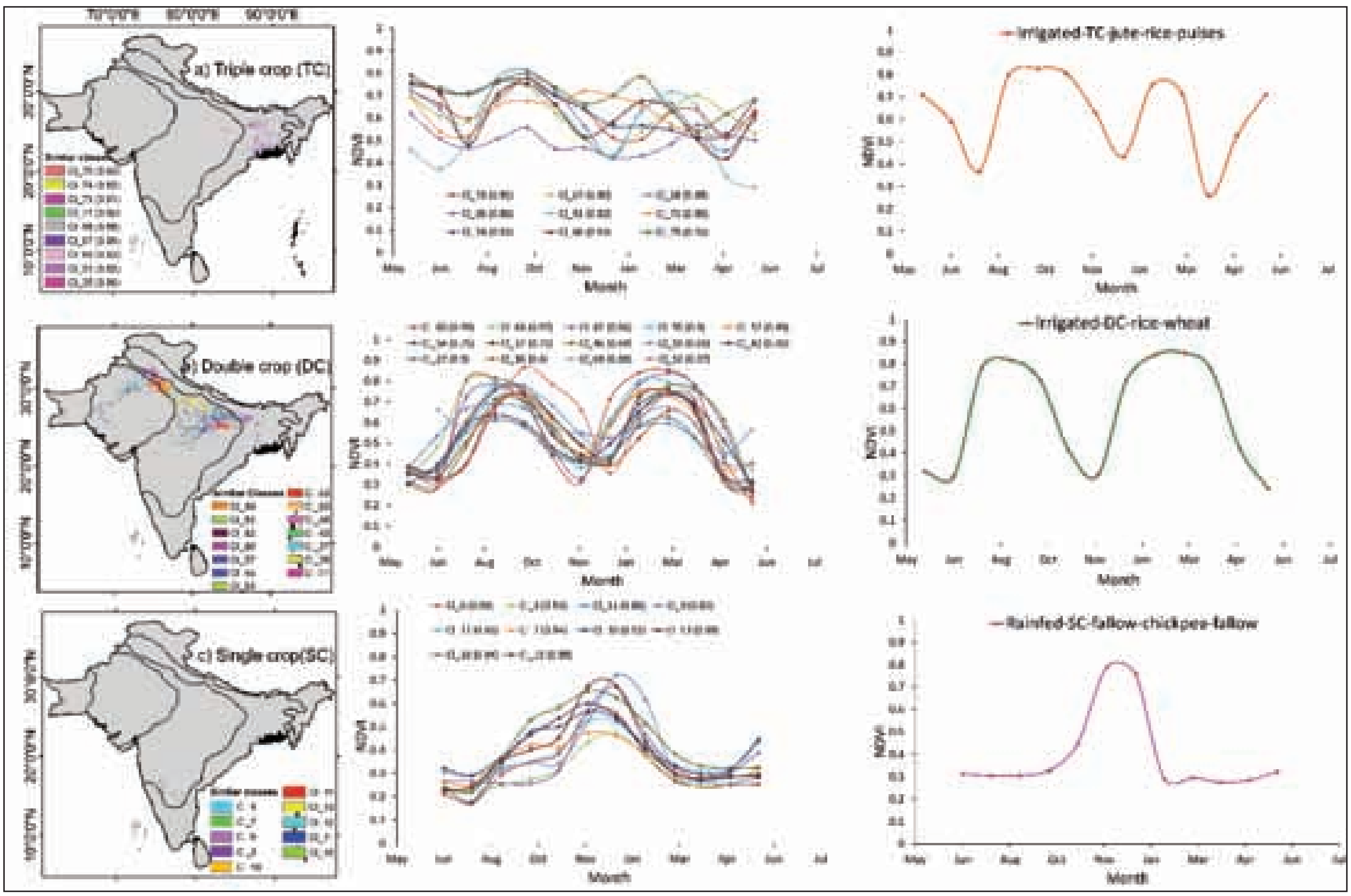

Figure 3: Spectral matching techniques (SMTs) to match class spectra with ideal spectra extracted from MODIS 250 m time series data.

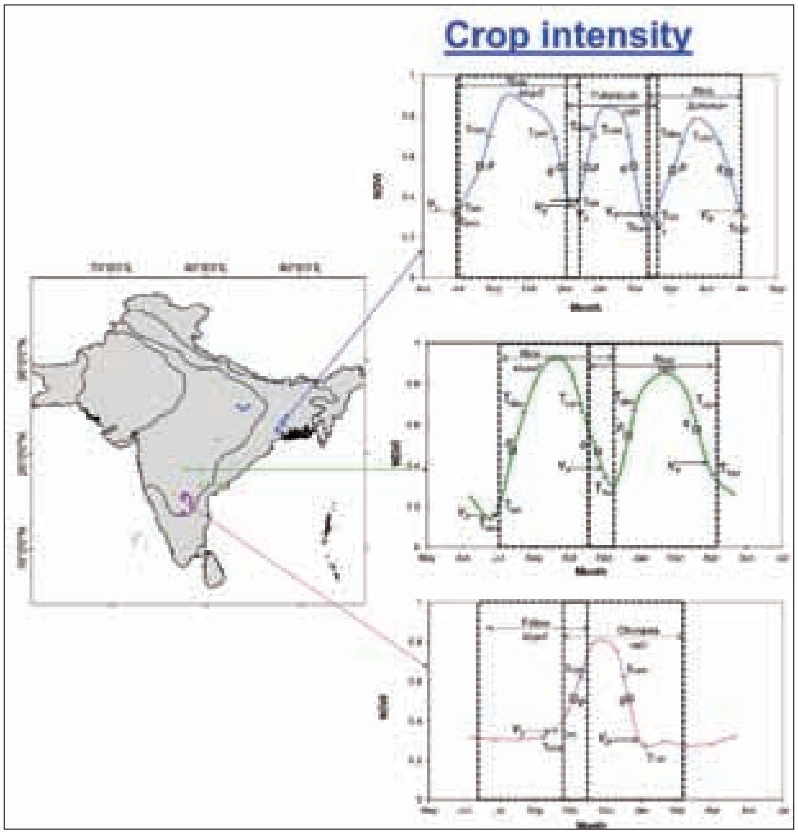

Figure 4: Spectral signatures obtained using MODIS derived NDVI time series data showing crop intensity. Temporal NDVI profile and transition dates for three crop seasons are shown. Each peak indicates a crop season.

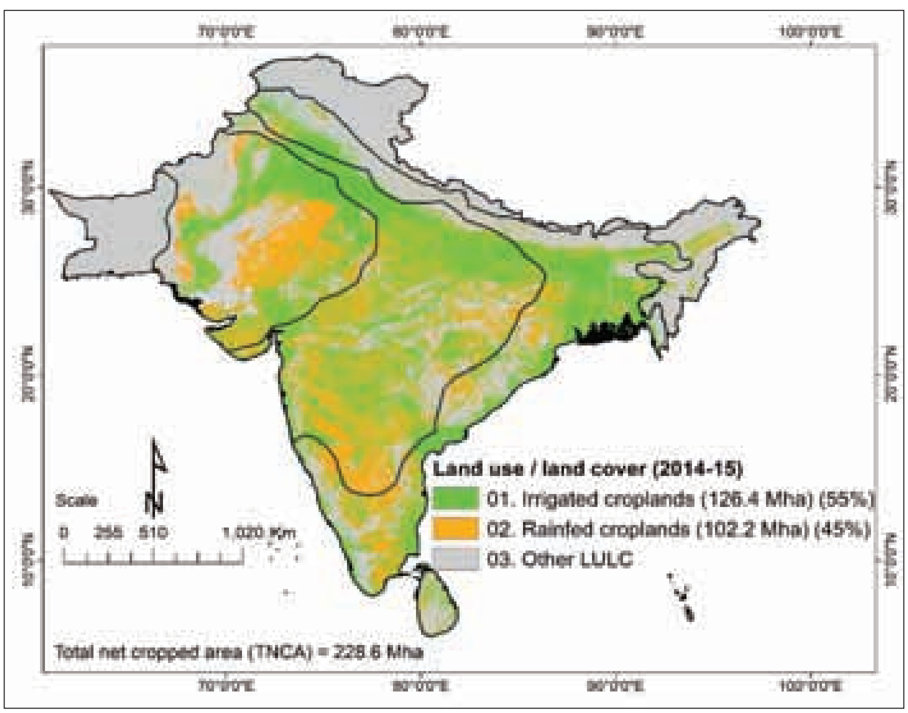

Figure 5: The Landsat derived irrigated versus rainfed cropland map of India (2014-15). The map was made using 30 m time-series data from Landsat 8 on the GEE platform.

Crop type\dominance

The spatial extent of the five irrigated crops (rice, soybean, maize, sugarcane and cotton) and five rainfed crops (pulses, rice, millet, sorghum and groundnut) were depicted in **Figure 6**. This distribution shows crop dominance in various regions of India. In the monsoon (rainy) season, most of the irrigated rice areas (Figure 6A) are concentrated in the northern part of India and along the rivers, amounting to almost 16% of the total cropped area. Irrigated soybean (Figure 6B) is seen mostly in Madhya Pradesh state of India, occupying about 6% of the total cropped area. Irrigated maize (Figure 6C) is found across India, accounting for about 8% of the total cropped area. Irrigated sugarcane (Figure 6D) with 2% of the cropped area is mostly located in north India whereas most of the irrigated cotton (Figure 6E), with 11% of total cropped area, is found in the southern part of India. In the dry areas, most of the crops sown during the monsoon season are dependent on rainfall: pulses (Figure 6F) grown on rainfed cropland are concentrated in the western part of India with almost 13% of the total cropped area; and rainfed rice (Figure 6G) is found in the eastern part of India with almost 11% of the total cropped area. Sorghum (Figure 6H) and Millet (Figure 6I) take a significant share (about 11%) of the rainfed area in India whereas rainfed groundnut area (Figure 14J) is located in the southern part of India with almost 3% of the total cropped area.

As most of the cropland in India has double intensity, crops are grown in winter and summer seasons (Figure 7), with crops like rice (Figure 7A), wheat (Figure 7B), and maize (Figure 7C) being cultivated with the help of irrigation facilities. The share of irrigated rice is about 7% of the total cropped area while irrigated maize takes almost 3%. The largest share of the total cropland area is taken by wheat, nearly 19%, mostly in north India. There are a few rainfed crops like chickpea (Figure 7D) and pulses (Figure 7E) that are sown in the winter and summer seasons, relying on the residual moisture in the field as well as atmospheric moisture, with almost 6% of the total cropped area.

Crop intensity

Crop intensity in India mainly depends upon water availability, either from rainfall or from irrigation, during the cropping seasons. Irrigated croplands allow double or triple cropping annually (in a 12-month period) whereas rainfed croplands are almost always limited to single crops due to rainfall events such as the South-West Monsoon (June-September) or North East Monsoon (October-December).

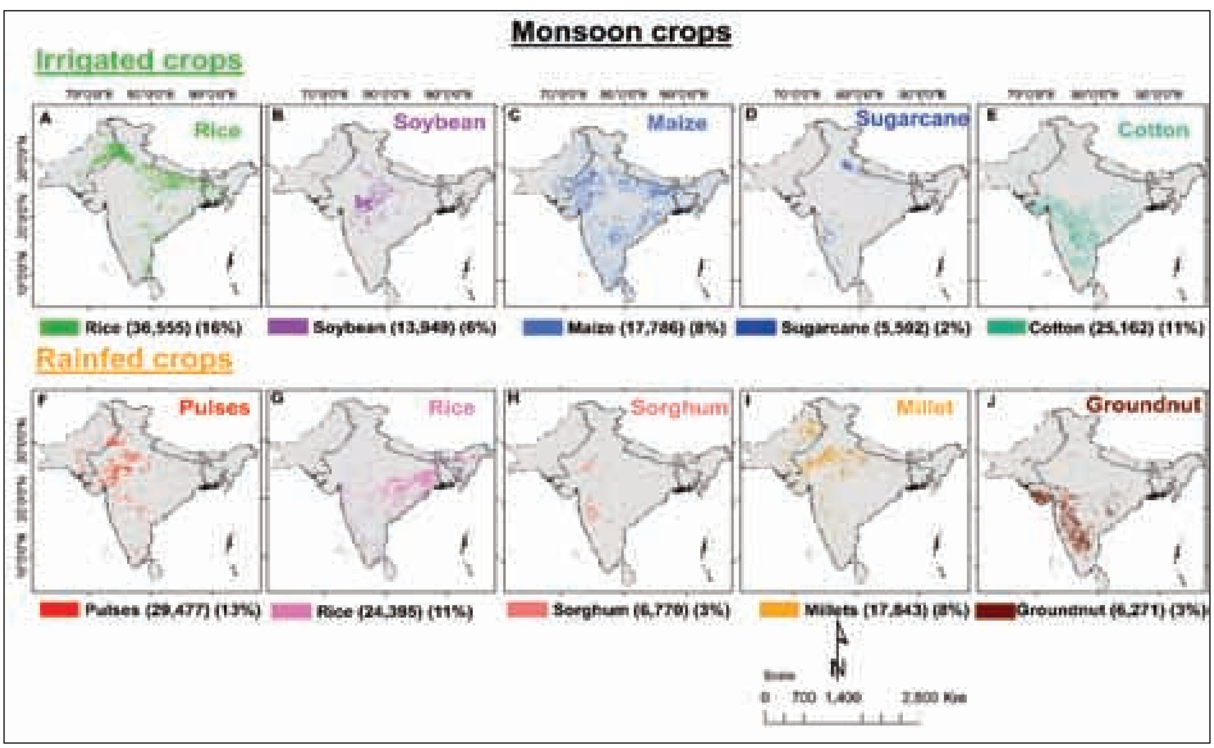

Figure 6: Spatial distribution of crop extent on irrigated and rainfed croplands in India during the *kharif* (monsoon) season of 2014-15. The mapping was done using MODIS time-series data. The 8 crops named above occupy 184 Mha (80.4% of the net cropped area) during the *kharif* season.

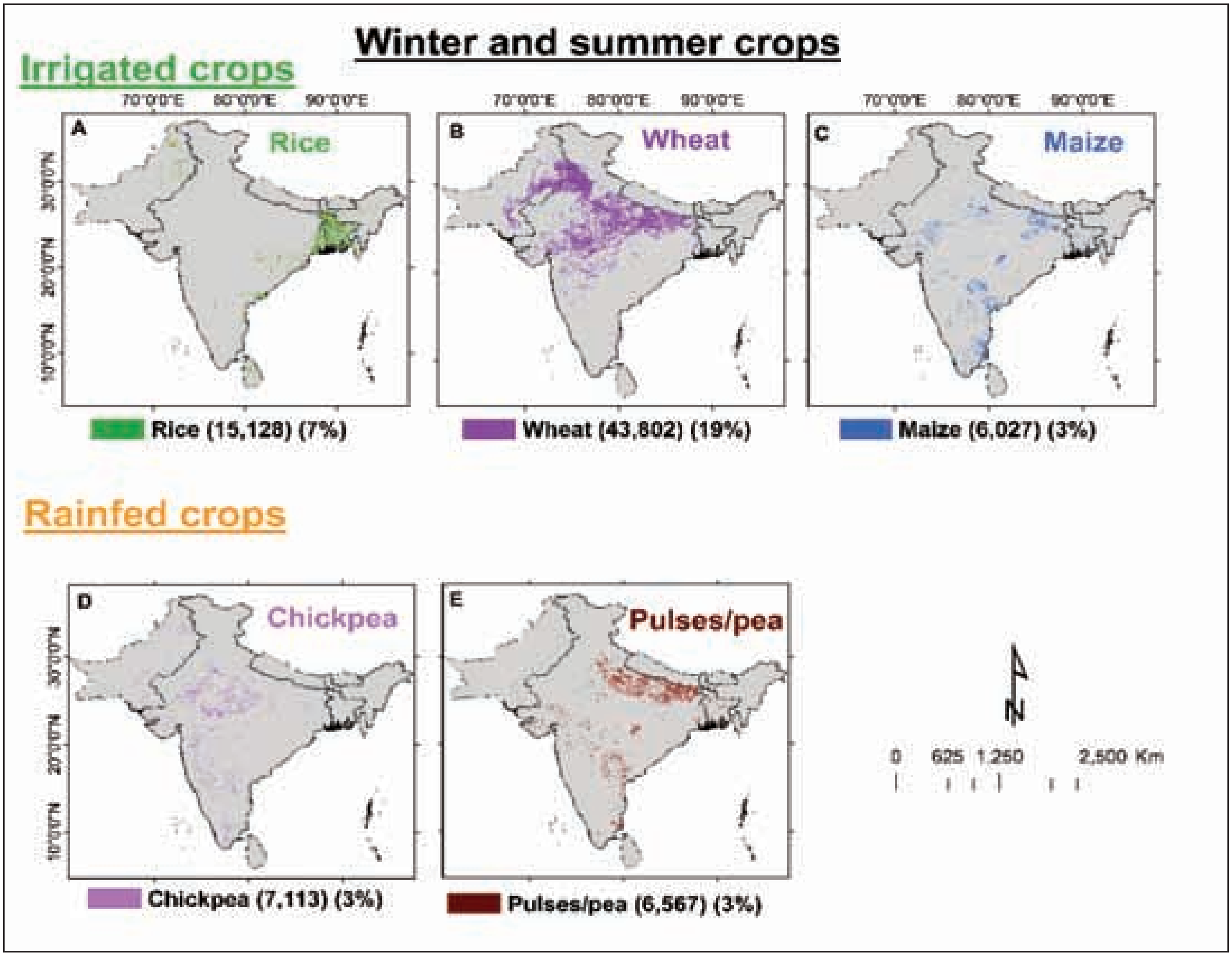

Figure 7: Season-wise crop type map, made by using MODIS time-series data, showing cropped area and percentage of total cropped area for India for the *rabi* season, 2014-15. The five crops shown above occupy 78.63 Mha or 34.4% of the total net cropped area.

The map in **Figure 8** shows that of the 160 Mha of croplands in India, 40.4% is in single crop, 55.3% double crop, and 4.3% triple crop. Single crop is mainly rainfed, double and triple crop is overwhelmingly irrigated. There is also significant irrigated areas in single crop. Triple crop is almost all in North East India. Double crop is in Ganges river basins and along other major rivers such as Mahanadhi and Krishna and Godavari. Rainfed areas are dominant in the Deccan Plateau and in the Rajasthan desert fringes.

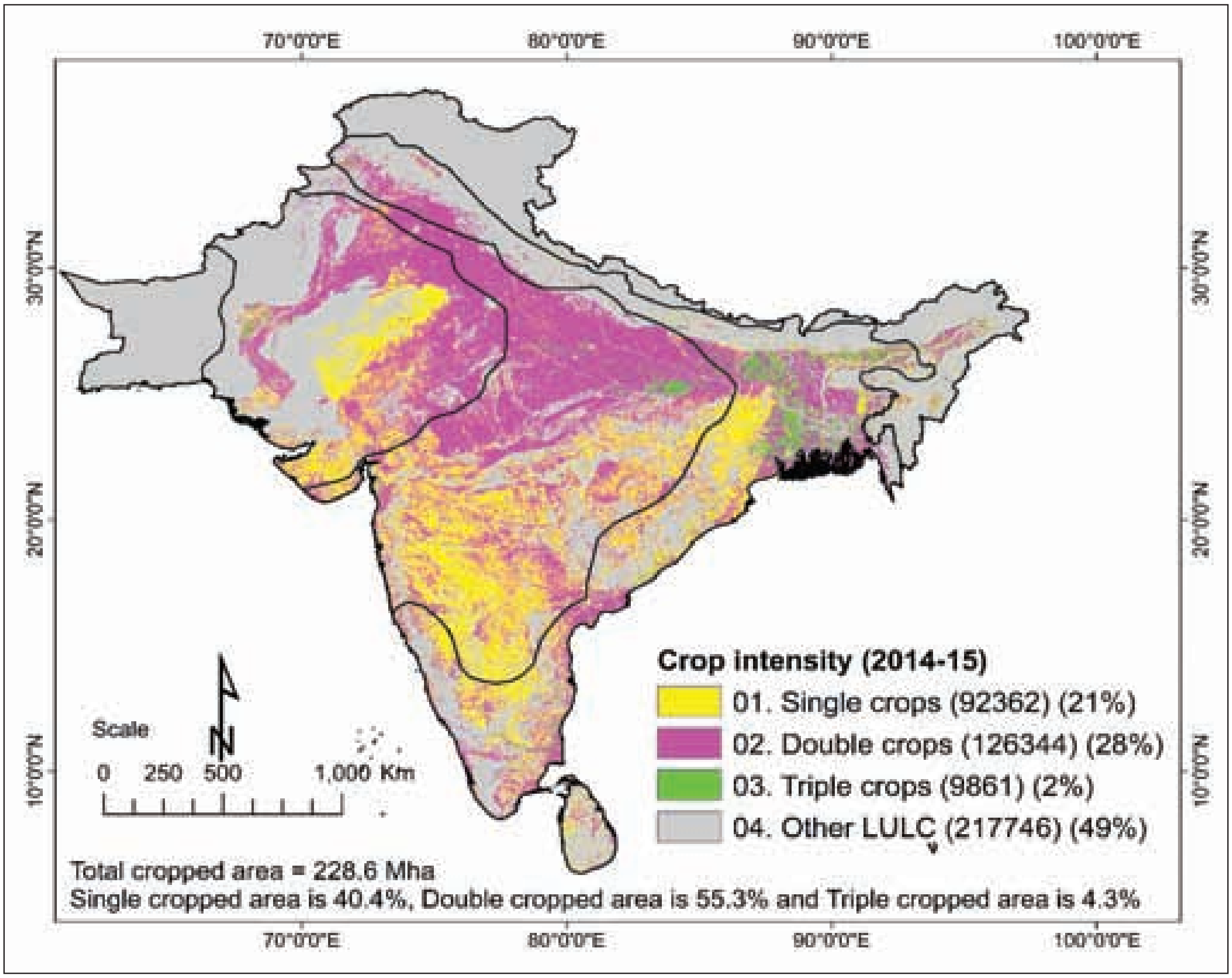

Figure 8: Cropping intensity map of South Asia (2014-15) produced by using MODIS 250 m NDVI time-series data.

Comparison of remote sensing-derived crop area statistics with national statistics

The crop type statistics derived from this study were compared with the crop type statistics obtained from traditional National statistics as shown in Figure 10. For major crops like rice, wheat, soybeans, cotton, sugarcane, and chickpea the areas derived in this study explained 82-98% variability relative to the National statistics **(Figure 9).** This clearly emphasizes the ability of MODIS 250 m time-series remote sensing data to accurately derive crop type areas. However, maize, groundnut and sorghum areas derived from remote sensing explained only 60-65% variability in National statistics. In case of ground nut and sorghum, there is wide range of variability in crop growth characteristics of these two rainfed crop depending on the rainfall variability. All irrigated crops, except maize explained over 80% variability. Irrigated maize, however, explained only 60% variability.

Overall, it can be stated that irrigated crops are mapped with significantly higher accuracies than rainfed crops, resulting in significantly better correlation of irrigated areas derived from remote sensing with the National statistics than with rainfed areas derived from remote sensing with National statistics **(Figure 9).**

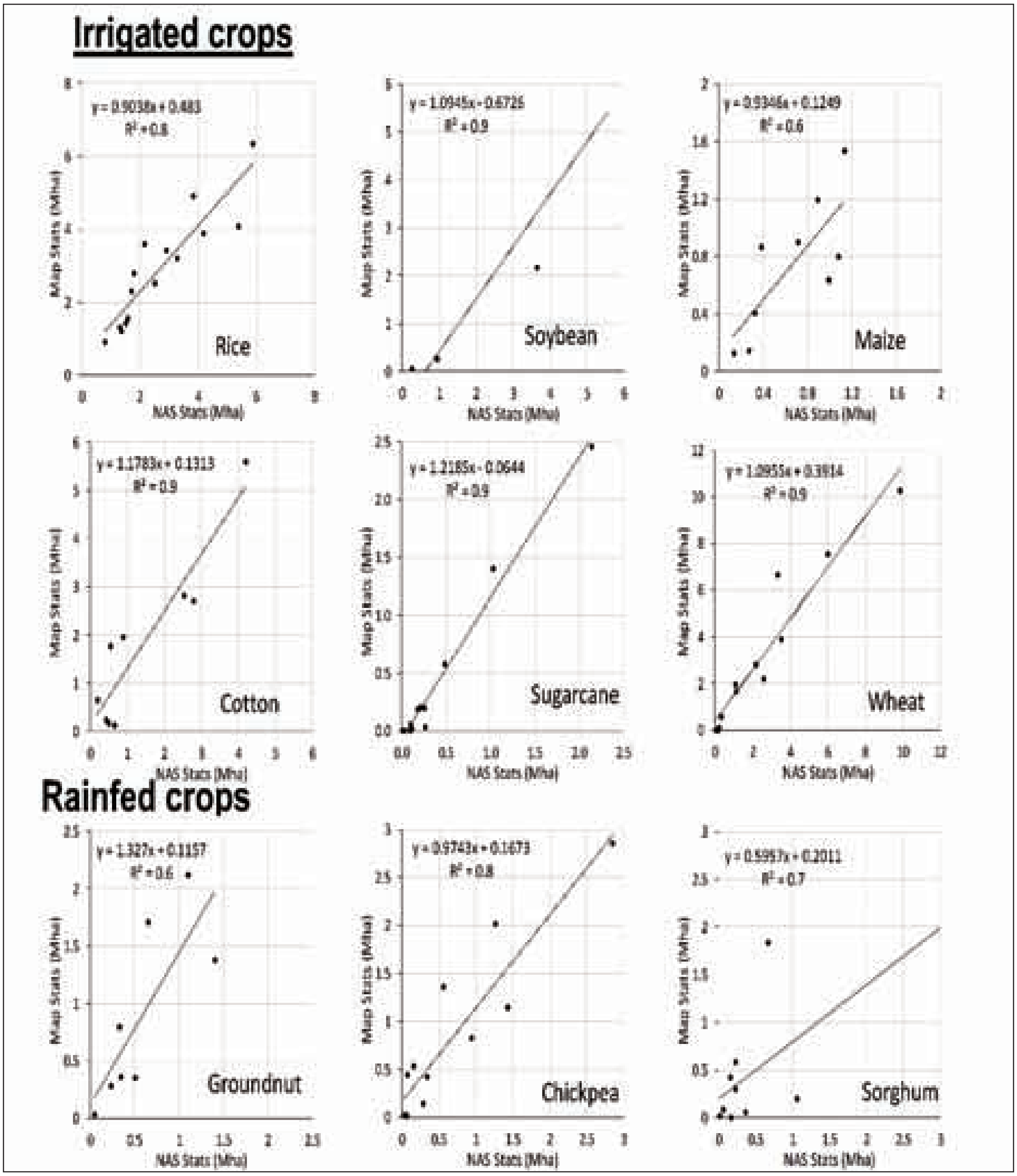

Figure 9: Comparison of remote sensing-derived crop areas with national statistics.

Conclusion

This study developed three distinct cropland products of India for the year 2014-2015 in support of food and water security assessments and management. These three cropland products were:

1. Irrigated croplands versus rainfed croplands using Landsat 30 m data;
2. Crop types using MODIS 250 m data and
3. Cropping intensity mapping using MODIS 250 m data

Time-series Landsat 30 m and MODIS 250 m analysis-ready data (ARD) cubes were developed and analyzed. The methods used employed machine-learning algorithms to identify irrigated and rainfed cropland areas, cropping intensities using phenological matrices, and crop types using quantitative spectral matching techniques (SMTs).

The computations were performed on the GEE cloud platform for the first product and on the workstations for the other two products.

The study established that the irrigated area in the whole of India was 55% o and rainfed areas amounted to 45% of the total net cropland area. The irrigated *versus* rainfed 30 m product has an overall accuracy of 79.8% whereas Crop types were mapped with accuracies ranging from 72% to 97%. The remote-sensing-derived crop type data explained 63-98% variability in the national statistics. Crop types were, generally, mapped with high degree of confidence, especially for irrigated crops where 80% or higher accuracies were achieved. Rainfed crops have higher uncertainty due to rainfall variability across large areas.

Acknowledgments

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Data Availability Statement

All data pertaining to this research are available on the public domain in the ICRISAT data portal (http://maps.icrisat.org/). These data include reference ground data used for training and validation as well as the cropland products presented in this paper. The cropland products released for the public include: irrigated and rainfed, cropping intensities, and crop types.

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