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RESEARCH ARTICLE

Menthol Mint (*Mentha arvensis* L.) Crop Acreage Estimation Using Multi-temporal Satellite Imagery

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Abstract

Crop acreage estimation is an essential component for forecasting crop production. Menthol mint acreage estimation is a necessity as the crop production data change every year due to fluctuations in the market prices of menthol mint oil; hence, the rate available to farmers also changes every year. These acreage estimation studies would be helpful in reducing the uncertainties of menthol mint production as lower price results in low production and high price results in higher production next year. Thus, it in turn would help in stabilizing the market prices. Nowadays, remote sensing technologies due to their availability and adaptability are being widely used for crop acreage estimation nationally and internationally. This study focuses on menthol mint crop acreage estimation in the Barabanki district of Uttar Pradesh, India, using 2017 Sentinel-2A satellite data. Adaptive maximum likelihood classification algorithm was applied after intensive ground survey to obtain reliable menthol mint crop acreage estimation for talukwise statistics. Results have shown that menthol mint was extensively cultivated in the Fatehpur and Barabanki taluks as compared to the Haidergarh and Ram Sanehi Ghat taluks of Barabanki district. Menthol mint crop acreage estimation in the study area was estimated to be about 58,284.70 ha with (89.13% and 87.23%; users and producer's accuracy) with overall accuracy (90.67%) and kappa value (0.844). In this study, early and late menthol mint crop acreage estimation was also attempted and it was found that about 26,123.50 ha and 29,911.40 ha were the area of early and late menthol mint, respectively. This method can be useful for localized-level crop acreage estimation from early to mature stage of menthol mint during its growing season.

Keywords Mentha · Crop acreage estimation · Remote sensing · Supervised classification · Barabanki district

Introduction

Crop acreage and yield prediction are two major components of crop production estimation. From the time Large Area Crop Inventory Experiment (Chhikara and Feiveson 1978) which integrated statistical surveys with satellite imagery, various researchers across the world have studied crop acreage estimation using available remote sensing data (high or low spatial resolution). Established procedures and algorithms based on low and high spatial resolution images (Landsat-TM, SPOT HRV, etc.) provide reliable estimation results (Lu et al. 2008) but they are not useful for large-scale estimation studies. Moderate-resolution images (MODIS, NOAA AVHRR and SPOT VGT) can cover large area but they are inaccurate in crop yield estimation due to mixed pixels (Badhwar et al. 1982; Guido and Richard 1998). Thus, high spatial resolution imagery has been found to be very effective in the estimation of crop acreage, especially for the small farm holders. The constraints in these type of data products are its availability and higher costs. Nowadays, medium- and high-resolution multispectral satellite products like Landsat and Sentinel-2 (which are open source and freely available) are being used commonly by researchers across the world to generate crop acreage at district level (Yedage et al. 2013; Ahmad 2019; Saxena et al. 2019).

In recent years, development in remote sensing technologies has significantly increased the availability of temporal satellite data products having spectral bands

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suitable for crop acreage estimation at regional scales. Sentinel-2 satellite due to its high spatio-temporal and open-source data availability offers a unique opportunity for researchers working on crop monitoring (Lambert et al. 2018). Sentinel-2 satellite provides 13 bands between 10 and 60 m spatial resolution bands; generally, the 10/20 m bands are used for agricultural studies because of the high spatial resolution and temporal data which is helpful in defining the crop ecology systematically (Segarra et al. 2020; Griffiths et al. 2019; Vanino et al. 2018; Zhang et al. 2017). These high spatial resolution data (10 m) have opened new possibilities for monitoring small-sized agricultural fields. Thus, this data product due to its inherent feature is very useful for the Indian subcontinent agricultural scientist for the crop monitoring and mapping studies. Various supervised classification methods have been used for crop acreage estimation, wherein training samples are required for classification studies (Liu et al. 2011). Among the available classification algorithms, adaptive maximum likelihood classification (MXL) is considered as the most accurate classification method (Bolstad and Lillesand 1991; Maselli et al. 1992). This method has a robust classifier, which has been used previously to obtain high precision results (Shlien and Smith 1975) and it also provides an index of certainty related to each pixel selected and the class it assigns during classification (Deilmai et al. 2014).

Menthol mint (*Mentha arvensis* L.) is a short-duration aromatic cash crop cultivated on large scale in Indo-Gangetic plains for its essential oil. The essential oil and its crystals are widely used in different products by pharmaceuticals, flavour and cosmetics industries extensively for inhalers, balms, cough syrup, hair oils, toothpaste, mouthwash, etc. (Singh and Khanuja 2007). The rise in global demand for menthol mint has helped in increasing its cultivation in India. Currently, India is the leading menthol mint producer with 80% of global contributions (Padalia et al. 2013; Vimal 2014) followed by China, Brazil and USA. Menthol mint is cultivated on about 2,50,000 ha area in India by about 5,00,000 farming families and creates employment opportunities in terms of more than 50,000,000 man-days per annum (Khan et al. 2020). In India, the major areas of menthol mint cultivation are Barabanki, Sitapur, Lucknow, Bareilly, Moradabad, Sambhal and Badaun districts of Uttar Pradesh.

Menthol mint is a very popular aromatic cash crop among the small and marginal farmers due to high profits from the crop (Singh et al. 2015). Menthol mint is commercially grown by the farmers in India as a short-season annual multicut crop with prevalent cropping practice adopted as of early mint and transplanted mint. The early mint crop with crop duration from mid-January to mid-April is commonly sown directly through suckers and takes about 120–125 days for maturity, and the transplanted mint has the crop duration from mid-March to early June propagated through transplanting of nursery plantlets and matures in 90–110 days only (Singh et al. 1998; Khan et al. 2020).

Menthol mint acreage estimation can provide reliable indicative data on the mint essential oil production as the essential oil is obtained from the above ground crop biomass through hydrodistillation; hence, these data are required by aromatic industries, researchers, government departments and policy planners for formulating prices and policies related to the crop. The prices of menthol mint essential oil and its acreage frequently fluctuate due to unavailability of systematic acreage data as currently manual methods of its acreage estimation are employed, which are time-consuming, costly and also inaccurate due to inherent errors. Hence, the consistent, accurate and timely availability of menthol mint acreage data is crucial for increasing the crop acreage. The present study explores the potential of adaptive maximum likelihood classification (MXL) on the cloud-free temporal Sentinel-2A satellite image to estimate taluk-level menthol mint acreage.

Materials and Methods

Study Area

The study area (Fig. 1), namely Barabanki district, Uttar Pradesh, is a part of Indo-Gangetic plains with subhumid climate and sandy loam soil. The main crop of the district is wheat and rice. This district area is well known nationally and internationally for its menthol mint cultivation in March–June months which are generally lean season for other field crops. Other major crops sown in the district are potato, mustard, sugarcane, gram, pea, maize, pigeon pea (Jafri 2008).

Data Used in the Study

Satellite Data

In the study area, menthol mint cultivation practices prevalent among the farmers are early mint crop (mid-February–March) and late transplanted mint (mid-March to 1st week of April). Three datasets comprise 15 March, 24 April and 14 May 2017; Sentinel-2A cloud-free data were downloaded from European Space Agency (ESA) Web site (https://scihub.copernicus.eu). The details of the Sentinel-2A bands used in this study are provided in Table 1.

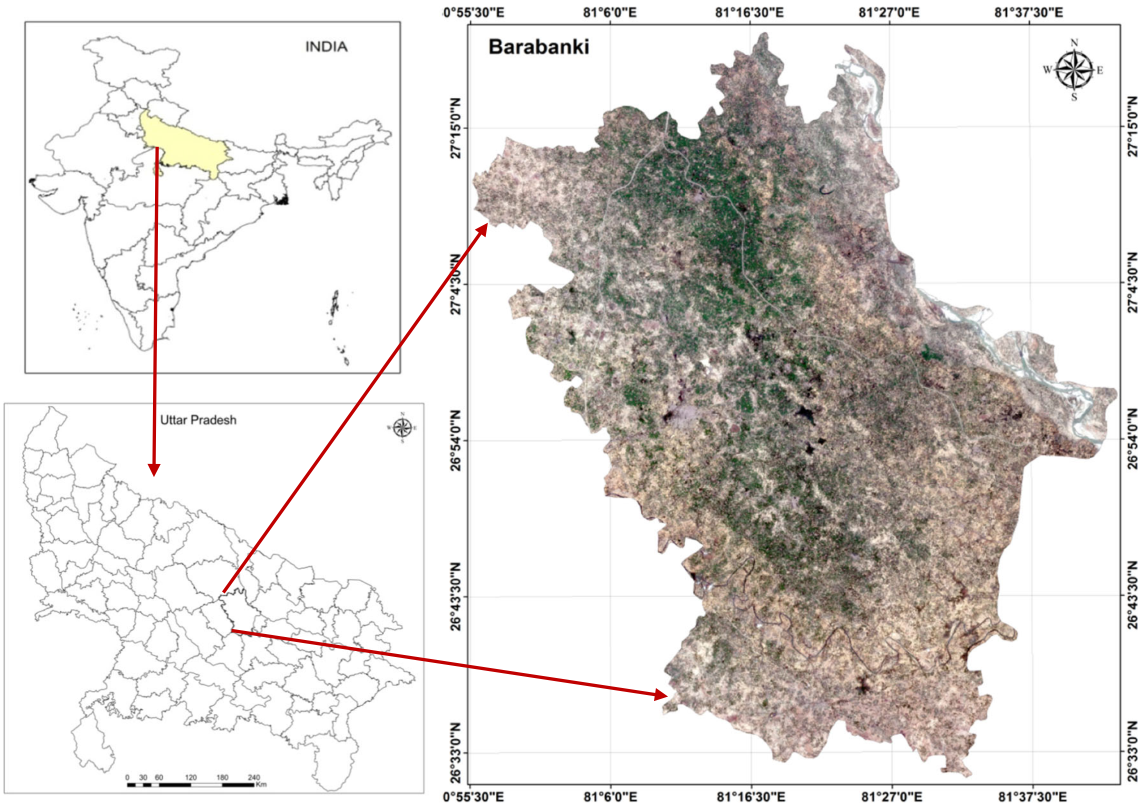

Fig. 1 Study area

Table 1 Spatial and spectral resolutions of Sentinel-2A bands used in this study (https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-2-msi/msi-instrument)

Band and type	Central wavelength (nm)	Spatial resolution (m)
Band 2 blue	492.4	10
Band 3 green	559.8	10
Band 4 red	664.6	10
Band 5 vegetation red edge	704.1	20
Band 6 vegetation red edge	740.5	20
Band 7 vegetation red edge	782.8	20
Band 8 NIR	832.8	10
Band 8a vegetation red edge	864.7	20
Band 11 SWIR	1613.7	20
Band 12 SWIR	2202.4	20

Field Data

Land use map derived from field data collected during crop growth period was used during the classification process on the satellite data, and random stratified sampling was applied on study area to predict the sampling location points for each land use type in the study area. In each sampling location, for menthol mint crop, five plots of 1 m^2 at four corners and one in centre were laid at each crop sampling location; thus, in total five GPS (ground control points) locations were recorded for each sampling point (Fig. 2).

Extensive field surveys were carried out during the mint growth period, wherein field data of initial, middle and mature stage of the menthol mint crop were recorded at each sampling location. Besides menthol mint crop data, other major crops and vegetation data (vegetable, orchards, maize, cucurbits, etc.) being grown extensively by farmers were also recorded. This intensive field survey provided the data on the menthol mint crop cultivation, its status and vigour. These data from the study area were used for training the algorithm and also for accuracy assessment.

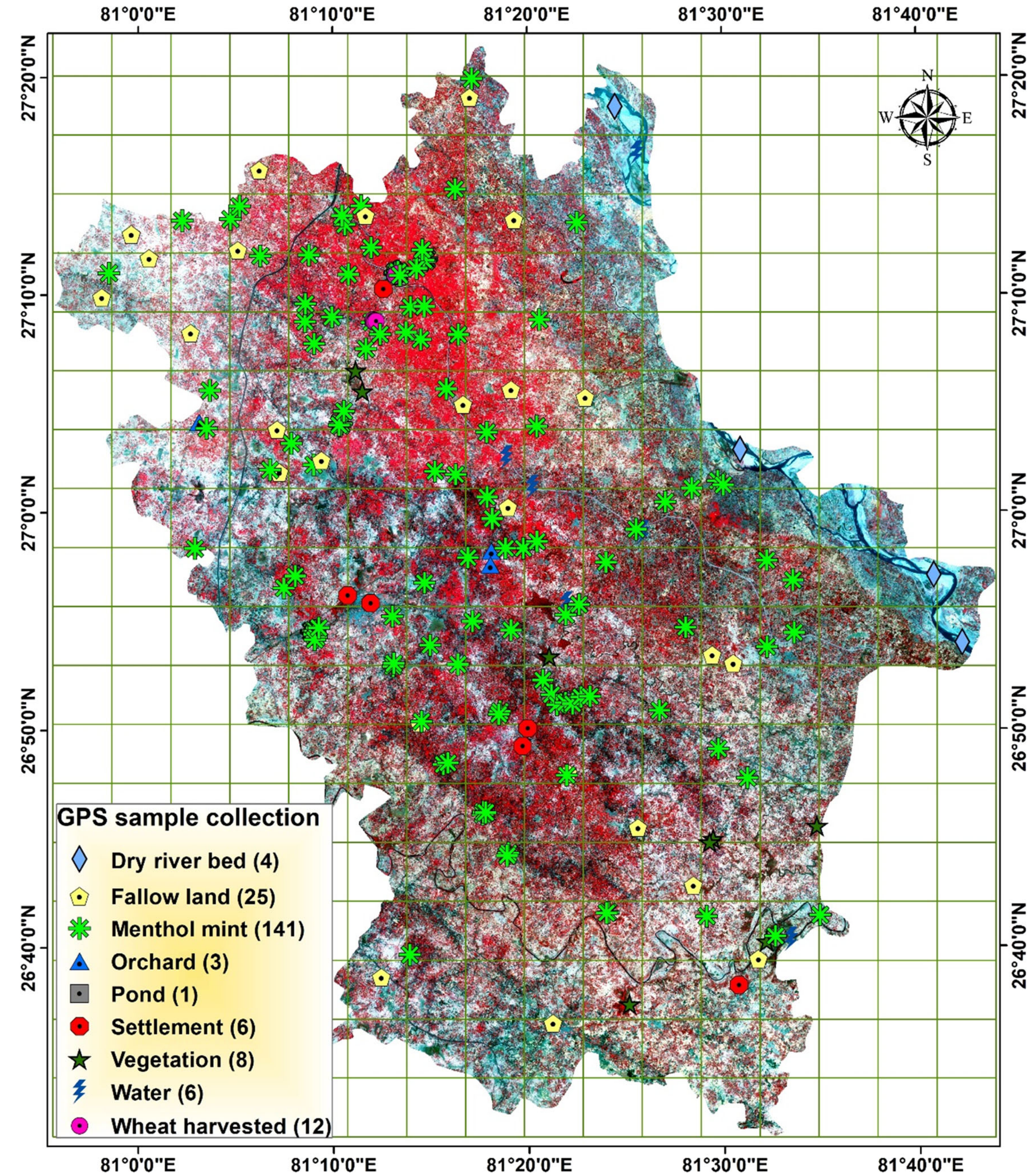

Fig. 2 Sample collection location

Ancillary Data/Software

The following data/software has been used in the study:

(a) Sentinel 2A satellite data—15 March, 24 April and 14 May 2017
(b) ERDAS Imagine 2014
(c) ArcGIS (10.8)

Methodology

The methodology adopted in this study makes use of the prevalent menthol mint crop in the study area during the mint crop growth period (early and late transplanted mint). Using the March and April Sentinel-2A satellite data, the early mint crop was successfully discriminated and using May Sentinel-2A data total acreage area of menthol mint in the study area could be delineated. This was due to identifiable discrimination in the spectral profile for mature

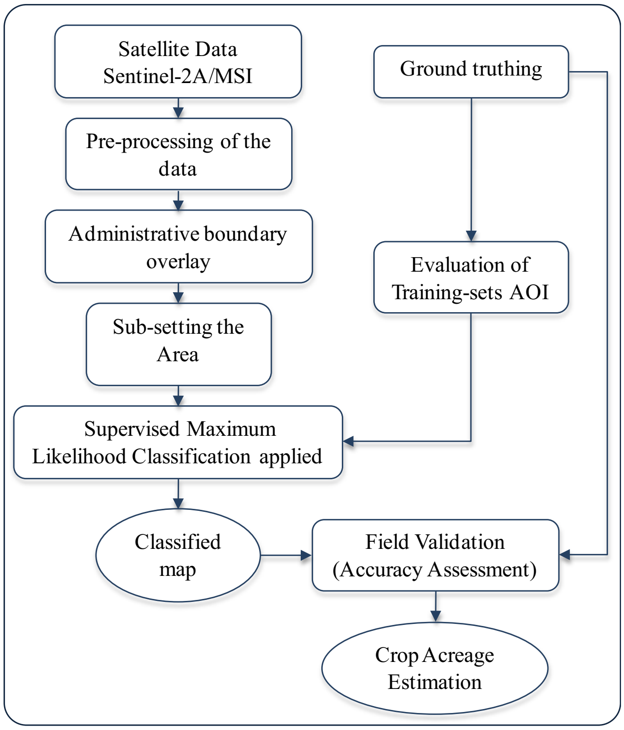

Fig. 3 Detailed methodology adopted for this work

mint crop from the cocultivated vegetables and other crops growing at the same time in the study area. Methodology adopted for this work is shown in Fig. 3.

Image Preprocessing

Sentinel-2A datasets were downloaded for the months of March, April and May 2017 and processed for geometric and atmospheric correction. Preprocessing of the Sentinel-2 satellite data was done to remove the inherent errors in data to make the data usable for further processes. Atmospheric correction was applied using sen2-cor plug-in (version 2.2.1) with SNAP (Sentinel Application Platform, version 5.0.0) (Gašparović and Jogun 2018; Muller-Wilm et al. 2013) on processed reflectance images from Top-Of-Atmosphere (TOA) MSI Level-1C, to Bottom-Of-Atmosphere (BOA) MSI Level-2A in order to reduce distortions caused by the atmosphere on electromagnetic radiation (absorption, scattering, reflection). Linear histogram equalization was then applied on the corrected image to improve the quality of the image for interpretation during the classification.

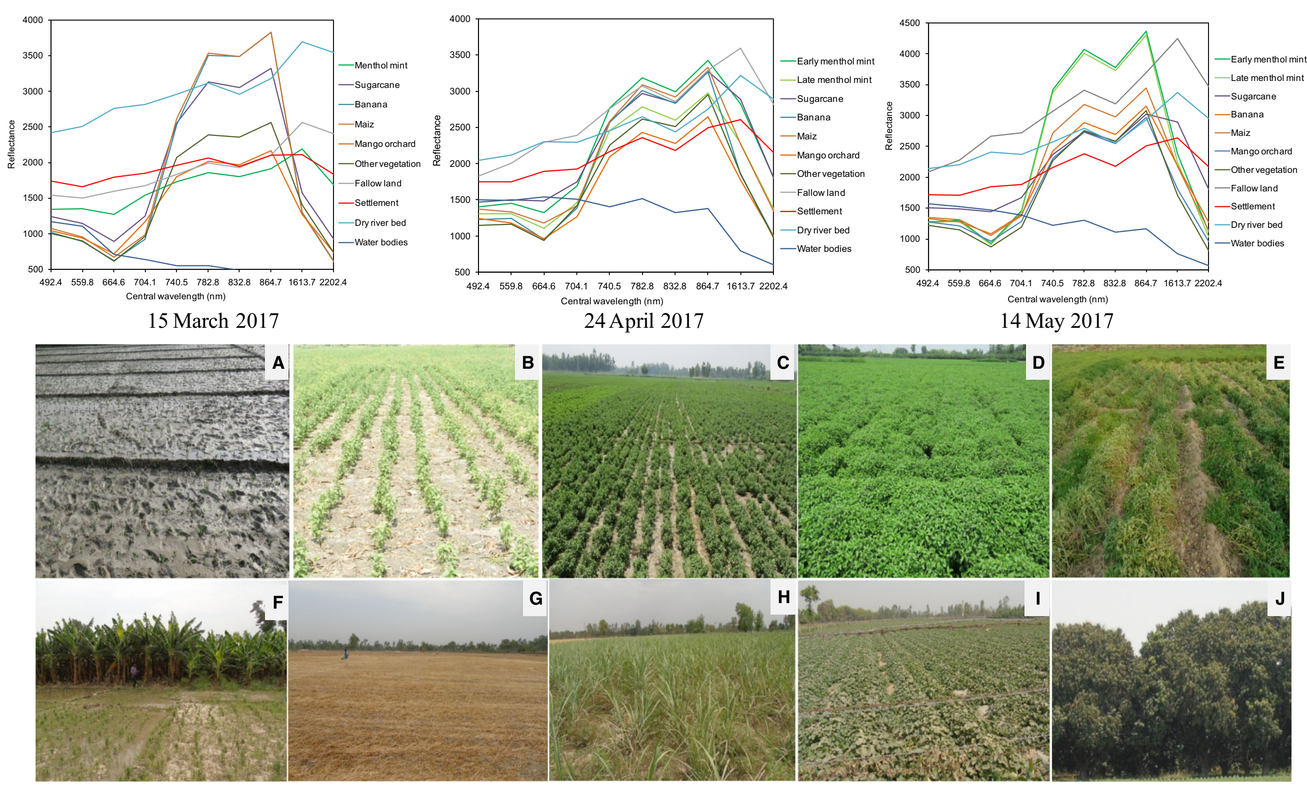

Fig. 4 Spectral profile of various classes during menthol mint crop growth period and field photographs in the study area, **a** transplanting menthol mint. **b** initial vegetative stages. **c** mid-vegetative stages. **d** maturing stages, **e** harvesting of menthol mint and **f–j** other vegetation classes and fallow land in the study area

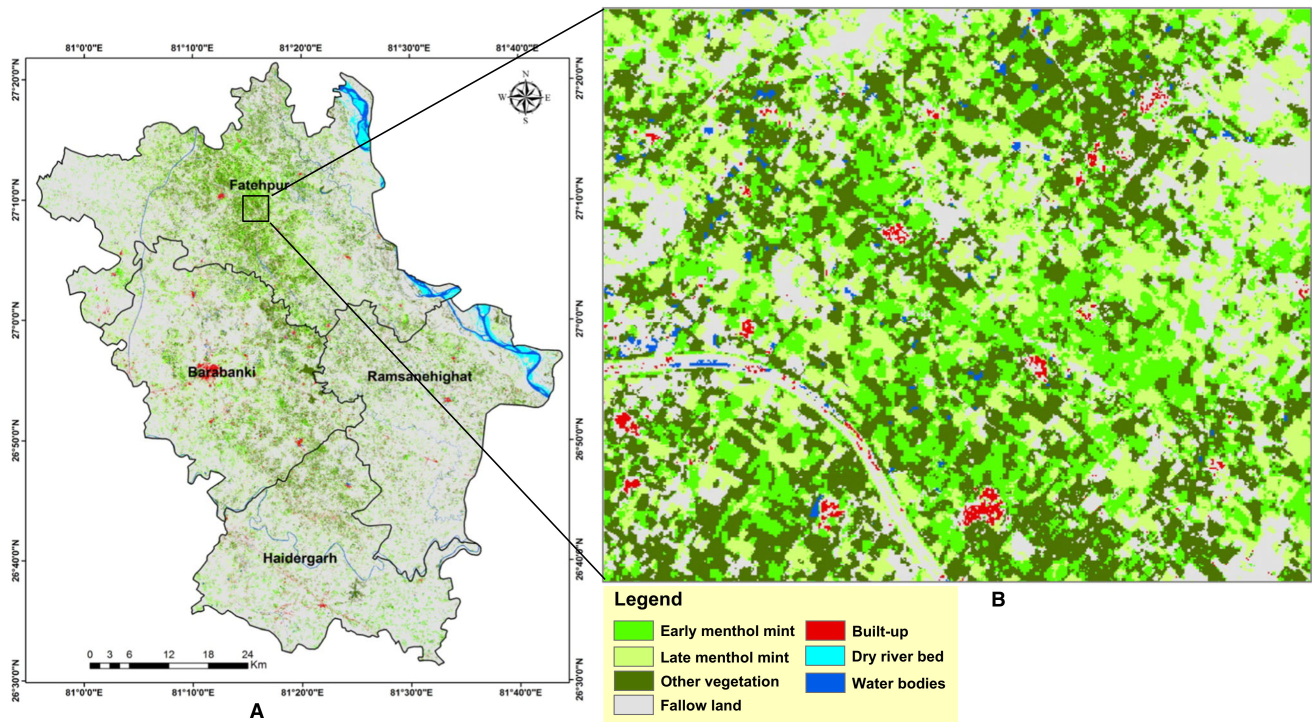

Fig. 5 Early and late transplanted menthol mint acreage map of Barabanki district (24 April 2017) (**a**). Study area classified map (**b**). Snapshot wherein early and late menthol mint crop fields are clearly distinguishable

Table 2 Classified area statistics of early and late transplanted menthol mint with other classes from 24 April 2017

Class name	Area	Area (%)
Early menthol mint	26,123.50	6.89
Late menthol mint	29,911.40	7.89
Vegetation	33,517.00	8.84
Fallow land	275,178.00	72.60
Settlement	4980.97	1.31
Dry riverbed	3201.15	0.84
Water	6095.51	1.61
Totals	379,007.53	100.00

Training-Set Generation

Training signatures were generated from corrected image using field data obtained during the intensive field survey. GPS location and crop-type information obtained from field was overlaid to identify the menthol mint crop training signatures for application of the classification algorithm. Satellite data of 15 March, 24 April and 14 May 2017, were used for generation of training signatures for early as well as late transplanted mint crop. It was found that these datasets were able to generate specific spectral signatures for menthol mint as compared to the cocultivated crops due to the maturity of the crop in the May month and six different classes were found to be suitable for the generation of training sets based on field survey data, spectral signatures and visual interpretation (Fig. 4). The total number of 49,904 ground pixels for early, that of 11,486 for late transplanted mint on 24 April 2017 imagery and that of 1,491,958 ground pixels were used on 14 May 2017 imagery used in MXL classifier during the classification process.

Classification Approach

Sentinel-2A multispectral satellite data have been used in various studies for large-area classification of vegetation (Immitzer et al. 2016). In the present work, adaptive maximum likelihood classification approach was used to estimate menthol mint crop acreage in the Barabanki district, Uttar Pradesh. The classes menthol mint, other vegetation, fallow land, built-up, dry riverbed and water bodies were obtained in the study area. The MXL classification approach was used in the study area, as there was greater probability of overlapping of menthol mint crop with other crops like vegetables, maize, etc. This approach has been used widely for the land cover classification (Richards and Jia 2006). MXL classifier is based on Bayesian probability theory, wherein during classification of overlapping signatures, pixels taken as training sets are assigned to the

Table 3 Accuracy assessment of supervised classification map with early and late transplanted menthol mint of 24 April 2017

Class name	Reference totals	Classified totals	Number correct	Producers accuracy (%)	Users accuracy (%)
Early menthol mint	22	21	17	77.27	80.95
Late menthol mint	63	24	14	22.22	58.33
Vegetation	46	26	19	41.30	73.08
Fallow land	152	218	149	98.03	68.35
Settlement	8	4	4	50.00	100.00
Dry riverbed	2	2	2	100.00	100.00
Water	6	5	5	83.33	100.00
Totals	300	300	210		
Overall accuracy	70.00%				
Overall kappa statistics	0.496				

class of highest probability. This classifier is considered to give more accurate results than minimum distance and Mahalanobis distance methods; however, it is much slower due to extra computations involved. Both minimum distance and Mahalanobis distance methods have been known to overestimate agricultural land (Al-Ahmadi and Hames 2009), and also Mahalanobis distance classifier assumes that the histograms of the bands have normal distribution (Perumal and Bhaskaran 2010) which is often not the case.

Results and Discussion

The cropping pattern of menthol mint was studied during initial, mid and mature crop growth stages using three-time-period satellite data, i.e. 15 March, 24 April and 14 May 2017, in the study area. The main aim of this study was to estimate the menthol mint acreage using Sentinel-2A satellite data in a single season, and hence 'vegetation' class which includes vegetables, orchards, sugarcane, other zaid crops such as maize, scrubland, forest, etc. has been grouped as a single class. On comparing the spectral profile of menthol mint crop with other features during the months of March, April and May (Fig. 4), the six major classes, viz. menthol mint, other vegetation, fallow land, built-up, dry riverbed and water bodies, were obtained. It was observed from the spectral profile of the menthol mint on 15 March data that there was mixing of early menthol mint with other classes (vegetables and crops), as menthol mint crop is in its initial stages and the canopy spectral reflectance is very low due to sparse canopy growth, hence mixing with vegetables and other crops.

On 24 April 2017 data, the early and late transplanted mint (transplantation done during the mid-March to first week of April) could be identified as the spectral profile of early mint was found to be distinct due to well-developed vigorous crop canopy in early mint fields (early sowing resulted in early maturing), as compared to the late transplanted mint (still in its initial vegetative stages); hence, low spectral reflectance was observed (Fig. 4). The MXL classifier was used for the classification of early and late menthol mint in the study area (Fig. 5a), and the classified map was obtained, wherein the early and late mint crop field could be identified clearly (Fig. 5b). The acreage was about 26,123.50 ha for early and about 29,911.40 ha for late menthol mint (Table 2). The accuracy for early mint (80.95% and 77.27%; users and producers accuracy, respectively) and for the late mint (58.33% and 22.22%; users and producers accuracy, respectively) was also obtained with overall accuracy (70.00%) and kappa value (0.496) on the data for 24 April 2017 (Table 3).

On the 14 May 2017 data, the classification of the early and late menthol mint was not possible, as the spectral profile of the early and late menthol mint was observed to be almost similar (Fig. 4). The field visits also confirmed the uniform canopy growth and similar pattern in the early as well as late menthol mint fields. This was due to the climatic condition (high temperature) favourable in the study area for the growth of menthol mint and the agro practices like frequent irrigations and fertilization adopted by the farmers in late menthol mint crop. As menthol mint crop harvesting in the study area starts from 20 May onwards, no further date satellite data were useful for classification of the early and late menthol mint acreage in the study area. These data were also used for obtaining the menthol mint acreage estimation in the Barabanki district (Fig. 6), wherein the total acreage was about 58,284.70 ha (Table 4) with an overall accuracy (90.67%) and kappa value (0.844) (Table 5).

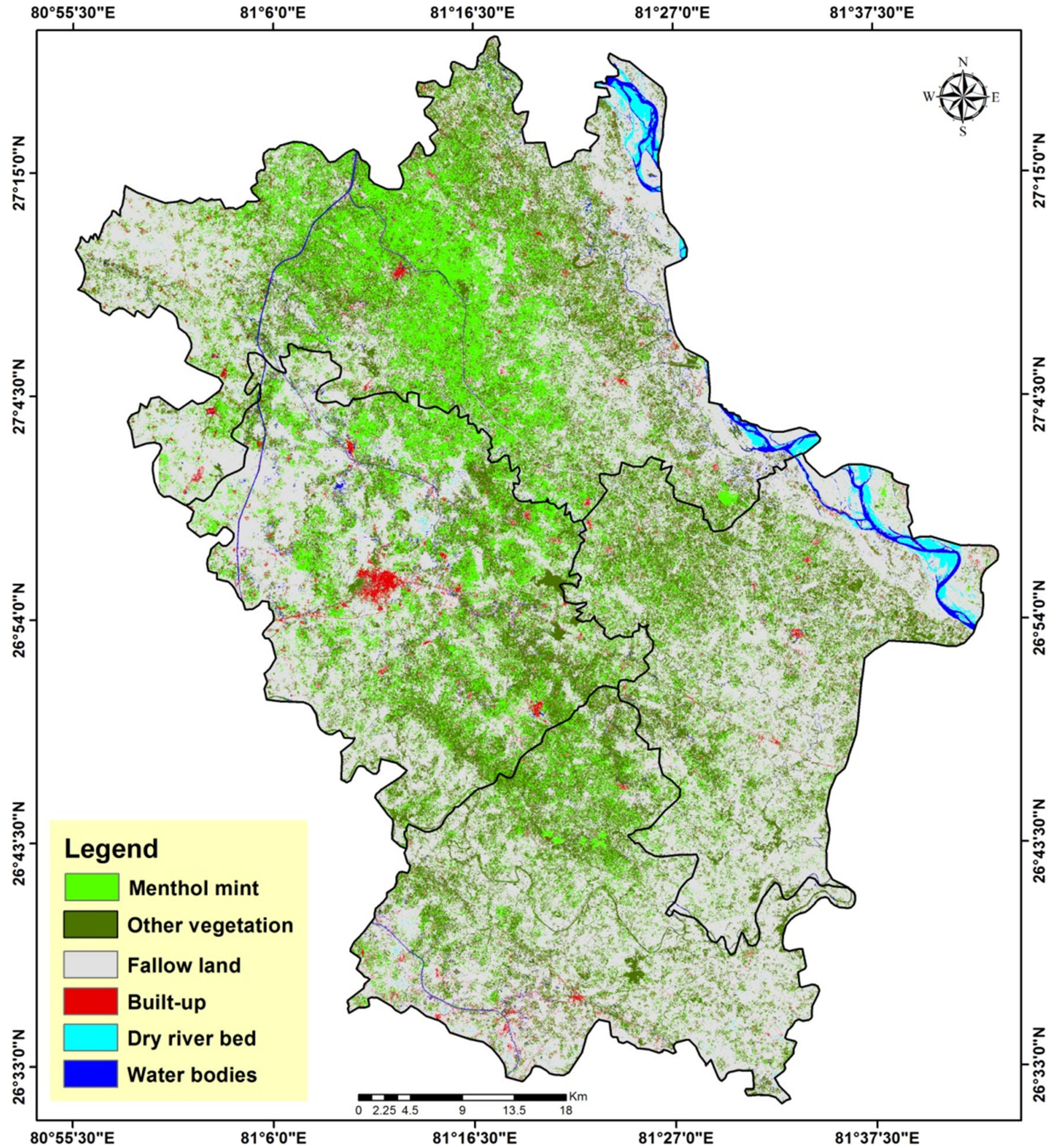

Fig. 6 Menthol mint acreage map of Barabanki district (14 May 2017)

Table 4 Classified area statistics of six classes of 14 May 2017

Class name	Area (ha)	Area (%)
Menthol mint	58,284.70	15.38
Vegetation	87,977.90	23.21
Fallow land	217,693.00	57.44
Settlement	6397.12	1.69
Dry riverbed	3043.06	0.80
Water	5611.23	1.48
Total	379,007.01	100.00

Accuracy Assessment

Validation of the menthol mint acreage estimation was carried out using the field survey data. Sampling points (300 locations) generated through the stratified random sampling process on classified image were validated by visit to the fields in the study area. The validation of classified image was carried out using the accuracy assessment tool in ERDAS IMAGINE 2014 software. Field-observed data were used as reference data for generated points. The accuracy assessment was done for the

Table 5 Accuracy assessment of supervised classification map 14 May 2017

Class name	Reference totals	Classified totals	Number correct	Producers accuracy (%)	Users accuracy (%)
Menthol mint	47	46	41	87.23	89.13
Vegetation	69	70	59	85.51	84.29
Fallow land	169	172	162	95.86	94.19
Settlement	6	5	3	50.00	60.00
Dry riverbed	2	2	2	100.00	100.00
Water	7	5	5	71.43	100.00
Totals	300	300	272		
Overall accuracy	90.67%				
Overall kappa statistics	0.844				

Table 6 Talukwise menthol mint acreage area statistics

Taluk	Area (ha)	Area (%)
Fatehpur	27,951.86	7.38
Barabanki	16,455.60	4.34
Haidergarh	7195.50	1.90
Ramsanehighat	6683.00	1.76

supervised classified map on 24 April and 14 May 2017 (Tables 3, 5).

Zonalwise Menthol Mint Area Estimation

Zonal statistics (Table 6) for menthol mint acreage estimation were also computed, and it was found that total area of 27,951.86 ha ($\sim$ 7.38%) in Fatehpur; 16,455.60 ha ($\sim$ 4.34%) in Barabanki; 7195.50 ha ($\sim$ 1.90%) in Haidergarh; and 6683.00 ha ($\sim$ 1.76%) in Ram Sanehi Ghat was under cultivation of menthol mint crop, respectively. This indicates that menthol mint acreage is more in the Fatehpur followed by Barabanki taluks, whereas it was low in Haidergarh and Ram Sanehi Ghat taluks of the district. The availability of irrigation facilities in these Fatehpur and Barabanki taluks seems to have contributed to this increase in acreage as menthol mint is water-loving crop and requires about 10–12 times irrigation during its growth period. In general, the results coincided with the crop phenology and management practices (sowing time, plant density) adopted by the farmers in the study area.

Conclusion

The feasibility of medium-resolution multi-temporal satellite data for the mapping and acreage yield estimation of menthol mint aromatic crop in Barabanki district was demonstrated with significant accuracy in this study. The adaptive maximum likelihood classification (MXL)-based classification performed on multiple scenes of Sentinel-2A data for the period corresponding to the maximum crop growth stages provided reliable acreage estimation of menthol mint crop, which can also be used for operational purpose. The absence of cloud-free data in the last week of May and the first week of June in the study area also necessitates the exploration of SAR (synthetic aperture radar) data for acreage estimation studies.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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