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Changes in rice cropping systems in the Poyang Lake Region, China during 2004–2010

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Abstract: Rice cropping systems not only characterize comprehensive utilization intensity of agricultural resources but also serve as the basis to enhance the provision services of agro-ecosystems. Yet, it is always affected by external factors, like agricultural policies. Since 2004, seven consecutive No.1 Central Documents issued by the Central Government have focused on agricultural development in China. So far, few studies have investigated the effects of these policies on the rice cropping systems. In this study, based upon the long-term field survey information on paddy rice fields, we proposed a method to discriminate the rice cropping systems with Landsat data and quantified the spatial variations of rice cropping systems in the Poyang Lake Region (PLR), China. The results revealed that: (1) from 2004 to 2010, the decrement of paddy rice field was 46.76 km^2 due to the land use change. (2) The temporal dynamics of NDVI derived from Landsat historical images could well characterize the temporal development of paddy rice fields. NDVI curves of single cropping rice fields showed one peak, while NDVI curves of double cropping rice fields displayed two peaks annually. NDVI of fallow field fluctuated between 0.15 and 0.40. NDVI of the flooded field during the transplanting period was relatively low, about 0.20±0.05, while NDVI during the period of panicle initiation to heading reached the highest level (above 0.80). Then, several temporal windows were determined based upon the NDVI variations of different rice cropping systems. (3) With the spatial pattern of paddy rice field and the NDVI threshold within optimum temporal windows, the spatial variation of rice cropping systems was very obvious, with an increased multiple cropping index of rice about 20.2% from 2004 to 2010. The result indicates that agricultural policies have greatly enhanced the food provision services in the PLR, China.

Keywords: rice cropping systems; NDVI; temporal windows; threshold method; Landsat; the Poyang Lake region (PLR)

1 Introduction

Rice (*Oryza sativa L.*) is one of the three primary cereals in China. In 2009, the harvested

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area and production quantity of rice account for 34% and 41% of the national cereals, respectively (FAOSTAT, 2009). However, the planting area and production capacity of rice are often influenced by various policies (Heerink *et al*., 2007; Tong *et al*., 2003; Yu *et al*., 2011). Since 2004, the Central Government of China has consecutively implemented several No.1 Documents aimed at promoting the development of agriculture, rural areas, and farmers with some major favorable policies. Besides, in 2009, the National Development and Reform Commission (NDRC) released the "National Plan for Expansion of Grain Production Capacity by 50 billion kilograms during 2009–2020." Under these circumstances, how will the cropping intensity or the multiple cropping index change? Delineating and mapping of rice cropping systems is of great importance for yield assessment (Silva *et al*., 2001), nutrition management (Dobermann *et al*., 2002) and methane emission monitoring (Huang *et al*., 1998; Li *et al*., 2011). In addition, it will also help to analyze the outbreak and spread of avian influenza (Gilbert *et al*., 2007; Martin *et al*., 2011). Conventional data source of rice cropping systems was mainly from statistical departments in different administrative units. However, this is a time-consuming process and generally neglects the spatial heterogeneity of the corresponding administrative unit.

Remote sensing has become an effective way to monitoring the vegetation changes. Vegetation index derived from satellite images serves as a powerful parameter for the crop growth information detection. Thereinto, Normalized Difference Vegetation Index (NDVI) calculated between red and near infrared (NIR) bands (Tucker, 1979) is the most widely used in vegetation monitoring. Satellite imagery from optical sensors has been widely utilized to discriminate and map the rice cropping systems (Peng *et al*., 2010; Sakamoto *et al*., 2006; Sakamoto *et al*., 2009; Xiao *et al*., 2002a, b; Xiao *et al*., 2002). The above-mentioned optical image is mainly Moderate Resolution Imaging Spectroradiometer (MODIS) due to its daily observations. The time-series MODIS vegetation index data holds great potential for describing the growth dynamics of rice fields over large area with relative simple cropping systems. Yet the mixed pixel effect poses a fundamental challenge in using the same method in regions with complex topographic relief and/or locations where paddy rice fields are much smaller than the MODIS pixels (Peng *et al*., 2010; Xiao *et al*., 2006; Xiao *et al*., 2005). Image of synthetic aperture radar (SAR) can also well detect and delineate complex rice cropping systems due to the all-weather image acquisition at fine spatial resolution (Bouvet *et al*., 2009; Liew *et al*., 1998; Torbick *et al*., 2011a; 2011b). Yet it is usually expensive to have SAR data to cover large area for mapping rice cropping systems.

Landsat image is another image data source for discrimination of various rice cropping systems in the tropical and subtropical rice growing areas (Xiao *et al*., 2002b). Landsat image has much finer spatial resolution (30 m) compared with MODIS data. The Landsat TM/ETM+ pixel size (0.09 ha) is close to the paddy rice field sizes in many regions of China. Furthermore, the US Geological Survey (USGS) has made Landsat continuous archive publicly available for no cost since October 2008 from the Global Visualization Viewer (GloVis) at http://glovis.usgs.gov and Earth Explorer at http://earthexplorer.usgs.gov. All these advantages have made Landsat data an alternative option for rice cropping systems variation monitoring. Nevertheless, the prevailing cloud cover makes the foremost challenge in analysis of Landsat data. Consequently, we proposed to utilize a few images within optimum temporal windows based upon the dynamics of NDVI over the entire growth period of paddy rice. The objective of this study is twofold: (1) to evaluate NDVI derived from Landsat image for delineating the growth characteristics of paddy rice fields; (2) to analyze the spatial variation of rice cropping systems from 2004 to 2010 in the Poyang Lake Region, China.

2 Materials and methods

2.1 Study area

In China, rice cropping systems range from single to triple cultivation per year along the latitudinal gradient from north to south (Ding, 1961). We selected the Poyang Lake Region (PLR) (Figure 1) to monitor rice cropping systems impacted by the nationwide agricultural policies – No.1 Central Documents. The PLR in this paper refers to the 12 administrative units (including ten agricultural counties, namely, Nanchang, Xinjian, Jinxian, Yongxiu, De'an, Xingzi, Hukou, Duchang, Poyang and Yugan; and two cities, i.e., Nanchang and Jiujiang) surrounding the biggest fresh water lake in China, with a total land area about 20289.50 km^2. The PLR is one of the important rice-producing regions in China with the characteristics of multiple cropping systems. The PLR is located in the north of Jiangxi Province and the south bank of the middle Yangtze River. The physiognomy of the PLR features low-lying plains near the lake and rivers, surrounded by mountains and hills to the east, north, and west.

Paddy rice is the dominant crop in the PLR. According to the Jiangxi Statistical Year-

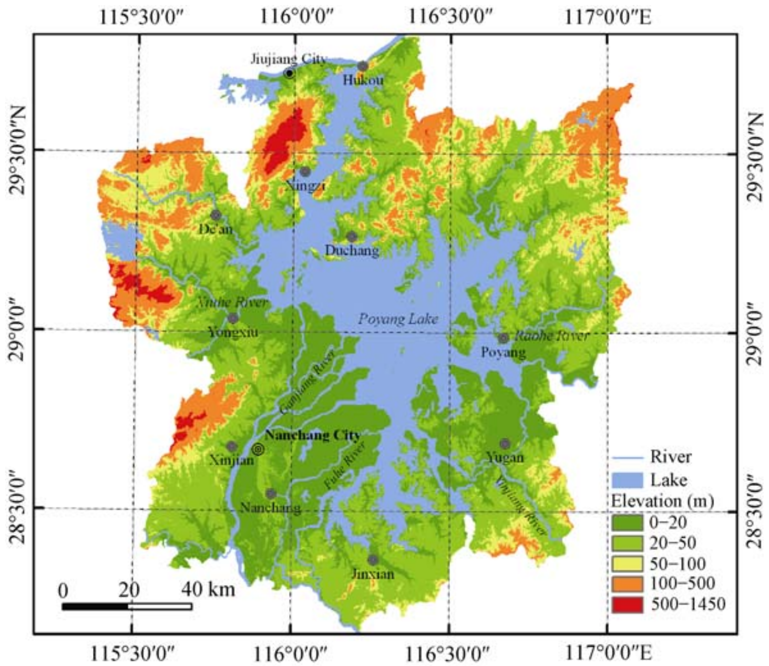

Figure 1 The location of the PLR in China showing the spatial distribution of lakes and rivers and elevation at about 30m resolution (from the USGS GloVis, http://glovis.usgs.gov/). The water body (rivers and lakes) was extracted from the Landsat ETM+ images over the PLR (P121R40, P121R39, and P122R40) in October 2010.

books from 2002 to 2010, the sown area of rice accounts for more than 90% of the total sown area of all crops; the output of rice makes up over 95% of the total output of grain. In terms of the Rice Planting Division of China, the PLR is located in the Central China double- and single-rice cropping region (Ding, 1961). Double cropping rice system consists of early rice and late rice, with sowing for early rice in late March, transplanting in late April, harvesting in late July, then followed by transplanting of late rice (sowing in late June), and harvesting in late October. Single cropping rice system only involves planting once a year for a given field with a comparatively longer growth period (from late May to early October), when compared with early rice and late rice (Figure 2). During the period from early November to mid-March of next year, there is no rice crop due to the low temperature. The cropping systems in the PLR are made up of rice-fallow and rice-rice-fallow. Therefore, the PLR in China is a very typical area for the analysis of rice cropping systems variations induced by the agricultural policies.

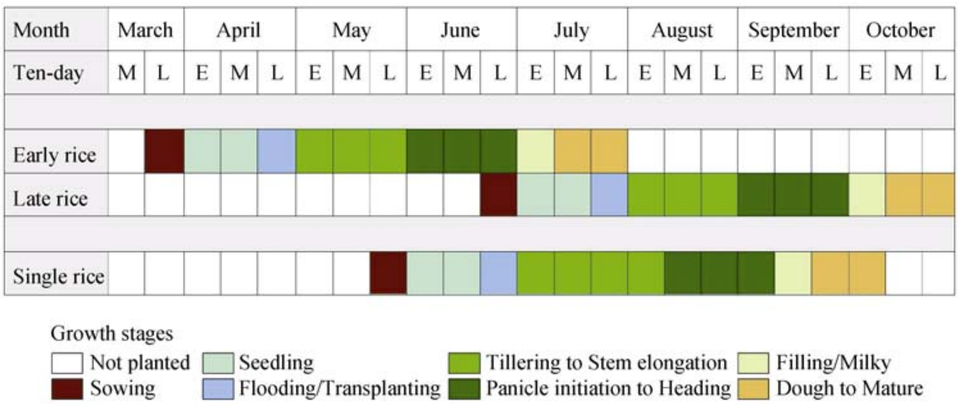

Figure 2 The calendar for different paddy rice growing systems per year in the PLR, China (Li *et al*., 2011)

2.2 Phenological data of paddy rice fields

Paddy rice phenology datasets from three meteorological monitoring stations located within the PLR (i.e., Nanchang, Yugan and Hukou) and four other in the surrounding counties were used to define the key rice phenological phases at the time scale of ten-day (Figure 2). There were six monitoring sites for double cropping rice and one for single cropping rice. We also referred to other materials, mainly the per ten-day Agro-meteorological Bulletin data of Jiangxi Province from 2002 to 2011 gathered from the Jiangxi Meteorological Bureau (http://www.weather.org.cn/). Then, the rice calendar in the PLR (Li *et al*., 2011) was validated during the repeatedly field investigations from 2007 to 2011.

2.3 Field survey data

During mid-to-late September 2010, an 8-day extensive ground survey on different paddy rice cropping systems (late rice and single rice) was conducted around the PLR. We used a handheld global positioning system (GPS) receiver (Trimble Juno-SB) to collect geographical information of the 148 sample sites. In early July 2011, another 8-day extensive field survey on different paddy rice cropping systems (early rice and single rice) was conducted in the PLR, and other 100 sample sites were obtained. All the sample sites are distributed within a rice-dominated surrounding area. The linear distance between any two GPS points was more than 2.0 km. The field truth information was used for paddy rice field interpretation and NDVI extraction. During the field surveys, the variation of rice cropping systems of the sample fields in the past five years was gathered through field interviews with local farmers.

Out of 248 field sites in 2010 and 2011 surveys, we selected 17 double rice sites and 19 single rice sites to extract the NDVI and construct time series data from Landsat images (Table 1). All the field sites (36 sites) were distributed in the 10 agricultural counties, with 1–4 sites per county.

Table 1 Geo-location of double- and single-cropping rice sample sites within the ten agricultural counties in 2010 and 2011

Counties	Longitude (E) and latitude (N)			
Nanchang	116.100341; 28.861684	116.134915; 28.770384	116.252972; 28.764000	116.011092; 28.571902
Xinjian	115.913710; 28.922191	116.146692; 28.924248	116.065163; 28.996257	116.028304; 29.008992
Jinxian	116.176269; 28.404437	116.293005; 28.373801	116.450270; 28.613232	116.226368; 28.576941
Yugan	116.584738; 28.888432	116.449920; 28.819729	116.726549; 28.767536	116.605358; 28.602893
Poyang	116.822682; 28.933663	116.645188; 29.364146	116.642283; 29.011641	116.758349; 28.906634
Duchang	116.519391; 29.350908	116.359407; 29.265840	116.275240; 29.279951	116.122266; 29.400897
Yongxiu	115.798545; 29.227029	115.751712; 29.215887	115.871128; 29.139124	115.762317; 29.031393
Hukou	N/A	N/A	116.256500; 29.625756	N/A
De'an	115.815274; 29.279990	N/A	115.763735; 29.337415	115.822284; 29.274430
Xingzi	116.041335; 29.493062	115.892454; 29.338904	115.851325; 29.234036	115.828301; 29.244702

Note: The underlined figures indicate the longitude and latitude of single rice sample sites, and the formatless figures are those of double rice sample sites. N/A indicates that there is no valid sample site gathered during the field surveys.

2.4 Landsat data and image pre-processing

All available Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper plus (ETM+) imagery (59 in total) with little or low cloud cover from 2004 to 2010 (Tables 2, 3 and 7)

Table 2 A list of Landsat TM/ETM+ images (121/40) within the past fives years used for calculating NDVI with the field survey sites collected in 2010 and 2011 (a total of 44 images)

Month	Early-	Mid-	Late-
January	2008-01-01	2010-01-14	2007-01-30
February	N/A	N/A	2010-02-23
March	N/A	2010-03-11	N/A
April	2009-04-09	2006-04-17	2010-04-28
May	2006-05-03, 2007-05-06	2009-05-11, 2006-05-19	2010-05-30
June	2009-06-04	2010-06-15, 2006-06-20	N/A
July	2011-07-04	2006-07-14	2007-07-25, 2007-07-27
August	2010-08-02	2007-08-10, 2010-08-18	2011-08-21, 2007-08-26
September	N/A	2008-09-13, 2010-09-19	2006-09-24, 2007-09-27, 2008-09-29
October	2009-10-02, 2010-10-05	2008-10-15	2010-10-21
November	2009-11-03, 2010-11-06	2006-11-11	2010-11-22, 2007-11-30
December	2008-12-02, 2010-12-08	2008-12-18	2009-12-21, 2006-12-29

were acquired over the PLR, which is covered by three path/row scenes (121/40, 121/39, and 122/40). These satellite data were collected from the USGS EDC (Global Visualization Viewer (GloVis) at http://glovis.usgs.gov) and Center for Earth Observation and Digital Earth (CEODE), Chinese Academy of Sciences (http://www.ceode.ac.cn/), respectively. All images data was Level 2 product which had been processed for radiometric and geometric calibration. We used the orthorectified Landsat imagery gathered from CEODE to carry out registrations with ENVI image processing software (4.7 version) and the Root Mean Square Error (RMS error) less than one pixel (or 30 m). The crossings or intersection of dykes and major roads were normally used as ground control points (GCP). Then, surface reflectance of all images was retrieved through radiometer calibration and atmospheric correction with ENVI software for NDVI calculation. In addition, for the ETM+ scenes (Table 7) used to discriminate rice cropping systems, we applied gap-fill method to improve the usability of data because of the Scan Line Corrector (SLC) failure. The method was proposed by International Scientific Data Service Platform, Computer Network Information Center, Chinese Academy of Sciences (http://datamirror.csdb.cn).

2.5 Vegetation index calculation

NDVI is calculated with surface reflectance values from red and NIR spectral bands (Tucker, 1979). The formula is as follows:

$$NDVI=\frac{\rho_{nir}-\rho_{red}}{\rho_{nir}+\rho_{red}}$$

We collected the cloud-free images (Table 2) for NDVI calculation over the PLR in the past five years and constructed the time-series NDVI temporal curves. As the NDVI of double- and single-cropping rice fields differs obviously during different growth periods, based on the typical sample sites at the farm to landscape scales, the corresponding NDVI range of typical growth phases were quantified, then also the time windows with noticeable NDVI differences between double- and single-cropping rice fields were determined; finally, we used threshold method to discriminate the rice cropping systems with a few images during optimum temporal windows.

2.6 Visual interpretation of paddy rice fields

We used the paddy field distribution map of 2000 in the PLR from Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences, as a base map, then selected several cloud-free Landsat TM/ETM+ images over the PLR (Table 3) and visually interpreted and updated the paddy rice pattern in 2004 and 2010. The classification result of paddy rice in 2000 was also interpreted from Landsat imagery with a validated accuracy over 90% (Liu *et al*., 2005). The updated paddy rice distribution data was used as a mask when conducing different rice cropping systems classification.

Table 3 Data list of Landsat images using for paddy rice field interpretation between 2004 and 2010 in the PLR, China

	Path=121, Row=40	Path=121, Row=39	Path=122, Row=40
TM	2009-06-04, 2009-10-26	2009-06-04	2009-10-17, 2010-10-04
ETM+	2010-08-02, 2010-10-05	2009-05-11, 2010-10-05	2009-06-19, 2010-10-28
	2004-10-04	2004-10-04	2004-09-25

2.7 Imaging features of double- and single-cropping rice fields

The imaging feature of rice fields alternates between exposed soils (or with shallow water) and rice plants in a year. It is relatively evident to discriminate double rice patches and single rice patches in the polder area with naked eye. Polder area for rice cultivation is very common in the PLR due to the historical reclamation for food production. We selected more sample sites of double- and single-cropping rice fields to delineate the corresponding NDVI dynamic at the landscape scale.

Based on the rice calendar of the PLR (Li *et al.*, 2011), take Lefeng Polder Area in the south of Poyang County for instance (Figure 3), using two Landsat-5 TM images of P121R40 in early June and late October, 2009 to show the imaging features of different rice copping patterns. In the image of June 4, 2009, the predominate bright green patches (like D, Figure 3, left panel) represented the fields with early rice plants in the panicle initiation phase, while the sporadic blue patches (like S, Figure 3, left panel) revealed that single rice fields was waterlogged. Field waterlogging during April to May is one major reason for single cropping rice planting in the PLR. In the image of October 26, 2009, the green patches represented the fields with late rice plants in the maturity phase (like D, Figure 3, right panel), while the pink patches mostly stood for the harvested single rice field (like S, Figure 3, right panel).

Similarly, we selected two TM/ETM+ images of P121R40 in 2004. One TM image was on July 24, 2004 when double cropping rice was prevalently in the period of rush-harvesting of early rice and followed by flooding and rush-transplanting for late rice *in situ*, and single cropping rice was in the tillering to stem elongation phase with rice plants fully covering the field background. The other ETM+ image was on October 4, 2004 when single rice plants were nearly harvested and double cropping rice (late rice) was in the grain filling phase.

Take Kangshan Polder Area (located in the northwest of Yugan County) for example (Figure 4), in the image of July 24, 2004, the bright green patches (like S1, S2 and S3, Figure 4, left panel) represented the fields with single rice plants in the tillering phase, while the pink patches (like D1 and D4, Figure 4, left panel) stood for the fields just reaped and/or the blue patches (like D2 and D3, Figure 4, left panel) referred to the flooded fields with the transplanting of late rice seedlings. In the image of October 4, 2004, this situation was just the opposite. Specifically, the bright green patches (like D1, D2, D3 and D4, Figure 4, right panel) meant the fields with growing late rice plants in the grain filling phase, whereas the pink patches indicated the harvested fields (like S1 and S2, Figure 4, right panel) or the harvesting fields (like S3, Figure 4, right panel) of single rice.

Based on the imaging characteristics, 425 field sites of double- and single-cropping rice were selected from the image acquired on the October 26, 2009. These sites used to extract NDVI information were well-distributed in the PLR. The average NDVI was used to evaluate the temporal dynamic of rice fields at the landscape scale. Also, 300 sites of double- and single-rice fields were well selected from the image of October 4, 2004. The corresponding NDVI were used to compare with the NDVI of 2010 since the image acquired date was very close.

3 Results and analysis

3.1 Temporal dynamics of NDVI at the farm scale

According to the 36 double- and single-cropping rice sites (Table 1), the corresponding

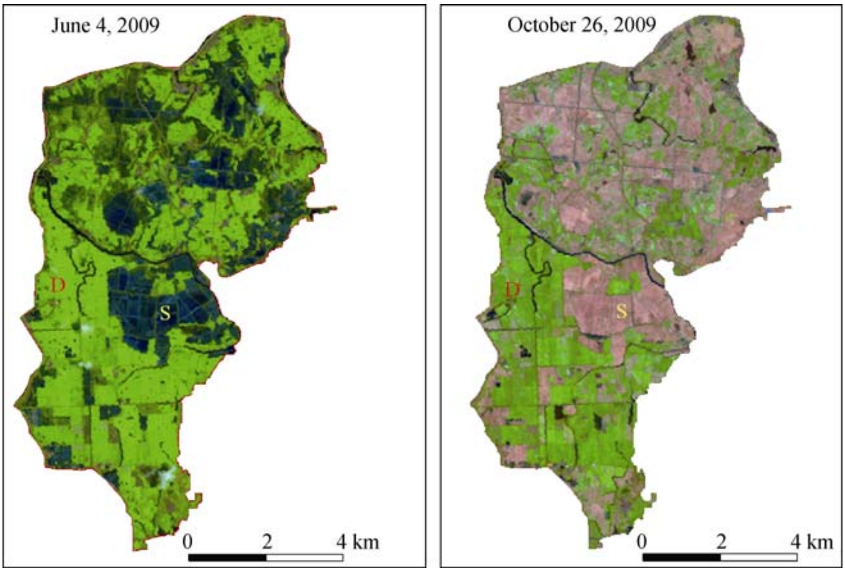

Figure 3 Imaging features of double- and single-cropping rice fields during diverse growth periods in the Lefeng Polder Area, Poyang County (Note: The green patches refer to the growing rice plants and the dark blue line refers to small rivers.)

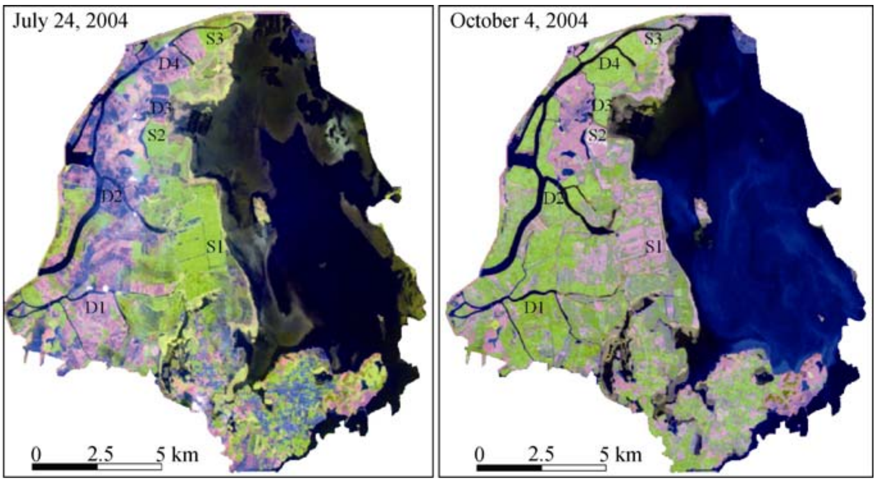

Figure 4 Imaging features of double- and single-cropping rice fields during diverse growth periods in the Kangshan Polder area, Yugan County. Note that the green patches refer to the growing rice plants; the dark blue line and polygon refer to water body (small rivers and lakes).

NDVI values was extracted from the Landsat TM/ETM+ images (Table 2), and then constructed the NDVI temporal dynamic curves (Figure 5). The single cropping rice fields showed one peak values of NDVI, while the double cropping rice fields displayed two peak values of NDVI annually.

Early rice plants in the PLR were usually transplanted during late April, almost 25–30 days after sowing. During this period, the early rice fields were plowed to bury the weeds, with land preparation and flooding for transplanting. NDVI of rice fields may decline to a very low level, about 0.20 (±0.05). After transplanting, there will be several days (3–5 days) to green up, and then soon enter the tillering phase. NDVI increases very remarkably as the rice seedlings cover the field background, and then reaches a plateau until grain filling phase with the value approximately about 0.80–0.95. There is a time conflict between the harvest of early rice and the transplanting of late rice plants, locally called “Rush-harvesting and Rush-transplanting”. So, it is very clear to see the sharp variations of NDVI of double cropping rice fields. Over the fallow period, NDVI shows a slight fluctuation between 0.15 and 0.40.

For any other type rice (single rice and late rice), the growing process of rice plants and its variation features are very similar with that of early rice during the periods from transplanting to harvest. However, an anomaly of NDVI occurred in Jinxian County (Figure 5, upper right) with the NDVI in the fallow period below zero due to the waterlogging.

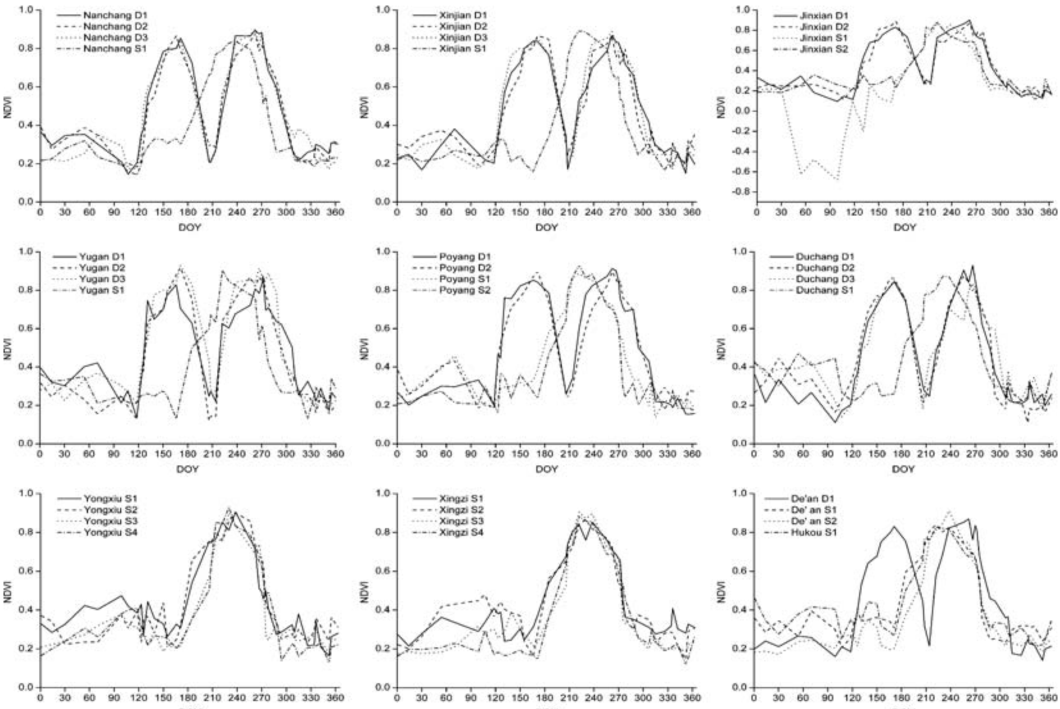

Figure 5 The NDVI curves derived from field sites of different rice cropping systems in the ten agricultural counties. Note that capital D represents the site taken from a double cropping rice field, and capital S stands for the site from a single cropping rice field.

It is important to note that the temporal dynamic of NDVI of double-and single-cropping rice at the farm scale shows obvious temporal difference during the rice growing season (mainly late April to late October). Specifically, in late April the NDVI of double rice is usually slightly less than that of single rice fields. From May to early July, the NDVI of double rice fields was bigger. The situation is just the opposite between mid-July and late August. After then, the NDVI of double rice fields was bigger than that of the counterpart once again. That is to say, NDVI information within different growth periods of various rice cropping systems is quite distinct. According to the NDVI of the 36 typical field sites, the thresholds of NDVI within corresponding growth periods were determined (Table 4).

Table 4 NDVI value range of different growth stages for early, single, and late rice in the PLR, China

	Germination to seedling		Flooding and transplanting		Tillering to stem elongation		Panicle initiation to heading		Grain filling to dough		Mature to harvest	
	Date*	NDVI	Date	NDVI	Date	NDVI	Date	NDVI	Date	NDVI	Date	NDVI
Early rice	3L–4M	0.2–0.4	4L	0.1–0.4	5E–5L	0.3–0.7	6E–6L	0.7–0.95	7E–7M	0.7–0.5	7L	0.5–0.2
Single rice	5L–6M	0.2–0.4	6L	0.1–0.4	7E–8E	0.3–0.8	8M–9E	0.7–0.95	9M–9L	0.7–0.5	10E	0.5–0.2
Late rice	6L–7M	0.2–0.4	7L	0.1–0.4	8E–8L	0.3–0.7	9E–9L	0.7–0.95	10E–10M	0.7–0.5	10L	0.5–0.2

* Note: The figure under the column of date refers to a certain month, and the capital letter E, M, and L refer to the first, middle and last ten-day of a month, respectively.

3.2 Temporal dynamics of NDVI at the landscape scale

Based on the farm-scale NDVI analysis above, our hypothesis is that the variation features of NDVI should be analogous at the landscape scale. According to the imaging characteristics of different cropping rice fields, other 425 sample sites of double- and single-cropping rice in 2010 were selected. With the same method, the corresponding NDVI of each site was retrieved. To compare the temporal variation of NDVI, multi-temporal images (Table 2) were utilized to construct the time-series NDVI data of rice fields. Figure 6 gives a good validation of the farm scale analysis. The NDVI variation curves of the two rice cropping systems were very similar to those at the farm scale.

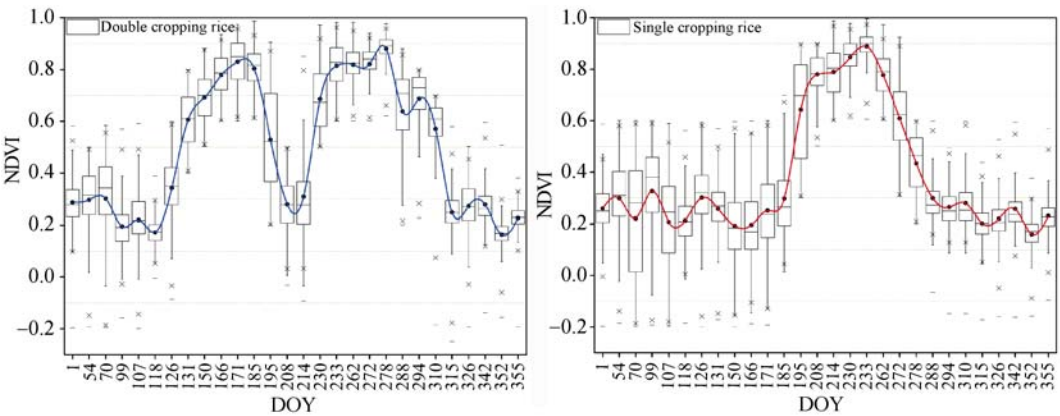

Figure 6 Temporal variation of NDVI of double- and single-cropping rice at the landscape scale

As there was no field survey data in 2004, we used the similar way to obtain field sites (150 each) of double- and single-cropping rice based upon the imaging traits (see Figure 4). For these 300 sample sites, corresponding NDVI information was purely derived from the ETM+ cloud-free images (seven, P121R40 only) in 2004 in order to avoid the impact of the adjustment of cropping system. The NDVI information in 2004 was used to compare with that of 2010. The acquired date of these ETM+ images was very close (Table 5). The analysis results showed that the corresponding NDVI values between 2004 and 2010 were very close too.

Table 5 Comparison of NDVI of rice field at the landscape scale in 2004 and 2010

	Double cropping rice			Single cropping rice		
	2004	2010	Difference value	2004	2010	Difference value
Feb. 23	0.2639	0.2965	–0.0326	0.2290	0.2986	–0.0696
Mar. 10–11	0.3438	0.3017	0.0421	0.3674	0.2214	0.1460
Apr. 27–28	0.1983	0.1725	0.0258	0.2376	0.2135	0.0241
Oct. 4–5	0.7993	0.8807	–0.0814	0.3268	0.4339	–0.1071
Oct. 20–21	0.5565	0.6873	–0.1308	0.2338	0.2638	–0.0300
Nov. 5–6	0.2409	0.5706	–0.3297	0.2062	0.2801	–0.0739
Dec. 7–8	0.2475	0.2750	–0.0275	0.2844	0.2572	0.0272

3.3 Spatial variation of paddy rice field from 2004 to 2010

According to the visual interpretation of images in 2004 and 2010, the total area of paddy rice field in the PLR were 6193.99 km^2 and 6147.23 km^2, respectively. Figure 7 shows the paddy rice field in the PLR was highly distributed in the lowland area, especially concentrated along the rivers and lakes, such as the Gan-Fu (Ganjiang River and Fuhe River) delta plain to the southwest of Poyang Lake and Xin-Rao (Xinjiang River and Raohe River) delta plain to the southeast.

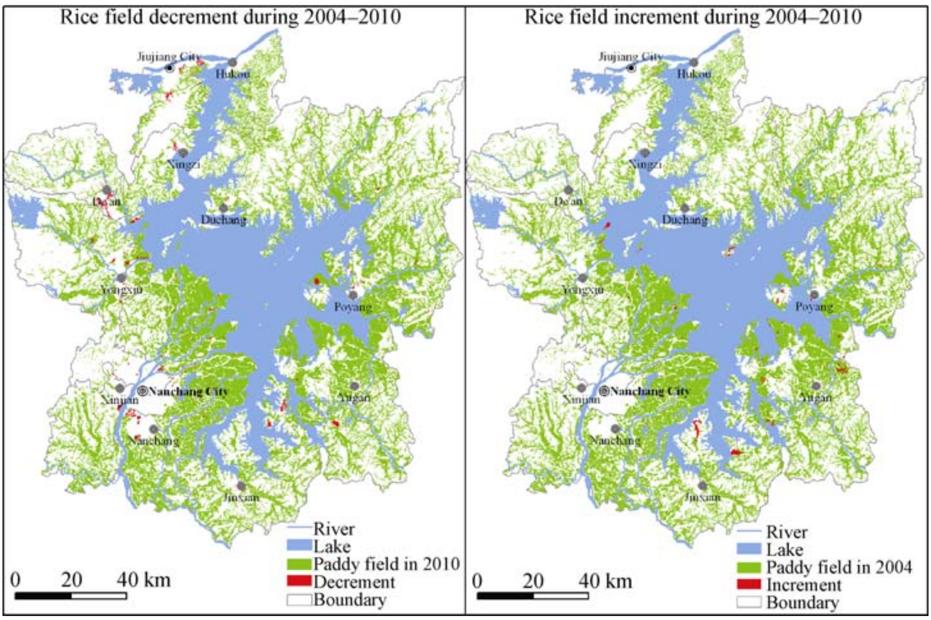

Figure 7 The spatial distribution of paddy rice field in 2004 (left panel) and 2010 (right panel) in the PLR, China

From 2004 to 2010, the decrement of paddy rice field was 46.76 km^2, with an annual reduction or loss of 7.79 km^2. Based on the field investigation, there are three main pathways for the loss of paddy rice fields: firstly, paddy rice field was converted into built-up areas for housing, urbanization and economic development, which occurred mostly in the suburbs of city and town areas like Nanchang city and Jiujiang city. Secondly, paddy rice fields were planted with other economic crops, such as cotton, water melon, and sugar cane. Cotton is mostly in the north of the PLR, like the lower Xiuhe River, and water melon and sugar cane are mainly in the south of the PLR, like water melon sporadically located in the Ganfu delta plain and sugar cane in the lower Raohe River. Thirdly, a small portion of paddy rice field has been transformed into wetland for aquaculture in the polder area in Poyang County.

There was also increment of paddy rice field in the polder area. Influenced by the agricultural policies, some wetland restoration area had started to plant rice, such as the Maju Polder Area (a partially restored polder) in Jinxian County. Table 6 showed the increment and decrement of paddy rice field in the ten agricultural counties. Since the decline of paddy rice field is an irreversible trend with the fast urbanization process, more and more attention should be given to the multiple cropping systems to ensure grain provision capacity (Yang *et al*., 2000).

Table 6 The changes in the area of paddy rice field from 2004 to 2010 in 12 counties or cities

	Agreement (ha)	Loss (ha)	Gain (ha)	Net change (ha)
Nanchang City area	5595.12	107.73	0	–107.73
Nanchang County	98434.08	1798.83	416.79	–1382.04
Xinjian County	74133.18	529.11	238.23	–290.88
Jinxian County	56726.46	977.49	1305	+327.51
Yongxiu County	42126.93	1027.08	457.20	–569.88
De’an County	16605.99	1103.40	0	–1103.40
Xingzi County	13515.57	507.06	121.95	–385.11
Jiujiang City area	12086.64	1103.67	120.15	–983.52
Hukou County	17797.68	37.17	5.76	–31.41
Duchang County	44815.68	498.42	346.41	–152.01
Poyang County	139785.03	1205.91	689.22	–516.69
Yugan County	87975.18	701.73	1235.70	+533.98
Total	609597.54	9597.60	4921.41	–4676.19

3.4 Spatial variation of rice cropping systems from 2004 to 2010

As there are several appropriate time windows per year for monitoring the spatial pattern of different rice cropping systems, in view of the data availability, three images over the PLR (Table 7) acquired in September and October were selected for rice cropping pattern classification in 2004 and 2010. In late September and early October, double cropping rice (late rice plants) is prevailing during the grain filling period with NDVI generally above 0.60, while single cropping rice is in the yellow maturity to harvest phase with notably decreased NDVI, usually below 0.50. For the just harvested rice fields, the corresponding NDVI would be much lower, in the order of approximately 0.30. Here, we separated single cropping rice (fields) from double cropping rice (plants) with the threshold value of NDVI by 0.55. The pixels from 0.55 inclusive to 1.0 will be classified as double cropping rice (fields); otherwise, pixels from zero to 0.55 will be considered as single cropping rice (fields).

The spatial variation of rice cropping systems from 2004 to 2010 in the PLR was very huge. In 2004 (Figure 8), the planting area for single cropping rice was 3213.17 km^2, and the

Table 7 Landsat images using for discriminating different rice cropping systems in 2004 and 2010

	P121-R40	P121-R39	P122-R40
Acquired date	2010-10-05	2010-10-05	2010-10-04
Sensor	Landsat-7	Landsat-7	Landsat-5
Acquired date	2004-10-04	2004-10-04	2004-09-25
Sensor	Landsat-7	Landsat-7	Landsat-7
Cloud cover (%)	0	0	0

planting area for double cropping rice was 2953.10 km^2. The multiple cropping index of paddy rice was about 147.2%. In 2010 (Figure 9), the planting area for single cropping rice decreased to 1926.07 km^2, and the planting area for double cropping rice increased to 4182.04 km^2. Correspondingly, the multiple cropping index of paddy rice was up to 167.4%. During the field investigation, we found that local farmers generally insisted that the rising grain price and other series of favorable agricultural policies (like exempting from the agricultural taxation and introducing direct grain planting subsidies) inspired their motivation to grow more double cropping rice. Figure 10 compares the spatial variation of double- and single-cropping rice between 2004 (the first year of issuing the No.1 Central Documents) and 2010 (the seventh year). For single- and double-cropping rice, they showed almost opposite change trend in the PLR from 2004 to 2010. Area reduction was the major feature of single cropping rice (Figure 10, left panel), while area increment was for double cropping rice (Figure 10, right panel). The noticeable contrast between 2004 and 2010 makes it relatively easy for identifying the spatial variation of the two cropping rice.

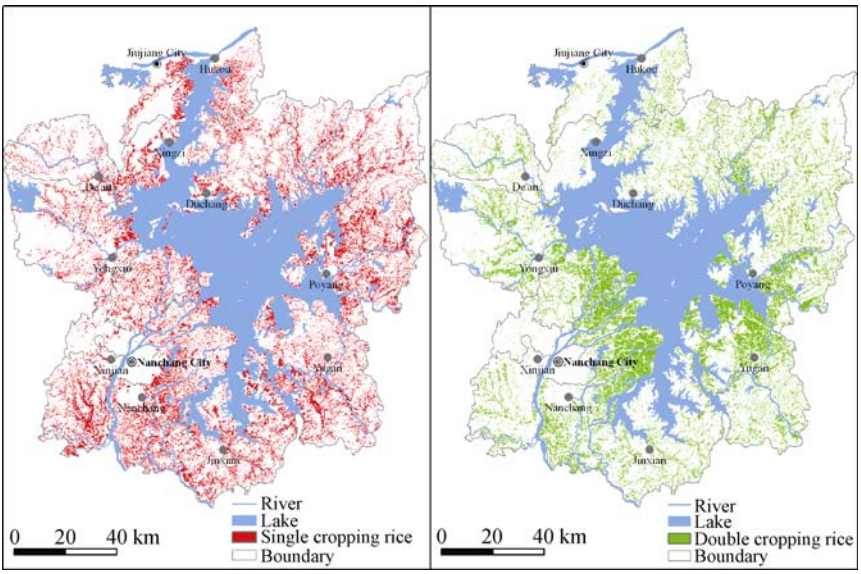

Figure 8 The spatial pattern of different rice cropping systems in 2004 in the PLR, China

4 Discussion and summary

Grain provision is always a fundamental issue in China. The grain yields in China dropped to the lowest level in 2003 after five-year continuous reduction from the highest level in 1998 (Zhang *et al.*, 2006). Since 2004, the Chinese government has restarted to promulgate

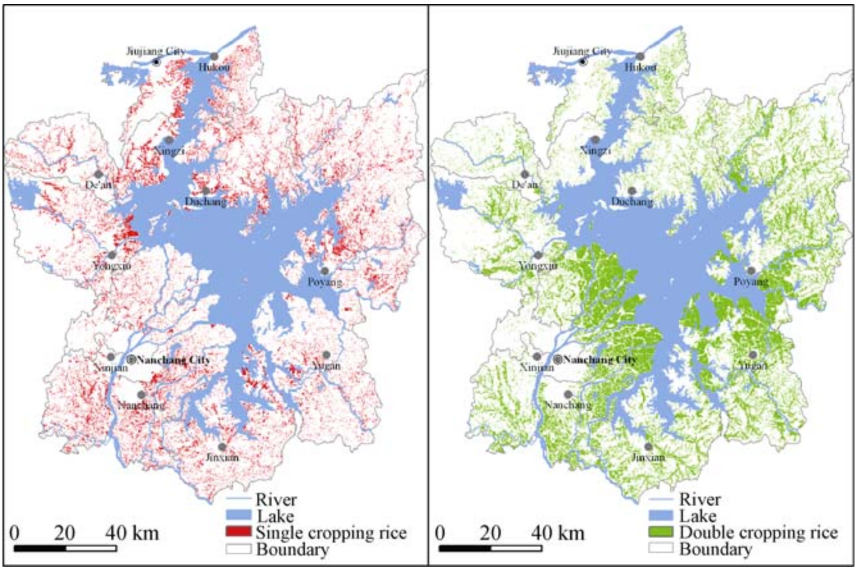

Figure 9 The spatial pattern of different rice cropping systems in 2010 in the PLR, China

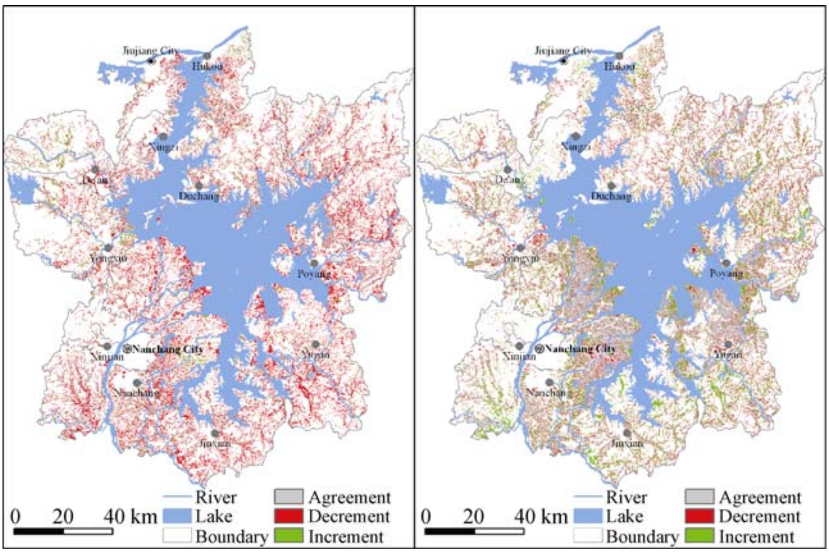

Figure 10 Spatial changes of single- and double-rice cropping systems from 2004 to 2010 in the PLR, China

consecutive No. 1 Central Documents focused on agricultural and rural development. Stable increase of grain production lays the foundation for rural development. With the rigid increment of grain demand and the continuous decrement of cropland inventory, the boost of multiple-cropping index has become an imperious issue in China (NDRC, 2009). Satellite derived rice cropping systems open a window of opportunity to quantify the expansion of grain production capacity. With the free access of Landsat data to public, it will certainly give more opportunity to understand the cropping pattern and the expansion of rice production capacity in China due to the importance of grain security.

A number of studies have determined the best temporal windows to carry out crop classification with Landsat data (Van Niel *et al*., 2004, 2003; Xiao *et al*., 2005). This research work not only covers the shortage of coarse spatial resolution of MODIS data, but also makes the crop detection and mapping possible. In this work, after discovering NDVI difference among various growth periods, we discriminated the rice cropping systems within optimum time windows in the PLR. Our analysis indicated that Landsat data highlighted the potential to discover the rice cropping pattern at the regional scale. However, this approach may not be practicable in the cloud impact regions due to the limited data source in the growth period of crops. The follow-up studies will give more attention to other better data sources, like the China Environment and Disaster Reduction satellites A and B (or HJ-1A and B). China Environment satellite HJ-1A and B with CCD camera launched in 2008 have the same spatial resolution with Landsat TM/ETM+, but with a shorter revisit cycle of four days and a bigger swath width of 350 km than the latter. It certainly will perfect the mapping method based on the optimum temporal windows with the HJ-1A and B CCD images. Beyond that, the plenty of data from CCD camera will contribute to make rice cropping systems monitoring better serve to the agriculture monitoring and yields estimation in the future.

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