Chin. Geogra. Sci. 2018 Vol. 28 No. 6 pp. 920–934
https://doi.org/10.1007/s11769-018-0985-z

Springer Science Press
www.springerlink.com/content/1002-0063

Comparative Study on Changes of Croplands Between North Korea and South Korea During 1990–2015

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Abstract: Studies on long-term change of cropland is of great significance to the utilization of land resources and the implementation of scientific agricultural policies. The Korean Peninsula, adjacent to China, plays an important role in the international environment of Northeast Asia. The Korean Peninsula includes South Korea and North Korea—two countries that have a great difference in their institutions and economic developments. Therefore, we aim to quantify the spatiotemporal changes of croplands in these two countries using Landsat Thematic Imager (TM) and Operational Land Imager (OLI) imagery, and to compare the differences of cropland changes between the two countries. This paper take full advantage of ODM approach (object-oriented segmentation and decision-tree classification based on multi-season imageries) to obtain the distribution of croplands in 1990 and 2015. Results showed that the overall classification accuracy of cropland data is 91.10% in 1990 and 92.52% in 2015. The croplands were mainly distributed in areas with slopes that were less than 8° and with elevations that were less than 300 m in the Korean Peninsula. However, in other region (slope > 8° or elevation > 300 m), the area and proportion of North Korea's croplands were significantly higher than that of South Korea. Croplands significantly increased by 15.02% in North Korea from 1990 to 2015. In contrast, croplands in South Korea slightly decreased by 1.32%. During the 25 years, policy shift, economic development, population growth, and urban sprawl played primary roles for cropland changes. Additionally, the regional differences of cropland changes were mainly due to different agriculture policies implemented by different countries. The achievements of this study can provide scientific guidance for the protection and sustainability of land resources.

Keywords: Landsat; object-oriented segmentation; decision tree; cropland; North Korea; South Korea

Citation: YU Hao, ZHANG Bai, WANG Zongming, 2018. Comparative Study on Changes of Croplands Between North Korea and South Korea During 1990–2015. *Chinese Geographical Science*, 28(6): 920–934. https://doi.org/10.1007/s11769-018-0985-z

1 Introduction

More than 75% of ice-free land shows signs of anthropogenic alterations (Ellis and Ramankutty, 2008) and the vast majority of anthropogenic disturbances have been made for agricultural purposes (Ellis et al., 2010). With expected population growth, and an increase in wealth in several major world regions, food security, and thus agricultural production, will remain important in the near future (Tilmana et al., 2011). While croplands covered only some 12% of the global land area, they supplied humanity with over 90% of food calories (Kastner et al., 2014). Demand for cropland products has increased strongly during the past decades, and this trend is expected to continue as population numbers and per capita consumption rates are bound to grow (Foley et al., 2011).

Globally, cropland area harvested for food production increased by 32% from 1960s, despite considerable increases in output per unit area (Burney et al., 2010; Kastner et al., 2012). Recent trends in cropland area change differ markedly between world regions: while

Received date: 2017-12-19; accepted date: 2018-03-06
Foundation item: Under the auspices of Key Deployment Project of Chinese Academy of Sciences (No. KZZD-EW-08-02)
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cropland area has been stable or slightly declining in developed regions and has declined considerably in the former Soviet Union, it has expanded in most other regions, albeit at different rates, with Sub-Saharan Africa, Southeast Asia and Latin America experiencing the fastest growth (FAO, 2015).

Cropland is one of the main sources of support for the food supply of the Korean Peninsula. In North Korea, the current grain output is unable to meet the demand for population growth, serious flooding and property damage, mainly by international rescue to alleviate the pressure on its grain demand (Lim et al., 2017). Moreover, the country's sparse agricultural resources limit agricultural growth (Michalk and Mueller, 2003). By contrast, South Korea is highly industrialized after several decades of phenomenal growth, but its agriculture is hampered by a lack of cropland which means it is, and will likely remain, a major importer of grains (Lyddon, 2016). Cropland changes in Korean Peninsula is crucial to sustainable development of economic and environment of the peninsula, even that of Northeast Asia. The mass variation of the quantity of cropland and spatial pattern change in the Korean Peninsula are remarkable (Park and Lee, 2014; FAO, 2015), alluding to the existence of obvious regional differences between South Korea and North Korea duo to the differences in their economic development patterns and politics (FAO, 2009). However, there were few researches on cropland variations of the Korean Peninsula, compared with those of forestland and other land cover types, especially in North Korea (Haggard et al., 1997; Engler et al., 2014; Tao et al., 2017).

Croplands of the Korean Peninsula has been mapped in different global land cover maps, such as the ISLSCP II (International Satellite Land-Surface Climatology Project, Initiative II) Historical Land Cover (Goldewijk et al., 2007), the IGBP-DIS (International Geosphere-Biosphere Programme Data and Information System) global land cover product (Loveland and Belward, 1997), the Global Land Cover (GLC2000) (Bartholomé and Belward, 2005), the MODIS (Moderate-resolution Imaging Spectroradiometer) global cover (Wu et al., 2009), the GlobCover 2009 (Ning et al., 2012), and the GlobeLand30 (Chen et al., 2015)—derived from data acquired over about 1 year at a spatial resolution of a quarter degree, 1000 m, 500 m, 300 m, and 30 m—characterized croplands according to various various definitions. The resolutions of most of the existing products are relatively low and most significant human activities on the surface of the land cannot be captured at this scale (Lei et al., 2016). Moreover, the accuracy of the classification production was relatively low due to the resolutions and methods of remote image classifications used in previous studies. In addition, for medium resolution global products (such as the GlobeLand30 product), the accuracy of these global datasets—when applied at regional scales—is uncertain (Ye et al., 2015). Until now, the Korean Peninsula does not have accurate cropland maps in different periods at medium spatial resolution (Chao et al., 2010; Hong et al., 2010). In the past, there were few studies on cropland changes and possible affecting factors in Korean Peninsula for a long time series.

Therefore, the aims of this paper are: 1) to improve the extraction accuracy of cropland (especially paddy fields and rainfed cropland) by combining object-oriented segmentation and decision-tree classification based on multi-season satellite data; 2) to produce 30 m resolution cropland products of the entire Korean Peninsula for 1990 and 2015 (hereinafter referred to as KP_Cropland) using Landsat TM/OLI imageries, and to explore dynamics of cropland extent during 1990–2015; and 3) to comparatively analyze the different trends of croplands changes between North Korea and South Korea. This research can provide technical support in mapping croplands, as well as provide data reference in related fields with global change and sustainability.

2 Materials and Methods

2.1 Study area

The Korean Peninsula is a peninsula in East Asia (33°09′00″N–43°14′44″N, 124°14′44″E–130°44′24″E). The total land area is about 22.5 × 10^6 ha. It connects with Russia in the northeast, with China in the northwest across the Yalu and Tumen rivers, and with Japan in the southeast across the Korea Strait. It extends southwards for about 1100 km from continental Asia into the Pacific Ocean and is surrounded by the East Sea to the east and the Yellow Sea (West Sea) to the west, it is surrounded by the ocean on three sides (Fig. 1). Mountain ranges largely occur on the eastern and northern parts of the peninsula. The Korean Peninsula experiences the four seasons: spring, summer, autumn and winter. The mean annual temperature is 12.2℃, ranging between 5.1℃–13.6℃. The annual precipitation is relatively high, with a mean of 1299 mm, about 70% of which is concentrated in the summer, especially during June–August. The East Asian monsoon drives the highly seasonal pattern of precipitation. Approximately 74.2 million people live on the Korean Peninsula (Lee and Miller-Rushing, 2014).

The Korean Peninsula includes two countries. One is a developing country in the north, called the Democratic People's Republic of Korea (D. P. R. Korea, North Korea), and the other is a developed country in the south, called the Republic of Korea (R. O. Korea, South Korea). These two countries differ greatly in climate and economy. North Korea experiences a combination of continental climate and oceanic climate, but most of the country experiences a humid continental climate. Summer tends to be by far the hottest, most humid, and rainiest time of year because of the southern and southeastern monsoon winds that carry moist air from the Pacific Ocean. Approximately 60% of all precipitation occurs between June and September. South Korea tends to have a humid continental climate and a humid subtropical climate. It is affected by the East Asian monsoon, with heavier precipitation than usual in summer during a short rainy season called plum rain, present at the end of June through to the end of July (https://en.wikipedia.org/). In terms of economic development, North Korea is much further behind compared with South Korea. In 2015, the GDP (gross domestic product) of South Korea was about 70 times as much as that of North Korea (FAO, 2015).

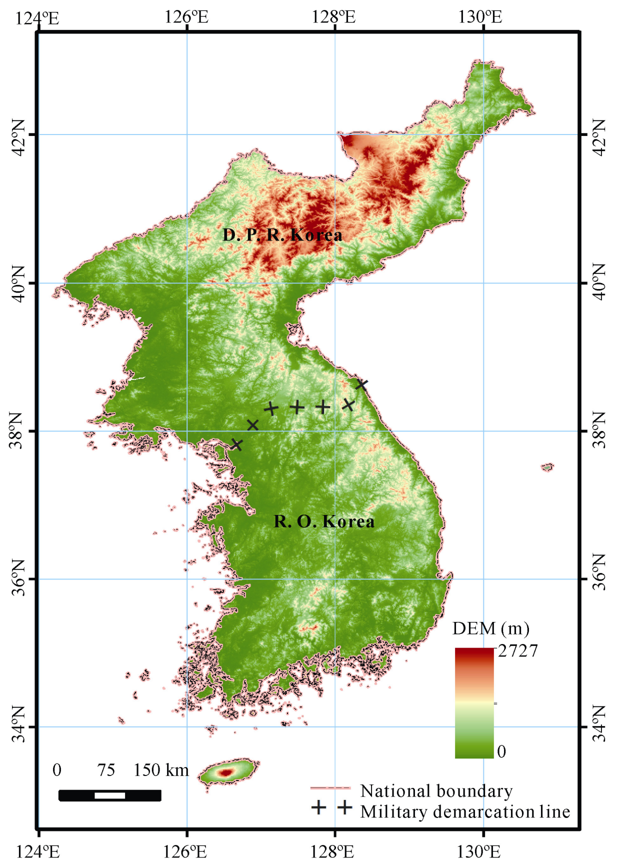

Fig. 1 Location of North Korea and South Korea and digital elevation model (DEM)

2.2 Data sources and pre-processing

In this paper, the land cover classification system consisted of seven basic land cover classes: forestland, grassland, wetland, water body, barren land, cropland, and built-up land. Cropland includes rainfed cropland and paddy field (Zhang et al., 2014; Ouyang et al., 2015; Lei et al., 2016). Distribution data of cropland and other land cover types for 1990 (Landsat TM) and 2015 (Landsat OLI) were acquired from medium resolution images in which the cloud coverage was less than 5%. In order to extract rainfed cropland and paddy field more accurately, we used multi-season imageries. In the case of image resources, as much as possible, it was ensured that the date acquired from the imageries were during the flooding/transplanting period (mid-April or early May) and the peak of the growing season (August or September) in the same image position. There were 89 scenes of satellite images (Fig. 2) from Landsat covering the study region were used, and 31 of these images were from 1990 and 58 of them were from 2015.

Auxiliary data, including the Digital Elevation Model (DEM, resolution 30 m) data, were downloaded from the Geospatial Data Cloud (http://www.gscloud.cn/); economic and demographic data were downloaded from the Food and Agriculture Organization of the United Nations (FAO, http://www.fao.org/home/en/); Boundary of Korean Peninsula and two countries' sub-divisions were supported by College of Science, Yanbian University; and the reference/validation sites for the classification of land covers from high resolution images were from Google Earth in 2015 (Fig. 3). In this paper, we focused on 595 sites in 1990 and 485 sites in 2015.

All images were geo-rectified to the Universal Transverse Mercator (UTM) coordinate system using the World Geodetic System (WGS) 1984 datum.

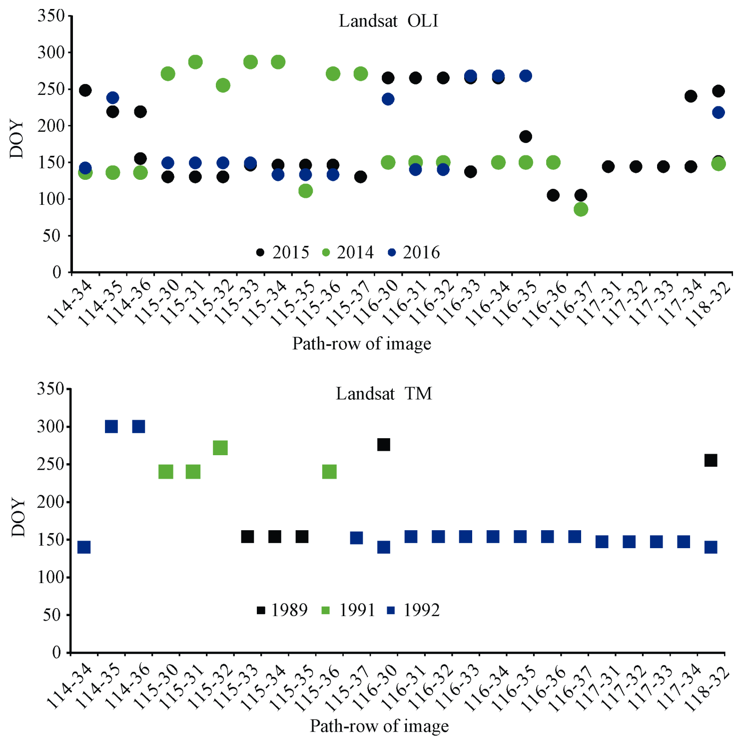

Fig. 2 The temporal distribution (DOY: day of year) of Landsat TM/OLI images for each tile on the Korean Peninsula.

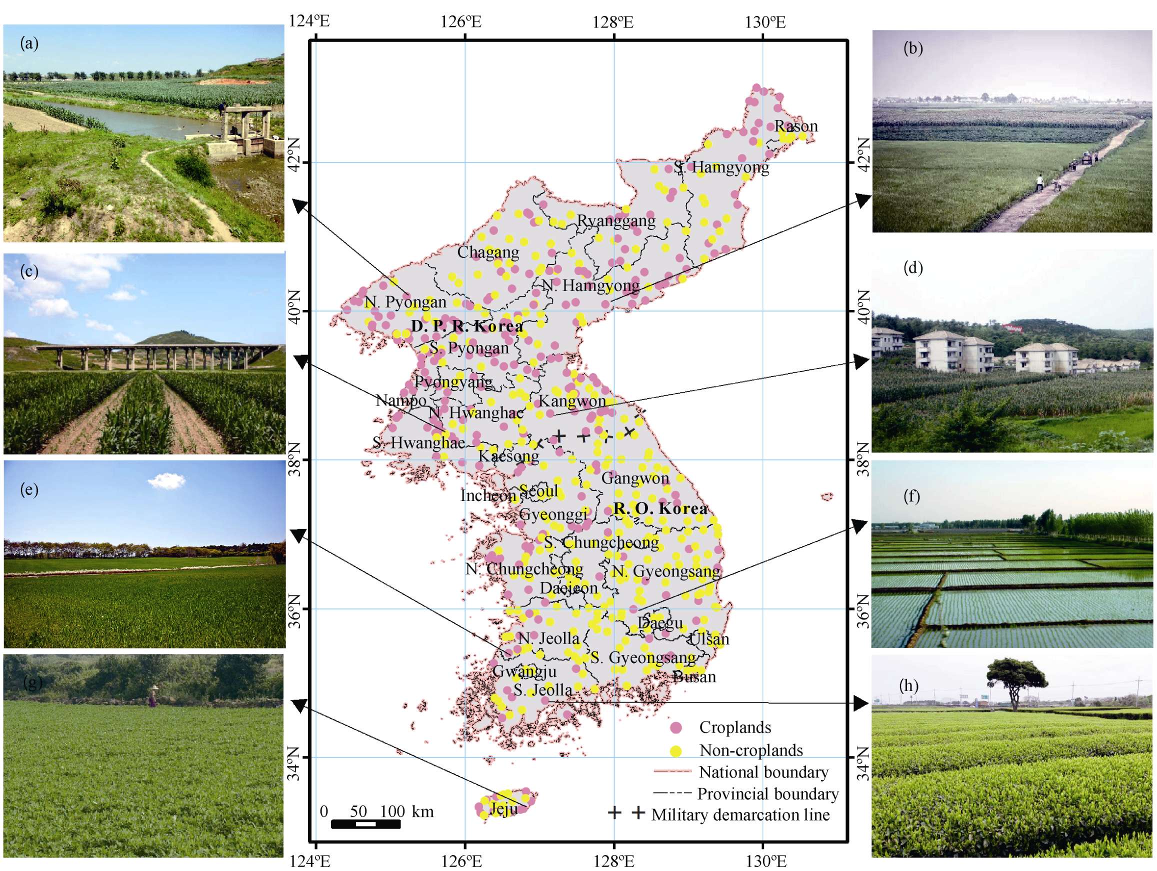

Fig. 3 Spatial distribution of reference/validation samples of the Korean Peninsula in 2015. (a)–(d) represent typical cropland in North Korea; (e)–(h) represent typical cropland in South Korea.

Atmospheric correction was performed using the FLAASH Model (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) that can correct both additive and multiplicative atmospheric effects (Jin et al., 2016b). Using ENVI 5.3, the study region was clipped from a mosaic of all the processed images. The spectral indices that link vegetation performance were calculated by the reflectance of corresponding bands, which included Normalized Differnce Vegetation Index (NDVI) (Xiao et al., 2002; Zhang et al., 2017a), Enhanced Vegetation Index (EVI) (Huete et al., 1997; Jiang et al., 2008), and Land Surface Water Index (LSWI) (Xiao et al., 2002; Jin et al., 2016a). The spectral indices were calculated using the following equations:

$$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}} \tag{1}$$

$$EVI = 2.5 \times \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + 6 \times \rho_{Red} - 7.5 \times \rho_{Blue} + 1} \tag{2}$$

$$LSWI = \frac{\rho_{NIR} - \rho_{SWIR1}}{\rho_{NIR} - \rho_{SWIR1}} \tag{3}$$

In these equations ρ_{Blue}, ρ_{Red}, ρ_{NIR} and ρ_{SWIR1} are the surface reflectance values of the blue band, the red band, the near-infrared band, and the shortwave-infrared band, respectively in the Landsat TM/OLI sensors.

2.3 Methods

In this paper, object-oriented segmentation and decision-tree classification based on multi-season imageries (ODM) were used to reconstruct historical data of cropland and other land cover types.

2.3.1 Object-oriented segmentation

Object-oriented segmentation would be able to avoid the ‘Salt and Pepper Noise’ that often exists in pixel-based classification results. Moreover, it fully takes into consideration spectral, shape, and texture features as well as topographical features to produce more accurate land cover (Lei et al., 2016). Imagery segmentation is the critical step in object-oriented classification because the results are directly affected by the segmentation scale and parameter settings (Chen et al., 2017). Object-oriented segmentation ensures the objects are spectrally more homogeneous within individual regions rather than between them and their neighbors. Ideally, they have distinct boundaries, and they are compact and representative (Yu et al., 2006). Imagery segmentation was carried out on the original multispectral and pan-sharpened imagery, which is the first step of extracting the information of remote sensing imageries (Gilbertson et al., 2017). Settings for the remaining segmentation parameters were determined by testing different segmentation input scenarios to evaluate their ability to delineate meaningful components based on classification and accuracy assessments (Castillejo- González et al., 2009). Scale, shape, and compactness were the three critical parameters. We used Ecognition 9.0 software to complete the segmentation task. Meanwhile, multi-segmentation was used in our research because the sensors that captured the images were different. The optimal values of these parameters were 15, 0.1 and 0.7 for the 1990 Landsat TM imageries, and 100, 0.1 and 0.7 for the 2015 Landsat OLI imageries, respectively.

2.3.2 Decision-tree classification based on multi-season imageries

A decision-tree is a classification procedure that repeatedly divides a set of training data into smaller subsets based on tests to one or more of the feature values (Song et al., 2017; Zhang et al., 2017b). Considering the unique nature of vegetation in the Korean Peninsula, decision making was based on repeatedly applying threshold values of NDVI, EVI, LSWI, elevation, and spectral reflectance, all of which were visually interpreted from calibration data and expert knowledge of the whole study area. To further improve the accuracy of land cover classification, we improved the decision-tree method by combing it with the multi-season imageries. Scientists paid more attention to those land cover types which changed frequently with seasons. Multi-temporal information can provide absolute advantages for land cover change extraction in different periods. At the same time, multi-temporal satellite imageries can improve our ability to distinguish between vegetation types by leveraging variability in phenological patterns across the landscape (Lei et al., 2016). In this paper, we used the imageries in the peak of the growing season to distinguish between vegetation types (forestland, cropland, grassland, and wetland) and non-vegetation types. Contrary to most land cover types, cropland varies strongly within very short time intervals. Most crop types have a vegetation period of several months (Bargiel, 2017). Paddy field has a different cropping calendar depending on the type of crop such as corn or soybean (Jin et al., 2016a). Rice seeds are usually planted in small seedbed nurseries in mid-April and the seedlings are transplanted to paddy fields after one month (Zhou et al., 2016). Flooding is a key practice of paddy agriculture and usually takes place about two weeks before transplanting (Qin et al., 2015; Gilbertson et al., 2017). In this paper, we take full advantage of the color difference to distinguish rainfed cropland and paddy fields of flooding period in mid-May due to the paddy fields in the period of water flooding showed apparently lower vegetation coverage compared with the rainfed cropland. ODM method can effectively utilize the difference of cropland and non-cropland performance on multi temporal imageries (June or September), as well as easily distinguish rainfed cropland from paddy fields by multi-temporal imageries of the flooding/transplanting period (mid-April or early May). Specific weights and ranges are shown in the following diagram (Fig. 4).

3 Results

3.1 Distribution of croplands in North Korea and South Korea

The assessment of accuracy of cropland data shows that the overall classification accuracy of Korean Peninsula in 1990 and 2015 was 91.10% and 92.52%, respectively. The overall classification of paddy field and rainfed cropland was 85.35% and 87.12%, respectively in 1990. The overall classification accuracy of rainfed cropland and paddy fields in 2015 was 88.14% and 89.22%, respectively. Thus, the accuracy assessment indicated that our interpretation results (KP_Cropland) met the research needs and highly consisted with those verification points which obtained from the high resolution imagery. Fig. 5 shows the spatial distribution of croplands on Korean Peninsula in 1990 and 2015.

The geographical characteristics of croplands distribution in North Korea and South Korea were different. The cropland area was 3832.64 × 10^3 ha in 2015, accounting for 30.76% of the total area of the North Korea. Rainfed cropland area was 3212.35 × 10^3 ha, and paddy rice area was 620.29 × 10^3 ha (Table 1). In North Korea, croplands were widely distributed in the whole region (Fig. 5). Croplands were mainly distributed in the west and east coastal regions, and a part of croplands were distributed at the mountainous areas in the middle of North Korea. About 84.35% of croplands were distributed in regions where elevations below 500 m; and 10.18% of croplands were distributed in elevation

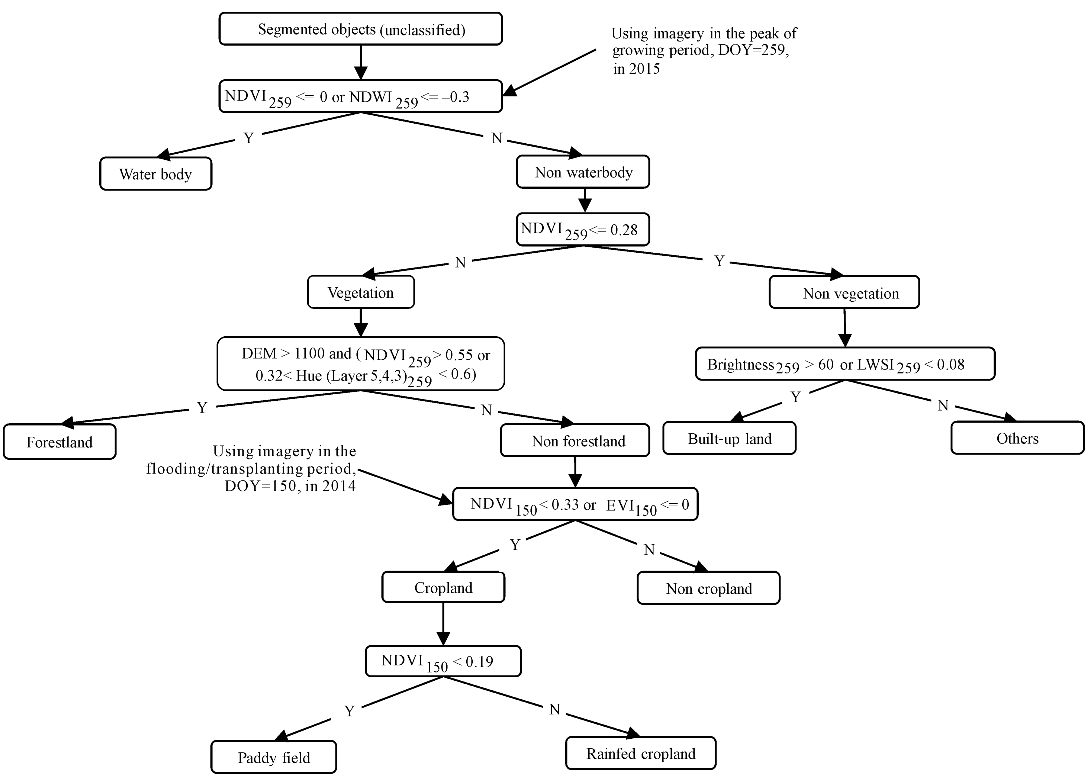

Fig. 4 Decision-tree models for cropland classification of the Korean Peninsula in 2015 using multi-temporal imageries (DOY: day of year).

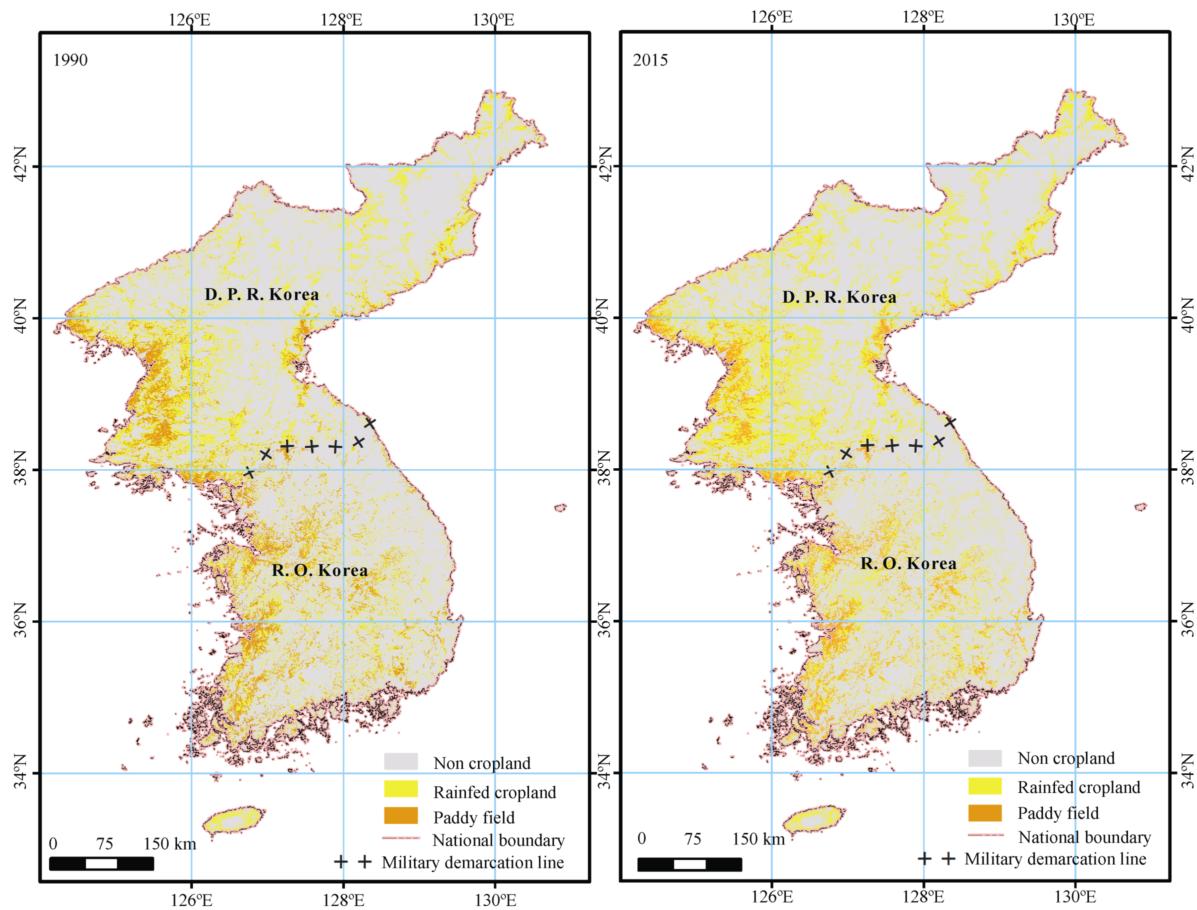

Fig. 5 Spatial distribution of croplands on Korean Peninsula in 1990 and 2015

Table 1 Croplands area change in North Korea and South Korea between 1990 and 2015

Cropland	North Korea			South Korea		
	1990 (10^3 ha)	2015 (10^3 ha)	Change area (10^3 ha)	1990 (10^3 ha)	2015 (10^3 ha)	Change area (10^3 ha)
Rainfed cropland	2584.07	3212.35	628.28	1685.59	1796.27	110.68
Paddy filed	748.12	620.29	–127.83	987.48	841.39	–146.08
Cropland	3332.19	3832.64	500.44	2673.08	2637.67	–35.41

Note: '–' represents the decrease

between 500–1000 m. Meanwhile, most of the croplands (80.23%) were concentrated in regions where slopes below 8°. The area and proportion of the cropland in the region of the slope of 8°–15° and elevation of 500–1000 m of North Korea is significantly higher than that in South Korea (Table 2). Rainfed croplands were concentrated in the flatlands of the west and south provinces (Fig. 5), and paddy fields were mainly distributed in the low slopes and low elevation region along the coastal area.

Our analysis estimated that the total area of cropland in South Korea was 2637.67 × 10^3 ha in 2015, accounting for 26.19% of the total area of the South Korea. Cropland included 1796.27 × 10^3 ha of rainfed cropland and 841.39 × 10^3 ha of paddy field. In South Korea, croplands were mainly distributed in south and west of the country (Fig. 5). About 93.10% of croplands were concentrated in region where elevation less than 300 m; and 87.86% of croplands were distributed at the region where slope below 8°, only 7.89% of croplands were distributed at slope within 8°–15°; There were also some croplands sporadically distributed in region where the slope >15° or elevation >500 m (Table 2). Rainfed croplands in South Korea were scattered in whole country. Paddy fields were mostly concentrated in the southwestern of coastal region, and there were also some paddy fields in the eastern coastal regions.

Table 2 Area and proportion of croplands in different elevation and slope on Korean Peninsula in 2015

Elevation (m)	North Korea		South Korea		Slope (°)	North Korea		South Korea	
	Area (10^3 ha)	Proportion (%)	Area (10^3 ha)	Proportion (%)		Area (10^3 ha)	Proportion (%)	Area (10^3 ha)	Proportion (%)
<100	1907.91	49.78	1801.31	68.29	<3	2357.97	61.52	1947.96	73.85
100–300	862.60	22.51	654.35	24.81	3–8	716.93	18.71	369.51	14.01
300–500	462.18	12.06	127.48	4.83	8–15	469.85	12.26	208.00	7.89
500–1000	390.20	10.18	53.10	2.01	15–25	261.27	6.82	102.97	3.90
>1000	209.75	5.47	1.42	0.05	>25	26.62	0.69	9.23	0.35

3.2 Changing trends of croplands in North Korea and South Korea

Changes in cropland in the two countries show the opposite trend during 1990–2015. North Korea's cropland area underwent obvious increase. North Korea had an increased cropland planting area with 500.44 × 10^3 ha. Rainfed croplands area increased 628.28 × 10^3 ha, and paddy fields area decreased 127.83 × 10^3 ha (Table 1). In South Korea, croplands area showed a slightly decreasing trend totally, the area decreased 35.41 × 10^3 ha. Rainfed croplands area increased 110.68 × 10^3 ha, and paddy fields area decreased 146.08 × 10^3 ha (Table 1). The increase area of rainfed croplands and decreased area of paddy fields was essentially flat. The spatial characteristics of croplands changes in North Korea and South Korea were different. In North Korea, expansion area of croplands were mainly distributed in the mountainous area with the average slope of 15° in the middle of the country (Fig. 6a); and lost area of croplands were mainly concentrated in the north and west regions. All provinces' croplands area increased except from S. Pyongan. The largest increase in cropland area was Chagang (116.56 × 10^3 ha) followed by N. Pyongan (102.96 × 10^3 ha), N. Hwanghae (64.12 × 10^3 ha), and S. Hamgyong (58.34 × 10^3 ha) from 1990 to 2015 (Table 3). Figs. 6b and 6c show forest transformed into cropland during this period in S. Pyongan.

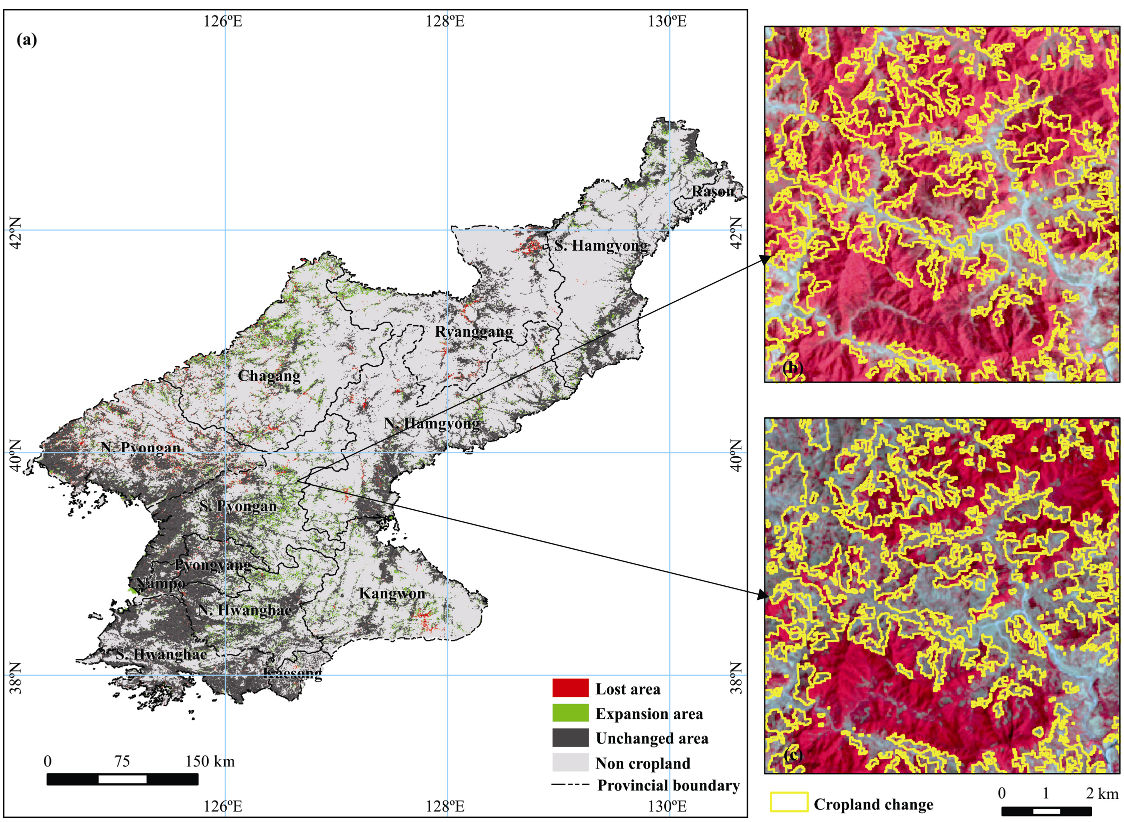

Fig. 6 Spatial distribution of cropland changes in North Korea from 1990–2015, and a typical example for cropland expansion in S. Pyongan by Landsat TM/OLI imagery. (a) Spatial distribution of cropland changes; (b) Landsat TM imagery in 1992; and (c) Landsat OLI imagery in 2015. Fig. 6b and Fig. 6c show forest transformed into cropland during this period in S. Pyongan.

Table 3 Croplands changes in provinces of North Korea and South Korea, 1990–2015

Province	North Korea				Province	South Korea			
	1990 (10^3 ha)	2015 (10^3 ha)	Change area (10^3 ha)	Change rate (%)		1990 (10^3 ha)	2015 (10^3 ha)	Change area (10^3 ha)	Change rate (%)
Chagang	237.53	354.09	116.56	49.07	Gyeonggi	331.29	298.86	–32.43	–9.79
N. Hwanghae	307.12	371.24	64.12	20.88	Seoul	2.55	1.56	–0.99	–38.82
S. Hwanghae	474.85	496.46	21.61	4.55	Incheon	5.50	3.26	–2.24	–40.73
Kangwon	211.24	261.78	50.54	23.93	Gangwon	208.52	205.73	–2.79	–1.34
Kaesong	54.42	58.76	4.34	7.98	N. Chungcheong	350.35	348.47	–1.88	–0.54
Ryanggang	215.99	221.97	5.98	2.77	S. Chungcheong	203.91	196.00	–7.91	–3.88
S. Pyongan	453.59	451.05	–2.54	–0.56	N. Gyeongsang	436.07	445.85	9.78	2.24
N. Pyongan	469.91	572.87	102.96	21.91	Daegu	8.52	7.96	–0.56	–6.57
Pyongyang	143.72	171.14	27.42	19.08	N. Jeolla	312.68	304.87	–7.81	–2.50
S. Hamgyong	308.57	366.91	58.34	18.91	S. Gyeongsang	262.22	263.75	1.52	0.58
N. Hamgyong	376.66	426.76	50.10	13.30	Busan	1.40	1.27	–0.13	–9.29
Rason	21.09	21.21	0.12	0.57	S. Jeolla	386.91	404.49	17.58	4.54
Nampo	57.51	58.40	0.89	1.55	Gwangju	21.16	18.00	–3.16	–14.93
					Sejong	17.99	16.14	–1.85	–10.29
					Daejeon	11.97	10.23	–1.74	–14.54
					Ulsan	19.03	21.41	2.39	12.55
					Jeju	93.01	89.82	–3.19	–3.43

Notes: '–' represents the decrease. N. means north; S. means south. Ulsan and Daejeon were included in N. Gyeongsang.

Compared with North Korea, the change of croplands in South Korea is not obvious spatially. The analysis result shows that most croplands were unchanged in South Korea during 1990 to 2015 (Fig.7a). The lost areas of cropland were mainly concentrated in economic circles with higher economic development, such as, Seoul (–38.82%), Incheon (–40.73%) and Gwangju (–14.93%). All provinces' cropland area decreased except from N. Gyeongsang and S. Gyeongsang (Table 3). The expansion area of cropland were mainly distributed at west coastal region. Figs. 7b and 7c show paddy field transformed into built-up land during this period. The largest increasing in cropland area was S. Jeolla (17.58 × 10^3 ha) followed by N. Gyeongsang (9.78 × 10^3 ha), S. Gyeongsang (3.91 × 10^3 ha).

4 Discussion

4.1 Comparison with existing land cover products

Uncertainty exists in our analysis of cropland transformations across Korea Peninsula. The small errors of remote sensing image acquisition, processing, classification and verification could bias our detection of land transformations. However, the area estimation, spatial distribution and dynamic changes of cropland through the ODM method are a significant improvement over other previous earlier estimates products, especially in Korean Peninsula. We chose three existing global products to compare with our KP_Cropland product. The global land cover classification data (0.25 degree coarse resolution) from the ISLSCP II Historical Land Cover in 1992 published by the Distributed Active Archive Center (DAAC, https://daac.ornl.gov/ISLSCP_II/guides/umd_landcover_xdeg.ht- ml), the global 300 m resolution land cover product GlobCover2009 (http://due.esrin.esa.int/globcover/) and the global 30 m resolution land cover product GlobeLand30 in 2010 (http://www.globallandcover.com / GLC30Download/ index.aspx). The reason for the selection of these three products was that the period of classified imageries in their products was similar to ours.

Compared with the ISLSCP II Land cover in 1992, the product precision of the KP_Cropland1990 had an absolute advantage over the precision of boundary extraction and the reconstruction and analysis of the historical data of the Korean Peninsula due to its relatively

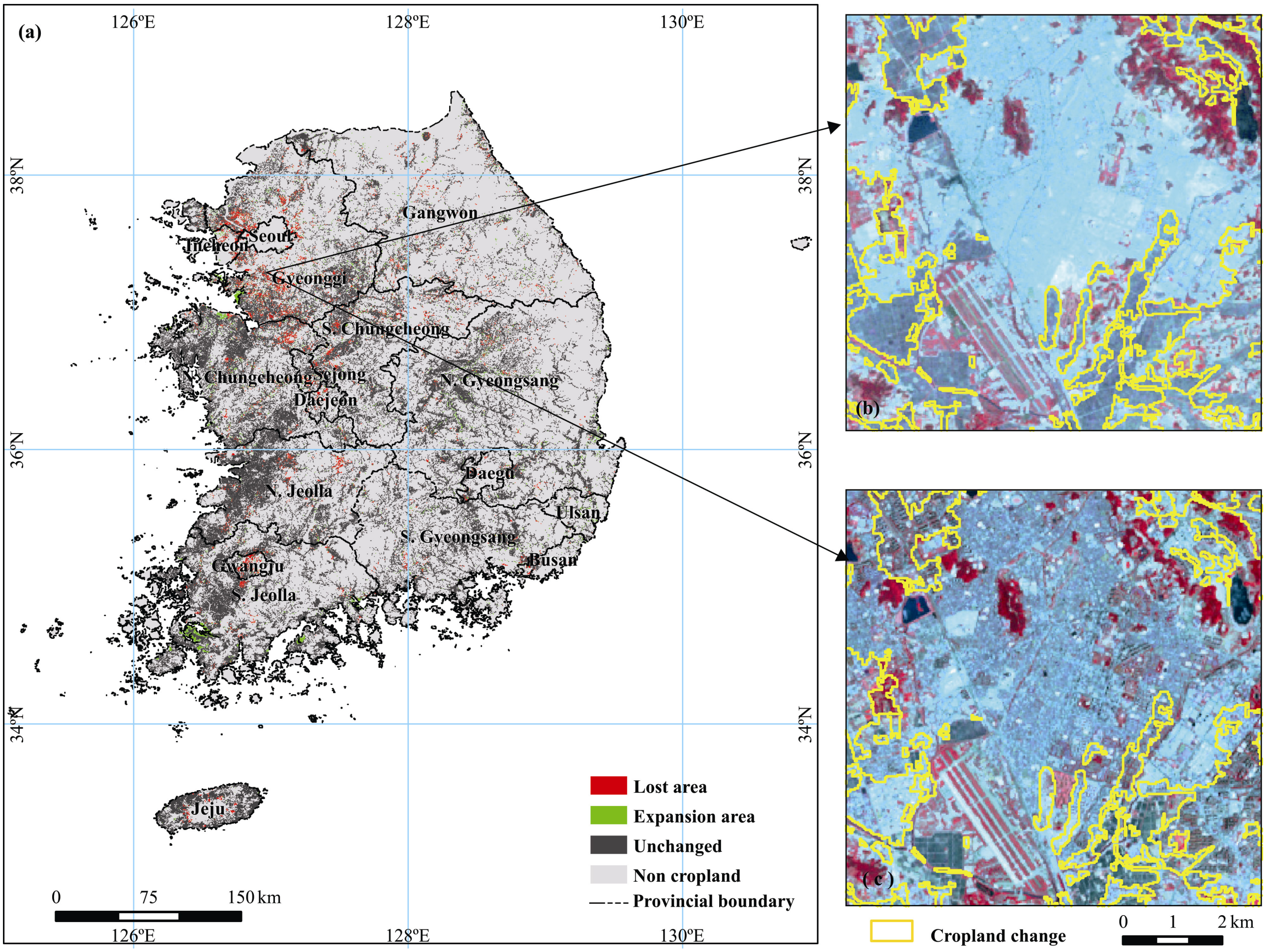

Fig. 7 Spatial distribution of cropland changes in South Korea from 1990–2015, and a typical example for cropland shrinkage in Gyeonggi by Landsat TM/OLI imagery. (a) Spatial distribution of cropland changes; (b) Landsat TM imagery in 1992; and (c) Landsat OLI imagery in 2015. Fig. 7b and Fig. 7c show paddy field transformed into built-up land during this period.

higher resolution. This is the same in the case of the Globercover2009 (Table 4). Subsequently, we carefully compared GlobeLand30 with the KP_Cropland2015 with the same resolution (30 m). It was found that the quality of KP_Cropland2015 was superior to the GlobeLand30 product from the result display and the extraction of cropland information (Fig. 8). The first and second columns of Fig. 8 show the imageries and classification of different land cover products in typical cropland regions of North Korea. The third and fourth columns show the imageries and classification of different land cover products in typical cropland region of South Korea. It is found that the veracity of North Korea's cropland classification was lower than that of South Korea in existing land cover products. In our product, the total accuracy of cropland information extraction was relatively higher in both North Korea and South Korea than existing land cover products (Wu et al., 2009; Olofsson et al., 2012). The cropland areas of GlobeLand30 in 2010 were larger than that of KP_Cropland2015 (Table 2), FAOSTAT reports the croplands in Korea Peninsula were increased from 1990–2015 (FAO, 2015). The main reason for this was that non-cropland areas (for example, forestlands or built-up lands) were erroneously divided into cropland (the second line of Fig. 8) areas and the product did not make full use of the variation in the presence of cropland in the multi-season imageries in the GlobeLand30 (Lei et al., 2016). However, the boundary of land cover is more accurate and clear in the KP_Cropland2015 by using characteristics of the cropland growth cycle and the expression of cropland on multi-season imageries. It is proved that we can establish more accurate historical cropland data using OMD methods in Korean Peninsula.

Table 4 Cropland areas of different land cover products in North Korea and South Korea

Country	Area (10^3 ha)	Product	Resolution	Year
North Korea	3332.19	KP_Cropland	30 m	1990
	2323.94	ISLSCP II Historical Land Cover	0.25 degree	1992
	2138.34	Globecover2009	300 m	2009
	3383.61	GlobeLand30	30 m	2010
	3832.65	KP_Cropland	30 m	2015
South Korea	2673.08	KP_Cropland	30 m	1990
	3491.24	ISLSCP II Historical Land Cover	0.25 degree	1992
	2801.16	Globecover2009	300 m	2009
	3562.79	GlobeLand30	30 m	2010
	2637.67	KP_Cropland	30 m	2015

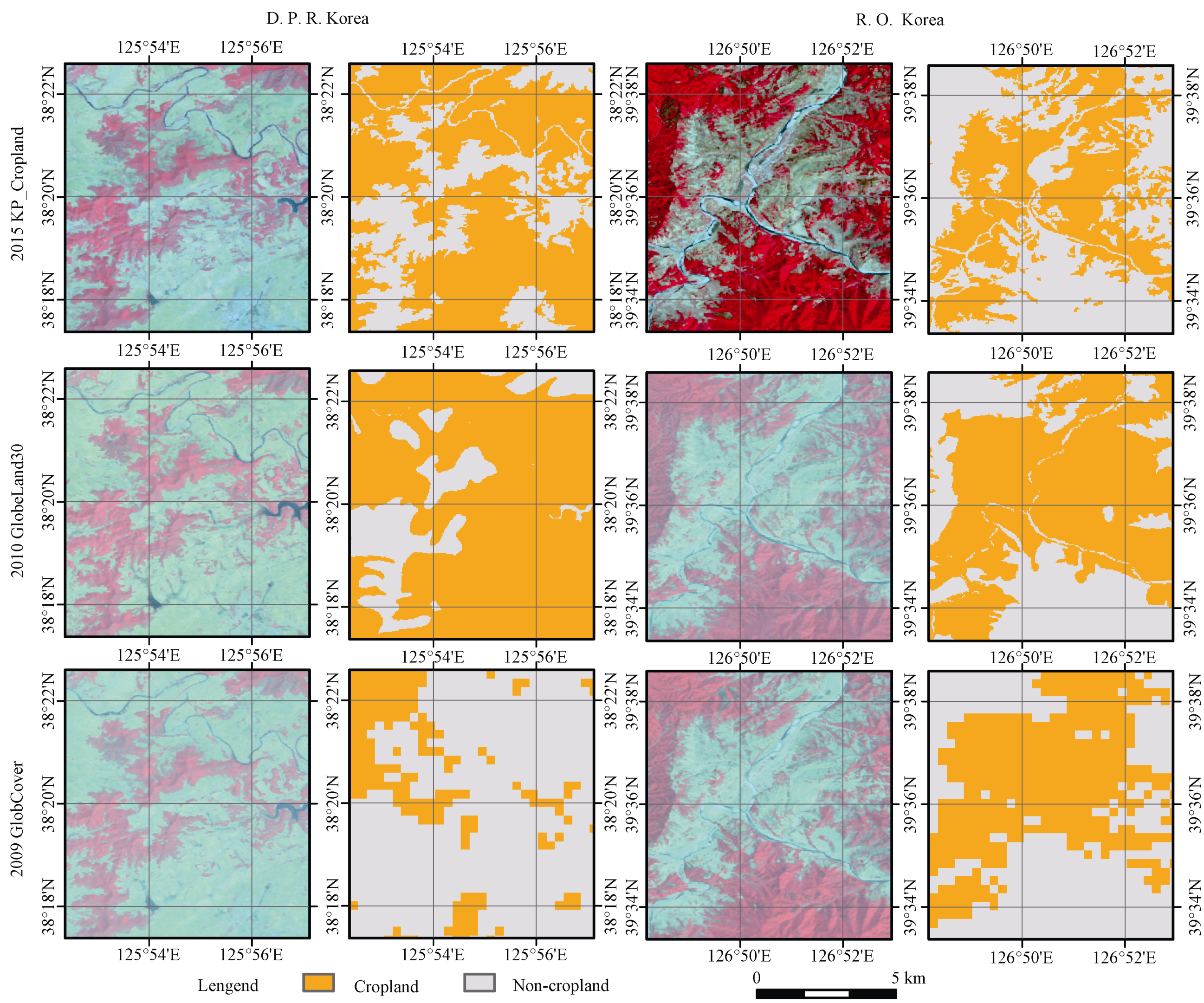

Fig. 8 Comparison of classification results among three land cover products in two typical cropland regions. (The first and third column are imageries in corresponding years, the second and fourth rows are land cover products).

4.2 Underlying drivers of cropland changes

Population growth has been the primary driving force of change relating to cropland, a land-use type that provides people with food (Zuo et al., 2014). During the study period, North Korea's total population increased by 25.00% from 2.02 million in 1990 to 2.52 million in 2015. The rural population was about 1.5 times numbers as of urban population. The rural and urban population increased by 17.11% and 29.88%, respectively, during 1990–2015 (FAO, 2015). It meant that the supply of agricultural products has been insufficient for the whole country. Meanwhile, the increase in the rural population and the increase in the agricultural labor force, and these encouraged the undertaking of a national survey to find more cultivable land to meet the demand of grain (Tang et al., 2012). In the same period, South Korea's total population showed an increasing trend, which increased from 4.29 million in 1990 to 5.06 million in 2015, with a rate of increase of 17.87%. Compared with North Korea, the proportion of rural population and urban population was lower than that of North Korea. Although the total population was increased, the rural population was decreased (22.43%) from 1990 to 2015. With the rapid urbanization in South Korea, a large number of rural populations poured into urban areas (Cho, 2002; Bae and Sellers, 2007) which lead to the reduction of the cropland labor force which inhibited the expansion of cropland in South Korea.

In economic, North Korea and South Korea were significantly different. Compared with other developing countries, North Korea is relatively backward in its economy. In contrast to the increasing trends of the global gross domestic product (GDP), the GDP of North Korea has shown a decreasing trend in the past decades (FAO, 2015). The economic downturn is mainly affected by heavy natural disasters, and American trade sanctions against North Korean economy brought great losses to the production of grain and to the economy as a whole (Michalk and Mueller, 2003), the investment in the agricultural economy was reduced. These led to cropland yield in North Korea declined, despite the cropland area increase. South Korea has been especially successful in developing its industrial-economic potential to the point at which it is now a major player in the global economy (ASIASOCIET, 2017). Additionally, there was a four-fold increase in GDP between 1990 and 2015 (FAO, 2015). The rapid growth of economy has accelerated the urbanization and industrial haul process in South Korea, which has resulted in the decrease of certain croplands close to the capital economic circle and industrial zone.

North Korea is a socialist republic and maintains a policy of isolation and South Korea is a developed country with a modern economy (Lee and Miller-Rushing, 2014). In the implementation of governmental agricultural policies, the orientation of the two countries is different, which is also an important reason for the difference of croplands change. In the 1990s, a series of natural disasters took place in North Korea; it caused great losses to the production of grain (Lee et al., 2003; Lee and Jin, 2008). Agricultural policies in North Korea were divided into two phases by agricultural policy innovations and natural disasters (Fig. 9): 1) the recovery period of cropland before 1990s was affected by a series of natural disasters. North Korea promulgated the agricultural law and popularized new group management mechanism to mitigate the damaging of natural disasters; 2) the period of encouraging the production of farmers to improve grain production capacity. North Korea is a country with high food self-sufficiency rates but has received long-term food aid owing to supply shortage. The North Korea government is encouraging farmers to plant a greater variety of crops, increase the use of higher-yielding seeds, expand double-cropping and crop rotation, and pushing new measures for agricultural reform by more harvest to farmers (Lim et al., 2017).

South Korea has more mature and positive policies to manage croplands (Song, 1998; Qiang, 2010; Zhang and Guo, 2014). Fig. 9 shows that the agricultural policies were divided into two parts in South Korea: 1) a period of cropland protection by increasing investment and technological innovation; 2) a green sustainable development period that was strongly pro-environment. Several comprehensive agricultural investment plans have been put in place to improve the infrastructure for production, processing, and distribution and have contributed to efficiency gains (OECD, 2008). After 2000, South Korea paid more attention to environmental protection and ecological restoration, aimed to reduce environmental pollution by chemical fertilizer and pesticide in cropland (Qiang, 2010). Meanwhile, some farming households gradually shifted from traditional rice cultivation to higher yield fruits and vegetables and

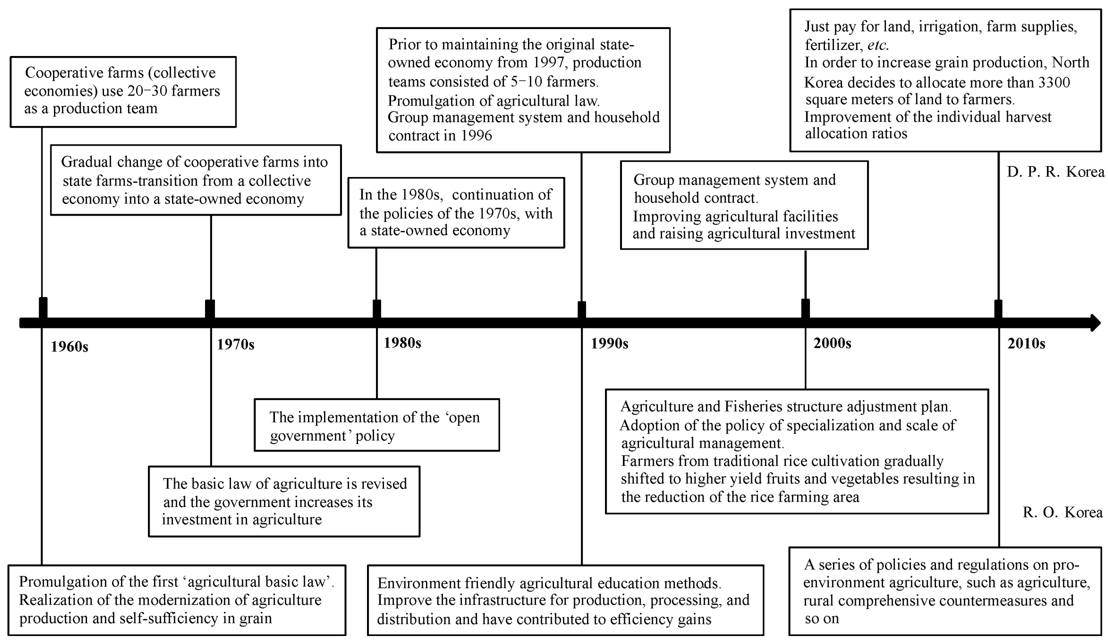

Fig. 9 Cropland development polices in North Korea and South Korea since the 1960s.

other forms of production and cultivation (Pan, 2008; Qiang, 2010; Joo and Mishra, 2013). These policies have led to a decline in the area of South Korea's cropland during 1990 to 2015.

5 Conclusions

Results show that using object-oriented segmentation, and spectral, seasonal and ancillary information, ODM classification is a straightforward way to improve the extraction accuracy of cropland boundaries. We established the KP_Cropland data products in 1990 and 2015 which provide scientific bases for the protection and sustainable utilization of cropland resources. To highlight the superiority of the national-adapted maps, we compared the KP_Cropland product to the existing global land cover maps from a similar time, and the contrasted result shows that KP_Cropland maps are better suited for depicting national cropland. Additionally, we identified the dynamic of croplands between North Korea and South Korea from 1990–2015. There are an opposite change trend of cropland between North Korea and South Korea from 1990 to 2015. Cropland in North Korea showed a remarkable increasing by 15.01%, South Korea's cropland showed a slightly decrease by 1.32%. The main driving forces on the cropland change characteristics were population and economic factors and policies. Furthermore, the changing differences in socio-economic factors between South Korea and North Korea have led to the variation of croplands. The elements of resources and environment and their changing information on the Korean Peninsula are of great significance to the study of resources and environment in Northeast Asia and even the whole world. The results drawn from our study can provide technical support in mapping products, as well as provide data reference in related fields with global change and sustainability.

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